Engineering of body scanners-2

Radiosurgery

Radiosurgery is a medical procedure that allows non-invasive treatment of benign and malignant tumors and other brain pathologies, such as trigeminal neuralgia and some cases of epilepsy. The initial application of radiosurgery was in the treatment of lesions in the brain, a technique also known as stereotactic radiosurgery (SRS). This method is usually referred to as radiosurgery and is used for treating small volumes within the head. Small tumors and arteriovenous malformations can be treated in this way. A treatment volume as small as 4 mm diameter can be produced. Excellent control of patient position is required if the irradiated volume coincides with the treatment volume.

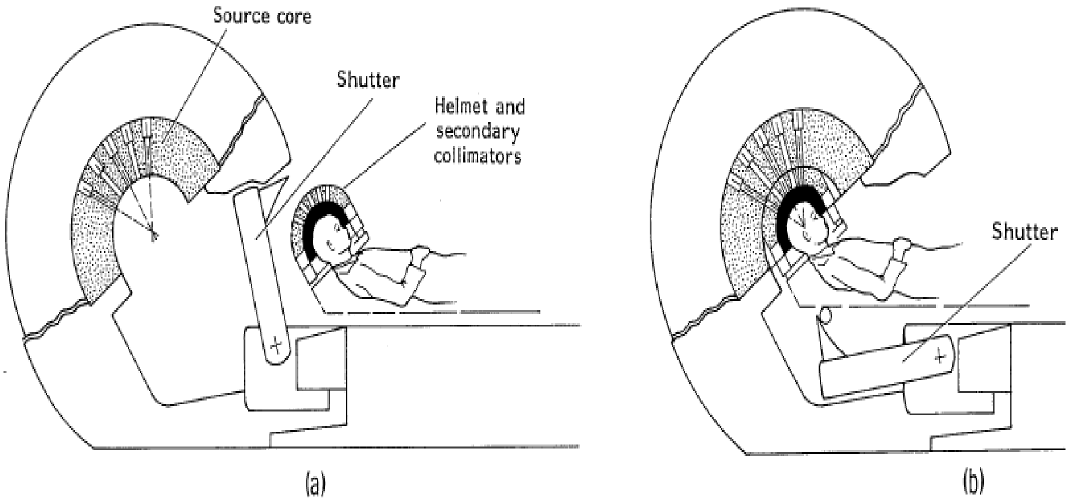

Figure 1. The Sheffield stereotactic radiosurgery unit. When the shutter is dropped the patient is moved such that the secondary collimators in the helmet line up with the primary collimators in the source core.

Beam collimators

The collimator confines the radiation beam to the appropriate size and direction. The primary collimator sets the maximum field size, and the secondary collimator adjusts the field size to that required for each individual treatment. The primary collimator is a thick metal block with a conical hole through the center. In an x-ray unit, the primary collimator will be part of the tube housing. In a linear accelerator, the primary collimator will be close to or incorporated in the x-ray target, and in a cobalt unit it will be part of the shielding or the shutter mechanism.

Two types of secondary collimator are used. For low photon energies (less than 500 kV) and a sourceto- skin distance (SSD) of less than 50 cm, an applicator will be used. At higher energies, or if the head of the treatment machine is to be rotated, a diaphragm is used.

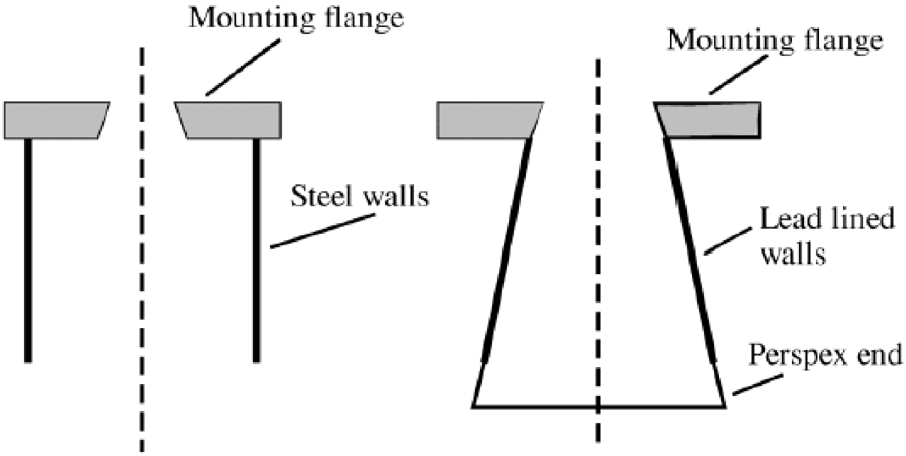

Figure 2. Parallel-sided (left) and 'Fulfield' (right) beam defining applicators. The end of the application defines the source-to-skin distance.

The applicator (figure 2) has a thick base (flange) which is attached to the treatment head, and which reduces the intensity outside the useful beam to less than 2%. The end of the applicator rests on the skin, and therefore defines the source-to-skin distance.

The area in contact with the skin defines the useful area of the beam. The walls of a parallel-sided applicator are not irradiated (figure 2) and may therefore be made of steel. The Fulfield applicator has lead-lined walls parallel to the edges of the beam and a Perspex end-plate to absorb the secondary electrons from the lead. The Perspex can be marked to show the position of the beam axis.

A large thickness of heavy metal is needed to reduce megavoltage beams to less than 2% outside the useful beam, so that an applicator would be excessively heavy. The diaphragm must be placed well away from the skin, as the energetic secondary electrons have a considerable range in air and would give a large dose to the skin. The diaphragm is constructed from a number of lead sheets which can be moved in and out to define the edges of the beam. Several different arrangements are used but they all give a rectangular beam. In the absence of an applicator, some means of visually defining the beam must be provided. This is done by placing a mirror in the beam, and shining a light beam through the diaphragm onto the patient (figure 3).

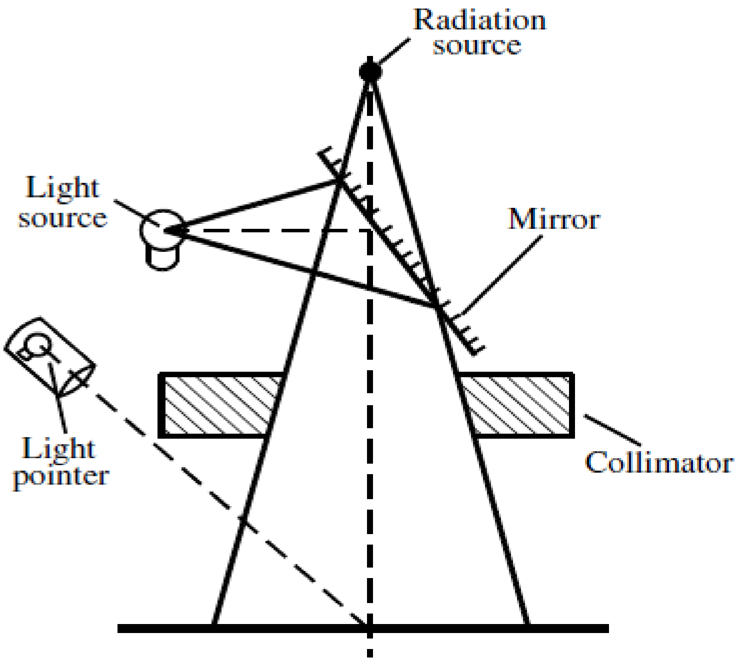

Figure 3 *The optical beam-defining system. The mirror, of course, is transparent to x- and γ -radiation. The combination of projected cross-wires (to define the beam centre), and a separate light pointer, can be used to define the source-to-skin distance.*

The linear accelerator

Linear accelerators can be used to produce beams of electrons or x-rays at energies between 4 and 25 MV. This is done using radio-frequency (RF) electromagnetic waves at a frequency of, typically 3 GHz, i.e. a wavelength of 10 cm. In free space the velocity of electromagnetic waves is 3×10^8 m s^{-1}. However, if the waves are confined in a waveguide (a hollow metal tube) which has suitably spaced metal diaphragms in it and a hole down the middle, the speed of propagation of the waves can be reduced. If the diaphragms are initially close together and get further apart as the waves travel down the waveguide, the waves will be accelerated (typically from 0.4 to 0.99 times the velocity of light). This principle is used in the linear accelerator. Electrons, produced by a heated tungsten filament, are injected into the end of the waveguide. The electrons are carried by the RF wave, and accelerate to a velocity equivalent to 4 MeV in about one meter. At the end of the waveguide, the RF energy is diverted into an absorber, and the electrons are either brought to rest in a transmission target, to produce x-rays, or pass through a thin window to be used as an electron beam.

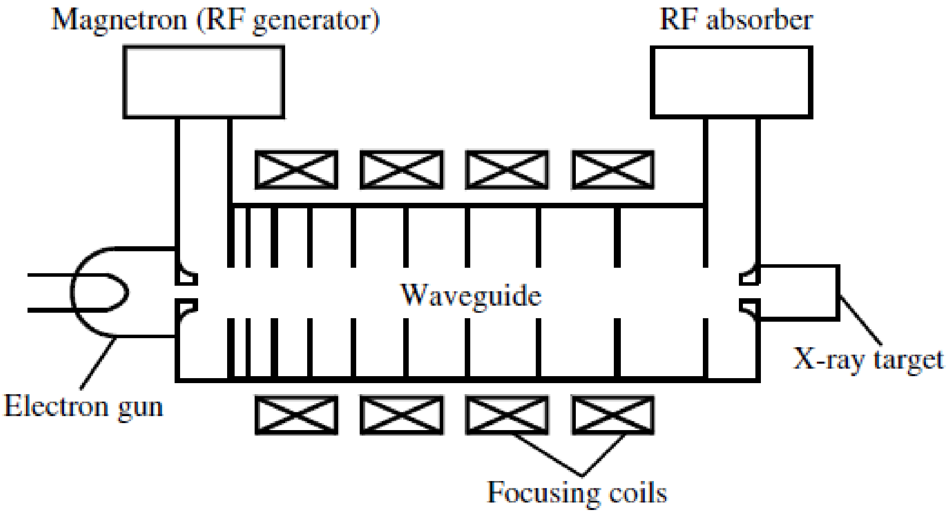

Figure 4. A greatly simplified diagram of a linear accelerator. The interior of the waveguide is maintained at a high vacuum by ion pumps. Electrons from the electron gun are accelerated down the waveguide either to strike the target and thus produce x-rays, or to pass through a thin window to give an external electron beam. The RF energy may be recirculated, instead of being dissipated as heat in the RF absorber.

The waveguide is pumped to a high vacuum, and the beam of electrons is focused by coils surrounding the waveguide. The beam is usually bent through 90° by a magnet before striking the target (figure 5) so that the linear accelerator can be conveniently mounted on a gantry. The maximum size of the x-ray beam is defined by the primary collimator. At these high energies, most of the x-rays are emitted along the line of travel of the electrons, so that the beam is more intense on the axis than to either side. The beam profile is made more uniform by correction with a beam flattening filter, which absorbs more energy from the centre of the beam than from the edges. The flattening filter is designed to make the beam intensity constant, to within 3%, from the centre of the beam to within 3 cm of the edge. The beam is pulsed at 100–500 pulses per second, and has an average intensity of about 200 cGy min^{-1} at 1 m from the tungsten–copper target with 200 pulses per second. Each pulse is about 2 μs long.

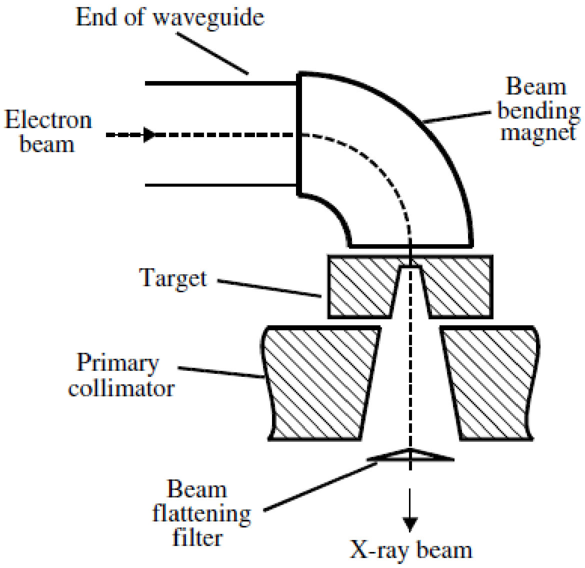

Figure 5: The treatment end of the linear accelerator. The electron beam is deflected magnetically through a right angle (this arrangement makes the whole machine more compact) and strikes the target. The resulting x-ray beam is collimated and passes through a beam flattening filter to adjust the beam uniformity.

cGy = centigray is unit of absorbed radiation dose equal to one hundredth (10−2) of a gray, or 1 rad.