AAPM Recommended Outline of Physics Topics for Diagnostic Residents
Version 1.0 (Based on Initial Draft 4)
Updated July 25, 2005

AAPM Syllabus Subcommittee of the Medical Physics Education of Physicians Committee
Philip Heintz, Ph.D. – Chair (Univ. New Mexico)
C. A. Kelsey, Ph.D. (Univ. New Mexico)
M. S. Al-Ghazhi, Ph.D. (UC Irvine)
H. Elson, Ph.D. (Univ. of Cincinnati)
E. P. Lief, Ph.D. (Maimonides Comprehensive Cancer Center)
R. J. Massoth, Ph.D. (Medical X-Ray Center, P.C.)
R. A. Price, Jr., Ph.D. (Fox Chase Cancer Center)
C. B. Saw, Ph.D. (Univ. of Pittsburgh)
C. L. Thomason, Ph.D. (St. Luke's Med. Center, Milwaukee, WI)
M. K. West, Ph.D. (International Medical Physics Services, OK)
F.-F. Yin, Ph.D. (Duke Univ. Med Center)

Subject Matter	**Teaching and Laboratory Relative Weights by Subject in Units of Instruction**
General Radiology Physics	
Structure of the Atom and Radiation Principles	1
Interaction of Radiation with Matter	2
Radiation Units	1
Diagnostic Radiology	
X-ray Production	0.5
X-ray Tubes	0.25
X-ray Generators	0.25
Film-Screen Radiography	0.5
Film Processing	0.25
Mammography	1.5
Fluoroscopy	2
Image Quality	5
Digital Radiography	3
Conventional Tomography	.25
Computed Tomography (CT)	3
MR: Basic Principles	2
MR: Imaging and Instrumentation	2
Ultrasound (including Doppler)	3
Computers in Radiology	2
Nuclear Medicine	
Radioactivity	.5
Decay Schemes	.5
Radioisotope Production	.5
Instrumentation	1

Counting Statistics	1
Scintillation Camera	1
Emission Tomography (PET and SPECT)	2
Radiation Protection	
Radiation Protection	2
Radionuclide Therapy	0.5
Regulatory	2
Patient Dosimetry	1
Radiation Biology	
Radiation Biology	3
Total Units of Instruction	44.25

Note: a "unit of instruction" should be weighted by a factor of one or more to determine the number of hours of lecture and/or laboratory work in that particular area.

General Radiology Physics

1. Structure of the Atom and Radiation Principles

Learning Objectives

The resident should:

1) *learn the structure of the atom, including types of nucleons, relation between atomic number and atomic mass, and electron orbits and binding energy.*
2) *be able to relate energy to wavelength and rest mass, and understand and describe an energy spectrum*
3) *learn about radioactivity, including decay processes, half life*
    a. Electromagnetic Radiation- x-rays and gamma-rays
    b. Electronic Structure of the Atom
    c. Characteristic X-rays
    d. Atomic Nucleus
    e. Radioactivity
    f. Radioactive Decay- alpha, beta, gamma, x-ray, electron, and positron decay
    g. Internal Conversion Electrons

2. Interaction of Radiation with Matter

Learning Objectives

The resident should learn

1) the physical description, random nature, and energy dependence of the four scatter and absorption interactions that x-ray photons undergo with individual atoms (coherent scatter, photoelectric effect, Compton effect, and pair production).

2) definitions of the key terms such as attenuation, scatter, beam geometry, linear and mass attenuation coefficients, energy transfer, energy absorption, half-value layer, and how these terms relate to radiation scatter and absorption through the exponential attenuation equation;

3) the physical description and energy dependence of the elastic and inelastic collision processes in matter for directly and indirectly ionizing particulate radiation

4) definitions of key terms such as linear energy transfer, specific ionization, mass stopping power, range, and how these terms relate to energy deposition by particulate radiation.

a. Particle Interactions (emphasize electron interactions)
b. LET
c. Bremsstrahlung Interactions
d. Positron Annihilation
e. Neutron Interactions
f. X and Gamma Interactions
    i. Rayleigh or Coherent Scattering
    ii. Compton Scattering
    iii. **Photoelectric Effect**
    iv. Pair Production
g. Attenuation of X and Gamma Rays
    i. Linear Attenuation Coefficient
    ii. Mass Attenuation Coefficient
    iii. HVL

3. Radiation Units

Learning Objectives

The resident should learn

1) definitions and units for kerma, exposure, absorbed dose, dose equivalent, and RBE dose, the conditions under which each quantity applies, and the physical basis for measuring or computing each quantity.

a. Absorbed Dose
b. Exposure
c. Equivalent Dose
d. Effective Dose
e. Quality factors and Tissue Weighting Factors

Diagnostic Radiology

4. X-ray Production

Learning Objectives

The resident should learn:

1) the concepts of beam production, including acceleration of electrons in diagnostic X-Ray tubes, Bremsstrahlung, X-Ray tube design, and characteristic radiation.

a. Bremsstrahlung Spectrum
b. Characteristic X-rays

5. X-ray Tubes

Learning Objectives

The resident should learn:

1) *the concepts X-Ray tube design, characteristics of the cathode, and anode*
2) *the concept of the heel effect, filtration, collimation*
3) *the concept of x-ray tube heat loads and technique charts.*

a. Cathode
b. Anode
c. Focal Spot
d. Heel Effect

e. Off-focus Radiation
f. X-ray Tube Insert and Housing
g. Filtration
h. Collimators
i. Heat Loading
j. Rating Charts

6. X-ray Generators

Learning Objectives

The resident should learn:

1) *the individual components of an x-ray generator,*
2) *the properties of a timer, phototimer*
    a. Generator Components
    b. Timer and Phototimer
    c. Power Ratings

7. Film-Screen Radiography

Learning Objectives

The resident should learn:

1) *the basic theory of film/screen radiography including magnification radiography*
2) *the properties of film/screen cassettes, screens, radiographic film, and grids*
    a. Basic projection geometry, Magnification
    b. Film Screen Cassettes
    c. Screen Characteristics
        i. Conversion Efficiency
        ii. Absorption Efficiency
        iii. Noise
    d. Film
        i. Physical characteristics
        ii. Optical density
        iii. HD curve
        iv. Contrast/Latitude
    e. Film screen systems
    f. Dose
    g. Anti-Scatter and Grids
        i. Bucky Factor
        ii. Grid frequency
        iii. Grid Ratio
        iv. Thickness/Material
        v. Artifacts

8. Film Processing

Learning Objectives

The resident should learn:

1) *the basic theory of film processing including formation of the latent image, wet and dry processing*

2) *about film processing artifacts and film processing quality assurance.*
    a. Film emulsion
    b. Latent Image
    c. Development
    d. Automatic Film Processor
    e. Artifacts
    f. Quality Assurance
    g. Laser Cameras
    h. Dry processing

9. Mammography

Learning Objectives

The resident should learn:

1) the basic theory of mammography including film/screen mammography and digital mammography.

2) *the importance of compression, grid, mammography film/screen system, proper film processing*

3) about mammography image characteristics including contrast and resolution

4) *About MQSA and quality control for mammography*
    a. X-ray tube
        i. Anode
        ii. Tube tilt
        iii. Focal spot
        iv. Filtration
        v. Collimation
        vi. Energy spectrum/ HVL
        vii. Output
    b. X-ray Generator
        i. Automatic Exposure Control
    c. Compression
    d. Bucky
        i. Grid Ratio and construction
        ii. Movement
    e. Magnification
    f. Screen-film systems
        i. Cassettes
        ii. Film
        iii. Film Sensitivity
        iv. Film Processing
        v. Film Viewing conditions
    g. Imaging Parameters
        i. Contrast
        ii. Noise
        iii. Resolution
        iv. Dose-Average Glandular Dose
    h. Quality Control

i. Stereotactic Breast Biopsy
j. Full Field Digital Mammography
k. CR Digital Mammography
l. Tomosynthesis
m. MQSA Regulations
    i. Accreditation
    ii. Certification
    iii. Inspection
    iv. Mammography Phantom

10. Fluoroscopy

Learning Objectives

The resident should learn:

1) *the basic principles of fluoroscopy, both analog and digital, continuous and pulsed*
2) *the function of the imaging chain components including the image intensifier, TV system, digital recording equipment, automatic brightness control*
3) *the magnitude of the dose to the patient and operator from fluoroscopy*
4) *the regulations for fluoroscopy users*
    a. Equipment description/ resolution
    b. Image Intensifier
        i. Input screen
        ii. Optics
        iii. Output phosphor
        iv. Conversion Gain
        v. Brightness Gain
        vi. Field of View-- Magnification
    c. Video System
        i. Hardware
        ii. Video Resolution
    d. Flat panel Digital Fluoroscopy
    e. Digital Photo-spot camera, Spot-film device Cine Camera
    f. Modes of operation- continuous, high dose rate, pulsed etc
    g. Automatic Brightness Control
    h. Image Quality
        i. Spatial Resolution- Include parts of imaging chain
        ii. Contrast Resolution and quantum noise
    i. Radiation Dose
        i. Patient dose rates- average, maximum, methods to reduce
        ii. Operator dose- effects of shielding
    j. Regulations
    k. Quality Assurance
        i. Collimation
        ii. Patient entrance dose
        iii. High and low contrast resolution measurements

11. Image Quality

Learning Objectives

The resident should learn:

1) *the basic theory of image formation, image contrast, resolution, MTF, Noise, quantum detection, sampling, aliasing*
2) *the definition of ROC curves*
    a. Magnification
    b. Contrast
        i. Subject contrast
        ii. Detector Contrast
            1. Film screen contrast
            2. Digital image contrast
            3. Displayed contrast
        iii. Radiographic Contrast
        iv. Displayed contrast (Digital Contrast)
    c. Spatial Resolution
        i. Mechanisms of Blur or Unsharpness
            1. Focal spot blur
            2. Geometric blur
            3. Motion blur
            4. Detector blur
            5. Composite blur
        ii. MTF (Point and line spread functions)
        iii. Practical QA measurements und Resolution Phantoms
    d. Noise
        i. Quantum Noise
        ii. Contrast Noise Ratio (Digital Images)
    e. Quantum Detection efficiency
    f. Sampling and Aliasing
    g. Contrast/Detail Curves
    h. Receiver Operating Characteristics (ROC)

12. Digital Radiography

Learning Objectives

The resident should learn:

1) *the basic theory of digital radiography*
2) *the properties of DR, CR, digital cassettes, CCD detectors*
3) *types of image processing, image subtraction angiography*
    a. CR Technology
    b. DR Technology
        i. Indirect Flat Panel
        ii. Direct Flat Panel
        iii. CCD Detectors
    c. Dose
    d. Soft Copy Devices
    e. Digital Image Processing
        i. Corrections

ii. Global Processing
iii. Convolution
iv. Filtering

f. Resolution
g. Digital Subtraction Angiography

13. Conventional Tomography
Learning Objectives
The resident should learn:
1) the basic concept of conventional linear tomography
Section thickness and tube arc
Section Location
Artifacts

14. Computed Tomography (CT)
Learning Objectives
The resident should learn:
1) *the basic theory of Computed Tomography Scanner*
2) *about the properties of CT detectors, helical and multislice CT units*
3) *the definition of the Hounsfield unit*
4) *magnitude of dose from a CT scan and the effect of kVp and mA on dose*
5) *to recognize CT artifacts*
    a. Basic Principles
    b. History 4-7 Generations
    c. Detectors
    d. Slice thickness- Single and Multi-Detectors
    e. Helical CT- Pitch and collimation
    f. Reconstruction Kernels- Bone and soft tissue
    g. CT Number- Hounsfield Units
    h. Display- Multi-image and 3D
    i. Dose
        i. Measurement
        ii. Patient
        iii. Pediatric
        iv. Modulated mA
    j. Image Quality
    k. Artifacts
        i. Beam Hardening
        ii. Motion
        iii. Partial Volume
        iv. Hardware failure (Detector)

15. MR: Basic Principles
Learning Objectives
The resident should learn:
1) *the basic theory of magnetism and magnetic residence*

2) *the definition of T1, T2, T2*, proton density, the Larmor frequency, free induction decay*
3) *to understand the principles of magnetic residence, and the magnetic properties of tissue*
    a. Magnetism
    b. Magnetic Nuclei
    c. Tissue Magnetization—including net magnetization vector
    d. Larmor Frequency
    e. Resonance
    f. Longitudinal Magnetization
    g. Transverse Magnetization
    h. 90 degree, 180 degree, alpha and RF pulses
    i. Free induction decay
    j. Proton density (PD)
    k. T1 Relaxation
    l. T2 Relaxation
    m. T2* Relaxation including Non-uniformity and magnetic susceptibility effects
    n. Free Induction Decay (FID)
    o. Basic Pulse Sequences
    p. TR and TE
    q. Weighted Images
    r. Signal from Flow

16. MR: Imaging and Instrumentation

Learning Objectives

The resident should learn:

1) *the basic theory of operation of an MRI unit*
2) *the properties of magnetic coils such a the main magnetic, gradient coils, shim coils, and surface coils*
3) *to understand slice encoding, frequency and phase encoding*
4) *the different types of pulse sequences, signal to noise ratio of MR images*
5) *what is K space*
6) *to appreciate the need for safety around MR units*
7) *to recognize MRI artifacts*
    a. Magnets
    b. Magnetic Field Gradients Coils (X, Y, Z)
    c. RF Coils
        i. Body, head, surface, phased array
    d. Shielding
        i. Active
        ii. Passive
        iii. RF faraday cage
    e. Slice Select Gradient (SEG)
    f. Frequency Encoded Gradient (FEG)
    g. Phase Encoded Gradient (PEG)
    h. Gradient Sequencing and Pulse Sequence Diagrams
    i. K- Space
    j. Imaging Sequences

i. Spin Echo
ii. Fast Spin Echo—echo train length
iii. Inversion Recovery—Stir Flair
iv. Gradient recalled echoes
v. Echo Planar imaging

k. T1, T2, PD weighting
l. Multi-planar Acquisition
    i. 2D vs. 3D imaging
    ii. Scan time for 2D vs. 3D
m. Resolution
    i. Pixel size
    ii. Slice thickness
n. SNR
    i. Voxel size
    ii. Static magnetic field strength
    iii. RF bandwidth
    iv. NSA,
    v. RF Coil
o. Angiography
    i. Time of flight
    ii. Phase Contrast
p. Artifacts
    i. Chemical shift
    ii. Patient motion
    iii. Wraparound, truncation
    iv. Zipper
    v. Ring
q. Clinical Contrast Agents- Gd-DTPA
r. Spectroscopy
s. MR Safety
    i. Screening patients
    ii. SAR Limits
t. Quality Assurance
    i. SNR
    ii. Resonant Frequency
    iii. ACR Accreditation phantom—weekly and annual tests

17. Ultrasound

Learning Objectives

The resident should learn:

1) *the basic theory of how an ultrasound unit works*
2) *about the properties of sound transmission, including reflection, refraction, scattering and attenuation.*
3) *about the properties of piezoelectric transducers, the ultrasound beam, its resolution*
4) *about focusing and steering the ultrasound beam*

5) *the different mode of ultrasound imaging including B mode scanning and real time imaging*
6) *to understand Doppler ultrasound, its limitations, and understand the artifacts*
7) *to recognize ultrasound artifacts*
    a. Characteristics of Sound
    b. Pressure, Intensity and dB
    c. Interactions of sound with matter
        i. Acoustic Impedance
        ii. Reflection
        iii. Refraction
        iv. Scattering
        v. Attenuation
    d. Transducers
        i. Piezoelectric Effect
        ii. Near field, Far field
        iii. Acoustic Profile
        iv. Focusing and lenses
    e. Types of Transducers
        i. Mechanical sector
        ii. Linear Array
        iii. Phased Array (Annular and Linear)
        iv. Curvilinear Array
    f. Focusing and steering
        i. Mechanical
        ii. Electronic Transmit
        iii. Electronic Receive
    g. Spatial Resolution
        i. Axial
        ii. Lateral
        iii. Slice Thickness
    h. Real Time Imaging
        i. Registration of echo in image
        ii. Lines of Sight
        iii. Frame Rate
        iv. Pulse Repetition Frequency
        v. Time Gain Compensation
    i. Display Modes
        i. A-mode
        ii. B-mode
        iii. M-mode
    j. Image Processing
        i. Time Gain Compensation
        ii. Logarithmic compression
        iii. Frame Averaging
        iv. Spatial Smoothing
    k. Harmonic Imaging

l. Elastography
m. 3D imaging
n. Image Quality, Contrast and Noise
o. Artifacts
    i. Shadowing
    ii. Enhancement
    iii. Miss registration
    iv. Reverberation
    v. Comet Tail
    vi. Ring Down
    vii. Mirror Image
    viii. Side Lobe
p. Doppler Ultrasound
    i. Doppler Shift
    ii. Continuous Wave Doppler
    iii. Pulsed Wave Doppler
    iv. Color Flow Imaging
    v. Power Doppler
    vi. Artifacts
        1. Aliasing
        2. Slice thickness
        3. Mirror Imaging
        4. Reverberation
q. Quality Assurance
    i. Tissue Equivalent Phantom
    ii. Distance measurement accuracy
    iii. Penetration
    iv. Uniformity
r. Ultrasound Bioeffects and Safety
    i. Cavitations
    ii. Thermal Mechanisms form Potential Effect
    iii. Thermal Index
    iv. Mechanical Index

18. Computers in Radiology

Learning Objectives

The resident should learn:

1) *how computers are used in radiology*
2) *about image display characteristics and monitor technology.*
3) *how PACS works and how networks operate.*
4) *to appreciate security problems associates with digital images*
5) *what is needed for quality assurance in a PACS environment.*
    a. Image display characteristics – resolution and image pixel depth
    b. Image processing
    c. Computer Aided Detection
    d. Networks

e. Teleradiology
f. Security
g. PACs
h. Image storage and transmission
i. Display of Images
j. Hardcopy Recording Device
k. QA (SMPTE Test Pattern)

Nuclear Medicine

19. Radioactivity

Learning Objectives

The resident should:

1) *learn about radioactivity and half life*
    a. Decay
    b. Half-life

20. Decay Schemes

Learning Objectives

The resident should learn:

1) *about decay processes including alpha decay, beta plus and minus decay, electron capture, isometric transition, nuclear fission and gamma decay*
    a. Alpha Decay
    b. Beta Minus Decay
    c. Beta Plus Decay
    d. Electron Capture
    e. Isomeric Transition
    f. Nuclear Fission
    g. Gamma Decay

21. Radioisotope Production

The resident should learn:

1) *how radioisotopes are produced by a cyclotron and a nuclear reactor*
2) *about the properties of radionuclides*
3) *about regulatory issues associated with radionuclides*
    a. Cyclotron Produced Isotopes
    b. Nuclear Reactor Produced Isotopes
        i. Fission Products
        ii. Neutron Products
    c. Radionuclide Generators
        i. Transient Equilibrium
        ii. Secular Equilibrium
    d. Radiopharmaceuticals
        i. General Properties
        ii. Methods of Localization

        iii. QC
    e. Regulatory
        i. Investigational Regulations
        ii. Written Directives
        iii. Medical Events
        iv. NRC Requirements

22. Instrumentation

The resident should learn:

1) about different technologies of counting equipment used in nuclear medicine

2) *how a NaI detector works*

- a. Detector types
    - i. Gas Filled
    - ii. Scintillation
    - iii. Semiconductor
- b. Data collection
- c. Spectroscopy
    - i. Single Channel Analyzer
    - ii. Multi Channel Analyzer
- d. NaI Detector
    - i. Thyroid
    - ii. Well
- e. Dose Calibrator

23. Counting Statistics

The resident should learn:

1) *to understand counting statistics and sources of error*

2) *about different probability distributions including Binomial, Poisson and Gaussian distributions.*

- a. Sources of Error
- b. Characterization of Data
    - i. Accuracy and Precision
    - ii. Mean, Mode, and Median
    - iii. Variance
    - iv. Standard Deviation
- c. Probability Distributions
    - i. Binomial
    - ii. Poisson
    - iii. Gaussian
    - iv. Confidence Levels
    - v. Propagation of Error

24. Scintillation Camera

The resident should learn:

1) how a gamma camera works

2) *about the performance of nuclear medicine gamma camera including the effect of collimators*
3) *to understand artifacts produced by gamma cameras*
4) *the use of computers in nuclear medicine*

    a. Anger Camera
    b. Crystals
    c. PM tubes
    d. Collimators
    e. Image formation
    f. Performance
    g. Spatial Linearity and Uniformity
    h. Artifacts
    i. Whole body scanning
    j. Computers
        i. Image processing
        ii. Subtraction
        iii. Ejection Fraction- grated studies
        iv. Spatial Filtering

25. Emission Tomography

The resident should learn:

1) *how a SPECT and PET camera works*
2) *to understand artifacts produced by SPECT and PET*
    a. SPECT
        i. Image reconstruction
        ii. Attenuation corrections
        iii. Multi headed Cameras
    b. PET
        i. Principles of Detection
        ii. Scanner Design
        iii. Data Acquisition
        iv. Image Fusion
    c. PET/CT

Radiation Protection

26. Radiation Protection

The resident should learn:

1) *the magnitude and source of natural background radiation*
2) *the units used in radiation protection and methods used to measure these units.*
3) *how to reduce dose to patient and operator: time, distance and shielding*
4) *how to design radiation shielding*
    a. Sources of Ionizing radiation
        i. Natural
        ii. Artificial

        iii. Medical
        iv. Background
    b. Dosimetry
        i. Dose Equivalent
        ii. GSD?
        iii. Personal Monitoring Equipment
            1. Film Badges
            2. TLD badges
        iv. Survey Instruments
            1. GM Counter
            2. Ionization Chamber
    c. Radiation Protection
        i. Time
        ii. Distance
        iii. Shielding
    d. Protective Barriers
        i. CT Scanner
        ii. Radiographic
        iii. Fluoroscopic
        iv. Nuclear Medicine

27. Radionuclide Therapy

The resident should learn:

1) *What isotopes are used in radionuclide therapy and precautions needed in giving this treatment.*
    a. Isotopes
    b. Dose
    c. Waste Disposal

28. Regulatory

The resident should learn:

1) *the different regulatory agencies and their rules and influence*
2) *what ALARA means*
3) *the dose limits applied in their local area*
    a. Agencies
        i. State
        ii. FDA
        iii. NRC
        iv. International
        v. MQSA
        vi. BEIR
        vii. NCRP
        viii. ACR
        ix. CRCPD
    b. Units
    c. Dose Limits

d. ALARA
e. NRC requirements

29. Patient Dosimetry

The resident should learn:

1) *the patient and users dose from typical diagnostic and therapy procedures*
2) *how to calculate the dose from these procedures*
    a. CT Dose
    b. Radiographic
    c. Fluoroscopy
    d. MIRD
    e. Occupational Exposures
    f. Patient Exposures and Estimation
    g. Application in Clinical Practice
        i. Mammography Screening
        ii. Pediatric CT
        iii. Recommendations for Therapeutic Abortion
        iv. Management of Pregnant Worker

Radiation Biology

30. Radiation Biology

The resident should learn:

1) *the basic principles of radiation biology including how energy is transferred to the cells, cell survival properties*
2) *the definition of genetic effects stochastic effects and Nonstochastic effects*
3) *probability of cancer induction by radiation*
4) *risk estimate as applied to radiation biology*
    a. Ionization and biomolecules
        i. Microdosimetry
        ii. Direct and indirect effect
        iii. Oxygen effect- OER
        iv. Linear Energy Transfer
    b. Cellular interactions
        i. Cell survival studies
        ii. Radiosensitivity and the cell cycle
        iii. Effects of dose, dose-rate, and fractionation
        iv. Target theory
        v. Apoptosis
        vi. Radio protectors and radiosensitizers
    c. Genetic effects
        i. Genetically significant dose
        ii. Doubling dose
    d. Stochastic effects
        i. Threshold vs. non-threshold
        ii. Dose-effect models

e. Nonstochastic effects
    i. Acute Radiation Syndrome
    ii. Hematopoietic Syndrome
    iii. GI Syndrome
    iv. Neurovascular Syndrome
    v. Tissue and organ effects
    vi. Skin Injury
f. Population Dosimetry
g. Risk estimation
    i. Genetic Risks
    ii. In utero Risks- Time of fetal maturation
    iii. Cancer Risks- Leukemia, Thyroid, Breast