

NUCLEAR MEDICINE INSTRUMENTATION

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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.

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.

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General Scientific Abbreviations

g = gram
 m = meter (cm = 0.01 meter, mm = 0.001 meter, nm = 10^{-9} meter)
 ml = milliliter
 cm² = square centimeter, cm³ = cubic centimeter
 sec = second (msec = 10^{-3} sec, μ sec = 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
 Δ V = 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, μ Ci = 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, μ Sv = 10^{-6} Sv)
 μ_t = 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 | ROM = read-only memory |
| MTF = modulation transfer function | RR = resolution recovery |
| MWSR = multiple window spatial registration | rSF = residual scatter fraction |
| N = counts (result of a single counting measurement) | R_{system} = system resolution |
| NECR = noise-equivalent count rate | SC = scatter compensation |
| NEMA = National Electrical Manufacturers Association | SCA = single-channel analyzer |
| NIST = National Institute of Standards and Testing | SI = Systeme International |
| OSEM = ordered-subsets expectation maximization | SMPTE = Society of Motion Picture and Television Engineers |
| PACS = picture archiving and communications system | SNMETS = Society of Nuclear Medicine Technologist Section |
| PET = positron emission tomography | SNR = signal-to-noise ratio |
| PHA = pulse-height analyzer | SPECT = single-photon emission computed tomography |
| PLES = parallel-line equal-spacing | SUV = standardized uptake value |
| PMT = photomultiplier tube | T = transmission image |
| PROM = programmable read-only memory | TBAC = transmission-based attenuation correction |
| PSF = point-spread function | TOF = time of flight |
| PSPMT = position-sensitive photomultiplier tube | UBP = unfiltered backprojection |
| PVE = partial volume effect | UFOV = useful field of view |
| q, Q = electrical charge | ULD = upper-level discriminator |
| QC = quality control | UV = ultraviolet |
| RAM = random access memory | VDT = video display terminal |
| RC = resistor-capacitor (circuit) | WAN = wide-area network |
| R_{coll} = collimator resolution | |
| R_{int} = intrinsic resolution | |
| RIS = radiology information system | |