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Academic Program Recommendations for Graduate Degrees in Medical Physics

Report of the Education and Training of Medical Physicists Committee

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The Education and Training of Medical Physicists Committee
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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, for example, 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, Radiation Protection and Radiation Safety, Radiobiology, 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, Safety, and Clinical Research and Scientific Communication. 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, the two broad subspecialties, Imaging Physics and Radiation Therapy Physics, are recognized. However, it is also acknowledged that these two subspecialities overlap in important areas, especially in areas of image-guided therapies and treatment planning. For each area, a sequence of appropriate sub-subjects is indicated, but there is a growing need for a general course in cross-sectional imaging that would include basics of contrast mechanisms, linear system theory, image reconstruction, and digital image processing as it applies to image guided procedures. For Image Science specifically, a basic course in the fundamentals of imaging in medicine is added to introduce students with an imaging subspeciality to the general concepts of image science, including the inverse problem, signal processing, digital image processing, image perception and quantitation. This is followed by modality-driven material that allows the imaging student to dive more deeply into the physics and systems engineering of the various modalities. It is noted that there is a growing body of research applying functional imaging procedures for therapy monitoring that requires quantitative imaging methods

and attention to reproducibility of image measures that may eventually find application in clinical practice. Similarly, "molecular" imaging techniques in modalities other than existing methods in nuclear imaging may also become clinically important. However, additional time will be required to gain perspective on how these emerging fields will impact the practicing medical physicist. For Radiation Therapy Physics, the sub-subjects are treatment regime and device driven. There is a need for an introductory applied image science course for those in the Radiation Therapy subspecialty. For both Imaging Physics and Radiation Therapy Physics, 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. Individual departments can give credit (when appropriate) to incoming students with previous course work that fulfills didactic MP training requirements.

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. Standard quantities and units are introduced early so that descriptions of radioactive decay, radiation interactions, the radiation field, and radiation dose 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 radiation protection and safety course.

All radiation measurements rely heavily on applications of charged-particle 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 radiation protection and safety. However, the proposed material constitutes 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 and serves to give the student perspective on the nuances of applying these principles to various situations.

2.1.2 Reduction Protection and Radiation Safety

Radiation protection and safety pervades the various subspecialties of medical physics. A study of radiation protection and safety includes discussion of the biological consequences of human radiation exposure. As such, a broad spectrum of topics is discussed. Special attention is given to protection and safety of the radiation worker and patient, as well as detection equipment and shielding analysis. An increasingly litigious society is reflected in extensive presentation of the regulatory environment. Complementary tutorial instruction should include a sequence of laboratory experiences focusing upon patient and employee radiation protection and safety as well as instrumentation, environmental sampling, bioassay, and the various aspects of shielding. The emphasis in this topic is to provide a broad knowledge base of radiation safety and protection supportive of the varied environments of medical physics.

2.1.3 Fundamentals of Imaging in Medicine

The topics are designed to introduce students with an imaging subspecialty to the general concepts of image science, including the inverse problem, signal processing, system performance, linear system theory, digital image processing, stochastic processes, image reconstruction, quantification, and decision theory.

2.1.4 Radiobiology

Every field of medical physics requires an understanding of the biological effects of radiation. 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. Radiobiology provides the basic connection between microscopic and molecular interactions of radiation with tissue and the cellular response. This material provides a solid biological and physiological background for understanding the effects of radiation on human tissues and the resulting safety policies and therapy regimens. These topics should be presented in a cohesive and consistent manner; not distributed among several related subjects such as radiation therapy physics, imaging physics, radiation protection and safety, and nuclear medicine.

2.1.5 Anatomy and Physiology

A strong understanding of anatomy and physiology (and associated terminology) is essential for a medical physicist to collaborate with his/her colleagues in medicine. 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 (especially on CT images used in treatment planning), 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. A basic introduction of cell physiology and function should be integrated to help the student understand basic concepts such as hypoxia, apoptosis, angiogenesis, hyperplasia, carcinogenesis, etc.

2.1.6 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.

2.1.6.1 *Computational Methods for Radiological Sciences*

Computer applications are an essential component of the tools that a medical physicist needs to perform basic tasks in the practice of medical physics, e.g., treatment planning, simulation, modeling, data analysis, and image processing. This section provides an introduction to some of these basic computational skills. It is assumed that a student entering into a medical physics graduate program possesses the basic computer application skills, and it is expected that this skill set is honed and augmented during graduate school.

2.1.6.2 *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. These would include more specific issues that arise with respect to recent patient privacy concerns and legislation specific to the Health Insurance Portability and Accountability Act (HIPAA) and compliance both in clinical practice and research.

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.

2.1.6.3 *Mathematical Methods for Radiological Sciences*

The clinical medical physicist must have a strong background in mathematical techniques related to the radiological sciences. Formal mathematical training should include an overview of the

following as they relate to medical physics: biostatistics, receiver operator characteristic curve analysis, mathematical modeling and simulation, optimization theory, linear and nonlinear regression techniques, and the Fourier transform (with convolution and filter applications).

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

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

2.1.6.5 *Clinical Research*

Research is an essential aspect of the medical physics discipline. In addition to university-based scientific research, medical physicist may be involved in clinical research. This research may be through national clinical trials or conducted by local university faculty. As part of their graduate training, the medical physics graduate student should be exposed to, and participate in, clinical research. Students should be familiar with research methods, ethics pertaining to human subject research and scientific communication (see section 2.1.6.6).

2.1.6.6 *Scientific Communication*

The ability to concisely, accurately, and fluently communicate research methods and results to a variety of audiences is essential in science. The medical physics student should be exposed to, and participate in, activities such as the preparation of proffered abstracts for scientific meetings, the creation of posters for such meetings, the oral presentation of research at such meetings, the preparation of manuscripts for peer review, and the scientific review of manuscripts submitted to peer-reviewed journals.

2.2 IMAGING SCIENCE

2.2.1 Mathematical Methods for Imaging in Medicine

A strong background in mathematics is required for imaging science. The medical physics graduate student should be well versed in the fundamentals of mathematics needed for understanding and developing imaging in medicine. This includes linear systems and Fourier transforms. Deterministic aspects such as image processing and reconstruction should be understood. Stochastic processes such as probability distribution functions, decision theory, noise, and filtering should all be included in the curriculum.

2.2.2 Conventional Planar X-Ray Imaging

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

2.2.3 Digital X-Ray Imaging and Computed Tomography

Image receptor technology has undergone a rapid change from film to filmless digital technology. The newer technologies, namely computed radiography and digital radiography, are outlined along with relevant image processing techniques. Signal processing in computed radiography is discussed. In digital radiography, conventional film viewers have been replaced by display monitors and, therefore, display monitors and quality control topics are discussed.

Computed tomography (CT) techniques are also discussed in this section, including recent advances in hardware and applications, e.g., multi-slice detectors, cone beam technology, etc. Use of axial, helical multi-slice, and cone-beam CT for diagnosis, treatment planning, and image-guided interventions should be discussed. The mathematics of image reconstruction should be introduced. Measurements of image quality, quality assurance, accreditation, and regulations should be addressed.

2.2.4 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. The field of ultrasound has evolved rapidly in recent years. Training should include basic information on acoustic physics, interaction of ultrasound with tissue, ultrasound transducers and arrays, 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. Measurements of image quality, quality assurance, accreditation, and regulations should be addressed.

2.2.5 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. The common uses and limitations of MRI as a tool for diagnosis and image-guided therapy should be discussed. Measurements of image quality, quality assurance, accreditation, and regulations should be addressed. Brief introductory material is provided on more advanced techniques.

2.2.6 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. The common uses and limitations of nuclear medicine modalities as tools for diagnosis and image-guided therapy should be discussed, as should quality assurance, accreditation, and regulatory issues.

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, related fundamental dosimetric quantity, and the methods of delivering dose are presented. The resultant dose distributions in tumors and normal tissue in patients are also 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, dose distribution, 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 interest, dose prescription criteria, dose modeling, and dose distribution are discussed. Specific aspects of photons, electrons, and other modalities are discussed. Methods of calculated and delivered dose verification are presented. Although dosimetry is a separate profession dedicated to treatment planning, a clinical physicist is expected to have a thorough understanding of treatment plan design. It is the responsibility of the clinical medical physicist to commission and to maintain the treatment planning systems.

2.3.5 Radiation Therapy Devices

A large number of tools including high-energy radiation delivery systems (conventional linear accelerators, compact accelerators utilized within tomotherapy and robotic delivery systems, and devices utilizing radioactive sources for external beam radiotherapy, etc.), 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 Light Ions

This section focuses on specialized types of ionizing radiation, such as neutrons, protons, and other light 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.

2.4 IMAGING FOR TREATMENT GUIDANCE AND MONITORING

2.4.1 Motion and Motion Management

In this section the concept of patient/organ motion is introduced. The various strategies for motion management during the planning and radiation delivery stages are discussed.

2.4.2 CT and 4D CT

The use of CT images for treatment planning with the application of treatment margins is described. The use of 4D CT for motion assessment in introduced. Various techniques/technologies are discussed such as multi-slice scanners and retrospective image correlation.

2.4.3 Portal Imaging

Acquisition and use of portal imaging for motion management is treated. The different technologies available are discussed. Combination of CT images and portal images via digitally reconstructed radiographs (DRR) is discussed.

2.4.4 Cone-Beam CT

Motion management through online imaging of the patient before/during treatment is introduced. The different technologies available using kV or MV images and the influence of photon scatter on the images are discussed.

2.4.5 MV CT

The use of megavoltage CT to manage motion in radiotherapy machines is outlined. MV image quality is discussed.

2.4.6 2D and 3D Ultrasound

The use of ultrasound imaging to manage motion is discussed. 2D and 3D ultrasound technologies are introduced. Use of ultrasound images for treatment planning is discussed.

2.4.7 Fusion, Registration, Deformation

Image deformation techniques needed to fuse different imaging modalities are described. Registration techniques are outlined.

2.4.8 Motion Management through Gating and Coaching

Motion management techniques through gated treatment and patient coaching are discussed.

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, including nuclear binding energy, n/p radio, fission, and nuclear bombardment
   (f) Radioactivity and modes of 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
   (c) Monoenergetic and polyenergetic spectra

4. Quantities and Units Used for Describing the Interaction of Ionizing Radiation with Matter

   (a) Terma, 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

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 as a function of energy and atomic number
   (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

9. Neutron Interactions with Matter

   (a) Neutron interactions including scatter, absorption kinematics, and cross sections
   (b) Shielding consideration for neutrons
   (c) Neutron kerma and absorbed dose calculations
   (d) Absorbed dose in a body phantom
   (e) Gamma-neutron mixed field dosimetry
   (f) 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) Energy distribution of electrons in matter (charged particle spectrum)
    (f) 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) Heat 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 (restricted and unrestricted stopping powers)
(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) and operation of electrometer
(f) Mean energy required to create an ion pair
(g) Saturation characteristics of ionization chambers: initial and general recombination, diffusion loss (understanding correction factors applied to ion chamber measurement)

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. Dosimetry and Phantoms for Special Beams (or Non-TG-51 Compliant Beams)

(a) Effects of partially exposed radiation detectors
(b) Effects of field size and time patterns in radiotherapy delivery
(c) Stereotactic beams
(d) Robotic linac: CyberKnife®
(e) Intensity-modulated radiation therapy
(f) Tomotherapy
(g) Phantoms for special beams (or non-TG-51 compliant beams)

21. Relative Dosimetry Techniques

    (a) Thermoluminescent dosimetry (TLD), including excitation and de-excitation of crystalline solids
    (b) Film dosimetry: radiographic film and radiochromic film (and understanding of issues with using film as an absolute dosimeter)
    (c) Semiconductor dosimeters: diodes
    (d) Optically stimulated luminescence (OSL)
    (e) MOSFET (metal oxide semiconductors—field effect transistor) dosimeters and diamond detectors
    (f) Gel dosimeters

22. Dosimetry by Pulse-Mode Detectors

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

23. Microdosimetry

3.1.2 Radiation Protection and 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) lntegral and active devices
   (c) Dynamic range and response sensitivities
   (d) Film, TLD, Lexan, and CR-39
   (e) Pocket ion chambers and GM counters
   (f) Pregnant workers and fetal dose limits

8. Internal Exposure

   (a) ICRP 26, ICRP 2A recommendations
   (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
    (e) Patient and fetal dose issues

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 Fundamentals of Imaging in Medicine

1. Mathematical Methods for Imaging in Medicine

2. Conventional Planar Imaging

3. Digital X-Ray Imaging and Computed Tomography

4. Ultrasound Imaging

5. Magnetic Resonance Imaging

6. Nuclear Medicine/Imaging

Note: Details of the subtopics are given under section 3.2.1.

3.1.4 Radiobiology

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) Hypofractionation and high doses per fraction
    (g) α/β 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

3.1.5 Anatomy and Physiology

1. Anatomical Nomenclature

   (a) Origin of anatomical names
   (b) Prefixes and suffixes
   (c) Anatomical position and body plane terminology

2. Bones and Bone Marrow

   (a) Classification (including spine)
   (b) Structure
   (c) Development
   (d) Function and relevance of marrow (red vs. yellow)
   (e) Radiographic appearance (x-ray, CT, MRI, nuclear medicine)

3. Brain and CNS

   (a) Anatomy
   (b) Brain structure and function
   (c) Nerve propagation and organization—diseases of the nervous system
   (d) Radiography and pathology

4. Thorax

   (a) Bones of the thorax
   (b) Organs in the thorax
   (c) Physiology
   (d) Radiography and pathology

5. Abdomen

   (a) Divisions and regions
   (b) Organs in the abdomen
   (c) Abdominal systems
   (d) Physiology
   (e) Radiography and pathology

6. Respiratory System

   (a) Organs
   (b) Physiology
   (c) Radiography and pathology

7. Digestive System

   (a) Divisions
   (b) Location, extension
   (c) Physiology
   (d) Radiography and pathology

8. Urinary System

   (a) Organs
   (b) Location
   (c) Physiology
   (d) Radiography and pathology

9. Reproductive System

   (a) Organs
   (b) Location
   (c) Physiology
   (d) Radiography and pathology

10. Circulatory System

    (a) Major components
    (b) Physiology
    (c) Radiography and pathology

3.1.6 Special Topics

3.1.6.1 *Computational Skills*

1. Spreadsheet, e.g., Excel™
2. Database, e.g., Access™, Oracle™
3. Scientific modeling and graphical package, e.g., MatLab™, IDL, Mathematica™
4. High-level language, e.g., C/CC++
5. High-level editor, word processing, and presentation software packages
6. Operating systems, e.g., UNIX/Windows® and scripting languages, e.g., Perl
7. Citation searching resources, 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) Essential concepts of DICOM (Digital Imaging and Communications in Medicine), interfacing, HL-7 (Health Level-7)
   (e) PACS (Picture Archiving and Communication System)

3.1.6.2 *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/HIPAA
   (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

3.1.6.3 *Mathematical Methods for Radiological 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) Determination of sample size for a study. Power analysis
(b) Two treatment groups consisting of different individuals
(c) Three or more treatment groups consisting of different individuals
(d) Before and after a single treatment in the same individuals
(e) Three or more treatments in the same individuals
(f) Associations between two or more variables

5. 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.
   (f) Mixed Estimation and Ridge Regression
   (g) Interpolation and extrapolation of models

6. Parametric and Non-parametric Models Efficiency of Procedures and Resampling Models.

7. Multivariate Analysis

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

8. Categorical Data-Analysis

   (a) Two-dimensional and three-dimensional tables
   (b) Odds Ratio and Relative Risk. Attributable risk
   (c) Logit and log-linear models
   (d) Receiver Operating Characteristic (ROC) analysis and interpretation. Sensitivity, specificity, and predictive value of a diagnostic test. Chance-corrected measures of reliability and validity of a diagnostic test
   (e) Inter-rater agreement. Kappa and weighted Kappa statistics

B. *Topics of Secondary Interest*

1. Multiple Comparisons—Bonferroni, Hommel, Tukey, etc., "adjustments" of significance levels (Neyman-Pearson model)

2. 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

3. Probit Regression Models. Bioassay

4. 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

5. 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

6. 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) Functional status measures. Generic (SF-36). Condition-specific
   (e) Data-base studies. Strengths (high external validity) and weaknesses (low internal validity). Data-Mining

7. Proportional Odds and Proportional Hazards Model of Ordinal Response

8. Quality Control Statistics. Univariate and Multivariate Control Charts

3.1.6.4 *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

3.1.6.5 *Clinical Research*

3.1.6.6 *Scientific Communication*

3.2 IMAGING SCIENCE

3.2.1 Mathematical Methods for Imaging in Medicine

A. *Deterministic Aspects*

1. Math Background: The complex plane, odd/even functions. The Dirac delta function

2. Introduction to Linear Systems

   (a) Fourier's theorem: Fourier series and the continuous Fourier transform
   (b) Properties of the Fourier transform
   (c) Gaussian, sinc, rect, sinusoid, and comb functions and essential Fourier transform pairs
   (d) The complex transfer function
   (e) The convolution principle
   (f) The edge response function
   (g) Auto and cross-correlation

3. Discrete Signal Processing

   (a) The sampling theorem
   (b) Sampling and restoration
   (c) The Discrete Fourier Transform (DFT)
   (d) Apodizing and aliasing
   (e) Approximate restoration from sampling (pixels)

4. 2D Digital Image Processing

   (a) Pixel transformations: the 2D affine transformation
   (b) The anti-aliasing affine transformations
   (c) Image registration: normalized mutual information, Woods algorithm
   (d) Filtering and image compression

5. Image Reconstruction

   (a) Line and edge responses: The Central Slice Theorem
   (b) Imaging from projections: The sinogram
   (c) Analytic and iterative reconstruction methods
   (d) Image registration in sinogram space
   (e) Compartmental modeling: Physiological and biochemical parametric mapping

B. *Stochastic Aspects*

1. Random Number Generators, Probability Density, and Distribution Functions

   (a) The binomial, Poisson, and Gaussian distributions
   (b) Moments: Expectation, mean, and variance
   (c) Fourier relationships: The characteristic function and the central limit theorem
   (d) Introduction to elementary decision theory
   (e) Signal-to-noise ratio
   (f) The Rose Model and the pre-whitened matched filter
   (g) Detective quantum efficiency and noise equivalent quanta

2. Decision Theory

   (a) Negative and positive predictive value; effect of noise on decision criteria
   (b) Joint and conditional probabilities; Bayes' theorem
   (c) Receiver Operating Characteristics (ROC)
   (d) Free-response receiver operating characteristics (FROC) [journal article]

3. Noise Averaging and Filtering

   (a) Principles of noise averaging: The covariance concept
   (b) Autocovariance and power spectrum concepts [Noise graphs]
   (c) Filtering: The inverse, Metz, Wiener, matched, and Wiener-Hellstrom filters [figures]
   (d) The propagation of error and the covariance matrix

4. Maximum Likelihood

   (a) Linear regression
   (b) The correlation coefficient
   (c) Eigenstructure of the covariance matrix
   (d) Optimization. The Levenberg—Marquardt and Nelder—Mead approaches
   (e) Expectation—maximization
   (f) OSEM and iterative deconvolution techniques

5. Tests of Significance

   (a) Chi-squared, *t*-test, F-test, statistical power
   (b) Analysis of variance
   (c) Statistical parametric mapping (SPM)

3.2.2 Conventional Planar X-Ray Imaging

1. X-Ray Production

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

(c) Bremsstrahlung
(d) Characteristic radiation
(e) Efficiency
(f) Efficacy (Output)
(g) Filtration, self-filtration, heel effect

2. Energizing and Controlling the X-Ray Tube

(a) kV production
(b) Voltage waveform and x-ray production
(c) Capacitors, rectifiers
(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
(f) Cooling charts

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 (geometric unsharpness)
(d) Receptor blur
(e) Composite blur

12. 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

13. Fluoroscopic Imaging Systems

    (a) Intensifier tubes
    (b) Video systems
    (c) The optical system and cameras
    (d) Receptor sensitivity
    (e) DSA

14. Dose and Dose Reduction Issues

3.2.3 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 systems and QC
    (f) Digital x-ray imaging systems

2. Computed Tomography Image Formation

    (a) The x-ray system
    (b) Detector system designs
    (c) Computer system
    (d) Display unit
    (e) Scanning
    (f) Image reconstruction
    (g) Volume or cone-beam CT
    (h) 4D CT

3. Computed Tomography Image Quality

   (a) Slice profiles, helical scan pitch
   (b) Contrast sensitivity—effects of kVp and mAs
   (c) High and low contrast resolution
   (d) Noise
   (e) Dose
   (f) Artifacts (beam hardening, partial volume effect, metal objects)
   (g) Quality assurance

4. Dose and Dose Reduction Issues

5. 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

3.2.4 Ultrasound Imaging

1. Ultrasound Plane Waves

   (a) Overview of mechanical and elastic properties of tissue
   (b) One-dimensional wave equation and harmonic solution (with nonrigorous extension to 3D and diverging waveforms)
   (c) Wave variables: pressure, particle velocity, displacement
   (d) Energy, power, and intensity (relation to pressure amplitude and particle velocity)
   (e) Decibel notation
   (f) Acoustical impedance
   (g) Reflection and transmission at interfaces

2. Propagation of Sound Waves through Tissue

   (a) Speed of sound
   (b) Attenuation, absorption, and tissue relaxation
   (c) Scattering
   (d) Nonlinear propagation; definition of B/A
   (e) Shock waves and harmonics

3. Single Element Transducers

   (a) General design considerations
   (b) Factors that affect frequency and bandwidth
   (c) Aperture physics: near/far field approximations; diffraction
   (d) Continuous wave beam patterns
   (e) Beam patterns for pulsed operation
   (f) Focusing

4. Transducer Arrays

   (a) Principle of 1-D array types (relation of shape/size/format to function)
   (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 (multidimensional arrays; focusing windows for broadband)

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) Dynamic range, compression analog-to-digital conversion, and signal demodulation
   (e) Beamforming (fully digital vs. hybrid)
   (f) A-mode, B-mode, M-mode, duplex/triplex modes of operation

6. B-Mode Imaging

   (a) Principal imaging methods
   (b) Image frame rate
   (c) Speckle statistics and compounding techniques
   (d) Harmonic imaging
   (e) Microbubble contrast
   (f) Overview of 3D and 4D imaging techniques

7. Continuous Wave and Pulsed Doppler

   (a) Doppler equation
   (b) Nature of the Doppler signal
   (c) Spectral analysis
   (d) Pulsed Doppler
   (e) Doppler signal processing (wall filter, phase-difference, cross-correlation, etc.)
   (f) Aliasing

8. Flow Imaging with Ultrasound

   (a) Review of physiological flow phenomena
   (b) Velocity imaging
   (c) Energy imaging
   (d) Information content on color flow images
   (e) Blood pool contrast agents

9. Equipment Performance Testing

   (a) Phantoms (materials, construction, maintenance)
   (b) Axial, lateral, and elevational resolution
   (c) Methods for measuring resolution
   (d) System sensitivity and visualization depth
   (e) Geometric accuracy in ultrasound and caliper measurements
   (f) Anechoic objects and gray-scale targets
   (g) Accreditation programs and accrediting bodies
   (h) Recommendations and standards (AIUM, ACR, AAPM)

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

    (a) Distal enhancement/shadowing
    (b) Reflection/mirror artifacts
    (c) Reverberation artifacts
    (d) Refraction artifacts
    (e) Speed of sound artifacts (geometric displacement/distortion; phase-aberration)
    (f) Doppler aliasing
    (g) Common transducer issues (vertical dropout; horizontal banding)

11. Bioeffects and Safety

    (a) Acoustic output measurements and regulatory limits
    (b) Real-time output labels: MI and TI and regulatory limits
    (c) Biological effects of ultrasound
    (d) Safe operating levels; ALARA and concepts of exposure
    (e) Contrast agent safety

(f) Safety and fetal imaging with modern ultrasound
(g) Recommendations and regulations (FDA, AIUM, NEMA, NCRP, ACR, AAPM)

3.2.5 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. 2D vs. 3D acquisitions
   (j) Properties of "*k*-space"

2. Hardware

   (a) The static magnetic field subsystem
      i. Common field strengths and magnet designs
      ii. Siting issues
   (b) The radiofrequency (RF) 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 flow sensitive sequences
    i. Flow-related phenoma
    ii. Time-of-flight MRA
    iii. Phase contrast MRA
    iv. Bolus contrast agent-enhanced MRA
    v. Perfusion sensitive imaging
    vi. Diffusion-weighted and diffusion tensor imaging
(h) Functional MRI neuroimaging techniques
    i. Physiological basis
    ii. Imaging methods
    iii. Experiment design and analysis
(i) MR spectroscopy (MRS) sequences
(j) Parallel imaging techniques

5. Artifacts and Methods for Artifact Rejection/Reduction

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

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

3.2.6 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, acquisition modes
      ii. Clinical PET imaging procedures
      iii. Quantitative PET imaging
      iv. Cine (4D) PET
   (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: Primary, secondary, and tertiary placement of collimators; rectangular (upper and lower jaws); circular; multileaf collimators

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
   (e) Tissue heterogeneities and corrections

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 vs. 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 ($\bar{E}$, 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 vs. virtual source
   iii. Side-scatter equilibrium

5. Special Photon and Electron Beams

(a) Intensity-modulated radiation therapy with photon beams
   i. Linacs with multileaf collimators
   ii. Tomotherapy
   iii. Stereotactic beams and robotic linacs
(b) Intensity-modulated radiation therapy with electron beams

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) Electronic brachytherapy
(j) 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) Dimensionality (2D, 2.5D, and 3D treatment plans)
   (e) Non-coplanar plans
   (f) Treatment planning with asymmetric collimators
   (g) Treatment planning with wedges (hard, dynamic, and virtual)
   (h) Treatment planning with multileaf collimators (MLCs)
   (i) Compensator design
   (j) 3-D treatment planning
   (k) Forward vs. inverse treatment planning
   (l) Inverse planning objectives and techniques. Optimization methods
   (m) Treatment planning with Monte Carlo techniques
   (n) Quality assurance of treatment planning systems
   (o) Biological modifiers/optimization

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. Computed 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. Bolus

(d) CT-simulator techniques
   i. Scout view images
   ii. Virtual simulation
   iii. Digitally reconstructed radiographs (DRRs)
   iv. CT number and (electron) density relation and calibration

(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 shape
   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)
   (h) Flattening filter (some machines treat without them and techniques with removal of FF)
   (i) Production of clinical electron beams (scattering foils)
   (j) Dose monitoring system
   (k) Beam collimation (photons vs. electrons)

3. Tomotherapy

   (a) Basic Design and Components
      i. Linear accelerator and magnetron
      ii. Tungsten shielding and beamstop and effects on scatter and leakage
      iii. Production of clinical proton beam: Beam profiles
      iv. Dose monitoring system
      v. Beam collimation
         A. Primary jaws and field width
         B. MLC construction and operation

vi. MV CT detector
    A. Design
    B. Operation and data acquisition system
    C. Image reconstruction
vii. Daily Quality Assurance (QA)

(b) Treatment Delivery
i. Helical delivery
ii. Image acquisition and fusion

(c) Treatment Planning System
i. Dose calculation algorithm
ii. Optimization parameters
iii. Pitch
iv. Modulation factor
v. Treatment sinogram
vi. Delivery Quality Assurance (QA)

4. CyberKnife®

(a) Basic Design and Component
i. Linear accelerator
ii. Robotic arm
iii. Patient couch six degrees of freedom for patient positioning
iv. Production of clinical photon beam: Beam profiles
v. Dose monitoring system
vi. Beam collimation
    A. Circular collimators
    B. Degrees of freedom for beam delivery
vii. X-ray imaging system
    A. Design
    B. Operation and data acquisition system
    C. Image reconstruction
viii. Daily Quality Assurance (QA)

(b) Treatment Delivery
i. Synchrony
ii. Image acquisition and fusion

(c) Treatment Planning System
i. Dose calculation algorithm
ii. Treatment planning system and image fusion and contouring station
iii. Optimization parameters
iv. Delivery Quality Assurance (QA)

5. Machine Acquisition

(a) Specification documents
(b) Treatment room design

(c) Bidding documents
(d) Machine installation
(e) Acceptance testing
(f) Machine commissioning

6. 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 and data flow in a clinical RT department
    ii. Client server systems
    iii. Radiotherapy imaging systems
    iv. Information system interfaces: DICOM-RT and Health Level-7 (HL-7) standards

7. Phantom Systems and Water Tanks

(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 and Hypofractionation
(j) Pulse Low Dose Rate (PLDR)

2. Intensity-Modulated Radiotherapy (IMRT)

(a) Dose delivery systems
    i. Single-slice collimators
    ii. Multileaf collimators
    iii. Tomotherapy
    iv. Volumetric arc therapy
(b) Dose delivery techniques
    i. Step-and-shoot
    ii. Sliding window
(c) Patient-specific QA

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 ($d^+ \rightarrow$ Be interaction)
    iii. Linear accelerators ($p^+ \rightarrow$ Be interaction)
    iv. Sealed source therapy (^{252}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

3.4 IMAGING FOR TREATMENT GUIDANCE AND MONITORING

3.4.1 Motion and Motion Management

(a) Musculoskeletal motion
(b) Cardiac motion
(c) Breathing motion
(d) Gastrointestinal motion
(e) Treatment margins, systematic and random errors
(f) Margin reduction strategies: on-line, off-line, adaptive

3.4.2 CT and 4D CT

(a) Image acquisition with single- and multi-slice CT
(b) Image quality
(c) Image reconstruction techniques
(d) Hounsfield Units for treatment planning (including Monte Carlo planning)
(e) Artifact rejection
(f) 4D CT: Principle
(g) Quantification of intrafraction motion
(h) Phase sorting
(i) 4D CT and dose planning
(j) Imaging dose
(k) Contrast media
(l) QA

3.4.3 Portal Imaging

(a) Portal film, electronic portal imaging
(b) Types of imaging panels, technologies
(c) Scatter
(d) Dose reconstruction (“in vivo dosimetry”)
(e) DRR calculation from CT

(f) Registration to DRR
(g) Imaging dose
(h) QA

3.4.4 Cone-Beam CT

(a) Large-field CT, field size
(b) kV and MV cone-beam CT
(c) Detectors, imaging panels
(d) Scatter, scatter rejection
(e) Imaging artifacts
(f) Planning with cone-beam images
(g) Imaging dose
(h) Cone-beam CT in external beam radiotherapy and brachytherapy
(i) QA

3.4.5 MV CT

(a) Tomotherapy imaging
(b) Image quality
(c) Imaging artifacts
(d) Planning with cone-beam images
(e) Imaging dose
(f) QA

3.4.6 2D and 3D Ultrasound

(a) 2D and 3D ultrasound technology
(b) Ultrasound probe tracking techniques
(c) Spatial registration of 2D ultrasound images
(d) Imaging parameters
(e) 3D image reconstruction
(f) Image contouring
(g) Fusion to other imaging modalities
(h) Use of ultrasound images for planning
(i) Interfraction motion
(j) Contrast media, pulse-inverted harmonic imaging
(k) QA

3.4.7 Fusion, Registration, Deformation

(a) Algorithms for fusion
(b) Algorithms for registration
(c) Multimodality imaging treatment planning
(d) Treatment planning and motion

3.4.8 Motion Management through Gating and Coaching

(a) Measuring techniques
(b) Gating techniques
(c) Active Breathing Control (ABC)

4 LABORATORY TRAINING

4.1 RADIATION PROTECTION AND 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 INSTRUMENTATION AND QUALITY ASSURANCE

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) Contrast
   (e) 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 QC
   (g) Soft-copy display calibration and QC

7. Evaluation of Imaging System Performance

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

8. Ultrasound

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

9. 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) Artifacts and strategies for artifact reduction
   (f) Acceptance testing, QC, and accreditation

10. 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 AND QUALITY ASSURANCE

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 INSTRUMENTATION, QUALITY ASSURANCE, AND CLINICAL STUDIES

1. Overview of Clinical Radiation Oncology: Attend multidisciplinary cancer conferences/ tumor boards and weekly peer review

2. Absorbed Dose Determinations

   (a) Calibrate a linac photon beam using TG-21 and TG-51 protocols
   (b) Calibrate a cobalt-60 beam, both isocentric 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: Perform mechanical QA

4. Photon Beams: Basic Dose Descriptors

(a) Defining GTV, CTV, PTV, and critical structures
(b) Perform direct PDD and TMR measurements. Calculate TMRs from the PDD data and compare to measurements
(c) Calculate treatment times (MU) for clinical (non IMRT) cases
(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, treatment delivery, and patient-specific QA. Perform new start and weekly chart checks. 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)

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