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**(Revision of AAPM Report No. 44)**

**ACADEMIC PROGRAM RECOMMENDATIONS  
FOR GRADUATE DEGREES  
IN MEDICAL PHYSICS**

**A Report Of The Education And Training  
Of Medical Physicists Committee**

November 2002

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**The Education And Training  
Of Medical Physicists Committee**  
(December 2001)

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## 1 INTRODUCTION

Since the first publication of this report in 1993, education in the field of Medical Physics has experienced considerable growth and change. However, much remains the same. The original document was written to provide guidance to medical physics training programs as to the minimal curriculum suitable for a Master of Science degree in medical physics. That document was organized around general topics and those more specific to different medical physics specialties. During the intervening years, medical physics has evolved dramatically in breadth and depth. This evolution has led to the need for a revision of the prior recommendations and the creation of the present document.

In this document, we more strongly reflect the relationship between a core curriculum that all medical physics Masters (M.S.) and Doctoral (Ph.D.) trainees should be well grounded in and the more specific aspects associated with the medical physics subspecialties. Clearly, the core curriculum serves as a basis for these more specific topics. For example, basic interactions physics is essential to all of radiation oncology, diagnostic radiology, nuclear medicine, and health physics. To some degree image science is required knowledge for any medical physicist, but details of magnetic resonance (MR) image science are more pertinent to the specialist. We also now recognize the importance of biostatistics, medical informatics, and medical ethics. The current clinical and research environment makes these essential tools for any practicing medical physicist.

As indicated in the Table of Contents, Core material includes Radiological Physics and Dosimetry, Health/Radiation Physics, Radiation Biology, and Anatomy and Physiology, and a sequence of Special Core Topics that make up a knowledge base of divergent materials. The latter include Computational Skills, Medical Ethics, Statistics, and Safety. As mentioned, the former are essential to all medical physics training and serve to act as a basis for more subspecialty training. The latter incorporate a knowledge base needed by all medical physicists but to a less comprehensive level. In fact, we anticipate that some of these subjects may have been covered in prior training. However, recent experience indicates that Medical Ethics and Statistics may require more in-depth coverage. During the next several years, the American Association of Physicists in Medicine (AAPM) will be monitoring the needs in these areas.

In addition to these Core (and Special Core) subjects, we now recognize the two broad subspecialties, Image Science and Radiation Therapy. For each area, a sequence of appropriate sub-subjects is indicated. For Image Science, these include modality-driven material as well as overall materials such as the inverse problem, signal processing, etc. For Radiation Therapy, these are treatment regime and device driven. For both Image Science and Radiation Therapy, training programs may implement the curriculum in different ways, combining topics, redistributing topics, and using other means to achieve the desired educational end. However, we anticipate that all the material will be presented. We also anticipate that programs may

choose to specialize in one or the other area providing even more extensive training. However, the essentials, as indicated, are needed for all programs.

Amongst programs accredited by the Commission on Accreditation of Medical Physics Education Programs, Inc. (CAMPEP), there is a common core of similarity, yet each program reflects the individual strengths and resources of personnel and facilities. As more programs have been granted CAMPEP accreditation, these guidelines for training are essential to ensure that the minimal curriculum represents the current needs of medical physics. The present document embodies these principles and serves as the basis of CAMPEP accreditation.

Beyond the foregoing, we anticipate that some of this training might be provided in earlier academic experiences, e.g., a Bachelor of Science (B.S.) degree or an M.S. degree in a related field. Obviously, selective admission requirements could implement such criteria.

An extensive bibliography of suggested resources is included. Again, selections are segregated by topical area. Entries are often duplicated as appropriate.

A special question concerns “clinical” training. Ultimately, a majority of medical physicists practice their training in a clinical environment. The combination of prior didactic clinical training and experience should eventually lead to “certification” or “licensure.” Without excessive elaboration, formal academic training can never hope to provide nor is it necessarily the proper environment for this clinical training. The best mechanism is embodied in residency training. Such training programs are now being accredited by CAMPEP.

## **2 TOPICAL DISCUSSION**

### **2.1 CORE TOPICS**

#### **2.1.1 Radiological Physics and Dosimetry**

The material in this section is designed to teach a graduate in physics (or engineering, with a strong physics and math background) the basics of radiological physics and dosimetry. Quantities and units are introduced early so that radioactive decay and radiation interactions can then be discussed, with emphasis on energy transfer and dose deposition.

Exponential attenuation under both narrow- and broad-beam conditions must be understood before a student can go on to shielding design in a health physics course.

All dosimetry relies heavily on applications of charged-particle equilibrium, radiation equilibrium, and/or cavity theory, hence these areas must be covered in detail before going on to study practical dosimetry with ion chambers and the several common condensed-media dosimeters.



In some programs it may be possible to teach the contents of this section in segments as parts of courses on radiotherapy physics, diagnostic radiology, nuclear medicine, and health physics. However, the proposed material makes a coherent course to be taught to entering students, with the more specialized courses to be given either later or simultaneously. Any resulting repetition of material results in useful “over-learning” of these fundamental topics.

### **2.1.2 Health Physics/Radiation Safety**

Radiation protection pervades the various subspecialties of medical physics. It provides the basic connection between microscopic interactions and cellular response. As such, a broad spectrum of topics is discussed. Special attention is given to detection equipment and shielding analysis. An increasingly litigious society is reflected in extensive presentation of the regulatory environment. Complementing tutorial instruction is a sequence of laboratory experiences focusing upon instrumentation, environmental sampling, bioassay, and several aspects of shielding. The emphasis in this topic is to provide a broad knowledge base supportive of the varied environments of medical physics.

### **2.1.3 Radiation Biology**

Effects of radiation occur in all fields of medical physics. Lack of understanding of the biological consequences of ionizing radiation has produced a recent flood of disinformation. Only by education can this situation be alleviated and eventually rectified. These topics should be presented in a cohesive and consistent manner; not distributed among several related subjects such as radiation therapy physics, health physics, and nuclear medicine.

### **2.1.4 Anatomy and Physiology**

After completing this material, the student should be able to interpret common medical terminology from knowledge of Greek and Latin root words. The student should be able to identify gross anatomical structures, define the major organ systems, and describe the physiological mechanisms for repair, maintenance, and growth. Anatomical structures and physiological function should be correlated with the imaging modalities used to view them.

### **2.1.5 Special Topics**

The following subjects are important to medical physics training. The details listed indicate the type and content of appropriate materials. Many institutions will incorporate these subjects throughout other components of their curricula. For example, computational skills might be covered in image science and radiotherapy.

#### 2.1.5.1 *Computational Skills*

Computer applications are an essential component of the tools that a medical physicist needs to perform basic tasks in the practice of medical physics. This section provides an introduction to some of these basic computational skills.

#### 2.1.5.2 *Professional Ethics/Conflict of Interest/Scientific Misconduct*

This material is intended to cover ethical issues in clinical medicine and scientific research, and in the professional conduct of the medical physicist. The term “ethics” is used here in the sense of a permissible standard of conduct for members of a profession. While different people may have different opinions of what is “ethical,” professions always have certain ethical standards or codes of conduct that are compiled in written form and are generally accepted by practitioners.

In addition to becoming familiar with written codes of conduct, the student should be introduced to commonly encountered situations in which a choice of actions is available, some of which would be considered unethical and some of which would be considered ethical, according to current standards of care or practice.

A case-based approach in a seminar setting with class participation is strongly recommended. This allows the student to put him- or herself in the place of an individual who faces an ethical dilemma and to explore variations of the case that is presented. It is also valuable for other faculty to attend, to offer comments, and to relate situations that they have encountered either first- or secondhand.

#### 2.1.5.3 *Statistical Methods In Medical Sciences*

The course provides the student with an overview of the three principal schools of statistical thought and their respective models, methods, and insights: (1) frequentist or Neyman-Pearson; (2) subjectivist or Bayesian; (3) resampling. The powerful Bayesian and resampling models have only recently been made fully useful to the scientist through major advances in numerical computation and in computer speed. The principal emphasis of the course is on the use of the Neyman-Pearson and Bayesian models, both parametric and nonparametric. The course will include the design of experiments and surveys and the acquisition, editing, analysis, interpretation, presentation, and reporting of data from empirical studies. Two of the secondary aims of the course are to provide the student with an appreciation of the great breadth of the useful applications of statistics in medicine and to enable the student to recognize those applications for which his or her current levels of skill may be inadequate and how and where to begin to remedy that lack when it becomes necessary to do so.

#### 2.1.5.4 *Safety: Electrical/Chemical/Biological/Elementary Radiation*

The medical physics practice environment exposes a medical physicist to many electrical, chemical, and biological hazards. An introductory course designed to familiarize a student with the hazards and necessary precautions is covered under this section.

## **2.2 IMAGING SCIENCE**

### **2.2.1 Conventional Planar Imaging**

Conventional planar imaging topics include radiography and fluoroscopic imaging. The topics in this section concentrate on the steps of patient imaging. Conventional planar imaging section includes production of X-rays, X-ray interaction with patient, making images using film screen systems, and processing of x-ray films. Image quality issues are addressed via several individual topics including grids, contrast, detail, noise, blur, etc.

### **2.2.2 Digital X-Ray Imaging and Computed Tomography**

Image receptor technology is undergoing a rapid change from film to film-less digital technology. The newer technologies, namely computed radiography and digital radiography, are outlined. Signal processing in computed radiography is discussed. In digital radiography the conventional receptors are being replaced by display monitors and the optimum parameters for the display monitors are discussed.

Computed tomography (CT) techniques are also discussed in this section, including recent advances in hardware and applications.

### **2.2.3 Ultrasound Imaging**

Ultrasound (US) imaging is used in numerous fields of medicine, and the equipment is located in many different departments in the hospital and clinic. Training should include basic information on propagation of waves through tissue, ultrasound transducers, and ultrasound imaging and Doppler instrumentation. Medical practitioners should be aware of safety issues relevant to ultrasound instruments, including the role of real-time acoustic output indices.

### **2.2.4 Magnetic Resonance Imaging**

The basic principles of magnetic resonance imaging (MRI) physics are discussed in this section. The emphasis is not on the more advanced MRI techniques, but on the development of a solid understanding of the basics of image formation and spatial accuracy, image contrast (for the most commonly utilized clinical pulse

sequences), primary clinical applications, and safety. Brief introductory material is provided on more advanced techniques.

### **2.2.5 Nuclear Medicine**

The basics of nuclear medicine physics are addressed in this section, including discussion of gamma cameras, positron emission tomography (PET) systems, single photon emission computed tomography (SPECT) systems, and newer technology systems such as PET/CT systems.

## **2.3 RADIATION THERAPY**

### **2.3.1 Radiation Oncology**

Radiation therapy is the clinical process that uses radiation for the treatment of a variety of cancers. It utilizes a variety of radiation sources with unique characteristics and procedures. These are used alone or in combination with other treatment modalities. This section provides an overall view of these modalities and identifies their roles in the management of cancer treatments.

### **2.3.2 External Beam Radiation Therapy**

The material in this section is designed to teach a graduate student the applications of external beams from equipment designed to produce collimated beams. The characterization of these beams and related fundamental dosimetric quantity and the methods of delivering dose distribution in tumors and normal tissue in patients are presented.

### **2.3.3 Brachytherapy**

Brachytherapy is a method of treatment in which radioactive sources are used to deliver radiation at a short distance by interstitial, intracavitary, or surface application. This section discusses the physical characteristics and clinical methodology of these services.

### **2.3.4 Treatment Planning**

This section deals very specifically with the treatment planning process in which regions of clinical interests, dose prescription criteria, dose modeling, and treatment planning are discussed. Specific aspects of photons, electrons, and other modalities are discussed. Methods of calculated and delivered dose verification are presented.

### **2.3.5 Radiation Therapy Devices**

A large number of tools ranging from high-energy accelerators to simulators, CT, US, MRI and PET imaging systems are needed to effectively deliver radiation therapy treatments. The physical design, maintenance, and quality assurance (QA) procedures are discussed in this section.

### **2.3.6 Special Techniques in Radiotherapy**

Due to significant growth in the field of radiation therapy during the last two decades some of the procedures are complex. These require specialized equipment, training, and added resources. These are categorized as special procedures and form part of this curriculum.

### **2.3.7 Radiation Therapy with Neutrons, Protons, and Heavy Ions**

This section focuses on specialized types of ionizing radiation, such as neutrons, protons, and other heavy ions and their use in radiation therapy.

### **2.3.8 Radiation Protection in Radiotherapy**

Courses in radiation protection pertinent to the radiation therapy environment prepare the radiation therapy physicist to address the needs of protecting the personnel and the general public in the radiation therapy department. The relevant regulations, methods of compliance, and record keeping are taught.

## **3 TOPICAL OUTLINE**

### **3.1 CORE TOPICS**

#### **3.1.1 Radiological Physics and Dosimetry**

1. Atomic and Nuclear Structure
  - (a) Basic definitions of atomic structures
  - (b) Rutherford model of the atom
  - (c) Bohr model of the hydrogen atom
  - (d) Multi-electron atoms
  - (e) Nuclear structure
  - (f) Radioactivity
  - (g) Modes of radioactive decay

2. Classification of Radiations
  - (a) Basic physical quantities and units used in radiation physics
  - (b) Types and sources of directly and indirectly ionizing radiations
  - (c) Description of ionizing radiation fields
3. Quantities and Units Used for Describing Radiation Fields
  - (a) Fluence and fluence rate
  - (b) Energy fluence and energy fluence rate
4. Quantities and Units Used for Describing the Interaction of Ionizing Radiation with Matter
  - (a) Kerma, collisional kerma, radiative kerma
  - (b) Absorbed dose
  - (c) Activity
  - (d) Energy transferred, net energy transferred, energy imparted
  - (e) Equivalent dose and quality factor
  - (f) Exposure
5. Indirectly Ionizing Radiations: Photon Beams
  - (a) X-ray transitions, characteristic radiation, ionization vs. excitation of atoms
  - (b) Moseley's law, x-ray line spectra, Hartree's theory of multi-electron atoms
  - (c) Radiation from accelerated charge, production of bremsstrahlung, Larmor relationship
  - (d) X-ray targets, bremsstrahlung yield
  - (e) Beam quality and filtering
  - (f) Energy deposition in tissue by photon beams
6. Exponential Attenuation
  - (a) Simple exponential attenuation
  - (b) Half-value layer, tenth-value layer, attenuation coefficients, interaction cross-sections
  - (c) Narrow vs. broad beam attenuation
  - (d) Buildup factor
  - (e) Spectral effects in attenuation, beam hardening and softening
  - (f) Reciprocity theorem
  - (g) Energy transfer coefficient, energy absorption coefficient
  - (h) Calculation of absorbed dose in photon beam interactions

7. Photon Interactions with Matter

- (a) Thomson scattering
- (b) Rayleigh scattering
- (c) Photoelectric effect
- (d) Compton scattering
- (e) Pair production, triplet production
- (f) Photonuclear reactions
- (g) Relative predominance of individual effects
- (h) Effects following individual photon interactions, fluorescence yield, Auger effect
- (i) Contributions of individual effects to the attenuation coefficient, energy transfer coefficient, and energy absorption coefficient

8. Indirectly Ionizing Radiations: Neutron Beams

- (a) Neutron types by kinetic energy
- (b) Neutron sources
- (c) Neutron beam specifications
- (d) Energy deposition in tissue by neutron beams

9. Neutron Interactions with Matter

- (a) Neutron interactions in tissue elements
- (b) Neutron kerma and absorbed dose calculations
- (c) Absorbed dose in a body phantom
- (d) Gamma-neutron mixed field dosimetry
- (e) Neutron quality factor

10. Directly Ionizing Radiations

- (a) Types of charged particle beams used clinically
- (b) Sources of charged particle beams
- (c) Energy deposition in tissue by charged particle beams

11. Interactions of Directly Ionizing Radiations with Matter

- (a) Stopping power (collisional and radiative), scattering power, range, straggling
- (b) Restricted stopping power, linear energy transfer
- (c) Orbital electron interactions
- (d) Nuclear interactions
- (e) Calculation of absorbed dose in charged particle interactions

12. Radioactive Decay

- (a) Total and partial decay constants
- (b) Units of activity
- (c) Mean-life and half-life
- (d) Parent-daughter relationships
- (e) Transient and secular equilibrium
- (f) Harvesting of daughter products
- (g) Radioactivation by nuclear interactions
- (h) Exposure rate constant and air-kerma rate constant

13. Charged Particle and Radiation Equilibrium

- (a) Radiation equilibrium
- (b) Charged particle equilibrium (CPE)
- (c) Relationships between absorbed dose, collisional kerma, and exposure under CPE
- (d) Conditions that enable CPE or cause its failure
- (e) Transient CPE

14. Radiation Dosimetry

- (a) Types and general characteristics of dosimeters
- (b) ICRU (International Commission on Radiation Units and Measurements) definitions of dosimetry quantities and units
- (c) Absolute vs. relative dosimetry techniques
- (d) Interpretation of dosimeter measurements

15. Calorimetric Dosimetry

- (a) Basic principles and measurement techniques
- (b) Thermal defect and thermal equilibrium
- (c) Thermocouples and thermistors
- (d) Adiabatic, isothermal, and constant temperature techniques

16. Chemical (Fricke) Dosimetry

- (a) Basic principles and measurement techniques
- (b) G-value and radiation chemical yield
- (c) Absorption spectroscopy

17. Cavity Theory

- (a) Bragg-Gray cavity theory and corollaries
- (b) Spencer-Attix and Burlin cavity theories



- (c) Fano's theorem
- (d) Stopping power averaging
- (e) Dose near interfaces

#### 18. Ionization Chambers

- (a) Basic configuration of ionization chambers
- (b) Standard free air ionization chamber
- (c) Cavity (thimble) ionization chamber
- (d) Extrapolation chamber
- (e) Measurement of chamber current (differential mode) and charge (integral mode)
- (f) Mean energy required to create an ion pair
- (g) Saturation characteristics of ionization chambers: initial and general recombination, diffusion loss

#### 19. Calibration of Photon and Electron Beams with Ionization Chambers

- (a) Cavity chamber calibration: air-kerma in air and dose in water
- (b) Dosimetry protocols: AAPM TG-21; AAPM TG-51; International Atomic Energy Agency Technical Report Series 398 (IAEA TRS-398)
- (c) Phantom materials for photon and electron beams

#### 20. Relative Dosimetry Techniques

- (a) Thermoluminescent dosimetry (TLD)
- (b) Film dosimetry: radiographic film and radiochromic film
- (c) Semiconductor dosimeters: diodes
- (d) Optically stimulated luminescence (OSL)
- (e) MOSFET (metal oxide semiconductors – field effect transistor) dosimeters and diamond detectors
- (f) Gel dosimeters

#### 21. Dosimetry by Pulse-Mode Detectors

- (a) Geiger-Müller (GM) counters and proportional counters
- (b) Scintillation dosimetry
- (c) Radiation survey meters
- (d) Neutron detectors

### **3.1.2 Health Physics/Radiation Safety**

#### 1. Introductions and Historical Perspective

- (a) Discovery and early application of ionizing radiation

- (b) Observed radiation injury
  - (c) Suggested radiation protection practices
  - (d) Pre-regulatory initiatives
2. Interaction Physics as Applied to Radiation Protection
- (a) Indirectly and directly ionizing radiation
  - (b) Bethe-Bloch formalism for coulomb scattering, shell effects, polarization phenomena, nuclear processes, adiabatic scattering, track structure, target phenomena, radioactive processes, Anderson-Ziegler parameterization, Janni tabulation, and effects due to mixtures and compounds
  - (c) Electromagnetic interaction: photoelectric effect, Compton effect, pair production, shower cascade phenomena
  - (d) Neutron interactions: elastic and non-elastic processes
3. Operational Dosimetry
- (a) Units
  - (b) Kerma and absorbed dose
  - (c) Dose equivalent
  - (d) Recommendations of the ICRU
  - (e) Recent changes in the neutron quality factor
4. Radiation Detection Instrumentation
- (a) Ionometry including proportional and GM counters
    - i. Electron-ion transport
    - ii. Pulse structure
    - iii. Microdosimetric devices
  - (b) Scintillation and TLD devices
    - i. Organic and inorganic solids and liquids
    - ii. Dose/dose equivalent interpretation
    - iii. TLD energy, dose, dose rate response
  - (c) Dose equivalent instrumentation
    - i. Energy dependence
    - ii. Pulse field response
5. Shielding: Properties and Design
- (a) Directly ionizing particles
  - (b) Indirectly ionizing particles
  - (c) Build-up parameterization

- (d) Stochastic sampling: Monte Carlo
    - i. Source description and sampling
    - ii. Interaction sampling
    - iii. Geometry effects
    - iv. Scoring
    - v. Public domain codes
  - (e) Particle Accelerators
    - i. Primary particle shielding
    - ii. Secondary-tertiary particle shielding
    - iii. Energy and particle type dependence
    - iv. Interlocks and access control
    - v. Modeling radiation environment
  - (f) NCRP (National Council on Radiation Protection and Measurements) shielding recommendations and techniques
6. Statistics
- (a) Statistical interpretation of instrument response
  - (b) Design of experiments
  - (c) Stochastic and nonstochastic error analysis
  - (d) Interpreting experimental results
7. Radiation Monitoring of Personnel
- (a) Instrumentation and techniques
  - (b) Integral and active devices
  - (c) Dynamic range and response sensitivities
  - (d) Film, TLD, Lexan, and CR-39
  - (e) Pocket ion chambers and GM counters
8. Internal Exposure
- (a) ICRP 26, ICRP 2A recommendations (revised and issued as ICRP 60)
  - (b) Medical Internal Radiation Dose (MIRD) dosimetry
  - (c) Monitoring and radiation control
  - (d) Biological assay
  - (e) Dispersion in a working environment
  - (f) Allowed limit of intake and derived air (or water) concentrations
9. Environmental Dispersion
- (a) Release of radionuclides to the environment
  - (b) Dosimetric consequences

- (c) Environmental Protection Agency (EPA) and U.S. Nuclear Regulatory Commission (NRC) air and water dispersion models

#### 10. Biological Effects

- (a) Basic radiation biology
- (b) Nonstochastic and stochastic responses
- (c) Biological experimental data base of radiation injury
- (d) BEIR (Biological Effects of Ionizing Radiation) and UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) Reports

#### 11. Regulations

- (a) What is; what is not
- (b) 10CFR19-70; 49USDOT300-399, 198; 219SFDA 278; 290SHA; 42USPHS; 40USEPA
- (c) States: agreement or not
- (d) Relationship to NCRP and ICRP (International Commission on Radiation Protection)

#### 12. High/Low Level Waste Disposal

- (a) USNRC/USDOE/USEPA Repository (U.S. Nuclear Regulatory Commission/ Department of Energy/Environmental Protection Agency)
- (b) Low level compacts
- (c) Future impacts

#### 13. Nonionizing Radiation

- (a) Electromagnetic and sound hazards
- (b) Device emission requirements
- (c) Measurement techniques
- (d) Regulatory control

### **3.1.3 Radiation Biology**

#### 1. Review of Interaction of Radiation with Matter

- (a) Types of radiation
- (b) Mechanisms of radiation absorption
- (c) Ionization density

2. Radiation Injury to DNA
  - (a) Radiation chemistry of water
  - (b) Structure of DNA and radiation-induced lesions
  - (c) Double-strand breaks
3. Repair of DNA Damage
  - (a) Excision repair
  - (b) Repair of double-strand breaks
4. Radiation-Induced Chromosome Damage and Repair
  - (a) Chromosome biology and aberrations
  - (b) Linear-quadratic model
5. Survival Curve Theory
  - (a) Target theory
  - (b) Survival curve models
    - i. Single-hit multitarget
    - ii. Linear-quadratic
  - (c) Cellular sensitivity
    - i. Single-hit multitarget
    - ii. Mechanisms of cell killing
6. Cell Death: Concepts of Cell Death (Apoptosis and Reproductive Cell Death)
7. Cellular Recovery Processes
  - (a) Types of radiation damage
  - (b) Potentially lethal and sublethal damage
  - (c) Fractionation effort
  - (d) Dose rate effects
8. Cell Cycle
  - (a) Cell kinetics and cycle phases
  - (b) Radiosensitivity and cell cycle position
  - (c) Radiation effects on cell cycle
9. Modifiers of Radiation Response – Sensitizers and Protectors
  - (a) Oxygen effect and other radiosensitizers
  - (b) Radioprotection

10. RBE, OER, and LET

- (a) Linear energy transfer (LET)
- (b) Relative biological effectiveness (RBE)
- (c) Oxygen enhancement ratio (OER)

11. Cell Kinetics

- (a) The cell cycle and quantitation of its constituent parts
- (b) The growth fraction and cell loss from tumors
- (c) Autoradiography and flow cytometry
- (d) The growth kinetics of human tumors

12. Radiation Injury to Tissues

- (a) Tissue and organ anatomy
- (b) Expression and measurement of damage

13. Radiation Pathology – Acute and Late Effects

- (a) Acute and late responding normal tissues
- (b) Pathogenesis of acute and late effects
- (c) Different kinds of late responses
- (d) Residual damage/Radiation Syndromes/Clinical TBI (total body irradiation)

14. Histopathology

- (a) General morphology of radiation injury
- (b) Morphology of cell death
- (c) Morphologic changes in irradiated tumors

15. Tumor Radiobiology

- (a) Basic tumor structure and physiology
- (b) Importance of hypoxic cells in tumors and importance of reoxygenation

16. Time, Dose, and Fractionation

- (a) The 4 R's of radiobiology
- (b) Volume effects
- (c) The basis of fractionation
- (d) Dose-response relationships for early and late responding normal tissues
- (e) Hyperfractionation and accelerated treatments

- (f) a/b model

#### 17. Radiation Genetics: Radiation Effects of Fertility and Mutagenesis

- (a) Target cells for infertility
- (b) Doses to result in temporary and permanent sterility
- (c) "Reverse-fractionation effect"
- (d) Mechanisms of mutation induction
- (e) Relative risk vs. absolute risk
- (f) Time course and latency period/Risks of cancer induction in different sites

#### 18. Molecular Mechanisms

- (a) Molecular cloning techniques
- (b) Gene analyses
- (c) Oncogenes and tumor suppressor genes

#### 19. Drug Radiation Interactions

##### **3.1.4 Anatomy and Physiology**

##### 1. Anatomical Nomenclature

- (a) Origin of anatomical names
- (b) Prefixes and suffixes
- (c) Anatomical position and body planes

##### 2. Bones

- (a) Classification
- (b) Structure
- (c) Development

##### 3. Spinal Column

- (a) Divisions of the spinal column
- (b) Vertebral structure
- (c) Radiography of the spinal column

##### 4. Thorax

- (a) Bones of the thorax
- (b) Organs in the thorax
- (c) Radiography of the thoracic structures

5. Abdomen

- (a) Divisions and regions
- (b) Organs in the abdomen
- (c) Abdominal systems

6. Respiratory System

- (a) Organs
- (b) Function
- (c) Radiography

7. Digestive System

- (a) Divisions
- (b) Location, extension
- (c) Function
- (d) Radiography

8. Urinary System

- (a) Organs
- (b) Location
- (c) Function
- (d) Radiography

9. Reproductive System

- (a) Organs
- (b) Location
- (c) Function
- (d) Radiography

10. Circulatory System

- (a) Major components
- (b) Function
- (c) Radiography
- (d) Visit to catheterization laboratory

11. Pathology

- (a) Identification of organs at autopsy
- (b) Organ location
- (c) Organ composition
- (d) Correlation of radiographic findings



### **3.1.5 Special Topics**

#### *3.1.5.1 Computational Skills*

1. Spreadsheet, e.g., Excel™
2. Database, e.g., Access™, FoxPro™, Oracle™
3. Scientific modeling and graphical package, e.g., MatLab™, IDL, Mathematica™
4. High-level language, e.g., C, Fortran, Visual Basic
5. High-level editor, word processing, and presentation software packages
6. Operating systems, e.g., UNIX, and scripting languages, e.g., Perl, Windows
7. Citation searching, e.g., Medline, PubMed
8. Statistical packages, e.g., SPSS, SYSTAT, SAS, STATISTICA™
9. Networking
  - (a) Types of networks, data rate, bandwidth
  - (b) Network infrastructure
  - (c) WAN, LAN (wide area network, local area network)
  - (d) Switching mechanisms
  - (e) Protocol structures
  - (f) Essential concepts of DICOM (Digital Imaging and Communications in Medicine), interfacing, HL-7 (Health Level-7)
  - (g) PACS (Picture Archiving and Communication System)

#### *3.1.5.2 Professional Ethics/Conflict of Interest/Scientific Misconduct*

1. Data, Patient Records, Measurement Results, and Reports
  - (a) Privacy and ownership
  - (b) Fair use issues
  - (c) Patent rights
  - (d) Archiving and record keeping
  - (e) Falsification of data
2. Publications and Presentations
  - (a) Authorship

- (b) Copyright
- (c) Peer review, confidentiality, and conflicts of interest
- (d) Plagiarism

### 3. General Professional Conduct

- (a) Interaction with colleagues
- (b) Fair competition for employment
- (c) Consulting and conflict of interest
- (d) “Whistle-blowing”

### 4. Medical Malpractice

- (a) Standard of care
- (b) Testimony as an expert witness
- (c) Rights and responsibility in communicating with patients and physicians

### 5. Research

- (a) Human subjects
- (b) Informed consent
- (c) Environmental health and safety
- (d) Dissemination of research results
- (e) Attribution
- (f) Conflict of interest

#### 3.1.5.3 *Statistical Methods in Medical Sciences*

##### A. *Topics of Primary Interest*

#### 1. Descriptive Statistics

- (a) Scales of measurement of observations: Nominal, Ordinal, Interval, Ratio
- (b) Univariate and multivariate observations
- (c) Distributions of observations (normal, binomial, lognormal, etc.). Graphical methods: Box Plots, Probability Plots, Loess Plots, Time Series, etc.
- (d) Population parameters vs. sample statistics
- (e) Distributions of statistics. Random sampling

#### 2. Probability

- (a) Classical
- (b) Bayesian

### 3. Models for Statistical Inference and Estimation

- (a) Target population. Sampled population. Samples. Tolerance intervals
- (b) Distributions of sampling statistics: Chi-squared, Student's t, F, etc.
- (c) Hypothesis testing. Point and interval estimation. Resampling methods
- (d) Significance tests, level of significance as "associated probability"
- (e) Test of hypothesis (Neyman-Pearson) vs. Probability of hypothesis (Bayes)
- (f) Confidence intervals (Neyman-Pearson) vs. credible intervals (Bayes)
- (g) Type I and Type II errors. Power of a statistical test. Null and alternative hypotheses. Multiple comparison problems (Neyman-Pearson). Probability of a hypothesis. Likelihood ratios. Bayes' factors (Bayes)

### 4. Experimental Design for Testing Hypotheses and Estimating Parameters.

#### Sensitivity Analysis

- (a) Two treatment groups consisting of different individuals
- (b) Three or more treatment groups consisting of different individuals
- (c) Before and after a single treatment in the same individuals
- (d) Three or more treatments in the same individuals
- (e) Associations between two or more variables

### 5. Design of Clinical Studies

- (a) Reliability and validity of a study: internal validity, external validity, etc. Random selection (population inference), random allocation (causal inference)
- (b) Design and analysis of randomized controlled studies. Strengths and weaknesses
- (c) Design and analysis of case-control and cohort studies. Strengths and weaknesses
- (d) Determination of sample size for a study. Power analysis
- (e) Functional status measures. Generic (SF-36). Condition-specific
- (f) Data-base studies. Strengths (high external validity) and weaknesses (low internal validity). Data-Mining

### 6. Regression Models

- (a) Simple and multiple regression models
- (b) Logistic regression models
- (c) Log-linear and Poisson models
- (d) Nonlinear models (Nonlinear in parameters)
- (e) "Goodness-of-Fit" measures and regression diagnostics. Measurement errors. Outlying/influential observations. Collinear variables

- (f) Mixed Estimation and Ridge Regression
  - (g) Interpolation and extrapolation of models
7. Survival Analysis. Time-to-Failure Models. Censored Observations. Survival and Hazard Functions
- (a) Kaplan-Meier model
  - (b) Life-table or actuarial model
  - (c) Proportional hazards model
  - (d) Weibull model
  - (e) “Goodness-of-Fit” and residual analysis
  - (f) Determination of sample size
8. Categorical Data-Analysis
- (a) Two-dimensional and three-dimensional tables
  - (b) Odds Ratio and Relative Risk. Attributable risk
  - (c) Logit and loglinear models
  - (d) Receiver Operating Characteristic (ROC) analysis and interpretation. Sensitivity, specificity and predictive value of a diagnostic test. Chance-corrected measures of reliability/validity of a diagnostic test
  - (e) Marginal homogeneity and McNemar tests
  - (f) Inter-rater agreement. Kappa and weighted Kappa statistics
- B. *Topics of Secondary Interest*
1. Parametric and Non-parametric Models. Efficiency of Procedures. Resampling Models. Exact Statistical Methods
2. Multiple Comparisons
- (a) Bonferroni, Hommel, Tukey, etc. “adjustments” of significance levels (Neyman-Pearson model)
  - (b) See also B3c below
3. Ensembles of Studies. Combining Information from Several Studies of the Same Issue. Meta-Analysis. Cross-Design Synthesis. Cochrane Collaboration. Interspecies Extrapolation of Dose-Response Functions
- (a) Meta-analysis
  - (b) Cross-design synthesis
  - (c) Empirical Bayes point and interval “shrinkage estimates” of parameters
4. Probit Regression Models. Bioassay

5. Multivariate Analysis

- (a) Cluster analysis
- (b) Discriminant analysis
- (c) Factor analysis
- (d) Principal component analysis

6. Time Series Analysis. Statistical Forecasting. Point and Interval Estimates

- (a) Trend (deterministic) vs. drift (stochastic)
- (b) Exponential smoothing and ARIMA models
- (c) Combining independent forecasts

7. Proportional Odds and Proportional Hazards Model of Ordinal Response

8. Quality Control Statistics. Univariate and Multivariate Control Charts

3.1.5.4 *Safety: Electrical/Chemical/Biological/Elementary Radiation*

1. Electrical Safety

- (a) High voltage sources
- (b) Specific safety procedures
- (c) Emergency interlocks

2. Hazard Communications Standards

3. Hazardous Materials

4. Material Safety Data Sheets

5. Environmental and Emergency Procedures

6. Radiation Safety

**3.2 IMAGING SCIENCE**

**3.2.1 Conventional Planar Imaging**

1. X-Ray Production

- (a) The x-ray tube
- (b) Electron energy
- (c) Bremsstrahlung

- (d) Characteristic radiation
- (e) Efficiency
- (f) Efficacy (Output)

2. Energizing and Controlling the X-Ray Tube

- (a) kV production
- (b) Voltage waveform and x-ray production
- (c) Capacitors
- (d) High-frequency power supplies
- (e) mA control
- (f) Exposure timing
- (g) Quality assurance procedures

3. X-Ray Tube Heating and Cooling

- (a) Heat production
- (b) Heat capacity
- (c) Focal spot area
- (d) Anode body
- (e) Tube housing

4. X-Ray Image Formation and Contrast

- (a) Contrast types
- (b) Effects of photon energy (kVp)
- (c) Area contrast

5. Scattered Radiation and Contrast

- (a) Contrast reduction
- (b) Collimation
- (c) Air gap
- (d) Grids
- (e) Grid penetration
- (f) Grid selection

6. Radiographic Receptors

- (a) Screen functions
- (b) Receptor sensitivity
- (c) Image blur
- (d) Image noise
- (e) Artifacts

7. The Photographic Process and Film Sensitivity

- (a) Film functions
- (b) Optical density
- (c) Film structure
- (d) The photographic process
- (e) Sensitivity
- (f) Processing quality control

8. Film Contrast Characteristics

- (a) Contrast transfer
- (b) Film latitude
- (c) Film types
- (d) Effects of processing
- (e) Film fog

9. Radiographic Density Control

- (a) The x-ray generator
- (b) Receptor sensitivity
- (c) Patient
- (d) Distance and area
- (e) Automatic exposure control

10. Blur, Resolution, and Visibility of Detail

- (a) Visibility of detail
- (b) Unsharpness
- (c) Resolution
- (d) Modulation Transfer Function (MTF)

11. Radiographic Detail

- (a) Object location and magnification
- (b) Motion blur
- (c) Focal spot blur
- (d) Receptor blur
- (e) Composite blur

12. Fluoroscopic Imaging Systems

- (a) Intensifier tubes
- (b) Video systems

- (c) The optical system and cameras
- (d) Receptor sensitivity

### 13. Image Noise

- (a) Effect on visibility
- (b) Quantum noise
- (c) Receptor sensitivity
- (d) Grain and structure noise
- (e) Electronic noise
- (f) Effect of noise on contrast
- (g) Effect of blur on noise
- (h) Image integration
- (i) Image subtraction

### **3.2.2 Digital X-Ray Imaging and Computed Tomography**

#### 1. Digital Imaging Systems and Image Processing

- (a) Digital images
- (b) Digital image receptors and conversion
- (c) Image processing
- (d) Image storage and retrieval
- (e) Image display and analysis
- (f) Digital x-ray imaging systems

#### 2. Computed Tomography Image Formation

- (a) The x-ray system
- (b) Detectors
- (c) Computer
- (d) Display unit and camera
- (e) Scanning
- (f) Image reconstruction
- (g) Volume or cone-beam CT

#### 3. Computed Tomography Image Quality

- (a) Contrast sensitivity
- (b) High and low contrast resolution
- (c) Noise
- (d) Artifacts
- (e) Quality assurance



#### 4. Specialized Digital Techniques

- (a) Image classification
- (b) Digital fluoroscopy
- (c) Time-dependent processing
- (d) Mask mode
- (e) Matched filters
- (f) Time Interval Difference (TID) Mode
- (g) Recursive temporal filters
- (h) Parametric imaging
- (i) Energy-dependent processing
- (j) K-edge imaging
- (k) Non-K-edge energy subtraction
- (l) Energy subtraction S/N (signal to noise)
- (m) Spatial frequency filtering
- (n) Dual energy noise reduction techniques
- (o) Image compensation techniques

### 3.2.3 Ultrasound Imaging

#### 1. Ultrasound Plane Waves

- (a) One-dimensional wave equation and harmonic solution
- (b) Wave variables: pressure, particle velocity, displacement
- (c) Intensity; relation to pressure amplitude
- (d) Decibel notation
- (e) Acoustical impedance
- (f) Reflection and transmission at interfaces

#### 2. Propagation of Sound Waves Through Tissue

- (a) Speed of sound
- (b) Attenuation and absorption
- (c) Scattering
- (d) Nonlinear propagation; definition of B/A

#### 3. Single Element Transducers

- (a) General design considerations
- (b) Factors that affect frequency and bandwidth
- (c) Continuous wave beam patterns
- (d) Beam patterns for pulsed operation
- (e) Focusing

4. Transducer Arrays
  - (a) Principle of 1-D array types
  - (b) Design; element layout, matching and backing material
  - (c) Multi-frequency operation
  - (d) Transmit beam forming; transmit focusing
  - (e) Beam forming during reception; receive focusing
  - (f) Apodization and dynamic aperture
  - (g) Estimates of axial and lateral resolution
  - (h) Slice thickness
5. Pulse Echo Equipment Signal Processing
  - (a) Pulsing characteristics, duty factors
  - (b) Transmit power
  - (c) Receiver gain; overall gain and TGC (temporal gain correction)
  - (d) Compression and demodulation
  - (e) Harmonic imaging
  - (f) A-mode, B-mode, M-mode
6. B-Mode Imaging
  - (a) Principal imaging methods
  - (b) Image frame rate
7. Continuous Wave and Pulsed Doppler
  - (a) Doppler equation
  - (b) Nature of the Doppler signal
  - (c) Spectral analysis
  - (d) Pulsed Doppler
  - (e) Aliasing
8. Flow Imaging with Ultrasound
  - (a) Velocity imaging
  - (b) Energy imaging
  - (c) Information content on color flow images
  - (d) Blood pool contrast agents
9. Equipment Performance Testing
  - (a) Axial, lateral and elevational resolution
  - (b) Methods for measuring resolution
  - (c) System sensitivity and visualization depth

## 10. Information and Artifacts in Gray Scale Imaging and Doppler

### 11. Bioeffects and Safety

- (a) Acoustic output measurements
- (b) Real-time output labels: MI and TI
- (c) Biological effects of ultrasound
- (d) Safe operating levels

### 3.2.4 Magnetic Resonance Imaging

#### 1. Basic Principles

- (a) Intrinsic and extrinsic parameters affecting MR image contrast
- (b) Required properties of nuclei that are useful in MR
- (c) The static magnetic field ( $B_0$ ) and the equilibrium distribution
- (d) The Larmor frequency and the radiofrequency field ( $B_1$ )
- (e) The lab and rotating frames of reference
- (f) Relaxation mechanisms ( $T_1$ ,  $T_2$ ,  $T_2^*$ ) and effects of common contrast agents
- (g) The basic spin-echo sequence
- (h) Contrast in spin-echo imaging
- (i) Spatial encoding using linear magnetic field gradients ( $G_x$ ,  $G_y$ ,  $G_z$ )
  - i. Slice selection
  - ii. Frequency-encoding
  - iii. Phase-encoding
  - iv. Spatial accuracy of MRI
- (j) Properties of “k-space”
- (k) The full spin-echo sequence

#### 2. Hardware

- (a) The static magnetic field subsystem
  - i. Common field strengths and magnet designs
  - ii. Siting issues
- (b) The radiofrequency field subsystem
  - i. Coil designs: volume, surface, phased array
  - ii. Radiofrequency shielding requirements (siting)
- (c) The gradient field subsystem
  - i. Maximum amplitudes, risetimes, and slew rates
  - ii. Eddy current effects and compensation techniques

### 3. Basic Image Quality Issues

- (a) Signal-to-noise ratio and contrast-to-noise ratio in MRI
- (b) Resolution
- (c) Image acquisition time

### 4. Basic Pulse Sequences

- (a) Spin-echo sequence
- (b) Gradient-echo sequences
- (c) Fast spin-echo sequence
- (d) Inversion recovery sequences and applications [STIR, FLAIR (Short Time Inversion Recovery, Fluid-Attenuated Inversion Recovery)]
- (e) Common sequence options (spatial and chemical saturation techniques)
- (f) Ultrafast imaging sequences (echo planar imaging and spiral techniques)
- (g) MR angiography (MRA) sequences
  - i. Flow-related phenomena
  - ii. Time-of-flight MRA
  - iii. Phase contrast MRA
  - iv. Bolus contrast agent-enhanced MRA
- (h) MR spectroscopy (MRS) sequences

### 5. Artifacts

- (a) Motion
- (b) Aliasing or “wrap-around”
- (c) Metal objects
- (d) Chemical shift
- (e) Truncation
- (f) System-related
  - i. Distortions
  - ii. Radiofrequency (RF) coil problems and RF interference
  - iii. Ghosting
  - iv. Receiver/memory/array processor problems

### 6. Safety and Bioeffects

- (a) Static field considerations (projectile, effects on implants, physiological effects)
- (b) RF field considerations (tissue heating, specific absorption rate, burn injuries)
- (c) Gradient field considerations (peripheral nerve stimulation, sound pressure levels)

- (d) Food and Drug Administration (FDA) guidelines
- (e) MR and pregnant patients, technologists, and nursing staff
- (f) Common MR contrast agents

#### 7. Quality Control

- (a) The ACR (American College of Radiology) standards related to MRI
- (b) The ACR MR Accreditation Program (MRAP)
- (c) The ACR MR Quality Control Manual and its recommended quality control aspects
- (d) Other guidelines, including AAPM task group reports and NEMA (National Electrical Manufacturers Association) reports

### 3.2.5 Nuclear Medicine/Imaging

#### 1. The Gamma Camera

- (a) Camera characteristics
- (b) Collimators
- (c) Crystals
- (d) Photomultiplier tube array
- (e) Image formation
- (f) Spectrometry
- (g) The pulse height analyzer

#### 2. Radionuclide Image Quality

- (a) Contrast
- (b) Blur and visibility of detail
- (c) Image noise
- (d) Uniformity
- (e) Clinical gamma camera applications

#### 3. Radionuclide Tomographic Imaging

- (a) Positron Emission Tomography (PET) and PET-CT
  - i. Principles of PET imaging, hardware, resolution
  - ii. Clinical PET imaging procedures
  - iii. Quantitative PET imaging
- (b) Single Photon Emission Computed Tomography (SPECT)
  - i. Principles of SPECT imaging, hardware, resolution
  - ii. Clinical SPECT imaging procedures
  - iii. Quantitative SPECT imaging

4. Statistics: Counting Error
5. Patient Exposure and Protection
  - (a) Internal dosimetry
  - (b) Clinical dosimetry and typical doses for common imaging procedures
  - (c) Radionuclide therapy dosimetry
6. Personnel Exposure and Protection
  - (a) Effective dose equivalents
  - (b) Exposure limits
  - (c) Exposure sources
  - (d) Area shielding
  - (e) Personnel shielding
  - (f) Exposure from radioactive sources
7. Radiation Measurement
  - (a) Ionization chambers
  - (b) Survey meters
  - (c) Activity measurement
8. Principles of Radiochemistry, Radioimmunoimaging, and the Radiopharmacy
  - (a) Radiochemistry principles
  - (b) Radioimmunoimaging and radioimmunotherapy principles
  - (c) Radiopharmacy techniques
9. Quality Control Issues in Nuclear Medicine

### **3.3 RADIATION THERAPY**

#### **3.3.1 Radiation Oncology**

1. Overview of Clinical Radiation Oncology
  - (a) Cancer incidence/etiology
  - (b) Cancer classification/staging
  - (c) Overview of treatment modalities:
    - i. Surgery
    - ii. Chemotherapy
    - iii. Radiation therapy

- A. Teletherapy (external beam therapy)
- B. Brachytherapy (Curie therapy)
- C. Neutron, proton and heavy charged particle therapy
- iv. Hyperthermia
- (d) Role of a clinical medical physicist
- (e) National and international medical physics and radiation oncology organizations

## 2. Radiobiological Basis of Radiation Therapy

- (a) Tumor control and normal tissue tolerance (therapeutic ratio)
- (b) Repair
- (c) Fractionation
- (d) Organ tolerances
- (e) Mathematical aspects of survival curves

### 3.3.2 External Beam Radiation Therapy

#### 1. Clinical Photon Beams: Description

- (a) Basic parameters: Field size, source-skin distance, source-axis distance, source-collimator distance
- (b) Field size options: Circular, square, rectangular, irregular
- (c) Field collimators: Rectangular (upper and lower jaws); circular; multileaf

#### 2. Clinical Photon Beams: Point Dose Calculations

- (a) Percentage depth dose (PDD)
- (b) Peak-scatter factor (PSF)
- (c) Tissue-air ratio (TAR)
- (d) Tissue-maximum ratio (TMR)
- (e) Tissue-phantom ratio (TPR)
- (f) Scatter function
- (g) Scatter-air ratio (SAR)
- (h) Scatter-maximum ratio (SMR)
- (i) Collimator factor
- (j) Relative dose factor/output factor
- (k) Off-axis ratio

#### 3. Clinical Photon Beams: Basic Clinical Dosimetry

- (a) Factors affecting the fundamental dosimetry quantities
- (b) Relationships between the fundamental dosimetry quantities

- (c) Collimator and phantom scatter corrections
- (d) Irregular fields and Clarkson's integration method

#### 4. Clinical Electron Beams

- (a) Electron treatment head
  - i. Energy selection
  - ii. Beam broadening methods: dual scattering foil vs. scanned beam
  - iii. Collimating methods: trimmers versus applicators (cones)
- (b) Depth-dose distribution
  - i. Characteristics ( $\bar{D}_s, D_x, R_{100}, R_{90}, R_p, R_{90-10}$ )
  - ii. Variation with energy and field size
- (c) Energy spectrum
  - i. Characteristics ( $E, E_p$ )
  - ii. Specification at surface (range-energy relationships) and depth
- (d) Dose distribution
  - i. Beam flatness and symmetry
  - ii. Penumbra
  - iii. Isodose plots
- (e) Determination of monitor units
  - i. Method of dose prescription
  - ii. Output factor formalisms
- (f) Effect of air gap on beam dosimetry
- (g) Fundamental principles
  - i. Square-root method
  - ii. Effective versus virtual source
  - iii. Side-scatter equilibrium

### 3.3.3 Brachytherapy

#### 1. Brachytherapy: Basic Physical Characteristics

- (a) Radionuclides used in brachytherapy
- (b) Source types used in brachytherapy
- (c) Sealed-source dosimetry (source strength, air kerma rate, absorbed dose calculation)
- (d) Source calibration, assay, and quality assurance
- (e) Source specifications and dosimetry

#### 2. Brachytherapy: Clinical Aspects

- (a) Brachytherapy techniques: Interstitial, intracavitary; surface applicators



- (b) Brachytherapy systems: Direct-loading vs. afterloading; manual vs. remote afterloading
- (c) Interstitial therapy: Manchester and Paris systems
- (d) Seed implants
- (e) Ultrasound-guided prostate seed implants
- (f) Gynecological intracavitary therapy
- (g) Clinical prescriptions and dose-volume histograms
- (h) Remote afterloading machines
- (i) Radiological models (linear-quadratic model)

### 3.3.4 Treatment Planning

1. Target Volume Definition and Dose Prescription Criteria (ICRU 50 and ICRU 62)
  - (a) Gross tumor volume (GTV)
  - (b) Clinical target volume (CTV)
  - (c) Planning target volume (PTV)
  - (d) Dose prescription point, isodose line, or isodose surface
  
2. Photon Beams: Dose Modeling and Treatment Planning
  - (a) Single field dose distribution
  - (b) Parameters influencing isodose curves and isodose surfaces
  - (c) Combination of fields
  - (d) Wedged and angled fields
  - (e) Corrections for SSD (source-to-surface distance), missing tissue, and inhomogeneities
  - (f) Dose specification and normalization
  
3. Photon Beams: Treatment Planning
  - (a) Acquisition of isodose data
  - (b) Computer hardware
  - (c) Common algorithms: Convolution, superposition, pencil beam
  - (d) Single-plane treatment plans
  - (e) Multiplane treatment plans
  - (f) Non-coplanar plans
  - (g) Treatment planning with asymmetric collimators
  - (h) Treatment planning with dynamic wedge
  - (i) Treatment planning with multileaf collimators (MLCs)
  - (j) Compensator design
  - (k) 3-D treatment planning
  - (l) Forward vs. inverse treatment planning

- (m) Treatment planning with Monte Carlo techniques
- (n) Quality assurance of treatment planning systems

#### 4. Clinical Photon Beams: Patient Application

- (a) Patient data acquisition
  - i. Contours
  - ii. Images: Plain film, electronic portal imaging device (EPID), computed radiography (CR)
  - iii. Computerized tomography (CT), ultrasound (US), single photon emission tomography (SPECT), magnetic resonance imaging (MRI), positron emission tomography (PET)
- (b) Conventional simulator techniques
  - i. Positioning/immobilization
  - ii. Use of contrast, markers, etc.
  - iii. Image parameters/optimization
- (c) Accessory devices and techniques:
  - i. Block cutting
  - ii. Compensators
  - iii. Portal verification images
- (d) CT-simulator techniques
  - i. Scout view images
  - ii. Virtual simulation
  - iii. Digitally-reconstructed radiographs (DRRs)
- (e) Special considerations
  - i. Skin dose
  - ii. Field matching
  - iii. Integral dose
  - iv. Dose volume histograms (DVHs): Differential (direct) and integral (cumulative)

#### 5. Clinical Electron Beams: Dose Modeling and Treatment Planning

- (a) Effects of patient and beam geometry
  - i. Air gap
  - ii. Beam obliquity
  - iii. Irregular patient surface
  - iv. Internal heterogeneities: bone, fat, lung, air
- (b) Dose algorithms
  - i. Analytical algorithms (e.g., Fermi-Eyges based pencil beam)
  - ii. Monte Carlo algorithms
  - iii. Clinical commissioning
  - iv. Quality assurance of treatment plans

- (c) Treatment planning techniques
  - i. Energy and field size selection
  - ii. Bolus: Constant thickness and shaped
  - iii. Collimation: Inserts, skin, internal
  - iv. Field abutment techniques
  - v. Photon-electron mixed beams
- (d) Special electron treatment techniques
  - i. Total skin irradiation
  - ii. Total limb irradiation
  - iii. Electron arc therapy
  - iv. Intraoperative electron therapy
  - v. Total scalp irradiation
  - vi. Craniospinal irradiation
  - vii. Conformal therapy

### 3.3.5 Radiation Therapy Devices

#### 1. Radiation Therapy Machines

- (a) Isotope units: cobalt-60 and cesium-137
- (b) Static accelerators
  - i. X-ray machines
  - ii. Neutron generators
- (c) Cyclic accelerators
  - i. Basics of linear accelerators (linacs)
  - ii. Betatron
  - iii. Microtron
  - iv. Cyclotron and synchrocyclotron
  - v. Synchrotron

#### 2. Linear Accelerator (Linac)

- (a) Basic design and components
- (b) Accelerating waveguide
- (c) Electron injection system
- (d) RF power generation
- (e) Electron beam transport
- (f) Linac treatment head
- (g) Production of clinical photon beams (target and flattening filter)
- (h) Production of clinical electron beams
- (i) Dose monitoring system
- (j) Beam collimation

### 3. Machine Acquisition

- (a) Specification documents
- (b) Treatment room design
- (c) Bidding documents
- (d) Machine installation
- (e) Acceptance testing
- (f) Machine commissioning

### 4. Quality Control/Quality Assurance (QC/QA)

- (a) Error analysis of total treatment process
- (b) Sources of QC and QA standards
- (c) Organizing a QA program
  - i. Staff assignment
  - ii. Equipment
  - iii. Traceability and redundancy
- (d) Dose delivery
  - i. Documentation requirements
  - ii. Portal verification techniques
  - iii. Record and verification systems
  - iv. In-Vivo dosimetry (TLD, diodes, and MOSFETs)
- (e) Specific QA guidelines
  - i. Machine sources
  - ii. Brachytherapy sources and applicators
  - iii. Block-cutting compensation systems
  - iv. Treatment planning systems
  - v. Multileaf collimators
  - vi. Intensity-modulated radiotherapy
  - vii. Dynamic wedges
- (f) Radiation Oncology Information Management systems
  - i. Network
  - ii. Client server systems
  - iii. Radiotherapy imaging systems
  - iv. Information system interfaces: DICOM-RT and Health Level-7 (HL-7) standards

### 5. Phantom Systems

- (a) Tissue equivalent materials for photon and electron beams
- (b) Calibration phantoms
- (c) Anthropomorphic phantoms
- (d) Beam scanning systems

### 3.3.6 Special Techniques in Radiotherapy

1. Special External Beam Radiotherapy Techniques: Basic Characteristics, Historical Development, Quality Assurance (Equipment And Treatment), Diseases Treated
  - (a) Total body irradiation (TBI)
  - (b) Total skin electron irradiation (TSEI)
  - (c) Stereotactic radiosurgery
  - (d) Stereotactic radiotherapy
  - (e) Endorectal irradiation
  - (f) Electron arc therapy
  - (g) Intraoperative radiotherapy
  - (h) Hyperthermia
  - (i) Hyperfractionation
2. Intensity-Modulated Radiotherapy (IMRT)
  - (a) Dose delivery systems
    - i. Single-slice collimators
    - ii. Multileaf collimators
    - iii. Tomotherapy
  - (b) Dose delivery techniques
    - i. Step-and-shoot
    - ii. Sliding window
    - iii. Dynamic IMRT

### 3.3.7 Radiation Therapy with Neutrons, Protons, and Heavy Ions

1. Rationale
  - (a) Physical
    - i. Comparison of depth dose distributions (Bragg peak)
    - ii. LET (Linear Energy Transfer)
  - (b) Biological
    - i. LET
    - ii. Hypoxia – OER (Oxygen Enhancement Ratio)
    - iii. RBE (Relative Biological Effectiveness)
2. Neutrons
  - (a) Production of neutrons
    - i. Deuterium-Tritium (DT) generators
    - ii. Cyclotrons ( $d^+ \text{ } \alpha \text{ Be}$  interaction)

- iii. Linear accelerators ( $p^+$   $\rightarrow$   $e^-$  Be interaction)
    - iv. Sealed source therapy ( $^{252}\text{Cf}$ )
  - (b) Interactions in tissue
    - i. Elastic scattering
    - ii. Inelastic scattering
    - iii. Neutron capture
    - iv. Spallation
  - (c) Depth dose and dosimetry
  - (d) Installations or facilities
  - (e) Boron Neutron Capture Therapy (BNCT)
- 3. Protons
  - (a) Production of protons
    - i. Linear accelerator
    - ii. Synchrotron
    - iii. Synchrocyclotron
  - (b) Interactions in tissue
    - i. Elastic atomic collisions
    - ii. Ionization and excitation
    - iii. Nuclear interactions
    - iv. Radioactive interactions (bremsstrahlung)
  - (c) Depth dose and dosimetry
  - (d) Beam shaping
  - (e) Installations or facilities
- 4. Heavy Ions (Helium, Carbon, Nitrogen, Neon, Argon)
  - (a) Production
    - i. Linear accelerator
    - ii. Synchrocyclotron
    - iii. Proton synchrotron
  - (b) Interactions in tissue
    - i. Elastic atomic collisions
    - ii. Ionization and excitation
    - iii. Nuclear interactions
    - iv. Radioactive interactions (bremsstrahlung)
  - (c) Depth dose and dosimetry
  - (d) Beam shaping
  - (e) Installations or facilities

### **3.3.8 Radiation Protection in Radiotherapy**

#### **1. Operational Safety Guidelines**

- (a) Regulatory agencies and regulatory requirements
- (b) Radiation surveys: Measurement techniques and equipment
- (c) Area personnel monitoring
- (d) External beam radiation sources
- (e) Brachytherapy sources

#### **2. Structural Shielding of Treatment Installations**

- (a) Definition of workload, occupancy factor, use factor, etc.
- (b) Definition of primary, scatter, and leakage barriers
- (c) Structural shielding design
  - i. Conventional simulator and CT-simulator installation
  - ii. Superficial and orthovoltage x-ray room
  - iii. Low dose rate (LDR) and high dose rate (HDR) remote afterloading brachytherapy installations
  - iv. Cobalt and low-energy linac installations
  - v. High-energy linac installations, protection against neutrons
  - vi. Intraoperative radiotherapy installations

## **4 LABORATORY TRAINING**

### **4.1 HEALTH PHYSICS/RADIATION SAFETY**

#### **1. Sample Analysis by Scintillation Detection**

- (a) Detector response vs. energy
- (b) Statistical considerations
- (c) USNRC leak test requirements
- (d) Sample preparation
- (e) Data analysis
- (f) Result interpretation

#### **2. Personnel Dosimeters: Photon-Electron**

- (a) Detector types and properties
- (b) Gamma-ray energy response
- (c) Dose response
- (d) Stability and reproducibility

3. Personnel Dosimeters: Neutrons
  - (a) Detector types and properties
  - (b) Neutron energy response
  - (c) Dose response
  - (d) Dose-equivalent response
  - (e) Stability and reproducibility
4. Leakage Radiation From Linear Accelerators
  - (a) Anticipated radiation fields
  - (b) Detector types and calibrations
  - (c) AAPM recommendations
  - (d) Measurement and analysis
  - (e) Neutron leakage
5. Neutron Survey Instruments
  - (a) Dose equivalent response: Bonner Sphere
  - (b) Energy independent response: Long Counter
  - (c) Calibration: Pu-Be
  - (d) Effective center and neutron response
  - (e) Data analysis and interpretation
6. Tritium Air Concentrations-Biological Burden Determination
  - (a) Air dispersion and sample collection
  - (b) Biosample collection
  - (c) Liquid scintillation counting techniques
  - (d) Derived air concentrations
  - (e) Deduced body burdens
7. CT-Diagnostic Suite Shielding Calculation
  - (a) Special needs and characteristics of sources
  - (b) Use of existing building materials
  - (c) Suite layout and personnel flow
  - (d) Calculation and interpretation
  - (e) Presentation of results
8. Particle Transport by Stochastic Sampling
  - (a) Generation of source histories
  - (b) Cross section preparation
  - (c) Geometry preparation



- (d) Explicit transport of histories
- (e) Scoring of results

9. Dose Estimates From Diagnostic Imaging Procedures

- (a) Fetal dose calculations
- (b) Pediatric dose issues
- (c) Risk estimates

## 4.2 DIAGNOSTIC IMAGING

1. X-Ray Production and Machine Output

- (a) Ionization chamber measurement
- (b) Effects of kVp, mA, exposure time
- (c) Effects of filtration
- (d) Measurement of half value layer

2. Radiographic (Film) Contrast

- (a) Densitometry, sensitometry
- (b) Effects of kV, mA, exposure time
- (c) H & D curves (Hurter & Driffield curves)
- (d) Processor

3. Film/Screen Systems

- (a) Speed
- (b) Resolution
- (c) Noise
- (d) Processors

4. Scatter Reduction

- (a) Grids
- (b) Air Gap
- (c) Collimation

5. Roentgenographic and Fluoroscopic Quality Control

- (a) Focal spot size
- (b) Radiation field/light field
- (c) Reproducibility, linearity
- (d) Dose calculation

- (e) Voltage measurement
- (f) Tomography, cine, rapid film changers
- (g) Fluoroscopy
- (h) Mammography
- (i) Dental

#### 6. Image Storage and Display Systems

- (a) Video systems
- (b) Hardcopy cameras
- (c) Optical disk
- (d) Magnetic storage media
- (e) Image processing
- (f) Network Q.C.
- (g) Soft-copy display calibration and Q.C.

#### 7. Nonionizing Imaging Techniques

- (a) Thermography
- (b) Visible light
- (c) Biomagnetism

#### 8. Evaluation of Imaging System Performance

- (a) MTF
- (b) ROC
- (c) Figures of Merit

#### 9. Ultrasound

- (a) Imaging principles
- (b) QC
- (c) Measurement of intensity, power

#### 10. Magnetic Resonance Imaging

- (a) Imaging principles
- (b) Basic pulse sequences and common imaging options
- (c) Radiofrequency and gradient coil design and specifications
- (d) Siting and safety
- (e) Acceptance testing, QC, and accreditation

#### 11. Computed Tomography

- (a) Imaging principles

- (b) Slice thickness
- (c) High and low contrast resolution
- (d) Beam profiles
- (e) Dose measurements
- (f) Helical z-axis characterization
- (g) Positioning light alignment
- (h) QC and accreditation

### **4.3 NUCLEAR MEDICINE INSTRUMENTATION**

#### **1. Mo-Tc Radionuclide Generator**

- (a) Elution and assay
- (b) Quality control

#### **2. Radioisotope Calibrator**

- (a) Quality control: Constancy, linearity, accuracy
- (b) Wipe testing of radionuclide standards

#### **3. Scintillation Detector Counting System**

- (a) Pulse output characteristics of each component
- (b) Determination of optimum multiplier phototube voltage

#### **4. Gamma Ray Spectrometry (NaI System)**

- (a) Calibration of single channel and multichannel analyzer systems
- (b) Measurement of linearity
- (c) Quality control
- (d) Dual isotope counting

#### **5. Scintillation Camera (Anger Type)**

- (a) Quality control: Flood field uniformity and spatial resolution; use of asymmetric windows for evaluating field uniformity and a crystal hydration
- (b) Effect of pulse height analyzer window size on contrast and spatial resolution
- (c) Measurement of resolving time
- (d) Measurement of intrinsic, extrinsic, and extrinsic in scatter spatial resolution and calculation of modulation transfer functions
- (e) Measurement of multiple window spatial registration errors
- (f) Quantitation of flood field uniformity

6. Single Photon Emission Computed Tomography (SPECT)
  - (a) Quality control: Center-of-rotation calibration and high count floods
  - (b) Comparison of planar and tomographic spatial resolution
  - (c) Measurement of field uniformity, RMS (root mean square) noise, accuracy of attenuation correction, and contrast
7. Positron Emission Tomography (PET)
  - (a) Quality control
  - (b) Measurement of singles rate, RMS noise, and contrast

#### **4.4 RADIATION THERAPY PHYSICS**

1. Overview of Clinical Radiation Oncology: Attend multidisciplinary cancer conferences/tumor boards
2. Absorbed Dose Determinations
  - (a) Calibrate a linac photon beam using TG-21 and TG-51 protocols
  - (b) Calibrate a cobalt-60 beam, both isocentrically and for SSD geometry
  - (c) Calibrate an electron beam, beginning with energy determination, using both TG-21 and TG-51 protocols
  - (d) Perform two clinical TLD measurements, including requisite calibrations
  - (e) Use film dosimetry to measure electron depth doses and to measure the flatness and symmetry of an electron beam
3. Radiation Machines: None
4. Photon Beams: Basic Dose Descriptors
  - (a) Defining GTV, CTV, PTV
  - (b) Perform direct PDD and TMR measurements. Calculate TMRs from the PDD data and compare to measurements
  - (c) Calculate treatment times for every clinical case
  - (d) Measure linac output factors
  - (e) Calculate SARs (or SMRs) from TMR data
  - (f) Calculate three cases of irregular fields, including one mantle field, both manually and by computer
  - (g) Calculate a rotational beam average TMR manually and by computer
5. Photon Beams: Dose Modeling, External Beams, and IMRT

6. Photon Beams: Patient Application, External Beams, and IMRT
7. Electron Beam Therapy
  - (a) Participate in all clinical patient treatment activities, including simulation, block cutting, treatment planning, and treatment delivery. Participate in chart rounds and patient follow-up
  - (b) Dose modeling for external beam therapy
8. Brachytherapy: In addition to clinical participation, perform cervix and planar implant calculations by hand and by computer, both for LDR and HDR
9. Radiation Protection: Calculate required shielding for a linac installation without beam stopper
10. Quality Assurance/Quality Control
  - (a) Carry out routine quality control tests on all radiation sources, block cutters, etc.
  - (b) Perform a complete annual quality control test on each beam type (cobalt, linac photon, electron, superficial/orthovoltage simulator)

## **5 BIBLIOGRAPHY**

### **5.1 ANATOMY AND PHYSIOLOGY**

- W.J. Bo. Basic Atlas of Sectional Anatomy with Correlated Imaging. 3rd ed. (W.B. Saunders Co., Philadelphia, PA, 1998).
- C.D. Clemente. Anatomy: A Regional Atlas of the Human Body. (Urban & Schwarzenberg, Baltimore, MD, 1997).
- J.T. Dennerll. Medical Terminology - A Programmed Text. 6th ed. (Delmar Publishers, Albany, NY, 1995).
- W. Lothar. Atlas of Radiological Anatomy, 3rd ed. (William & Wilkins, Baltimore, MD, 1997).
- M. Mallett. Handbook of Anatomy and Physiology for Students of Medical Radiation Technology. 3rd ed. (The Burnell Company/Publishers, Inc., 1990).
- NCRP, Report No. 82. SI Units in Radiation Protection and Measurements: Recommendations of the National Council on Radiation Protection and Measurements. (National Council on Radiation Protection and Measurements, Washington, DC, 1985).

- R.A. Novelline. Squire's Fundamentals of Radiology. 5th ed. (Harvard University Press, Cambridge, MA, 1997).
- E.J. Taylor. Dorland's Illustrated Medical Dictionary. 29th ed. (W.B. Saunders Co., Philadelphia, PA, 2000).
- G.J. Tortora and S.R. Grabowski. Principles of Anatomy and Physiology. 9th ed. (Benjamin Cummings Publishing Company, Inc., San Francisco, CA, 2000).
- A.J. Vander, J.H. Shamon, and D.S. Luciano. Human Physiology, The Mechanisms of Body Function. 7th. ed. (McGraw Hill, Boston, MA, 2000).
- J.B. Weinstein, J.K.T. Lee, and S.S. Sagel. A Pocket Atlas of Normal CT Anatomy. (Raven Press, New York, NY, 1985).
- J. Weir and P. Abrahams. An Imaging Atlas of Radiological Anatomy. (Year Book Medical Publishers, Inc., Chicago, IL, 1996).

## **5.2 BASIC RADIOLOGICAL PHYSICS AND OTHER CORE TOPICS**

- F.H. Attix. Introduction of Radiological Physics and Radiation Dosimetry. (John Wiley & Sons, New York, NY, 1986).
- F.H. Attix, W.C. Roesch, and E. Tochilin. Radiation Dosimetry. 2nd ed. (Academic Press, New York, NY, 1968).
- K. Becker. Solid State Dosimetry. (CRC Press, Inc., Cleveland, OH, 1973).
- A.R. Benedetto, H.K. Huang, and D.P. Ragan. Computers in Medical Physics. AAPM Monograph No. 17. (American Institute of Physics, New York, NY, 1988).
- S. Bevalacqua. Basic Health Physics: Problems and Solutions. (John Wiley & Sons, New York, NY, 1999).
- P.R. Bevington. Data Reduction and Error Analysis for the Physical Sciences. 2nd ed. (McGraw-Hill, New York, NY, 1992).
- J.R. Cameron, N. Suntharalingam, and G.N. Kenney. Thermoluminescent Dosimetry. (University of Wisconsin Press, Madison, WI, 1968).
- L.L. Carter and E.D. Cashwell. "Particle Transport Simulation with the Monte Carlo Method." (National Technology Information Service, U.S. Dept. of Commerce, Oak Ridge, TN, 1975).

- Robley D. Evans. *The Atomic Nucleus*. (McGraw-Hill Company, New York, NY, 1955).
- R.E Faw and J.K. Shultis. *Principles of Radiation Shielding*. (Prentice-Hall, New York, NY, 2000).
- R.B. Firestone, C.M. Baglin, and F.S.Y. Chu. *Table of Isotopes*. 8th ed. (John Wiley & Sons, New York, NY, 1999).
- H.E. Johns and J.R. Cunningham. *The Physics of Radiology*. 4th ed. (Charles C Thomas, Springfield, IL, 1983).
- K.R. Kase and W.R. Nelson. *Concepts of Radiation Dosimetry*. (Pergamon Press, New York, NY, 1978).
- G.F. Knoll. *Radiation Detection and Measurement*. 3rd ed. (John Wiley & Sons, New York, NY, 2000).
- W.R. Leo. *Techniques for Nuclear and Particle Physics Experiments: A How-To Approach*. 2nd ed. (Springer-Verlag, New York, NY, 1994).
- W.J Price. *Nuclear Radiation Detection*. 2nd ed. (McGraw-Hill, New York, NY, 1964).

### **5.3 ELECTRONICS**

- F.J. Holler, J.P. Avery, S.R. Crouch et al. *Experiments in Electronics, Instrumentation and Microcomputers*. (Benjamin Cummings Publishing Company, Inc., San Francisco, CA, 1982).
- H.D. Segall et al. *ELC Syllabus*. ASNR 39th Annual Meeting (CD ROM).
- P. Horowitz and W. Hill. *The Art of Electronics*. (Cambridge University Press, 1989).

### **5.4 HEALTH PHYSICS - RADIATION PROTECTION**

- G.D. Fullerton, R.G. Waggener, D.T. Kopp et al. *Biological Risks of Medical Irradiation*. AAPM Monograph No. 5. (American Institute of Physics, New York, NY, 1980).
- ICRP No. 26. *Recommendations of the International Commission on Radiological Protection*. (Elsevier Science, 1977).
- ICRP No. 60. *1990 Recommendations of the International Commission on Radiological Protection*. (Elsevier Science, 1990).

- ICRU, Report No. 20. "Radiation Protection Instrumentation and its Application." (International Commission on Radiation Units and Measurements, Bethesda, MD, 1971).
- ICRU, Report No. 22. "Measurement of Low-Level Radioactivity." (International Commission on Radiation Units and Measurements, Bethesda, MD, 1972).
- ICRU, Report No. 61. "Nuclear Data for Neutron and Proton Radiotherapy and for Radiation Protection." (International Commission on Radiation Units and Measurements, Bethesda, MD, 2000).
- R.G. Jager. Engineering Compendium on Radiation Shielding. (Springer-Verlag, New York, NY, 1968).
- P. McGinley. Shielding Techniques for Radiation Oncology Facilities. (Medical Physics Publishing Corporation, Madison, WI, 1998).
- K.Z. Morgan and J.E. Turner. Principles of Radiation Protection. (Krieger, New York, NY, 1973).
- NCRP, Report No. 38. "Protection Against Neutron Radiation: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1971).
- NCRP, Report No. 49. "Structural Shielding Design and Evaluation for Medical Use of X-rays and Gamma Rays of Energy up to 10 MeV: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1976).
- NCRP, Report No. 50. "Environmental Radiation Measurements: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1977).
- NCRP, Report No. 51. "Radiation Protection Guidelines for 0.1-100 MeV Particle Accelerator Facilities: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1977).
- NCRP, Report No. 53. "Review of NCRP Radiation Dose Limit for Embryo and Fetus in Occupationally Exposed Women: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1977).



- NCRP, Report No. 54. “Medical Radiation Exposure of Pregnant and Potentially Pregnant Women: Recommendations of the National Council on Radiation Protection and Measurements.” (National Council on Radiation Protection and Measurements, Washington, DC, 1977).
- NCRP, Report No. 79. “Neutron Contamination From Medical Electron Accelerators: Recommendations of the National Council on Radiation Protection and Measurements.” (National Council on Radiation Protection and Measurements, Washington, DC, 1984).
- NCRP, Report No. 82. “SI Units in Radiation Protection and Measurements: Recommendations of the National Council on Radiation Protection and Measurements.” (National Council on Radiation Protection and Measurements, Washington, DC, 1985).
- NCRP, Report No. 84. “General Concepts for the Dosimetry of Internally Deposited Radionuclides: Recommendations of the National Council on Radiation Protection and Measurements.” (National Council on Radiation Protection and Measurements, Washington, DC, 1985).
- NCRP, Report No. 112. “Calibration of Survey Instruments Used in Radiation Protection for the Assessment of Ionizing Radiation Fields and Radioactive Surface Contamination: Recommendations of the National Council on Radiation Protection and Measurements.” (National Council on Radiation Protection and Measurements, Washington, DC, 1991).
- NCRP, Report No. 116. “Limits of Exposure to Ionizing Radiation: Recommendations of the National Council on Radiation Protection and Measurements.” (National Council on Radiation Protection and Measurements, Washington, DC, 1993).
- NCRP, Report No. 122. “Use of Personal Monitors to Estimate Effective Dose Equivalent and Effective Dose to Workers for Exposure to Low-LET Radiation: Recommendations of the National Council on Radiation Protection and Measurements.” (National Council on Radiation Protection and Measurements, Washington, DC, 1995).
- W.J Price. Nuclear Radiation Detection. 2nd ed. (McGraw-Hill, New York, NY, 1964).
- N.M. Schaeffer. “Reactor Shielding for Nuclear Engineers.” (U.S. Atomic Energy Commission Office of Information Services, Oak Ridge, TN, 1973).
- J. Shapiro. Radiation Protection: A Guide for Scientists and Physicians. 3rd ed. (Harvard University Press, Cambridge, MA, 1990).

- B. Shleieu, L.A. Slaback, and B.K. Birky. Handbook of Health Physics and Radiological Health. 3rd ed. (Williams and Wilkins, Baltimore, MD, 1998).
- R.H. Thomas and H.W. Patterson. Accelerator Health Physics. (Academic Press, New York, NY, 1973).
- J.E. Turner. Atoms, Radiation, and Radiation Protection. 2nd ed. (John Wiley & Sons, New York, NY, 1995).
- J. Wood. Computational Methods in Reactor Shielding. (Pergamon Press, Oxford, UK, 1982).

## 5.5 IMAGING SCIENCE

- I.N. Bankman. Handbook of Medical Imaging. 1st ed. (Academic Press, San Diego, CA, 2000).
- H.H. Barrett and W. Swindell. Radiological Imaging: The Theory of Image Formation Detection, and Processing. (Academic Press, New York, NY, 1996).
- J.T. Bushberg, J.A. Seibert, E.M. Leidholdt, Jr., J.M. Boone. The Essential Physics of Medical Imaging. (Williams and Wilkins, Baltimore, MD, 1994).
- Z.H. Cho, J.P. Jones, and M. Singh. Foundations of Medical Imaging. (Wiley, New York, NY, 1993).
- T.S. Curry, J.E. Dowdey, and R.C. Murry. Christensen's Introduction to the Physics of Diagnostic Radiology. 4th ed. (Lea & Febiger, Malvern, PA, 1990).
- J.C. Dainty and R. Shaw. Image Science. (Academic Press, New York, NY, 1974).
- P.P. Dendy and B. Heaton. Physics of Diagnostic Radiology. (Institute of Physics Publishing, London, UK, 1999).
- Kunio Doi, Lawrence Lanzl, and Pei-Jan Paul Lin. Recent Developments in Digital Imaging. AAPM Monograph No. 12. (American Institute of Physics, New York, NY, 1984).
- G.D. Frey and P. Sprawls. The Expanding Role of Medical Physics in Diagnostic Imaging. AAPM Monograph No. 23. (American Institute of Physics, New York, NY, 1997).
- Gary D. Fullerton, W.R. Hendee, J.C. Casher et al. Electronic Imaging in Medicine. AAPM Monograph No. 11. (American Institute of Physics, New York, NY, 1984).

- David G. Gadian. Nuclear Magnetic Resonance and its Application to Living Systems. (Oxford University Press, New York, NY, 1990).
- A. Gottschalk, P.B. Hoffer, and E.J. Potchen. Diagnostic Nuclear Medicine. 2nd ed. (Williams and Wilkins, Baltimore, MD, 1988).
- E.M Haacke, R.W. Brown, M.R. Thompson, R. Venkatesan. Magnetic Resonance Imaging. Physical Principles and Sequence Design. (Wiley-Liss, New York, NY, 1999).
- B. Hasegawa. The Physics of Medical Imaging. 2nd ed. (Medical Physics Publishing, Madison, WI, 1991).
- H.K. Haung. Elements of Digital Radiology. (Prentice-Hall, Englewoods Cliffs, NJ, 1980).
- A.G. Haus. The Physics of Medical Imaging: Recording System Measurements and Techniques. AAPM Monograph No. 3. (American Institute of Physics, New York, NY, 1979).
- J. Hazle and A. Boyer. Imaging in Radiation Therapy. AAPM Monograph No. 24. (Medical Physics Publishing, Madison, WI, 1998).
- W.R. Hendee and E.R. Rittenour. Medical Imaging Physics. (John Wiley & Sons, Chicago, 2001).
- G.T. Herman. Image Reconstruction from Projections: The Fundamentals of Computerized Tomography. (Academic Press, New York, NY, 1980).
- ICRU, Report No. 25. "Conceptual Basis for the Determination of Dose Equivalent." (International Commission on Radiation Units and Measurements, Bethesda, MD, 1975).
- H.E. Johns and J.R. Cunningham. The Physics of Radiology. 4th ed. (Charles C Thomas, Springfield, IL, 1983).
- W.A. Kalender. Computed Tomography. (Publicis MCD Verlag, Munich, Germany, 2000).
- Z.P. Liang and P.C. Lauterbur. Principles of Magnetic Resonance Imaging. (IEEE Press, 2000).
- A. Macovski. Medical Imaging Systems. (Prentice-Hall, Englewood Cliffs, NJ, 1983).
- P. McGinley. Shielding Techniques for Radiation Oncology Facilities. (Medical Physics Publishing, Madison, WI, 1998).

- C.L. Morgan. Basic Principles of Computed Tomography. (University Park Press, Baltimore, MD, 1983).
- P.G. Morris. Nuclear Magnetic Resonance Imaging in Medicine. (Clarendon Press, Oxford, UK, 1986).
- NCRP, Report No. 48. "Radiation Protection for Medical and Allied Health Personnel: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1976).
- NCRP, Report No. 49. "Structural Shielding Design and Evaluation for Medical Use of X-rays and Gamma Rays of Energy up to 10 MeV: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1976).
- NCRP, Report No. 51. "Radiation Protection Guidelines for 0.1-100 MeV Particle Accelerator Facilities: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1977).
- NCRP, Report No. 53. "Review of NCRP Radiation Dose Limit for Embryo and Fetus in Occupationally Exposed Women: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1977).
- NCRP, Report No. 54. "Medical Radiation Exposure of Pregnant and Potentially Pregnant Women: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1977).
- NCRP, Report No. 80. "Induction of Thyroid Cancer by Ionizing Radiation: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1985).
- NCRP, Report No. 82. "SI Units in Radiation Protection and Measurements: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1985).
- NCRP, Report No. 93. "Ionizing Radiation Exposure of the Population of the United States: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1987).

- NCRP, Report No. 94. "Exposure to the Population in the United States and Canada from Natural Background Radiation: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1987).
- NCRP, Report No. 122. "Use of Personal Monitors to Estimate Effective Dose Equivalent and Effective Dose to Workers for Exposure to Low-LET Radiation: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1995).
- S. Nudelman and D.D. Patton. *Imaging for Medicine*. (Plenum Press, New York, NY, 1980).
- C.L. Partain. *Magnetic Resonance Imaging*. 2nd ed. (W.B. Saunders Co., Philadelphia, PA, 1988).
- A.F. Seibert and K.A. Filipow. *Practical Digital Imaging and PACS*. AAPM Monograph No. 25. (Medical Physics Publishing, Madison, WI, 1999).
- J. Shapiro. *Radiation Protection: A Guide for Scientists and Physicians*. 3rd ed. (Harvard University Press, Cambridge, MA, 1990).
- F.G. Shellock and E. Kanal. *Magnetic Resonance. Bioeffects, Safety, and Patient Management*. (Lippincott-Raven, Philadelphia, PA, 1996).
- J.A. Swets and R.M. Pickett. *Evaluation of Diagnostic Systems: Methods from Signal Detection Theory*. (University Press, New York, NY, 1982).
- M.M. Ter-Pogossian. *The Physical Aspects of Diagnostic Radiology*. (Harper & Row, New York, NY, 1967).
- S.R. Thomas and Robert L. Dixon. *NMR in Medicine: The Instrumentation and Clinical Applications*. AAPM Monograph No. 15. (American Institute of Physics, New York, NY, 1985).
- R.W. Waggener and C.R. Wilson. *Quality Assurance in Diagnostic Radiology*. AAPM Monograph No. 4. (American Institute of Physics, New York, NY, 1979).
- S. Webb. *The Physics of Medical Imaging*. (Adam Hilger, Philadelphia, PA, 1988).
- A.B. Wolbarst. *Physics of Radiology*. (Medical Physics Publishing, Madison, WI, 2000).

## **5.6 MEDICAL PHYSIOLOGY AND INTERMEDIATE PHYSICS FOR MEDICINE AND BIOLOGY**

- T.H. Berquist, R.L. Ehman, and G.R. May. Pocket Atlas of MRI Body Anatomy. (Raven Press, New York, NY, 1987).
- W.F. Ganong. Review of Medical Physiology. 19th ed. (Lange, Los Altos, CA, 1999).
- A.C. Guyton. Textbook of Medical Physiology. 9th ed. (W.B. Saunders Co., Philadelphia, PA, 1996).
- W.R. Hendee, E.L. Chaney, and R.P. Rossi. Radiologic Physics Equipment and Quality Control. (Year Book Medical Publishers, Chicago, IL, 1977).
- Russell K. Hobbie. Intermediate Physics for Medicine and Biology. 3rd ed. (Springer-Verlag, New York, NY, 1997).
- H.E. Johns and J.R. Cunningham. The Physics of Radiology. 4th ed. (Charles C Thomas, Springfield, IL, 1983).
- NCRP, Report No. 66. "Mammography: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1980).
- NCRP, Report No. 68. "Radiation Protection in Pediatric Radiology: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1981).

## **5.7 MEDICAL STATISTICS AND MATHEMATICAL METHODS**

- AAPM Report No. 43. "Quality Assessment and Improvement of Dose Response Models: Some Effects of Study Weaknesses on Study Findings." "C'est Magnifique?" D. Herbert, Principal Author. (Medical Physics Publishing, Madison, WI, 1993).
- D.G. Altman. Practical Statistics for Medical Research. (Chapman & Hall, NY, 1995).
- G.B. Arfken and H.J. Weber. Mathematical Methods for Physicists. (Academic Press, San Diego, CA, 1995).
- P. Armitage and G. Berry. Statistical Methods in Medical Research. 3rd ed. (Blackwell Scientific Pub., Oxford, 1994).

- J.C. Bailar III and F. Mosteller (eds.). *Medical Uses of Statistics*. 2nd ed. (New England Journal of Medicine, Boston, MA, 1992).
- D.M. Bates and D.G. Watts. *Nonlinear Regression Analysis and Its Applications*. (John Wiley & Sons, NY, 1988).
- J. Bélair, L. Glass, U. an Der Heiden, and J. Milton (eds.). *Dynamical Disease. Mathematical Analysis of Human Illness*. (American Institute of Physics, Woodbury, NY, 1995).
- D.A. Belsley, E. Kuh, and R.E. Welsch. *Regression Diagnostics. Identifying Influential Data and Sources of Collinearity*. (John Wiley & Sons, NY, 1980).
- D.A. Berry and D.K. Stangl. *Bayesian Biostatistics*. (Marcel Dekker, NY, 1996).
- P.R. Bevington. *Data Reduction and Error Analysis for the Physical Sciences*. 2nd ed. (McGraw-Hill, New York, 1992).
- G.E.P. Box, W.G. Hunter, and J.S. Hunter. *Statistics for Experimenters. An Introduction to Design, Data Analysis, and Model Building*. (John Wiley & Sons, New York, 1978).
- R.N. Bracewell. *The Fourier Transform and Its Applications*. (McGraw-Hill, New York, 1978).
- D. Brown and P. Rothery. *Models in Biology: Mathematics, Statistics and Computing*. (John Wiley & Sons Ltd., West Sussex, UK, 1993).
- B.P. Carlin and T.A. Louis. *Bayes and Empirical Bayes Methods for Data Analysis*. 2nd ed. (Chapman & Hall/CRC, Boca Raton, FL, 2000).
- S. Chow and J. Liu. *Design and Analysis of Clinical Trials. Concepts and Methodologies*. (John Wiley & Sons, New York, 1998).
- D. Collett. *Modelling Survival Data in Medical Research*. (Chapman & Hall, New York, 1994).
- N.R. Draper and H. Smith. *Applied Regression Analysis*. 2nd ed. (John Wiley & Sons, New York, 1981).
- D.M. Eddy, V. Hasselblad, and R. Shachter. *Meta-Analysis by the Confidence Profile Method. The Statistical Synthesis of Evidence*. (Academic Press, Boston, MA, 1992).
- L. Edelstein-Keshet. *Mathematical Models in Biology*. (McGraw-Hill, New York, 1988).

- B. Efron and R.J. Tibshirani. *An Introduction to the Bootstrap*. (Chapman & Hall/CRC Press, Boca Raton, 1993).
- J.P. Egan. *Signal Detection Theory and ROC Analysis*. (Academic Press, New York, 1975).
- B.S. Everitt. *Statistical Methods for Medical Investigations*. (Oxford University Press, New York, 1989).
- B.S. Everitt and A. Pickles. *Statistical Aspects of the Design and Analysis of Clinical Trials*. (Imperial College Press, London, 1999).
- K. Falconer. *Fractal Geometry. Mathematical Foundations and Applications*. (John Wiley & Sons, New York, 1990).
- D.J. Finney. *Probit Analysis*. 3rd ed. (Cambridge University Press, Cambridge, UK, 1971).
- L.D. Fisher and G. van Belle. *Biostatistics. A Methodology for the Health Sciences*. (John Wiley & Sons, New York, 1993).
- J.L. Fleiss. *The Design and Analysis of Clinical Experiments*. (John Wiley & Sons, New York, 1986).
- S.A. Glantz. *Primer of Biostatistics*. 3rd ed. (McGraw-Hill, New York, 1981).
- R.M. Groves. *Survey Errors and Survey Costs*. (John Wiley & Sons, New York, 1989).
- R.J. Harris. *A Primer of Multivariate Statistics*. (Academic Press, New York, 1975).
- L. V. Hedges and I. Olkin. *Statistical Methods for Meta-Analysis*. (Academic Press, San Diego, CA, 1985).
- D.E. Herbert (ed.). *Chaos and the Changing Nature of Science and Medicine: An Introduction*. AIP Conference Proceedings 376. (American Institute of Physics, Woodbury, NY, 1996).
- D.E. Herbert and R.H. Meyers. *Multiple Regression Analysis: Applications in the Health Sciences*. AAPM Monograph No. 13. (American Institute of Physics, New York, 1984).
- D.C. Hoaglin, F. Mosteller, and J.W. Tukey (eds.). *Exploring Data Tables, Trends, and Shapes*. (John Wiley & Sons, New York, 1985).
- D.W. Hosmer and S. Lemeshow. *Applied Logistic Regression*. (John Wiley & Sons, New York, 1989).



- H.A. Kahn and C.T. Sempos. *Statistical Methods in Epidemiology*. (Oxford University Press, New York, 1989).
- M.G. Kendall and W.R. Buckland. *A Dictionary of Statistical Terms*. (Hafner Pub. Co., New York, 1971).
- R.G. Knapp and M.C. Miller. *Clinical Epidemiology and Biostatistics*. (NMS from Williams & Wilkins, Baltimore, MD, 1992).
- J.F. Lawless. *Statistical Models and Methods for Lifetime Data*. John Wiley & Sons, New York, 1982).
- Leaverton, P.A. *A Review of Biostatistics*. Little, Brown & Co. Boston, MA. 1995.
- Little, R.J.A. and Rubin, D.B. *Statistical Analysis with Missing Data*. John Wiley & Sons. NY. 1987.
- B.F.J. Manly. *Randomization, Bootstrap and Monte Carlo Methods in Biology*. 2nd ed. (Chapman & Hall, London. 1997).
- F.H.C. Marriott. *The Interpretation of Multiple Observations*. (Academic Press, New York, 1974).
- P. McCullagh and J.A. Nelder. *Generalized Linear Models*. 2nd ed. (Chapman & Hall, New York, 1989).
- D.C. Montgomery. *Design and Analysis of Experiments*. 4th ed. (John Wiley & Sons, New York, 1997).
- D.C. Montgomery and E.A. Peck. *Introduction to Linear Regression Analysis*. 2nd ed. (John Wiley & Sons, New York, 1992).
- D.C. Montgomery. *Introduction to Statistical Quality Control*. 2nd ed. (John Wiley & Sons, New York, 1985).
- D.F. Morrison. *Multivariate Statistical Methods*. (McGraw-Hill, New York, 1967).
- National Research Council. *Combining Information. Statistical Issues and Opportunities for Research*. (National Academy Press, Washington, DC, 1992).
- W.H. Press, S.A. Teukolsky, W.T. Vetterling, and B.P. Flannery. *Numerical Recipes in C*. (Cambridge University Press, Cambridge, UK, 1992).
- R.K. Riegelman. *Studying a Study and Testing a Test*. (Little, Brown & Co., Boston, MA, 1981).

- J.J. Schlesselman. Case-Control Studies. Design, Conduct, Analysis. (Oxford University Press, New York, 1982).
- M.R. Selwyn. Principles of Experimental Design for the Life Sciences. (CRC Press, Boca Raton, FL, 1996).
- S. Siegel and N.J. Castellan. Nonparametric Statistics for the Behavioral Sciences. 2nd ed. (McGraw-Hill, Boston, MA, 1988).
- P. Sprent and N.C. Smeeton. Applied Nonparametric Statistical Methods. 3rd ed. (Chapman & Hall/CRC, Boca Raton, FL, 2001).
- S. Strogatz. Nonlinear Dynamics and Chaos. (Addison-Wesley, New York, 1994).
- J.A. Swets and R.M. Pickett. Evaluation of Diagnostic Systems. (Academic Press, New York, 1982).
- T.D.V. Swinscow. Statistics at Square One. (British Medical Journal, London, 1983).
- F. Verhulst. Nonlinear Differential Equations and Dynamical Systems. (Springer-Verlag, 1990).
- F.E. Yates (ed.). Self-Organizing Systems. The Emergence of Order. (Plenum Press, New York, 1987).

#### **Software**

- D.M. Eddy and V. Hasselblad. FAST\*PRO. Software for Meta-Analysis by the Confidence Profile Method. (Academic Press, San Diego, CA, 1992).
- J.D. Elashoff. nQuery Advisor Version 3.0 User's Guide. (Los Angeles, CA, 1999).
- EGRET for Windows. Software for the Analysis of Biomedical and Epidemiological Studies. User Manual. Cytel Software Corp. (Cambridge, MA, 1999).
- P.M. Gahlinger and J.H. Abramson. Computer Programs for Epidemiologic Analysis. PEPI Version 2. (USD Inc., Stone Mountain, GA, 1995).
- Statistical Solutions. Versatile Methods for Data Analysis. SOLAS for missing data analysis 2.0 User Reference. (Statistical Solutions, Saugus, MA, 1999).
- StatXact 4 for Windows. Statistical Software for Exact Nonparametric Inference User Manual. (Cytel Software Corp., Cambridge, MA, 1999).

- LogXact for Windows. Logistic Regression Software Featuring Exact Methods User Manual. (Cytel Software Corp., Cambridge, MA, 1996).
- SYSTAT Version 10. (SPSS Inc., Chicago, IL, 2000).
- ReSampling Stats Version 1. (ReSampling Stats, Inc., Arlington, VA, 1999).

## 5.8 NUCLEAR MEDICINE

- AAPM Report No. 6. "Scintillation Camera Acceptance Testing and Performance Evaluation." (American Institute of Physics, New York, 1980).
- AAPM Report No. 9. "Computer-Aided Scintillation Camera Acceptance Testing." (American Institute of Physics, New York, 1981).
- AAPM Report No. 22. "Rotation Scintillation Camera SPECT Acceptance Testing and Quality Control." (American Institute of Physics, New York, 1987).
- D.R. Bernier, P.E. Christian, J.K. Langan, and L.D. Wells (eds.). Nuclear Medicine Technology and Techniques. (Mosby, St. Louis, MO, 1989).
- P.J. Early and D. Bruce Sodee. Principles and Practice of Nuclear Medicine. 2nd edition (Mosby, St. Louis, MO, 1995).
- P.J. Ell and B.L. Holman. Computed Emission Tomography. (Oxford University Press, New York, 1982).
- R.J. English and S.E. Brown. Single-Photon Emission Computed Tomography: A Primer. 3rd edition. (The Society of Nuclear Medicine, Inc., New York, 1995).
- R.B. Firestone, C.M. Baglin, and F.S.Y. Chu. Table of Isotopes. 8th ed. (John Wiley & Sons, New York, 1999).
- G.D. Frey and M.V. Yester. Expanding the Role of Medical Physics in Nuclear Medicine. AAPM Monograph No. 18. (American Institute of Physics, New York, 1989).
- M.L. Goris and P.A. Briandet. A Clinical and Mathematical Introduction to Computer Processing of Scintigraphic Images. (Raven Press, New York, 1983).
- R.E. Henkin et al., (eds.) Nuclear Medicine. (Chapters 1-39 for basic science, others for clinical applications). (Mosby, St. Louis, MO, 1996).
- G.J. Hine. Instrumentation in Nuclear Medicine. (Academic Press, New York, 1967).

- G.J. Hine and J.A. Sorenson. Instrumentation in Nuclear Medicine. (Academic Press, New York, 1974).
- J.G. Kereiakes and K.R. Corey. Biophysical Aspects of Medical Use of Technetium-99m. AAPM Monograph No. 1. (American Institute of Physics, New York, 1976).
- K.S. Krane. Introductory Nuclear Physics. (John Wiley & Sons, New York, 1987).
- N.A. Lassen and W. Perl. Tracer Kinetic Methods in Medical Physiology. (Raven Press, New York, 1979).
- R. Loevinger, T.F. Budinger, and E.E. Watson. MIRD Primer for Absorbed Dose Calculations, Revised Edition. (The Society of Nuclear Medicine, Inc., New York, 1991).
- NCRP Report No. 84. "General Concepts for the Dosimetry of Internally Deposited Radionuclides: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1985).
- T. Phan and R. Wasnich. Practical Nuclear Pharmacy. 2nd ed. (Banyan Enterprises, Ltd., Honolulu, HI, 1981).
- D.V. Rao, R. Chandra, and M.C. Graham. Physics of Nuclear Medicine: Recent Advances. AAPM Monograph No. 10. (American Institute of Physics, New York, 1984).
- G.B. Saha. Fundamentals of Nuclear Pharmacy. 3rd edition. (Springer-Verlag, New York, 1992).
- M.P. Sandler. Diagnostic Nuclear Medicine. 3rd ed. (Williams and Wilkins, Baltimore, MD, 1996).
- D.B. Sodee and P.J. Early. Mosby's Manual of Nuclear Medicine Procedures. 3rd ed. (Mosby-Year Book, St. Louis, MO, 1981).
- J.A. Sorenson and M.E. Phelps. Physics in Nuclear Medicine. 2nd ed. (Grune & Stratton, Inc., Orlando, FL, 1987).
- P. Sprawls. The Physics and Instrumentation of Nuclear Medicine. (University Park Press, Baltimore, MD, 1981).
- R.G. Waggener, J.G. Kereiakes, and R.J. Shalek. Handbook of Medical Physics. (CRC Press, Inc., Boca Raton, FL, 1984).
- L. Williams. Nuclear Medical Physics. (CRC Press, Inc., Boca Raton, FL, 1987).

## 5.9 RADIATION THERAPY PHYSICS

- R.J. Schulz, P. R. Almond, J. R. Cunningham, J. G. Holt, R. Loevinger, N. Suntharalingam, K. A. Wright, R. Nath, and G. D. Lempert. (1983). “AAPM TG-21: A protocol for the determination of absorbed dose from high-energy photon and electron beams.” *Med. Phys.* 10:741–771.
- AAPM Report No. 13. “Physical Aspects of Quality Assurance in Radiation Therapy.” (American Institute of Physics, New York, 1984).
- AAPM Report No. 17. “The Physical Aspects of Total & Half Body Photon Irradiation.” (American Institute of Physics, New York, 1986).
- AAPM Report No. 19. “Neutron Measurements Around High Energy X-Ray Radio Therapy Machines.” (American Institute of Physics, New York, 1987).
- AAPM Report No. 21. “Specification of Brachytherapy Source Strength.” (American Institute of Physics, New York, 1987).
- AAPM Report No. 23. “Total Skin Electron Therapy: Technique and Dosimetry.” (American Institute of Physics, New York, 1987).
- AAPM Report No. 46. “Comprehensive QA for Radiation Oncology.” (American Institute of Physics, New York, 1994).
- AAPM Report No. 47. “AAPM Code of Practice for Radiotherapy Accelerators.” (American Institute of Physics, New York, 1994).
- AAPM Report No. 62. “Quality Assurance for Clinical Radiotherapy Treatment.” (American Institute of Physics, New York, 1998.).
- AAPM Report No. 67. “Protocol for Clinical Reference Dosimetry of High-Energy Photon and Electron Beams.” (American Institute of Physics, New York, 1999).
- G.C. Bentel, C.E. Nelson, and K.T. Noell. *Treatment Planning & Dose Calculation in Radiation Oncology*. 4th ed. (Pergamon Press, New York, 1989).
- V.T. DeVita, S. Hellman, and S.A. Rosenburg. *Cancer: Principles and Practice of Oncology*. 5th ed. (J.B. Lippincott-Raven, Philadelphia, PA, 1997).
- J. Dobbs, A. Barrett, and D. Ash. *Practical Radiotherapy Planning*. 3rd ed. (Arnold, London, UK, 1999).
- J.F. Fowler. *Nuclear Particles in Cancer Treatment*. (Adam Hilger Ltd., Philadelphia, PA, 1981).
- H.A. Gilbert and A.R. Kagan. *Modern Radiation Oncology: Classic Literature and Current Management*. (Harper & Row, Hagerstown, MD, 1978).

- T.J. Godden. Physical Aspects of Brachytherapy. (Adam Hilger Ltd., Philadelphia, PA, 1988).
- D. Greene and P.C. Williams. Linear Accelerators for Radiation Therapy. 2nd ed. (Institute of Physics Publishing, London, UK, 1997).
- J. Hazle and A. Boyer. Imaging in Radiation Therapy. AAPM Monograph No. 24. (Medical Physics Publishing, Madison, WI, 1998).
- J.L. Horton. Handbook of Radiation Therapy Physics. (Prentice-Hall, Englewood Cliffs, NJ, 1987).
- IAEA. Atlas of Radiation Dose Distributions. (International Atomic Energy Agency, Vienna, Austria, 1965).
- IAEA Report No. 23. "Absorbed Dose Determination in Photon and Electron Beams: An International Code of Practice." (International Atomic Energy Agency, Vienna, Austria, 1987).
- ICRU. Dose Specifications for Reporting External Beam Therapy with Photons & Electrons. (International Commission on Radiation Units and Measurements, Washington DC, 1978).
- ICRU Report No. 23. "Measurement of Absorbed Dose in a Phantom Irradiated by a Single Beam of X or Gamma Rays." (International Commission on Radiation Units and Measurements, Washington, DC, 1973).
- ICRU Report No. 24. "Determination of Absorbed Dose in a Patient Irradiated by X or Gamma Rays in Radiotherapy Procedures." (International Commission on Radiation Units and Measurements, Bethesda, MD, 1976).
- ICRU Report No. 33. "Radiation Quantities & Units." (International Commission on Radiation Units and Measurements, Bethesda, MD, 1980).
- ICRU Report No. 35. "Radiation Dosimetry: Electron Beams with Energies Between 1 & 50 MeV." (International Commission on Radiation Units and Measurements, Bethesda, MD, 1984).
- ICRU Report No. 38. "Dose & Volume Specifications for Reporting Intracavitary Therapy in Gynecology." (International Commission on Radiation Units and Measurements, Bethesda, MD, 1985).
- ICRU Report No. 42. "Use of Computers in External Beam Radiotherapy Procedures with High-Energy Photons & Electrons." (International Commission on Radiation Units and Measurements, Bethesda, MD, 1987).

- ICRU Report No. 50. “Prescribing, Recording and Reporting Photon Beam Therapy.” (International Commission on Radiation Units and Measurements, Bethesda, MD, 1993).
- ICRU Report No. 61. “Nuclear Data for Neutron and Proton Radiotherapy and for Radiation Protection.” (International Commission on Radiation Units and Measurements, Bethesda, MD, 2000).
- S.K. Jani. CT Simulation for Radiotherapy. (Medical Physics Publishing, Madison, WI, 1993).
- H.E. Johns and J.R. Cunningham. The Physics of Radiology. 4th ed. (Charles C Thomas, Springfield, IL, 1983).
- C.J. Karzmark and C.S. Nunan. Medical Electron Accelerators. (McGraw Hill, New York, 1993).
- J.G. Kereiakes, H.R. Elson, and C.G. Born. Radiation Oncology Physics. AAPM Monograph No. 15. (American Institute of Physics, New York, 1986).
- F.M. Khan. The Physics of Radiation Therapy. 2nd ed. (Williams and Wilkins, Baltimore, MD, 1994).
- F.M. Khan and R. Potish. Treatment Planning in Radiation Oncology. (Williams and Wilkins, Baltimore MD, 1998).
- S.C. Klevenhagen. Physics and Dosimetry of Therapy Electron Beams. (Medical Physics Publishing, Madison, WI, 1993).
- T.R. Mackie and J.R. Palta. Teletherapy: Present and Future. AAPM Monograph No. 22, (Advanced Medical Publishing, Madison, WI, 1996).
- P. McGinley. Shielding Techniques for Radiation Oncology Facilities. (Medical Physics Publishing, Madison, WI, 1998).
- W.J. Meredith and J.B. Massey. Fundamental Physics of Radiology. 3rd ed. (J. Wright, Bristol, UK, 1977).
- P. Metcalfe, T. Kron, and P. Hoban. The Physics of Radiotherapy X-Rays from Linear Accelerators. (Medical Physics Publishing, Madison, WI, 1997).
- S. Mizer, R.R. Schiller, and J.A. Deye. Radiation Therapy Simulation Workbook. (Pergamon Press, New York, 1986).
- W.T. Moss, W.N Brand, and H. Battifora. Radiation Oncology: Rationale, Technique, Results. 6th ed. (Mosby-Year Book, St. Louis, MO, 1989).

- NCRP Report No. 79. “Neutron Contamination From Medical Electron Accelerators: Recommendations of the National Council on Radiation Protection and Measurements.” (National Council on Radiation Protection and Measurements, Washington, DC, 1984).
- NCRP Report No. 82. “SI Units in Radiation Protection and Measurements: Recommendations of the National Council on Radiation Protection and Measurements.” (National Council on Radiation Protection and Measurements, Washington, DC, 1985).
- G.H. Nussbaum. Physical Aspects of Hyperthermia. AAPM Monograph No. 8. (American Institute of Physics, New York, 1982).
- C.G. Orton and F. Bagne. Practical Aspects of Electron Beam Treatment Planning. AAPM Monograph No. 2. (American Institute of Physics, New York, 1978).
- B.R. Paliwal, F.W. Hentzel, and M. Dewhirst. Biological, Physical and Clinical Aspects of Hyperthermia. AAPM Monograph No. 16. (American Institute of Physics, New York, 1988).
- B. Pierquin and G. Marinello. Practical Manual of Brachytherapy. (Medical Physics Publishing, Madison, WI, 1997).
- J.A. Purdy. Advances in Radiation Oncology Physics. AAPM Monograph No. 19. (American Institute of Physics, New York, 1992).
- P. Rubin and R.F. Bakemeier. Clinical Oncology for Medical Students and Physicians: A Multidisciplinary Approach. 5th ed. (American Cancer Society, New York, 1978).
- D.R. Shearer. Recent Advances in Brachytherapy Physics. AAPM Monograph No. 7. (American Institute of Physics, New York, 1981).
- A.S. Shiu and D.E. Mellenberg. General Practice of Radiation Oncology Physics in the 21st Century. (Medical Physics Publishing, Madison, WI, 2000).
- A. Smith. Radiation Therapy Physics. (Springer-Verlag, New York, 1995).
- J.E. Turner. Atoms, Radiation, and Radiation Protection. 2nd ed. (John Wiley & Sons, New York, 1995).
- J. Van Dyk (ed.). The Modern Technology of Radiation Oncology. (Medical Physics Publishing, Madison, WI, 1999).
- S. Webb. The Physics of Three Dimensional Radiation Therapy. (Institute of Physics Publishing, Philadelphia, PA, 1993).



- S. Webb. *The Physics of Conformal Radiotherapy*. (Institute of Physics Publishing, Philadelphia, PA, 1997).
- S. Webb. *Intensity-modulated Radiation Therapy*. (Institute of Physics Publishing, Philadelphia, PA, 2001).
- J.B. Weinstein, J.K.T. Lee, and S.S. Sagel. *A Pocket Atlas of Normal CT Anatomy*. (Raven Press, New York, 1985).
- J. Weir and P. Abrams. *An Atlas of Radiological Anatomy*. (Year Book Medical Publishers, Inc, Chicago, IL, 1986).
- J.R. Williams and D.I. Thwaites. *Radiotherapy Physics in Practice*. (Oxford University Press, New York, 1994).
- J.F. Williamson, B.R. Thomadsen, and R. Nath. *Brachytherapy Physics*. AAPM Monograph No. 20. (Medical Physics Publishing, Madison, WI, 1995).
- A.E. Wright and A. Boyer. *Advances in Radiation Therapy Treatment Planning*. Monograph No. 9. (American Institute of Physics, New York, 1982).

### **5.10 RADIOBIOLOGY**

- BEIR, Report No. VI. "Health Effects of Exposure to Radon." (National Academy Press, Washington, DC, 1999).
- A.P. Casarett. *Radiation Biology*. (Prentice-Hall, Englewood Cliffs, NJ, 1968).
- H. Cember. *Introduction to Health Physics*. 3rd ed. (McGraw Hill, New York, 1996).
- G.V. Dalrymple. *Medical Radiation Biology*. (W.B. Saunders Co., Philadelphia, PA, 1973).
- G.D. Fullerton, R.G. Waggener, D.T. Kopp et al. *Biological Risks of Medical Irradiation*. AAPM Monograph No. 5. (American Institute of Physics, New York, 1980).
- E.J. Hall. *Radiobiology for the Radiologist*. 4th ed. (J.B. Lippincott, Philadelphia, PA, 1994).
- NCRP Report No. 43. "Review of the Current State of Radiation Protection Philosophy: Recommendations of the National Council on Radiation Protection and Measurements." (National Council on Radiation Protection and Measurements, Washington, DC, 1975).

- NCRP Report No. 64. “Influence of Dose and its Distribution in Time on Dose-Response Relationships for Low-LET Radiation: Recommendations of the National Council on Radiation Protection and Measurements.” (National Council on Radiation Protection and Measurements, Washington, DC, 1980).
- NCRP Report No. 80. “Induction of Thyroid Cancer by Ionizing Radiation: Recommendations of the National Council on Radiation Protection and Measurements.” (National Council on Radiation Protection and Measurements, Washington, DC, 1985).
- NCRP Report No. 93. “Ionizing Radiation Exposure of the Population of the United States: Recommendations of the National Council on Radiation Protection and Measurements.” (National Council on Radiation Protection and Measurements, Washington, DC, 1987).
- NCRP Report No. 94. “Exposure to the Population in the United States and Canada from Natural Background Radiation: Recommendations of the National Council on Radiation Protection and Measurements.” (National Council on Radiation Protection and Measurements, Washington, DC, 1987).
- NCRP Report No. 116. “Limits of Exposure to Ionizing Radiation: Recommendations of the National Council on Radiation Protection and Measurements.” (National Council on Radiation Protection and Measurements, Washington, DC, 1993).
- D.J. Pizzarello. Radiation Biology. (CRC Press, Inc., Boca Raton, FL, 1982).
- K.N. Prasad. Human Radiation Biology. (Harper & Row, Hagerstown, MD, 1974).
- P. Rubin and G.W. Casarett. Clinical Radiation Pathology. (W.B. Saunders Co., Philadelphia, PA, 1968).

## **5.11 ULTRASOUND**

- AIUM. Standard Methods for Measuring Performance of Pulse-Echo Ultrasound Equipment. (American Institute for Diagnostic Ultrasound Equipment, Lural, MD, 1990).
- AIUM. Performance Criteria and Measurements for Doppler Ultrasound Devices. (American Institute for Diagnostic Ultrasound Equipment, Lural, MD, 1993).
- AIUM. AIUM Quality Assurance Manual for Gray-scale Ultrasound Scanners. (American Institute for Diagnostic Ultrasound Equipment, Lural, MD, 1995).

- AIUM. Methods for Measuring Performance of Pulse-Echo Ultrasound Equipment. Part II, Digital Methods. (American Institute for Diagnostic Ultrasound Equipment, Lural, MD, 1995).
- AIUM. Recommended Ultrasound Terminology. (American Institute for Diagnostic Ultrasound Equipment, Lural, MD, 1997).
- AIUM. Acoustic Output Measurement Standard for Diagnostic Ultrasound Equipment. (American Institute for Ultrasound in Medicine, Lural, MD, 1998).
- AIUM. Acoustic Output Labeling Standard for Diagnostic Ultrasound Equipment. (American Institute for Diagnostic Ultrasound Equipment, Lural, MD, 1998).
- D.A. Christensen. Ultrasonic Bioinstrumentation. (John Wiley & Sons, New York, 1988).
- D. Evans, W. McDicken, R. Skidmore et al. Doppler Ultrasound Physics, Instrumentation and Clinical Applications. (John Wiley & Sons, New York, 2000).
- G.D. Fullerton and J.A. Zagzebski. Medical Physics of CT and Ultrasound: Tissue Imaging and Characterization. AAPM Monograph No. 6. (American Institute of Physics, New York, 1980).
- L.W. Goldman and J.B. Fowlkes. Medical CT and Ultrasound: Current Techniques and Applications. AAPM Monograph 21. (American Institute of Physics, New York, 1995).
- A. Goldstein and R. Powis. Medical Ultrasonic Diagnosis, Physical Acoustics. (Academic Press, San Diego, CA, 1999).
- M.P. Goodsitt, P. Carson, S. Witt et al. (1998). "Real-time B-mode ultrasound quality control test procedures." *Med. Phys.* 25:1385–1406.
- D. Hyckes, W.R. Hendrick, and D.E. Strachman. Ultrasound Physics and Instrumentation. 2nd ed. (Mosby-Year Book, St. Louis, MO, 1992).
- ICRU Report No. 61. "Tissue Substitutes, Phantoms, and Computational Modeling in Medical Ultrasound. (International Commission on Radiation Units and Measurements, Bethesda, MD, 1998).
- J.A. Jensen. Estimation of Blood Velocities Using Ultrasound: A Signal Processing Approach. (Cambridge University Press, Cambridge, MA, 1996).
- L.E. Kinsler, A.R. Frey, A.B. Coppens et al. Fundamental of Acoustics. 3rd ed. (John Wiley & Sons, New York, 1982).

- K.K. Shung and G.A. Thieme. Ultrasonic Scattering in Biological Tissues. (CRC Press, Inc., Boca Raton, FL, 1993).
- J.H. Smith and J.A. Zagzebski. Basic Doppler Physics. (Medical Physics Publishing, Madison, WI, 1991).
- P.N.T. Wells. Biomedical Ultrasonics. (Academic Press, New York, 1976).
- J.A. Zagzebski. Essentials of Ultrasonic Physics. (Mosby-Year Book, St. Louis, MO, 1996).

### **5.12 PROFESSIONAL**

- K.R. Hogstrom and J.L. Horton. Introduction to the Professional Aspects of Medical Physics. (University of Texas M.D. Anderson Cancer Center, Houston, TX, 1999).
- R.J. Shalek and D.S. Gooden. Medical Physicists and Malpractice. (Medical Physics Publishing, Madison, WI, 1996).

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