ENGG 167

MEDICAL IMAGING

Lecture *21: Friday, Nov. 17*

Radiation Therapy I

References: The Modern Technology of Radiation Oncology, Ed. J. van Dyk, Med. Phys. Publ., 1999. (Chapter 11)
Principles and Practice of Radiation Therapy, Vol 1 Introduction to Radiation Therapy, C. M. Washington, D. T. Leaver, Mosby Year-Book Inc, 1996.

Radiation Therapy – Part I

1) Dose response
2) Cobalt Therapy
3) Linear Accelerators
4) Depth Dose Curves
5) Treatment Planning
6) Model-based treatment planning

Radiation Therapy

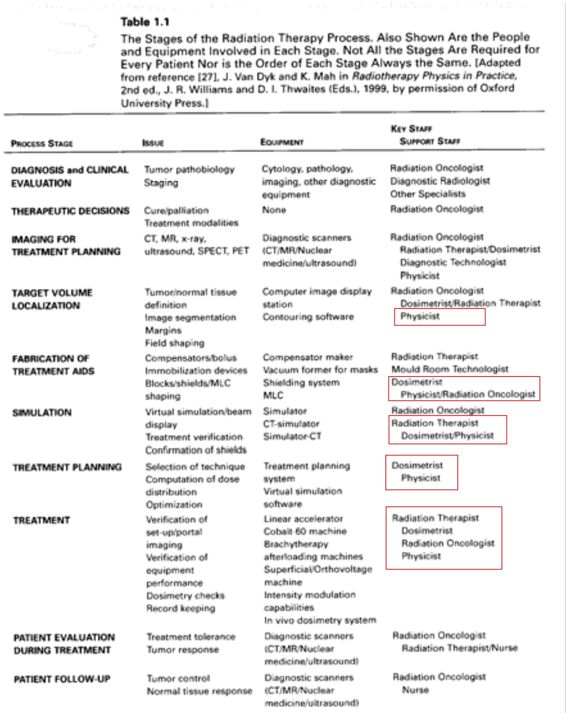


Table 1.1

The Stages of the Radiation Therapy Process. Also Shown Are the People and Equipment Involved in Each Stage. Not All the Stages Are Required for Every Patient Nor is the Order of Each Stage Always the Same. [Adapted from reference [27], J. Van Dyk and K. Mah in *Radiotherapy Physics in Practice*, 2nd ed., J. R. Williams and D. I. Thwaites (Eds.), 1999, by permission of Oxford University Press.]

Process Stage	Issue	Equipment	Key Staff Support Staff
DIAGNOSIS and CLINICAL EVALUATION	Tumor pathobiology Staging	Cytology, pathology, imaging, other diagnostic equipment	Radiation Oncologist Diagnostic Radiologist Other Specialists
THERAPEUTIC DECISIONS	Cure/palliation Treatment modalities	None	Radiation Oncologist
IMAGING FOR TREATMENT PLANNING	CT, MR, x-ray, ultrasound, SPECT, PET	Diagnostic scanners (CT/MR/Nuclear medicine/ultrasound)	Radiation Oncologist Radiation Therapist/Dosimetrist Diagnostic Technologist Physicist
TARGET VOLUME LOCALIZATION	Tumor/normal tissue definition Image segmentation Margins Field shaping	Computer image display station Contouring software	Radiation Oncologist Dosimetrist/Radiation Therapist Physicist
FABRICATION OF TREATMENT AIDS	Compensators/bolus Immobilization devices Blocks/shields/MLC shaping	Compensator maker Vacuum former for masks Shielding system MLC	Radiation Therapist Mould Room Technologist Dosimetrist Physicist/Radiation Oncologist
SIMULATION	Virtual simulation/beam display Treatment verification Confirmation of shields	Simulator CT-simulator Simulator-CT	Radiation Oncologist Radiation Therapist Dosimetrist/Physicist
TREATMENT PLANNING	Selection of technique Computation of dose distribution Optimization	Treatment planning system Virtual simulation software	Dosimetrist Physicist
TREATMENT	Verification of set-up/portal imaging Verification of equipment performance Dosimetry checks Record keeping	Linear accelerator Cobalt-60 machine Brachytherapy afterloading machines Superficial/Orthovoltage machine Intensity modulation capabilities In vivo dosimetry system	Radiation Therapist Dosimetrist Radiation Oncologist Physicist
PATIENT EVALUATION DURING TREATMENT	Treatment tolerance Tumor response	Diagnostic scanners (CT/MR/Nuclear medicine/ultrasound)	Radiation Oncologist Radiation Therapist/Nurse
PATIENT FOLLOW-UP	Tumor control Normal tissue response	Diagnostic scanners (CT/MR/Nuclear medicine/ultrasound)	Radiation Oncologist Nurse

Additional
Physicist functions:

System specification
Treatment room planning
Construction supervision
System purchasing
System installation
System Quality Audit

Ref: Van Dyke

Radiation dose-response curves

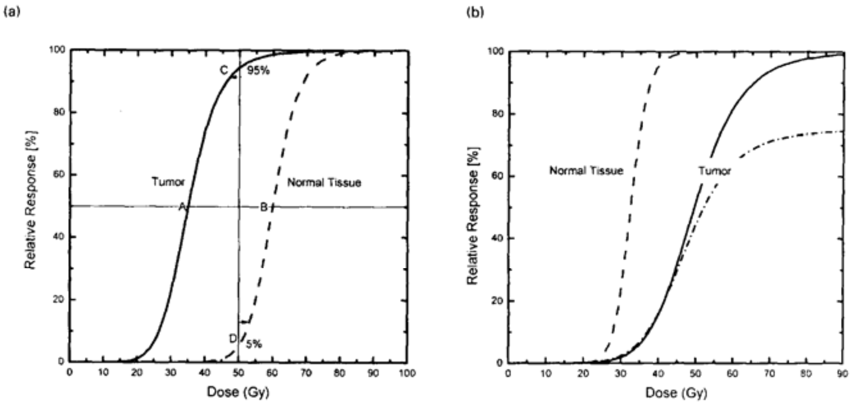


Figure 1.6
Schematic dose-response curves for tumor control and normal tissue response. (a) The classical presentation. (b) A more realistic representation of dose-response curves for both tumors and normal tissues. The small arrows in (a) near the 5% and 95% response levels give an indication of the effect on dose response when there is a 5% deviation from the intended dose.

Ref: Van Dyk

Radiation treatment planning

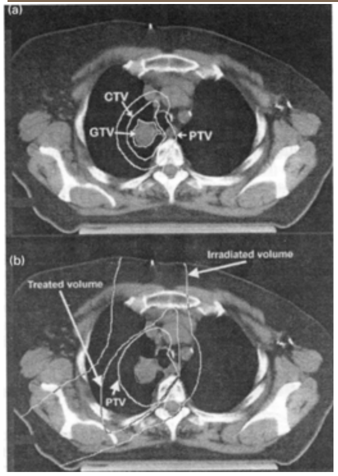


Figure 1.7
(a) A CT image of the mid-thorax showing cancer of the lung. The tumor mass is outlined as the GTV. The CTV and the PTV are also shown. (b) The same CT image as in (a) showing the PTV, the treated volume, and the irradiated volume. A two-field technique was used with anterior and posterior oblique fields of 6 MV x-rays. [Adapted from reference [28], S. Webb, "The Physics of Three-Dimensional Radiation Therapy: Conformal Radiotherapy, Radiosurgery and Treatment Planning," 1993 by permission of IOP Publishing Limited, Bristol, UK.]

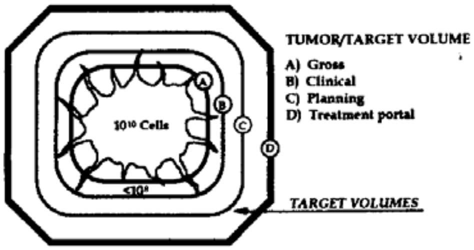


Figure 1.8
Schematic representation of target volumes in radiation therapy. The treatment portal is the actual irradiation field and includes the tumor volume (GTV), potential areas of local and microscopic spread (CTV), a margin to allow for uncertainty in patient setup and organ motion (PTV), and finally a margin to allow for the variation in dose falloff between the high-dose region and the actual beam edge. [Reprinted from reference [20], "Overview" by C. A. Perez, L. W. Brady, and J. L. Roti, in *Principles and Practice of Radiation Oncology*, C. A. Perez, L. W. Brady (Eds.), 1998, pp. 1–78, by permission of Lippincott-Raven, Philadelphia, PA.]

Ref: Van Dyk

Orthovoltage X-ray therapy device – Pantak 300 (300 kVp)

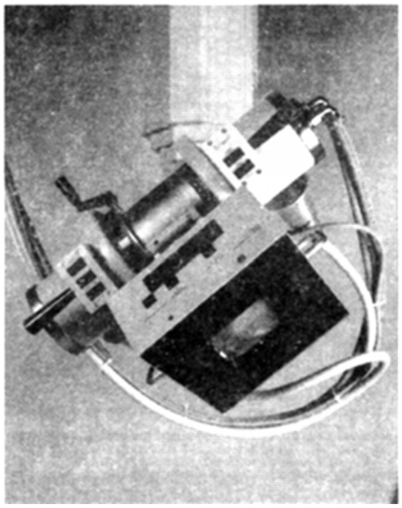
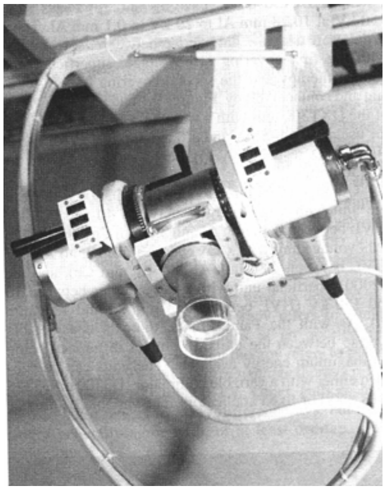
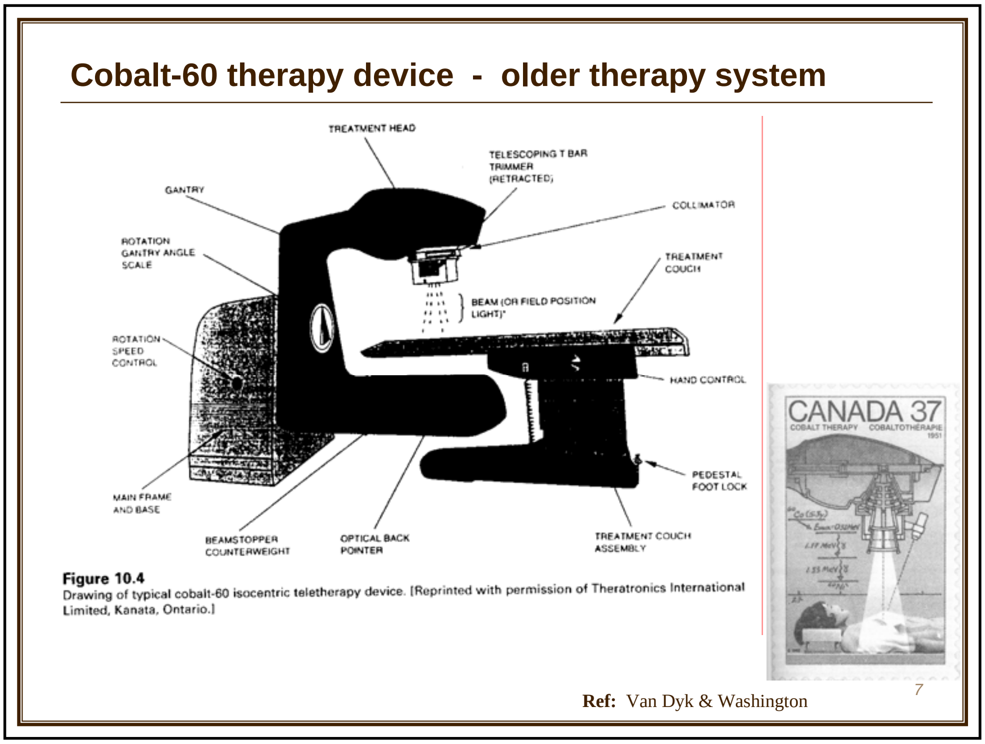


Figure 9.1
View of the Pantak DXT300 orthovoltage x-ray unit with a variable collimator attached for use at 50 cm SSD.



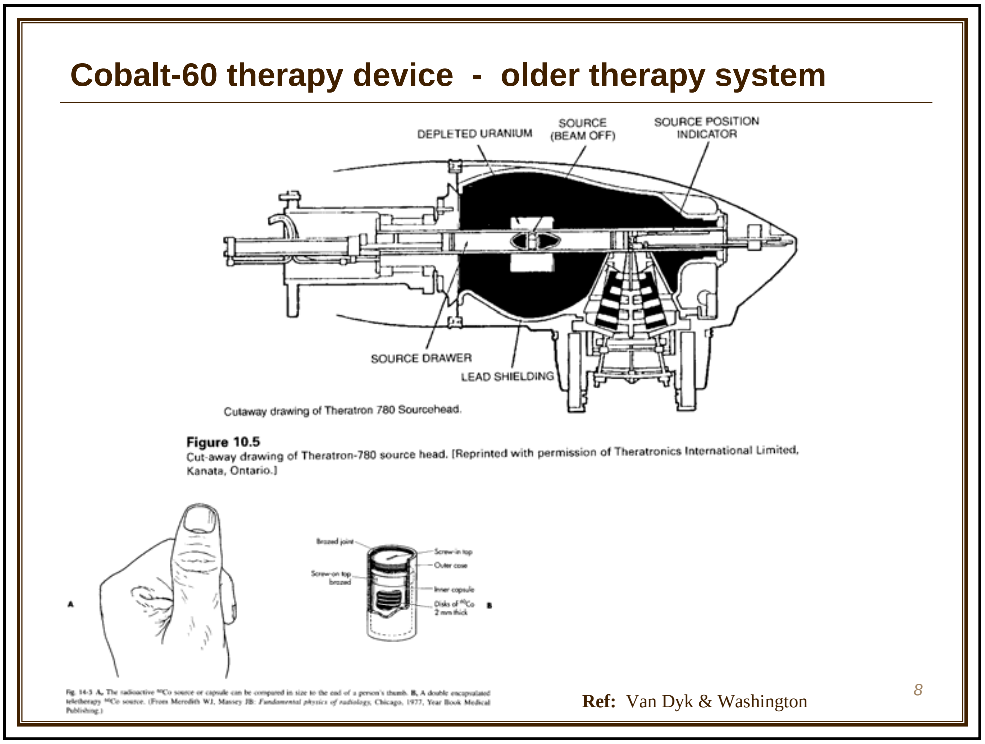
Ref: Van Dyk



Cobalt-60 therapy device - older therapy system

Figure 10.4
Drawing of typical cobalt-60 isocentric teletherapy device. [Reprinted with permission of Theratronics International Limited, Kanata, Ontario.]

Ref: Van Dyk & Washington



Cobalt-60 therapy device - older therapy system

Cutaway drawing of Theratron 780 Sourcehead.

Figure 10.5
Cut-away drawing of Theratron-780 source head. [Reprinted with permission of Theratronics International Limited, Kanata, Ontario.]

Fig. 14-3 **A,** The radioactive ^{60}Co source or capsule can be compared in size to the end of a person's thumb. **B,** A double encapsulated teletherapy ^{60}Co source. (From Meredith WJ, Massey JB: *Fundamental physics of radiology,* Chicago, 1977, Year Book Medical Publishing.)

Ref: Van Dyk & Washington

Linear Accelerator (LINAC)

Ref: Van Dyk

Linear Accelerator (LINAC) schematic

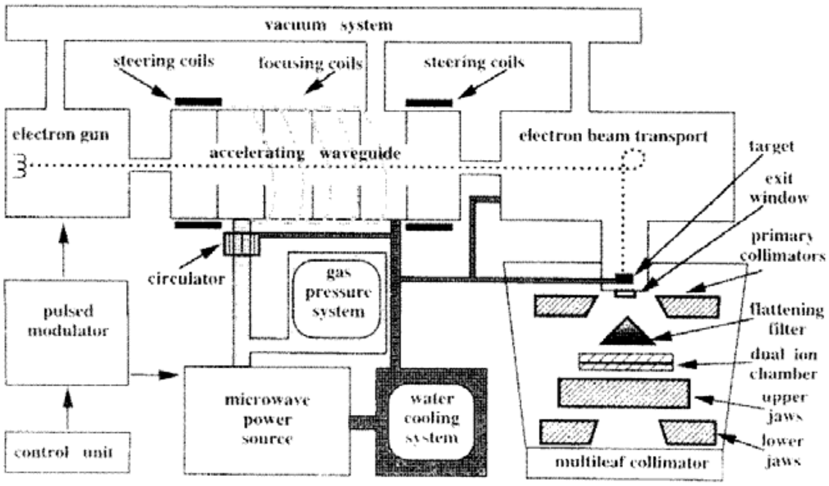


Figure 11.3
Schematic diagram of a typical S-band medical linac.

Ref: Van Dyk

Different LINAC designs

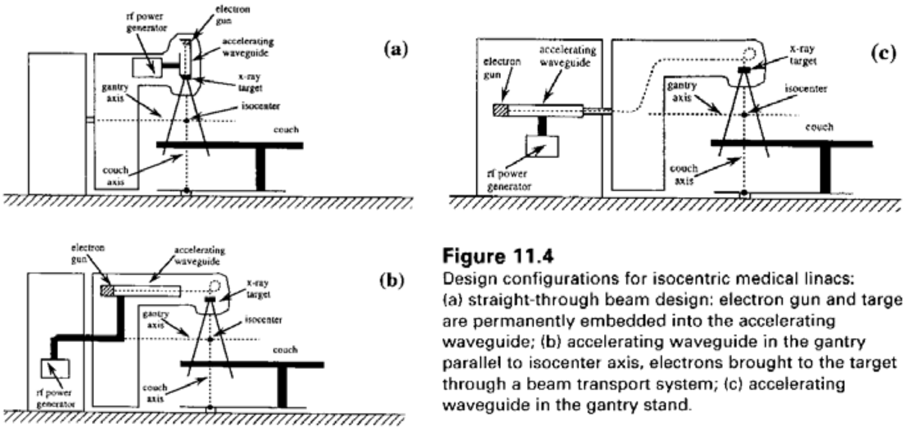


Figure 11.4
Design configurations for isocentric medical linacs: (a) straight-through beam design: electron gun and target are permanently embedded into the accelerating waveguide; (b) accelerating waveguide in the gantry parallel to isocenter axis, electrons brought to the target through a beam transport system; (c) accelerating waveguide in the gantry stand.

Ref: Van Dyk

Electron gun pulses electrons into waveguide

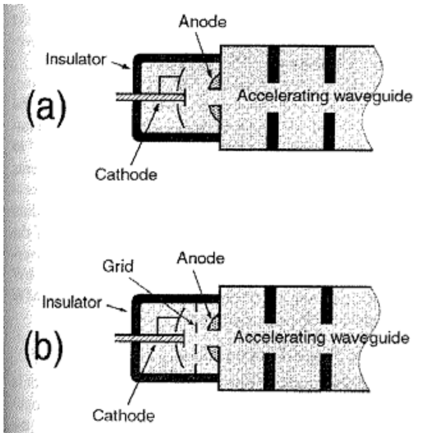


Figure 11.8
Schematic diagrams of two types of electron guns: (a) diode type and (b) triode type. The guns are attached to a travelling wave accelerating waveguide.

Thermionic emission of electrons.

In static emission, typically near –20kV used for acceleration of beam into waveguide.

In pulsed emission, pulses of –150V and +180V oscillate with respect to the cathode.

Ref: Van Dyk

Waveguide accelerator

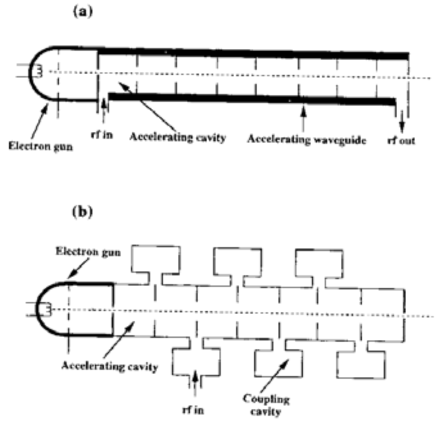


Figure 11.6
Schematic diagrams of (a) travelling wave accelerating waveguide and (b) standing wave accelerating waveguide. A triode-type electron gun is shown on the left, attached to the accelerating waveguides.

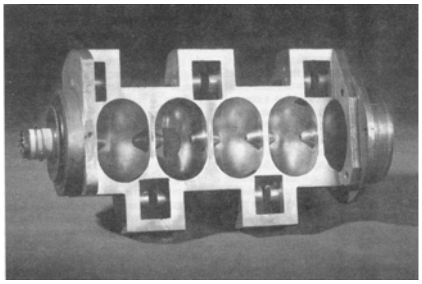


Figure 11.7
A photograph of a 6 MeV standing wave accelerating waveguide with permanently imbedded electron gun on the left and tungsten target on the right.

Ref: Van Dyk

Waveguide accelerator

Evacuated or dielectric filled cylindrical cavities, tuned for a specific frequency. (2.856 GHz)

Must be modified such that phase velocity, $\nu_{ph} < c$, since $\nu_{ph} = \nu_{part}$, particle velocity.

This is accomplished with cylindrical disks placed at quarter wavelength spacings

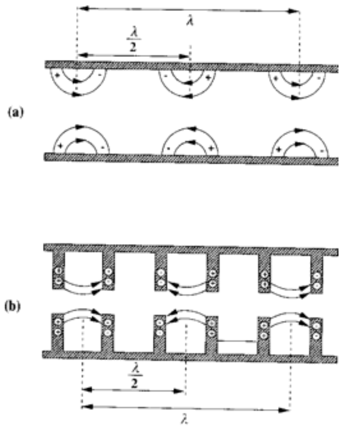
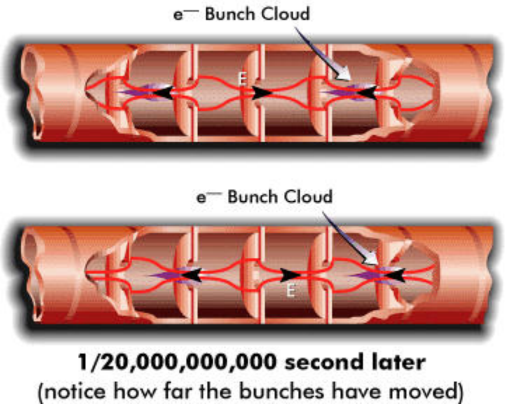


Figure 11.5
Travelling electric field patterns and charge distributions at one instant of time in a plane containing the axis of the cylindrical waveguides: (a) for a uniform waveguide and (b) for a disk-loaded waveguide.

Ref: Van Dyk

Waveguide accelerator

The spacing of the cavities is matched to the wavelength of the microwaves. The spacing allows the electric and magnetic fields to repeat their pattern every three cavities. Electrons or positrons in the beam come through the cavities in small bunches. The arrival of each bunch is timed so that it gets a “push” from the electric field across the cavities.



Ref: http://www.howstuffworks.com

RF generation for electron pulse acceleration – magnetrons and klystrons

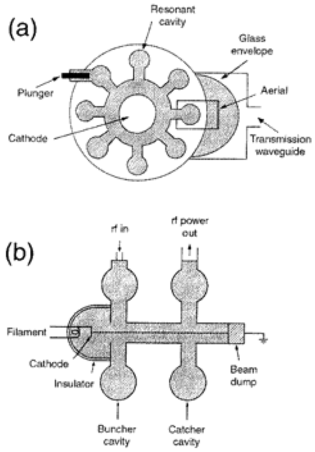


Figure 11.9
Schematic diagrams of radiofrequency power generator: (a) magnetron and (b) klystron.

Magnetron
Resonant cavities deliver energy to electrons as they spiral around a magnetic field. Coupling of electrons to aerial delivers RF power. Typically used for < 6MeV powers.

Klystron
Resonant cavities deliver energy to electrons as they travel from cathode to beam dump. Design of buncher and catcher cavities provides maximal coupling of RF power to and from electron beam. Typically used for > 6 MeV powers.

Ref: Van Dyk

Microwave power transfer to accerator

Typical frequency is 2.856 GHz for medical linacs.

TE_{01} mode waveguides used to transfer RF power

Pressurized with dielectric gas (freon or SF_6) to 2 atm. pressure

Circulator also required, which is a component allowing one way transfer of the RF (composed of a ferrite such as ceramic mixed with iron), making back reflections into klystron impossible.

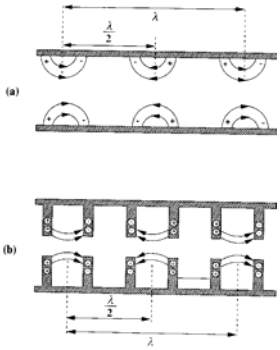


Figure 11.5
Travelling electric field patterns and charge distributions at one instant of time in a plane containing the axis of the cylindrical waveguides: (a) for a uniform waveguide and (b) for a disk-loaded waveguide.

Ref: Van Dyk

Electron beam steering systems

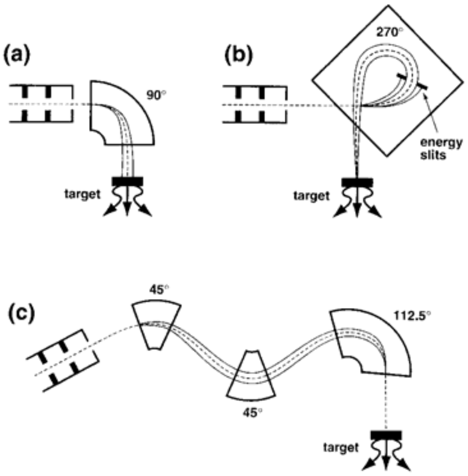


Figure 11.11
Schematic diagram of three systems for electron beam bending: (a) 90° bending; (b) 270° bending; and (c) slalom system incorporating two 45° magnets and a 112.5° magnet.

Ref: Van Dyk

LINAC head components – photon and electron modes

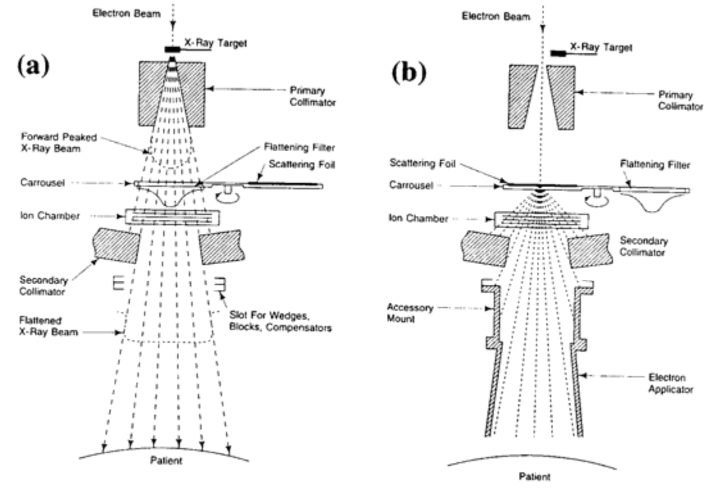


Figure 11.13
Schematic diagrams of main medical linac head components: (a) for the photon mode with target and flattening filter in the beam and (b) for the electron mode with scattering foil in the beam. [Reprinted from reference [51], *Medical Electron Accelerators* by C. J. Karzmark, C. Nunan, and E. Tanabe, copyright 1993, McGraw-Hill. Reproduced with permission from the McGraw-Hill Companies.]

Ref: Van Dyk

LINAC beam parameters which need to be measured

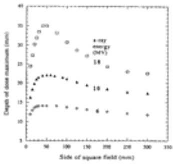


Figure 11.20
Depths of dose maximum d_{max} against field size of 6, 10, and 18 MV photon beams. [Reprinted from reference [96], with permission from AAPM.]

Percentage depth-dose – measured with small ionization chamber translated vertically down along the central line. Max value called d_{max}.

Beam profiles – horizontal measure of dose falloff in penumbral regions between 20% and 80% maximum dose.
Flatness - $F = 100 \times (D_{max}-D_{min})/(D_{max}+D_{min})$ across the region >80%

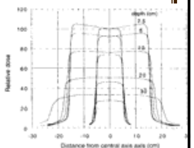


Figure 11.21
An example of beam profiles for two field sizes (10 × 10 and 30 × 30 cm²) and a 10 MV photon beam at various depths in water. The central axis dose levels are scaled b
the two fields.

Dose field factors – correction factor for doses generated from different field sizes. Most machines set for 1 MU = 1 cGy delivered at d_{max} in water on the central axis for 10x10 cm^2 field

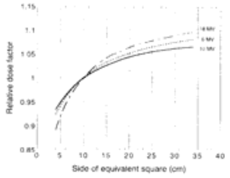
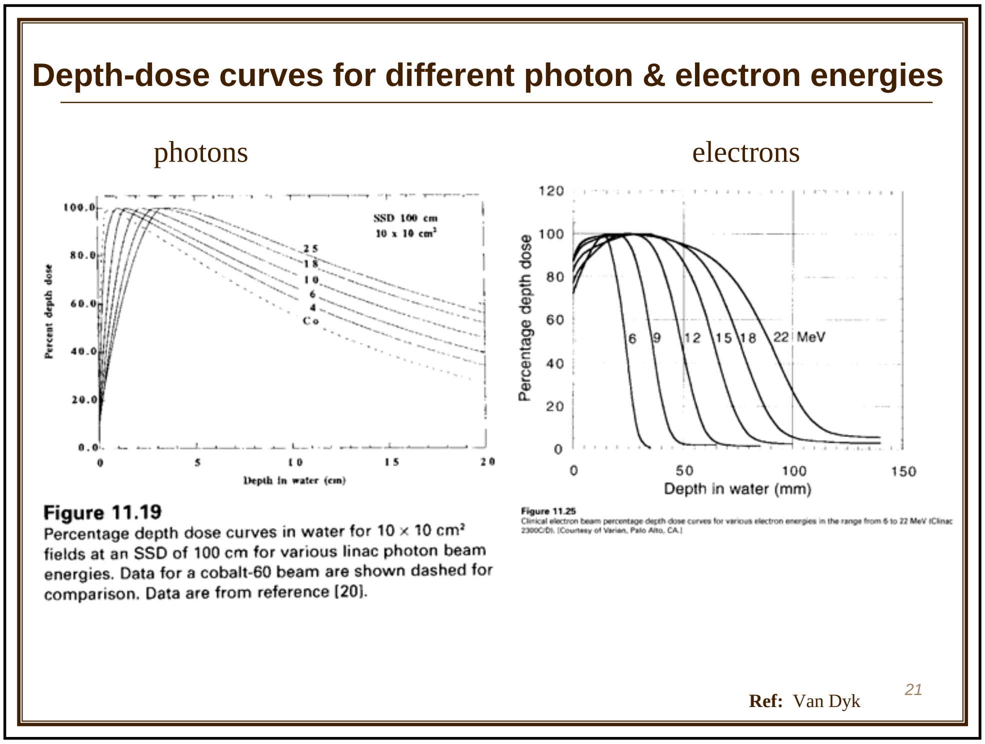


Figure 11.22
Dose field factors (relative dose factors) for three photon beam energies (6, 10, and 18 MV) against field size.

Ref: Van Dyk



Depth-dose curves for different photon & electron energies

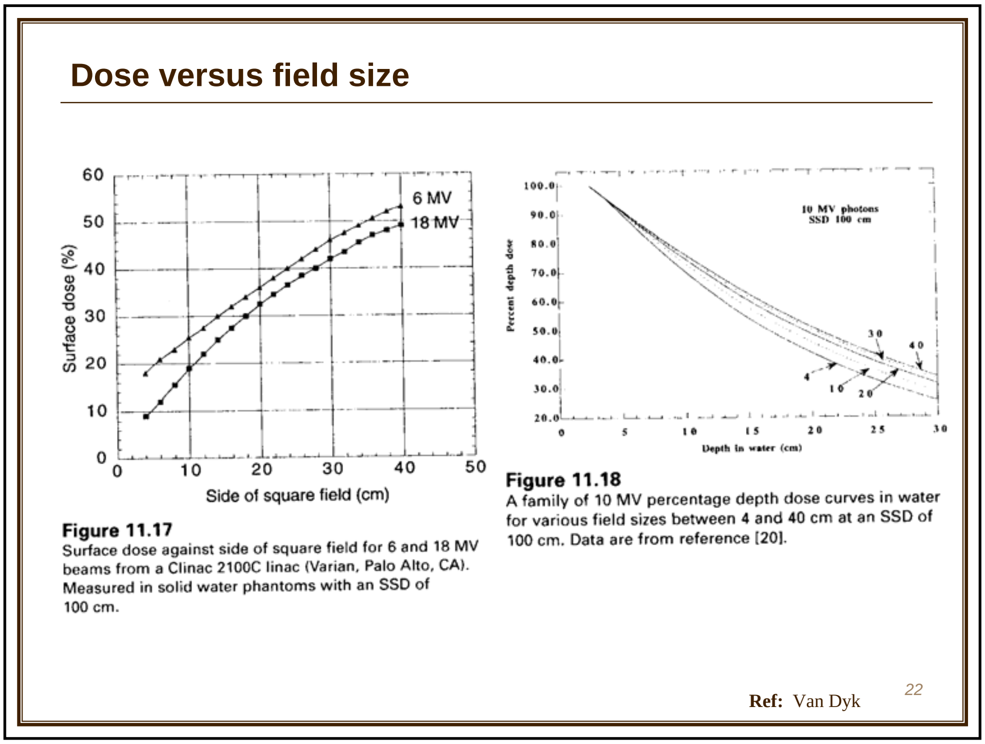
photons

electrons

Figure 11.19
Percentage depth dose curves in water for 10 × 10 cm² fields at an SSD of 100 cm for various linac photon beam energies. Data for a cobalt-60 beam are shown dashed for comparison. Data are from reference [20].

Figure 11.25
Clinical electron beam percentage depth dose curves for various electron energies in the range from 6 to 22 MeV (Clinac 2300C/D). (Courtesy of Varian, Palo Alto, CA.)

Ref: Van Dyk



Dose versus field size

Figure 11.17
Surface dose against side of square field for 6 and 18 MV beams from a Clinac 2100C linac (Varian, Palo Alto, CA). Measured in solid water phantoms with an SSD of 100 cm.

Figure 11.18
A family of 10 MV percentage depth dose curves in water for various field sizes between 4 and 40 cm at an SSD of 100 cm. Data are from reference [20].

Ref: Van Dyk

Iso-dose lines in water and inhomogeneous phantoms

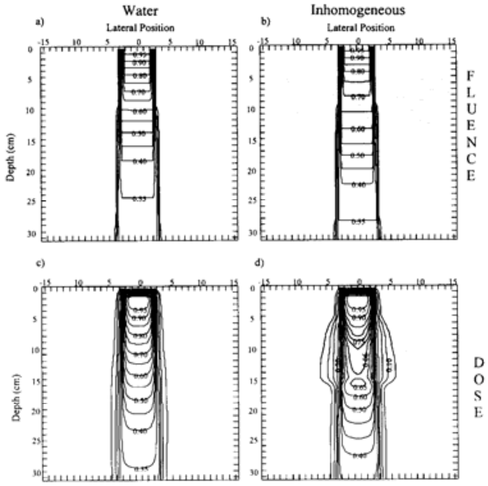


Figure 8.12
FLUENCE and DOSE distributions for a beam of 5.0 MeV photons (5 x 5 cm² field) incident on a water phantom (a & c) and a slab phantom with a cork insert (b & d). FLUENCE distribution in a water phantom (a). FLUENCE distribution in a water-cork-water phantom (b). DOSE distribution in a water phantom (c). DOSE distribution in a water-cork-water phantom (d). Note the dose reduction in the central region of the cork and the penumbral flaring of the beam. [Adapted with permission from reference [8].]

Ref: Van Dyk

Cobalt-60 beam profile vs. 6 MeV beam

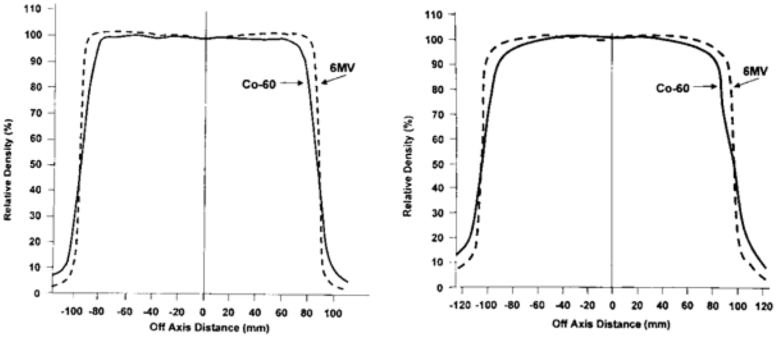


Figure 10.11
Comparative transverse beam profiles for an 18 cm × 18 cm field at 100 cm SSD for a cobalt-60 (T-1000) unit (solid curve) with trimmers at 45 cm and a 6 MV linac (Varian 6/100) (dashed curve) at 1.0 cm depth (left panel) and 10.0 cm depth (right panel).

Ref: Van Dyk

Cobalt-60 beam profile vs 6MeV beam

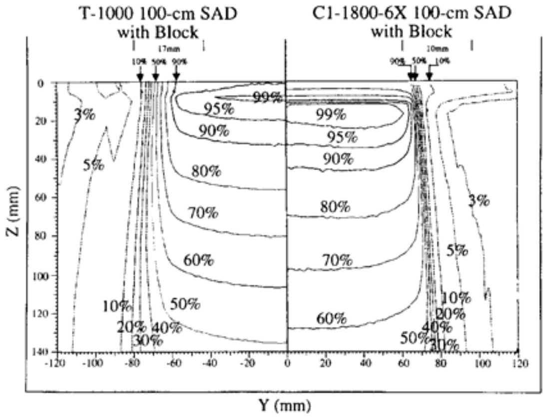


Figure 10.16
Comparisons of a 100 cm SSD 14 cm × 14 cm T-1000 beam to a 6 MV beam.

Ref: Van Dyk

Treatment Planning

- Prediction of dose delivery in heterogeneous patient tissues.
- Each patient requires a separate dose plan.
- Prediction of tissues to hit and tissues to spare
- Model-based simulation based upon CT scan
- Optimization

Ref: Van Dyk

Model-based prediction of dose

Figure 5.13
(a) MRI image showing GTV (white region) with a CTV (white line) and PTV (black line). (b) CT image showing the same CTV and PTV as in (a). Software tools produce automatic margins (uniform or non-uniform) to produce PTVs quickly and accurately. (c) The PTV can be graphically overlaid onto the DRR in the beam's eye view. [Reprinted from reference number [55], "Simulation and Imaging for Radiation Therapy Planning," by J. Van Dyk and K. Mah in *Radiotherapy Physics in Practice*, J. R. Williams and D. I. Thwaites (Eds.), 1993, by permission of Oxford University Press.]

Figure 5.12
Target volume contours showing the use of an automated margin on transverse image for the same patient of Figures 5.6 and 5.8.

Ref: Van Dyk

Treatment planning with CT scans - I

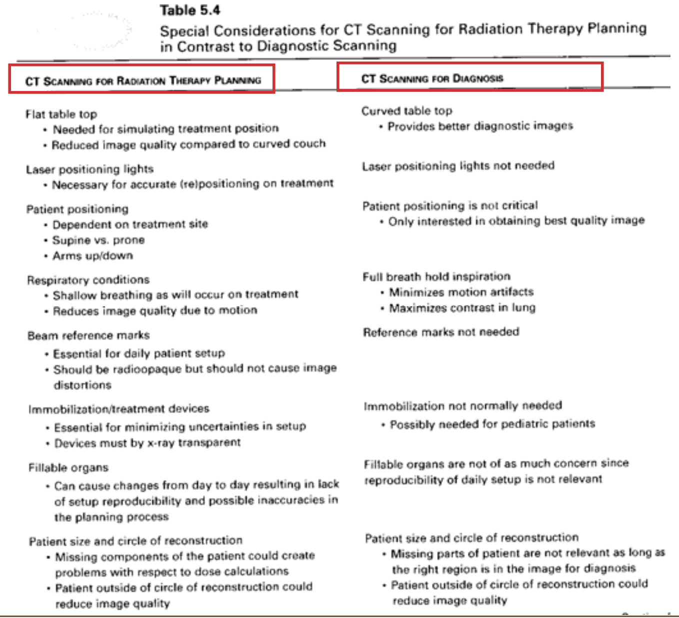


Table 5.4
Special Considerations for CT Scanning for Radiation Therapy Planning in Contrast to Diagnostic Scanning

CT SCANNING FOR RADIATION THERAPY PLANNING	CT SCANNING FOR DIAGNOSIS
Flat table top • Needed for simulating treatment position • Reduced image quality compared to curved couch	Curved table top • Provides better diagnostic images
Laser positioning lights • Necessary for accurate (re)positioning on treatment	Laser positioning lights not needed
Patient positioning • Dependent on treatment site • Supine vs. prone • Arms up/down	Patient positioning is not critical • Only interested in obtaining best quality image
Respiratory conditions • Shallow breathing as will occur on treatment • Reduces image quality due to motion	Full breath hold inspiration • Minimizes motion artifacts • Maximizes contrast in lung
Beam reference marks • Essential for daily patient setup • Should be radioopaque but should not cause image distortions	Reference marks not needed
Immobilization/treatment devices • Essential for minimizing uncertainties in setup • Devices must by x-ray transparent	Immobilization not normally needed • Possibly needed for pediatric patients
Fillable organs • Can cause changes from day to day resulting in lack of setup reproducibility and possible inaccuracies in the planning process	Fillable organs are not of as much concern since reproducibility of daily setup is not relevant
Patient size and circle of reconstruction • Missing components of the patient could create problems with respect to dose calculations • Patient outside of circle of reconstruction could reduce image quality	Patient size and circle of reconstruction • Missing parts of patient are not relevant as long as the right region is in the image for diagnosis • Patient outside of circle of reconstruction could reduce image quality

Ref: Van Dyk

Treatment planning with CT scans - II

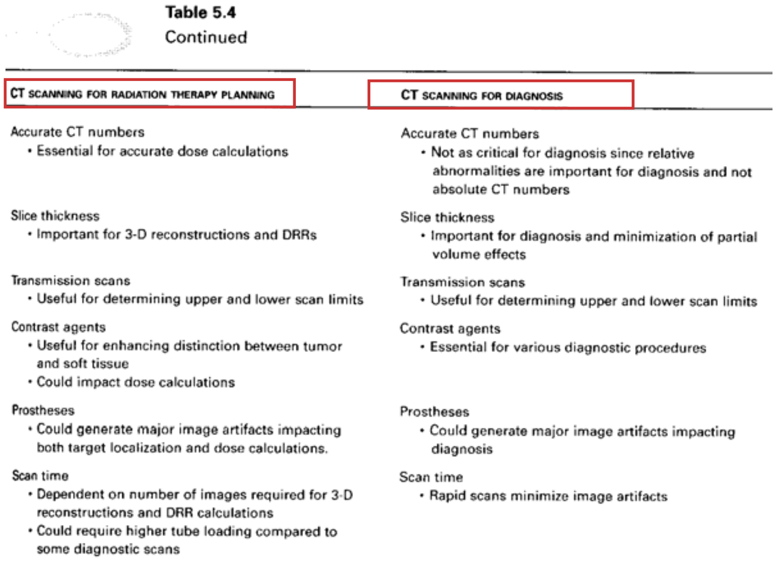


Table 5.4
Continued

CT SCANNING FOR RADIATION THERAPY PLANNING	CT SCANNING FOR DIAGNOSIS
Accurate CT numbers • Essential for accurate dose calculations	Accurate CT numbers • Not as critical for diagnosis since relative abnormalities are important for diagnosis and not absolute CT numbers
Slice thickness • Important for 3-D reconstructions and DRRs	Slice thickness • Important for diagnosis and minimization of partial volume effects
Transmission scans • Useful for determining upper and lower scan limits	Transmission scans • Useful for determining upper and lower scan limits
Contrast agents • Useful for enhancing distinction between tumor and soft tissue • Could impact dose calculations	Contrast agents • Essential for various diagnostic procedures
Prostheses • Could generate major image artifacts impacting both target localization and dose calculations.	Prostheses • Could generate major image artifacts impacting diagnosis
Scan time • Dependent on number of images required for 3-D reconstructions and DRR calculations • Could require higher tube loading compared to some diagnostic scans	Scan time • Rapid scans minimize image artifacts

Ref: Van Dyk

Patient immobilization procedures

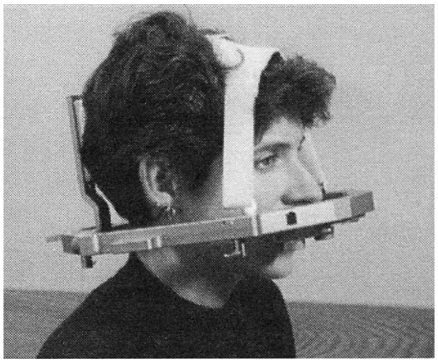


Figure 3.15
The Gill-Thomas-Cosman (GTC) stereotactic frame consists of a dental impression and an occipital plate, formed to the posterior surface of the patient's head, and a strap that forces the impressions against the head. [Courtesy of Radionics, Inc., Burlington, Massachusetts.]

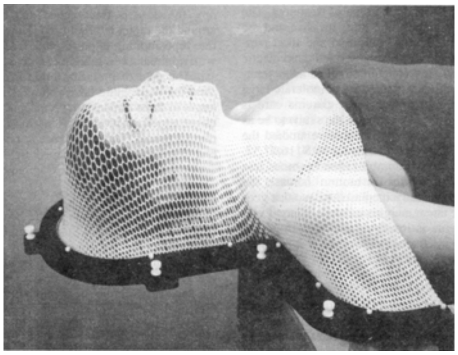


Figure 3.13
Extending the thermoplastic immobilization mask to include the shoulders may improve the accuracy of field matching between opposed lateral and an anterior lower-neck/supraclavicular field. [Courtesy of MED-TEC, Inc., Orange City, Iowa.]

Ref: Van Dyk

Accuracy limits in positioning

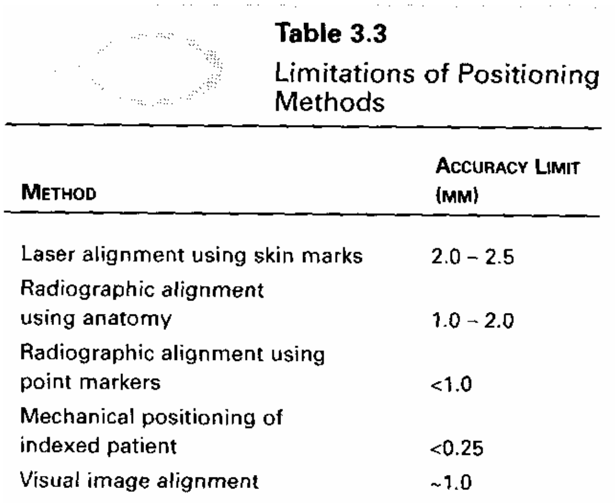


Table 3.3
Limitations of Positioning Methods

METHOD	ACCURACY LIMIT (MM)
Laser alignment using skin marks	2.0 – 2.5
Radiographic alignment using anatomy	1.0 – 2.0
Radiographic alignment using point markers	<1.0
Mechanical positioning of indexed patient	<0.25
Visual image alignment	~1.0

Ref: Van Dyk

Journal Club IV– Industrial/Product Review

•Look through journals handed out , as well as web links on class website.

•Choose a product/company to present.

•Give me the name of the product/company **before Wednesday**.

Things you need to present:
•Overview of product (pictures)
• technical specifications
•How is it used ? (main medical imaging procedures)
•Who has used it ? (search360 or medline ?)
•What competition is there for this product? (other companies etc.)