Joseph John Bevelacqua

Contemporary Health Physics

Problems and Solutions

Second, Updated and Enlarged Edition

WILEY-VCH

WILEY-VCH Verlag GmbH & Co. KGaA

Joseph John Bevelacqua

Contemporary Health Physics

Related Titles

Bevelacqua, J. J.

Health Physics in 21st Century

2008
ISBN: 978-3-527-40822-1

Hendee, W. R., Ibbott, G. S., Hendee, E. G.

Radiation Therapy Physics

2004
ISBN: 978-0-471-39493-8

Turner, J. E.

Atoms, Radiation, and Radiation Protection

2007
ISBN: 978-3-527-40606-7

Lieser, K. H.

Nuclear and Radiochemistry
Fundamentals and Applications

2001
ISBN: 978-3-527-30317-5

Andrä, W., Nowak, H. (Eds.)

Magnetism in Medicine
A Handbook

2007
ISBN: 978-3-527-40558-9

Bevelacqua, J. J.

Basic Health Physics
Problems and Solutions

1999
ISBN: 978-0-471-29711-9

Martin, J. E.

Physics for Radiation Protection
A Handbook

2006
ISBN: 978-3-527-40611-1

Attix, F. H.

Introduction to Radiological Physics and Radiation Dosimetry

1986
ISBN: 978-0-471-01146-0

Joseph John Bevelacqua

Contemporary Health Physics

Problems and Solutions

Second, Updated and Enlarged Edition

WILEY-VCH

WILEY-VCH Verlag GmbH & Co. KGaA

The Author

Dr. Joseph John Bevelacqua
Bevelacqua Resources
Richland, WA 99352, USA
Bevelresou@aol.com

Cover

3-D cutaway view of the compact muon solenoid (CMS) at the Large Hadron Collider at CERN (CMS) detector

Library of Congress Card No.:
applied for

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <http://dnb.d-nb.de>.

Composition Manuela Treindl, Laaber
Printing Strauss GmbH, Mörlenbach
Bookbinding Litges & Dopf GmbH, Heppenheim

Printed in the Federal Republic of Germany
Printed on acid-free paper

ISBN: 978-3-527-40824-5

This book is dedicated to my wife, Terry. Her love and understanding have been of great assistance to the completion of this text.

Preface to the Second Edition

The second edition of *Contemporary Health Physics: Problems and Solutions* has several new features. There is a new chapter on nonionizing radiation and four new appendixes. The new appendixes provide a compilation of key health physics relationships, a discussion of production equations and their applications, a mathematical review, and a set of radionuclides of health physics significance and their associated data. The text also incorporates a more extensive use of SI units. New problems are cast within an SI format, and a number of first edition problems are converted to SI units.

Additional discussion has been added to Chapters 2–7 to reflect new health physics recommendations, new reports, and emerging technologies. In the Medical Health Physics chapter, discussion has been added regarding neutron and heavy-ion therapy and the use of alpha-emitting radiopharmaceuticals. Recent recommendations of the National Council on Radiation Protection and Measurements (NCRP) regarding shielding in imaging and therapy facilities, and management of radionuclide therapy patients are incorporated into the second edition.

A section on research reactors and an expanded presentation of fusion energy have been added to the University Health Physics chapter. Discussion of open and closed fuel cycles and the Tokai Mura criticality were added to the Fuel Cycle chapter. The Power Reactor chapter has been enhanced by including a description of Generation I, II, III, and IV reactors, major instrumentation systems, updated radioactive waste processing approaches, and new NCRP hot-particle recommendations.

The Environmental Health Physics chapter has been expanded to address the isotopes and pathways associated with reprocessing options in open and closed fuel cycles and the intentional dispersal of radioactive material. A presentation of muon colliders and associated neutrino doses, synchrotron light sources, cascade reactions, the Large Hadron Collider, and ALARA aspects of shielding high-energy accelerators have been added to the Accelerator Health Physics chapter.

The problem and solution set was expanded from 375 to over 500 entries including nonionizing radiation questions. This expansion further develops the text material and provides additional practical application examples. These problems also attempt to capture the evolving nature of the Part II American Board of Health Physics Certification Examination. Detailed solutions are provided for all problems.

In addition to new NCRP and International Commission on Radiological Protection (ICRP) Reports, a discussion of updated internal dosimetry models, including the human alimentary tract and the human respiratory tract models, have been incorporated into Appendix IV. Appendix IV has also been revised to include a discussion of the 2007 Recommendations of the ICRP. Appendix V has been expanded to incorporate a discussion of the BEIR VII Report that evaluates health risks from exposure to low levels of ionizing radiation.

Since one of the purposes of this text is to maintain the technical focus for students preparing for the American Board of Health Physics Certification Examinations, the majority of the problems were derived from questions that appeared on previous examinations. As a prior panel member, vice chair, and chair of the Part II Examination Panel, I would like to thank my panel and all others whose exam questions have been utilized in formulating questions for this textbook.

The author is also fortunate to have worked with colleagues, students, mentors, and teachers who have shared their wisdom and knowledge, provided encouragement or otherwise influenced the content of this text. The following individuals are acknowledged for their assistance during the author's career: Dick Amato, John Auxier, Lee Booth, Ed Carr, Paul Dirac, Bill Halliday, Tom Hess, Gordon Lodde, Bob Nelson, John Philpott, Lew Pitchford, John Poston, John Rawlings, Don Robson, Bob Rogan, Mike Slobodien, Jim Tarpinian, Jim Turner, and George Vargo. The continuing encouragement of my wife Terry is gratefully acknowledged.

I would also like to thank the staff of Wiley-VCH with whom I have enjoyed working, particularly Anja Tschörtner, Ulrike Werner, Hans-Jochen Schmitt and Dr. Alexander Grossmann. The advice and encouragement of George Telecki of John Wiley and Sons, Inc. is also acknowledged.

Richland, Washington USA
June 15, 2008

Joseph John Bevelacqua, PhD, CHP
President,
Bevelacqua Resources

Preface to the First Edition

This book contains over 375 problems in health physics and discusses their practical applications. It assumes that the reader is familiar with the science of radiation protection and is either an active participant in that field or interested in learning more about the health physics profession. In particular, this text is particularly useful to individuals preparing for the American Board of Health Physics Certification Examination.

The first part of this book provides an overview of the scientific basis for the field of health physics. The reader is provided with a comprehensive set of references supplemented by appendices that outline selected concepts required to fully appreciate the specialized Part II material. Over 130 problems and their solutions are provided to permit the reader to demonstrate a sound knowledge of health physics fundamentals. The problems are set within scenarios that are intended to enhance the reader's existing knowledge by demonstrating the basic principles in complex situations requiring a sound knowledge of both theoretical health physics principles and good judgment.

Part II provides the reader with examples of the concepts and calculations frequently encountered in the various fields of health physics. Chapter titles are selected to loosely conform to the various subfields of the health physics profession – that is, medical, university, fuel cycle, power reactor, environmental, and accelerator health physics. The problems are intended to illustrate general concepts within the framework of specific areas such as medical or power reactor health physics.

In addition to illustrating the fundamental concepts of health physics, the collection includes a large number of detailed problems that are often encountered by the radiation protection professional. Some of these problems involve considerable effort, whereas others are more simplistic and can be solved from traditional lectures in health physics. In addition, there are problems which address topics not usually covered in existing texts. These problems are not presented as isolated bits of health physics knowledge, but are introduced within a scenario that stimulates an integrated professional approach to the problem. Professional judgment and sound health physics principles are emphasized.

The third part of this book provides the solutions to the problems presented in the first and second parts. Many of these are worked in considerable detail to further illustrate and emphasize the concepts introduced in Parts I and II.

The present collection of problems is largely based upon the American Board of Health Physics Comprehensive Examination. The author was privileged to serve for four years as a member, Vice-Chairman, and Chairman of the ABHP Comprehensive Panel of Examiners. The experience gained in the development of this examination and the weaknesses of candidates attempting this examination have affected the content of this work.

The author is deeply indebted to the members of the examination panels and the ABHP Board for their professional interaction which greatly expanded the author's own health physics knowledge. The opinions and interpretations reflected in this work are the author's and do not necessarily reflect those of his current or previous employers.

Wisconsin Electric Power Company *Joseph John Bevelacqua*

A Note on Units

In the United States many regulations, most reporting requirements, and a large portion of practicing health physicists utilize traditional units (Ci, R, rad, rem, etc.). The use of traditional units is currently in conflict with much of the international community and scientific publications which have adopted the SI system (Bq, C kg^{-1}, Gy, Sv, etc.).

The Second Edition of *Contemporary Health Physics* utilizes both traditional and SI units. Traditional units are selected because they are what the practicing health physicist will most frequently encounter in daily assignments and they can be easily related to their SI counterparts. Traditional units are also utilized to ensure that communications between the health physicist and the health physics technician are clearly understood.

The Second Edition attempts to strike a balanced view of units. All new problems have been recast in terms of SI units. This acknowledges the inevitable adoption of the international set of units. Although many of the existing problems are in traditional units, a number of First Edition problems have been converted to the SI system.

The conflict of units will remain until the United States adopts the SI system in its regulations. This should be done over a period of years in order to ensure that all health physicists are thoroughly familiar and comfortable with the SI units.

For those that feel more comfortable with the traditional system, the following conversion factors are provided:

SI Unit	Traditional Unit
Bq	2.70×10^{-11} Ci
Gy	100 rad
C kg^{-1} of air	3881 R
Sv	100 rem

As the reader can quickly note, the choice of units is more a matter of familiarity rather than scientific rigor. By using these simple factors, the reader should begin to feel more comfortable with either set of units.

Contents

Part I
Basic Concepts: Theory and Problems

1
Introduction

Health physics or radiation protection is the science dealing with the protection of radiation workers and the general public from the harmful effects of radiation. Health physicists work in a variety of environments, including medical facilities, facilities utilizing nonionizing radiation, universities, accelerator complexes, power reactors, and fuel cycle facilities. The health physicist is responsible for the radiological safety aspects of facility equipment and services. Radiological assessments of plant equipment, facility modifications, design changes, employee exposures, or the assessment of radiological effluents are key functions of a health physicist.

The fundamental tools of the health physicist include the fields of mechanics, electricity and magnetism, energy transfer, quantum mechanics. Atomic and nuclear structure, radioactive transformations, and the interaction of radiation with matter are the cornerstones of health physics knowledge. Application of these fundamental tools permits the health physicist to measure, quantify, and control radiation exposures to affected groups.

Introductory health physics texts typically cover these topics in several hundred pages. Because the scope of this text builds upon these fundamental concepts, we will not repeat them herein. The reader is referred to the texts listed as references to this chapter for a discussion of health physics fundamentals. We will, however, provide several appendices that illustrate selected fundamental concepts. Also included is an extensive set of scenarios, including over 160 worked examples, that illustrate the fundamental concepts and permit the reader to assess his or her knowledge of these concepts. Because the fundamentals are needed to fully understand the remaining chapters in this text, a review of the scenarios in this chapter is recommended.

1.1
Scenarios

Scenario 1.1

One of your neighbors, while digging up his back yard to build a pool, has discovered some old planks. Another neighbor, who has been investigating the possibility of the existence of a Viking settlement in the area, believes that the planks may be significant. He wishes to conduct an archeological expedition prior to any further construction. You offer to carbon date the wood to help settle the argument.

1.1 Carbon dating is possible because:
   a. The specific activity of carbon-14 in living organisms has changed over time, and one can identify the era of time the organism lived based on its current specific activity.
   b. Carbon-14 is in secular equilibrium with its daughter.
   c. The specific activity of carbon-14 in living organisms is relatively constant through time, but decays after the death of the organism.
   d. The specific activity of carbon-14 in wood increases over time due to shrinkage of the wood.

1.2 Calculate the approximate age of the wood given the following:

   C-14 $T_{1/2} = 5715$ years

   Specific activity for C-14 in a nearby living tree = 1.67×10^{-1} Bq/g

   Specific activity for C-14 in the old wooden plank = 1.50×10^{-1} Bq/g

Scenario 1.2

A nearby hospital has received a shipment of a Mo-99 generator. The shipment contained 1000 mCi of Mo-99 when manufactured. It arrived at the hospital 48 h after its production. The decay scheme is illustrated in Figure 1.1.

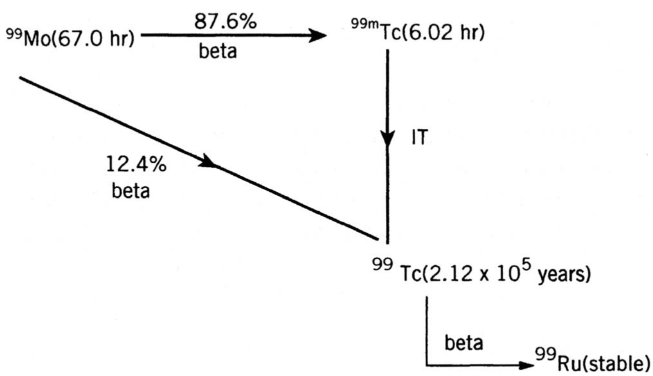

Figure 1.1 Decay scheme for Mo-99.