RESOURCE LETTER

Resource Letters are guides for college and university physicists, astronomers, and other scientists to literature, websites, and other teaching aids. Each Resource Letter focuses on a particular topic and is intended to help teachers improve course content in a specific field of physics or to introduce nonspecialists to this field. The Resource Letters Editorial Board meets at the AAPT Winter Meeting to choose topics for which Resource Letters will be commissioned during the ensuing year. Items in the Resource Letter below are labeled with the letter E to indicate elementary level or material of general interest to persons seeking to become informed in the field, the letter I to indicate intermediate level or somewhat specialized material, or the letter A to indicate advanced or specialized material. No Resource Letter is meant to be exhaustive and complete; in time there may be more than one Resource Letter on a given subject. A complete list by field of all Resource Letters published to date is at the website www.kzoo.edu/ajp/letters.html. Suggestions for future Resource Letters, including those of high pedagogical value, are welcome and should be sent to Professor Roger H. Stuewer, Editor, AAPT Resource Letters, School of Physics and Astronomy, University of Minnesota, 116 Church Street SE, Minneapolis, MN 55455; e-mail: rstuewer@physics.umn.edu

Resource Letter MPRT-1: Medical Physics in Radiation Therapy

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This resource letter provides a guide to the literature on medical physics in the field of radiation therapy. Journal articles, books, and websites are cited for the following topics: radiological physics, particle accelerators, radiation dose measurements, protocols for radiation dose measurements, radiation shielding and radiation protection, neutron, proton, and heavy-ion therapies, imaging for radiation therapy, brachytherapy, quality assurance, treatment planning, dose calculations, and intensity-modulated and image-guided therapy.

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I. INTRODUCTION

As the name implies, medical physics deals with physics as applied to medicine; it is sometimes called "applied clinical physics." The four main branches of medical physics are the physics of radiation therapy, the physics of medical imaging, the physics of nuclear medicine, and health physics.

The goal of this resource letter is to provide a guide to the literature for the first branch of medical physics—the physics of radiation therapy (also known as "radiation oncology physics," "therapeutic radiologic physics," or "radiotherapy physics")—whose main application is the treatment of cancer with ionizing radiation. The references given here are not intended to be exhaustive, but are intended to provide some guidance for nonspecialists or for those wanting to explore the field.

Cancer is the second-leading cause of death in the United States and a major cause worldwide. Approximately half of all cancer treatments in the United States use radiation therapy. The goal of radiation therapy is to kill tumor cells by causing irreparable damage to their DNA, while exposing normal cells to as little damage as possible. This is done with targeted beams of ionizing radiation—photons, electrons, neutrons, protons, or heavy ions (e.g., carbon ions). At present, most treatments use photons. Radiotherapy of all kinds is divided into two types: teletherapy (long-range therapy—radiation enters the tumor from outside the body) and brachytherapy (short-range therapy—radiation comes from radioactive sources placed inside the body).

II. RELATED RESOURCE LETTERS

1. **Resource Letter PA-1 on Particle Accelerators**, John P. Blewett, Am. J. Phys. **34**, 742–752 (1966).
2. **Resource Letter XR-1 on X-Rays**, Leonard Muldawer, Am. J. Phys. **37**, 123–134 (1969).
3. **Resource Letter MP-1: Medical physics**, Russell K. Hobbie, Am. J. Phys. **53**, 822–829 (1985).
4. **Resource Letter MI-1: Medical imaging**, Stephen J. Riederer, Am. J. Phys. **60**, 682–693 (1992).
5. **Resource Letter EIRLD-1: Effects of ionizing radiation at low doses**, Richard Wilson, Am. J. Phys. **67**, 372–377 (1999).
6. **Resource Letter PBA-1: Particle beams and accelerators**, Alexander W. Chao, Am. J. Phys. **74**, 855–862 (2006).
7. **Resource Letter MP-2: Medical physics**, Russell K. Hobbie and Bradley J. Roth, Am. J. Phys. (forthcoming).

III. JOURNALS

Applied Radiation and Isotopes
Brachytherapy Journal
British Journal of Radiology
International Journal of Radiation Oncology, Biology, Physics
Journal of Applied Clinical Medical Physics
Journal of the American Brachytherapy Society
Journal of the Canadian Association of Radiologists
Medical Dosimetry
Medical Physics
Nuclear Instruments and Methods
Physica Medica: European Journal of Medical Physics
Physics in Medicine and Biology
Radiation Physics and Chemistry
Radiation Research
Radiology
Radiotherapy and Oncology

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IV. CONFERENCE PROCEEDINGS

8. American Association of Physicists in Medicine Summer School Proceedings.
9. American Institute of Physics Conference Proceedings, Mexican Symposia on Medical Physics. There is a symposium every two years.
10. "International Workshop on Monte Carlo Techniques in Radiotherapy Delivery and Verification," J. Phys.: Conf. Ser. **102**, 011001–012027 (2008). Available at ⟨http://www.iop.org/EJ/toc/1742-6596/102/1⟩.
11. Proceedings of the International Conference on Luminescence Dosimetry.
12. Proceedings of the International Conference on the Use of Computers in Radiotherapy.
13. "Standards and Codes of Practice in Medical Radiation Dosimetry," Proceedings of an International Symposium, 25–28 November 2002 (International Atomic Energy Agency, Vienna, 2002).

V. REFERENCES

A. Radiological physics and general references

Radiological physics is concerned with the physics of ionizing radiation, including atomic models, x-ray production, and interactions of neutrons, charged particles, and photons with matter. The energy lost by a fast charged particle owing to ionization is given by the Bethe–Bloch formula. The fundamental physics of the interaction of ionizing radiation with matter comes from early papers by Bethe, Bohr, Eyges, Fermi, and others.

14. **Radiation Oncology—A Physicist's Eye View**, Michael Goitein (Springer Science+Business Media, LLC, New York, 2008). An excellent starting point for those new to the field or just wanting to learn more about it. (E)
15. **The Physics of Radiology**, Harold Elford Johns and John Robert Cunningham, 4th ed. (Charles C. Thomas, Springfield, Illinois, 1983). A standard text; excellent, but somewhat dated. (I)
16. **The Physics of Radiation Therapy**, Faiz M. Khan, 3rd ed. (Lippincott Williams and Wilkins, Philadelphia, PA, 2003). Most useful as a handbook or a reference to those who already know the subject. If you work in this field and you ask someone a question, you will sometimes be told, "It's in Khan!" or, "Look it up in Khan!" However, this is not the best place for a beginner to start. Difficulty level varies quite a bit throughout the book. A fourth edition is now available; these comments apply to the third edition. (I, A)
17. **The Modern Technology of Radiation Oncology—A Compendium for Medical Physicists and Radiation Oncologists**, Vols. 1 and 2, edited by Jacob Van Dyk (Medical Physics, Madison, WI, 1999 and 2005). A clinical approach to the subject. (I)
18. **Handbook of Radiotherapy Physics—Theory and Practice**, edited by P. Mayles, A. Nahum, and J. C. Rosenwald (Taylor & Francis, New York, 2007). A comprehensive and well-written reference (1432 pages). (I)
19. **Introduction to Radiological Physics and Radiation Dosimetry**, Frank Herbert Attix (Wiley-VCH, Weinheim, Germany, 1986). (A)
20. **Foundation of Radiological Physics**, Cheng B. Saw (C. B. Saw, LLC, Omaha, Nebraska, 2004). Starts with basic mathematics and general college-level physics. (E, I)
21. **Absorption of Ionizing Radiation**, David W. Anderson (U. Park Press, Baltimore, 1984). Good discussion of the physics of the interaction of photons, neutrons, and charged particles with matter. Good discussion of excitation processes in semiconductors (helpful for understanding semiconductor diode radiation detectors). (I)
22. **Radiation Dosimetry**, Vol. 1, "Fundamentals," edited by Frank H. Attix and William C. Roesch, 2nd ed. (Academic, New York, 1968). A very good book with much useful physics. (A)
23. **Radiation Dosimetry**, Vol. 2, "Instrumentation," edited by Frank H. Attix and William C. Roesch, 2nd ed. (Academic, New York, 1966). Covers the physics and design of instruments to measure radiation dose. Very good discussion of the relevant physics. (A)
24. **Radiation Dosimetry**, Vol. 3, "Sources, fields, measurements, and applications," edited by Frank H. Attix and Eugene Tochilin, 2nd ed. (Academic, New York, 1969). Covers a wide range of topics, with a good discussion of the relevant physics. Also covers other topics such as radiation in space flight and the use of radiation to sterilize food or medical supplies. (A)
25. "Radiation in the treatment of cancer," Arthur L. Boyer, Michael Goitein, Antony J. Lomax, and Eros S. Pedroni, Phys. Today **55**(9), 34–36 (2002). (E)
26. **Radiation Physics for Medical Physicists**, E. B. Podgorsak (Springer-Verlag, New York, 2006). Discusses the physics of ionizing radiation. Has chapters on modern physics, the Rutherford–Bohr atomic model, production of x-rays, collisions, interactions of charged particles and photons with matter, and radioactivity. Very readable. (I)
27. **Radiation Oncology Physics: A Handbook for Teachers and Students**, edited by E. B. Podgorsak (International Atomic Energy Agency, Vienna, 2005). Clear and readable. Also available on the Internet (see Sec. VIII, "WEBSITES"). (I)
28. **Interaction of Particles and Radiation with Matter**, V. Balashov (Springer-Verlag, New York, 1997). Based on 14 lectures given at Moscow State University. (A)
29. **The Fundamentals of Radiological Science**, John Hale (Charles C. Thomas, Springfield, IL, 1974). Starts with a review of basic mathematics and physics. Discusses atomic and nuclear physics, methods of producing radiation, interaction of radiation with matter, radiation dose, and exposure. (E)
30. **Radiation Therapy Physics**, William R. Hendee, Geoffrey S. Ibbott, and Eric G. Hendee, 3rd ed. (Wiley, Hoboken, NJ, 2005). (I)
31. **Physics and Dosimetry of Therapy Electron Beams**, Stanley C. Klevenhagen (Medical Physics, Madison, WI, 1993). Comprehensive discussion of fundamental electron physics, measurement theory, ionization chambers, measurements, and absorbed-dose calibration. (A)
32. **Physics of Nuclei and Particles**, Vol. 1, Pierre Marmier and Eric Sheldon (Academic, New York, 1994). See especially Chap. 4 ("Passage of Ionizing Radiation through Matter"), Chap. 6 ("Radioactivity"), and Appendix H ("Radiation Dosimetry"). There are two other volumes with the same title, but only this volume is directly relevant to radiotherapy. (I, A)
33. "On the theory of the decrease of velocity of moving electrified particles on passing through matter," N. Bohr, Philos. Mag. **25**(145), 10–31 (1913). (A)
34. "Über die Streuung von Strahlung durch freie Elektronen nach der neuen relativistischen Quantendynamik von Dirac," O. Klein and Y. Nishina, Z. Phys. **52**, 853–868 (1929). (A)
35. "On the stopping of fast particles and on the creation of positive electrons," H. Bethe and W. Heitler, Proc. R. Soc. London, Ser. A **146**, 83–112 (1934). (A)
36. "Multiple scattering with energy loss," Leonard Eyges, Phys. Rev. **74**(10), 1534–1535 (1948). Today the theory described here is referred to as the "Fermi–Eyges theory." Describes the effect of multiple small-angle Coulomb scattering of electrons. (A)
37. "Part II: Passage of radiations through matter," H. A. Bethe and J. Ashkin, in **Experimental Nuclear Physics**, Vol. 1, edited by E. Segrè (Wiley, New York, 1953), pp. 166–357. (A)
38. "Review of electron therapy physics," Kenneth R. Hogstrom and Peter R. Almond, Phys. Med. Biol. **51**(13), R455–R489 (2006). (A)
39. "Electron dose calculation using multiple-scattering theory: A new theory of multiple scattering," David Jette, Med. Phys. **23**(4), 459–477 (1996). (A)
40. "Multiple scattering theory for total skin electron beam design," John A. Antolak and Kenneth R. Hogstrom, Med. Phys. **25**(6), 851–859 (1998). (A)

B. Particle accelerators

The workhorse of radiation oncology is the medical linear electron accelerator, which produces a high-energy beam of electrons. The electrons can be used directly for electron therapy. Photons are produced through the bremsstrahlung effect by allowing the electrons to strike a material such as tungsten. As of June 2000, there were about 15 000 particle accelerators in the world; about 5000 of these were used for radiotherapy (David Robin, Ref. 48, Lecture 1).

41. **The Physics of Radiotherapy X-Rays from Linear Accelerators**, Peter Metcalfe, Tomas Kron, and Peter Hoban (Medical Physics, Madison, WI, 2002). Written for radiation oncology physicists. Explains how linear accelerators work. Has chapters on x-ray beam properties, treatment planning, photon-beam modeling, inhomogeneity corrections, Monte Carlo programs to model dose distributions, and the response of tumors and normal tissue to radiation. Good list of references at the end of each chapter. Comprehensive and clinically oriented approach. (I)
42. **Medical Electron Accelerators**, C. J. Karzmark, Craig S. Nunan, and Eiji Tanabe (McGraw-Hill, Health Professions Division, New York, 1993). The standard reference on medical linear electron accelerators. (I, A)
43. **A Primer on Theory and Operation of Linear Accelerators in Radiation Therapy**, C. J. Karzmark and Robert J. Morton (Medical Physics, Madison, WI, 1989). A condensed version of Ref. 42. (I)
44. **Linear Accelerators for Radiation Therapy**, David Greene and Peter C. Williams, 2nd ed. (Institute of Physics, Bristol, 1997). Describes how a medical linear accelerator works, including descriptions of the waveguide, microwave system, high-voltage power supplies, vacuum and cooling systems, electron-beam optics, treatment head, dose monitoring and control system, beam shaping system, mechanical systems, controls, and interlocks, along with discussions of calibration, radiation protection, room design, and accelerator operation. (I)
45. **Classical Electrodynamics**, John David Jackson, 3rd ed. (Wiley, New York, 1999). (A)
46. "Electron linear accelerators for radiation therapy: History, principles and contemporary developments," C. J. Karzmark and Neil C. Pering, Phys. Med. Biol. **18**(3), 321–354 (1973). Review article. (I)
47. **Particle Accelerator Physics***,* Helmut Wiedemann, 3rd ed. (Springer-Verlag, Berlin, 2007). Combines the contents of three earlier volumes into one volume. (A)
48. "Fundamental accelerator theory, simulations and measurements lab," Soren Prestemon, David Robin, and Fernando Sannibale, Arizona State University, Phoenix, January 16–27, 2006. Available at ⟨http://controls.als.lbl.gov/als_physics/Fernando/USPASJan06Lectures/⟩. A series of lectures on particle accelerators. Lecture 1, on history, is quite interesting. Lecture 4 is an excellent discussion of linear accelerators, radio frequency accelerating structures, circular accelerators, and klystrons. (A)
49. "Introduction to electrodynamics for microwave linear accelerators," David Whittum, Stanford Linear Accelerator Center, Stanford University, SLAC-PUB-7802 (April 1982). Available at ⟨http://www.slac.stanford.edu/pubs/slacpubs/7000/slac-pub-7802.html⟩. (I, A)
50. "Introduction to microwave linacs," David Whittum, Stanford Linear Accelerator Center, Stanford University, SLAC-PUB-8026 (December 1998). Available at ⟨http://www.slac.stanford.edu/pubs/slacpubs/8000/slac-pub-8026.html⟩. (I, A)
51. **Proton Radiotherapy Accelerators**, Wioletta Wieszczycka and Waldemar H. Scharf (Word Scientific, River Edge, NJ, 2001). (I)
52. **Biomedical Particle Accelerators**, Waldemar H. Scharf (American Institute of Physics, Woodbury, NY, 1994). (I)

C. Radiation dose measurements

1. General references

Absorbed radiation dose is measured in gray (Gy), which is defined to be equal to 1 J of energy absorbed per kg of material: $1\ \text{Gy}=1\ \text{J/kg}$. The older, non-SI unit is the rad ($1\ \text{cGy}=1\ \text{rad}$). The medical physicist is responsible for calibrating the radiation output of the various radiotherapy treatment devices.

Dose calibrations are performed using dose to water as the standard:

> "For dosimetric work, the human body has been considered water equivalent for two main reasons: First, differences in atomic composition and density between water and soft tissues are small and the accuracy in absorbed dose determination is not high enough to justify the small correction these differences introduce; second, determination of the size and composition of the various internal organs is complicated, and to assume that the whole body is water equivalent is believed to be a safer basis for dosimetry." (Andrée Dutreix and André Bridier, Ref. 55, Chap. 3, p. 169).

53. Special issue on Radiation Dosimetry, Metrologia **46**, S1–S138 (2009). (I)
54. **Radiation Detection and Measurement**, Glenn F. Knoll, 3rd ed. (Wiley, New York, 2000). A standard reference on radiation detection. (I)
55. **The Dosimetry of Ionizing Radiation**, Vol. 1, edited by Kenneth R. Kase, Bengt E. Bjärngard, and Frank H. Attix (Academic, Orlando, FL, 1985). Discusses the theoretical basis for dosimetry. (A)
56. **The Dosimetry of Ionizing Radiation**, Vol. 2, edited by Kenneth R. Kase, Bengt E. Bjärngard, and Frank H. Attix (Academic, Orlando, FL, 1987). Includes good discussions of the relationship between dosimetry and radiobiology, ionization chambers, and calorimeters. (A)

2. Calorimeters

Calorimeters directly measure the energy absorbed through the small temperature increase that occurs when a material is irradiated. Calorimeters are designed to properly take into account thermal drifts and thermal gradients. Several different kinds of materials are used: water, graphite, graphite-water (where the dose to a small piece of graphite is measured in a water tank), and polystyrene-water.

57. "Advances in calorimetry for radiation dosimetry," Steve R. Domen, Ref. 56, pp. 245–320. A nice discussion of calorimeter theory, design, and measurements. (I, A)

3. Chemical dosimeters

Chemical dosimeters measure radiation dose by measuring a chemical change in a fluid, solid, or gas. The two basic types are aqueous dosimeters (using ferrous sulfate, ceric sulfate, ferrous sulfate-cupric sulfate, or oxalic acid) and nonaqueous dosimeters (nitrous oxide and various polymers). The most famous type is the Fricke dosimeter where the absorbed dose of radiation affects the rate of oxidation of an aerated ferrous sulfate solution. Fricke dosimeters can measure the radiation dose to within 1%–2%. Newer methods include the use of a gel that is optically read out.

58. "The chemical action of roentgen rays on dilute ferrous sulphate solutions as a measure of dose," Hugo Fricke and Sterne Morse, Am. J. Roentgenol., Radium Ther., and Nucl. Med. **18**(5), 430–432 (1927). One of the original papers on the Fricke dosimeter. (I)
59. "The action of x-rays on ferrous sulphate solutions," Hugo Fricke and Sterne Morse, Philos. Mag. **7**(41), 129–141 (1929). (I)

4. Computed radiography

Computed radiography (CR) is a digital alternative to film. X-rays excite electrons in the CR plate into metastable states. The material is read out through a laser beam, which causes the excited electrons to fall back to the ground state, emitting light. CR plates have a wide dynamic range compared to film along with many of the advantages of film except that no chemicals are needed for development. The plates are reusable. The image fades exponentially after exposure and should be read out within several hours from the time of exposure.

60. "Digital radiography using storage phosphors," Ralph Schaetzing, Bruce R. Whiting, Anthony R. Lubinsky, and James F. Owen, in **Digital Imaging in Diagnostic Radiology**, edited by John D. Newell, Jr. and Charles A. Kelsey (Churchill Livingstone, New York, 1990), pp. 107–138. (I)

61. "The physics of computed radiography," J. A. Rowlands, Phys. Med. Biol. **47**, R123–R166 (2002). Excellent resource with extensive references. A good place to start if you want to learn about CR in depth. (I, A)

62. "Evaluation of a computed radiography system for megavoltage photon beam dosimetry," Arthur J. Olch, Med. Phys. **32**(9), 2987–2999 (2005). A good discussion focusing on using CR for two-dimensional dosimetry (to replace film) in radiotherapy. (I)

63. "The physics of computed radiography: Measurements of pulse height spectra of photostimulable phosphor screens using prompt luminescence," Kristina N. Watt, Kuo Yan, Giovanni DeCrescenzo, and J. A. Rowlands, Med. Phys. **32**(12), 3589–3598 (2005). (A)

64. "Dose response of $\mathrm{BaFBrI:Eu^{2+}}$ storage phosphor plates exposed to megavoltage photon beams," H. Harold Li, Albin L. Gonzalez, Huaying Ji, and Dennis M. Duggan, Med. Phys. **34**(1), 103–111 (2007). (A)

5. Film

Film is relatively low cost and provides planar information with high spatial resolution. Unfortunately, owing to the relatively high atomic number of the silver grains, film overresponds to low-energy photons owing to the photoelectric effect. To achieve the greatest accuracy one must only use films from the same batch and pay careful attention to film processing parameters.

Suppose that a piece of film is exposed to radiation of photon fluence F (where F is the number of photons incident per unit area perpendicular to the direction of incidence) and then developed. We can read the developed film by measuring how much light is transmitted through the film. The optical density is defined as $D=\log_{10}(I_0/I)$, where I_0 is the incident light intensity and I is the transmitted light intensity. If we define $k=\log_{10}(e)$, a=average area of a developed grain, and N=total number of grains per unit area in the emulsion, then it can be shown (Ref. 65, pp. 331, 335–337) that for low fluence ($aF \ll 1$) the optical density is given by $D \approx ka^2NF$.

65. "Dosimetry with photographic emulsions," Robert A. Dudley, in **Radiation Dosimetry**, edited by Frank H. Attix and William C. Roesch (Academic, New York, 1966), Vol. 2, pp. 325–387. (I)

66. "Radiochromic film dosimetry: Recommendations of AAPM Radiation Therapy Committee Task Group 55," Azam Niroomand-Rad, Charles Robert Blackwell, Bert M. Coursey, Kenneth P. Gall, James M. Galvin, William L. McLaughlin, Ali S. Meigooni, Ravinder Nath, James E. Rodgers, and Christopher G. Soares, Med. Phys. **25**(11), 2093–2115 (1998). Radiochromic film is a more convenient alternative to standard film. It changes color after exposure to radiation and does not require chemical processing. (I)

6. Ionization chambers

Ionization chambers collect the charge produced by ionizing radiation (which is measured with an electrometer). This charge is then used to determine the absorbed dose. Several chamber geometries are used, including cylindrical, parallel plate, and re-entrant. The charge can be collected in various substances. Air is most commonly used, but other gases can be used, as well as various liquids. For accurate measurements, the problems of recombination and polarity effects must be addressed. The most widely used ionization chamber for megavoltage therapy measurements is the cylindrical chamber (known as the Farmer chamber), which is accurate to within 1%–2%. In most cases in radiotherapy medical physics, an ionization chamber measurement is the "gold standard."

67. "Ionization chambers," J. W. Boag, Ref. 56, pp. 169–243. A very good discussion of the physics and design of ionization chambers. (I)

68. "Ionizing radiation dosimetry and medical physics," D. W. O. Rogers, Phys. Can. **51**(4), 178–181 (1995). A good introduction to the theory upon which ionization chamber measurements are based. (I)

69. "Dosimetry instrumentation," L. J. Humphries and T. W. Slowey, in **Radiation Oncology Physics 1986**, Medical Physics Monograph No. 15, edited by James G. Kereiakes, Howard R. Elson, and Clifford G. Born (American Institute of Physics, New York, 1987), pp. 110–138. Excellent discussion of the hardware aspects of ionization chambers and electrometers. (I)

70. Ionization Chambers and Counters—Experimental Techniques, Bruno B. Rossi and Hans H. Staub (McGraw-Hill, New York, 1949). Part of a series of books documenting unclassified scientific work done on the Manhattan Project. Owing to the magnitude of the writing project, the writers did not feel that it would be practical to include references. Discusses the physics, properties, and construction of radiation detectors based on ionization. (A)

71. Review of data and methods recommended in the international code of practice for dosimetry, IAEA Technical Reports Series No. 381, The Use of Plane Parallel Ionization Chambers in High Energy Electron and Photon Beams, International Atomic Energy Agency (IAEA), IAEA-TECDOC-1173 (IAEA, Vienna, 2000). Available at ⟨http://www-pub.iaea.org/mtcd/publications/pdf/te_1173_prn.pdf⟩. (A)

72. Ionization Chambers and Counters, D. H. Wilkinson (Cambridge U. P., Cambridge, 1950). (A)

7. Semiconductor detectors

Radiation incident on a semiconductor diode induces a current that is proportional to the radiation dose. One advantage of diodes is that they can be placed on a patient's skin.

73. For an excellent discussion of semiconductor detectors, see Ref. 54, Chap. 11 ("Semiconductor diode detectors"), pp. 337–386. (I)

74. Another excellent discussion is found in Ref. 21, Chap. 12 ("Excitation and de-excitation in crystalline solids"), pp. 281–313. The chapter also has sections on thermoluminescence and film emulsion. (I, A)

75. "Bandgap dependence and related features of radiation ionization energies in semiconductors," Claude A. Klein, J. Appl. Phys. **39**(4), 2029–2038 (1968). (A)

76. "Diode in vivo dosimetry for patients receiving external beam radiation therapy," Task Group 62 of the Radiation Therapy Subcommittee, American Association of Physicists in Medicine Report No. 87 (Medical Physics, Madison, WI, 2005). (I)

77. "Use of silicon detectors in medical physics," Luis Manuel Montaño Zetina, AIP Conf. Proc. **857**, 355–363 (2006). (I)

8. Thermoluminescent dosimeters

Since the Middle Ages, it has been known that certain rocks give off light when heated. In the 17th century, Robert Boyle heated a diamond in a dark room and observed that light was given off. In a thermoluminescent material, ionizing radiation absorbed in the material causes electrons to be stored in metastable states. Heating the material can cause the electrons to return to their ground state. The energy released is related to the initial dose of radiation. Thermoluminescent dosimeters (TLDs) can be used as personal dosimeters for radiation protection and as dosimetric devices to measure radiation dose absorbed in a material (thermoluminescent effects can also be used for the dating of rocks). A common TLD material is lithium fluoride, which is "among the best-studied materials on earth" (Ref. 81, preface). It has an effective atomic number close to that of human tissue, it is durable, and can be manufactured in a variety of shapes. Thermoluminescent materials are like CR plates in that both materials utilize radiation-induced metastable states.

78. **Thermoluminescence of Solids**, S. W. S. McKeever (Cambridge U. P., Cambridge, 1985). (I)
79. **Thermoluminescent Dosimetry**, J. R. Cameron, N. Suntharalingam, and G. N. Kenney (U. of Wisconsin Press, Madison, WI, 1968). (I)
80. "Luminescence dosimetry," C. J. Karzmark, F. H. Attix, and Catharine L. Wingate, Science **150**(3694), 391–394 (1965). Summarizes the First International Conference on Luminescence Dosimetry (Ref. 84). (I)
81. **Solid State Dosimetry**, Klaus Becker (CRC, Boca Raton, FL, 1973). Includes an interesting discussion of the history of solid-state dosimetry. It is a good reference for thermoluminescence, although (despite its name) it has very little information on semiconductor diode detectors. (I)
82. "Phosphorescence and electron traps. I. The study of trap distributions," J. T. Randall and M. H. F. Wilkins, Proc. R. Soc. London, Ser. A **184**, 365–389 (1945). (I)
83. "Phosphorescence and electron traps. II. The interpretation of long-period phosphorescence," J. T. Randall and M. H. F. Wilkins, Proc. R. Soc. London, Ser. A **184**, 390–407 (1945). (I)
84. **Luminescence Dosimetry**, Proceedings of the First International Conference on Luminescence Dosimetry, Stanford, CA, 21–23 June 1965, AEC Symposium, Vol. 8, CONF-650637 (Division of Technical Information, U. S. Atomic Energy Commission, 1967). According to John Cameron, this is "perhaps the most important" reference on thermoluminescence dosimetry. (A)

D. Protocols for radiation dose measurements

Using ionization chambers and electrometers traceable to a national standards laboratory, the medical physicist determines the radiation dose in water to within a percent or so through a standard methodology. Since the disturbing influence of the chamber itself is accounted for, the protocols determine the dose to water at a specified location in the absence of the chamber. Correction factors include those for temperature, pressure, ion recombination, electrometer error, and chamber polarity effects.

85. "Anniversary Paper: Fifty years of AAPM involvement in radiation dosimetry," G. Ibbott, C.-M. Ma, D. W. O. Rogers, S. M. Seltzer, and J. F. Williamson, Med. Phys. **35**, 1418–1427 (2008). Reviews measurement protocols, standards, calibration, and calibration laboratories. Provides a good overview of the subject. (E, I)
86. "A protocol for the determination of absorbed dose from high-energy photon and electron beams," Robert J. Schulz, Peter R. Almond, John R. Cunningham, J. Garrett Holt, Robert Loevinger, Nagalingam Suntharalingam, Kenneth A. Wright, Ravinder Nath, and Geoffrey D. Lempert, Task Group 21 [TG-21], Radiation Therapy Committee, American Association of Physicists in Medicine, Med. Phys. **10**, 741–771 (1983). Not the current protocol, but useful for its physics-based approach. The absorbed dose is measured in liquid water or various water-equivalent plastic materials. (A)
87. "AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams," Peter R. Almond, Peter J. Biggs, B. M. Coursey, W. F. Hanson, M. Saiful Huq, Ravinder Nath, and D. W. O. Rogers, Med. Phys. **26**, 1847–1870 (1999). Current protocol for measuring radiation dose in megavoltage radiation therapy, used mainly in the United States and Canada. Based on TG-21, yet explains less of the physics than does TG-21. Requires that the measurement medium be liquid water. (A)
88. **Absorbed Dose Determination in External Beam Radiotherapy: An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water**, International Atomic Energy Agency (IAEA), Technical Report Series, TRS-398 (IAEA, Vienna, 2000). Describes the current international protocol for measurement of radiation dose. Available at ⟨http://www-pub.iaea.org/MTCD/publications/PDF/TRS398_scr.pdf⟩. (A)

E. Radiation shielding and radiation protection

Medical physicists determine the shielding needed to keep radiation dose to the public and to radiation workers at safe levels. Radiation dose depends on machine output, distance from the machine, shielding thickness, type of shielding material (concrete is common), the amount of time the machine is in use, and the expected time spent near the machine. The calculations account for the primary radiation beam, scattered radiation, radiation leaking from the machine, and neutrons.

89. **Shielding Techniques for Radiation Oncology Facilities**, Patton H. McGinley, 2nd ed. (Medical Physics, Madison, WI, 2002). Starts with an introduction to the history of shielding design. (I)
90. **Structural Shielding Design and Evaluation for Megavoltage X- and Gamma-Ray Radiotherapy Facilities**, National Council on Radiation Protection and Measurements (NCRP) Report No. 151 (NCRP, Bethesda, MD, 2005). The current standard recommendations for radiotherapy shielding in the United States. Areas near radiation sources are divided into two types: controlled areas (limited-access areas where exposure for radiation workers is monitored) and uncontrolled areas (areas accessible to the general public). Biologically effective dose is measured in Sv (for x-rays, 1 Sv=1 Gy). NCRP recommends that radiation workers get less than 50 mSv/yr. Pregnant radiation workers are limited to .5 mSv/month (approximately 5 mSv/yr). Shielding is conservatively designed to limit the equivalent dose received by radiation workers to 5 mSv/yr and that for the general public to 1 mSv/yr. The report contains explanations and examples of shielding calculations, along with data tables and references. (I)
91. **Atoms, Radiation, and Radiation Protection**, James E. Turner, 2nd ed. (Wiley, New York, 1995). Good discussion of many aspects of medical physics, including interactions, detection, dosimetry, chemical and biological effects, exposure limits, and radiation protection. Contains annotated references at the end of each chapter. (I)
92. **Introduction to Health Physics**, Herman Cember and Thomas E. Johnson, 4th ed. (McGraw-Hill Medical, New York, 2009). An excellent starting point for learning about health physics. (I)

F. Neutron, proton, and heavy-ion therapies

Although most treatments today use photons (with some use of electrons), patients have been treated with other particles such as neutrons and protons. Use of proton and heavy-ion therapies is increasing.

1. Fast neutrons

Fast neutron beams are those with a kinetic energy greater than 0.1 MeV. Fast neutrons have been used as an alternative to photon beams and electron beams. "As a rough comparison, one can state that in terms of tissue penetration, a 14 MeV neutron beam is equivalent to a cobalt-60 gamma-ray beam and a 70 MeV neutron beam is equivalent to an 8 MV megavoltage x-ray beam" (Ref. 26, p. 182). However, as far as I know, neutrons are not now used clinically.

93. "Fast neutron beams," J. E. Shaw and A. Kacperek, **Br. J. Radiol., Suppl. 25**, 120–130 (1996). Data on fast neutron beams. (A)

94. "An evaluation of the results of neutron therapy trials," William Duncan, Acta Oncol. **33**(3), 299–306 (1994). This article notes the disappointing clinical results obtained with neutrons: "There is no convincing evidence that fast neutrons are either as safe or as effective in cancer control as photon therapy" (*ibid.*, p. 299). (A)

2. Protons and heavy ions

Protons and heavy ions deposit most of their energy at the end of their range, giving a "Bragg peak" in the plot of energy *versus* range. This is desirable since there is essentially no "exit dose."

95. "Overview of hadron therapy: Rationales, present status and future prospects," D. T. L. Jones, Radiochim. Acta **89**, 235–244 (2001). Very clear and readable. (I)

96. "Treating cancer with protons," Michael Goitein, Antony J. Lomax, and Eros S. Pedroni, Phys. Today **55**(9), 45–50 (2002). (E)

97. "Proton therapy," Alfred R. Smith, Phys. Med. Biol. **51**, R491–R504 (2006). A historical review of proton therapy. (E)

98. **Proton and Charged Particle Radiotherapy**, edited by Thomas F. DeLaney and Hanne M. Kooy (Lippincott Williams and Wilkins, Philadelphia, 2008). Has chapters on history, radiobiology, facility design, particle accelerators, proton delivery systems, quality assurance, patient positioning, and treatment planning, along with many clinical examples. (I)

99. "Vision 20/20: Proton therapy," Alfred R. Smith, Med. Phys. **36**(2), 556–568 (2009). (I)

100. "Penetration of protons, alpha particles, and mesons," U. Fano, Annu. Rev. Nucl. Sci. **13**, 1–66 (1963). Reviews the theory of stopping power (i.e., energy loss), mainly for protons. (A)

101. "Proton beams," A. Kacperek and J. E. Shaw, **Br. J. Radiol. Suppl. 25**, 131–137 (1996). Data on proton beams. (A)

102. "The future of heavy ion radiotherapy," Oliver Jäkel, Christian P. Karger, and Jürgen Debus, Med. Phys. **35**, 5653–5663 (2008). (I)

103. **Prescribing, Recording, and Reporting Proton-Beam Therapy**, International Commission on Radiation Units and Measurements, J. ICRU **7**(2), 1–210 (2007). (I)

104. Issue focusing on "Heavy ions in biophysics and medical physics," New J. Phys. **10** (2008). (A)

G. Imaging for radiation therapy

Imaging techniques are important in radiation therapy to locate the areas to be treated, to plan the treatment, and to ensure that the radiation is properly targeted during treatment. Increasingly, therapy is guided by images taken during treatment.

105. **The Essential Physics of Medical Imaging**, Jerrold T. Bushberg, J. Anthony Seibert, Edwin M. Leidholdt, Jr., and John M. Boone, 2nd ed. (Lippincott Williams and Wilkins, Philadelphia, 2002). Comprehensive and wordy but readable. (I)

106. **Medical Imaging Physics**, William R. Hendee and E. Russell Ritenour, 4th ed. (Wiley-Liss, New York, 2002). (I)

H. Brachytherapy

Brachytherapy is a form of radiation therapy in which radiation sources are placed inside the body, typically using existing body cavities or with hollow needles. Medical physicists have a large role to play in such therapy.

107. "Dosimetry of interstitial brachytherapy sources: Recommendations of the AAPM Radiation Therapy Committee Task Group No. 43," Ravinder Nath, Lowell L. Anderson, Gary Luxton, Keith A. Weaver, Jeffrey F. Williamson, and Ali S. Meigooni, Med. Phys. **22**(2), 209–234 (1995). Contains numerous typographical errors. Although superseded by Ref. 108, this version has some background information not in the updated report. (I)

108. "Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations," Mark J. Rivard, Bert M. Coursey, Larry A. DeWerd, William F. Hanson, M. Saiful Huq, Geoffrey S. Ibbott, Michael G. Mitch, Ravinder Nath, and Jeffrey F. Williamson, Med. Phys. **31**(3), 633–674 (2004). For errata, see Med. Phys. **31**(12), 3532–3533 (2004). (I)

109. "Supplement to the 2004 update of the AAPM Task Group No. 43 Report," Mark J. Rivard, Wayne M. Butler, Larry A. DeWerd, M. Saiful Huq, Geoffrey S. Ibbott, Ali S. Meigooni, Christopher S. Melhus, Michael G. Mitch, Ravinder Nath, and Jeffrey F. Williamson, Med. Phys. **34**(6), 2187–2205 (2007). (A)

110. "Analysis of treatment delivery errors in brachytherapy using formal risk analysis techniques," B. Thomadsen, S. Lin, P. Laemmrich, T. Waller, A. Cheng, B. Caldwell, R. Rankin, and J. Stitt, Int. J. Radiat. Oncol., Biol., Phys. **57**(5), 1492–1508 (2003). (I)

111. **Brachytherapy Physics**, Proceedings of the Joint American Association of Physicists in Medicine and American Brachytherapy Society Summer School, Seattle University, Seattle WA, 18–22 July 2005, Medical Physics Monograph No. 31, edited by Bruce R. Thomadsen, Mark J. Rivard, and Wayne M. Butler, 2nd ed., (Medical Physics, Madison, WI, 2005). (I)

I. Quality assurance (QA)

Among other duties, medical physicists are responsible for quality assurance.

112. "Comprehensive QA for radiation oncology: Report of AAPM Radiation Therapy Committee Task Group 40," Gerald J. Kutcher, Lawrence Coia, Michael Gillin, William F. Hanson, Steven Leibel, Robert J. Morton, Jatinder R. Palta, James A. Purdy, Lawrence E. Reinstein, Goran K. Svensson, Mona Weller, and Linda Wingfield, Med. Phys. **21**, 581–618 (1994). Current recommendations for quality assurance from the American Association of Physicists in Medicine. These recommendations do not carry the force of law, but many regulatory agencies follow them. (I)

113. **Quality Assurance for Radiation Therapy**, edited by Jeffrey F. Williamson and Bruce R. Thomadsen, Int. J. Radiat. Oncol., Biol., Phys. Supplement **71**, S1–S214 (2008). (I)

114. **Quality Assurance in Radiotherapy Physics**, Proceedings of an American College of Medical Physics Symposium, May 1991, edited by George Starkschall and John Horton (Medical Physics, Madison, WI, 1991). (I)

J. Treatment planning

A physician prescribes a certain dose of radiation to a certain location in a patient. Treatment planning is the process of determining how to deliver that dose. In external beam therapy, this is achieved through choosing the number of beams, beam intensity and energy, distance to the patient, beam shape, angle, etc. In some clinics, medical physicists prepare the treatment plans. They also check plans prepared by others to make sure that they are all right. In the planning process, the planned dose of radiation is usually determined using dose calculation algorithms, as described in the next section.

115. "The role of medical physicists and the AAPM in the development of treatment planning and optimization," Colin G. Orton, Thomas R. Bortfeld, Andrzej Niemierko, and Jan Unkelbach, Med. Phys. **35**, 4911–4923 (2008). Reviews the history of radiotherapy treatment planning, with an emphasis on optimization. (I, A).

116. **Treatment Planning in Radiation Oncology**, edited by Faiz M. Khan, 2nd ed. (Lippincott Williams and Wilkins, Philadelphia, 2007). Uses probably the smallest type font you will ever see in a book. (A)

117. **Radiation Therapy Planning**, Gunilla C. Bentel, 2nd ed. (McGraw-Hill, New York, 1996). Has problems and solutions. Readable. Very practical. Has some nice information on physics, including dose calculations. (E, I)

118. **Patient Positioning and Immobilization in Radiation Oncology**, Gunilla C. Bentel (McGraw-Hill, New York, 1999). A "clinical guide" with problems and solutions. (I)

119. **Commissioning and Quality Assurance of Computerized Planning Systems for Radiation Treatment of Cancer**, Technical Reports Series No. 430 (International Atomic Energy Agency, Vienna, 2004). Available online at ⟨http://www-pub.iaea.org/mtcd/publications/pdf/trs430_web.pdf⟩. (I)

120. **Prescribing, Recording, and Reporting Photon Beam Therapy**, International Commission on Radiation Units and Measurements, ICRU Report 50 (ICRU, Bethesda, MD, 1993). Recommendations for how to define the volumes (e.g., target volumes) used to prescribe a radiotherapy treatment. (I)

121. **Prescribing, Recording and Reporting Photon Beam Therapy (Supplement to ICRU Report 50)**, International Commission on Radiation Units and Measurements, ICRU Report No. 62 (ICRU, Bethesda, MD, 1999). (I)

K. Dose calculations

Computerized dose calculation algorithms are used to calculate the radiation dose at various points in a patient.

122. "A simple algorithm for the transport of gamma rays in a medium," F. Arqueros and G. D. Montesinos, Am. J. Phys. **71**(1), 38–45 (2003). Readable explanation of a Monte Carlo algorithm that simulates the passage of 1-MeV gamma rays through a medium. (I)

123. "Patient dose computation methods," edited by Jean-Claude Rosenwald and Philip Mayles, Ref. 18, pp. 545–631. A good discussion of dose computation methods for photons and electrons, including Monte Carlo methods. (I)

124. "Efficient photon beam dose calculations using DOSXYZnrc with BEAMnrc," I. Kawrakow and B. R. B. Walters, Med. Phys. **33**(8), 3046–3056 (2006). (A)

125. Anders Ahnesjö, "Collapsed cone convolution of radiant energy for photon dose calculation in heterogeneous media," Med. Phys. **16**(4), 577–592 (1989). This paper describes the physics behind the "CCC" algorithm, which is an example of an algorithm currently used to create treatment plans for radiotherapy patients. (A)

126. A widely used Monte Carlo code in medical physics is the EGSnrc code, described at ⟨http://www.irs.inms.nrc.ca/EGSnrc/EGSnrc.html⟩. (A)

L. Intensity-modulated and image-guided therapy

Treatments are becoming more sophisticated through the use of intensity-modulated therapy and image-guided therapy. In intensity-modulated radiation therapy (IMRT), the sizes and shapes (which vary during treatment) of multiple radiation beams are chosen to optimize the treatment. In image-guided radiation therapy (IGRT), images taken during treatment are used to target the radiation beams. Another refinement (4DCT) is to make movies using multiple computed tomography (CT) images to show how a tumor changes position with time (for example, due to breathing). This information is used to plan treatments and in some cases to deliver the treatments as well. Stereotactic body radiation therapy (SBRT) uses relatively few tightly focused beams to deliver large doses in relatively few treatments. Many of the references given below also discuss ways to quantify and correct for movement (of the patient or of the tumor) during treatment.

127. **Contemporary IMRT–Developing Physics and Clinical Implementation**, Steve Webb (Institute of Physics, Bristol, 2005). Covers all aspects of IMRT. Has a good section on "Measuring and accounting for patient/tumor movement" (pp. 319–368). A good first reference for IMRT. (I)

128. "Planning and delivery of intensity-modulated radiation therapy," Cedric X. Yu, Christopher J. Amies, and Michelle Svatos, Med. Phys. **35**, 5233–5241 (2008). Reviews the current state-of-the-art in IMRT and makes predictions of future advances. (I)

129. **Practical Essentials of Intensity Modulated Radiation Therapy**, edited by K. S. Clifford Chao, Smith Apisarnthanarax, and Gokhan Ozyigit, 2nd ed. (Lippincott Williams and Wilkins, Philadelphia, 2005). While this book takes a clinical approach, it does have some useful physics. Chapter 1 summarizes IMRT physics and quality assurance. Chapter 2 discusses treatment planning. (A)

130. "The physics of intensity-modulated radiation therapy," Arthur L. Boyer, Phys. Today **55**(9), 38–43 (2002). (I)

131. "Intensity-modulated radiotherapy: Current status and issues of interest," Intensity Modulated Radiation Therapy Collaborative Working Group, Int. J. Radiat. Oncol., Biol., Phys. **51**(4), 880–914 (2001). (I)

132. **Image-Guided IMRT**, edited by Thomas Bortfeld, Rupert Schmidt-Ullrich, Wilfried De Neve, and David E. Wazer (Springer-Verlag, Berlin, 2006). Covers IMRT, IGRT, and 4DCT. (I, A)

133. **IMRT, IGRT, SBRT—Advances in the Treatment Planning and Delivery of Radiotherapy**, edited by John L. Meyer, B. D. Kavanagh, J. A. Purdy, and R. Timmerman (Karger, New York, 2007). Also covers 4DCT. (A)

M. Miscellaneous

134. **Radiobiology for the Radiologist**, Eric J. Hall and Amato J. Giaccia, 6th ed. (Lippincott Williams and Wilkins, Philadelphia, 2006). The standard radiobiology reference. (A)

135. **Meandering in Medical Physics: A Personal Account of Hospital Physics**, J. E. Roberts (Institute of Physics, Philadelphia, 1999). An account of the author's career in medical physics in Great Britain from 1932 to 1969. (E)

136. "History of medical physics," John G. Laughlin, Phys. Today **36**(7), 26–33 (1983). (E)

137. "Anniversary Paper: A sampling of novel technologies and the role of medical physicists in radiation oncology," Stephen Balter and James M. Balter, Med. Phys. **35**, 5641–5652 (2008). Looks at some technologies used in medical physics during the past 50 years. (I)

138. "The 2007 Recommendations of the International Commission on Radiological Protection," ICRP Publication 103, edited by J. Valentin, Ann. ICRP **37**, 1–332 (2007). Recommendations related to the details of calculating risk due to ionizing radiation. (I, A)

VI. DATA

A. General data

139. **Medical Physics Data Book**, edited by Thomas N. Padikal (U. S. Department of Commerce, National Bureau of Standards, March 1982). Contains data for many areas of medical physics including nuclear medicine and diagnostic imaging. Chapter 4 deals with radiation therapy. (A)

140. **Stopping Powers For Electrons and Positrons**, International Commission on Radiation Units and Measurements (ICRU) ICRU Report No. 37 (ICRU, Bethesda, MD, 1984). (A)

141. **Photon, Electron, Proton and Neutron Interaction Data for Body Tissues**, International Commission on Radiation Units and Measurements (ICRU), ICRU Report No. 46 (ICRU, Bethesda, MD, 1992). (A)

142. **Stopping Powers and Ranges for Protons and Alpha Particles**, International Commission on Radiation Units and Measurements (ICRU), ICRU Report No. 49 (ICRU, Bethesda, MD, 1993). (A)

143. "Calculation of photon mass energy-transfer coefficients and mass energy-absorption coefficients," Stephen M. Seltzer, Radiat. Res. **136**(2), 147–170 (1993). (A)

B. Linear-accelerator data

In radiotherapy, "depth-dose" data consist of tables of absorbed dose *versus* depth in a material (usually water). Data are tabulated for different photon energies, photon-beam size (called "field size"), and distance from the photon source to the surface of the material.

144. "Central axis depth dose data for use in radiotherapy: 1996—A survey of depth doses and related data measured in water or equivalent media," prepared by a Joint Working Party of the British Institute of Radiology and the Institution of Physics and Engineering in Medicine and Biology, S. C. Klevenhagen, working party chairman (London, British Institute of Radiology, 1996). British Journal of Radiology [BJR] Supplement 25. Contains tables of measured data for absorbed doses of radiation *versus* depth and field size for low-energy x-rays, cesium-137 gamma-ray beams, cobalt-60 gamma-ray beams, megavoltage x-ray beams (2–50 MV), electron beams, fast neutron beams, and proton beams. Useful if you want to look at typical data or see if your measured results are reasonable. Also has useful appendices. (A)

145. **Handbook of Dosimetry Data for Radiotherapy**, Shirish K. Jani (CRC, Boca Raton, FL, 1993). Contains data on radiation dose *versus* depth for photon beams, energy and range data for electron beams, special treatment procedures, and nuclear sources. (A)

VII. EDUCATION

146. Study Guide 2007, "Part I—General Medical Physics," American Board of Medical Physics. Available at ⟨http://www.abmpexam.com/GMP%20Study%20Guide.htm⟩.

147. "ASTRO/AAPM Jointly Recommended Core Curriculum, Proposed by the ASTRO Ad-hoc Committee on Physics Curriculum for Radiation Oncology Residents," Approved by the AAPM Medical Physics Education of Physicians Committee, July 2005. Available at ⟨http://www.aapm.org/education/teachingaids.asp⟩. (I)

148. "AAPM Recommended Radiologic Physics Curriculum for Radiation Oncology Residents," Richard J. Massoth, AAPM 2006 Physics Education Forum, Atlanta, Georgia (January 22, 2006). Available at ⟨http://www.aapm.org/education/teachingaids.asp⟩. (I)

149. "Academic program recommendations for graduate degrees in medical physics," A Report of the Education and Training Of Medical Physicists Committee, Bhudatt R. Paliwal, James C. H. Chu, Paul M. DeLuca, Jr., Arnold Feldman, Ellen E. Grein, Donald E. Herbert, Edward F. Jackson, Faiz M. Khan, Richard L. Maughan, Venkataramanan Natarajan, Ervin B. Podgorsak, E. Russell Ritenour, and Mohammed K. Zaidi, AAPM Report No. 79 (Medical Physics, Madison, WI, 2002). Available at ⟨http://www.aapm.org/pubs/reports/⟩. Contains an extensive bibliography. (I)

150. "Essentials and guidelines for hospital-based medical physics residency training programs," Report of the Subcommittee on Residency Training and Promotion of the Education and Training of Medical Physics [*sic*] Committee of the AAPM Education Council, edited by Richard G. Lane, AAPM Report No. 90 (Medical Physics, Madison, WI, 2006). Available at ⟨http://www.aapm.org/pubs/reports/⟩. (I)

VIII. WEBSITES

A. Books, papers, and reports on the Internet

151. AAPM reports (including the Task Group reports mentioned above) are available at ⟨http://www.aapm.org/pubs/reports/⟩.

152. "Fundamentals of dosimetry based on absorbed-dose standards," D. W. O. Rogers, National Research Council of Canada, available at ⟨http://www.irs.inms.nrc.ca/papers/AAPMSS96/ss96_html.html⟩.

153. **Radiation Oncology Physics: A Handbook for Teachers and Students**, edited by E. B. Podgorsak (International Atomic Energy Agency, Vienna, 2005). Available in its entirety at ⟨http://www-naweb.iaea.org/nahu/dmrp/syllabus.shtm⟩.

154. E. B. Podgorsak, G. H. Hartmann, and S. Vatnitsky, slide set for Ref. 153, available at ⟨http://www-naweb.iaea.org/nahu/dmrp/slides.shtm⟩.

155. "Lessons learned from accidental exposures in radiotherapy," International Atomic Energy Agency (IAEA), IAEA Safety Reports Series No. 17 (IAEA, Vienna, 2000). Available at ⟨http://www-pub.iaea.org/MTCD/publications/PDF/Pub1084_web.pdf⟩.

B. Data

156. "Physics data and standards," National Nuclear Data Center ⟨http://www.nndc.bnl.gov/⟩.

157. "Photon attenuation data," Nuclear Data Services, International Atomic Energy Agency ⟨http://www-nds.iaea.org/reports/nds-195.htm⟩.

158. X. Allen Li and D. W. O. Rogers, "Electron mass scattering powers: Monte Carlo and analytical calculations," Ionizing Radiation Standards, Institute for National Measurement Standards, National Research Council of Canada, ⟨http://www.irs.inms.nrc.ca/papers/MSP95/msp.html⟩.

C. Organizations

159. International Atomic Energy Agency (IAEA), ⟨http://www.iaea.org⟩.

160. "Radiological protection of patients," International Atomic Energy Agency (see especially the "Radiotherapy" section), ⟨http://rpop.iaea.org/RPoP/RPoP/Content/index.htm⟩.

161. "Dosimetry and medical radiation physics," IAEA, ⟨http://www-naweb.iaea.org/nahu/dmrp/⟩.

162. "Nucleus catalogue of information resources," IAEA, ⟨http://nucleus.iaea.org/NUCLEUS/nucleus/Content/CatalogueOfInformationResources/BrowseCatalogue.jsp⟩.

163. "Nuclear data services," IAEA, ⟨http://www-nds.iaea.or.at⟩.

164. International Commission on Radiological Protection (ICRP), ⟨http://www.icrp.org⟩.

165. International Commission on Radiation Units and Measurements (ICRU), ⟨http://www.icru.org⟩.

166. National Council on Radiation Protection and Measurements (NCRP), ⟨http://www.ncrponline.org⟩.

167. National Institute of Standards and Technology, ⟨http://www.physics.nist.gov/PhysRefData⟩.

168. National Nuclear Data Center, ⟨http://www.nndc.bnl.gov⟩.

169. Nuclear Regulatory Commission (NRC), ⟨http://www.nrc.gov⟩.

170. Radiological Physics Center, ⟨http://rpc.mdanderson.org/RPC/home.htm⟩: Funded by the National Cancer Institute. Assures that radiation oncology groups participating in clinical trials are delivering consistent doses of radiation.

171. U. S. Particle Accelerator School, ⟨http://uspas.fnal.gov⟩.

D. Professional societies

172. American Association of Physicists in Medicine (AAPM), ⟨http://www.aapm.org⟩. Some AAPM presentations are available at ⟨http://www.aapm.org/meetings/virtual_library/⟩. Particularly interesting are the presentations from the 2008 AAPM workshop on the teaching of physics and medical physics.

173. American Board of Radiology (ABR), ⟨http://www.theabr.org⟩.

174. American Board of Medical Physics (ABMP), ⟨http://www.abmpexam.com⟩.

175. American College of Medical Physics (ACMP), ⟨http://www.acmp.org⟩.

176. American College of Radiology (ACR), ⟨http://www.acr.org⟩.

177. American Society for Therapeutic Radiology and Oncology (ASTRO), ⟨http://www.astro.org⟩.

178. Asia–Oceania Federation of Organizations for Medical Physics (AFOMP), ⟨http://www.afomp.org⟩.

179. Canadian College of Physicists in Medicine (CCPM), ⟨http://www.ccpm.ca⟩.

180. Canadian Organization of Medical Physicists (COMP), ⟨http://www.medphys.ca⟩.

181. European Federation of Organisations for Medical Physics (EFOMP), ⟨http://www.efomp.org⟩.

182. International Organization for Medical Physics (IOMP), ⟨http://www.iomp.org⟩.

183. Radiological Society of North America (RSNA), ⟨http://www.rsna.org⟩.

IX. RECOMMENDED PATH THROUGH THE LITERATURE

The best single reference for a newcomer to the field is Goitein (Ref. 14). It is clear, up to date, readable, complete, and gives a good explanation of what medical physicists do. For a person who does not want to enter the field but is just curious or needs to get some information and does not want to spend any money, a good place to start is the free on-line book by Podgorsak (Ref. 153). Van Dyk (Ref. 17) is a good place to start for those who want a clinical emphasis. The book by Turner (Ref. 91) has good problems (some with answers) and covers many aspects of the subject.

For those wanting to make a career of Medical Physics, a small but good starting library would consist of Goitein (Ref. 14), Hendee *et al.* (Ref. 30), Johns and Cunningham (Ref. 15), Khan (Ref. 16), Podgorsak (Ref. 153), Turner (Ref. 91), and van Dyk (Ref. 17). Khan is more useful once you have learned the material. If you have more money, you could add Attix (Ref. 19) and Podgorsak's book on radiation physics (Ref. 26). Cember and Johnson (Ref. 92) is a good addition if you are interested in the health-physics aspects of radiotherapy.

If you were restricted to one book and wanted to learn as much as possible, then the handbook of Mayles *et al.* (Ref. 18) is worthy of serious consideration.

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