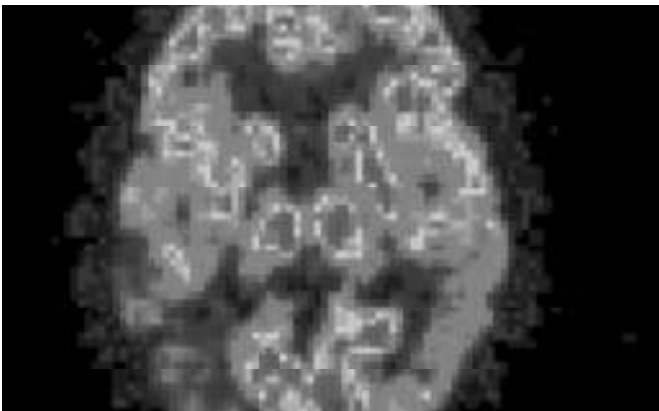




SECOND EDITION



Nuclear Medicine INSTRUMENTATION

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As a first-time author, I have a tremendous sense of satisfaction to be asked to prepare a second edition. Many thanks to my fellow nuclear medicine technology program directors who were willing to give a brand-new textbook a try. I am delighted to have the opportunity to correct mistakes, concepts, clarify and bring various topics to a more current state of affairs. I am also quite pleased to have two contributing authors for this edition. Michael Teters and Fady Kassem are medical physicists with wide experience in radiology and a deep understanding of nuclear medicine instrumentation. Both have been of great assistance to me in the process of preparing the Second Edition. Fady in particular contributed the initial draft of the chapter on magnetic resonance imaging, for which I am very grateful.

I have made major changes in a number of chapters and have added two new chapters. I would like to call your attention to these:

- Chapter 2—there is a new concept map elucidating the operation of a scintillation detector, a better description of calibration, and clarification of energy resolution (the property being measured) vs FWHM (the mechanism by which it is measured).
- Chapter 5—the section on non-Anger cameras was rewritten to address planar devices only, with descriptions of non-Anger SPECT systems in Chapter 12.
- Chapter 12—this chapter was updated to include recent improvements, a section on noise regularization, and more information on implementation and clinical benefits. Both software methods of incorporating improvements and non-Anger 3D imaging systems are discussed.
- Chapter 15—photos of a PET tomograph taken apart are included so that the reader can see crystals, septa, electronics, and a rod source. The description of direct and cross-planes is expanded. There is decreased emphasis on 2D vs 3D imaging, and new sections on dynamic and gated imaging and organ-specific PET systems are included.
- Chapter 16—the section on the SUV is rewritten to reflect its increasing importance, and a new section on the benefits of time-of-flight PET is included.
- Chapter 19—this is a completely new chapter on MRI, written as the first PET/MRI scanners are coming into clinical use. It aims to provide a modest rather than in-depth level of understanding of MRI as well as the technological challenges and clinical benefits of combining MRI with PET imaging.
- Appendix A—this has been extensively rewritten to emphasize the consequences of radiation interactions.
- Appendix F—this is a new appendix on laboratory accreditation; references to the requirements of accrediting agencies are also sprinkled throughout the text as appropriate.

How to Use this Text

- **Parts:** The text is broken into four parts that, for the most part, can be comprehended separately, without reference to the others. The only exception is that an understanding of Part II (Gamma Cameras) is assumed in Part III (Single-Photon Emission Computed Tomography).
- **Key terms:** Important words and phrases are italicized when they are introduced. These terms are defined in the new glossary found at the end of the book.
- **Abbreviations:** All abbreviations are spelled out at their first mention in each chapter. A comprehensive list of abbreviations and scientific units are provided in the front matter and a general list is printed inside the back cover as a helpful reference.
- **Sample calculations:** These are included to illustrate the mathematical application of the referenced equations throughout the text.
- **Appendices:** The appendices provide a deeper level of understanding for those who are interested in greater insight on specific topics.
- **References:** I have cited resources used in writing and updating this edition. They may or may not be helpful in expanding learning.
- **Additional resources:** I have compiled a list of additional resources to provide readers with helpful books and articles that will aide in further learning.



ACKNOWLEDGMENTS

When I was in graduate school, I wrote a paper on the environmental effects of the practice of nuclear medicine. In the paper, I referred a number of times to nuclear medicine *technologists*. The professor, a nuclear engineer, crossed out every occurrence of that word and wrote the word *technician* in its place. When I asked why he did that, he replied that “technologist” implied an understanding of the technology. I was quite insulted by that and vowed that my students would have a good understanding of the technology that underlies nuclear medicine. So, my first (somewhat backhanded) acknowledgment is to Dr. Maurice Robkin for providing the impetus for me to write this textbook.

As is true of many books, this work reflects my own understanding, which has been shaped by many other people, a few of whom I would therefore like to acknowledge. Dr. Paul Brown taught me nuclear medicine and has always been a role model. Barbara Ratliff, CNMT, taught the instrumentation course in my training program for many years, and the chapters on gamma cameras and SPECT imaging were originally based on her lecture notes. I have benefitted from a number of continuing-education sessions at national nuclear medicine meetings and the insights of those who truly are experts in the field. Drs. Mike Yester and Tom Lewellen, and Robert Hobbs, MS, provided initial reviews of different sections of the first edition. Tony Knight read through the entire manuscript of the first edition several times.

For this second edition, I would like to express my deep gratitude to Fady Kassem and Michael Teters for assisting me with this edition; their advice, guidance, and clarification on the finer points of medical physics were invaluable. Fady provided the first draft of the chapter on MRI,

and tirelessly reviewed my additions and edits. Several people who I consider giants in the field of nuclear medicine, including Dr. F. David Rollo, Dr. Michael Phelps, and Dr. Thomas Budinger, allowed me to use figures that they had created. I am grateful to my publisher, Jones & Bartlett Learning, my production editor Amy Rose, and my art editor Joanna Lundeen. Some of the work was done by people I did not have the pleasure of meeting, but the copyeditor and proofreader provided several rounds of careful reading and editing (and certainly got an education in nuclear medicine instrumentation while doing so).

I would especially like to acknowledge my fellow nuclear medicine educators. I appreciate those who let me know about errors in the first edition and made suggestions for improvements. I am grateful to those who have given me encouragement, especially those who have indicated that their ability to teach this subject has been enhanced by the textbook. My goal in writing this text was to address a significant deficit in our available resources, and your praise has given me the assurance that I have indeed met that goal.

My students continue to give me inspiration, as I see their understanding of the field reach higher and higher levels. Every year, through their struggles, I gain new insights. My coworkers at Virginia Mason Medical Center, and more recently at Bellevue College, have been supportive and encouraging. Finally and most importantly, I thank my husband, Peter, and my daughter, Krysta, for their patience through the many, many hours spent preparing the first and then the second edition. Publication of this text has been a labor of love for my profession, but it has been possible only because of the love and support of my family.



ABOUT THE AUTHOR

Jennifer Prekeges, MS, CNMT, graduated from the nuclear medicine technology program at the Veterans Administration Medical Center in Portland, Oregon, in 1980. Prior to attending that program, she received a bachelor of arts degree in biology and chemistry from Whitman College in Walla Walla, Washington. Jennifer worked as a nuclear medicine technologist for 20 years in the Seattle, Washington, area, and has been involved in nuclear medicine education since about 1983. She started the nuclear medicine technology program at Bellevue College in 1989, after receiving a master of science degree in radiological sciences from the University of Washington. She simultaneously directed the program and worked as a staff technologist at Virginia Mason Medical Center

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LIST OF ABBREVIATIONS

General Scientific Abbreviations

g = gram
 m = meter
 cm = 0.01 meter; cm² = square centimeter, cm³ = cubic centimeter
 ml = milliliter
 in = inch
 sec = second
 hr = hour
 ° = degrees of a circle
 °C, °F = degrees on the Celsius (centigrade) or Fahrenheit temperature scales
 Hz = Hertz (cycles/sec)
 V = volts
 eV = electron volt
 kVp = kilovolt peak
 ΔV = electrical potential difference between two charged objects
 A = ampere
 C = capacitance or Coulomb
 cts = counts
 cps = counts/second
 cpm = counts/minute
 dpm = disintegrations per minute
 dps = disintegrations per second
 Ci = Curie
 Bq = Becquerel
 ppm = parts per million
 R = Roentgen
 rem = Roentgen-equivalent man
 s.d. = standard deviation
 σ = standard deviation based on Poisson estimation
 Sv = Sievert
 τ = time constant (e.g., in a RC circuit)
 T = tesla
 μ_l = linear attenuation coefficient
 μ_m = mass attenuation coefficient
 1D = one-dimensional
 2D = two-dimensional
 3D = three-dimensional
 4D = four-dimensional

Standard order-of-magnitude abbreviations:

G = giga = ×10⁹
 M = mega = ×10⁶
 k = kilo = ×10³
 m = milli = ×10⁻³
 μ = micro = ×10⁻⁶

n = nano = ×10⁻⁹
 p = pico = ×10⁻¹²

Greek Letters

Uppercase	Lowercase	Name
A	α	alpha
B	β	beta
Γ	γ	gamma
Δ	δ	delta
E	ε	epsilon
Z	ζ	zeta
H	η	eta
Θ	θ	theta
I	ι	iota
K	κ	kappa
Λ	λ	lambda
M	μ	mu
N	ν	nu
Ξ	ξ	xi
O	ο	omicron
Π	π	pi
P	ρ	rho
Σ	σ	sigma
T	τ	tau
Υ	υ	upsilon
Φ	φ	phi
X	χ	chi
Ψ	ψ	psi
Ω	ω	omega

Other Abbreviations

AAPM = American Association of Physicists in Medicine
 AC = attenuation correction
 ACF = attenuation correction factor
 ACR = American College of Radiology
 ADC = analog-to-digital converter
 ALU = arithmetic-logic unit
 AOR = axis of rotation
 ARRT = American Registry of Radiologic Technologists
 BGO = bismuth germanate

CFOV = central field of view
 CNR = contrast–noise ratio
 COR = center of rotation
 CPU = central processing unit
 CR = capacitor-resistor (circuit)
 CRT = cathode ray tube
 CSF = cerebrospinal fluid
 CT = computed tomography
 CTDI = CT dose index
 CTW = coincidence timing window
 CV = coefficient of variation
 CZT = cadmium–zinc–tellurium
 DAS = data acquisition system
 DCA = decimal counting assembly
 DICOM = Digital Imaging and Communications in
 Medicine
 DLP = dose-length product
 E = emission image
 ECG = electrocardiogram
 EM = expectation maximization
 FBP = filtered backprojection
 FDA = (United States) Food and Drug Administration
 FDG = F-18 fluorodeoxyglucose
 FID = free induction decay
 fMRI = functional MRI
 FORE = Fourier rebinning
 FOV = field of view
 FT = Fourier transform
 FWHM = full-width at half-maximum
 FWTM = full-width at tenth-maximum
 GI = gastrointestinal
 GSO = gadolinium oxyorthosilicate
 GUI = graphical user interface
 HIS = hospital information system
 HU = Hounsfield units
 IAC = Intersocietal Accreditation Commission
 ICANL = Intersocietal Commission on Accreditation of
 Nuclear Laboratories
 IEC = International Electrotechnical Commission
 IMRT = intensity-modulated radiation therapy
 IV = intravenous
 JCAHO = Joint Commission on Accreditation of
 Healthcare Organizations
 LAN = local-area network
 LCD = liquid crystal display
 LEAP = low-energy all-purpose
 LED = light-emitting diode
 LLD = lower-level discriminator
 LOR = line of response
 LSF = line-spread function
 LSO = lutetium oxyorthosilicate
 LUT = look-up table
 LYSO = lutetium yttrium oxyorthosilicate
 MAP = maximum a posteriori
 MCA = multichannel analyzer
 MIP = maximum intensity projection
 MIPPA = Medicare Improvements for Patients and
 Providers Act
 ML = maximum likelihood
 MLEM = maximum-likelihood expectation maximization

MPI = myocardial perfusion imaging
 MR, MRI = magnetic resonance imaging
 MTF = modulation transfer function
 MWSR = multiple window spatial registration
 NaI (TI) = thallium-activated sodium iodide scintillation
 crystal
 NECR = noise-equivalent count rate
 NEMA = National Electrical Manufacturers Association
 NEX = number of excitations
 NIST = National Institute of Standards and Testing
 NMR = nuclear magnetic resonance
 NR = noise regularization
 NSA = number of signal averages
 OS = operating system
 OSEM = ordered-subsets expectation maximization
 PACS = picture archiving and communications system
 PET = positron emission tomography
 PHA = pulse-height analyzer
 PLES = parallel-line equal-spacing
 PMT = photomultiplier tube
 PP = pulse programmer
 PROM = programmable read-only memory
 PSF = point-spread function
 PSPMT = position-sensitive photomultiplier tube
 PVE = partial volume effect
 q, Q = electrical charge
 QC = quality control
 R_{coll} = collimator resolution
 R_{int} = intrinsic resolution
 R_{system} = system resolution
 RAM = random access memory
 RC = resistor-capacitor (circuit)
 RF = radio frequency
 RIS = radiology information system
 ROM = read-only memory
 RR = resolution recovery
 rSF = residual scatter fraction
 SC = scatter compensation
 SCA = single-channel analyzer
 SI = Systeme International
 SMPTE = Society of Motion Picture and Television
 Engineers
 SNM = Society of Nuclear Medicine
 SNMETS = Society of Nuclear Medicine Technologist
 Section
 SNR = signal-to-noise ratio
 SPECT = single-photon emission computed tomography
 SUV = standardized uptake value
 T = transmission image
 TBAC = transmission-based attenuation correction
 TE = time to echo
 TJC = The Joint Commission
 TOF = time of flight
 TR = time to repetition
 UBP = unfiltered backprojection
 UFOV = useful field of view
 ULD = upper-level discriminator
 UV = ultraviolet
 VDT = video display terminal
 WAN = wide-area network