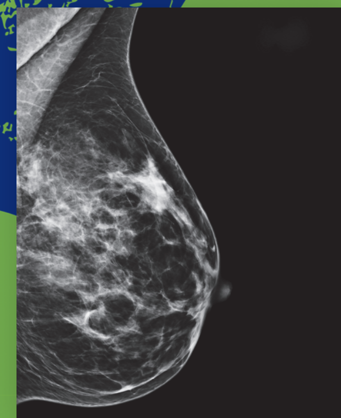
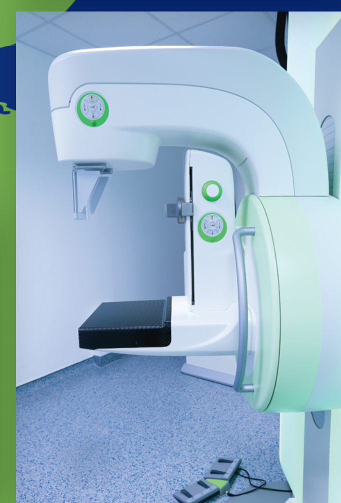
RADIATION PROTECTION

in Diagnostic X-Ray Imaging





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Dedication

This book is dedicated with love and affection to my son, Dave, and daughter-in-law, Priscilla, two smart and hard-working young people; and to my clever and beautiful granddaughter, Claire. You bring so much joy and happiness to our lives.

Euclid Seeram

To my wonderful little people who keep knocking their heads and to my wonderful big person who keeps knocking my head.

Patrick C. Brennan

Brief Contents

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Preface

Radiation protection in diagnostic imaging has evolved through the years, ever since the discovery and use of x-rays to image the human body in 1895. Such evolution has demonstrated several cardinal principles, concepts, procedures, and techniques to reduce the dose to the patient. Such dose-reduction strategies became very important as a result of the evolving knowledge of the biological effects of radiation exposure on both animals and humans, which provides the fundamental basis for radiation protection. The data from human exposure comes from the early instances in which individuals were exposed to high doses, including exposures among radiologists and physicists, individuals working in radiation and nuclear power industries, survivors of the atomic bomb explosions at Hiroshima and Nagasaki, and people living near sites of nuclear reactor accidents, such as the catastrophes at Three Mile Island and Chernobyl. Furthermore, another important source of data on biological effects of radiation exposure has been identified in the Biological Effects of Ionizing Radiation (BEIR) reports. Specifically, Section 7 of BEIR Report VII, presents data on exposure of patients to high doses from medical radiation. It is interesting to note that of the data sources mentioned above, the BEIR VII report puts the maximum emphasis on the data from the Hiroshima and Nagasaki atomic bomb survivors, which has been collected by the Radiation Effects Research Foundation (RERF). Another important concept derived from these studies is that of a dose–risk model, sometimes referred to as a dose–response relationship. The model shows what happens to the risk of radiation injury as the dose increases. Several models have subsequently emerged, and therefore the obvious question in the minds of medical imaging personnel is, which model is best suited when imaging patients? In this regard, Hendee and O'Connor (2012; p. 316) state that while the Linear No Threshold (LNT) model is most widely utilized,

> This model is not chosen because there is solid biologic or epidemiologic data supporting its use. Rather, it is used because of its simplicity and because it is a conservative approach . . . For the purpose of establishing radiation protection standards for occupationally exposed individuals and members of the public, a conservative model that overestimates the risk is preferred over a model that underestimates risk.

With the above ideas in mind, radiation protection is now an integral part of the curriculum in radiologic technology—and more importantly, it provides significant tools to protect not only the patient, but radiology personnel and members of the public as well. For example, a recent and well-established tool in radiation protection is *optimization of the dose-image quality relationship,* in an effort to reduce the dose to as low as reasonably achievable (ALARA) and not compromise the diagnostic quality of the image. This tool has become commonplace in digital radiography (DR) and digital fluoroscopy (DF), and in computed tomography (CT). Yet another popular tool for use in optimization of radiation protection is the diagnostic reference level (DRL) concept. The American College of Radiology (ACR) defines the DRL as "an investigation level to identify unusually high radiation dose or exposure levels for common diagnostic medical x-ray procedures." In 2012, the National Council on Radiation Protection and Measurements (NCRP) developed Report No. 172: *Reference Levels and Achievable Doses in Medical and Dental Imaging: Recommendations for the United States,* "… intended to reach a broad audience of all interested in radiation safety and health protection in medicine."

In addition, several recent developments have been introduced to address the increasing dose to the patient, not only in DR (exposure creep) but also in CT. These include updated knowledge of the exposure indicator and its effect on radiation dose in DR and the use of automatic tube current modulation (ATCM) and iterative image reconstruction algorithms in CT to reduce the noise in the image, and to reduce the dose to the patient. Another significant development that is now receiving attention in North America is that of image quality assessment tools for use in dose optimization studies. These tools include the use of quantitative objective physical measures as well as subjective observer performance when evaluating images in a clinical environment. Observer performance methods fall into two categories depending on the nature of the primary viewing task. If the task of the observer is lesion detection in the image, the method used would be the Receiver Operating Characteristics (ROC) analysis. If the viewing task is the visualization of anatomical structures, the method used would be Visual Grading Analysis (VGA).

Keeping these recent developments in mind, the purpose of this book is to provide a text that brings together a number of the critical issues in radiologic protection and presents these in an understandable way to individuals such as clinicians, radiographers, and other individuals who do not have an in-depth knowledge of medical physics. In particular, it will:

1. Provide a current and detailed overview of the biological effects of radiation exposure, because this topic establishes a firm rationale for radiation protection.
2. Outline the fundamental physical principles and technical aspects of radiation protection, including the essential physics for radiation protection, radiation exposure, dosimetry, dose limits, and the factors affecting dose in DR, DF, and CT.
3. Outline the major components of the DRL and its use in dose optimization.
4. Outline image quality assessment tools for use in dose-image quality optimization studies.

5. Outline the current regulatory and guidance recommendations for radiation protection in diagnostic imaging.
6. Explain the role of quality assurance/quality control in optimization of radiation protection in diagnostic imaging.

With the above objectives in mind, this book can be used as an introduction to radiation protection in diagnostic radiography, as a reference for the professional technologist, and as a supplement for applied fields such as biomedical engineering technology and dental hygiene programs.

Structure of the Book

Radiation Protection Overview

The first three chapters of the text are intended to orient and review the essential background needed for a thorough understanding of the nature and scope of radiation protection. Chapter 1 is a pivotal chapter, and its purpose is to provide a comprehensive overview of the fundamentals of radiation protection and to show a roadmap of topics to be covered in the rest of the book. While Chapter 2 reviews the basic physics necessary for a clear understanding of radiation protection and assumes that the reader has a background in high school-level physics, Chapter 3 outlines the nature of radiation exposure and dosimetry.

Biological Effects of Radiation

Chapter 4 is dedicated to the biological effects of radiation and provides the rationale for radiation protection.

General Radiation Protection Principles and Concepts

The next six chapters are dedicated to explaining general radiation protection principles and concepts. While Chapter 5 presents a detailed description of current radiation protection standards, Chapter 6 examines various international and national radiation protection organizations that are instrumental in developing and promulgating various radiation protection guidelines and recommendations for the safe use of ionizing radiation in medicine. Chapters 7, 8, 9, and 10 should be considered pivotal chapters as well because they deal with the technical factors affecting dose in radiography, fluoroscopy, digital radiography, and CT, respectively.

Tools for Dose Optimization Studies

The following four chapters relate to tools for dose optimization studies. Specifically, Chapter 11 outlines the fundamental tools for image quality assessment for use in dose optimization studies and provides an example of a dose optimization study in computed radiography (CR) imaging. Chapter 12 presents a detailed description of DRLs and how they relate to dose optimization. Chapters 13 and 14 address elements relating to regulatory and guidance recommendations and protective shielding requirements for diagnostic radiology, respectively.

Radiation Protection Through Quality Control

Finally, Chapter 15 discusses the role of quality assurance and quality control in the protection of patients and personnel.

Key Features

A significant challenge in writing this textbook was to meet the wide and varied requirements of its users, both students and instructors alike. In doing so, we have written the materials in a comprehensive manner in order to maintain the student's interest and attention. An important pedagogical feature is the use of detailed chapter outlines and learning objectives at the beginning of each chapter.

- **Outline:** The purpose of the outline is to orient the student to the main topics that will be covered.
- **Learning Objectives:** The use of the learning objectives is to emphasize the importance of each of the topics and subtopics covered through the use of action verbs, such as define, identify, describe, discuss, and outline, for example. Furthermore, the objectives provide criteria for examination.
- **Summary of Key Concepts:** These appear at the end of each chapter and provide readers with a tool to aid in study of the material.
- **Discussion Questions:** These are also provided at the end of each chapter for critical engagement of the material.

The content of this book is intended to meet the educational requirements (for entry to practice) of the following professional radiologic technology associations:

- American Society of Radiologic Technologists (ASRT)
- Canadian Association of Medical Radiation Technologists (CAMRT)
- College of Radiographers in the United Kingdom
- Radiography societies and associations in Asia, Australia, Europe, and Africa

An important consideration to note, however, is that the regulatory and guidance recommendations of all countries could not be included in this textbook, and therefore readers must consult radiation protection reports of their respective national radiation protection organizations and agencies.

Instructor Resources

In addition to the features included in the book, resources have been provided to aid in instruction of the material:

- Lecture outlines in PowerPoint format for each chapter
- A guide for mapping the textbook content to ASRT (American Association of Radiologic Technologists) and the CAMRT (Canadian Association of Medical Radiation Technologists)
- Chapter quizzes and chapter-specific test questions
- Practice activities
- Course syllabi for planning your lessons

Radiation protection in diagnostic imaging is an integral part of the education and skill set of radiologic technologists who play a significant role in the optimization of the radiation dose to the population. This book offers one small step in achieving that goal.

Best wishes in your pursuit of the study of radiation protection of patients, personnel, and members of the public.

Euclid Seeram, PhD, MSc, BSc, FCAMRT
Patrick C. Brennan, PhD

Acknowledgments

The single most important and satisfying task in writing a textbook of this nature is to acknowledge the encouragement of those individuals who perceive the value of the contribution to the literature.

The scope and content of this book are built around the work of several radiation protection organizations made up of expert radiobiologists, medical physicists, and radiologists, who have done the original research. In reality, they are the tacit authors of this text. Each of us, Euclid and Patrick, expresses our gratitude specifically in two parts of this acknowledgments section.

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Euclid Seeram

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Hans Swan, PhD, and Rob Davidson, PhD, both from Charles Sturt University in Australia, and Stewart Bushong, ScD, from Baylor College of Medicine in Houston, Texas, have provided me with a good deal of encouragement and explanations of radiation dose optimization in their roles as supervisors of my PhD dissertation, entitled *Optimization of the Exposure Indicator of a Computed Radiography Imaging System as a Radiation Dose Management Strategy.*

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Patrick C. Brennan

I am deeply grateful to the University of Sydney for providing me with special study leave to facilitate this text and to all my colleagues for providing much-needed data and expert advice. Thanks are also due to expert agencies such as the Health Protection Agency, UK, (Steve Ebdon-Jackson) and the International Commission on Radiological Protection, whose wealth of superb publications made this task so much easier. I will always be very appreciative of Horace and Michaela at Caffe La Mura, for providing the perfect environment to write. Finally, and very importantly, many many thanks are due to Ms. Phuong Trieu; I am indebted to her for her expertise and huge persistence in helping me provide almost all the figures contained within this text.

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Dr. Euclid Seeram is currently an honorary senior lecturer, adjunct associate professor, and adjunct professor at the University of Sydney, Australia; Monash University, Australia; and Charles Sturt University, Australia; respectively. He has published over 55 papers in professional and peer review radiologic technology journals and has had 20 textbooks published to date on computed tomography, computers in radiology, radiographic instrumentation, digital radiography, and radiation protection. Presently, he is on the editorial boards for *Radiography, Biomedical Imaging and Intervention Journal*, *International Journal of Radiology and Medical Imaging*, and the *Journal of Allied Health*. Furthermore, he is currently on the international advisory panel for the *Journal of Medical Radiation Sciences*, and is a founding member and an invited peer reviewer for the *Journal of Medical Imaging and Radiation Sciences*. His current research interests are focused on radiation dose optimization in CT and digital radiography imaging systems and he has published several papers on these two topics.

Patrick C. Brennan, PhD

Patrick C. Brennan is currently Professor of Medical Imaging and Associate Dean, International at the Faculty of Health Sciences, University of Sydney, Australia. In the latter role and within the last 3 years he has forged productive interdisciplinary research and teaching collaborations across health sciences with the leading institutions in China, Southeast Asia, the Middle East, and the Americas. He is also leader of the University of Sydney's Breast Cancer Special Interest Group, consisting of over 100 academic members. Since 2011, he has been (with Professor Warwick Lee) National Co-Director of BREAST. He has won 2 medals of excellence for teaching and has acted as undergraduate, graduate, and PhD examiner in 9 universities across Europe, Asia, and the Americas.

In 2009 he moved from the School of Medicine in University College Dublin, where he was an Associate Professor and Head of Diagnostic Imaging, to the University of Sydney. His new role was to establish an active research group focusing on medical imaging while helping to transform the current teaching program. Since that time he has established a Medical Image Optimization and Perception Group (MIOPeG), which is now leading the world in medical imaging research, with publications in the highest ranking international imaging journals.

Professor Brennan's research involves exploring novel technologies and techniques that enhance the detection of clinical indicators of disease while minimizing risk to the patient. His research has involved most major imaging modalities including x-ray, computerized tomography, ultrasound, and magnetic resonance imaging, with a particular focus on breast and chest imaging. In line with government priorities, his research findings have translated into improved diagnosis and management of important disease states such as cancer, musculoskeletal injury, arthritis, and multiple sclerosis. He is recognized as a leader in clinical translation of medical imaging optimization and radiological perception.

Professor Brennan has presented at the major international imaging meetings, including the annual meetings of the Radiological Society of North America, European Congress, UK Radiological Congress, International Society of Optical Engineering, and Medical Imaging Perception Society. He has published over 180 original papers and these have been accepted by the leading radiological journals such as *Radiology*, *Radiography*, *American Journal of Roentgenology*, *Academic Radiology*, *European Radiology*, and *British Journal of Radiology*.

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