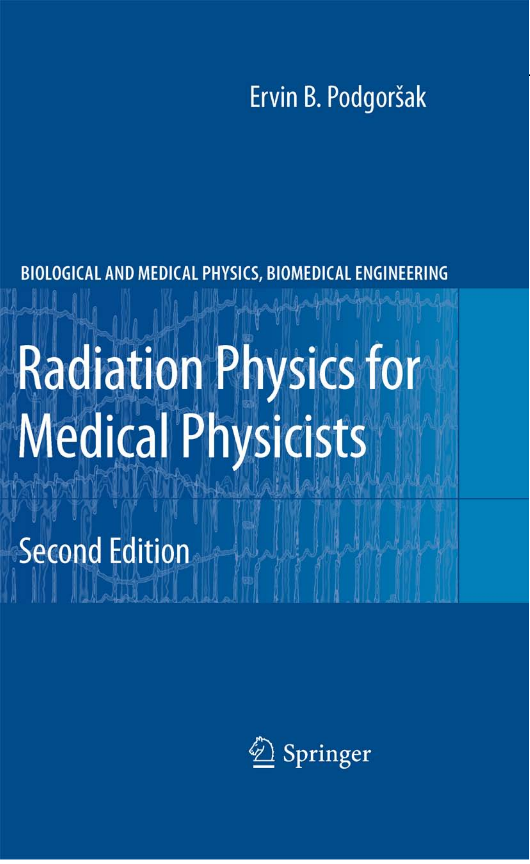
Ervin B. Podgoršak
BIOLOGICAL AND MEDICAL PHYSICS, BIOMEDICAL ENGINEERING
Radiation Physics for Medical Physicists
Second Edition
Springer

BIOLOGICAL AND MEDICAL PHYSICS,
BIOMEDICAL ENGINEERING

Please view available titles
in *Biological And Medical Physics, Biomedical Engineering*
on series homepage http://www.springer.com/series/3740

BIOLOGICAL AND MEDICAL PHYSICS, BIOMEDICAL ENGINEERING

The fields of biological and medical physics and biomedical engineering are broad, multidisciplinary and dynamic. They lie at the crossroads of frontier research in physics, biology, chemistry, and medicine. The Biological and Medical Physics, Biomedical Engineering Series is intended to be comprehensive, covering a broad range of topics important to the study of the physical, chemical and biological sciences. Its goal is to provide scientists and engineers with textbooks, monographs, and reference works to address the growing need for information.

Books in the series emphasize established and emergent areas of science including molecular, membrane, and mathematical biophysics; photosynthetic energy harvesting and conversion; information processing; physical principles of genetics; sensory communications; automata networks, neural networks, and cellular automata. Equally important will be coverage of applied aspects of biological and medical physics and biomedical engineering such as molecular electronic components and devices, biosensors, medicine, imaging, physical principles of renewable energy production, advanced prostheses, and environmental control and engineering.

E.B. Podgoršak

Radiation Physics for Medical Physicists

Second, Enlarged Edition

With 190 Figures, 80 Tables

Springer

Professor Ervin B. Podgoršak, Ph.D., FCCPM, FAAPM, FACMP, DABMP
Centre universitaire de santé McGill
McGill University Health Centre
Department of Medical Physics
1650 avenue Cedar
Montréal, Québec H3G 1A4, Canada
E-mail: epodgorsak@medphys.mcgill.ca

Biological and Medical Physics, Biomedical Engineering ISSN 1618-7210
ISBN 978-3-642-00874-0 e-ISBN 978-3-642-008745-7
DOI 10.1007/978-3-642-008745-7
Springer Heidelberg Dordrecht London New York

Library of Congress Control Number: 2009931704

Cover design: SPi Publisher Services

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Mariani za razumevanje in pomoč

Preface

This book is intended as a textbook for a radiation physics course in academic medical physics graduate programs as well as a reference book for candidates preparing for certification examinations in medical physics subspecialities. The book may also be of interest to many professionals, not only physicists, who in their daily occupations deal with various aspects of medical physics or radiation physics and have a need or desire to improve their understanding of radiation physics.

Medical physics is a rapidly growing specialty of physics, concerned with the application of physics to medicine, mainly but not exclusively in the application of ionizing radiation to diagnosis and treatment of human disease. In contrast to other physics specialties, such as nuclear physics, condensed matter physics, and high-energy physics, studies of modern medical physics attract a much broader base of professionals, including graduate students in medical physics; medical residents and technology students in radiation oncology and diagnostic imaging; students in biomedical engineering; and students in radiation safety and radiation dosimetry educational programs. These professionals have diverse background knowledge of physics and mathematics, but they all have a common need to improve their knowledge and understanding of the physical concepts that govern the application of ionizing radiation in diagnosis and treatment of disease.

Numerous textbooks that cover the various subspecialties of medical physics are available, but they generally make a transition from the elementary basic physics directly to the intricacies of the given medical physics subspecialty. The intent of this textbook is to provide the missing link between the elementary physics and the physics of the subspecialties of medical physics.

The textbook is based on notes that I developed over the past 30 years of teaching radiation physics to M.Sc. and Ph.D. students in medical physics at McGill University in Montreal. It contains 14 chapters, each chapter covering a specific group of subjects related to radiation physics that, in my opinion, form the basic knowledge required from professionals working in contemporary medical physics.

Most of the subjects covered in this textbook can be found discussed in greater detail in many other specialized physics texts, such as nuclear physics, quantum mechanics, and modern physics, etc. However, these texts are aimed at students in a specific physics specialty, giving more in-depth knowledge of the particular specialty but providing no evident link with medical physics and radiation physics. Some of these important specialized texts are listed in the bibliography at the end of this book for the benefit of readers who wish to attain a better insight into subjects discussed in this book. To recognize the importance of relevant history for understanding of modern physics and medical physics, Appendix C provides short biographies on scientists whose work is discussed in this book.

I am indebted to my colleagues in the Medical Physics department of the McGill University Health Centre for their encouragement, approval and tolerance of my concentrating on the book during the past year. I am greatly indebted to my former students and/or colleagues Dr. Geoffrey Dean, Dr. François DeBlois, Dr. Slobodan Dević, Michael D.C. Evans, Marina Olivares, William Parker, Horacio Patrocinio, Dr. Matthew B. Podgorsak and Dr. Jan P. Seuntjens who helped me with discussions on specific topics as well as with advice on how to present certain ideas to make the text flow better. I also appreciate constructive comments by Prof. José M. Fernandez-Varea from the University of Barcelona and Prof. Pedro Andreo from the University of Stockholm and the Karolinska University Hospital.

Special thanks are due to my colleague Dr. Wamied Abdel-Rahman, not only for helpful discussions of the subject matter, but also for his skillful drawing of figures presented in the book and for significant contributions to Chapters 7 and 12. Secretarial help from Ms. Margery Knewstubb and Ms. Tatjana Nišić is very much appreciated.

I received my undergraduate physics education at the University of Ljubljana in Slovenia. I would like to thank the many teachers from the University of Ljubljana who introduced me to the beauty of physics and provided me with the knowledge that allowed me to continue my studies in the USA and Canada.

My sincere appreciation is due to my former teachers and mentors Professors John R. Cameron and Paul R. Moran from the University of Wisconsin in Madison and Professors Harold E. Johns and John R. Cunningham from the University of Toronto who introduced me to medical physics; a truly rewarding profession that brings together one's love of physics and compassion for patients.

Finally, I gratefully acknowledge that the completion of this book could not have been accomplished without the support and encouragement of my spouse Mariana. Especially appreciated are her enthusiasm for the project and her tolerance of the seemingly endless hours I spent on the project during the past several years.

Montréal, October 2009 *Ervin B. Podgoršak*

Medical Physics: A Specialty and Profession

1 Medical Physics and Its Subspecialties

Medical physics is a branch of physics concerned with the application of physics to medicine. It deals mainly, but not exclusively, with the use of ionizing radiation in diagnosis and treatment of human disease.

Diagnostic procedures involving ionizing radiation use relatively low energy x rays in the 100 kV range (*diagnostic radiology*) or γ rays (*nuclear medicine* also known as *molecular imaging*); therapeutic procedures involving ionizing radiation most commonly use high energy megavoltage x rays and γ rays or megavoltage electrons (*radiotherapy* also known as *radiation therapy*, *radiation oncology*, and *therapeutic radiology*).

Other applications of physics in diagnosis of disease include the use of nuclear magnetic resonance in anatomic, functional, and spectroscopic magnetic resonance imaging (MRI); ultrasound (US) in imaging; bioelectrical investigations of the brain (*electroencephalography*) and heart (*electrocardiography*); biomagnetic investigations of the brain (*magnetoencephalography*); and infrared radiation in *thermography*. Physicists are also involved in the use of heat for cancer therapy (*hyperthermia*), in applications of lasers for surgery, and in medical informatics.

During the past two decades medical physics has undergone a tremendous evolution, progressing from a branch of applied science on the fringes of physics into an important mainstream discipline that can now be placed on equal footing with other more traditional branches of physics such as nuclear physics, particle physics and condensed matter physics. Since the number of new jobs in medical physics is growing faster than the number of jobs in other specialties of physics, universities are under much pressure to develop new graduate programs in medical physics or to expand their existing medical physics programs.

The medical physics specialty covers several diverse areas of medicine. It is therefore customary for medical physicists to concentrate on and work in only one of the four specific subspecialties of medical physics:

1. *Diagnostic radiology physics* dealing with diagnostic imaging with x rays, ultrasound and magnetic resonance.
2. *Nuclear medicine physics* also referred to as *molecular imaging physics* dealing with diagnostic imaging using radionuclides.
3. *Radiotherapy physics* or *radiation oncology physics* dealing with treatment of cancer with ionizing radiation.
4. *Health physics* dealing with the study of radiation hazards and radiation protection.

2 Brief History of Use of Ionizing Radiation in Medicine

The study and use of ionizing radiation started with three important discoveries: *x rays* by Wilhelm Röntgen in 1895, *natural radioactivity* by Henri Becquerel in 1896, and *radium* by Pierre and Marie Curie in 1898. Since then, ionizing radiation has played an important role in atomic and nuclear physics where it ushered in the era of quantum mechanics, provided the impetus for development of radiology and radiotherapy as medical specialties and medical physics as a specialty of physics. In addition, ionizing radiation also proved useful in many other diverse areas of human endeavor, such as in industry, power generation, waste management, and security services.

The potential benefit of x ray use in medicine for imaging and treatment of cancer was recognized within a few weeks of Röntgen's discovery of x rays. Two new medical specialties: radiology and radiotherapy evolved rapidly, both relying heavily on physicists for routine use of radiation as well as for development of new techniques and equipment.

Initially, most technological advances in medical use of ionizing radiation were related to: (1) improvements in efficient x-ray beam delivery; (2) development of analog imaging techniques; (3) optimization of image quality with concurrent minimization of delivered dose; and (4) an increase in beam energies for radiotherapy.

During the past two decades, on the other hand, most developments in radiation medicine were related to integration of computers in imaging, development of digital diagnostic imaging techniques, and incorporation of computers into therapeutic dose delivery with high-energy linear accelerators. Radiation dosimetry and treatment planning have also undergone tremendous advances in recent years: from development of new absolute and relative dosimetry techniques to improved theoretical understanding of basic radiation interactions with human tissues, and to the introduction of Monte Carlo techniques in the determination of dose distributions resulting from penetration of ionizing radiation into tissue.

Currently, ionizing radiation is used in medicine for imaging in diagnostic radiology and nuclear medicine, for treatment of cancer in radiotherapy, for blood irradiation to prevent transfusion-associated graft versus host disease, and for sterilization of single use medical devices. The equipment used for modern imaging and radiotherapy is very complex and requires continuous maintenance, servicing, and calibration to ensure optimal as well as safe performance. Optimal performance in imaging implies acquisition of optimized image quality for lowest possible patient radiation dose, while in radiotherapy it implies a numerically and spatially accurate dose delivery to the prescribed target. Optimal performance can only be achieved with services provided by engineers who maintain and service the equipment, and medical physicists who deal with calibration of equipment, *in vitro* and *in vivo* dose measurement, dosimetry and treatment planning, as well as quality assurance of image acquisition and patient dose delivery.

3 Educational Requirements for Medical Physicists

Pioneers and early workers in medical physics came from traditional branches of physics. By chance they ended up working in nuclear medicine, radiology, or radiotherapy, and through on-the-job training developed the necessary skills and knowledge required for work in medical environment. In addition to clinical work, they also promoted medical physics as science as well as profession, and developed graduate medical physics educational programs, first through special medical physics courses offered as electives in physics departments and more recently through independent, well-structured medical physics academic programs that lead directly to graduate degrees in medical physics.

Since medical physicists occupy a responsible position in the medical environment, they are required to have a broad background of education and experience. The requirement for basic education in physics and mathematics is obvious, but the close working relationship of medical physicists with physicians and medical scientists also requires some familiarity with basic medical sciences, such as anatomy, physiology, genetics, and biochemistry.

Today's sophistication of modern medical physics and the complexity of the technologies applied to diagnosis and treatment of human disease by radiation demand a stringent approach to becoming a member of the medical physics profession. Currently, the most common path to a career in medical physics is academic progression, through a B.Sc. degree in one of the physical sciences but preferably in physics, to a M.Sc. degree in medical physics, and then to a Ph.D. degree in medical physics.

The minimum academic requirement for a practicing medical physicist is M.Sc. degree in medical physics, and this level is adequate for physicists who are mainly interested in clinical and service responsibilities. However, medical physicists working in academic environments should possess a Ph.D. degree in medical physics.

Academic education alone does not make a medical physicist. In addition to academic education, practical experience with medical problems and equipment is essential, and this may be acquired through on-the-job clinical education or, preferably, through a structured two-year traineeship (also referred to as internship or residency) program in a hospital after graduation with M.Sc. or Ph.D. degree in medical physics.

Because medical physicists work in health care and their work directly or indirectly affects patient safety and well-being, standards for their didactic and clinical education, work, and professional conduct are set and maintained by various professional bodies through the processes of educational accreditation, professional certification, and professional licensure. Accreditation is usually given to institutions, while certification and licensure are given to individual professionals. As the profession of medical physics matures, these processes are becoming more and more stringent to ensure quality of work and protection of patients undergoing diagnostic or therapeutic procedures using ionizing radiation.

In relation to the medical physics profession, *accreditation*, *certification*, and *licensure* are defined as follows:

- *Educational accreditation* represents an attestation by an appropriate accreditation agency that the accredited educational program (M.Sc. and/or Ph.D.) or clinical residency education program, offered by a given educational institution, typically a University incorporating a medical school, provides quality education in medical physics and meets applicable standards.
- *Professional certification* in medical physics like in other professions is obtained from a national professional society and attests that the certified medical physicist is able to competently execute a job or task in the area covered by the certification. The certification is usually attained through a rigorous examination process run by an appropriate national medical physics organization or medical organization. With respect to expiry there are two types of professional certification: (1) lifetime and (2) more commonly, time-limited typically to 5 or 10 years. For continued certification, the time-limited certificates must be renewed before expiry, usually through a rigorous "maintenance of certification" (MOC) process involving continuing education.
- While professional certification attests to the competence of a professional in certain field, it does not confer legal right to practice. Certain jurisdictions require by law that medical physicists demonstrate competence before they are legally allowed to practice. This legal requirement is referred to as *licensure* and the examination process is often similar to that used for professional certification except that professional certification is conferred by a professional organization while licensure is conferred by a government agency. Thus, certification and licensure deal with the same professional issues but differ in legal status they confer.

4 Accreditation of Medical Physics Educational Programs

Many universities around the world offer academic and clinical educational programs in medical physics. To achieve international recognition for its graduates, a medical physics educational program should hold accreditation by an international accreditation body that attests to the program's meeting rigorous academic and clinical standards in medical physics. Currently, there is only one such international body, the *Commission on Accreditation of Medical Physics Educational Programs* (CAMPEP) – www.campep.org/, founded in the late 1980s and sponsored by four organizations: the American Association of Physicists in Medicine (AAPM), the American College of Medical Physics (ACMP), the American College of Radiology (ACR), and the Canadian College of Physicists in Medicine (CCPM). In September 2009, 58 medical physics education programs (21 academic and 37 residency programs) were accredited by the CAMPEP. Several other jurisdictions are studying or setting up accreditation services for academic medical physics programs.

5 Certification of Medical Physicists

Several national professional medical physics organizations certify the competence of medical physicists. The certification is obtained through passing a rigorous written and oral examination that can be taken by candidates who possess M.Sc. or Ph.D. degree in medical physics and have completed an accredited residency in medical physics. Currently, the residency requirement is relaxed and a minimum of two years of work experience in medical physics after graduation with M.Sc. or Ph.D. degree in medical physics is also accepted, because of the shortage of available residency positions. However, in the future, graduation from an accredited medical physics academic program as well as an accredited medical physics residency education program will likely become mandatory for admission to write the medical physics certification examination.

The medical physics certification attests to the candidate's competence in the delivery of patient care in one of the subspecialties of medical physics. The requirement that its medical physics staff be certified provides a medical institution with the necessary mechanism to ensure that high standard medical physics services are given to its patients.

6 Appointments and Areas of Activities

Medical physicists are involved in four areas of activity: (1) *Clinical service and consultation*; (2) *Research and development*; (3) *Teaching*; and (4) *Administration*. They are usually employed in hospitals and other medical care facilities. Frequently, the hospital is associated with a medical school and medical physicists are members of its academic staff. In many non-teaching hospitals, physicists hold professional appointments in one of the clinical departments and are members of the professional staff of the hospital. Larger teaching hospitals usually employ a number of medical physicists who are organized into medical physics departments that provide medical physics services to clinical departments.

7 Medical Physics Organizations

Medical physicists are organized in national, regional, and international medical physics organizations. The objectives of these organizations generally are to advance the medical physics practice and profession through:

- Promoting medical physics education and training.
- Promoting the advancement in status and stature of the medical physics profession.
- Lobbying for a formal national and international recognition of medical physics as a profession.
- Holding regular meetings and conferences as well as publishing journals, proceedings, reports, and newsletters to disseminate scientific knowledge and discuss professional issues of interest to medical physicists.
- Improving the scientific knowledge and technical skills of physicists working in medicine.
- Sponsoring accreditation commissions for academic and residency programs in medical physics, and organizing certification programs as well as maintenance of certification and continuing education programs for medical physicists.
- Developing professional standards and quality assurance procedures for applications of physics in medicine.
- Fostering collaborations with other medical physics organizations as well as other related scientific and professional organizations.

The ***International Organization for Medical Physics*** (IOMP) is the largest medical physics organization representing 16,500 medical physicists worldwide and 80 adhering national member organizations (www.iomp.org). The organization was founded in 1963, largely through the efforts of the UK-based *Hospital Physicists' Association* (HPA) which was the first national body of medical physicists in the world. The four national founding members of the IOMP were the UK, US, Sweden and Canada.

According to the inaugural statutes of the IOMP, each interested country was to join the IOMP through a National Committee for Medical Physics which was to coordinate medical physics interests within its own country and select delegates to represent it at the general meeting of the IOMP.

In retrospect, the requirement for joining the IOMP through a National Committee proved to have been successful in stimulating medical physicists in many countries to first form their national organization and then through the national organization join the IOMP. During the first 45 years of its existence, the IOMP grew from its original four sponsors to 80 national sponsoring organizations spanning all continents of the world.

The IOMP speaks on professional and scientific issues of interest to the world community of medical physicists. In particular, it co-sponsors the *Journal of Applied Clinical Medical Physics* (JACMP), and sponsors the *World Congress on Medical Physics and Biomedical Engineering* that is held every three years and attracts several thousand medical physicists and engineers from around the world.

The IOMP also sponsors regular Conferences on Medical Physics with specific objectives aiming at developing local medical physics services, strengthening the links amongst regional medical physicists, and promoting the medical physics profession in regions and countries where holding a large World Congress would not be feasible.

In addition to representing 80 adhering national medical physics organizations, the IOMP also represents 4 regional medical physics federations and is in the process of adding two more regional federations to its roster. The four existing regional federations are:

- Asia-Oceania Federation of Organizations for Medical Physics (AFOMP)
- European Federation of Organisations for Medical Physics (EFOMP)
- Latin American Medical Physics Association (Associação Latino-americana de Fisica Medica – ALFIM)
- Southeast Asian Federation for Medical Physics (SEAFOMP)

In addition to the four established regional medical physics organizations, there are two federations in the process of formation: Federation of African Medical Physics Organisations (FAMPO) and Middle East Federation of Organisations for Medical Physics (MEFOMP).

From the list above we note that all continents except North America are covered by one or more regional medical physics organizations. North America consisting of only three countries, on the other hand, is covered well by the American Association of Physicists in Medicine (AAPM). The AAPM, despite being formed in 1958 as a U.S. national medical physics organization, can also be considered an international organization open to all practicing medical physicists irrespective of their country of work. Most Canadian medical physicists, in addition to supporting their national Canadian medical physics organizations, also belong to the AAPM and so do many Mexican medical physicists. It is thus reasonable to assume that the AAPM, in addition to playing the role of one of the 80 national IOMP sponsoring countries, also plays the role of a regional organization covering North America. For reasons of language, Mexico is one of the 11 countries sponsoring the ALFIM.

The ***European Federation of Organizations for Medical Physics*** (EFOMP) – www.efomp.org/ was founded in 1980 in London by 18 European Community members to serve as an umbrella organization to all national member medical physics organizations in Europe. It became the largest regional medical physics organization in the world, currently covering 39 national medical physics organizations representing over 5000 medical physicists from the 27 European Union (EU) countries and 12 countries adjacent to the EU.

The EFOMP's mission is:

1. to harmonize and advance medical physics at an utmost level both in its professional, clinical, and scientific expression throughout Europe.
2. to strengthen and make more effective the activities of the national member organizations by bringing about and maintaining systematic exchange of professional and scientific information, by the formulation of common policies, and by promoting education and training programs in medical physics.

The EFOMP accomplishes its mission by:

- Organizing congresses, meetings, and special courses.
- Publishing the journal "Physica Medica: *The European Journal of Medical Physics*" (EJMP), sponsoring four other scientific journals, and publishing an electronic bulletin "*The European Medical Physics News*".
- Harmonizing European education and training in medical physics.
- Improving the profession and practice of medical physics in Europe.
- Encouraging the formation of organizations for medical physics where such organizations do not exist.
- Making recommendations on the appropriate general responsibilities, organizational relationships, and roles of medical physicists.

The ***Asia-Oceania Federation of Organizations for Medical Physics*** (AFOMP) – www.afomp.org/ was founded in 2000 and is currently sponsored by 16 regional countries. The federation publishes a newsletter and works closely with its member organizations as well as with the IOMP on professional and educational issues of interest to medical physicists in the region. It also organizes a regional medical physics congress on a yearly basis, cosponsors the "*Journal of the Australasian College of Physical Scientists and Engineers in Medicine*", and is developing an accreditation program for academic medical physics programs as well as a certification program for medical physicists.

The ***American Association of Physicists in Medicine*** (AAPM), founded in 1958 (www.aapm.org), is the most prominent and by far the largest national medical physics organization in the world. It has over 6300 members, many of them from countries other than the US, making the AAPM the most international of the national medical physics organizations.

According to the AAPM "*The mission of the Association is to advance the practice of physics in medicine and biology by encouraging innovative research and development, disseminating scientific and technical information, fostering the education and professional development of medical physicists, and promoting the highest quality medical services for patients*".

The AAPM is a very active organization involved in promotion of medical physics through:

- Sponsoring a monthly scientific journal "*Medical Physics*".
- Organizing two yearly international scientific meetings; one a free standing meeting and the other held in conjunction with the Radiological Society of North America (RSNA) annual meeting.
- Conducting annual summer schools on relevant medical physics or clinical subjects.
- Publishing task group reports and summer school proceedings.
- Publishing a bi-monthly Newsletter about AAPM activities and items of interest to AAPM members. It contains timely information and serves as a forum for debate about professional and educational issues of interest to AAPM members.
- Hosting a virtual library that contains many of the continuing education courses presented at the AAPM annual meetings.
- Providing a variety of educational and training programs in cooperation with medical physics organizations throughout the world.
- Sponsoring the Commission on Accreditation of Medical Physics Educational Programs (CAMPEP) with three other organizations.

8 Medical Physics Around the World

Of the 80 national medical physics organizations that are sponsoring the IOMP, most have a relatively small number of members, as evident from the average number of members for the 80 countries that amounts to about 200. There are only a few countries that have national organizations exceeding 500 members: USA 6300; UK 1700; Germany 1100; India 850; Japan 780; Italy 730; Spain 510; and Canada 500.

Since it is reasonable to assume that the IOMP represents the majority of practicing medical physicists worldwide, one may estimate the current average concentration of medical physicists in the world at 2.5 per million population. However, there are large variations in this concentration from one region to another and from one country to another. For example, developed countries employ from 10 to 20 medical physicists per million population, while there are several developing countries with no medical physicists and many countries with less than 1 medical physicist per million population.

Considering the rapidly evolving technological base in modern medicine which requires an ever-increasing technical input from physicists, engineers, and technicians, the potential for growth in demand for medical physicists in the future is obvious. This is especially so for developing countries with many of them making serious efforts to modernize their health care services and in dire need of a significant improvement in their technological health care base not only in terms of equipment but also in terms of trained personnel to operate and maintain it.

9 Career in Medical Physics

Many academic and clinical educational programs are now available to an aspiring medical physicist for entering the medical physics profession. The ideal educational and professional steps are as follows:

1. *Undergraduate B.Sc. degree in physics* (typical duration: 4 years)
2. *Graduate degree* (M.Sc. and/or Ph.D.) *in medical physics* from an accredited medical physics program. Typical duration of M.Sc. program is 2 years; typical duration of Ph.D. program is 3 years after M.Sc. studies.
3. *Residency in medical physics* from an accredited residency program in medical physics. Typical duration of a residency program for a resident holding M.Sc. or Ph.D. degree in medical physics is 2 years.
4. Successful completion of a national *certification examination* in one of the four subspecialties of medical physics (as soon as possible upon completion of residency).

In principle, becoming a medical physicist through the four steps listed above is feasible; however, in practice, the steps are still somewhat difficult to follow because of the relatively low number of accredited academic and residency programs in medical physics. The number of these programs is growing, however. We are now in a transition period and within a decade, progression through the four steps listed above is likely to become mandatory for physicists entering the medical physics profession, similarly to the physicians entering the medical profession. The sooner broad-based didactic and clinical education through accredited educational programs in medical physics become the norm, the better it will be for the medical physics profession and for patients the profession serves.

A career in medical physics is very rewarding and the work of medical physicists is interesting and versatile. A characteristic of modern societies is their ever-increasing preoccupation with health. Research in cancer and heart disease is growing yearly and many new methods for diagnosis and therapy are physical in nature, requiring the special skills of medical physicists not only in research but also in the direct application to patient care.

Undergraduate students with a strong background in science in general and physics in particular who decide upon a career in medical physics will find their studies of medical physics interesting and enjoyable, their employment prospects after completion of studies excellent, and their professional life satisfying and rewarding.

Physics played an important role in the development of imaging and treatment of disease with ionizing radiation and provided the scientific base, initially for the understanding of the production of radiation, its interaction with matter, and its measurement, and, during recent years, for the technological development of equipment used for imaging and delivery of radiation dose. The importance of modern technology and computerization in radiation medicine has been increasing steadily and dramatically, resulting in extremely sophisticated, efficient, and accurate equipment that is also very costly.

Medical physicists, with their scientific education in general and their understanding of modern imaging and radiation therapy in particular, are well placed to play an important role in safe, efficient and cost-effective use of high technology in diagnosis and treatment of disease with radiation, be it as part of an engineering team that designs the equipment or part of a medical team that purchases the equipment and uses it for patient care. Medical physicists also get involved in general health technology assessment as part of a biomedical engineering team that offers impartial and objective evaluation of medical devices to ensure that they meet appropriate standards of safety, quality, and performance both technically and clinically.

As part of medical team, medical physicists are involved with writing specifications for high technology equipment before it is purchased, with negotiating conditions for its purchase, with organizing its acceptance and commissioning upon delivery by the vendor, as well as with organizing the equipment maintenance, servicing and calibration upon its acceptance and commissioning. Medical physicists also deal with governmental regulatory agencies and ensure that hospitals and clinics meet regulatory requirements to make the use of radiation in diagnosis and treatment of disease as safe as possible for both the patients and staff.

Contents