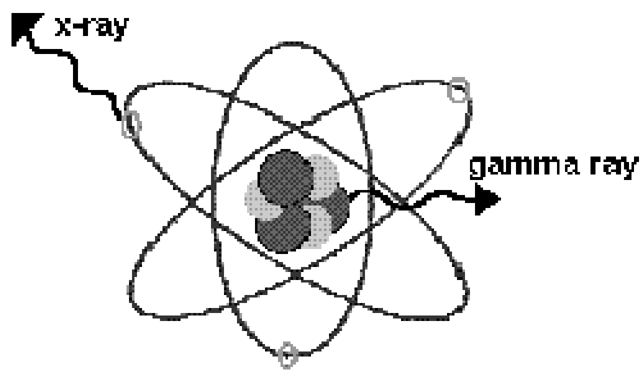
Basic Dosimetry Calculations in Brachytherapy

Dose from a Point Source

Exposure (X) is used for gamma ray and X-ray sources and measures the amount of ionization in air caused by the source. The unit of exposure is the Roentgen.



Dose from a Point Source

Survey meters such as the Geiger Mueller meter measure exposure rate (X/T) in units of Roentgen/hour (R/h) or milliRoentgen/hour (mR/h).

Dose from a Point Source

- Exposure rate is a convenient measure of the exposure at a given distance from a source per unit time, and has direct application to radiation dosimetry. It is expressed in terms of both the activity (A) of the source and in terms of the type of radiation emitted from the source, represented by the exposure rate constant Γ (the greek letter, Gamma).
- $X/T = \Gamma A/D^2$, where D is the distance from the source.

Dose from a Point Source

The units for exposure rate constant are:

$R\ cm^2 / (mCi\ h)$

The exposure rate constant is a measure of the amount of energy released due to ionization by gamma rays and/or X-rays from a particular source, and takes into account the relative intensities and energies of the photons from each source.

Sealed Photon Sources Used in Brachytherapy

The units for exposure rate constant (Γ) are:

R cm^2 / (mCi h)

Some typical values of exposure rates for radioisotopes commonly used in Brachytherapy are given in Tab1e 11.1 (next slide below). The exposure is simply: X = ΓAT/D2

Sealed Photon Sources Used in Brachytherapy

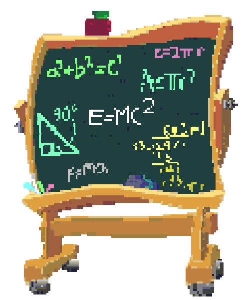
Radioisotope	Half Life	Energy (MeV)	Half value layer in Lead (mm)	Exposure Rate Constant (Rcm2)/(mCih)
Ra-226	1600 y	0.83 avg.	8	8.25
Rn- 222	3.83 d	0.83 avg	8	10.15
Co-60	5.26 y	1.25 avg.	11	13.07
Cs-137	30.0 y	0.662	5.5	3.36
Ir-192	74.2 d	0.38 avg.	2.5	4.69
Au-198	2.7 d	0.412	2.5	2.38
I-125/I-125 Liquid	60.2 d	0.018 avg.	0.025	1.46
Pd-103	17.0 d	0.021 avg.	0.008	1.48

Exposure

Exposure refers to the ionization produced in air. We are more interested in dose to tissue. Dose is defined as the amount of energy deposited in any substance by ionizing radiation, per unit mass of the substance. It is expressed numerically in rads (traditional units) or grays (SI units). A Roentgen-to-centiGray conversion factor will change the exposure rate in air to a dose rate in tissue.

f_{med}

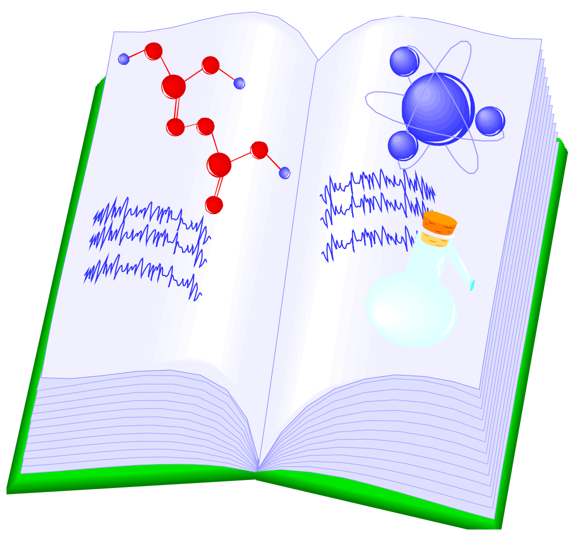
The Roentgen-to-centiGray conversion factor is f_{med}. This factor is slightly energy dependent and also depends on the media (water, muscle, bone) where we want to measure the dose.



f_{med}

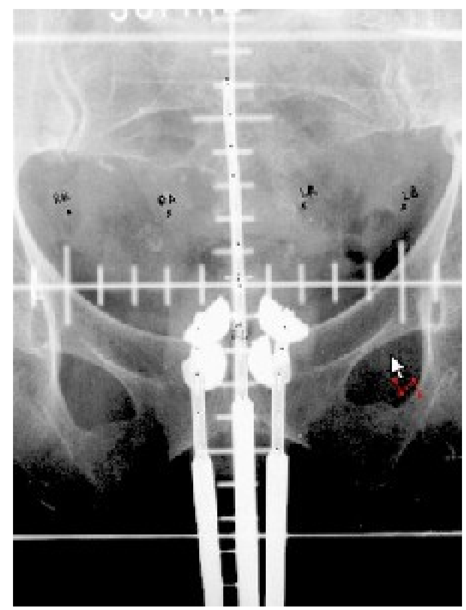
A typical value for f_{med} in tissue is 0.965 cGy/R.

Dose = (f med) ΓAT/D



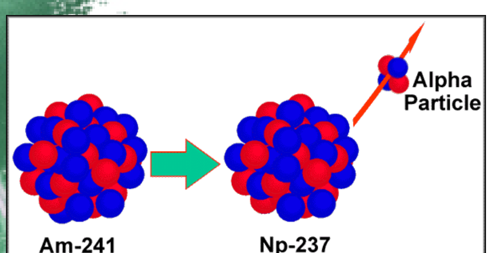
Source Strength, Source Decay and Source Location

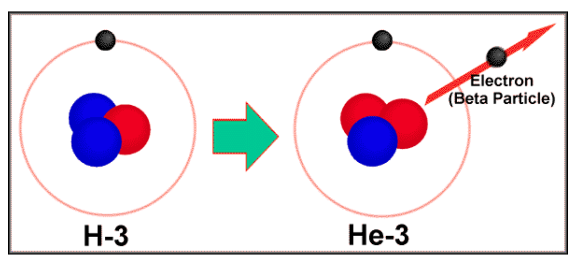
All Brachytherapy treatments involve the use of radioisotopes that are implanted, ingested by or inserted into a patient to deliver a prescribed dose.

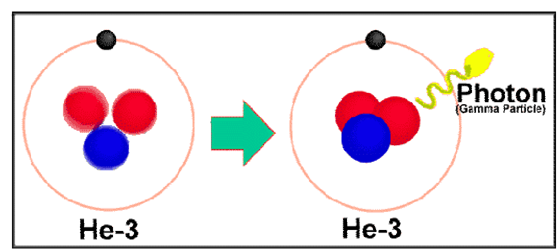


Source Strength, Source Decay and Source Location

The radioisotopes will have an associated activity or strength specified by the manufacturer that will be different (because of decay) at the time of the actual implant.

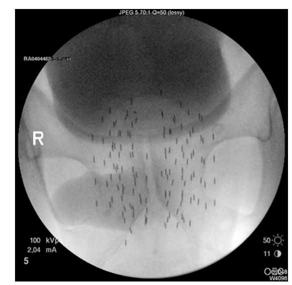






Source Strength, Source Decay and Source Location

The first step in any Brachytherapy treatment will be to determine, and/or verify, the actual source strength or activity on the day the source is received at the clinic, and calculate what it will be at the time of the implant. This is accomplished with the decay equation:



Activity (implant day) =

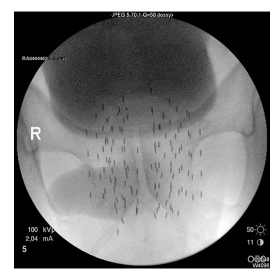
A (manufacturer assay day) exp (-(In(2))(t/τ:)

Source Strength, Source Decay and Source Location

Activity (implant day) =

A (manufacturer assay day) exp (-(In(2))(t/τ)

Where In(2) is the natural logarithm of 2, t is the time elapsed between the implant day and the manufacturer's assay date and τ is the half-life of the source.

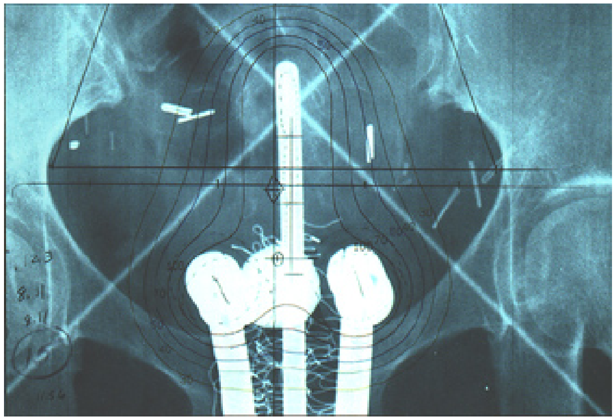


Source Strength, Source Decay and Source Location

- Section 35.432 of 10 CFR states that, before the first medical use of a Brachytherapy source, the licensee shall determine the source output or activity using a dosimetry system. This is typically an electrometer and a well chamber with a calibration traceable to the National Institute of Standards and Technology (NIST) or to a calibration laboratory accredited by the American Association of Physicists in Medicine (AAPM), within the previous 2 years.

Source Strength, Source Decay and Source Location

Some sources, such as cesium tubes require specialized dosimetry systems that are beyond the scope of a typical clinical environment. For these sources the calibration certificate provided by the manufacturer has sufficient information (and pedigree) for an authorized medical physicist to determine the correct source strength or activity at the time of the implant.

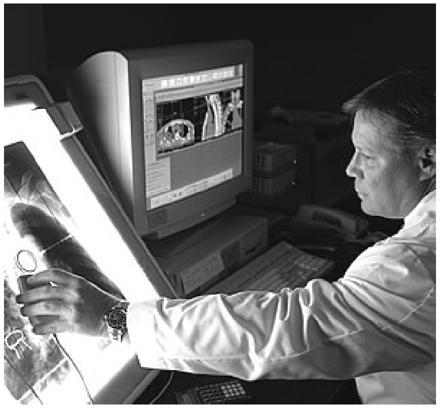


Source Strength, Source Decay and Source Location

It is imperative that the calibration information for each source is correct and accurate and that the source is decayed correctly and accurately. Section 35.433 explicitly states that only an authorized medical physicist shall calculate the activity of each strontium-90 source that is used to determine the treatment times for ophthalmic treatments. The same criteria should apply to all therapeutic sources.

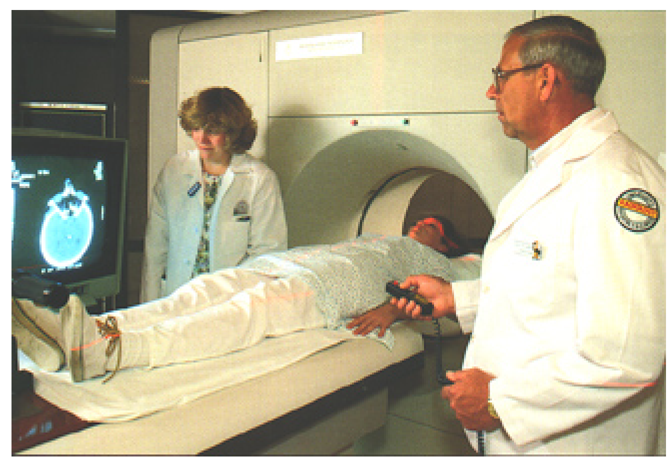
Source Strength, Source Decay and Source Location

The medical physicist (or dosimetrist working under the direct supervision of a medical physicist) must also have a means of verifying the exact location of the (sealed) sources within the applicators and inside the patient.



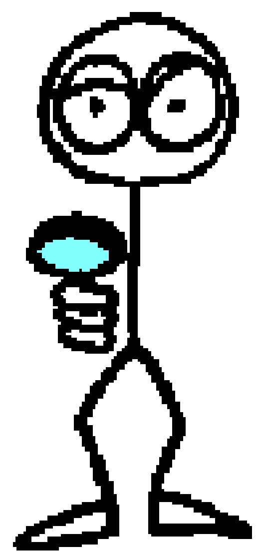
Source Strength, Source Decay and Source Location

- X-rays or CT images of the patient with "dummy sources" (i.e., inactive sources with the same physical properties as the "real sources") inside the applicators will provide this information.



Source Strength, Source Decay and Source Location

In order to determine the correct location of the sources from the X-rays or CT images, the correct magnification factor must be used.



Source Strength, Source Decay and Source Location

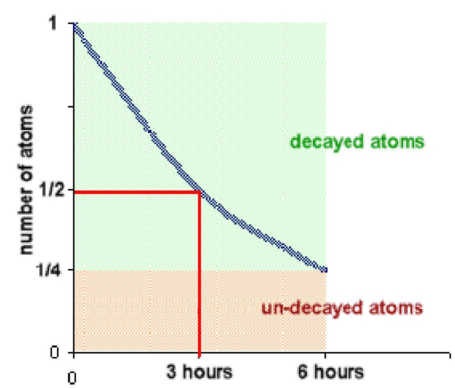
- For some implants this can be accomplished by placing a magnification ring on the patient at the same level as the implant. If a graticule, or some other means of establishing the correct magnification factor for an X-ray or CT is used, an acceptance test of the system must be performed before first use, with a phantom of known geometry, and the documentation from this test must be available for inspection.

Computer-based Treatment Planning Software

Brachytherapy implants can either be permanent implants, where the sources remain in the patient even after they have decayed, or temporary implants, where the sources are in the patient for a limited time and are then removed.

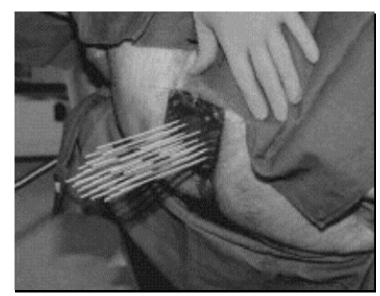
Computer-based Treatment Planning Software

For permanent implants the work of the medical physicist is to determine the number of sources, the strength of the sources and the location of the sources needed to deliver the correct therapeutic dose over several half-lives.



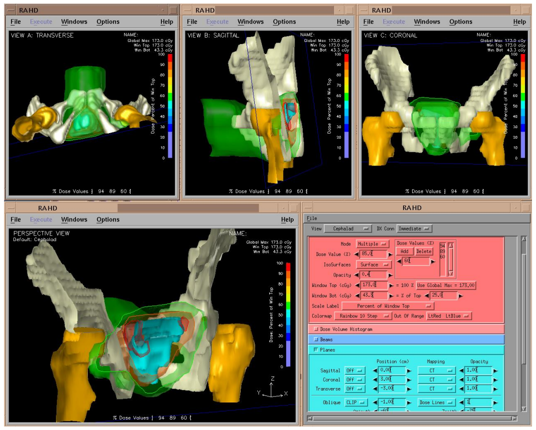
Computer-based Treatment Planning Software

For a temporary implant the work of the medical physicist is to determine the number, strength, and location of the sources, as well as the time the sources will remain in the patient, in order to deliver the correct therapeutic dose.



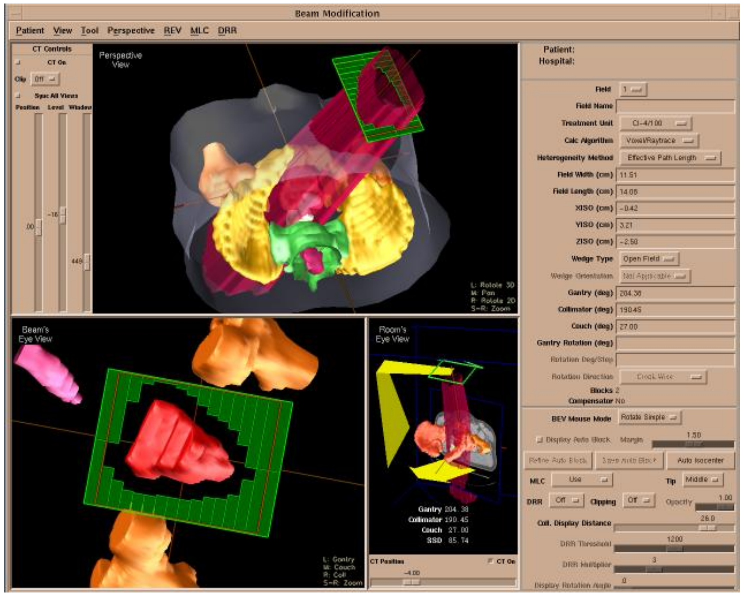
Computer-based Treatment Planning Software

- Several computer based treatment planning systems are available to help the medical physicist determine the best implant parameters to achieve the prescription dose specified by the authorized user.



Computer-based Treatment Planning Software

The licensee has a responsibility to verify that the computer based planning system utilized in the clinic is calculating the dose correctly.



Computer-based Treatment Planning Software

Section 35.457 & 35.657 requires that the licensee shall perform acceptance testing on the treatment planning computer system in accordance with published protocols accepted by nationally recognized bodies (such as the American Association of Physicists in Medicine).

Computer-based Treatment Planning Software

At a minimum, the acceptance testing must include, as applicable, verification of:

- the source-specific input parameters required by the dose calculation algorithm,
- the accuracy of dose, dwell time, and treatment time calculations at representative points,
- the accuracy of isodose plots and graphic displays, and
- the accuracy of the software used to determine sealed source positions from radiographic images.

Computer-based Treatment Planning Software

In the case of a high dose rate implant, where the dose is delivered at the treatment console per the computer-based plan, Section 35.657 applies and requires verification of:

- the source-specific input parameters required by the dose calculation algorithm,
- the accuracy of dose, dwell time, and treatment time calculations at representative points,
- the accuracy of isodose plots and graphic displays,
- the accuracy of the software used to determine sealed source positions from radiographic or CT images, and
- the accuracy of electronic transfer of the treatment delivery parameters to the treatment delivery unit from the treatment planning system

Brachytherapy Calibrations Used to Verify Computer Based Treatment Plans

Implants that have a smaller amount of seeds can be checked manually, using the same point dose approximation. From the computer printout the user can determine the coordinates of the source and the coordinates of the dose point and compute the distance between them. With this known distance, the prescribed dose, and the activity of the source, the medical physicist can calculate the dwell time for the source to deliver the prescribed dose. This computed value should agree (within 10%) with the dwell time determined by the computer software.

Non Computer Based Treatment Plans

- In the early days of Brachytherapy, computer programs were not available to compute isodose lines for sources used in an implant. Instead, other methods were used to determine the best source placement to achieve the therapeutic objectives.

Non Computer Based Treatment Plans

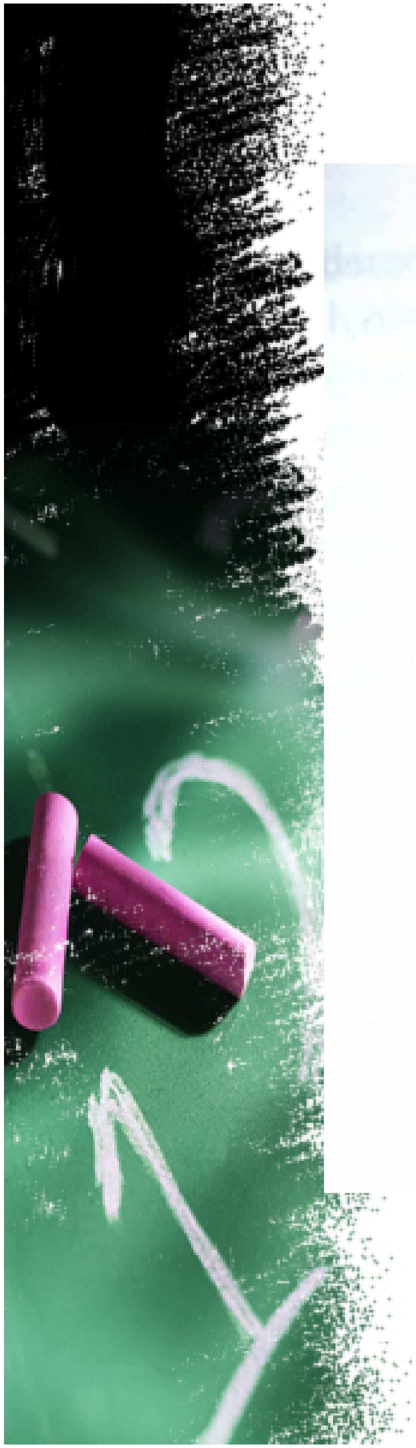
- One of these, the along and away tables, can be used to calculate the dose, to a prescription point, from cesium tube sources in an intracavitary implant, typically consisting of a tandem and two ovoids.

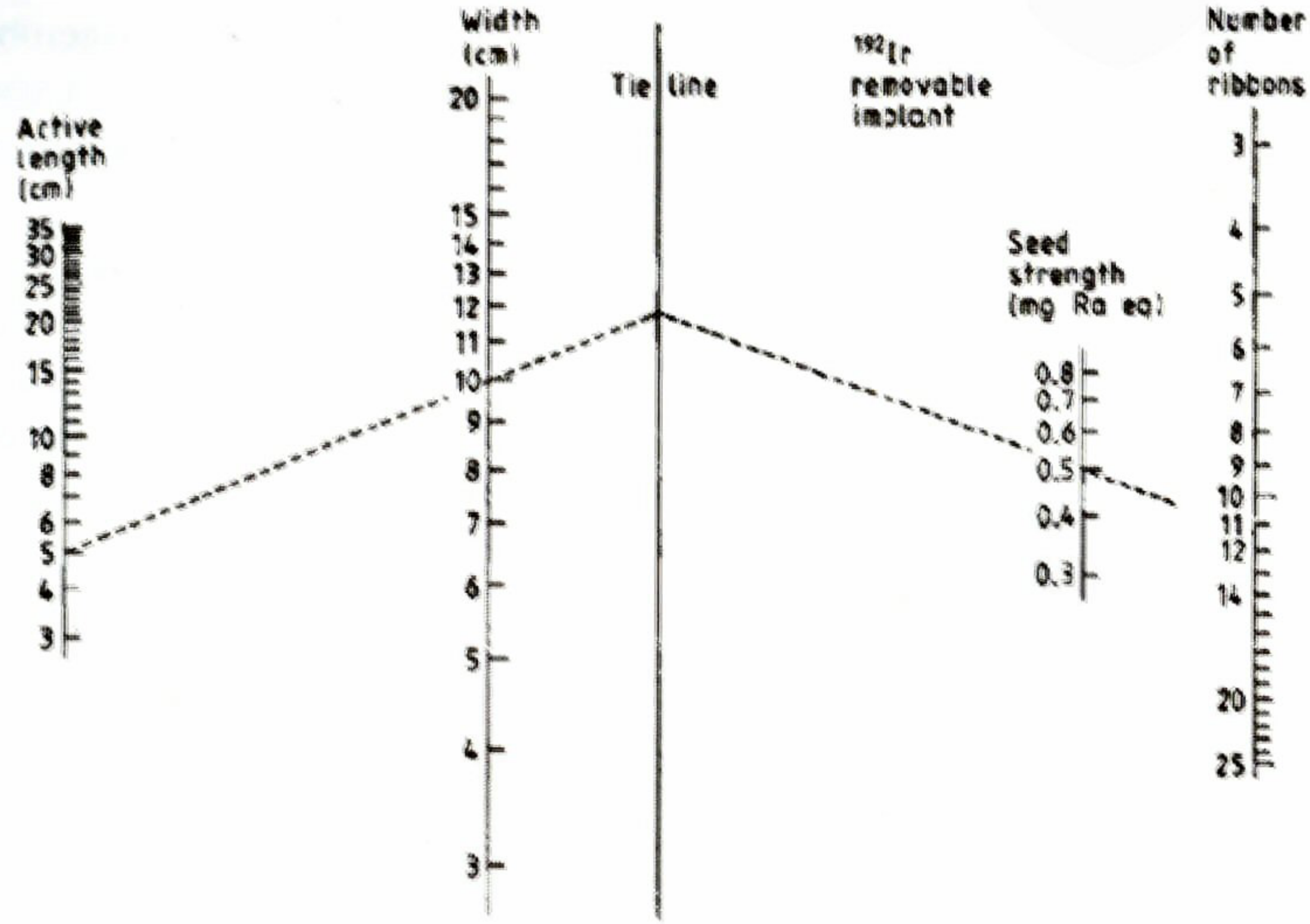
Non Computer Based Treatment Plans

- The along and away tables can also be used to check an intracavitary implant that was planned with a computer treatment planning system. The basis for these tables are very careful experimental measurements in a two dimensional array.

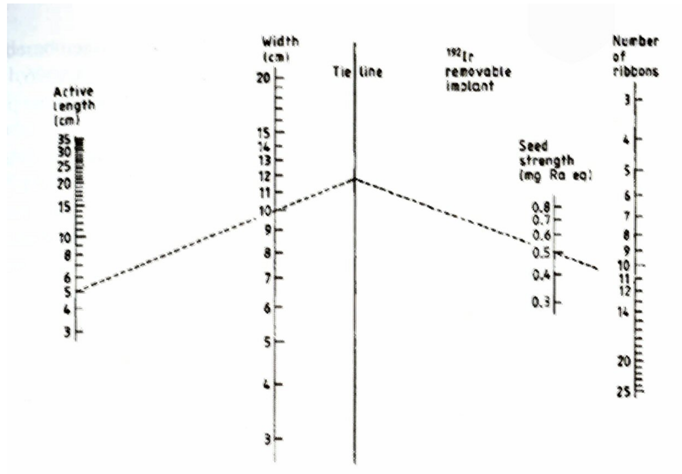
Non Computer Based Treatment Plans

Another method that has been utilized for decades are nomograms. Nomograms are a clever method of graphic correlation between the implant parameters for a certain implant area or volume





Active length (cm)
Width (cm)
Tie line
^{192}Ir removable implant
Seed strength (mg Ra eq)
Number of ribbons



- These nomograms consist of multiple lines, each scaled for a particular set of implant parameters, such as volume, total and individual seed activities, number of seeds, and seed spacing.

- The nomograms are designed for a particular application with a particular prescribed dose. For instance, some of the earlier nomograms were designed for prostate implants with 160 Gy prescribed dose, using uniform distribution of the seeds. Typically 75% of the sources were placed in ribbons (needles) along the periphery of the prostate and 25% of the sources were placed inside the prostate (avoiding the urethra).