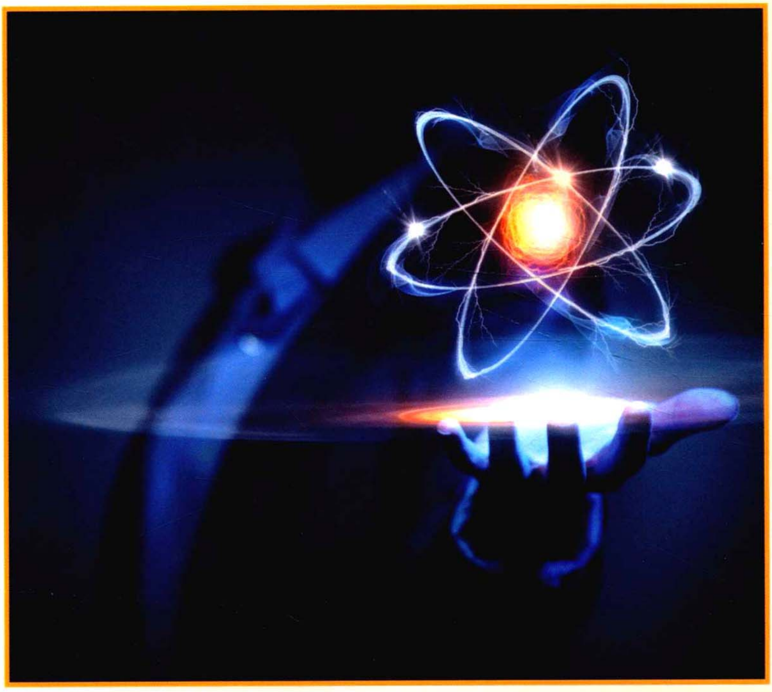
Series in Medical Physics and Biomedical Engineering

THE PRACTICE OF INTERNAL DOSIMETRY IN NUCLEAR MEDICINE



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The Practice of Internal Dosimetry in Nuclear Medicine

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Series Preface

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The International Organization for Medical Physics

The IOMP represents over 18,000 medical physicists worldwide and has a membership of 80 national and 6 regional organizations, together with a number of corporate members. Membership by default was accorded to individual medical physicists of all national member organizations.

The mission of the IOMP is to advance medical physics practice worldwide by disseminating scientific and technical information, fostering the educational and professional development of medical physics, and promoting the highest quality of medical physics services for patients.

A World Congress on Medical Physics and Biomedical Engineering is held every three years in cooperation with the International Federation for Medical and Biological Engineering (IFMBE) and International Union for Physics and Engineering Sciences in Medicine (IUPESM). A regionally-based international conference, the International Congress of Medical Physics (ICMP) is held between world congresses. IOMP also sponsors international conferences, workshops, and courses.

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The IOMP website (www.iomp.org) contains information on all its activities, policy statements 1 and 2, and "IOMP: Review and Way Forward," which outlines all the activities and plans of IOMP for the future.

Preface

In 2008, I wrote a book entitled *Fundamentals of Nuclear Medicine Dosimetry*. This was rather a "how to" manual for performing internal dose calculations for application in nuclear medicine. I noted in the preface to this work that there "I reveal practically all of my methods and secrets for practical internal dose calculations." I was not worried about this, particularly; I have plenty of work to do, and am most interested in growth in the area of patient-individualized dosimetry (the subject of Chapter 8 of this book). Hence, even if others learn to do what I do, it is no problem; I will always have enough work. This current book is more descriptive of the current state of the science. In Chapter 1, I go over the mathematical fundamentals again and show a few sample calculations, but the rest of the book describes anthropomorphic models, dosimetric models, and types and uses of diagnostic and therapeutic radiopharmaceuticals. In Chapter 8, I continue my impassioned plea for the nuclear medicine community to treat our nuclear medicine therapy patients with the same high standard of care that our external beam therapy patients enjoy daily. There appears to be hope on the horizon in Europe, and perhaps that will translate into changes in the United States and other countries. There are marvelous drugs on the market that are not being used, and others that are being used in a *one-size-fits-all* method that provides suboptimal therapeutic quality. People could be walking away from many cancers with a more aggressive use of therapeutic radiopharmaceuticals, and there are few side effects during the therapy phase, unlike the severe discomfort, hair loss, etc., in chemotherapy. I remain optimistic that my colleagues will one day be persuaded.

I have been quite blessed to be a part of this exciting field of nuclear medicine dosimetry for over 30 years now. I was honestly surprised when I received an offer from Oak Ridge Associated Universities for my first position out of college with a master's degree in engineering (emphasis on health physics), working at the Radiation Internal Dose Information Center under the tutelage of two of the greats, Evelyn Watson and Roger Cloutier. My fellow students wondered at my choice, since they knew that I could get a much better starting salary in other areas of the nuclear industry. I knew a golden opportunity when I saw it. I spent 15 years learning this field and meeting many fascinating people in the radiopharmaceutical and academic worlds. Today, I look back with gratitude to all of those who have taught me so much and been good friends. I thank God (literally) for all of this, and hope that the material in this text is useful to other professionals in the field.

Author

Michael Stabin is an associate professor in the Department of Radiology and Radiological Sciences at Vanderbilt University in Nashville, Tennessee. Before that, he was a visiting professor at the Universidade Federal de Pernambuco in Recife, Brazil, for 2 years and was a scientist at the Radiation Internal Dose Information Center of Oak Ridge Institute for Science and Education in Oak Ridge, Tennessee, for 15 years. He has a bachelor of science and a master of engineering degree in environmental engineering (health physics emphasis) from the University of Florida, Gainesville, Florida, and received his PhD in nuclear engineering (health physics emphasis) from the University of Tennessee, Knoxville, Tennessee. He is a Certified Health Physicist (1988, recertified in 2000, 2004, 2008, and 2012). He is a member of the Health Physics Society and the Society of Nuclear Medicine. He has over 150 publications in the open literature, mostly in the area of internal dosimetry for nuclear medicine applications, including complete textbooks on health physics and internal dose assessment. He has served as member and chair of the American Board of Health Physics Certification Examination Panel (Part I and II), and as an associate editor of the *Health Physics Journal* from 1992 until now. He also serves on task groups of the Society of Nuclear Medicine (the RAdiation

Dose Assessment Resource, or RADAR), American Association of Physicists in Medicine (AAPM), and the International Commission on Radiological Protection (ICRP). He has developed several models, methods, and tools that have become widely used in the nuclear medicine community, including the MIRDOSE and OLINDA/EXM personal computer software codes for internal dose calculations.

Contents

Chapter 1

Basic Principles of Internal Dosimetry Calculations

Paracelsus, born Philippus Aureolus Theophrastus Bombastus von Hohenheim in 1493, is regarded as the "father of toxicology." He is associated with the quote "Everything is poison, there is poison in everything. Only the dose makes a thing not a poison." In the science of radiation protection, the quantity of central focus is *dose*, which has a very specific definition, to be given shortly. Many radiation effects, be they positive or negative, are generally related to the dose of radiation that a person, animal, or other biological entity has received. Indeed, dose to physical structures can produce radiation damage at high enough levels as well. Thus, radiation protection professionals (health physicists)* focus much of their daily efforts in evaluating radiation doses and their possible consequences.

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* Paul Frame explores some possible origins of this unusual term at http://www.orau.org/ptp/articlesstories/names.htm#healthphysics, noting that "The term Health Physics originated in the Metallurgical Laboratory at the University of Chicago in 1942, but it is not known exactly why, or by whom, the term was chosen. Most likely, the term was coined by Robert Stone or Arthur Compton."

However, as we will see, this quantity *dose* in radiation protection is often modified by certain factors to account for specific biological responses, and so is an imperfect, although necessary, quantity to calculate or measure.

Radiation doses may be received from external or internal sources. This text is devoted to the evaluation of internal doses (most appropriately called *internal dose assessment* rather than *dosimetry*, as measurements are typically not involved; nonetheless, *internal dosimetry* is the term generally used), and specifically internal doses received due to the practice of nuclear medicine. Internal exposures to radioactive materials also occur in some industrial practices; while all of the principles involved in the calculations are the same, the applications are different and will not be treated in much detail in this text.

Quantities and Units

The basic quantity of radiation dosimetry is *absorbed dose*, which is just the energy absorbed by any object per unit mass of the object. Absorbed dose is relevant for any kind of radiation being absorbed by any kind of matter. Of course, we are mostly interested in the absorbed dose to human tissue, but one may calculate the absorbed dose to any material (e.g., air, water, wood). The textbook definition of absorbed dose is:

$$\frac{d\varepsilon}{dm} \tag{1.1}$$

where $d\varepsilon$ is the differential energy deposited in mass dm. So, for any application, we just need to calculate how much energy is absorbed by an object and divide by its mass. The quantity of absorbed dose is the gray (Gy), which is 1 J/kg. In internal dose calculations, our objects are either normal tissues or tumors, although we may also be interested in dose to different regions of organs (e.g., kidney medulla vs. kidney cortex), and we can even go to the voxel level to calculate doses to very small portions of organs, depending on the resolution of our images. Many radiation effects are well predicted by the simple quantity absorbed dose, but other more complicated quantities are sometimes needed to explain all of the radiation effects we observe; we will describe attempts to characterize these other quantities later in the chapter. But, to begin the discussion, we will describe how to calculate the quantity absorbed dose for internal emitters. A simple equation for the absorbed dose rate in an organ can be shown as (Stabin 2008):

$$\dot{D} = \frac{k\, A \sum_i n_i\, E_i\, \phi_i}{m} \tag{1.2}$$

where:

$\dot{D}$ is the absorbed dose rate (Gy/s)
A is the activity in the organ (MBq)
n_i is the number of radiations with energy E_i emitted per nuclear transformation
E_i is the energy per radiation (MeV)
ϕ_i is the fraction of energy E_i emitted per decay that is absorbed in the organ
m is the mass of the organ (kg)
k is a proportionality constant that expresses the dose in the desired units, given the units employed for the other terms (e.g., Gy – kg/MBq – s – MeV)

For the equation as described here, k would be:

$$k = \left(\frac{10^6 \text{ dis}}{\text{MBq} - \text{s}}\right)\left(\frac{\text{Gy} - \text{kg}}{1 \text{ J}}\right)\left(\frac{1.6 \times 10^{-13} \text{ J}}{\text{MeV}}\right)$$

$$= 1.6 \times 10^{-7}\left(\frac{\text{Gy} - \text{kg}}{\text{MBq} - \text{s} - \text{MeV}}\right) \tag{1.3}$$