

# Nuclear Medicine Residency Curriculum Resource Compendium- Preview

Molecular Imaging Center of Excellence Education Task Force

***Introduction***

The field of Nuclear Medicine is rapidly moving to embrace the general concepts of molecular imaging. We are ideally placed to become the leaders in this field, but this will become reality only if the current academic nuclear medicine physicians and scientists learn, understand and teach the appropriate concepts to the next generation. Although the official nuclear medicine training program requirements will not change for four to five years, we should begin to incorporate more molecular imaging into our programs much sooner. The material presented in this document should provide us with the initial resources we need to make it happen.

These resources should provide an excellent basis for strengthening existing training programs as we move into the era of molecular imaging. The “basic” resources are intended to be the primary resources used by current faculty and residents; the full list is intended to help define the expanding field of molecular imaging. It is not expected that all these resources will be immediately incorporated into all programs. In addition, these resources are presented for comment. Please send suggestions if some of the resources seem excessive or there appear to be gaps or areas not covered.

**Resource Areas:**

Physics and Instrumentation.....3

Radiation Biology.....12

Molecular and Cellular Biology.....19

Molecular Imaging Agents.....21

# Physics and Instrumentation Resources List

## Overall Resources

### Lectures

- *SNM Basic Science of Nuclear Medicine CD Modules*. Nos. 3 & 4 (of 11 total). (CDs will include additional topics in 2008–2009.)

### Books

- Cherry SR, Sorenson JA, Phelps ME. *Physics in Nuclear Medicine*. 3rd ed. Philadelphia: Saunders; 2003.
- Mettler FA, Guiberteau MJ. *Essentials of Nuclear Medicine Imaging*. 5th ed. Philadelphia: Saunders Elsevier; 2006. Key chapters are part of chapter 1, all of chapter 2, and part of chapter 3.
- Ziessman HA, O'Malley JP, Thrall JH. *Nuclear Medicine: The Requisites in Radiology*. 3rd ed. Philadelphia: Elsevier Mosby; 2006. Key chapters are 2–4.
- Ell PJ, Gambhir SS. *Nuclear Medicine in Clinical Diagnosis and Treatment*. 3<sup>rd</sup> ed. Churchill Livingstone; 2004
- Sandler MP, et al., eds. *Diagnostic Nuclear Medicine*. 4th ed. Philadelphia: Lippincott Williams & Wilkins; 2003.
- Henken RE, et al. *Nuclear Medicine*. 2nd ed. 2 vols. Philadelphia: Mosby Elsevier; 2006.
- Christian, PE, Waterstram, R, Kristen M. *Nuclear Medicine and PET/CT Technology and Techniques* 6th ed. St. Louis: Mosby; 2007.
- Von Schulthess, GK. *Molecular Anatomic Imaging PET-CT and SPECT-CT Integrated Modality Imaging* 2nd Ed. Philadelphia: LWW; 2007.

## 1. Physics

### Basic Resources

- Cherry SR, Sorenson JA, Phelps ME. *Physics in Nuclear Medicine*. 3rd ed. Philadelphia: Saunders; 2003. Key chapters are 2–6.
- Chandra R. *Nuclear Medicine Physics: The Basics*. 6<sup>th</sup> ed. Philadelphia: Lippincott Williams & Wilkins; 2004.

### ***Further Reading***

- Saha GB. *Physics and Radiobiology of Nuclear Medicine*. 3rd ed. New York: Springer; 2006.
- Patton JA. Introduction to nuclear physics. *Radiographics*. 1998;18(4):995–1007.

### **Structure of matter**

- Cherry SR, Sorenson JA, Phelps ME. *Physics in Nuclear Medicine*. 3rd ed. Philadelphia: Saunders; 2003: Chap. 2.

### **Modes of radioactive decay**

- <http://isotopes.lbl.gov/education/isotopes.htm>
- Cherry SR, Sorenson JA, Phelps ME. *Physics in Nuclear Medicine*. 3rd ed. Philadelphia: Saunders; 2003: Chap. 3.

### **Particle and photon emissions**

- Cherry SR, Sorenson JA, Phelps ME. *Physics in Nuclear Medicine*. 3rd ed. Philadelphia: Saunders; 2003: Chap. 3.

### **Interactions of radiation with matter.**

- Cherry SR, Sorenson JA, Phelps ME. *Physics in Nuclear Medicine*. 3rd ed. Philadelphia: Saunders; 2003: Chap. 6.
- <http://physics.nist.gov/PhysRefData/XrayMassCoef/cover.html>.
  - *This is a great resource for basic information about attenuation coefficients in many common materials.*
- <http://physics.nist.gov/PhysRefData/Xcom/html/xcom1.html>.
  - *This is a companion site that will provide tabular and graphical representations of attenuation coefficient values as a function of material and photon energy.*

## **2. Instrumentation**

### ***Basic Resources***

- Cherry SR, Sorenson JA, Phelps ME. *Physics in Nuclear Medicine*. 3rd ed. Philadelphia: Saunders; 2003: Chaps. 7, 8, 10–19.
- Mettler FA, Guiberteau MJ. *Essentials of Nuclear Medicine Imaging*. 5th ed. Philadelphia: Saunders Elsevier; 2006. Key chapters are part of chapter 1, all of chapter 2, and part of chapter 3.

- Ziessman HA, O'Malley JP, Thrall JH. *Nuclear Medicine: The Requisites in Radiology*. 3<sup>rd</sup> ed. Philadelphia: Elsevier Mosby; 2006 Key chapters are 2-4.
- Ell PJ, Gambhir SS. *Nuclear Medicine in Clinical Diagnosis and Treatment*. 3<sup>rd</sup> ed. Churchill Livingstone; 2004
- Saha G. *Physics and Radiobiology of Nuclear Medicine*. 3rd ed. New York: Springer; 2006: Chaps. 7–13.
- Graham, L. Stephen, L, Links, Jonathan M. “Instrumentation.” *Nuclear Medicine and PET/CT Technology and Techniques*. 6<sup>th</sup> Ed. Christian, Paul E., Waterstram-Rich, Kristen M. St. Louis: Mosby, 2007. 59-104

### ***Further Reading***

#### **Principles of instrumentation used in detection, measurement, and imaging of radioactivity with special emphasis on gamma cameras**

- Ranger NT. Radiation detectors in nuclear medicine. *Radiographics*. 1999;19(2):481–502.
- *Gamma Cameras: Basic Science of Nuclear Medicine*. [CD]. Society of Nuclear Medicine. Chap. Madsen.

#### **SPECT and PET devices**

- *Basic Science of Nuclear Medicine*. [CD]. Society of Nuclear Medicine. Chap. Moses.
- Wernick M, Aarsvold J., eds. *Emission Tomography: The Fundamentals of PET and SPECT*. Boston: Academic Press; 2004: Chap. 10.
- Zaidi H, Hasegawa B. *Determination of the attenuation map in emission tomography*. *J Nucl Med*. 2003;44(2):291–315.
- Zaidi H. Recent developments and future trends in nuclear medicine instrumentation. *Z Med Phys*. 2006;16(1):5–17.
- Rahmim A, Zaidi H. PET versus SPECT: strengths, limitations and challenges. *Nucl Med Commun*. 2008;29(3):193–207.
- Gelfand MJ, Lemen LC. PET/CT and SPECT/CT dosimetry in children: the challenge to the pediatric imager. *Semin Nucl Med*. 2007;37(5):391–398.

## **SPECT**

- Miller TR. The AAPM/RSNA physics tutorial for residents. Clinical aspects of emission tomography. *Radiographics*. 1996;16(3):661–668.
- Tsui BM. The AAPM/RSNA physics tutorial for residents. Physics of SPECT. *Radiographics*. 1996;16(1):173–183.
- Jaszczak RJ. The early years of single photon emission computed tomography (SPECT): an anthology of selected reminiscences. *Phys Med Biol*. 2006;51(13):R99–R115.
- Madsen MT. Recent advances in SPECT imaging. *J Nucl Med*. 2007;48(4):661–673.
- Zaidi H, Koral KF. Scatter modeling and compensation in emission tomography. *Eur J Nucl Med Mol Imaging*. 2004;31(5):761–782.
- Bateman TM, Cullom SJ. Attenuation correction single-photon emission computed tomography myocardial perfusion imaging. *Semin Nucl Med*. 2005;35(1):37–51.
- O'Connor MK, Kemp BJ. Single-photon emission computed tomography/computed tomography: basic instrumentation and innovations. *Semin Nucl Med*. 2006;36(4):258–266.
- Patton JA, Turkington TG. SPECT/CT physical principles and attenuation correction. *J Nucl Med Technol*. 2008;36(1):1–10.
- Seo Y, Mari C, Hasegawa BH. Technological development and advances in single-photon emission computed tomography/computed tomography. *Semin Nucl Med*. 2008;38(3):177–198.

## **SPECT Reconstruction**

- Madsen MT. The AAPM/RSNA physics tutorial for residents. Introduction to emission CT. *Radiographics*. 1995;15(4):975–991.

## **PET**

- Votaw JR. The AAPM/RSNA physics tutorial for residents. Physics of PET. *Radiographics*. 1995;15(5):1179–1190.
- Muehllehner G, Karp JS. Positron emission tomography. *Phys Med Biol*. 2006;51(13):R117–R137.
- Zaidi H. Scatter modeling and correction strategies in fully 3-D PET. *Nucl Med Commun*. 2001;22(11):1181–1184.
- Sureshbabu W, Mawlawi O. PET/CT imaging artifacts. *J Nucl Med Technol*. 2005;33(3):156–161; quiz 163–164.

- Blodgett TM, Meltzer CC, Townsend DW. PET/CT: form and function. *Radiology*. 2007;242(2):360–385.
- Nehmeh SA, Erdi YE. Respiratory motion in positron emission tomography/computed tomography: a review. *Semin Nucl Med*. 2008;38(3):167–176.
- Pichler BJ, Wehrl HF, Kolb A, Judenhofer MS. Positron emission tomography/magnetic resonance imaging: the next generation of multimodality imaging? *Semin Nucl Med*. 2008;38(3):199–208.
- Townsend DW. Positron emission tomography/computed tomography. *Semin Nucl Med*. 2008;38(3):152–166.
- Townsend DW. Multimodality imaging of structure and function. *Phys Med Biol*. 2008;53(4):R1-R39.

#### **Associated electronic instrumentation and computers employed in image production and display.**

- *Basic Science of Nuclear Medicine*. [CD]. Society of Nuclear Medicine. Chap. Fahey.

#### **Instrumentation principles of magnetic resonance imaging**

- Pooley RA. AAPM/RSNA physics tutorial for residents: fundamental physics of MR imaging. *Radiographics*. 2005;25(4):1087–1099.
- Jacobs MA, Ibrahim TS, Ouwerkerk R. AAPM/RSNA physics tutorials for residents: MR imaging: brief overview and emerging applications. *Radiographics*. 2007;27(4):1213–1229.
- Zhuo J, Gullapalli RP. AAPM/RSNA physics tutorial for residents: MR artifacts, safety, and quality control. *Radiographics*. 2006;26(1):275–297.
- Ohno Y, Hatabu H. Basics concepts and clinical applications of oxygen-enhanced MR imaging. *Eur J Radiol*. 2007;64(3):320–328.
- Willinek WA, Schild HH. Clinical advantages of 3.0 T MRI over 1.5 T. *Eur J Radiol*. 2008;65(1):2–14.

#### **Instrumentation principles of ultrasound**

- Hall TJ. AAPM/RSNA physics tutorial for residents: topics in US: beyond the basics: elasticity imaging with US. *Radiographics*. 2003;23(6):1657–1671.
- Boote EJ. AAPM/RSNA physics tutorial for residents: topics in US: Doppler US techniques: concepts of blood flow detection and flow dynamics. *Radiographics*. 2003;23(5):1315–1327.

### **Instrumentation principles of multi-slice computed tomography**

- Webb S, ed. *The Physics of Medical Imaging*. Philadelphia: Hilger; 1988.
- Bushberg JT, Seibert JA, Leidholdt EM Jr, Boone JM. *The Essential Physics of Medical Imaging*. 2nd ed. Philadelphia: Lippincott Williams & Wilkins; 2002.

### **Articles**

- McKetty MH. The AAPM/RSNA physics tutorial for residents. X-ray attenuation. *Radiographics*. 1998;18(1):151–163; quiz 149.
- Bushberg JT. The AAPM/RSNA physics tutorial for residents. X-ray interactions. *Radiographics*. 1998;18(2):457–468.
- McCollough CH. The AAPM/RSNA physics tutorial for residents. X-ray production. *Radiographics*. 1997;17(4):967–984.
- Cody DD. AAPM/RSNA physics tutorial for residents: topics in CT. Image processing in CT. *Radiographics*. 2002;22(5):1255–1268.
- McNitt-Gray MF. AAPM/RSNA physics tutorial for residents: topics in CT. Radiation dose in CT. *Radiographics*. 2002;22(6):1541–1553.
- McCollough CH, Bruesewitz MR, Kofler JM Jr. CT dose reduction and dose management tools: overview of available options. *Radiographics*. 2006;26(2):503–512.
- Goldman LW. Principles of CT: radiation dose and image quality. *J Nucl Med Technol*. 2007;35(4):213–225; quiz 226–228.
- Mahesh M, Cody D. Physics of cardiac imaging with multiple-row detector CT. *Radiographics*. 2007;27:1495–1509.

### **Small animal imaging instrumentation (SPECT, PET, Optical, MR, etc)**

- King MA, Pretorius PH, Farncombe T, Beekman FJ. Introduction to the physics of molecular imaging with radioactive tracers in small animals. *J Cell Biochem Suppl*. 2002;39:221–230.
- Meikle SR, Kench P, Kassiou M, Banati RB. Small animal SPECT and its place in the matrix of molecular imaging technologies. *Phys Med Biol*. 2005;50(22):R45–R61.
- Levin CS. Primer on molecular imaging technology. *Eur J Nucl Med Mol Imaging*. 2005;32(suppl 2):S325–S345.
- Lecchi M, Ottobrini L, Martelli C, Del Sole A, Lucignani G. Instrumentation and probes for molecular and cellular imaging. *Q J Nucl Med Mol Imaging*. 2007;51(2):111–126.

- Levin CS. Primer on molecular imaging technology. *Eur J Nucl Med Mol Imaging*. 2005;32(suppl 2):S325–S345.
- Beekman F, van der Have F. The pinhole: gateway to ultra-high-resolution three-dimensional radionuclide imaging. *Eur J Nucl Med Mol Imaging*. 2007;34(2):151–161.
- Rowland DJ, Cherry SR. Small-animal preclinical nuclear medicine instrumentation and methodology. *Semin Nucl Med*. 2008;38(3):209–222.
- Culver J, Akers W, Achilefu S. Multimodality molecular imaging with combined optical and SPECT/PET modalities. *J Nucl Med*. 2008;49(2):169–172.
- Driehuys B, Nouis J, Badea A, Bucholz E, Ghaghada K, Petiet A, Hedlund LW. Small animal imaging with magnetic resonance microscopy. *Ilar J*. 2008;49(1):35–53.

### 3. Mathematics

#### *Basic Resources*

- Cherry SR, Sorenson JA, Phelps ME. Nuclear counting statistics. In: *Physics in Nuclear Medicine*. 3rd ed. Philadelphia: Saunders; 2003: Chapters 9 and 19

#### *Further Reading*

##### **Statistics**

- O'Brien PC, Shampo MA, Robertson JS. Statistics for nuclear medicine. Introduction, descriptive statistics, and graphic displays. *J Nucl Med*. 1983;24(1):83-88.
- O'Brien PC, Shampo MA, Robertson JS. Statistics for nuclear medicine. Part 2. Estimation from samples and t-tests. *J Nucl Med*. 1983;24(2):165–171.
- O'Brien PC, Shampo MA, Robertson JS. Statistics for nuclear medicine. Part 3. A. Comparing two proportions (the relative deviate test and chi-square equivalent). B. Counting data. *J Nucl Med*. 1983;24(3):269–272.
- O'Brien PC, Shampo MA, Robertson JS. Statistics for nuclear medicine. Part 4. Regression. *J Nucl Med*. 1983;24(4):363–365.
- O'Brien PC, Shampo MA, Robertson JS. Statistics for nuclear medicine. Part 5. Survivorship studies. *J Nucl Med*. 1983;24(5):444–446.

- O'Brien PC, Shampo MA, Robertson JS. Statistics for nuclear medicine. Part 6. Normal values, evaluating a new diagnostic procedure, sequential methods, and conclusion. *J Nucl Med.* 1983;24(6):535–541.

#### **Computational image-processing**

- Cherry SR, Sorenson JA, Phelps ME. *Physics in Nuclear Medicine.* 3rd ed. Philadelphia: Saunders; 2003: Chap. 19.
- Lee KH. *Computers in Nuclear Medicine: A Practical Approach.* 2nd ed. Reston, VA: Society of Nuclear Medicine; 2005.
- Gelfand MJ, Thomas SR, eds. *Effective Use of Computers in Nuclear Medicine: Practical Clinical Applications in the Imaging Laboratory.* New York: McGraw-Hill; 1988.

### **4. Imaging Science**

#### **Basic Resources**

- Cherry SR, Sorenson JA, Phelps ME. *Physics in Nuclear Medicine.* 3rd ed. Philadelphia: Saunders; 2003. Key chapters are 15, 16, and 19.

#### **Further Reading**

- Freeman LM. *Clinical Radionuclide Imaging.* Vol. 3. 3rd ed. Orlando, FL: Grune & Stratton; 1986: Chap. 20.
- Soret M, Bacharach SL, Buvat I. Partial-volume effect in PET tumor imaging. *J Nucl Med.* 2007;48(6):932–945.
- Metz CE. Receiver operating characteristic analysis: a tool for the quantitative evaluation of observer performance and imaging systems. *J Am Coll Radiol.* 2006;3(6):413–422.
- Barrett HH, Myers KJ. *Foundations of Image Science.* Hoboken, NJ: Wiley-Interscience; 2004.
  - *A very high-level and mathematically sophisticated comprehensive review.*

### **5. Medical decision-making with an emphasis on efficacy of imaging**

#### **Basic Resources**

- Ell PJ, Gambhir SS. *Nuclear Medicine in Clinical Diagnosis and Treatment.* 3<sup>rd</sup> ed. Churchill Livingstone; 2004

- McNeil BJ, Keller E, Adelstein SJ. Primer on certain elements of medical decision making. *N Engl J Med.* 1975;293:211–215.
  - *One of the early articles on the fundamentals of medical decision making.*

### ***Further Reading***

#### ***Books***

- Sox HC, et al. *Medical Decision Making*. Philadelphia: American College of Physicians; 2007.
  - *Introductory text on medical decision making.*
- Weinstein MC, et al. *Clinical Decision Analysis*. Philadelphia: W.B. Saunders; 1980.
  - *Good basic reference on clinical decision making.*
- Ingelfinger JA, et al. *Biostatistics in Clinical Medicine*. New York: MacMillan Publishing Co., Inc.; 1983.
  - *Another good introductory text on clinical decision making.*
- Kuhns LR, Thornbury JR, Fryback D. *Decision Making in Imaging*. Chicago: Year Book Medical Publishers; 1989.
  - *Basics of decision analysis. Section IV on Radiation Risk is particularly interesting.*

#### ***Articles***

- Fryback DG, Thornbury JR. The efficacy of diagnostic imaging. *Med Decis Making.* 1991;11(2):88–94.
- Patton D. Introduction to medical decision making. *Semin Nucl Med.* 1978;8:273–278.
  - *Good basic introduction to medical decision making.*

# Radiation Biology Resources List

## 1. Biological effects of ionizing radiation at the organism, tissue and the cellular level

### *Basic Resources*

- Kassis AI, Adelstein SJ. Radiobiologic principles in radionuclide therapy. *J Nucl Med.* 2005;46(suppl):4S-12S.
- Willers H, Held KD. Introduction to clinical radiation biology. *Hematol Oncol Clin N Am.* 2006;20:1–24.

### *Further Reading*

- Hall EJ, Giaccia AJ. *Radiobiology for the Radiologist.* 6<sup>th</sup> ed. Philadelphia: Lippincott Williams & Wilkins; 2006.
  - *The standard, complete radiobiology text book. Essential if you really want to understand radiobiology.*
  -
- Murray D, McEwan AJ. Radiobiology of systemic radiation therapy. *Cancer Biother Radiopharm.* 2007;22(1):1–23.
  - *Excellent review of the literature. Very heavy reading, though. Good after seeing the science basics (Freeman).*
  -
- Fowler JF. Development of radiobiology for oncology—a personal view. *Phys Med Biol.* 2006;51:R263–R286.
  - *Nice historical review and explanation of where we are. Mainly to be read by the practicing oncology physician or physicist for perspective.*

## 2. Means of reducing radiation exposure

### *Basic Resources*

- Ell PJ, Gambhir SS. Radiation protection and dosimetry in clinical practice. In: Livingstone C, ed. *Nuclear Medicine in Clinical Diagnosis and Treatment.* 3rd ed. 2004:1871–1902, especially pp. 1877–1880 and 1884–1898.
- Bushberg JT, Leidholdt EM Jr. Radiation protection. In: Sandler MP, Coleman RE, Patton JA, Wackers F, Gottschalk A, eds. *Diagnostic Nuclear Medicine.* 4th ed. Philadelphia: Lippincott Williams & Wilkins; 2003:133–163.
  - *Good review of radiation protection.*

### *Further Reading*

- National Council on Radiation Protection and Measurements (NCRP) Report No. 105 (<http://www.ncrponline.org/Publications/105press.html>); Radiation Protection for Medical and Allied Health Personnel. Report No. 116

(<http://www.ncrponline.org/Publications/116press.html>) Limitation of Exposure to Ionizing Radiation. Proceedings No. 14  
([http://www.ncrponline.org/Publications/Annual\\_Mtg\\_Proc/1992Program.html](http://www.ncrponline.org/Publications/Annual_Mtg_Proc/1992Program.html)); Radiation Protection in Medicine.

- Nuclear Regulatory Commission (NRC). 10 CFR 20 and 10 CFR 35. [www.nrc.gov/reading-rm/doc-collections/cfr/](http://www.nrc.gov/reading-rm/doc-collections/cfr/).
  - *The source for standards and regulations.*
  -
- Society of Nuclear Medicine. General Imaging; Use of Radiopharmaceuticals. In *Society of Nuclear Medicine Procedure Guidelines*, Reston, VA (<http://interactive.snm.org/index.cfm?PageID=772>)
  - *Good description of proper technique and precautions to limit radiation exposure.*
  -

### 3. Calculation of radiation dose

#### *Basic Resources*

##### **Standardized methods for obtaining human and animal data for use in dosimetry calculations**

- Siegel J, Thomas S, Stubbs J, Stabin M, Hays M, Koral K, Robertson J, Howell R, Wessels B, Fisher D, Weber D, Brill A. MIRD pamphlet no. 16: Techniques for quantitative radiopharmaceutical biodistribution data acquisition and analysis for use in human radiation dose estimates. *J Nucl Med.* 1999;40:37S-61S.

##### **Standardized dose estimates for radiopharmaceuticals—adults and pediatric subjects**

- International Commission on Radiological Protection (ICRP). *Radiation Dose Estimates for Radiopharmaceuticals*. Publications 53 and 80, with addenda. Oxford: Pergamon Press; 1983–1991.
- RADAR Web site (<http://www.doseinfo-radar.com/NMdoses.xls>).
  - *Includes brief description of biokinetic models underlying the calculations.*

##### **Standardized dose estimates for radiopharmaceuticals—pregnant women**

- Russell JR, Stabin MG, Sparks RB, Watson EE. Radiation absorbed dose to the embryo/fetus from radiopharmaceuticals. *Health Phys.* 1997;73(5):756–769.
- RADAR Web site (<http://www.doseinfo-radar.com/pregtables.doc>). Dose estimates for unique cases for the pregnant patient—dose to fetal thyroid, dose to hyperthyroid patients, conception following administration of radioiodines. All data, with references, on the RADAR Web site (<http://www.doseinfo-radar.com/RADAR-INT-NM.html>).

- ANSI Standard N13.54, Fetal Radiation Dose Calculations, <http://hps.org/hpssc/>.
  - *Nice section at the end about how to interpret and communicate radiation dose and risk to a pregnant subject or her physician, by Dr. Robert Brent.*

### **Didactic information about internal dose calculations**

- Stabin M. *Fundamentals of Nuclear Medicine Dosimetry*. New York: Springer; 2008: Chaps 2–5.
- Loevinger R, Budinger TF, Watson EE. *MIRD Primer for Absorbed Dose Calculations*. New York: Society of Nuclear Medicine; 1988.
- Stabin MG. Internal radiation dosimetry. In: Henkin RE, Bales MA, Dillahay GL, Halema JR, Karesh SM, Wagner RH, Zimmer AM, eds. *Nuclear Medicine*. Vol. 1. 2nd ed. St. Louis, MO: Mosby; 2006:313–331.
- Zanzonico PB. Internal radionuclide radiation dosimetry: a review of basic concepts and recent developments. *J Nucl Med*. 2000;41:297–308.
- Stabin MG, Siegel JA. Physical models and dose factors for use in internal dose assessment. *Health Physics*. 2003;85(3):294–310.
- Stabin MG, Brill AB. Quantitative imaging-based dosimetry and treatment planning in radionuclide therapy. In: Zaidi H, ed. *Quantitative Analysis of Nuclear Medicine Images*. New York: Springer; 2005.
- Siegel J, Thomas S, Stubbs J, Stabin M, Hays M, Koral K, Robertson J, Howell R, Wessels B, Fisher D, Weber D, Brill A. MIRD pamphlet no. 16: Techniques for quantitative radiopharmaceutical biodistribution data acquisition and analysis for use in human radiation dose estimates. *J Nucl Med*. 1999;40:37S-61S.

### **Decay data for dose calculations**

#### ***Publications***

- Eckerman K, Endo A. *MIRD: Radionuclide Data and Decay Schemes*. 2008 MIRD compendium. New York: Society of Nuclear Medicine; 2008.
- International Commission on Radiological Protection (ICRP). *Radionuclide Transformations—Energy and Intensity of Emissions*. Publication 38. Oxford: Pergamon Press; 1983.
- Stabin MG, da Luz CQPL. New decay data for internal and external dose assessment. The 2002 RADAR compendium. *Health Phys*. 2002;83(4):471–475.

### **Web sites**

- JAERI (<http://www.jaeri.go.jp/>)
- Brookhaven National Laboratory (<http://www.nndc.bnl.gov/>)
- National Institute of Standards and Technology (<http://physics.nist.gov/PhysRefData/contents.html>)
- Lund University (<http://nucleardata.nuclear.lu.se/nucleardata/toi/index.asp>)
- 2002 RADAR compendium (<http://www.doseinfo-radar.com/RADARDecay.html>)

### **Specific absorbed fractions for standard anthropomorphic phantoms—adult, pediatric, pregnant female**

- Adult and pediatric: Cristy M, Eckerman K. *Specific Absorbed Fractions of Energy at Various Ages from Internal Photons Sources*. ORNL/TM-8381 V1-V7. Oak Ridge, TN: Oak Ridge National Laboratory; 1987.
- Pregnant female: Stabin M, Watson E, Cristy M, Ryman J, Eckerman K, Davis J, Marshall D, Gehlen K. *Mathematical Models and Specific Absorbed Fractions of Photon Energy in the Nonpregnant Adult Female and at the End of Each Trimester of Pregnancy*. ORNL/TM-12907. Oak Ridge, TN: Oak Ridge National Laboratory; 1995.
- Electronic tables of all specific absorbed fractions available on the RADAR Web site (<http://www.doseinfo-radar.com/RADARphan.html>).

### **“Dose Calculators” for standard radiology and nuclear medicine exams, with consent language provided**

- Duke Radiation Safety Committee ([http://www.safety.duke.edu/RadSafety/consents/irbcf\\_asp/adults/default.asp](http://www.safety.duke.edu/RadSafety/consents/irbcf_asp/adults/default.asp))
- RADAR Web site (<http://www.doseinfo-radar.com/RADARDoseRiskCalc.html>)

### **Overview of internal dose literature of MIRD, RADAR, ICRP, NCRP, and others**

- RADAR Web page (<http://www.doseinfo-radar.com/RADARLit.html>)

### **General Internet Resources on Dose Assessment**

- The RADAR dose information site ([www.doseinfo-radar.com](http://www.doseinfo-radar.com))

- Health Physics Society. Ask the experts: dose and dose calculations. <http://hps.org/publicinformation/ate/cat51.html>
- University of Michigan Health Physics Web Site (<http://www.umich.edu/~radinfo/>)

#### 4. Evaluation of radiation overexposure; and medical management of persons overexposed to ionizing radiation

##### *Basic Resources*

- Mettler FA, Jr, Voelz GL. Major radiation exposure—what to expect and how to respond. *N Engl J Med*. 2002;346:1554–1561.
  - *Excellent summary of the medical care of patients overexposed to radiation.*
- *AFRRI Pocket Guide, Emergency Radiation Medical Response September 2007*. Available at: <http://www.afri.usuhs.mil/www/outreach/pdf/pcktcad.pdf>
  - *A brief synopsis of Medical Management of Radiological Casualties Handbook. 2nd ed. Bethesda, MD: Military Medical Operations, Armed Forces Radiobiology Research Institute cited below.*

##### *Further Reading*

- Mettler FA Jr. Medical resources and requirements for responding to radiological terrorism. *Health Phys*. 2005;89(5):488–493.
- Koenig KL, Goans RE, Hatchett RJ, Mettler FA, Jr, Schumacher TA, Noji EK, Jarrett DG. Medical treatment of radiological casualties: current concepts. *Ann Emerg Med*. 2005;45(6):643–652.
- *Medical Management of Radiological Casualties Handbook*. 2nd ed. Bethesda, MD: Military Medical Operations, Armed Forces Radiobiology Research Institute. Available at: <http://www.afri.usuhs.mil/www/outreach/pdf/2edmmrchandbook.pdf>
  - *166 page military manual on the medical management of radiological casualties.*
- National Council on Radiation Protection and Measurements. *Management of Persons Accidentally Contaminated with Radionuclides*. NCRP Report 65; 1980. Available at: [www.ncrponline.org/Publications/65press.html](http://www.ncrponline.org/Publications/65press.html)
  - *Treatment of internal contamination is complex. This 220 page guide is being updated and the new version of the guide should be available in 2008.*

- Biodosimetry Assessment Tool (BAT). Version 1.0. Available at:  
<http://www.afri.usuhs.mil/www/outreach/biodostools.htm>
  - *This program was released on September 21, 2007 as a tool to deliver diagnostic information (clinical signs and symptoms, physical dosimetry, etc.) to federal health care providers responsible for the management of radiation casualties. It is designed primarily for early use after a radiation incident and permits collection, integration and archiving of data obtained from patients accidentally exposed to ionizing radiation.*
  
- Centers for Disease Control and Prevention. *Population monitoring in radiation emergencies: a guide for state and local public health planners*. August 2007. Predecisional draft. Available at:  
<http://emergency.cdc.gov/radiation/pdf/population-monitoring-guide.pdf>
  - *75 pages on the important topic of decontamination and subsequent medical monitoring when there are mass casualties due to an event that results in radiation exposure and/or radioactive contamination.*

#### **Web sites**

- REACTS Web site—Provides 24/7 assistance as well as training for the management of radiation casualties.  
<http://orise.orau.gov/reacts/pubs-resources.htm>  
<http://orise.orau.gov/reacts/guide/index.htm>
  
- The CDC Web site for the management of a terrorist event involving radiation and/ or radioactive materials.  
<http://emergency.cdc.gov/radiation/>  
<http://emergency.cdc.gov/radiation/training.asp>
  
- The HHS Web site for the management of a terrorist event involving radiation and/ or radioactive materials. *Very simple*.  
<http://www.hhs.gov/disasters/emergency/manmadedisasters/radiation/index.html>
  
- The Homeland Security Web site for a terrorist event involving radiation and/ or radioactive materials.  
<http://www.ready.gov/america/beinformed/radiation.html>  
<http://www.ready.gov/america/beinformed/nuclear.html>

## 5. Radioactive materials regulatory issues

### *Basic Resources*

- Harolds J, Graham MM, Maurer A, Guiberteau MJ, Miller TR, Vydareny K. Nuclear medicine/radiology training and certification requirements: recent changes. *Acad Radiol.* 2006;13(11):1405–1409.
  - *A simplified summary of the current NRC requirements as they apply to training. This would be a good starting point in trying to understand the regulations.*
- Foens CS, Fairobent BS, Guiberteau MJ. 10 CFR Part 35: Changes to the NRC rule governing the medical use of radioisotopes and implications for radiologic practice. *J Am Coll Radiol.* 2006;3:96–101.
  - *Concise and clear review of the historical perspective, overview of the revised rule and explanation of the new training and certification processes.*

### *Further Reading*

- Siegel J. *Guide for Diagnostic Nuclear Medicine.* Reston, VA: Society of Nuclear Medicine; 2001. Available at: [www.nrc.gov/materials/miau/miau-reg-initiatives/guide\\_2002.pdf](http://www.nrc.gov/materials/miau/miau-reg-initiatives/guide_2002.pdf)
  - *This sounds like a textbook of nuclear medicine, but since it comes from the NRC is primarily about radiation safety and the regulations. It is nothing short of fantastic. Good overview; clear and easy to understand.*
- Nuclear Regulatory Commission. Part 35: medical use of byproduct material. Available at: <http://www.nrc.gov/reading-rm/doc-collections/cfr/part035/full-text.html>
- Nuclear Regulatory Commission. Part 20: standards for protection against ionizing radiation. Available at: <http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/full-text.html>
  - *These are the full text documents of the NRC regulations affecting nuclear medicine. The regulations are challenging to read and often refer to other parts of the document.*

# Molecular and Cellular Biology Resources List

## Basic principles of molecular and cellular biology, and examples of imaging molecular and cellular targets and processes

### *Basic Resources*

- Massoud TF, Gambhir SS. Molecular imaging in living subjects: seeing fundamental biological processes in a new light. *Genes & Dev.* 2003;17:545–580.
- Gambhir SS, Massoud TF. Molecular imaging fundamentals. In: Ell PJ, Gambhir SS, eds. *Nuclear Medicine in Clinical Diagnosis and Treatment*. Vol. 2. 3rd ed. London: Elsevier Limited; 2004:1845–1870.

### *Further Reading*

- Gambhir SS, Deroose C, Walls Z. Cell biology fundamentals. In: Ell PJ, Gambhir SS, eds. *Nuclear Medicine in Clinical Diagnosis and Treatment*. Vol. 2. 3rd ed. London: Elsevier Limited; 2004:1687–1712.
- Massoud T, Gambhir SS. Integrating noninvasive molecular imaging into molecular medicine: an evolving paradigm. *Trends Mol Med.* 2007;13:183–191.

### *Books*

- Gambhir SS. *Molecular imaging: a primer*. 2008. In Press. Projected publication date is January 2009.
- Semmler W, Schwaiger M. *Molecular imaging I (Handbook of experimental pharmacology)*. 2008.
- Semmler W, Schwaiger M. *Molecular imaging II (Handbook of experimental pharmacology)*. 2008.

### *Journal Review Articles- General*

- Park JM, Gambhir SS. Multimodality radionuclide, fluorescence, and bioluminescence small-animal imaging. *Proc IEEE.* 2005;93(4):771–783.
- Margolis DJA, Hoffman JM, Herfkens RJ, Jeffrey RB, Quon A, Gambhir SS. Molecular imaging techniques in body imaging. *Radiology.* 2007;245:333–356.

## ***Journal Review Articles- By Application Area***

### **Reporter Gene Usage**

- Gross S, Piwnica-Worms D. Spying on cancer: molecular imaging in vivo with genetically encoded reporters. *Cancer Cell*. 2005;7(1):5–15.
- Serganova I, Ponomarev V, Blasberg R. Human reporter genes: potential use in clinical studies. *Nucl Med Biol*. 2007;34:791–807.

### **Drug Discovery**

- Gross S, Piwnica-Worms D. Molecular imaging strategies for drug discovery and development. *Curr Opin Chem Biol*. 2006;10:334–342.

### **Cancer**

- Weissleder R, Pittet M. Imaging in the era of molecular oncology. *Nature*. 2008;452:580–589.
- Weissleder R. Molecular imaging in cancer. *Science*. 2006;312:1168–1171.

### **Neurosciences**

- Hammoud D, Hoffman J., Pomper M. Molecular neuroimaging: from conventional to emerging techniques. *Radiology*. 2007;245(1):21–42.
- Andreas HJ, Winkler A, Castro MG, Lowenstein P. Human gene therapy and imaging in neurological diseases. *Eur J Nucl Med Mol Imaging*. 2005;32:S358–S383.

### **Cardiology**

- Wu JC, Bengel FM, Gambhir SS. Cardiovascular molecular imaging. *Radiology*. 2007;244(2):337–355.
- Zhang SJ, Wu JC. Comparison of imaging techniques for tracking cardiac stem cell therapy. *J Nucl Med*. 2007;48(12):1916-1919.

### **Immunology**

- Gross S, Piwnica-Worms D. Veni, vidi, vici: in vivo molecular imaging of immune response. *Immunity*. 2007;27(10):533–538.

### **Angiogenesis**

- Advances in anatomical, functional, and molecular imaging of angiogenesis. *J Nucl Med*. 2008; 49: 511-514.

# Molecular Imaging Agents Resources List

## 1. Established radiopharmaceuticals

### *Basic Resources*

- Welch MJ, Redvanly CS, eds. *Handbook of Radiopharmaceuticals: Radiochemistry and Applications*. New York: Wiley; 2003.
- Saha GB. *Fundamentals of Nuclear Pharmacy*. 5th ed. New York: Springer-Verlag; 2004.
- Phelps ME, ed. *PET: Molecular Imaging and Its Biological Applications*. New York: Springer-Verlag; 2004:1–124.
  - *This is a detailed overview of PET including instrumentation, radiochemistry, kinetic modeling, preclinical and clinical applications.*

## 2. Emerging Radiopharmaceuticals: Production, radiochemistry, pharmacokinetics

### *Basic Resources*

- Welch MJ, Laforest R, Lewis JS. Production of non-standard PET radionuclides and the application of radiopharmaceuticals labeled with these nuclides. [Review.] *Ernst Schering Res Found Workshop*. 2007;(62):159–181.
- Cherry SR. The 2006 Henry N. Wagner lecture: of mice and men (and positrons)—advances in PET imaging technology. *J Nucl Med*. 2006;47(11):1735–1745.

### **Antibodies**

- Wu AM, Olafsen T. Antibodies for molecular imaging of cancer. *The Cancer Journal: The Journal of Principles and Practice of Oncology*. In press.

### **Peptides**

- Knight LC. Radiolabeled peptides for tumor imaging. In: Welch MJ, Redvanly CS, eds. *Handbook of Radiopharmaceuticals: Radiochemistry and Applications*. New York: Wiley; 2003:643–684.
- Weiner RE, Thakur ML. Developments of radiolabeled peptides. In: Chinol M, Paganelli G., eds. *Radionuclide Peptide Cancer Therapy*. New York: Taylor & Francis; 2006:41–85.
- Liu S. Radiolabeled multimeric cyclic RGD peptides as integrin  $\alpha v \beta 3$  targeted radiotracers for tumor imaging. *Mol Pharm*. 2006;3(5):472–487.

### ***Further Reading***

- Massoud TF, Spencer RP. Radiopharmaceuticals for cancer imaging: nature, mechanisms of localization, and molecular targets. In: Ell PJ, Gambhir SS, eds. *Nuclear Medicine in Clinical Diagnosis and Treatment*. Vol. 1. 3rd ed. London: Elsevier Limited; 2004:3–14.
- Optimization of synthesis and quality control procedures for the preparation of  $^{18}\text{F}$  and  $^{123}\text{I}$  labeled peptides for nuclear medicine. IAEA, TECDOC 1310; 2002. Available at: [http://www-pub.iaea.org/MTCD/publications/PDF/te\\_1310\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/te_1310_web.pdf)
- Labelling of small biomolecules using novel technetium-99m cores. IAEA, Technical Reports series 459; 2007. Available at: [http://www-pub.iaea.org/MTCD/publications/PDF/trs459\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/trs459_web.pdf)
- Development of agents for imaging CNS receptors based on  $^{99\text{m}}\text{Tc}$ . IAEA, Technical Reports series 459; 2004. Available at: [http://www-pub.iaea.org/MTCD/publications/PDF/TRS426\\_web.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/TRS426_web.pdf)
- Ponto JA. Radiopharmaceuticals. *Radiographics*. 1998;18(6):1395–1404.

### **3. Non-radioactive agents (e.g., optical, ultrasound, MR, CT): fluorescent dyes and proteins (including near-infrared), microbubbles, nanoparticles, contrast agents.**

### **Bioluminescence and optical imaging**

#### ***Basic Resources***

- Weissleder R, Ntziachristos V. Shedding light onto live molecular targets. *Nature Medicine* 2003;9:123–128. [all optical imaging; excellent overview]
- Thorne, SH, Contag CH. Using in vivo bioluminescence imaging to shed light on cancer biology. *Proc IEEE*. 2005;93(4):750–762.
- Wang LV, Wu H. *Biomedical Optics: Principles and Imaging*. New York: John Wiley and Sons; 2007: Sections 8.9 & 8.10, Chaps. 9, 11, & 12.

#### ***Further Reading***

- Welsh DK, Kay SA. Bioluminescence imaging in living organisms. *Curr Opin Biotechnol*. 2005;16(1):73–78.
- Contag C. In vivo pathology: seeing with molecular specificity and cellular resolution in the living body. *Annu Rev Pathol Mech Dis*. 2007;2:277–305.
- Wang G, Cong W, Shen H, Qian X, Henry M, Wang Y. Overview of bioluminescence tomography—a new molecular imaging modality. *Front Biosci*. 2008;13:1281–1293.

- Culver J, Akers W, Achilefu S. Multimodality molecular imaging with combined optical and SPECT/PET modalities. *J Nucl Med.* 2008;49:169–172. <http://jnm.snmjournals.org/cgi/content/abstract/49/2/169>
- Optical imaging: current applications and future directions. *J Nucl Med.* 2008; 49: 1-4.

## **Fluorescent imaging probes**

### ***Basic Resources***

- Rao J, Draglescu-Andrasi A, Yao H. Fluorescence imaging in vivo: recent advances. *Curr Opin Biotechnol.* 2007;18:17–25.
- Ntziachristos V. Fluorescence molecular imaging. *Annu Rev Biomed Eng.* 2006; 8:1–33.

### ***Further Reading***

- Kovar JL, Simpson MA, Schutz-Geschwender A, Oliver DM. A systematic approach to the development of fluorescence contrast agents for optical imaging of mouse cancer models. *Anal Biochem.* 2007;367:1–12.
- Shaner NC, Stienbach PA, Tsien RY. A guide to choosing fluorescent proteins. *Nat Methods.* 2005;2:905–909.

## **Nanoparticles in molecular imaging**

### ***Basic Resources***

- Sharma P, Brown S, Walter G, Santra S, Moudgil B. Nanoparticles for bioimaging. *Adv Colloid Interface Sci.* 2006;123:471–485.

### ***Further Reading***

- Mitra A, Nan A, Line B, Ghandehari H. Nanocarriers for nuclear imaging and radiotherapy of cancer. *Curr Pharm Des.* 2006;12:4729–4749.
- Michalet X, Pinaud FF, Bentolila LA, et al. Quantum dots for live cells, *in vivo* imaging, and diagnostics. *Science.* 2005;307:538–544.
- Nie S, Xing Y, Kim GJ, Simons JW. Nanotechnology applications in cancer. *Annu Rev Biomed Eng.* 2007;9:257–288.

## Small Animal Imaging

### *Basic Resources*

- Culver J, Akers W, Achilefu S. Multimodality molecular imaging with combined optical and SPECT/PET modalities. *J Nucl Med.* 2008;49:169–172. <http://jnm.snmjournals.org/cgi/content/abstract/49/2/169>
- Beckmann N, Kneuer R, Gremlich HU, Karmouty-Quintana H, Blé FX, Müller M. In vivo mouse imaging and spectroscopy in drug discovery. *NMR Biomed.* 2007;20(3):154–185.
- Koo V, Hamilton PW, Williamson K. Non-invasive in vivo imaging in small animal research. *Cell Oncol.* 2006;28(4):127–139.
- Cherry SR. In-vivo whole-body imaging of the laboratory mouse. In: Fox JG, ed. *The Mouse in Biomedical Research*. 2nd ed. Boston: Elsevier; 2007:487–509. *This is a good introductory chapter that discusses each small animal imaging modality, how it is used, and what are the applications.*

### **Websites with Educational Opportunities and Information on Molecular Imaging**

- <http://srs.snm.org/index.cfm?pageid=5328&rpId=3029>
- <http://mips.stanford.edu/public/classes/bioe222/2007/>

### **JNM Review Articles**

- Molecular and Functional MRI of the Tumor Microenvironment. *J Nucl Med.* 2008; 49: 687-690.