Two-Dimensional Treatment Planning
Current two-dimensional (2-D) treatment planning is based on standardized treatment techniques applied to classes of patients thought to be similar (i.e., lung tumors, brain tumors, etc.). This process makes use of an X-ray simulator, a 2-D computer treatment planning system used for calculation of dose distributions for X-rays and electron treatment beams, weekly port film (similar to standard X-ray film), and treatment verification.

Computer 2-D treatment planning is limited to generating dose distributions in a single, or a few planes of the patient’s target volume.

For 2-D treatment planning, the radiation therapy simulator is widely used. This physical simulator mimics the functions and motions of a radiation therapy treatment unit. It also uses a diagnostic X-ray tube to simulate the radiation properties of the treatment beam. A simulator allows the beam direction and treatment fields to be determined to encompass the target volume and spare normal structures excessive radiation. Until recently, physicians were limited to the use of conventional simulation. Now the use of computed tomography (CT) and magnetic resonance imaging (MRI) have made it easier to obtain more accurate tumor localization, which has led to 3-Dimensional (3-D) treatment planning.

Three-Dimensional Treatment Planning and Delivery
Several developments have moved radiation oncology into a new era, with three-dimensional conformal radiation therapy (3-DCRT). Modern imaging technologies provide a 3-D view of the cancer patient’s anatomy which allows the radiation oncologist to more accurately identify tumor and their relationship with other tissues. 3-D treatment planning (computer simulation of patient anatomy and radiation dose delivery) has the potential to improve cancer survival rates and quality of life. This is possible because 3-D treatment planning provides the ability to deliver higher doses to more accurately defined tumor and at the same time lower doses to normal tissues. This reduces treatment side effects.

In 3-DCRT, treatment techniques are better tailored to the individual patient's situation based on the extent and location of disease and normal anatomy. It is an integrated process that involves several steps:

- constructing a patient repositioning/immobilization device, and obtaining a volumetric image data set of the patient (usually CT scans)
- defining image-based (CT) volumes and internal organs at risk for radiation damage
- designing beam shapes and beam orientations to avoid excessive radiation dose to non-tumor bearing tissues
• calculating volumetric (3-D) radiation dose distributions and the subsequent evaluation and optimization of the 3-D dose distribution
• plan and treatment verification - for example, verifying that the treatment setup is consistent with the computer simulation and the dose delivered as planned. All of these tasks make up 3-DCRT and are discussed below.

**Step 1: Patient Immobilization, Anatomic Localization, and CT Acquisition**

Treatment position and setup are defined in the CT simulator suite. Immobilization devices, required for all patients undergoing 3-DCRT, are fabricated in the CT suite. Once patient positioning has been optimized and verified, the CT scanning takes place. The physician defines the anatomic boundaries of the CT scan. An Intravenous (IV) contrast is used when appropriate. Generally, as many as 100 slices per study are acquired for our patients undergoing CT simulation for 3-D planning.

**Step 2: Tumor/Target Volume Delineation and Isocenter Definition**

Once the CT data set has been acquired, it is transferred to a computer workstation for normal tissue and tumor/target volume delineation. We define tumor and target volumes based on the conventions of the International Commission on Radiation Units and Measurements (ICRU). Briefly, this convention defines the “gross tumor volume” (GTV) as all known gross disease; the “clinical target volume” (CTV) is a volume surrounding the GTV and including areas of potential microscopic disease spread; and the “planning target volume” (PTV) provides a margin around the CTV to allow for day-to-day variation in treatment setup and internal organ motion to ensure that full dose is delivered to all identified diseased tissue. The shape of the radiation beam is designed to conform to the PTV.

The isocenter is a point near the center of the CTV at which all the radiation fields are aimed for that particular CTV. There are circumstances in which the center of the CTV does not define the intended isocenter for the anticipated therapy. In these circumstances, an initial reference point is defined near the anticipated isocenter location. This reference point is then marked on the patient and the immobilization device. Subsequent shifts from this reference point to the actual isocenter planned during virtual simulation are calculated. These shifts are then performed at the time of the “verification simulation” or the first day of treatment setup and the adjusted isocenter is then marked on the patient and immobilization device.

The computer graphics workstation uses image (contouring) software that allows rapid definition of normal tissues and tumor/target volumes. A computer mouse is used to define structures on a slice-by-slice basis. While the user draws contours defining various structures, they can be displayed simultaneously on a reference image in anterior and lateral projections.

**Step 3: Virtual Simulation**

Systems have been developed which integrate a CT scanner with features designed for radiation therapy with an advanced 3-D radiation therapy planning computer. The virtual simulation software provides many advanced image manipulation and viewing
advantages. These systems allow for all of the features of the physical simulator plus additional imaging features which are impossible on a physical simulator. Radiation field placement, and isocenter definition take place during this step (without the patient having to be present for this potentially lengthy procedure). The choice of beam directions and beam aperture design (radiation field shape) can be individually optimized by using a Beam’s-Eye-View display. The patient anatomy is displayed so that the viewer’s eye “sees” what the beam sees to maximize target coverage through a beam direction and aperture that minimizes critical structure radiation.

**Step 4: Plan Evaluation and Optimization**

After an initial beam arrangement is devised and each beam’s desired isocenter dose (prescription dose) is assigned, the radiation dose (isodose) distributions are calculated and displayed. A 3-D graphical display (Room-View) allows a global overview of tumor coverage and normal tissue dose. 2-D displays also are helpful to evaluate isodose distributions on transverse, sagittal, or coronal CT based images. To further assist the radiation oncologist, dose-volume histograms (DVH) are calculated and displayed for each contoured structure and target volume. DVHs are extremely helpful in quickly determining adequate coverage of target volumes and evaluating the dose to surrounding critical structures.

**Step 5: Plan Implementation and Treatment Delivery Verification**

It is essential that the patient be positioned correctly and that the beam parameters be accurately set on the treatment unit. This involves ensuring that the therapist fully understands the method of immobilization and beam orientation being used for implementation of the treatments and follows the instructions precisely. Patients that are immobilized with a thermal plastic mask or custom foam devices are set up to coordinates that are monitored by a record and verify computer system which helps ensure that the daily set-ups are consistent and correct. We use weekly films for portal verification to verify that the patient is set up properly. A dose verification measurement is performed on all X-ray ports to ensure that the radiation dose actually delivered by each beam is correct.

**Advantages**

CT-simulation/3-D radiation therapy treatment planning offers significant advantages over conventional simulation and 2-D treatment planning. Virtual simulation/3-D treatment planning system allows for the simulation of the patient’s treatment without their physical presence after the CT scan is obtained. This is more convenient for patients and saves them from further fatigue. Furthermore, as the plan and treatment course evolves, the patient need not return to the scanner for treatment modifications. Another advantage of the 3-D virtual simulation process is the display of the defined target volumes and critical structures that allow the choice of optimal beam projections and the design of treatment apertures to maximize target volume coverage and minimize treatment of adjacent tissues. Linking the 3-D dose planning system to the simulation system allows for better dosimetric optimization above that which is achievable with geometric optimization alone.