NUCLEAR MEDICINE
INSTRUMENTATION

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PREFACE

Nuclear medicine textbooks are generally written as comprehensive texts. Some try to include both the basic science and the clinical practice of nuclear medicine. Others cover the science of nuclear medicine in a broad fashion. Few deal with instruments and imaging processes in as much depth as I feel is needed for the nuclear medicine technologist of the 21st century. I have therefore made the choice not to deal with other aspects of nuclear medicine physics. The text assumes an understanding of radioactivity and interactions in matter, and starts with the detection of radiation. A brief review of atomic structure and radiation interactions is provided in Appendix A.

A few comments on the organizational aspects of the text: Each of the four parts can for the most part be comprehended separately, without reference to the others, except that an understanding of Part II (gamma cameras) is assumed in Part III (single-photon emission computed tomography). Useful terms are italicized at the point of definition. Abbreviations are spelled out at their first mention, and a list of abbreviations is provided on page xxi. Sample calculations are included to illustrate how the math works, for those who can't look at an equation and immediately see how it is applied. The appendices provide a deeper level of understanding than may be needed for clinical practice, but which some readers may desire. The end notes for each chapter include two lists. "References" document cited facts, but may not be helpful for overall understanding; for the latter purpose, the "Additional Resources" are more accessible.

The constantly changing nature of technology presents a challenge to every author addressing any aspect of technology. I have tried to find a balance between the "old" and the "new" that makes sense to me. Some would argue that this text contains too much "old" technology, but I have found that knowing how things used to work helps me to better understand how they function today. Others would argue that not enough of the "new" is included. As a technologist with 20-plus years of experience, I have tried to provide a thorough explanation of those instruments that are in common clinical use. I have also deliberately not included aspects of radiation physics and detection (e.g., pair production interaction, proportional counter, liquid scintillation detector) that are not in routine use in nuclear medicine departments.

Another criticism of this text would be that I have not called on experts to contribute to this effort. That was also a deliberate choice on my part. I wanted to keep the level and tone of writing the same throughout, and I especially wanted to aim the textbook at the level of understanding of the technologist student. Rather than using multiple coauthors, I have included the lists of additional resources at the end of each chapter. These are books and articles that I have found helpful and believe readers might wish to draw on. I would refer those who desire more depth to them.

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. Needless to say, 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 acknowledgment is to Dr. Maurice Robkin for providing the impetus for writing this textbook.

As is true of any book, this work reflects the understanding of the author, which in turn has been shaped by many other people. I would therefore like to acknowledge a few of those folks. 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 her lecture notes formed the basis for the chapters on gamma cameras and SPECT imaging. Drs. Mike Yester and Tom Lewellen, and Robert Hobbs, MS, provided initial reviews of different sections, keeping me on the right track more than once. Greg Passmore, PhD, kindly reviewed the sample calculations. Tony Knight read through the entire manuscript several times. My students have also provided feedback and found typographical errors (in exchange for extra-credit points). I am indebted to the reviewers for their careful reading, corrections, and constructive criticisms, and especially to David Cella, Maro Gartside, and Julie Bolduc at Jones and Bartlett for their efforts on my behalf. My coworkers at Virginia Mason Medical Center and more recently at Bellevue College, and my professional colleagues throughout the country, have been supportive and encouraging. Finally and most importantly, I thank my husband, Peter, and my daughter, Krysta, for their love and patience through the many, many weekends given over to this project.

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 for the first 14 years of its existence, moving to a full-time position at Bellevue College in 2003. In addition to her work as an educator, Jennifer has served as a director and secretary of the Nuclear Medicine Technology Certification Board (1997–2005), reviewer for the *Journal of Nuclear Medicine Technology* (1995–present), member of the Academic Affairs committee of the Society of Nuclear Medicine Technologist Section (1995–1997 and 1998–1999), and copresident of the Pacific Northwest Chapter, Society of Nuclear Medicine Technologist Section (1999–2000). She has authored eight journal articles and one book chapter in addition to this text. In her spare time, she enjoys reading, birdwatching, cross-stitching, and Sudoku puzzles.

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LIST OF ABBREVIATIONS

General Scientific Abbreviations

g = gram
m = meter (cm = 0.01 meter, mm = 0.001 meter, nm = 10^{-9} meter)
ml = milliliter
cm^2 = square centimeter, cm^3 = cubic centimeter
sec = second (msec = 10^{-3} sec, μsec = 10^{-6} sec, nsec = 10^{-9} sec)
hr = hour
°C, °F = Celcius or centigrade, Fahrenheit temperature scales
Hz = Hertz (GHz = 10^9 Hertz)
V = volts
kVp = kilovolt peak
mV = 10^{-3} volt
ΔV = electrical potential difference between two charged objects
A = ampere (pA = 10^{-12} ampere, mA = 10^{-3} ampere)
C = capacitance or Coulomb
cts = counts (cps = counts/second, cpm = counts/minute)
dpm = disintegrations per minute
dps = disintegrations per second
Ci = Curie (mCi = 10^{-3} Curie, μCi = 10^{-6} Curie)
Bq = Becquerel (kBq = 10^3 Becquerel, MBq = 10^6 Becquerel, GBq = 10^9 Becquerel)
eV = electron volt (keV = 10^3 electron volts, MeV = 10^6 electron volts)
R = Roentgen (mR = 10^{-3} Roentgen)
rem = rRoentgen-equivalent man, mrem = 10^{-3} rem
s.d. = standard deviation
Sv = Sievert (mSv = 10^{-3} Sievert, uSv = 10^{-6} Sv)
μ_l = linear attenuation coefficient
μ_m = mass attenuation coefficient

Other Abbreviations

1D = one-dimensional
2D = two-dimensional
3D = three-dimensional
4D = four-dimensional
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
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
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
FDG = F-18 fluorodeoxyglucose
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
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
M = mean (average of multiple counting measurements)
MCA = multichannel analyzer
MIP = maximum intensity projection
ML = maximum likelihood
MLEM = maximum-likelihood expectation maximization

MRI = magnetic resonance imaging
MTF = modulation transfer function
MWSR = multiple window spatial registration
N = counts (result of a single counting measurement)
NECR = noise-equivalent count rate
NEMA = National Electrical Manufacturers Association
NIST = National Institute of Standards and Testing
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
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
RAM = random access memory
RC = resistor-capacitor (circuit)
R_{coll} = collimator resolution
R_{int} = intrinsic resolution
RIS = radiology information system
ROM = read-only memory
RR = resolution recovery
rSF = residual scatter fraction
R_{system} = system resolution
SC = scatter compensation
SCA = single-channel analyzer
SI = Systeme International
SMPTE = Society of Motion Picture and Television Engineers
SNMTS = 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
TOF = time of flight
UBP = unfiltered backprojection
UFOV = useful field of view
ULD = upper-level discriminator
UV = ultraviolet
VDT = video display terminal
WAN = wide-area network