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PHYSICS CONTRIBUTION

THE AMERICAN SOCIETY FOR RADIATION ONCOLOGY'S 2010 CORE PHYSICS CURRICULUM FOR RADIATION ONCOLOGY RESIDENTS

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Purpose: In 2004, the American Society for Radiation Oncology (ASTRO) published its first physics education curriculum for residents, which was updated in 2007. A committee composed of physicists and physicians from various residency program teaching institutions was reconvened again to update the curriculum in 2009.
Methods and Materials: Members of this committee have associations with ASTRO, the American Association of Physicists in Medicine, the Association of Residents in Radiation Oncology, the American Board of Radiology (ABR), and the American College of Radiology. Members reviewed and updated assigned subjects from the last curriculum. The updated curriculum was carefully reviewed by a representative from the ABR and other physics and clinical experts.
Results: The new curriculum resulted in a recommended 56-h course, excluding initial orientation. Learning objectives are provided for each subject area, and a detailed outline of material to be covered is given for each lecture hour. Some recent changes in the curriculum include the addition of Radiation Incidents and Bioterrorism Response Training as a subject and updates that reflect new treatment techniques and modalities in a number of core subjects. The new curriculum was approved by the ASTRO board in April 2010. We anticipate that physicists will use this curriculum for structuring their teaching programs, and subsequently the ABR will adopt this educational program for its written examination. Currently, the American College of Radiology uses the ASTRO curriculum for their training examination topics. In addition to the curriculum, the committee updated suggested references and the glossary.
Conclusions: The ASTRO physics education curriculum for radiation oncology residents has been updated. To ensure continued commitment to a current and relevant curriculum, the subject matter will be updated again in 2 years. © **2011 Elsevier Inc.**

ASTRO, Radiation oncology, Physics, Education, Core curriculum.

INTRODUCTION

In 2002 the Radiation Physics Committee of the American Society for Radiation Oncology (ASTRO) appointed an ad hoc "Committee on Physics Teaching to Medical Residents." The main objective of this committee was to develop a core curriculum for physics teaching in radiation oncology residency programs with the explicit goal of improving consistency in radiation oncology physics teaching intensity and subject matter (1, 2). This is the third in a series of these core physics curricula for radiation oncology medical residents with updates to the subjects and added references from previous versions.

The Accreditation Council for Graduate Medical Education instituted the Outcome Project in 2001. The project introduced six core competencies into the process of graduate medical training: patient care, medical knowledge, practice-based learning and improvement, interpersonal and communication skills, professionalism, and systems-based practice. The

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project finished the phases of definition and integration in 2001–2006 and is currently in Phase 3 of "resident performance data as the basis for improvement and providing evidence for accreditation review" (3). One of the key competencies is medical knowledge. It is essential to define not only the scope of the knowledge required for medical practice of a certain specialty but also the assessment of the degree of acquisition of such knowledge. Successful radiation oncology practice requires strong physics background knowledge.

The available assessment of physics knowledge comes from the pass rate for the American Board of Radiology (ABR) written examination and the American College of Radiology (ACR)'s in-training examination scores. Both of these organizations have physics examination committees that strive to update examination questions for relevance and accuracy. The challenge is in deciding the relevancy and corresponding complexity of information presented in the training programs; this physics curriculum will address this issue. In summary, by updating previous curricula, this physics curriculum aims to continue to improve teaching contents and assessment consistency.

METHODS AND MATERIALS

The committee was composed of physicists and physicians from various teaching institutions with active residency programs. Members had associations with the American Association of Physicists in Medicine, ASTRO, the Association of Residents in Radiation Oncology, the ABR, or the ACR. The latter two organizations' representatives were on their respective physics examination committees, which provided a feedback loop between the examining organizations and ASTRO.

For the new curriculum, members reviewed and updated assigned subjects from the last curriculum. Each subject had up to three reviewers contributing to the update. Once the edits were compiled, the committee held a face-to-face meeting to finalize the subject matter included in the curriculum.

RESULTS

The new curriculum resulted in a recommended 56-h course, excluding initial orientation. The committee also decided to complement some particular subjects with hands-on experience obtained during a physics rotation. Table 1 summarizes the curriculum.

Table 1. Recommended subjects, teaching hours, and suggested options for textbook chapters and references for physics teaching to radiation oncology

Subject	Hours	References
0. Orientation	4	Khan Ch. 9–26; Hendee Ch. 4–16
1. Atomic and Nuclear Structure	2	Khan Ch. 1; Cherry Ch. 2
2. Production of X-rays, Photons, and Electrons	2	Khan Ch. 3; Hendee Ch. 2
3. Treatment Machines and Generators; Simulators and Simulation Tools	3	Khan Ch. 4 & 7; Metcalfe Ch. 1; Van Dyk Ch. 4–7
4. Radiation Interactions	3	Khan Ch. 5; Metcalfe Ch. 2; Cherry Ch. 6; Hendee Ch. 3; Bushberg Ch. 3
5. Radiation Beam Quality and Dose	2	Khan Ch. 7; Hendee Ch. 4
6. Radiation Measurement and Calibration	3*	Khan Ch. 8; Hendee Ch. 5 & 6; AAPM TG-51
7. Photons Beam Characteristics and Dosimetry	7*	Khan Ch. 11–13; Metcalfe Ch. 6; Bentel Ch. 4–6; AAPM TG-34; Wu 2007; Solan 2004; Hurkmans 2005; AAPM TG-36; Halperin Ch. 19
8. Electron Beam Characteristics and Dosimetry	2	Khan Ch. 14; AAPM TG-25/70
9. Informatics	1	http://wiki.ihe.net/index.php?title=Radiation_Oncology
10. Imaging for Radiation Oncology	4	Van Dyk Ch. 2; Curry Ch. 10–16, 19, 20, 22–24; Sprawls (entire book); Khan Ch. 25; Kessler & Roberson; Kessler
11. 3D-CRT Including ICRU Concepts and Beam-Related Biology	3*	Khan & Potish Ch. 4, 10, 18–28; ICRU-50, -62; AAPM TG-76
12. Assessment of Patient Setup and Verification	2*	Van Dyk Ch. 7; Bentel (entire book); Curran; AAPM TG-76; Khan Ch. 25
13. Intensity-Modulated Radiotherapy	3*	Khan Ch. 20; Palta (entire book); Ezzell; Mundt & Roeske (entire book)
14. Special Procedures	3	Khan Ch. 21 & 18; Metcalfe Ch. 5; AAPM TG-29, -30, -42, -101
15. Brachytherapy	6	Khan Ch. 22–24; Thomadsen Ch. 41–49 & Ch. 28–33; Pötter; AAPM TG 43[US]
16. Quality Assurance	2	Khan Ch. 17; AAPM TG-40; AAPM TG-142
17. Radiation Protection and Shielding	2	Khan Ch. 16; NCRP 151; Thomadsen Ch. 10; McGinley (entire book); NRC 35
18. Radiopharmaceutical Physics and Dosimetry	2	Khan Ch. 15; Cherry Ch.5; Thomadsen Ch. 11
19. Hyperthermia	1	Hall Ch. 28; Van Dyk Ch. 22
20. Particle Therapy	2	Van Dyk Ch. 20 & 21; Khan Ch. 26
21. Radiation Incidents and Bioterrorism Response Training	1	Grey (entire book); Levi (entire book); CDCP, ACR PD

See Appendix E1 for complete references.

Abbreviations: Ch. = chapter(s); AAPM TG = American Association of Physicists in Medicine Task Group; DICOM = Digital Imaging and Communications in Medicine; 3D-CRT = three-dimensional conformal radiotherapy; ICRU = International Commission on Radiation Units and Measurements; NCRP = National Council on Radiation Protection and Measurements; NRC = Nuclear Regulatory Commission; CDCP = Centers for Diseases Control and Prevention; ACR PD = American College of Radiology.

* Indicates subject matter that should be complemented during a physics rotation.

Some of the pertinent changes since 2007 include revisions to the following subjects: Imaging for Radiation Oncology; Three-Dimensional Conformal Radiotherapy, including International Commission on Radiation Units and Measurements concepts and beam-related biology; Assessment of Patient Setup and Verification; Intensity-Modulated Radiotherapy; Special Procedures; Brachytherapy; and Particle Therapy. Radiation Incidents and Bioterrorism Response Training was added to the curriculum.

After careful review of the teaching flow, the subject hours were slightly adjusted, and subjects were reordered. The appendix was revised to describe the details and learning objectives for each subject. In addition, the glossary was updated.

DISCUSSION

The updated curriculum was completed and approved by the ASTRO Board of Directors in April 2010. Changes were made to update the curriculum according to technological needs and to strengthen the educational experience of medical residents in radiation oncology physics. It is our hope that the physicists teaching medical residents will adopt the recommended curriculum and that the ABR will consider using the curriculum to develop its written physics examination for medical residents. The ACR has already used the previous ASTRO curriculum to develop their training examinations question bank.

The 2007 ASTRO curriculum report (1) illustrated that there are many variations in physics instruction to medical residents across training programs. Even though most residency programs provide physics courses to Postgraduate Year 2 residents, some teach different subjects (or levels) to different year residents. The total classroom time ranges widely from program to program (24–118 h). Such lack of consistency clearly demonstrates varying emphases in and commitment to physics teaching in training programs across the country. Inadequate classroom time can be detrimental to the educational experience and training of radiation oncology residents.

Our committee developed a revised curriculum that includes 56 h of lectures, which will provide the necessary consistency as the previous two curricula strived to do. Each residency program should embrace the revised curriculum and make a commitment to provide recommended classroom time for residents to take this physics course in its entirety at least once during their resident training. The course should be supplemented with hands-on training in subjects that include radiation measurement and calibration, photon-beam characteristics and dosimetry, assessment of patient setup and verification, three-dimensional treatment planning, and intensity-modulated radiotherapy. Hands-on training is most useful for residents in the latter part of their training.

Finally, the committee did not make a recommendation for a textbook for the lecture-based physics course. This decision is left to each individual institution. However, suggested references are included (see Appendix E1 and Table 1) for instructors to evaluate for use in teaching or as recommended student reading. We anticipate that future curricula will be available online and will include teaching modules and associated examination questions for each section. The curriculum will be updated again in 2 years.

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Appendix 1
Suggested Learning Material for Residents (Referenced in Table 1)

- ACR PD - Disaster Preparedness for Radiology Professionals, Response to Radiological Terrorism, A Primer for Radiologists, Radiation Oncologists and Medical Physicists © 2006 American College of Radiology, ACR Disaster Planning Task Force, Product code: P-DISASTER06, American College of Radiology (www.acr.org)
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- AAPM TG-30 - C.J. Karzmark, J. Anderson, A. Buffa, et al. Total skin electron therapy: Technique and dosimetry Report of TG 30. New York: American Institute of Physics, 1988.
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Multimedia Learning Material:

- Barton, M B and Thode, R J Distance learning in the Applied Sciences of Oncology Radiotherapy and Oncology In Press, Corrected Proof

Appendix 2
ASTRO's 2010 Physics Curriculum for Residents

Format As Follows:

#. Subject (# of lectures/hrs)
Learning Objectives
A. Unique Lecture For Subject
- Main Topic(S) Within Lecture
Subtopic within given lecture

*Learning objectives marked with * should be complemented with hands on training during a physics rotation*

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0. Orientation (4 Lectures)
Learning Objectives
The resident should learn:
A general overview of the radiation therapy processes, devices, software systems and radiation safety concerns.

A. Overview of Planning Process from Simulation to Treatment (1 hour)
B. General Operation of Simulation Devices (30 minutes)
C. Overview of Linear Accelerator Systems and Operation (30 minutes)
D. Introduction to Treatment Immobilization, Localization, and Verification (30 minutes)
E. Basic Monitor Units (MU) Calculations Appropriate for Emergency Patients (45 minutes)
F. Radiation Safety (45 minutes)
G. Introductory Lectures for Special Procedures and Quality Assurance (optional).

1. Atomic and Nuclear Structure (2 Lectures)
Learning Objectives
The resident should learn:

1. *the structure of the atom, including types of nucleons, relation between atomic number and atomic mass, and electron orbits and binding energy, and be able to relate energy to wavelength and rest mass, and understand and describe an energy spectrum(with respect to isotopes and/or linear accelerators)*
2. *about radioactivity, including decay processes, probability, half life, parent-daughter relationships, equilibrium, and nuclear activation*

A. The Atom
- Protons, Neutrons, Electrons (charge, rest mass)
- Atomic Number and Atomic Mass
- Strong and Weak Nuclear Forces
- Orbital Electron Shells (binding energy, transitions)
- Wave and Quantum Models of Radiation
- Energy and Wavelength, Energy Spectrum

B. Radioactivity and Decay
- Decay Processes (of commonly used isotopes for imaging/therapy as appropriate) Alpha, Beta, Electromagnetic (gamma, IC). Auger Emission
- Activity, Half Life, Mean Life
- Probability and Decay Constant
- Mathematical Calculations of Radioactive Decay
- Nuclear Stability
- Radioactive Series
- Nuclear Reactions

2. Production of Photons and Electrons (2 Lectures)

Learning Objectives

The resident should learn:

1. *the means by which x rays are produced in a linear accelerator, in diagnostic x-ray units, and orthovoltage units,*
2. *production of bremsstrahlung produced x rays and characteristic x rays,*
3. *the major components of a linear accelerator and their function,*
4. *about teletherapy treatment units (i.e. Gamma Knife) employing radioactive materials*

A. Basic Physics of X-ray Beam Production
- Bremsstrahlung Production of X- rays
- Characteristic Radiation
- X-Ray Energy Spectrum

B. Generation of Beams
- X-ray Generator: Anode, Cathode kVp, mA, Focal Spot, Line Focus Principle, Rotating Anode
- Diagnostic X-ray Tube Design
- Differences between Diagnostic Tubes and Therapy Tubes (hooded anode)
- Gamma- radiation Teletherapy Sources (Co-60)
- Linear Accelerator Production of X- rays and Electrons

3. Treatment Machines and Generators; Simulators and Simulation Tools (3 Lectures)

Learning Objectives

The resident should learn:

1. *the mechanics and delivery of radiation with respect to wave guides, magnetron v. klystron for production systems*
2. *the production and delivery of electrons by the electron gun, and scattering foil vs.scanning*
3. *the production and delivery of photons including the target and flattening filter*
4. *the benefits and limitations of multi-leaf collimators and cerrobend shielding and hand-blocking of photons*
5. *the purpose and use of monitor chambers*
6. *the production and collimation of superficial photons*
7. *an alternative to conventional linacs (e.g. Cobalt units…)*
8. *the production of low energy x-rays for imaging*

9. *the differences in film and other imaging modalities for simulation*

A. Linear Accelerators
- Mechanical Properties: Types of Motion, Isocenter
- Operational Theory of Wave Guides (standing wave, traveling wave)
- Bending Magnet Systems
- Photon Beam Delivery
- Electron Beam Delivery
- Beam Energy
- Monitor Chamber

B. Linac Collimation Systems
- Primary and Secondary Collimators
- Electron Applicators
- Multileaf Collimators
- Other Collimation Systems (radiosurgery)
- Radiation and Light Fields (including field size definition)

C. Other Teletherapy
- Cobalt Units (Gamma Knife)
- Therapeutic X-ray (<300 kVp)

D. Simulators
- Mechanical and Radiographic Operation
- Fluoroscopy, Flat Panel Detectors, and Intensifiers
- CT Simulation Machinery
- CT Simulation Operation
- Simulators with CT Capability

4. Radiation Interactions (3 Lectures)

Learning Objectives

The resident should learn:

1. *the physical description, random nature, and energy dependence of the five scatter and absorption interactions that x-ray photons undergo with individual atoms (coherent scatter, photoelectric effect, compton effect, pair production, and photonuclear disintegration)*
2. *the definitions of 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. *the definitions of key terms such as linear energy transfer, mass stopping power, range, and how these terms relate to energy deposition by particulate radiation.*

A. Interactions of X and γ Rays with Matter
- Scatter vs. Absorption of Radiation

- Coherent Scatter
- Photoelectric Effect
- Compton Effect
- Pair Production
- Photonuclear Disintegration

B. Attenuation of Photon Beams
- Attenuation, Energy Transfer, and Energy Absorption
- Exponential Attenuation Equation
- Attenuation Coefficients
- Half-value Layer
- Beam Geometry

C. Interactions of Particulate Radiation
- Directly and Indirectly Ionizing Particles
- Elastic and Inelastic Collisions with Orbital Electrons and the Nucleus
- Linear Energy Transfer, Specific Ionization, Mass Stopping Power, Range
- Interactions of Electrons
- Interactions of Heavy Charged Particles (i.e. protons)
- Interactions of Neutrons

5. Radiation Beam Quality and Dose (2 Lectures)

Learning Objectives

The resident should learn:

1. *the physical characteristics of monoenergetic and polyenergetic photon and particle beams and terms such as energy spectrum, effective energy, filtration, and homogeneity that are used to describe such beam*
2. *the definitions and units for kerma, exposure, absorbed dose, equivalent dose and RBE dose, the conditions under which each quantity applies, and the physical basis for measuring or computing each quantity*
3. *how absorbed dose can be determined from exposure, and the historical development of this approach.*

A. Monoenergetic and Polyenergetic Bremsstrahlung Beams
- Energy Spectra for Bremsstrahlung Beams
- Effects of Electron Energy, Filtration, Beam Geometry
- HVL_1 and HVL_2
- Effective Energy
- Clinical Indices for Megavoltage Beams (e.g., PDD at reference depth)

B. Dose Quantities and Units
- Evolution of Dose Units
- Kerma
- Exposure
- Absorbed Dose

C. Relationships of Kerma, Dose, Exposure

- Dose Equivalent
- RBE Dose
- Calculation of Absorbed Dose from Exposure
- Bragg-Gray Cavity Theory

6. Radiation Measurement and Calibration (3 Lectures)

Learning Objectives

The resident should learn:

1. *Bragg-Gray cavity theory and its importance in radiation dosimetry.*
2. *stopping power ratios and the effective point of measurement for radiation dosimetry.*
3. *how photon and electron beams are calibrated, the dose calibration parameters, and the calibration protocols for performing linac calibrations. TG51*
4. *how to determine exposure and dose from radioactive sources.*
5. *the various methods by which to measure absorbed dose. These should include calorimetry, chemical dosimetry, solid state detectors, and film dosimetry.*
6. *devices used for clinical dosimetry (film, diodes, TLDs, etc.)*

A. Calculation of Dose

- Calculation of Absorbed Dose from Exposure – Historical Perspective (in light of TG51)
- Bragg-Gray Cavity Theory – Stopping Powers, Effective Point of Measurement

B. Dose Output Calibration

- Ionization Chambers (Cylindrical, Parallel-Plate Electrometers, Ionization Chamber Correction Factors)
- Calibration of Megavoltage Beams
  - Photon beams
  - Electron beams
  - Dose calibration parameters
  - TG-51(theory and overview)
- Exposure from Radioactive Sources
- Other Methods of Measuring Absorbed Dose
  - Calorimetry
  - Chemical Dosimetry (Fricke Solution, BANG Polymer Gel Dosimetry)

C. Clinical Dosimetry

- Solid State Detectors
  - Thermoluminescent dosimeters (TLD)
  - Optically Stimulated Luminescence (OSL)
  - Diode detectors
  - Metal Oxide Field Effect Transistor (MOSFET) detectors
  - Detector arrays (for IMRT/TomoTherapy verification)
  - Implantable dosimeters (DVS, Sicel)
- Film Dosimetry (IMRT verification dosimetry)
  - Optical density, base + fog, saturation
  - XV2 film
  - EDR2 film

Radiochromic film
Processors in film dosimetry

7. Photons and Beam Characteristics and Dosimetry (7 Lectures)

Learning Objectives

The resident should learn:

1. *basic dosimetric concepts of photon beams*
2. *how these concepts relate to calculation concepts*
3. *basic calculation parameters*
4. *how these parameters relate to one another and how to cross convert*
5. *how parameters depend on SSD and SAD setups*
6. *how beam modifiers affect beams and calculations*
7. *basic treatment planning arrangements and strategies*
8. *how beam shaping affects isodose distributions*
9. *surface and exit dose characteristics*
10. *interface dosimetry considerations*
11. *heterogeneity corrections and effects on dose distributions*
12. *beam matching techniques and understanding of peripheral dose*
13. *special considerations for pacemaker, defibrillator, pain pumps, other implantable devices, pregnant patients*

A. External Beam Dosimetry Concepts (Part I)
- Dosimetric Variables from Calibration
  - Inverse square law
  - Backscatter factor
- Electron Buildup
- Percent Depth Dose
- Penumbra, Flatness & symmetry
- Mayneord F-factor
- Definition of area (collimator, scatter, patient)
- Equivalent Squares

B. External Beam Dosimetry Concepts (Part II)
- Primary vs. Scatter
- Scatter to Primary Ratio
- Tissue Air Ratio
- Tissue-phantom Ratio
- Tissue-maximum Ratio
- Converting PDD to TMR
- Dose Normalization and Prescription

C. System of Dose Calculations
- Monitor Unit Calculations
  - Calibration
  - Collimator Scatter Factor and Phantom Scatter Factor

Clarkson integration
Field Size Correction Factors
Beam Modifier Factors (wedges)
Patient Attenuation Factors
Output Factor
-Calculations in Practice
SAD Technique
SAD Treatment and SAD Calibration
SAD Treatment and SSD Calibration
SAD Rotational Treatment
SSD Technique
SSD Treatment same as SSD of Calibration
SSD Treatment Different from SSD of Calibration
SSD Treatment and SAD Calibration
Calculation of Maximum Dose in parallel opposed field plans

D. Computerized Treatment Planning
- Beam Models (i.e. Clarkson integration, Convolution, Monte Carlo)
- Isodoses
- Beam Combination (2-, 3-, 4-, 6- field techniques)
- Beam Weighting
- Irregular Fields
- Bolus
- Arc Rotation Therapy

E. Computerized Treatment Planning Strategies
- Surface and Buildup Dose
- Entrance and Exit Dose
- Penumbra
- Grid Size
- Wedge Isodose Curves and Techniques
Wedge angle and hinge angle
Wedge factor
- Wedge and Compensator Techniques
Wedge pair
Open and wedged field combination
Custom compensators
Different types of wedges (universal, dynamic, physical, segmentation)

F. Surface Corrections & Heterogeneity Calculations
- Effects and Corrections for Surface Obliquities
- Corrections and Limitations for Inhomogeneities
Simple 1-D and 2-D methods
Convolution and Superposition methods
Monte Carlo methods
Dose perturbations at interfaces

G. Adjoining Fields & Special Dosimetry Problems
- Two-Field Matching
- Three-Field Matching
- Craniospinal Field Matching
- Treatment Considerations for Pacemaker, Defibrillators, and Pain Pumps
- Gonadal Dose, Measurement and Minimization
- Pregnant Patient, Considerations and Dosimetry

8. Electron Beam Characteristics and Dosimetry (2 Lectures)

Learning Objectives

The resident should learn:

1. *the basic characteristics of electron beams for therapy, including components of a depth-dose curve as a function of energy, electron interactions, isodoses, oblique incidence, skin dose, and electron dose measurement techniques.*
2. *the nature of treatment planning with electrons, including simple rules for selecting energy based on treatment depth and range, effect of field size, bolus, and field shaping (especially for small fields), about field matching with photons and other electron fields, internal shielding, backscatter, and the effects of inhomogeneities on electron isodoses.*

A. Basic Characteristics
- Depth-dose Characteristics
- CSDA Range, Maximum Range, Practical Range, Bremsstrahlung "tail."
- Energy vs. Depth
- Electron Skin Dose
- Isodoses
- Oblique Incidence
- Effective Source Distance/Virtual SSD
- Dose Rate and MU Calculations

B. Treatment Planning with Electrons
- Selection of Energy, Field Size
- Bolus for Surface Buildup
- Bolus for Depth-range Compensation
- Field Shaping
- Electron-electron Matching
- Electron-photon Matching
- Electron Backscatter Dosimetry
- Inhomogeneities
- Internal Shielding
- External Shielding (i.e, eye shields, Bremmstrahlung Production, Energy and Shielding Material Thickness)

9. Informatics (1 Lecture)

Learning Objectives

The resident should learn:

1. *the various Information Systems and how they communicate with imaging, planning and delivery systems*
2. *methods of data transfer, storage, and security*

   A. DICOM
   B. PACS
   C. Network Integration and Integrity
   D. Storage and Archival
   E. System Maintenance
   F. Physics and IT Staff Roles

10. Imaging for Radiation Oncology (4 Lectures)
Learning Objectives
The resident should learn:
1. *the principles and factors influencing radiographic imaging in the MV and kV ranges*
2. *commonly used in-room imaging equipment technology and its use*
3. *imaging technology and related physical principles for treatment planning (CT, and MRI)*
4. *the generation of a DRR*
5. *nuclear Medicine imaging applied to Radiation Oncology (PET,SPECT)*
6. *image registration methods typically used to aid in treatment planning*
7. *quality assurance procedures to aid in successful integration of imaging within Radiation Oncology*

A. Radiography Fundamentals
- Diagnostic Imaging Physical Principles
  - Physical principles
  - Digital images: pixel size, gray scale, image storage size, window/level
  - Impact on quality
  - Systems
- Port Film Imaging
  - Film types and cassettes
- Electronic Portal Imaging
  - Overview of electronic portal imaging devices
  - Types of portal imaging devices
  - Clinical applications of EPID technology in daily practice
- kV Flat Panel Detectors
  - Room mounted systems
  - Gantry mounted systems

B. CT and PET
- CT
  - Contrast agents
  - Principles of image formation (Hounsfield numbers, CT numbers, etc.)
  - Image reconstruction

Systems (large bore, small bore, single/multi detector, conebeam and FOV)
Factors influencing image artifacts
Image quality
Dose
4D CT

- PET
  - Principles of image formation
  - Detection
  - Reconstruction (brief)
  - Quantitative use of PET (SUV)
  - Artifacts

C. MRI and Ultrasound

- MRI Scanning
  - Physical principles of image formation
  - Signal generation
  - Sources of contrast
  - Artifacts
  - T1, T2, TE, TR imaging characteristics
  - Advantages & limitations of MRI
- Ultrasound
  - Physical principles of image formation
  - Systems (endorectal, volumetric, planar)
  - Utility in diagnosis and patient positioning
  - Artifacts and image distortion

D. Image Processing for Treatment Planning

- Image Enhancement: Review of Methods Used to Enhance Image Quality
  - Adjusting scanner technique to improve contrast
  - Window-level
  - Post-processing filters
- Segmentation:
  - Basic definition
  - Overview of segmentation techniques
    - Manual and automatic techniques
    - Intensity-based vs. contour (model)-based techniques
  - Methods used to generate margins (boolean operations used to include/exclude structures, and/or/nor, etc.)
  - Clinical examples
- Registration:
  - Basic definition
  - Overview of registration techniques
    - Intensity-based vs. model (contour)-based
    - Rigid vs. deformable
  - Pros and cons of different registration methods
  - Methods for validation of image registration

Clinical examples

E. Hybrid Systems (incl. SPECT)
- Quality Assurance
- Image Transfer Process
- Imager QA

11. 3D CRT Including ICRU Concepts and Beam Related Biology (3 Lectures)
Learning Objectives
The resident should learn:

1. *the intended goals and technologies needed for planning and delivering volumetric (3DCRT) vs. non-volumetric planning*
2. *the concepts associated with 3DCRT planning including uniform vs. non-uniform tumor dose distributions, non-biological and biological models for computing dose-volume metric*
3. *the ICRU definitions and reporting recommendations for tumor related volumes such as GTV, CTV, and PTV*
4. *the magnitudes, sources, and implications of day-to-day treatment variabilities*

A. 3D CRT Concepts; Volumetric vs. Non-volumetric
- ICRU Reports 50 and 62: GTV, CTV, PTV, ITV, OAR, PRV
- Contouring Variability
- Systematic and Random Setup Variability
- Combining Margins
- Patient Motion

B. Treatment Planning
- Virtual Simulation
- BEV
- Beam Selection
- Non-coplanar Beams
- 4D Planning

C. Plan Evaluation and Comparison
- Cumulative Dose Volume Histogram (DVH): What is it? How is it calculated? Minimum Dose, Maximum Dose
- Dose Statistics: V_D (volume receiving a dose of at least D), D_V (dose received by volume V), Conformity Index, Integral Dose
- Comparison of DVH's, Limitations of DVH
- Biological Models: Serial vs. Parallel Tissue Structure
- Biological Indices: TCP, NTCP, EUD

D. Prescribing and Reporting
- How to Write a Proper Prescription for 3D CRT
- Dose Reporting

12. Assessment of Patient Setup and Verification (2 Lectures)

Learning Objectives

The resident should learn:

1. *the principles and devices currently associated with patient positioning and immobilization*
2. *imaging methods applied in the treatment position for localization of the target and critical structures prior to treatment*
3. *use of in-room measurements for post-treatment adjustments*
4. *the use of these resultant images and localization data for potentially modifying the initial treatment plan via an adaptive planning strategy*

A. Positioning and Immobilization Methods and Devices
- Table Coordinates, Lasers, Distance Indicators
- Positioning Options (calibrated frames, optical and video guidance, etc.)
- Immobilization Methods (thermoplastic masks, bite blocks, etc.)
- Breathing Motion Management Techniques

B. Treatment Verification
- X-Ray-based Systems
  - Film (e.g. TL film for verification)
  - Electronic Portal Imagers (EPIDs)
- X-ray Imaging for IGRT
  - General overview of IGRT process and imaging for IGRT
  - Systems available and currently in-use for IGRT:
    - Cone-beam CT (kV and MV)
    - Digital Tomosynthesis (DTA)
    - CT-on-rails
    - Linac-based implementations
      - Varian
      - Elekta
      - Siemens
      - Tomotherapy
      - Cyberknife (Accuray)
      - Novalis (BrainLab Exactrac system).
- Non-x-ray Based IGRT Systems
  - Ultrasound (2D and 3D ultrasound systems)
  - Optical systems (e.g. based on surface matching (RT Align))
    - Monitor interfraction motion
    - Monitor intrafraction motion
  - Tracking Devices (e.g. implanted EM beacons (Calypso))
    - Monitor interfraction motion
    - Monitor intrafraction motion
  - MR-based systems
    - Simulation
    - Treatment verification
- IGRT-based Verification Process

Treatment image verification process – overview of the on-line imaging process and methods used to generate shifts for patient on-line correction (includes image processing at treatment console)
Clinical examples of image verification and treatment at treatment console
Imaging strategies and examples for off-line corrections and adaptive RT.

- Dosimetry Based
  Diodes
  TLDs
  MOSFET
  Implantable dosimeters (e.g. DVS (Sicel Technologies) - capable of monitoring dose, real-time during treatment)
- Adaptive Planning Concepts

13. Intensity Modulated Radiation Therapy (IMRT) (3 Lectures)
Learning Objectives
The resident should learn:

1. *the details of the different delivery systems including advantages, differences and limitations*
2. *the differences for simulation and positioning compared with conventional therapy*
3. *the principles of forward and inverse planning and optimization algorithms*
4. *the issues with inverse planning*
5. *systematic and patient specific quality assurance*

A Concepts of IMRT
- Intensity Maps
- Advantages/Disadvantages of IMRT

B. IMRT Delivery Systems
- Segmental MLC (SMLC) and Dynamic MLC (DMLC)
- Helical Tomotherapy
- Robotic Linac
- Intensity Modulated Arc Therapy (IMAT)
- Compensators
- Leaf Sequencing Algorithms

C. Dose Prescription & Inverse Planning
- Discuss Concept of PRVs
- Forward and Inverse Planning Optimization Concepts
  Cost/Objective function
  Optimization: stochastic vs. non-stochastic methods, gradient method, simulated annealing, global vs. local minima
- Planning Issues
  Adjacent/over lapping structures
  Limitations on segment size and MU
  Number, energy and placement of beams
  Aperture based optimization (e.g. As used for breast IMRT)

Plan evaluation specific to IMRT: hot spots, deliverability

D. IMRT Quality Assurance
- Commissioning of Planning and Delivery
- System QA
- Patient Specific
- QA Tools and Metrics

E. Whole Body Dose
- Ratio of MU for IMRT vs. Conventional Treatment
- Whole Body Dose for Different Types of IMRT Delivery, Effect of Beam Energy

14. Special Procedures (3 Lectures)

Learning Objectives

The resident should learn:

1. *the basis of stereotactic radiation therapy delivery and dosimetry*
2. *SRT, extracranial treatments including immobilization and localization systems*
3. *dosimetry of small field irradiation including SRS cones and micro/mini MLCs*
4. *TBI techniques and large field dosimetry*
5. *Logistics and dosimetric considerations for TSET and e-arc*

A. Cranial Stereotactic Systems
- Linac Based
  - Frames vs. Frameless
  - Delivery and Positioning
    - Arc vs. mMLC
  - Planning and TP Commissioning
  - Quality Assurance
- Gamma Knife
- Robotic Linac
- Prescriptions
- Dosimetry
  - PDD, TMR
  - Outputs
  - Profiles

B. Extracranial
- Delivery and Positioning
- Planning and TP Commissioning
- Prescriptions
- Dosimetry
  - PDD, TMR
  - Outputs
  - Profiles
- Patient QA

C. Other Special Procedures
- Photon Total Body Irradiation
  - Simulation
  - Patient set-up (Lateral, AP/AP, multifield: advantages and disadvantages)
  - Dosimetry
  - Selection of energy, field size, distance, dose-rate considerations
  - MU calculations
- TSET
- Electron Arc

15. Brachytherapy (6 Lectures)

Learning Objectives

The resident should learn:

1. *characteristics of the individual sources: Half-life, photon energy, half-value layer shielding, exposure rate constant and typical clinical use.*
2. *source strength units: Activity, Apparent activity, Air Kerma Strength, Exposure rate, Equivalent of mg hours of radium, and NIST Standards for calibration*
3. *the application of high dose rate vs. low dose rate in terms of alpha/beta ratios, fractionation, and dose equivalence*
4. *specification and differences of linear and point sources*
5. *implant systems and related dosimetry*
6. *implantation techniques for surface and interstitial implants regarding the sources used, and how they are optimized especially for prostate and breast treatments*
7. *dose calculations for temporary versus permanent implants, e.g. for prostate cancer treatments*
8. *gynecologic applicators: Fletcher-type applicators tandem and ring, vaginal cylinders, interstitial templates and the treatment planning systems for each applicator system*
9. *cervix dosimetry conventions: Milligram-Hours, Manchester System, ICRU 37 reporting recommendations, normal tissue reference points, image guidance initiatives (GEC-ESTRO guidelines)*
10. *radiation detectors used for calibration and patient safety during implants*
11. *implant loading specifics of dose rates, delivery devices, safety concerns, emergency procedures and shielding for both patients and personnel*
12. *discuss NRC and state regulations regarding use, storage and shipping of sources.*
13. *quality assurance and safety program development*

A. Radioactive Sources (General Information) and Calibration

the Sources of Radioisotopes: Natural, Man Made (Methods)
- Radium – Disadvantages of Radium, Effect of Source Casing
- Cesium-137
- Cobalt-60
- Iridium-192
- Iodine-125
- Cesium-131
- Palladium-103
- Strontium-90
- Iodine-131

- Specification of Source Strength
- Linear Sources
- Seeds
- Exposure Rate Calibration

B. Calculations of Dose Distributions
- Biological Considerations of Dose, Dose Rate, and Fractionation
- Calculation of Dose from a Point Source
- Calculation of Dose from a Line Source (TG-43)

C. Implantation Techniques
- Remote and Manual
- Electronic Brachytherapy
- Surface Molds/Plaques
- Interstitial Therapy
    - Prostate Brachytherapy
        - HDR vs. LDR treatments
        - Planning Techniques
        - Uniform vs. Peripheral
    - Breast Brachytherapy
    - Single Catheter vs. Multiple Catheter Planning

D. Gynecological Implants
- General Information (advantages/disadvantages)
- Manual Afterloading Methods
- Remote Afterloading Units
- Comparisons between HDR, LDR, PDR Methods
- Intracavitary Therapy
    - Intact uterus (cervical cancer)
        - Paris, Manchester systems
        - ICRU 37 reporting guidelines
            - Points A, B
            - ICRU bladder and rectal reference points
            - Milligram-Hours, reference air kerma
        - Image-guidance
            - GEC-ESTRO guidelines
        - Applicator types
            - Fletcher –type applicators (shielded, non-shielded)
            - Manchester ovoids
            - Tandem and ring
    - Post-hysterectomy vagina
        - Dose specification (surface, depth)
- Interstitial Therapy

E. Systems of Implant Dosimetry
- Historical (Paterson-Parker)
- Computerized TP Process and Calculations

- Units, Decay
- Applicators
- Limitations
- Imaging

F. Quality Assurance and Safety
- Quality Assurance
  - Placement Verification
  - Treatment Planning Accuracy
  - Applicator Integrity
- Safety
  - Detectors
  - Regulatory Requirements
  - Surveys
  - Inventory and Wipe Tests
  - Shipping and Receiving
  - Source Handling
- High Dose Rate Remote Afterloaders Specific
  - Wire, source, safe, channels, source activity and size, dwell times, position accuracy, safety features, emergency procedures.

16. Quality Assurance (2 Lectures)

Learning Objectives

The resident should learn:

1. *the goals of a departmental quality assurance program, the staffing required to perform these quality assurance activities, and the duties and responsibilities of the individuals associated with the quality assurance program.*
2. *what is entailed in making equipment selections in radiation therapy and the content of equipment specification.*
3. *what is involved in acceptance testing of a radiation system (e.g. linac, Brachy system) and in commissioning both the radiation system and a treatment planning system.*
4. *what radiation system quality assurance is required on a daily, monthly, and yearly basis and the tolerances associated with these tests*.

A. Overview of Quality Assurance in Radiation Therapy
- Goals, Regulations
- Continuing Quality Improvement vs. QA
- Staffing
  - Roles, training, duties & responsibilities of individuals
- Equipment Specifications
- Error Analysis and Prevention

B. Radiation System and Imaging System QA
- Acceptance Testing – e.g. Linac and Brachy Systems
- Commissioning – e.g. Linac and Brachy Systems
- Data Required
- Treatment Planning Commissioning and Quality Assurance

- Routine Quality Assurance and Test Tolerance
    - Daily QA
    - Monthly QA
    - Yearly QA
- Quality Assurance of Imaging Apparatus
    - Portal imagers
    - CT-Simulators
    - Conventional Simulators
    - Cone beam CT – kV and/or MV
    - Processors

C. Patient/Process QA
- Plan QA
- Routine "Chart" Checks
- In Vivo Verification

17. Radiation Protection and Shielding (2 Lectures)

Learning Objectives

The resident should learn:

1. *the general concept of shielding, including ALARA and Federal Regulations.*
2. *the units of personnel exposure, sources of radiation (man made and natural), and means of calculating and measuring exposure for compliance with regulations.*
3. *components of a safety program, including NRC definitions and the role of a radiation safety committee.*

A. Radiation Safety
- Concepts and Units
    - Radiation protection standards
    - Quality factors
    - Definitions for radiation protection
    - Equivalent dose, dose equivalent
    - Effective dose equivalent
- Types of Radiation Exposure NCRP 160
    - Natural background radiation
    - Man-made radiation
    - NRC exposure limits
- Protection Regulations
    - NRC definitions
        - Medical event
        - Authorized user
    - NRC administrative requirements
        - Radiation safety program
        - Radiation safety officer
        - Radiation safety committee
    - NRC regulatory requirements (including security)

Personnel monitoring

B. Radiation Shielding
- Treatment Room Design
  - Controlled/Uncontrolled areas
  - Types of barriers
  - Factors in shielding calculations– NCRP #151
    - Workload (W)
    - Use factor (U)
    - Occupancy factor (T)
    - Distance
- Shielding Calculations (including IMRT)
  - Primary radiation barrier
  - Secondary barrier
  - Neutron shielding for high energy photon and electron beams
  - Maze and treatment room door
- Sealed Source Storage
- Protection Equipment and Surveys
  - Operating principles of gas-filled detectors
  - Operating characteristics of radiation monitoring equipment
    - Ionization chambers
    - Geiger-Mueller counters
    - Neutron detectors
- Shielding Requirements for Conventional Simulators, CT Simulators
- HDR Unit Shielding (linac vault vs. dedicated bunker)
- TBI

18. Radiopharmaceutical Physics and Dosimetry (2 Lectures)

Learning Objectives

The resident should learn:

1. *methods of radiopharmaceutical production*
2. *clinical treatments using internally administered radioisotopes*
3. *internal dosimetry*
4. *safety and regulations*

A. Methods of Production and Clinical Treatments
- Reactor-produced Isotopes
- Cyclotron-based Production
- Radiochemistry Basics
- Clinical Treatments using Internally Administered Radioisotopes
  - Iodine treatment for thyroid
  - Radioimmunotherapy
  - Emerging treatments

B. Internal Dosimetry and Safety
- Dosimetry Systems
- Compartmental Models

- MIRD Method
- Dose Estimates for Embryo/fetus and Breast-feeding Infant
- Radiation Safety
    - Equipment
        - Survey meters, NaI probes, well counters, radionuclide calibrators
        - Instrument quality controls and checks
    - Safety procedures
        - Radiation protection, including internal protection, spill response and decontamination, inpatient and outpatient therapy precautions, written directive, medical event, radioactive package receipt, and area surveys/removable contamination wipe tests
    - Regulations

19. Hyperthermia (1 lecture)

Learning Objectives

The resident should learn:

1. *basic physics of Hyperthermia and how this applies clinically*
2. *hyperthermia systems*
3. *thermometry*

A. Physics Aspects of Hyperthermia
- The Bio-heat Equation and Simplified Solutions.
- Specific Absorption Rate (SAR).
- Thermal Aspects of Blood Flow/Perfusion

B. External Superficial Electromagnetic Hyperthermia Applicators.

C. Interstitial Electromagnetic Hyperthermia Applicators

D. Ultrasound Hyperthermia Systems
- Electromagnetic Applicators for Regional Hyperthermia
- Thermometry Performance Criteria, Tests, and Artifacts.

20. Particle Therapy (2 lectures)

Learning Objectives

The resident should learn:

1. *basic physics and safety of neutron and proton beams*
2. *configurations of proton and neutron delivery systems*
3. *treatment planning considerations for particle therapy*
4. *Other heavy particles, such as carbon, oxygen, etc…*

A. Types of Particles
- Protons
- Neutrons
- Heavy Particles
    - Carbon, Oxygen, Neon

B. Delivery Systems
- Cyclotrons
- Synchrotrons
- Synchro-cyclotrons
- Quality Assurance
- Protons, Heavy Particles
  - Dosimetry
  - SOBP
  - Range
  - Profiles
  - Shielding and Neutrons
  - Scanning Systems
- Neutrons
  - Dosimetry
  - Energy and beam characteristics
  - Shielding

B. Planning and Biology
- Protons, Heavy Particles
  - CTV-PTV Concepts
  - CT #, Relative Stopping Power Ratio, and WET
  - TP Strategies
    - Clinical sites
    - Trajectories
    - Patch planning
- RBE
  - Protons
  - Neutrons
  - Heavy Particles

21. Radiation Incidents and Bioterrorism Response Training (1 lecture only)
Learning Objectives
The resident should *learn*:
1. the types of radiation threat scenarios
2. the exploitable sources of radioactive contamination
3. the types of radiation incidents(see comments below)
4. medical involvement with regard to the hospital response, patient medical management and counseling needed.

A. Radiation Threat Scenarios
- A Nuclear Detonation
- A Nuclear Reaction which results if high-grade nuclear material were allowed to form a critical mass ("criticality") and release large amounts of gamma and neutron radiation without a nuclear explosion.
- A Radioactive Release from a Radiation Dispersal Device

B. Exploitable Sources of Radioactive Contamination

- Radiation Sources and Contaminants Found in Nature
- Radiation Sources Related to the Nuclear Fuel Cycle
- Radiation Sources Used in Medical Diagnosis and Therapy
- Radiation Sources Present in Military Equipment
- Radiation Sources Used in Industry
- Radioactive Equipment and Materials Which May Require Transportation

C. Types of Radiation Incidents/Accidents

- Typical Medical Doses
- Environmental Doses
- Relative Hazard Associated Doses

D. Hospital Response

-Pertinent Information About The Terrorist Incident:

When did it occur?
What type and how much radioactive material may be involved?
What medical problems may be present besides radionuclide contamination?
What measurements have been made at this site (For example, air monitors, fixed radiation monitors, nasal smear counts and skin contamination levels)?
Are industrial, biological or chemical materials exposure expected in addition to radionuclides?

- Questions About The Status Of The Patient Should Include:

What radionuclides do not contaminate the patient?
Where/What are the radiation measurements on the patient's surface?
What is known about the chemical and physical properties of the compounds containing the radionuclides?
Has decontamination been attempted and with what success?
What therapeutic measures have been taken?

- The Ten Basics of Response
- Order of Management and Treatment of Radiological Casualties

Classification of radiation injuries
Local skin absorbed doses
Total body external doses

- Medical Management
- Patient Radiological Assessment

The externally exposed patient
The contaminated and injured patient
Treatment of internal contamination
Treatment for selected internal contaminants

- Summary of Evaluation and Treatment Procedures for Internal Contamination
- Radiation Counseling

Acute effects
Cancer risks
Genetic risks
Teratogenic risks

- Basic Rules for Handling Contaminated Patients

Appendix 3

Glossary

AAPM- American Association of Physicists in Medicine

ALARA- "as low as reasonably achievable"

AP/PA- anterior-to-posterior/posterior-to-anterior beam projection

BANG- Bis (N, N'-methylene-bisacrylamide), acrylamide, nitrogen and gelatine

BEV- beam's eye view

CSDA- continuous slowing down approximation

CT- computed tomography

CTV- clinical target volume

DEW – Dielectric wall

DICOM- digital imaging and communications in medicine

DMLC- dynamic multi-leaf collimation

DRR- digitally reconstructed radiograph

DVH- dose volume histogram

e-arc- electron arc

EPID- electronic portal imaging device

ESRT- extracranial stereotactic radiotherapy

FET- field effect transistor

FOV- field of view

GTV- gross tumor volume

HDR- high dose rate

ICRU- International Commission on Radiation Units and Measurements

IMRT- intensity modulated radiotherapy

IS- information systems

IT- information technology

Kerma- kinetic energy released in medium

kV- kilo voltage

kVp- kilo voltage peak

LDR- low dose rate

(I)MAT- Intensity modulated arc therapy

mg- milligram

MIRD- medical internal radiation dose committee

MLC- multi-leaf collimator

MOSFET- metal oxide semi-conductor field effect transistor

MRI- magnetic resonance imaging

MU- monitor unit

MV- megavoltage

MVCT- megavoltage computed tomography

NRC- Nuclear Regulatory Commission

NCRP- National Council on Radiation Protection and Measurements

NTCP- normal tissue complication probability

NIST- national institute of standards and technology

NaI- sodium iodide

PACS- picture archiving and communication system

PDD- percent depth dose

PET- positron emission tomography

PRV- planning organ at risk volume

PTV- planning target volume

QA- quality assurance

RBE- relative biologic effectiveness

SAD- source-to-axis distance

SMLC- segmental multi-leaf collimation

SPECT- single photon emission computed tomography

SRS- stereotactic radiosurgury

SRT- stereotactic radiotherapy

SSD- source-to-skin (or source-to-surface) distance

SUV- standardized uptake value

TBI- total body irradiation

TCP- tumor control probability

TE- time to echo (MRI)

TG #- task group report number # (AAPM)

TLD- thermoluminescent dosimetry

TMR- tissue maximum ration

TP- treatment planning (system)

TR- time of repetition (MRI)

TSET- total skin electron therapy

T1- longitudinal relaxation time (MRI)

T2- transverse relaxation time (MRI)

1D- one-dimensional

2D- two-dimensional

3DCRT- three-dimensional conformal radiotherapy

4D- four-dimensional