AAPM REPORT NO. 44

ACADEMIC PROGRAM FOR MASTER OF SCIENCE DEGREE IN MEDICAL PHYSICS

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A REPORT OF THE EDUCATION AND TRAINING OF MEDICAL, PHYSICISTS COMMITTEE, AMERICAN ASSOCIATION OF PHYSICISTS IN MEDICINE

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Contents

1 INTRODUCTION 1

2 TOPICAL DISCUSSION 3
- 2.1 Anatomy and Physiology 3
- 2.2 Diagnostic Imaging 3
- 2.3 Electronics 3
- 2.4 Health Physics-Radiation Protection 4
- 2.5 Nuclear Medicine 5
- 2.6 Physics of Medicine and Biology 5
- 2.7 Radiation Biology 5
- 2.8 Radiological Physics and Dosimetry 6
- 2.9 Radiation Therapy Physics 6

3 TOPICAL OUTLINE 7
- 3.1 Anatomy and Physiology 7
- 3.2 Diagnostic Imaging 9
- 3.3 Electronics 11
- 3.4 Health Physics-Radiation Protection 14
- 3.5 Nuclear Medicine 18
- 3.6 Physics of Medicine and Biology 21
- 3.7 Radiation Biology 24
- 3.8 Radiological Physics and Dosimetry 26
- 3.9 Radiation Therapy Physics 30

4 BIBLIOGRAPHY 36
- 4.1 Anatomy and Physiology 36
- 4.2 Diagnostic Imaging 36
  - 4.2.1 General References 36
  - 4.2.2 Image Science 37
  - 4.2.3 Imaging Systems 37
  - 4.2.4 AAPM Monographs 38
- 4.3 Electronics 38
- 4.4 Health Physics-Radiation Protection 39
  - 4.4.1 General 39

4.4.2 Instrumentation 40
4.4.3 Shielding 41
4.4.4 Radiation Biology 42
4.4.5 Miscellaneous References 42
4.5 Nuclear Medicine 42
4.6 Intermediate Physics for Medicine and Biology 44
4.6.1 Additional References: 44
4.7 Radiobiology 44
4.8 Radiation Therapy Physics 46

5 LABORATORY TRAINING 51
5.1 Laboratory for Diagnostic Imaging 51
5.2 Laboratory for Electronics 53
5.3 Laboratory for Health Physics-Radiation Protection 54
5.4 Laboratory for Nuclear Medicine Instrumentation 57
5.5 Laboratory for Radiation Therapy Physics 58

6 GRADUATE PROGRAMS IN MEDICAL PHYSICS 60

1 INTRODUCTION

In the past two decades, Medical Physics has emerged from small splinter groups of applied physicists to a well-defined scientific discipline. Not unexpectedly, academic programs providing training in Medical Physics were established to meet the monotonically increasing demand for medical physicists. As this discipline has matured, the educational requirements have also become more clearly defined.

Existing academic programs contain a core of similarity yet reflect the individual strengths and resources of personnel and facilities. As more programs are created and existing programs seek AAPM accreditation, some guidelines for an academic program are needed. Such an endeavor is fraught with pitfalls, however. Hence this committee has collected a set of topics that provides the minimum level of training an M.S. graduate would be expected to have. By no means is it suggested that the program outlined here is ideal or should be viewed as a satisfactory endpoint. Bather, the proposed program represents a solid foundation to build upon.

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

Training is organized into topical areas. Each area is outlined by topics and subtopics. The format is similar to a course outline. This is not to imply that a topical area translates into a one or two semester course format. Rather the integral of all areas indicates the proposed training to be accomplished by some convenient course structure. For some topics, training beyond tutorial contact is through laboratory sequences. These are separately indicated.

A 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, most notably in radiation therapy. This situation may 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 clinical training. Every attempt is made to provide a foundation for a smooth transition to clinical applications in the suggested program. The final solution to this recurrent problem may reside with a “residency” program similar to the postgraduate training for clinical physicians.

2 TOPICAL DISCUSSION

2.1 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.

2.2 Diagnostic Imaging

The topics listed in this section cover many (not all) of those that should be included in a medical physics master's degree training program. The desired level of learning to be attained in each topic area is not specified, in order to allow different programs the flexibility to emphasize selected areas. However, the broad nature and ever-expanding scope of diagnostic imaging necessitate that most of these topics be covered to some extent as an integral part of the training program.

2.3 Electronics

The primary purpose of an electronics course in medical physics training is two-fold.

1. Since medical physicists make use of a wide variety of electronic test and measurement equipment, the material should give the student enough basic knowledge to understand the principles involved in a measurement, the applicability of the instrumentation to that measurement and its limitations in regard to successfully completing the measurement.

2. Much of the apparatus used by medical physicists is electronic or electro-mechanical equipment of a high level of sophistication (e.g.

linac, CT scanners, x-ray units). The physicist should be able to recognize electronic malfunctions in the equipment and pinpoint the fault to a general area or functional unit within the system. The course should aim to enable the student to recognize faults in simple circuits and to understand the general philosophy behind fault finding in electronic circuits. It should give sufficient, basic knowledge to allow the physicist. to converse intelligently with the electronic/electrical engineering staff who arc responsible for the repair and maintenance of the equipment.

The prerequisites for the course should be elementary electricity and magnetism as taught in a general Physics Course as offered by a University Physics Department in the freshman year. An introductory General Physics course designed for physics and engineering students would be the ideal, although a course designed for students in biology, chemistry and medicine would suffice.

The course itself should be at the level of an undergraduate basic electronics course as taught by a University Physics Department, again although a course designed for physics and engineering students would be ideal, a. course for biologists, chemists and medical students would suffice. The course should include a laboratory class which runs in parallel with the didactic lectures, and reinforces the material taught in the lectures. An outline of the laboratory class is given. Simple circuits which relate to the course content should be built and then their operating characteristics should be investigated using the relevant instrumentation. The time spent on the laboratory class should be at least equal to that, spent in didatic lectures.

2.4 Health Physics-Radiation Protection

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 are discussed. Special attention is given detection apparatus and shielding analysis. An increasingly litiguous society is reflected in extensive presentation of the regulatory environment. Complimenting tutorial instruction are a sequence of laboratory experiences focussing upon instrumentation, environmental sampling, bioassay, and several aspects of shielding. The emphasis in this topic is to provide a broad base supportive of the varied environments of medical physics.

2.5 Nuclear Medicine

The purpose of this course of instruction is to provide a comprehensive overview of nuclear medicine physics. Previous experience in Nuclear Medicine is not required but students must have a solid knowledge of lower and upper division physics and appropriate facility with mathematics.

Since many of the instruments share a common underpinning with other subspecialties and topics, careful integration is needed. An alternative approach would be to segregate instrumentation essentials in a separate topic.

2.6 Physics of Medicine and Biology

Numerous applications of physics principles occur in medicine, biology, and physiology that are not directly covered in the subspecialties. Examples are fluid flow dynamics encountered in the cardiovascular system, electrolytic solutions and membrane-ion transport phenomena, and absorption and dissolution of soluble gases. These topics provide the physical principles essential to physiology and anatomy and greatly expand the understanding of such topics by physicists.

2.7 Radiation Biology

Effects of ionizing 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.

2.8 Radiological Physics and Dosimetry

The material in this section is designed to teach a graduate in physics (or engineering, with strong physics and math) 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, this 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 “overlearning” of these fundamental topics.

2.9 Radiation Therapy Physics

Radiation therapy physics is an area of medical physics where experience must supplement theory and where superficial knowledge may be dangerous. As an M.S. program may provide only limited clinical exposure, an intensive clinical practicum should follow. Such a “residency” was recently proposed by the AAPM Presidential Ad Hoc Committee on the Clinical Training of Radiological Physicists in their report, "Essentials and Guidelines for Hospital-Based Medical Physics Residency Training Programs.”

A parallel laboratory experience complementing the subject matter is essential. Direct clinical contact would be preferable. For those students anticipating a radiation therapy specialty, the subject should be covered in greater depth and for a longer period. A concommitant increase in clinical experience should accompany such training.

3 TOPICAL OUTLINE

3.1 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. The Thorax
   - (a) Bones of the thorax
   - (b) Organs in the thorax
   - (c) Radiography of the thoracic structures
5. The Abdomen
   - (a) Divisions and regions
   - (b) Organs in the abdomen
   - (c) Abdominal systems
6. Respiratory System
   - (a) Organs

(b) Function

(c) Radiography of system

7. Digestive System

(a) Divisions

(b) Location, extension

(c) Function

(d) Radiography of system

8. Urinary System

(a) Organs

(b) Location

(c) Function

(d) Radiography of system

9. Reproductive System

(a) Organs

(b) Location

(c) Radiography of system

10. Circulatory System

(a) Major components

(b) Radiography of system

(c) Visit to Catheterization Laboratory

11. Pathology

(a) Identification of organs at autopsy

(b) Organ location

(c) Organ composition

(d) Correlation of radiographic findings

3.2 Diagnostic Imaging

1. Signal Sources
   - (a) Visible light, heat (IR), sound, ESR, and EM fields
   - (b) Radionuclides, x-ray, and other
2. Physical Characteristics of Ionizing Radiation Sources
   - (a) Radionuclides (types of emission origin, half-life, λ, etc.)
   - (b) X-ray (generators and tubes)
3. Imaged Object
   - (a) Attenuation, absorption, transmission, scatter, contrast
4. Signal Detection-Detectors and Their Characteristics
   - (a) Screens
   - (b) Film
   - (c) Image intensifier
5. Planar, Tomographic, and Cross-sectional Image Formation and Quality Definition
   - (a) Signal/noise
   - (b) NEQ and DQE
   - (c) Resolution and MTF
   - (d) Latitude and contrast sensitivity
6. Image Improvement
   - (a) Scatter reduction techniques
   - (b) Energy discrimination
7. Image Displays and Their Characteristics
   - (a) Films

(b) Paper-printed images

(c) CRT, stereo displays, holographic

8. Image Enhancement-Post Processing

   (a) Color display

   (b) Subtraction

   (c) AHE, USM, LPF, HPF

9. Special Requirements for Specific Procedures

   (a) Mammography

   (b) Bone density absorptiometry

   (c) CT

   (d) Angio-magnification

   (e) Dental

10. Measurements of Image Quality

11. QA Procedures

12. Generation of Images from Nonionizing Radiation Sources

   (a) Visible light

   (b) Thermography

   (c) Ultrasound

   (d) NMR

   (e) SQUID

13. Contemporary Issues

   (a) Patient dose documentation

   (b) PACS

   (c) Measurements of diagnostic accuracy (ROC)

3.3 Electronics

1. Passive Components and Networks

   (a) Review of DC circuits

   (b) Review of AC circuits

   (c) Network analysis

   Thevenin's Theorem, Norton's Equivalent Circuit Theorem. Networks requiring Thevenin's Theorem or Kirchhoff's Laws for solution

2. Electronic Instrumentation

   (a) Basic analog meters

   Moving coil and moving iron meters, dynamometer. Measurement of RMS values, AC and DC measurements. Use of basic meters as an ammeter, voltmeter, ohmmeter or wattmeter.

   (b) Measuring instruments

   Analog multimeter, Wheatstone bridge, AC bridges, potentiometer, DVM, DMM and electrometer.

   (c) Oscilloscope

   Basic components, operation and use.

   (d) Other instruments

   Signal generator, frequency counter and attenuator.

   (e) Related topics

   Transmission lines and relays and other electro-mechanical devices.

3. Input Transducers

   (a) Resistive input transducers

   Photoresistor and thermistor

   (b) Current input transducers

Ionization chamber

(c) Voltage input transducer

Thermocouple, photovoltaic cell and photodiode

4. Diodes and Some Applications

(a) Diodes

Vacuum and semiconductor diodes, physical model for semiconductor diode, the p-n junction. Diode action; current-voltage characteristics.

(b) Rectification and filtering

Half-wave and full-wave rectification. Low pass and high pass filters.

(c) Zener diode

Current-voltage characteristic; use as a voltage regulator.

5. Transistors

(a) Transistor types

Bipolar junction, junction FET, MOSFET; basic structure and operation, current-voltage characteristics, load line.

(b) Applications of transistors

Amplifier circuits and switching circuits. Choice of transistor; interpretation of specification sheets.

6. Amplifier Circuits and Operational Amplifiers

(a) Fundamental amplifier properties

Input and output impedance, gain, frequency response, feedback

(b) Amplifier types

Cascade, AC and DC, noninverting and inverting, difference and differential amplifiers

(c) Practical operational amplifiers and basic circuits

Inverting and noninverting amplifiers, voltage-follower summing and difference amplifiers, current-to-voltage and voltage-to-current converter.

(d) Specifications of real operational amplifiers

Open loop gain, bandwidth, selecting an op amp; interpreting specification sheet.

7. Digital Basics

(a) Basic logic gates

AND, OR, NAND, NOR Gates and Truth Tables.

(b) Gate construction

TTL, CMOS.

(c) Boolean algebra

(d) Flip-flops

(e) Numbering systems

Decimal, Binary, BCD, Octal, Hexadecimal.

8. Digital Circuits

(a) Counters and registers

(b) Multiplexing

(c) Timing and control

Monostable and astable multivibrator, Schmitt trigger

(d) Conversions between analog and digital domains

DAC and ADC.

(e) Voltage to frequency conversions

9. Noise

(a) Origins of noise

Thermal noise, shot noise and flicker noise

(b) Reduction of noise

Shielding, ground loops, differential amplifier configurations, filtering and signal averaging techniques

3.4 Health Physics-Radiation Protection

1. Introduction 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, radiative 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 nonelastic 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 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
   (b) 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) EPA and UNSNRC 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 and UNSCEAR 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

12. High/Low Level Waste Disposal

(a) USNRC/USDOE/USEPA Repository

(b) Low level compacts

(c) Future impacts

13. Radon

(a) Physical basis of decay chain

(b) Transport and dispersion

(c) Dosimetry

(d) Measurement techniques

(e) Regulatory position

14. Nonionizing Radiation

(a) Electromagnetic and sound hazards

(b) Device emission requirements

(c) Measurement techniques

(d) Regulatory control

3.5 Nuclear Medicine

1. Radioactive Materials

   (a) Nuclear structure

   (h) Decay schemes

   (c) Production of radionuclides

      i. Reactors

      ii. Accelerators

   (d) Statistics of radioactive decay

2. Instrumentation

   (a) Rectilinear scanners

      i. Design and operation

      ii. Quality control

      iii. Clinical applications

   (b) Scintillation cameras

      i. P1anar systems

         A. Design and operation (including computer interface)

         B. Hard copy output devices

         C. Acceptance testing

         D. Quality control

         E. Clinical applications (including transmission scanning)

      ii. SPECT systems

         A. Gantry control and computer interfacing

         B. Principles of reconstruction

         C. Acceptance testing

         D. Quality control

         E. Clinical applications

      iii. PET systems

         A. Design and operation

         B. Acceptance testing

C. Quality control
D. Clinical applications

(c) Alternative imaging systems

i. Pressurized proportional chambers
ii. Harvard brain imager
iii. Dedicated SPECT systems

(d) Scintillation counter systems (including thyroid uptake)

i. Electronic and mechanical components
ii. Acceptance testing and quality control
iii. Interfacing to computer systems
iv. Clinical applications

(e) Liquid scintillation counters

i. Principles of operation and design
ii. Quality control
iii. Interfacing to computer systems

(f) Semiconductor systems

i. Spectroscopy
ii. Fluorescence scanning

(g) Well ionization chambers (dose calibrators)

i. Design and operation
ii. Sources of error
iii. Quality control

3. Radiopharmacy

(a) Generator systems

(b) Preparation of radiopharmaceuticals from kits

(c) Quality control of radiopharmaceuticals

(d) Radionuclides for specific clinical applications

4. Computers

(a) Hardware operation

(b) Software

(c) Peripheral connections and operation

(d) Acceptance testing and quality control

(e) Clinical applications

5. Internal Radiation Dosimetry

   (a) Systems for calculating absorbed dose

      i. Classical equations and methodology

      ii. Medical Internal Radiation Dose (MIRD) methodology

      iii. Introduction to modeling and tracer kinetics

      iv. Calculations for radionuclide therapy

   (b) Typical patient absorbed doses for diagnostic and therapeutic procedures

6. Radiation Safety

   (a) Surveys of radiation areas

   (b) Principles and mechanisms of protection for personnel and patients

   (c) Exposure rate levels associated with the preparation and administration of radioactive materials for diagnostic and therapeutic use

   (d) Exposure rate levels from patients undergoing diagnostic and therapeutic procedures

   (e) Handling of radiation accident patients

   (f) Implementation of the ALARA principle

7. Design of Nuclear Medicine Facilities

   (a) Radioactive materials storage and laboratory areas

   (b) Air exhaust design

(c) Patient procedures area
(d) Dark room
(e) Departmental layout (personnel and patient flow)
(f) General safety requirements
(g) Floor loading for equipment
(h) Electrical power and air conditioning requirements

8. Regulations

   (a) Federal, state, and local regulations and requirements
   (h) Regulatory inspections (state, NRC)
   (c) License application, renewal
   (d) Accreditation requirements (JCAHO)
   (e) Accreditation site visits (JCAHO)

3.6 Physics of Medicine and Biology

1. Review of Statistics and Probability

   (a) Parent populations and samples
   (b) Binomial, Gaussian and Poisson distributions

2. Mechanics Applied to Body Systems

   (a) Forces on the Achilles tendon and hip
   (b) Mechanics of using a cane

3. Hydrostatics

   (a) Viscous flow in a tube
   (b) Transport in an infinite medium
   (c) Flow, flux, and continuity
   (d) Particle motion in a liquid-the Langevin form of Newton's second law

(e) Newtonian fluids-viscosity-Stokes' law

4. Diffusion

   (a) Fick's first law
   (b) Diffusion related to viscosity
   (c) Fick's second law and applications

5. Transport Through Semipermeable Membranes

   (a) Osmotic pressure
   (b) Plasma exchange in capillaries
   (c) Edema; osmotic diuresis; osmotic fragility of red blood cells
   (d) Volume transport; solute transport; the artificial kidney
   (e) External forces on solute molecules; ionic solutes and equilibrium electric fields in membranes
   (f) Ion movement in solution involving diffusion, solvent drag and electric fields
   (g) Nernst-Planck equation and the Goldman equation

6. Nerve Cell Structure

   (a) Nonmyelinated and myelinated axons
   (b) Introduction to the electrical nature of nerve impulse transmission
   (c) Review of electrostatics

7. Electrodynamics Emphasizing Relevance to Nerve Impulse Conduction

   (a) Current density
   (b) Conductivity
   (c) Kirchhoff's laws

8. Charge Distribution in the Resting Nerve Cell

9. Leakage Currents Across the Axon Membrane in the Absence of Myelination

10. Resistance of the Axon

11. Nerve Impulse and Transmission Across a Synapse

    (a) Application of Kirchhoff's laws to wave equation for nerve impulse transmission in nonmyelinated axons.

    (b) Small voltage changes not involving changes in membrane conductance (electronus)

    (c) Voltage clamp experiments

12. Hodgkin-Huxley Model for Membrane Current

    (a) Voltage changes in the axially clamped axon following electrical stimulation as tests of the Hodgkin-Huxley model

    (b) Solutions of the wave equation [propagation) for nonmyelinated axons employing the Hodgkin-Huxley model.

13. Nerve Impulse Propagation in Myelinated Axons; Myelin Sheath Conductance and Capacitance; Saltatory Conduction.

14. Electrocardiograms Taking the Body to be a Uniform Conductor

15. Kidney

    (a) Structure of the nephron

    (b) A physicist's view of the glomerulus

16. Nonionic Filtration by the Glomerulus-Transport Through Pores of Particles Having Diameters of the Order of the Pore Diameters.

17. Theory and Experiment of Verniory

18. Biomagnetism, Including Generation of Magnetic Fields by Electric Currents in the Body and Their Detection; Physical Principles of the DC SQUID.

3.7 Radiation Biology

1. Basic Physical and Chemical Mechanisms
   - (a) Excitation
   - (b) Ionization (neutral and charged particle radiations)
   - (c) Free radical production (direct and indirect action)
   - (d) LET, dose
2. Cellular Radiation Biology
   - (a) Law of Bergonie and Tribondean
   - (b) Cell cycles, sensitivities
   - (c) Cell survival curves
   - (d) Target theory, D_o, D_{37}, D_q, n, etc.
   - (e) Modification of Survival: repair, fractionation, dose rate effects, oxygen effect (OER), RBE, dose equivalent
3. Tissue and Organ Responses
   - (a) Sensitive tissues (gonads, hematopoietic, gut)
   - (b) Low dose concerns (genetics)
   - (c) Developing fetus
4. Acute Radiation Syndrome
   - (a) CNS
   - (b) GI
   - (c) Hematopoietic
   - (d) Immunologic
   - (e) Reproductive suppression
5. Carcinogenesis
   - (a) Mechanics of cancer induction

(b) Human and other animals

(c) Atomic bomb survivors and leukemia

(d) Other irradiated groups (Radiologists, radium dial painters, ankylosing spondilitics, uranium miners, tubercular women, mastitis patients, thymic and tonsil enlargements, etc.)

(e) BIER Report

6. Genetic Effects

(a) Mutations

(b) Experimental animal data

(c) Human effects

(d) Genetically significant dose

7. Radiological Basis of Radiotherapy

(a) Differential response of tumors and normal tissue

(b) Repair

(c) Fractionation

(d) Organ tolerances

(e) T, D, F, dose rate and volume effects

(f) High LET radiations

(g) Hyperthermia

(h) Cell sensitizers

8. Sources of Exposure

(a) Natural background

(b) Medical radiation

(c) Other manufactured sources

9. Maximum Permissible Doses

(a) State and Federal regulations

(b) Recommendations (NCRP, ICRU, etc.)

10. Risk Versus Benefit

    (a) Screening
    (b) Diagnostic radiation doses

3.8 Radiological Physics and Dosimetry

1. Ionizing Radiation

    (a) Types and sources of ionizing radiation
    (b) Description of ionizing radiation fields

2. Quantities for Describing the Interaction of Ionizing Radiation with Matter

    (a) Energy imparted, energy transferred, and net energy transferred
    (b) Kerma and collision-kerma
    (c) Absorbed dose
    (d) Exposure
    (e) Dose equivalent and quality factor

3. Exponential Attenuation

    (a) Simple exponential attenuation
    (b) Exponential attenuation for plural modes of absorption
    (c) Narrow- vs. broad-beam attenuation
    (d) Spectral effects in attenuation
    (e) Buildup factor
    (f) Reciprocity theorem

4. Charged-Particle and Radiation Equilibria

    (a) Radiation equilibrium

(b) Charged-particle equilibrium (CPE)

(c) Relationships between absorbed dose, collision kerma and exposure under CPE conditions

(d) Conditions that enable CPE, or cause its failure

(e) Transient CPE

5. Absorbed Dose in Radioactive Media

(a) Radioactive disintegration processes

(b) Energy available for absorbed dose

6. Radioactive Decay

(a) Total and partial decay constants

(b) Units of activity

(c) Mean life and half-life

(d) Parent-daughter relationships

(e) Activity equilibria

(f) Harvesting of daughter products

(g) Radioactivation by nuclear interactions

(h) Exposure-rate and air-kerma-rate constants

7. Photon Interactions in Matter

(a) Compton effect

(b) Photoelectric effect

(c) Pair production

(d) Rayleigh scattering

(e) Photonuclear interactions

(f) Coefficients for attenuation, energy transfer, and energy absorption

8. Charged-Particle Interactions in Matter

(a) Types of Coulomb-force interactions

(b) Stopping power

(c) Range

(d) Calculation of absorbed dose

9. X-Ray Production and Quality

(a) Fluorescence

(b) Bremsstrahlung

(c) Beam quality

(d) Filtering

10. Cavity Theory

(a) Bragg-Gray theory and corollaries

(b) Spencer cavity theory

(c) Burlin cavity theory

(d) Stopping-power averaging

(e) Fano theorem

(f) Dose near interfaces

11. Dosimetry Fundamentals

(a) ICRU definitions of dosimetric qualities and units

(b) Interpretation of dosimeter measurements

(c) General characteristics of dosimeters

12. Ionization Chambers

(a) Free-air and free-electron chamber

(b) Cavity chambers

(c) Charge and current measurements

(d) Saturation and ionic recombination

(e) W

13. Radiotherapy Application of Ion Chambers

(a) Cavity chamber calibration

(b) N_X, N_K, and N_{gas}

(c) In-air photon beam measurements

(d) Absorbed-dose measurement in phantoms, for photon and electron beams

(e) Water phantoms, and substitute phantom media

14. Integrating Dosimeters

(a) Thermoluminescent dosimeters

(b) Photographic dosimetry

(c) Chemical dosimetry

(d) Calorimetric dosimetry

15. Dosimetry by Pulse-Mode Detectors

(a) GM and proportional counters

(b) Scintillation dosimetry

(c) Semiconductor dosimetry

16. Neutron Interactions and Dosimetry

(a) Neutron types by kinetic energy

(b) Neutron interactions in tissue elements

(c) Neutron kerma and absorbed dose calculations

(d) Neutron sources

(e) Neutron quality factor

(f) Absorbed dose in a body phantom

(g) Gamma-neutron mixed-field dosimetry

(h) Microdosimetry

3.9 Radiation Therapy Physics

1. Overview of Clinical Radiation Oncology
    (a) Cancer incidence/etiology
    (b) Cancer classification/staging
        i. Review lymphatic drainage
    (c) Overview of treatment modalities
        i. Surgery
        ii. Chemotherapy
        iii. Radiotherapy
            A. Teletherapy
            B. Brachytherapy
            C. Neutron, proton and high Z therapy
        iv. Hyperthermia
    (d) Review of pertinent, radiobiology
        i. Dose response curves
        ii. The 4 R's
        iii. The relationship of volume and time to radiation effects (TDF, Alpha/Beta Ratios)
        iv. Side effects/complications
        v. Tolerance doses for normal tissues and tumors
    (e) The role of a Clinical Medical Physicist
2. Phantom Systems
    (a) Calibration phantoms
    (b) Anthropomorphic phantoms
    (c) Tissue-mimicking materials
    (d) Properties of beam scanning systems
3. Radiation Machines
    (a) Kilovoltage units

(b) Co-60

(c) Linac design and operation

(d) Betatrons/microtrons (general information)

(e) Particle beams (general information)

4. Photon Beams: Basic Clinical Dosimetry

   (a) Depth dose distributions

   (b) Definitions; relationships and factors affecting PDD, TAR, SAR, TMR, TPR, SMR, BSF.

   (c) Collimator and phantom scatter corrections

   (d) Irregular fields

      i. Off-axis factors

      ii. Clarkson's Method

   (e) Dose calibration

5. Photon Beams: Dose Modeling/Treatment Planning

   (a) Acquisition of isodose data

   (b) Parameters influencing isodose curves

   (c) Combination of fields

   (d) Wedge and angle effects

   (e) Corrections for SSD and inhomogeneities

   (f) Dose specification and normalization

   (g) Computerized beam modeling

      i. Hardware

      ii. Common algorithms

      iii. Single-plane plans

      iv. Multiplane plans

      v. Noncoplanar plans

      vi. Asymmetric collimators

vii. Compensator design
viii. 3-D planning (general information)

6. Photon Beams: Patient Application

   (a) Patient data acquisition
      i. Images (plain films, CT, US, NM, MRI)
      ii. Contours
   (b) Simulator techniques
      i. Positioning/immobilization
      ii. Use of contrast, markers, etc.
      iii. Image parameters/optimization
   (c) Accessory devices/techniques
      i. Block-cutting
      ii. Compensators
      iii. Portal/verification films
   (d) Special considerations
      i. Skin dose
      ii. Adjacent fields
      iii. Tangential fields
      iv. Integral dose
      v. Hemibody/whole body techniques

7. Electron Beams: Basic Clinical Dosimetry

   (a) Basic characteristics
      i. Electron interactions
      ii. Detector characteristics
      iii. Measurement techniques
   (b) Beam characteristics
      i. Energy determination

ii. Depth-dose (surface dose, x-ray contamination, isodose/D_{max} shift, etc.)
iii. Profiles/isodose curves
iv, Output factors/virtual source position

8. Electron Beams: Dose Modeling and Treatment Planning

(a) Special effects

i. Air gap/obliquity effects
ii. Internal inhomogenity

(b) Computer algorithms

(c) Treatment planning

i. Energy selection/photon-electron mixing
ii. Use of bolus
iii. Field shaping
iv. Field abuttment
v. Conventional techniques

(d) Advanced techniques (general information)

i. Total skin irradiation
ii. Electron arc therapy

9. Brachytherapy

(a) Source characteristics and strength specifications
(b) Implant dosimetry systems
(c) Implantation/application techniques
(d) Dose computations/dose specifications
(e) Dose rate considerations
(f) Clinical examples: ^{137}Cs, ^{192}Ir, ^{125}I, ^{198}Au
(g) Neutron sources
(h) Other radionuclides

10. Radiation Protection

(a) Regulatory requirements

(b) Structural shielding design

i. Cobalt and linac teletherapy

ii. Neutrons

iii. Brachytherapy (low-dose rate/high-dose rate)

iv. X-ray Rooms (superficial, orthovoltage, simulators)

(c) Operational safety guidelines

i. Machine sources

ii. Brachytherapy

iii. Area and personnel monitoring

iv. Radiation surveys (techniques and instruments)

11. Quality Assurance/Quality Control

(a) Error analysis of total treatment process

(b) Sources of QA/QC standards

(c) Organizing a QA program

i. Staff assignments

ii. Equipment

iii. Traceability/redundancy

(d) Treatments/dose delivery

i. Documentation requirements

ii. Portal/verification film techniques

iii. Record and verification systems

iv. Real time surface dosimetry (diodes)

(e) Machine acquisition (purchase, installation, acceptance)

(f) Specific guidelines

i. Machine sources

ii. Brachytherapy Sources and applicators

iii. Block-cutting/compensation systems

iv. Computers/dosimetry systems

12. Special Topics (Optional)

(a) Hyperthermia

(b) Intra-operative radiotherapy (photon and electron)

(c) Radiosurgery

(d) Hyperfractionation

(e) Conformal beam therapy

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5 LABORATORY TRAINING

5.1 Laboratory for 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 and D 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

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) Receiver coil design
    (c) Magnetic field mapping
    (d) QC

11. Computed Tomography

    (a) Imaging principles
    (b) QC

5.2 Laboratory for Electronics

1. Electronic instrumentation

    (a) Brief review on the practical use of measuring instruments.
    (b) Instruction on the use of the oscilloscope.
    (c) Instruction on the use of a signal generator and a function generator.

2. Diodes

    (a) Plot diode characteristics.
    (b) Rectification and filtering. Build half-wave and full-wave rectifier circuits. Low and high-band pass filters and investigate their operational characteristics.
    (c) Zener diode. Plot diode characteristics and build a simple voltage regulator.

3. Transistors

    (a) Plot transistor current-voltage characteristics and load-line.
    (b) Build simple amplifier and switching circuits.

4. Operational Amplifiers

(a) Investigate AC and DC response, gain limitations, frequency response and the effects of input and output impedance in a simple voltage amplifier circuits.

(b) Practical operational amplifiers. Build circuits for noninverting and inverting amplifiers, voltage-follower, current-to-voltage converter, summing and difference amplifiers. Investigate response of these circuits in relation to specification data.

5. Digital Basics

   (a) Basic logic gates. Investigate characteristics of AND, OR, NAND, NOR gates using TTL or CMOS.

   (b) Use logic gates to build flip-flops and investigate their characteristics,

6. Digital Circuits

   (a) Build simple circuits using TTL or CMOS counter and register chip.

   (b) Use multiplexer chip in a simple circuit.

   (c) Build simple circuit using TTL or CMOS Schmitt trigger, a stable and monostable multivibrator chips.

   (d) Use ADC and DAC chips in circuit.

   (e) Build simple circuit using a VFC.

7. Noise

   (a) Reduction of noise. This topic should be dealt with as it arises in the laboratory class.

5.3 Laboratory for Health Physics-Radiation Protection

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 Prom 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. Analysis of Iodine and Cesium in Milk
    (a) Reactor produced air concentrations
    (b) Sample preparation
    (c) Measurement techniques
    (d) Data analysis and interpretation

9. 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

5.4 Laboratory for 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 photomultiplier tube 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 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 noise, accuracy of attenuation correction, and contrast

7. Positron Emission Tomography (PET)

   (a) Quality control

   (b) Measurement of singles rate, RMS noise, and contrast

5.5 Laboratory for Radiation Therapy Physics

1. Overview of Clinical Radiation Oncology

   (a) Attend multidisciplinary cancer conferences/tumor boards.

2. Absorbed Dose Determinations

   (a) Calibrate a linac photon beam using C_λ and TG-21 protocols

   (b) Calibrate a cobalt-60 beam, both isocentrically and for SSD geometry.

   (c) Calibrate an electron beam, beginning with energy determination, using both CE and TG-21 protocols.

   (d) Perform 2 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 Descripters

   (a) Perform direct PDD and TMR measurements. Calculate TMRs from the PDD data and compare to measurements.

(b) Calculate treatment times for every clinical case.

(c) Measure linac output factors.

(d) Calculate SARs (or SMRs) from TMR data.

(e) Calculate three cases of irregular fields, including one mantle field, both manually and by computer.

(f) Calculate a rotational beam average TMR manually and by computer.

5. Photon Beams: Dose Modeling

6. Photon Beams: Patient Application

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.

8. Brachytherapy

   (a) In addition to clinical participation, perform cervix and planar implant calculations by hand and by computer.

9. Radiation Protection

   (a) Calculate required shielding for a linac installation without beam-stop.

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).

6 GRADUATE PROGRAMS IN MEDICAL PHYSICS

An updated listing of graduate programs in Medical Physics may be obtained from the AAPM headquarters office.

M.S. AND PH.D. PROGRAMS IN MEDICAL PHYSICS
(* Indicates Institutions Offering Postdoctoral Programs)
(† Indicates Institutions Offering Clinical Residency Programs)
(‡ Indicates Institutions Offering Bioengineering Programs)

ALABAMA

Gary T. Barnes; Tel: (205) 934-5131
University of Alabama at Birmingham *
169 South 19th Street
Birmingham, AL 35233

CALIFORNIA

Geoffrey Owen; Tel: (415) 642-4131
University of California-Berkeley
102 Donner Lab
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Moses A. Greenfield; Tel: (310) 206-2967
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Department of Radiological Sciences
Medical Physics Division
10833 LeConte Avenue
Los Angeles, CA 90024-1721

Lynn J. Verhey; Tel: (415) 476-1208
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Radiation Oncology Department
Physics Section L-75, Box 0226
San Francisco, CA 94143-0226

COLORADO

R. Edward Hendrick; Tel: (303) 270-7379
University of Colorado HSC
Department of Radiology
4200 East Ninth Avenue
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Denver, CO 80262

FLORIDA

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Gainesville, FL 32610-0385

Libby Brateman; Tel: (904) 392-1401
University of Florida
Department of Nuclear Engineering Sciences
202 Nuclear Science Center
Gainesville, FL 32611

Richard L. Morin; Tel: (904) 223-2000
Mayo Clinic †
Clinical Medical Physics Residency Program
Radiologic Physics
4500 San Pablo Road
Jacksonville, FL 32224
(Prereq.: Medical Physics Ph.D. or Equivalent)

GEORGIA

Said Abdel-Khalik; Tel: (404) 894-3721
Georgia Institute of Technology
Nuclear Engineering & Health Physics
Atlanta, GA 30322

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1653 W. Congress Parkway
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MINNESOTA

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Dept. of Radiology, Box 292
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Clinical Medical Physics Residency Program
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200 First Street, S.W.
Rochester, MN 55905
(Prereq.: Medical Physics Ph.D. or Equivalent)

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