Outline and Objectives

• Introduce the concept and motivation for radiation therapy
• Describe the two main classes of treatment
• Describe the most common equipment
• Look at the physics of the radiation beams
• Walk through the stages of radiation therapy
• Give an additional example illustrating the need for physics

Cancer

• In 2006 in Canada there will be
  • an estimated 153,100 new cases of cancer
  • 70,400 cancer deaths
• More than 1 in 3 people in Canada will develop a cancer at some time in their lifetime (38% of women, 43% of men)
• About one half of these people will undergo radiation therapy at some time in their course of treatment

Indications for Radiation Therapy

• RT may be used with both curative and palliative intent.
• A major advantage in curative treatment for cancers is that RT often allows control of cancer with preservation of organ function.
  • Larynx RT allows preservation of the voice, not achieved with Laryngectomy.

Indications for Radiation Therapy

• also useful in situations where the anatomical extent of a cancer precludes surgery,
  • e.g., in nasopharyngeal cancers or advanced cervical cancers.
• In addition, it may be used in the situation where surgery is impossible because of the patient’s general condition.
  • e.g., as curative therapy for early lung cancers if the patient cannot withstand thoracotomy.

Who Uses Medical Radiation?

• ~ 250 Nuclear medicine departments and clinics
• ~ 40 cancer clinics
• ~ Tens of thousands of X-ray users
Radiation Therapy

**DEFINITION**

Radiation therapy is the use of ionizing radiation in the treatment of patients with disease.

Mechanism of Radiation Therapy

e.g. x-rays:

- photons produced interact in tissue and produce secondary electrons and free radicals.
- If interactions in right location these products can cause damage to cellular DNA,
- results in the loss of reproductive integrity, cells die when they go to reproduce
- THIS IS A SIMPLE VIEW: repair etc. make picture more complicated

MACROSCOPIC VIEW

- X-ray BEAM
- Interaction site (some unlucky atom)
- Photoelectron path
- Of destruction

SUB-CELLULAR VIEW
DNA DAMAGE

- photon
- Interaction site
- IONIZATION
- Uncoiled DNA
- "Double Strand Break" often leads to permanent damage

Mechanism of Radiation Therapy

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Radiation Therapy

- ∴ it is a myth that radiation therapy works by burning cells, works by rendering cells incapable of dividing.
- As the damage inflicted by radiation is not apparent until a cell attempts to reproduce, the effects of radiation on a tumour are rarely immediate.
- May take a prolonged period of time for a tumour to regress following radiation therapy.

Dose response for Radiation Therapy

- The probability of tumour response is a complicated function of dose.
- Given by Sigmoid curve
- Details depend on specific cancer

The Problem

- There is always a tradeoff between killing tumour and sparing normal tissue.
- Have to limit doses to normal tissues.
- 10% errors are clinically detectible.
- 5% margin of error

Radiation Therapy Delivery

- Dose delivery usually given in a series of treatments over many weeks. ‘Fractionation’ schedule depends on site. e.g.:
  - Curative Breast 16 fractions to 40 Gy
  - Curative Prostate 35 fractions to 78 Gy
  - Palliative 1-5 fractions to 10-20 Gy

What is Dose?

- Energy per Unit Mass
- 1 Gray = 1 Gy = 1 Joule/kg
- Ultimately the energy ends up as heat
  \[ \Delta T \sim 3 \times 10^{-4} \, ^\circ C \]
Role of Radiation Therapy: Example Cervix Cancer

Survival (%)

- No Treatment
- Early era 1930-40’s
- Modern MV era 1960-1970’s

Sources of Radiation

- Radiation therapy may be given by beams of radiation from outside the patient’s body (teletherapy).
- or by radioactive materials placed within the body (brachytherapy).

Ionizing Radiation for Therapy

- Radium – no longer used
- Co-60 sources for cancer treatment
- Teletherapy with LINACS
- Brachytherapy – wires & seeds
- Effective & efficient
  - ~$3500 per patient,
  - ~7 years of life extension per patient
- Estimated radiation therapy patients per year worldwide: 5.5 million

c/o Bob Irwin CNSC

Teletherapy (Radiation Beams)

Brachytherapy - HDR

10 Ci of $^{192}$Ir
3.5mm x 0.9mm dia.
(25,000 transfers)

Brachytherapy Seeds

$^{125}$I, $t_{1/2} = 60$ days
Teletherapy Units (examples)

- Linear accelerator or linac
- Cobalt-60 unit

At the KRCC, we have a cobalt unit and four linear accelerators. The linacs deliver x-rays maximum energy of 6 or 15 MeV. Three linacs can also deliver electron beams with energies from 6 to 20 MeV.

Linacs

- Our simplest 4MV linac

Electron Stream

Accelerating Structure
Electron Interactions with Matter
Electron Can:
- Generate new electrons (ionization)
- Generate new photons → Creating X-rays
- Deflect or Scatter
- Be absorbed
**X-ray Attenuation**

- Photon beam loses photons as it passes through
  - Attenuation (average # photons lost)

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<th>Energy per Photon</th>
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<tr>
<td>1.5</td>
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Half value layers:
- 1.25
- 3
- 6
- 12
- 24

**Electron penetration**

- Electron beam loses energy continuously
  - Stopping Power (average energy lost)
    - 2 MeV per cm

<table>
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**How does Photon become Dose?**

- Ionization of atoms
- Energy transferred from secondary electrons
- Photons are indirectly ionizing

**Why is there a Buildup Region?**

- Photon to dose is not a localized process
- Scattered photons
- Scattered electrons
- Interaction
**Buildup Region**

- Energy transferred to electrons from photon interactions near the surface will be deposited deeper in.

**Photon Dose Deposition**

Why does photon energy affect dose?

- Different types of interactions
- Probability of interactions depends on energy and material
- Relative probability of interactions in water
- Energy spectrum out of linac
- Lower energy photons absorbed more readily

Why does photon energy affect dose deposition

- Different types of interactions
  - Coherent or Raleigh scattering (<25 keV)
  - Photoelectric effect (dominates below 100 keV)
  - Incoherent or Compton Scattering (>200 keV)
  - Pair production (above 1.02 MeV)
  - Photodistintegration (~ 10 MeV or more)

**Example: two films taken at different energies**

Diagnostic x-rays (kVp)  MV port film

**X-ray attenuation and materials**

CT# is a measure of x-ray attenuation

Water  Lung  Soft Tissue  Bone  Glass  Aluminum  CT Number

0.0  500  1000  1500

0.0  0.5  1.0  1.5  2.0  2.5

Relative Electron Density
**Beam Commissioning**

- Water tank set up for acceptance tests.
- Wellhofer system.
- IC10 field and reference ion chambers.
- No central axis deviation correction.

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**Percent Dept Doses: Radiation penetration**

- Increasing depth

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**Radiation Therapy**

- Cobalt-60
- 6 MV x-rays

**Radiation Therapy**

- e.g., single fields

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**Prostate Treatment**

- e.g., 4 field prostate treatment
- 6 MV x-rays

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**The Solution for Cobalt-60**

- e.g., 16 field prostate treatment
- 6 MV x-rays
4 Essential Stages of Radiotherapy

1. Target Delineation (Imaging) “Find It”
2. Dose Simulation/Planning “Plan It”
3. Treatment Delivery “Treat It”
4. Treatment Verification “Check It”

The National Library of Medicine’s
Visible Human Project (TM)

Human-Computer Interaction Lab
Univ. of Maryland at College Park

Imaging

Treatment Planning: Dose calculation
Point Spread Kernel

Incident photons interact at a point.

Average energy deposition pattern (10^6 interacting photons).

Monte Carlo Simulation

Mackie et al., PMB, 33, 1, (1988).

Convolution/Superposition Algorithm also has 2 Steps

Convolution in Homogeneous Absorber

\[ D(r) = \int_{V} T(r') \cdot A(r - r') \, d^3r' \]

\[ T = T_0 \exp (-\mu(pixelpath \times pixel u)) \]

Inhomogeneities affect TERMA and Kernels

Superposition Results: Lung Slab Phantom

Radiation Delivery

Superposition Results: Lung Slab Phantom

5x5 cm^2

Dose [MeV/g.cm^2]

Depth [cm]

TERMA

Distorted Scatter Kernel

T = T_0 \exp (-\mu(pixelpath \times pixel))

CMS

C/o Jerry Battista LRCC

C/o Jerry Battista LRCC

C/o Jerry Battista LRCC

C/o Jerry Battista LRCC

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C/o Jerry Battista LRCC

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C/o Jerry Battista LRCC
**MLC**

(MultiLeaf Collimator)

**Adjust MLC and add beams**

**Intensity Modulation**

**IMRT**

C/o Jerry Battista LRCC

**Helical Tomotherapy**

- Source on CT-like ring gantry
- Narrow fan beam treats a ‘slice’ at a time

**Cobalt-60 Tomotherapy**

Conformal dose delivery

Integral Dose Instantaneous Fluence

On-line imaging
Are there other reasons one needs Physics?
The Panama Accident:

Conformal Therapy with Blocks

Blocks Incorporated into Treatment Plans

Identification of Problem

Clinical Summary

- 28 patients treated with incorrect doses
  - 12 have since died
  - 5 (+4) attributable to overdose

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- Bob Irwin CNSC
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- John Schreiner, Ph.D, FCCPM, Kingston RCC
**Typical Medical Physics Department**

- **Department Head - Medical Physicist**
- **Medical Physicists - MSc or PhD in Medical Physics**
  - Machine Selection and Commissioning, Quality Assurance, Technique Development
  - Treatment Planning consultation, supervision, Brachytherapy on-site or on-call
  - Check treatment plans generated by dosimetrists
  - LINAC calibration etc (responsible for accuracy of all radiation sources!!!)
  - Radiation Safety (in early design), Research and Development, Teaching, Admin
- **Dosimetrists - usually RT’s with special training in “dosimetry”**
  - Do bulk of computerized radiation treatment planning, sometimes with Physicists help
  - Technique development, Site group, Teaching
- **Linear Accelerator Service Electronics Technicians**
  - Repair and preventative maintenance on all radiation generating machines
- **Physics Assistants**
  - Do bulk of routine Quality Assurance tasks
  - Assist in making specific beam modifiers for patients and in patient dosimetry (TLD’s)
  - QA development and some technique development

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**Rando Studies**

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**Photons to Dose Tracking the Energy**

1. Photon from Machine (Total Energy)
2. Interacts with Atom
3. Scattered Photon (Less Energy)
4. Energetic Electron
5. Interacts with Atom
6. Photon from Machine (Total Energy)
7. Energy (Dose) to Area