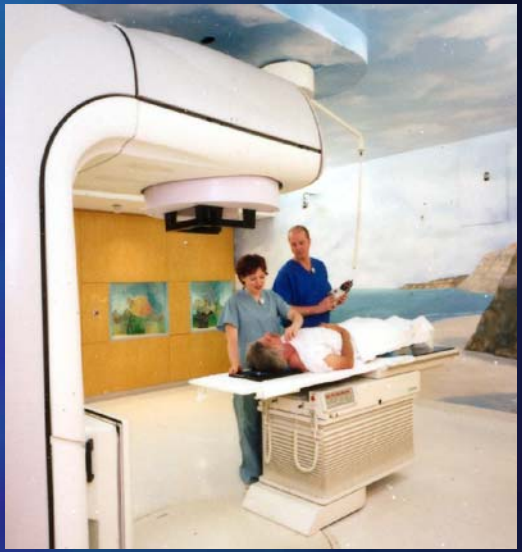
An Overview of Radiotherapy for Healthcare Professionals

The American Society for Therapeutic Radiology and Oncology

Introduction

- Radiation has been an effective tool for treating cancer for over 100 years
- More than 60 percent of patients diagnosed with cancer will receive radiation therapy as part of their treatment
  - Today, more than 1 million cancer patients are treated annually with radiation
- Radiation oncologists are cancer specialists who manage cancer patients with radiation for either cure or palliation



Patient being treated with modern radiation therapy equipment.

Overview

- What is the physical and biological basis for radiation?
- What are the clinical applications of radiation in the management of cancer?
- What types of radiation are available?
- What is the process for treatment?
  - Simulation
  - Treatment planning
  - Delivery of radiation
- Summary

A Brief History of Radiation

- Wilhelm Roentgen discovered *X-rays* on November 8, 1895, while experimenting with a gas-filled cathode tube
  - He noted an image of the bones of his hand projected on a screen when placed between the tube and the fluorescent screen
  - He wrote a carefully reasoned explanation of the phenomenon within two months

Early radiograph taken by Roentgen, January, 1896.

A Brief History of Radiation, Pt II

- In 1896, Henri Becquerel discovered *radioactivity* while experimenting with pitchblende (i.e., uranium salts) and a shrouded photographic plate
- Pierre and Marie Curie announced the discovery of radium and polonium in 1898
- These elements emitted α, β and γ *rays*

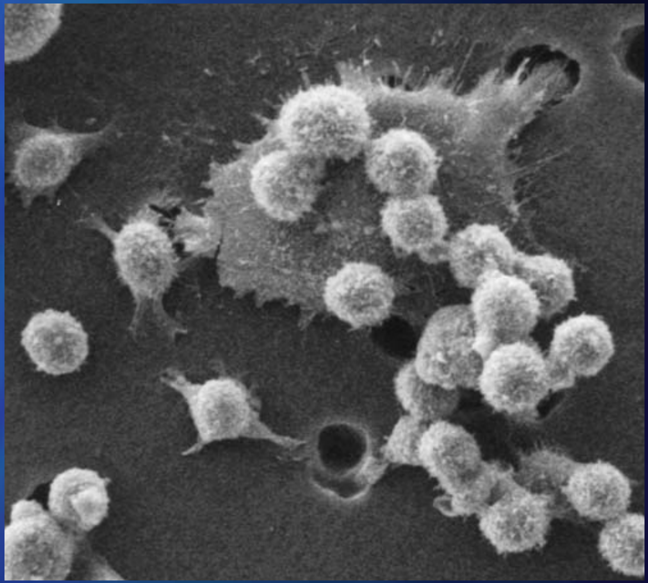
Image of Becquerel's photographic plate fogged by exposure to radiation from uranium salts.

X-rays and Gamma Radiation

- Both are forms of *ionizing* radiation
- X-rays and γ-rays are collectively referred to as *photons* and are considered a form of *electromagnetic radiation*
  - Energy is produced when an accelerated electron strikes a target, decelerates and emits X-rays
  - Gamma-radiation occurs when an unstable nucleus gives off excess energy in the form of γ-rays as it decays to a more stable form

Radiotherapy at the Cellular Level

- Radiation used for cancer treatment is called *ionizing radiation* because it forms ions as it passes through tissues and dislodges electrons from atoms
  - Ions are atoms that have acquired an electrical charge through the gain or loss of an electron
    - Ionization, in turn, can cause cell death or a genetic change
- Molecular damage may occur through *direct* or *indirect ionization*
  - DNA is the most important target molecule
  - Water is the primary mediator of indirect ionization by formation of free radicals



An image of cancer cells.

Effects of Ionizing Radiation

- Ionization within cells results in physical, chemical and biological changes
  - Indirect Effect:
    - Damage to DNA molecule by formation of free radicals
      - Complex chain of chemical reactions in the cell resulting in toxic changes which adversely affect the cell
  - Direct Effect:
    - Damage to DNA molecule
      - Breakage of one or both chains of DNA molecule
      - Breakage of hydrogen bond
      - Faulty cross-linkage
- The net result on cancer cells is an inability to grow and subsequently reproduce

What Is the Biologic Basis for Radiation Therapy?

- Radiation therapy works by damaging the DNA within cancer cells and destroying their ability to reproduce
  - When the damaged cancer cells are killed by radiation, the body naturally eliminates them
  - Normal cells can be affected by radiation, but they are able to repair themselves
    - All tissues have a tolerance level, or maximum dose, beyond which irreparable damage may occur
- Although some cancers may be treated with radiation alone, it is often combined with other treatments, such as surgery and/or chemotherapy

Modern treatment planning helps spare more healthy tissue from radiation.

A Basic Radiobiologic Principle

- *Fractionation*, or dividing the total dose into small daily fractions over several weeks, produces better tumor control than a single large fraction
  - Experiments performed in Paris in the 1920s and 1930s confirmed this principle
- Fractionation spares normal tissue through *repair* and *repopulation* while increasing damage to tumor cells through *redistribution* and *reoxygenation*

The Four R's of Radiobiology

- The modern basis for fractionation is better understood and more complex
  - **Repair** of sublethal damage to cells between fractions caused by radiation
  - **Repopulation** or regrowth of cells between fractions
  - **Redistribution** of cells into radiosensitive phases of cell cycle
  - **Reoxygenation** of hypoxic cells to make them more sensitive to radiation

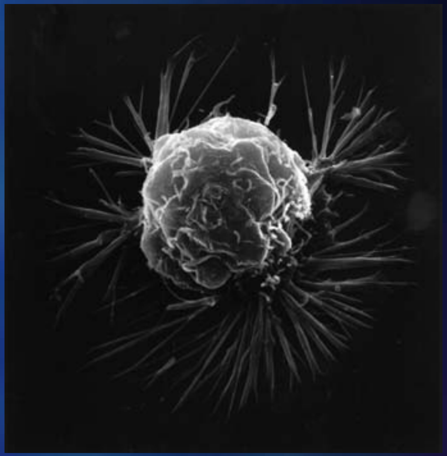
Clinical Uses for Radiation Therapy

Painless external beam radiation treatments are usually scheduled five days a week and continue for one to ten weeks.

- Therapeutic radiation serves two major functions
  - To cure cancer
    - Destroy tumors that have not spread.
    - Reduce the risk that cancer will return after surgery or chemotherapy
  - To reduce or palliate symptoms
    - Shrink tumors affecting quality of life, e.g., a lung tumor causing shortness of breath
    - Alleviate pain by reducing the size of a tumor

Radiation Therapy for Cancer

- Radiation therapy plays a major role in the management of many common cancers
  - Breast, prostate, lung, colorectal, pancreas, esophagus, head and neck, brain, skin, gynecologic, lymphomas, bladder cancers and sarcomas
    - The four most commonly treated malignancies are lung, breast, prostate and colorectal cancers
      - Radiotherapy is often used in the multimodality management of pediatric malignancies
    - Treatment may be for cure or for palliation
  - There is a small risk that radiation may cause a secondary cancer many years after treatment
    - This risk is balanced by the potential for curative treatment with radiotherapy



A breast cancer cell.

Measuring Radiation Doses

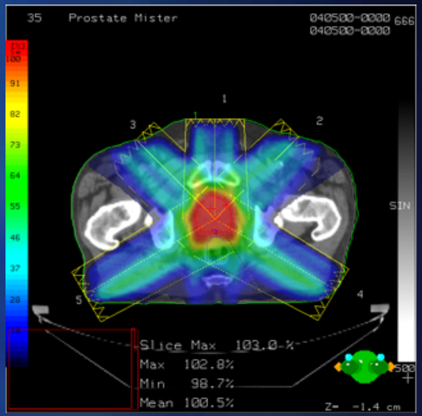
- Absorbed dose is the quantity of radiation absorbed from a beam per unit mass of absorbing material
  - The *rad*, or "radiation absorbed dose," is the traditional basic unit, and is defined as 100 ergs absorbed/gm
  - The modern unit is the *Gray* (Gy), and is defined as 1 joule absorbed/kg
    - Dose may be prescribed as Gy or cGy
      - 1 Gy = 100 cGy (centigray)
      - 1 cGy = 1 rad

The Radiation Oncology Team

- Radiation Oncologist
  - The doctor who prescribes and oversees the radiation therapy treatments
- Medical Radiation Physicist
  - Ensures that treatment plans are properly tailored for each patient, and is responsible for the calibration and accuracy of treatment equipment
- Dosimetrist
  - Works with the radiation oncologist and medical physicist to calculate the proper dose of radiation given to the tumor
- Radiation Therapist
  - Administers the daily radiation under the doctor’s prescription and supervision
- Radiation Oncology Nurse
  - Interacts with the patient and family at the time of consultation, throughout the treatment process and during follow-up care

Process of Care: Initial Steps

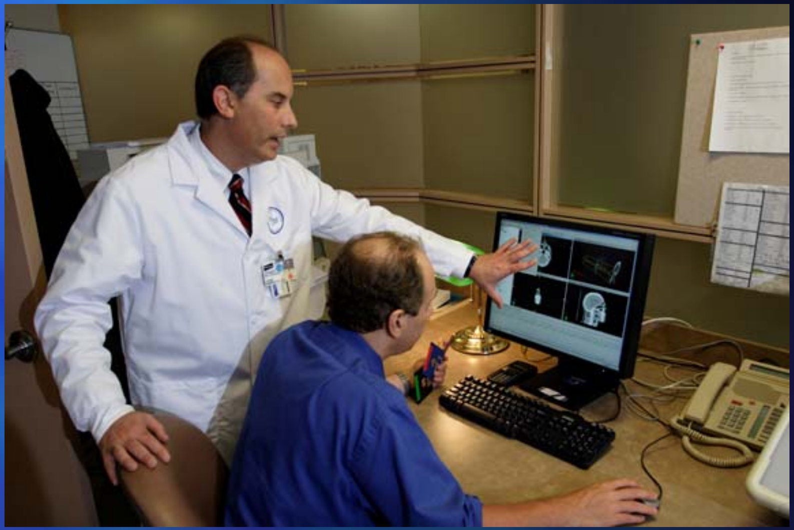
- Patients are referred for consultation
  - This is usually done after a tissue diagnosis has been established
    - Treatment plan is recommended by the radiation oncologist
      - Care is coordinated with other physicians
- Simulation is carried out
  - Provides a blueprint for treatment
    - Usually done as a treatment planning CT scan
      - Patient set up in the treatment position
      - Immobilization may be used to ensure daily reproducibility



Dose distribution for a man with prostate cancer.

Process of Care: Treatment Planning

- Sophisticated software is used to carefully derive an appropriate treatment plan for each patient
  - Computerized algorithms enable the treatment plan to spare as much healthy tissue as possible
  - Physicist and dosimetrist work together create the optimal treatment plan for each individual patient



Radiation oncologists work with medical physicists and dosimetrists to plan treatment to deliver a maximum dose of radiation to the tumor and avoid healthy tissue.

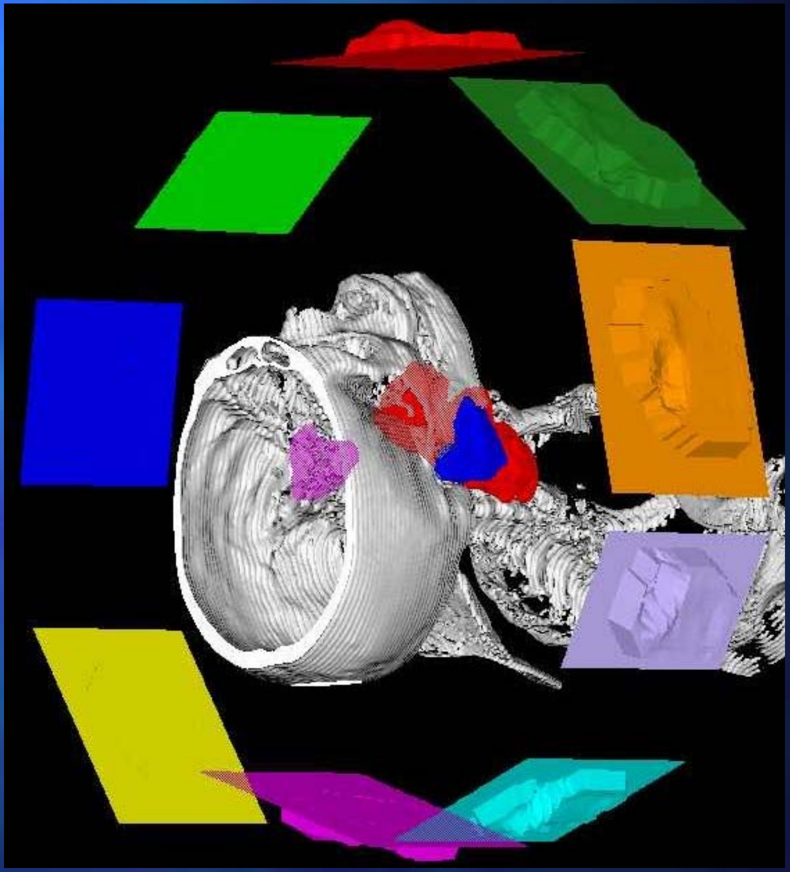
Process of Care: Delivery of Radiation Therapy

The type of treatment used will depend on the location, size and type of cancer.

- Radiation therapy can be delivered two ways
  - *External beam* radiation therapy typically delivers radiation using a linear accelerator
  - Internal radiation therapy, called *brachytherapy*, involves placing radioactive sources into or near the tumor

Types of External Beam Radiation Therapy

- Three-dimensional conformal radiation therapy (3D-CRT)
  - Uses CT or MRI scans, creating a 3-D picture of the tumor
    - Improved precision minimizes normal tissue damage
- Intensity modulated radiation therapy (IMRT)
  - A sophisticated form of 3D-CRT
  - Radiation is broken into many “beamlets,” the intensity of each can be adjusted individually
    - IMRT is the most important advance in radiotherapy in more than 40 years



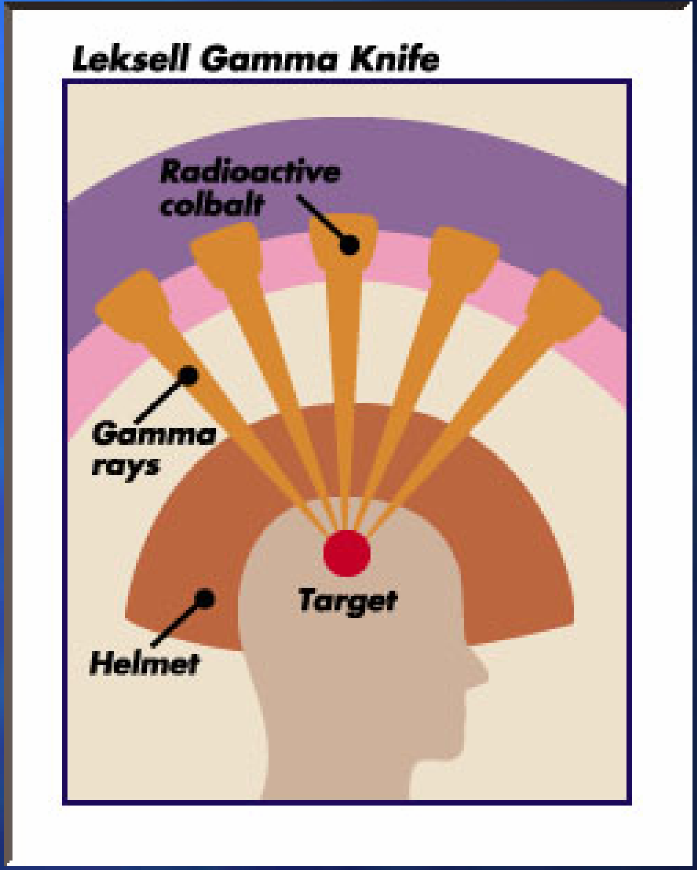
Nine-field IMRT head and neck 3-D schematic.

Image-Guided Radiation Therapy

- Specially designed linear accelerators for IGRT
  - Capable of performing CT scans or standard X-ray images
    - Implanted *fiducial* markers are aligned daily
      - Ensures daily reproducibility to accurately treat the target
      - Should further decrease treatment-related morbidity

Stereotactic Radiotherapy

- External fiducials allow the radiation oncologist to focus very thin beams of radiation at small tumors
  - When used in a single treatment for tumors in the head, it is called *stereotactic radiosurgery (SRS)*
  - When used in multiple treatments or for other parts of the body, it's called *stereotactic body radiation therapy (SBRT)*



Stereotactic Body Radiotherapy

- Another format for IGRT
  - Similar to stereotactic radiosurgery (SRS)
  - High doses of radiation are delivered using tiny fields over three to five days
    - Usually extracranial sites
      - Although *fractionated* intracranial SRS would qualify as SBRT
      - Spine, liver metastases, adrenal metastases, lung metastases and pancreas are all potential sites
        - Prostate cancer, primary lung cancer and hepatocellular carcinomas being investigated
      - Respiratory gating used for lung and abdominal tumors
        - Allows radiation to be delivered only during specific periods in the breathing cycle

Particle Therapy

- Proton Beam Therapy
  - Uses protons rather than X-rays to treat cancer
  - Allows doctors to focus most of the radiation dose at a certain depth within the body, which better spares nearby normal tissue
- Neutron Beam Therapy
  - A specialized form of radiation therapy used to treat certain tumors that are very difficult to manage using conventional radiation therapy
  - Neutrons have a greater biologic impact on the tumor than a similar dose of conventional radiation therapy
- These treatments are only available in a few locations in the U.S.

Internal Radiation Therapy

- Radioactive sources are implanted into the tumor or surrounding tissue
  - Commonly called *brachytherapy*
    - “Brachy” is Greek for “short distance”
  - Purpose is to deliver high doses of radiation to the desired target while minimizing the dose to surrounding normal tissues
    - Radioactive sources used are thin wires, ribbons, capsules or seeds.
      - Isotopes used include ^{125}I, ^{103}Pd, ^{192}Ir, ^{137}Cs
    - These can be either permanently or temporarily placed in the body
  - Brachytherapy itself is not painful, but the applicators may cause discomfort

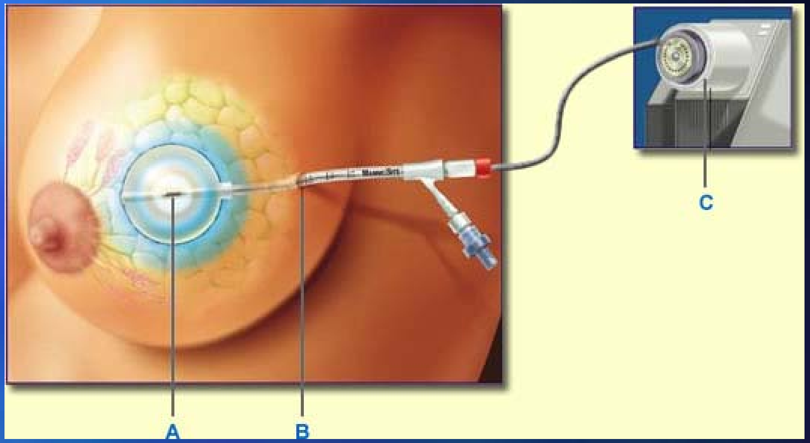
Radioactive seeds for a permanent prostate implant, an example of low-dose-rate brachytherapy.

Types of Brachytherapy

- Intracavity implants
  - Radioactive sources are placed near the tumor (cervix, trachea)
- Interstitial implants
  - Sources placed directly into the tissue (prostate, vagina)
- Intra-operative implants
  - Surface applicator is in direct contact with the surgical tumor bed (soft tissue sarcoma)
    - Procedures often require anesthesia and brief hospitalization
    - Radiation delivered to the site through specially designed applicators or catheters

Dose Rate for Brachytherapy

- Low-Dose-Rate (LDR)
  - Radiation delivered over the course of 48 to 120 hours
    - Gynecologic, breast, head and neck, and prostate cancers may be treated with low-dose-rate brachytherapy
- High-Dose-Rate (HDR)
  - High energy source delivers the dose in a matter of minutes rather than days
    - Gynecologic, breast and some prostate implants may use use high-dose-rate brachytherapy



HDR brachytherapy for breast cancer using MammoSite catheter (B) with an Iridium-192 source (A) and a high-dose-rate afterloader (C). This is an example of a temporary high-dose-rate implant.

Brachytherapy Implant Duration

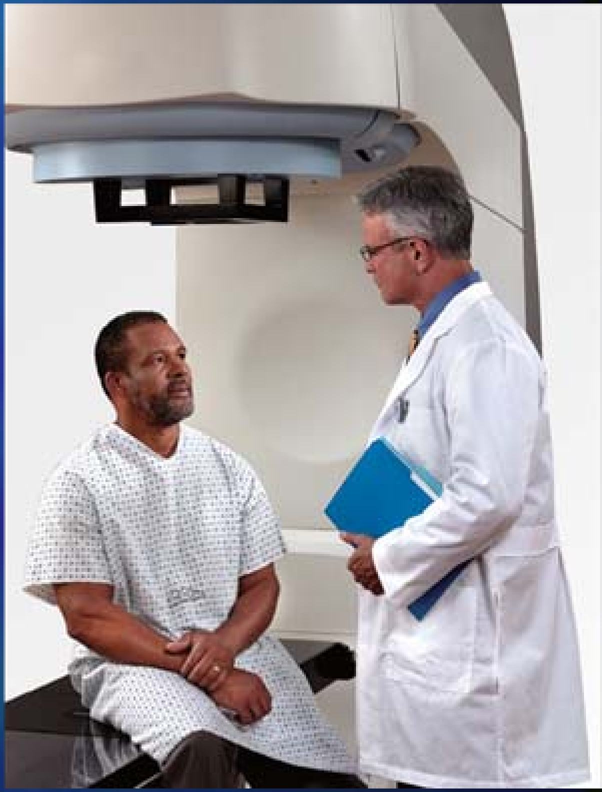
- Implants may be either permanent or temporary
  - Temporary implants are left in the body for several hours to several days
    - Patient may require hospitalization during the implant depending on the treatment site (e.g., cervix)
    - Examples include low-dose-rate gyn implants and high-dose rate prostate or breast implants
  - Permanent implants release small amounts of radiation over a period of several months
    - Patients receiving permanent implants may be minimally radioactive and should avoid close contact with children or pregnant women
      - They will receive very specific instructions on safety from their patient care team
    - Examples include low-dose rate prostate implants ("seeds")

Systemic Radiation Therapy

- Radiation can also be delivered by an injection.
  - Radioactive particles can be dissolved in a small amount of fluid and injected into a blood vessel
    - Metastron (^{89}Strontium) and Quadramet (^{153}Samarium) are radioactive isotopes used for treating bone metastases
    - The radioactive isotope is absorbed primarily in cancer cells
- Radioactive isotopes may also be attached to an antibody targeted at tumor cells
  - This approach is useful in the treatment of certain lymphomas
    - Examples include Bexxar and Zevalin

Palliative Radiotherapy

- Many cancer patients receive radiotherapy for symptom relief
- Commonly used to relieve pain from bone cancers
  - About 50 percent of patients receive total relief from their pain
  - 80 to 90 percent of patients will derive some relief
- Other palliative uses:
  - Spinal cord compression
  - Vascular compression, e.g., superior vena cava syndrome
  - Bronchial obstruction
  - Bleeding from gastrointestinal or gynecologic tumors
  - Esophageal obstruction



Radiation can provide relief for pain.

Common Radiation Side Effects

Unlike the systemic side effects from chemotherapy, radiation therapy usually only impacts the area that received radiation.

- Side effects are limited to the area treated and usually resolve 2-6 weeks post radiation
  - Breast – swelling, skin irritation
  - Abdomen – nausea, vomiting, diarrhea
  - Chest – cough, shortness of breath
  - Head and neck – taste alterations, dry mouth, mucositis, skin irritation
  - Brain – hair loss, scalp irritation
  - Pelvis – diarrhea, cramping, urinary frequency, vaginal irritation
  - Fatigue is often seen when large areas are irradiated
    - Breast, abdomen, pelvis, whole brain

Fast Facts About Radiation Therapy and Cancer

- Nearly two-thirds of all cancer patients will receive radiation therapy during their illness.
- In 2005, over 1 million patients were treated with radiation.
- In 2005, patients made nearly 24 million treatment visits to more than 2,000 hospitals and freestanding radiation therapy centers.
- Three cancers – breast, prostate and lung cancer – make up nearly 60% of all patients receiving radiotherapy.
- The average radiation oncologist sees between 200 and 300 patients annually.

Summary

- Radiotherapy is a well established modality for the treatment of numerous malignancies
  - Most common: breast, lung, prostate, colorectal
- Treatment is safe, quick and painless with tolerable short term side effects
  - Morbidity localized to area irradiated
- Radiation oncologists are specialists trained to treat cancer with a variety of forms of radiation
  - External beam, brachytherapy, stereotactic

For More Information...

- The American Society for Therapeutic Radiology and Oncology (ASTRO) can provide information on radiation therapy.
- Visit www.rtanswers.org to view information on how radiation therapy works to treat various cancers.