Brachytherapy Planning and Quality Assurance

- Classical implant systems
- Most common clinical applications and modern dosimetry methods
- Quality assurance

Classical implant systems

- Manchester (Paterson-Parker)
- Quimby
- Paris
- With the advent of computerized treatment planning these are little used today with the possible exception of the Manchester System for cervix cancer treatments

The Manchester System

- Aims at producing as uniform a dose as possible within the treatment volume
- Sources of variable strength used
- Rules provided for placement of sources of different strengths
- Tables provided to determine treatment time
- Originally devised for Ra-226 but later extended to Cs-137

The Quimby System

- Developed by Edith Quimby at Memorial Hospital, New York
- Required uniform distribution of same strength sources
- Produced non-uniform dose distributions
- Tables provided to determine treatment times
- Originally devised for Ra-226 and Rn-222 seeds but later extended to Ir-192 and I-125

The Paris System

- Designed for Ir-192 wires but later extended to Ir-192 seeds in strands
- The sources should be equidistant arranged in patterns (squares or triangles)
- The dose (called the “basal dose”) is the arithmetic mean of the minimum dose rates located half-way between the sources in the well defined patterns
- Tables provided to determine treatment times

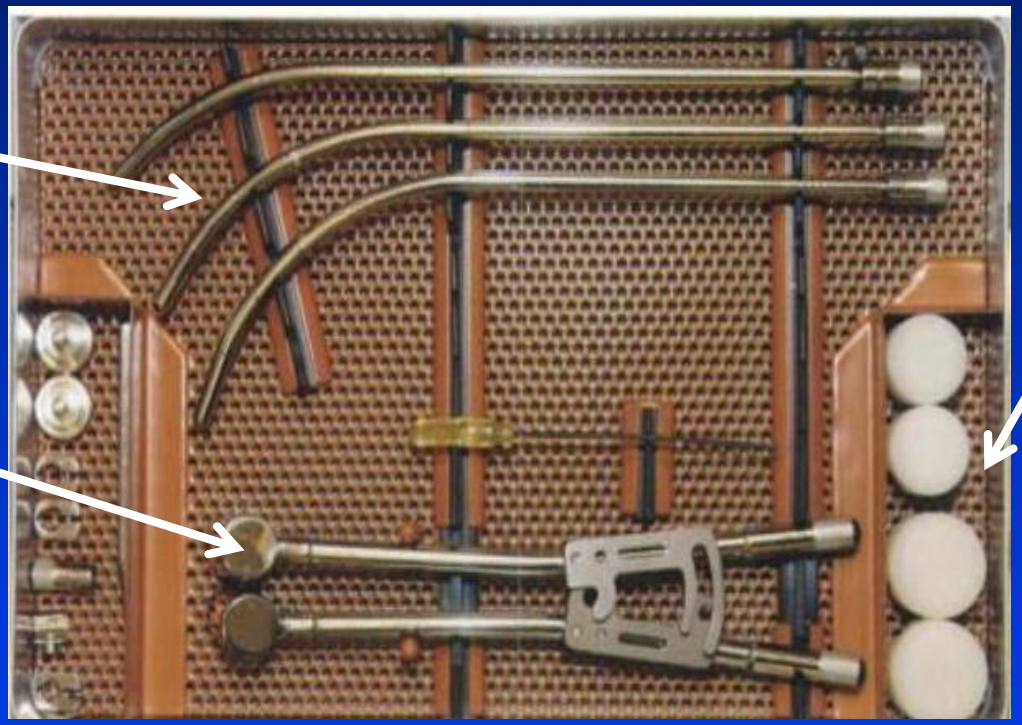
Most common clinical applications

- Gynecological treatments
- Prostate implants
- Breast implants

Gynecological brachytherapy

- Uterine cervix
- Vagina
- Endometrium

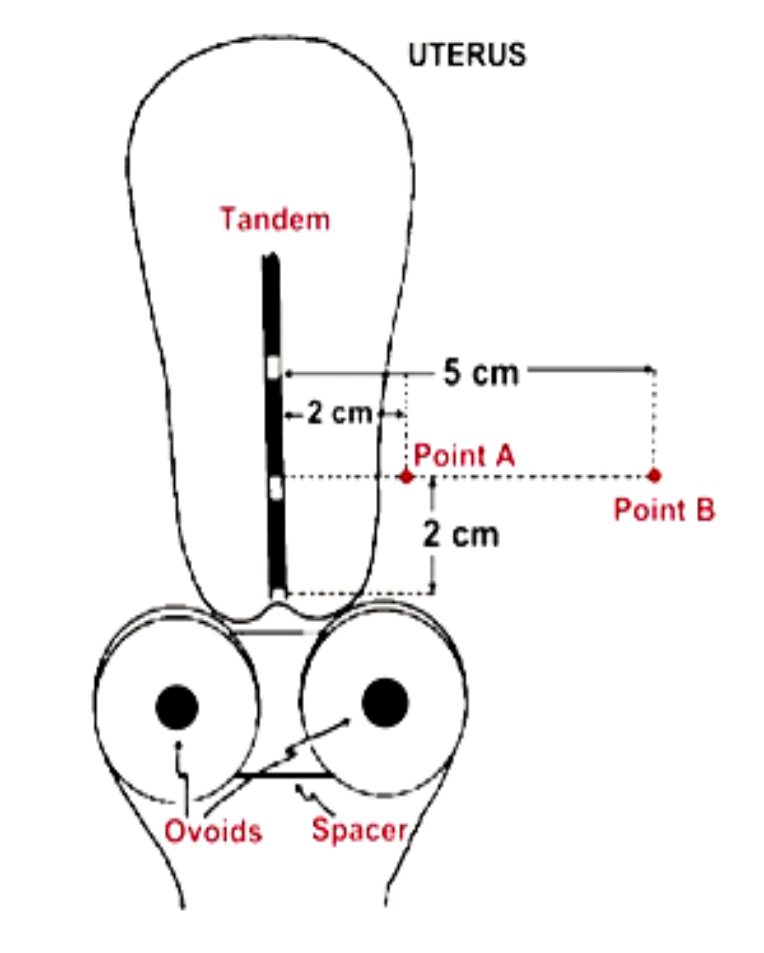
Cervix cancer: Manchester System Fletcher-Suit tandem and ovoids



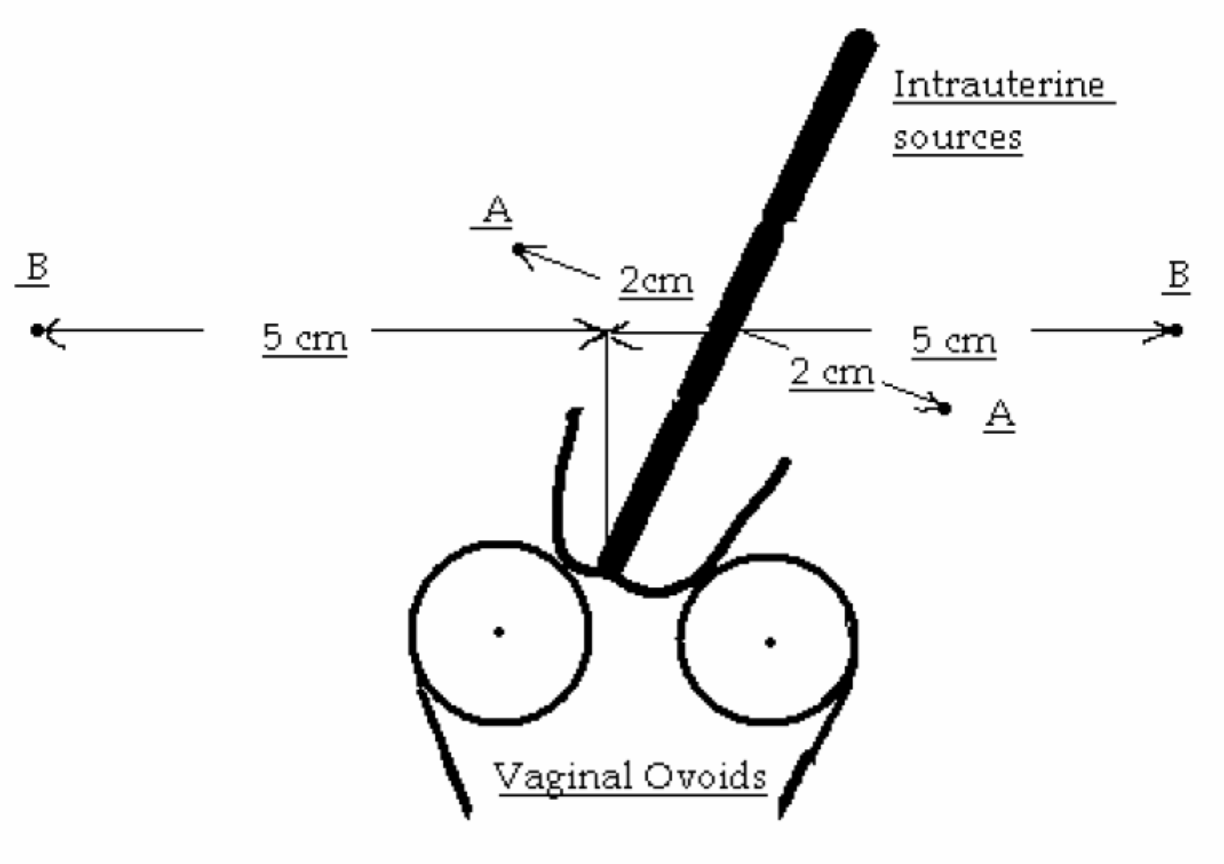
Tandem and ovoids are inserted into the uterine canal and vagina, respectively

Some newer cervix cancer applicators

Manchester System: doses were calculated at two points, A and B



Off-axis tandem



Meigooni, 2005

The American Brachytherapy Society recommended doses with LDR

		External irradiation (Gy)			LDR brachytherapy (Gy)	
Tumor stage	Tumor extent	Whole pelvis	Pelvic wall	Parametrial boost (Gy)	Dose to point A	Total dose to point A (Gy)
IA1		0	0	0	50–60	50–60
IA2 Selected IB1	Superficial ulceration less than 1 cm in diameter or involving fewer than two quadrants	0	0	0	60–70	60–70
IB1		19.8 or 45	50.4 or 45	0	55 or 30–35	75 or 75–80
IB2, IIA,†		45	45	0	40	85
IIB†		45	45	9–15	40	85
III†		45–50	45–50	9–15	40	85–90
IIB, IIIB, IV	Poor pelvic anatomy, patient not readily treated with intracavitary insertions (barrel-shaped cervix not regressing, inability to locate external os)	50	50	9–15	40	90
	Or interstitial	39.6–45	39.6–45	0–15	35–40*‡	75–85*‡

The American Brachytherapy Society recommended Point A doses with HDR for early disease

EBRT (Gy) @ 1.8 Gy/fraction	No. of HDR fractions	HDR dose/ fraction
20	6	7.5
20	7	6.5
20	8	6.0
45	5	6.0
45	6	5.3

Abbreviations: EBRT = external beam radiation therapy; HDR = high-dose-rate; LDR = low-dose-rate.

The American Brachytherapy Society recommended Point A doses with HDR for advanced disease

EBRT (Gy) @ 1.8 Gy/fraction	No. of HDR fractions	HDR dose/ fraction
45	5	6.5
45	6	5.8
50.4	4	7.0
50.4	5	6.0
50.4	6	5.3

Abbreviations: EBRT = external beam radiation therapy; HDR = high-dose-rate; LDR = low-dose-rate.

Vaginal brachytherapy

- Can be treated low dose rate although, nowadays, most commonly, high dose rate
- Usually use cylindrical applicator of appropriate diameter
- Stepping pattern designed to give uniform dose around the applicator at selected depth in tissue, typically 0.5 cm

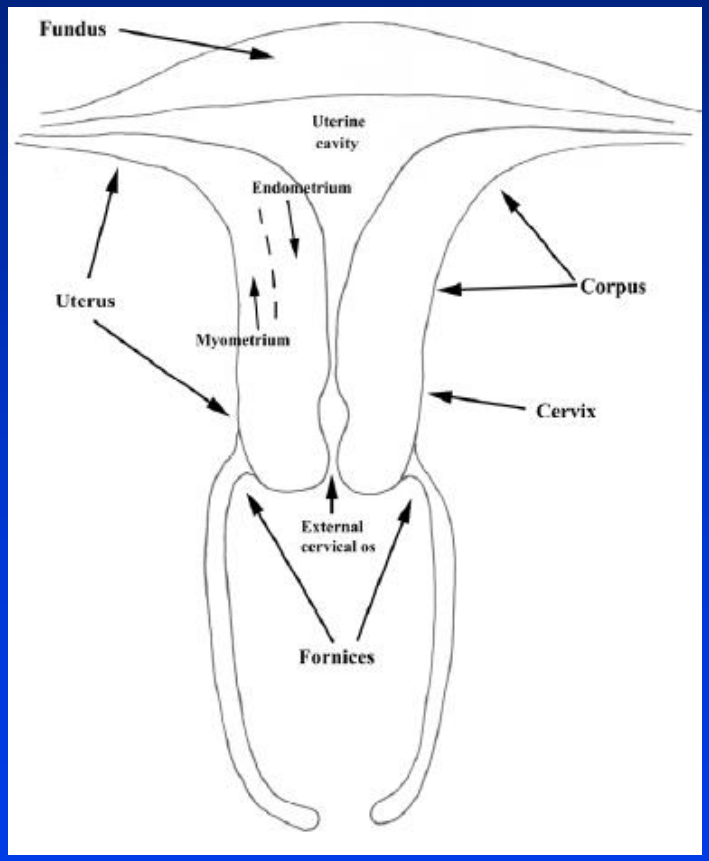
Intracavitary applicators used for vaginal brachytherapy

Use the largest diameter applicator that is comfortable for the patient so as to produce the best depth dose

Endometrial brachytherapy

- Can be treated low dose rate although, nowadays, most commonly, high dose rate
- For post-hysterectomy patients
  - *treat the vagina (vaginal cuff brachytherapy)*
- For other patients
  - *treat the vagina plus the uterine cavity with special applicator*

Endometrial brachytherapy



Typical dose distribution

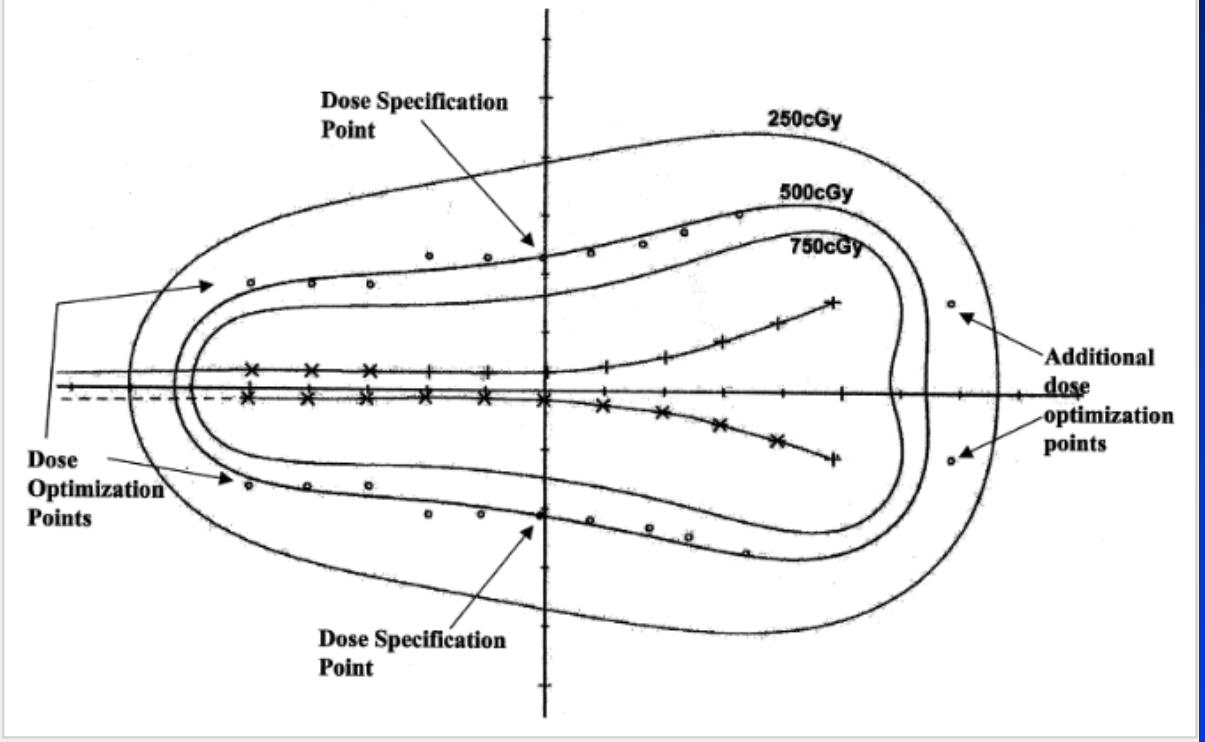


Fig. 4

Examples of isodose distribution of an optimized treatment plan for treating inoperable primary endometrial cancer with a Y-shaped applicator.

IJROBP October 1, 2000 Volume 48, Issue 3, Pages 779–790

ABS HDR dose guidelines (if no added external beam)

No. of HDR fractions	HDR dose/fx
4	8.5 Gy at 2 cm
5	7.3 Gy at 2 cm
6	6.4 Gy at 2 cm
7	5.7 Gy at 2 cm

HDR doses are specified at 2 cm from the midpoint of intrauterine sources

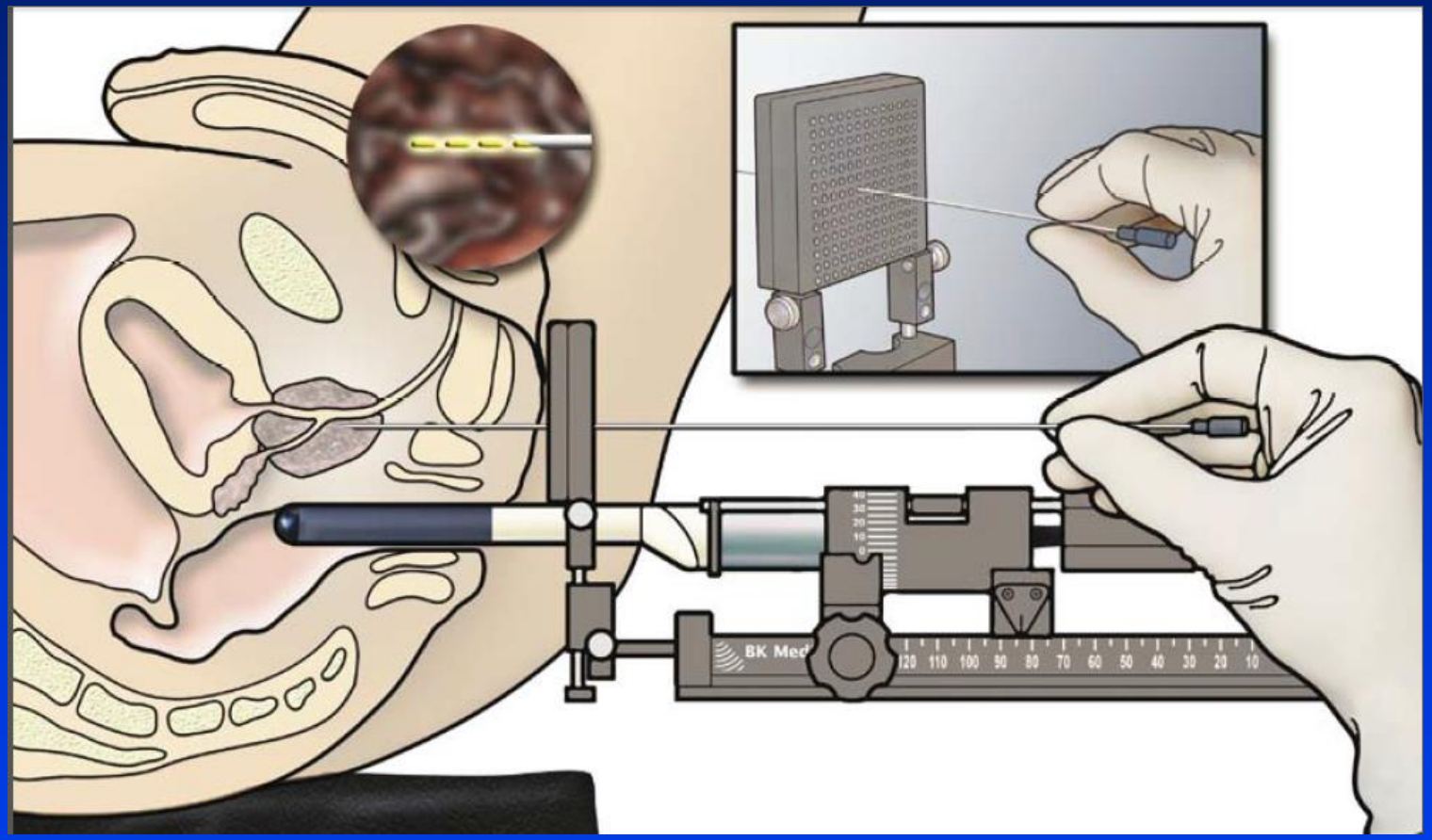
IJROBP October 1, 2000 Volume 48, Issue 3, Pages 779–790

Prostate brachytherapy

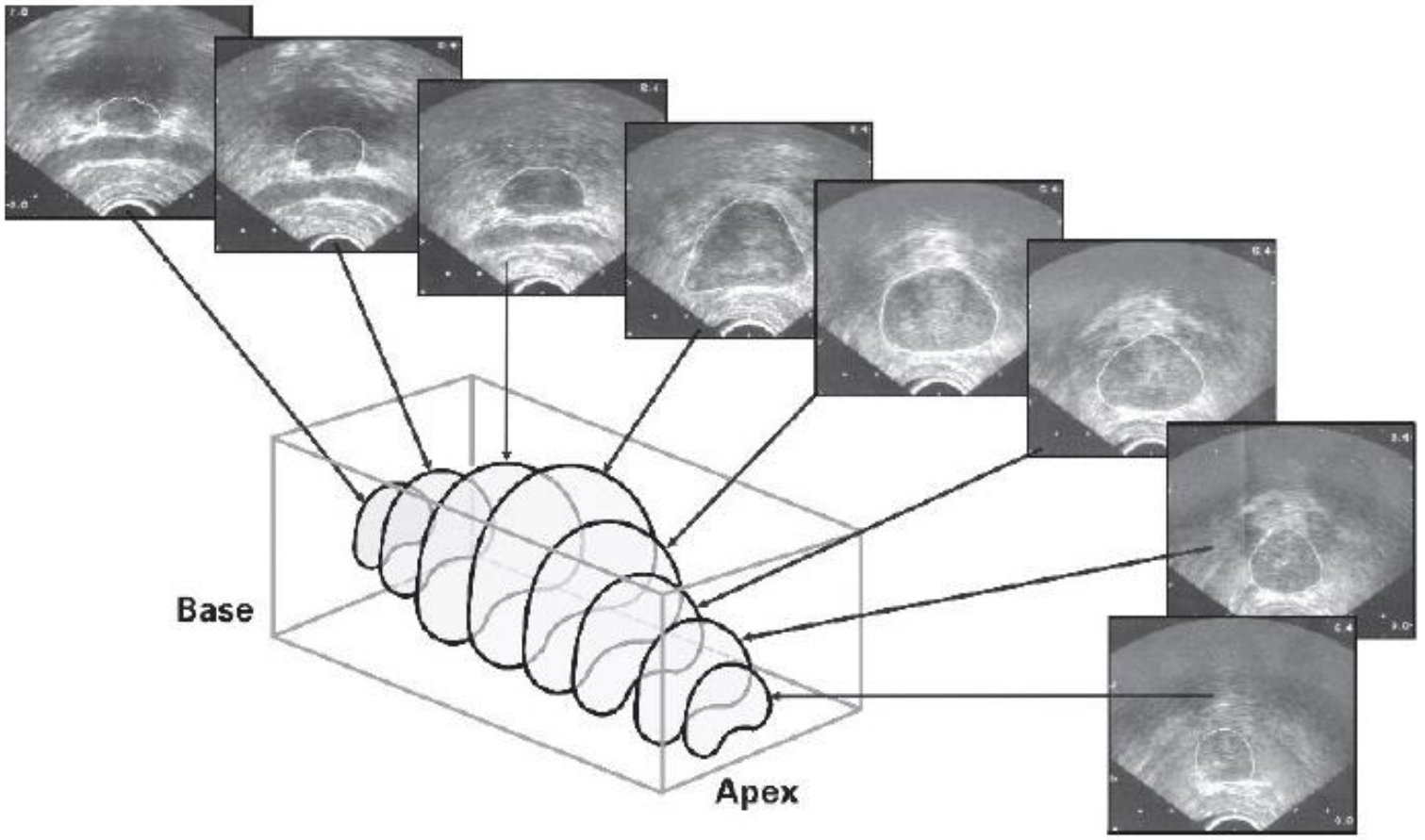
- There are two major alternatives:
- Permanent implants with either

  I-125 or Pd-103 seeds
- Temporary high dose rate implants with Ir-192 or electronic brachytherapy

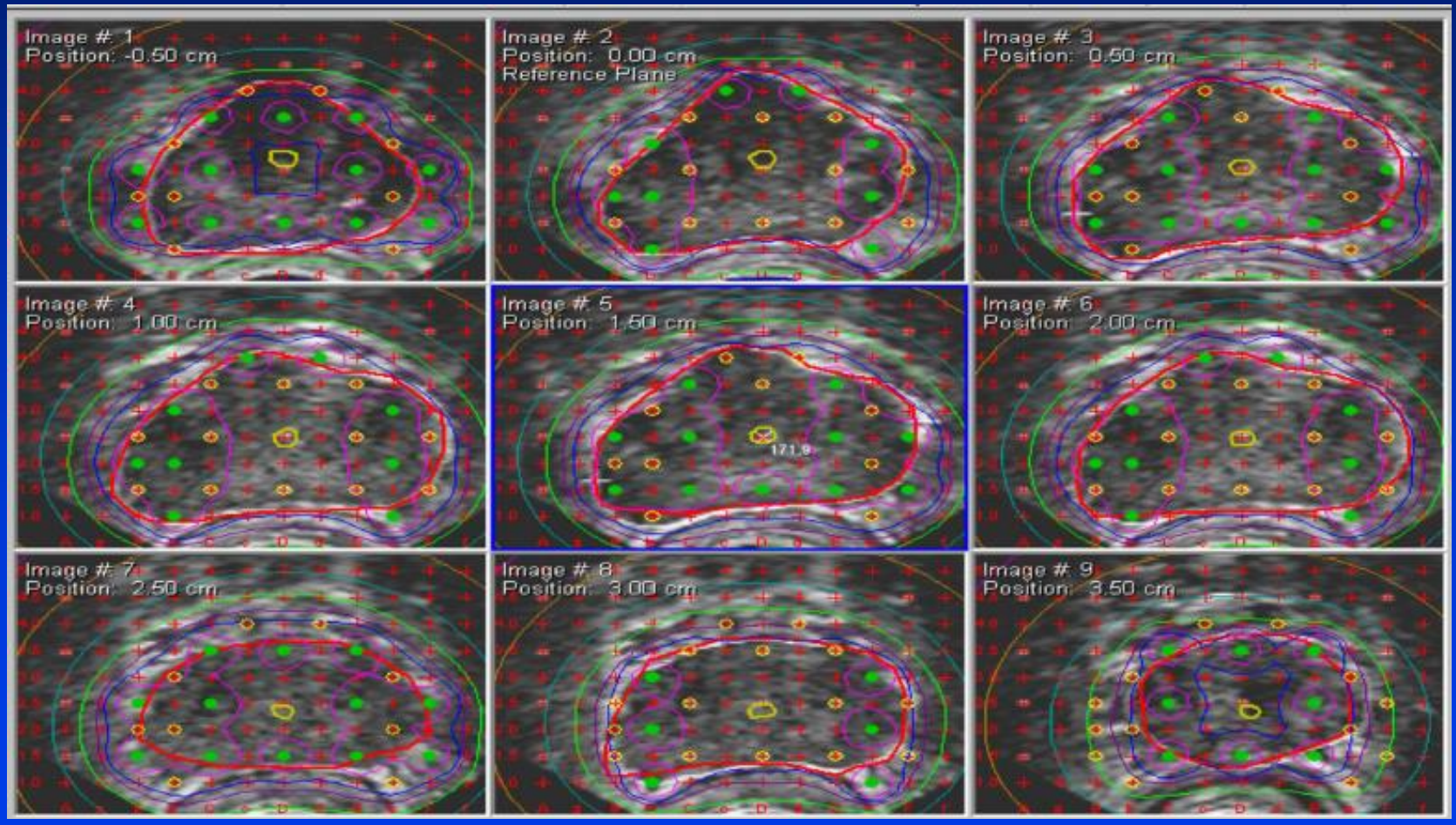
Ultrasound-Guided Transperineal Prostate Brachytherapy



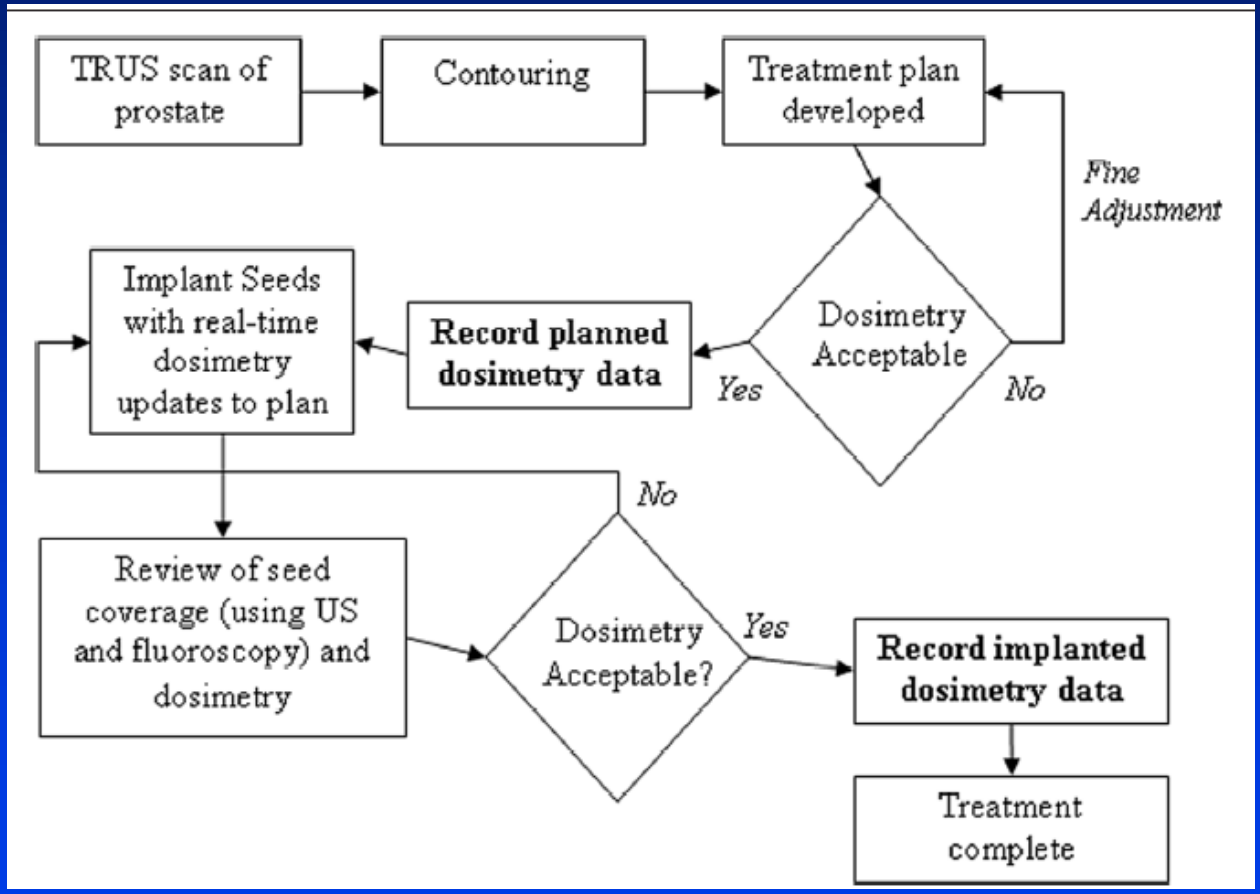
Series of transrectal ultrasound (TRUS) images



TRUS images used for planning



Schematic of the planning and treatment process for permanent implants



Moorrees et al. Radiation Oncology 2012, 7:196

Sources used for permanent prostate implants

- With I-125 (half life 60 days) the dose is delivered over many months
- With Pd-103 (half life 17 days) the dose is delivered over many weeks
- The total dose delivered to infinity is calculated by the formula:

  Total dose = (initial dose rate) x (mean life)

Examples

1. If the initial dose rate for an I-125 implant is 7 cGy/h, then the total dose to complete decay is:

   7 x 1.44 x 60 x 24 = 14,515 cGy

   i.e. about 145 Gy

2. If the initial dose rate for a Pd-103 implant is 21 cGy/h, then the total dose to complete decay is:

   21 x 1.44 x 17 x 24 = 12,338 cGy

   i.e. about 123 Gy

American Brachytherapy Society recommended total doses for prostate treatments

Prescription doses to the planning target volume	
^{125}I	
Monotherapy	140–160 Gy
Combination	
EBRT	41.4–50.4 Gy (1.8 Gy/d[a])
PPB dose	108–110 Gy
^{103}Pd	
Monotherapy	110–125 Gy
Combination	
EBRT	41.4–50.4 Gy (1.8 Gy/d[a])
PPB dose	90–100 Gy

PPB = permanent prostate brachytherapy; EBRT = external beam radiation therapy.

[a] 2 Gy/d also acceptable.

ABS Prostate TG suggested doses for HDR prostate treatments

For monotherapy either

10.5 Gy x 3 fractions

or 8.5-9.5 Gy x 4 fractions

or 6.0-7.5 Gy x 6 fractions

ABS Prostate TG suggested doses for HDR prostate treatments

As a boost in combination with 36-40 Gy EBRT

15 Gy x 1 fraction

or, with 40-50 Gy EBRT either

9.5-10.5 Gy x 2 fractions

or 5.5-7.5 Gy x 3 fractions

or 4.0-6.0 Gy x 4 fractions

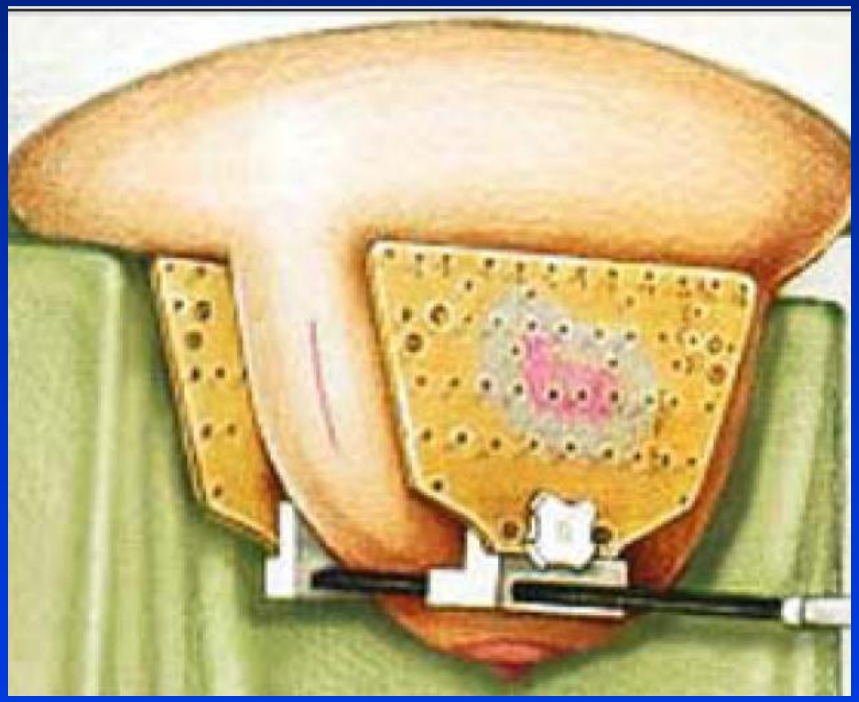
Accelerated Partial Breast Irradiation (APBI)

- Brachytherapy for breast cancer can be used after lumpectomy either as a boost to external beam therapy or as monotherapy
- Two major techniques are applied

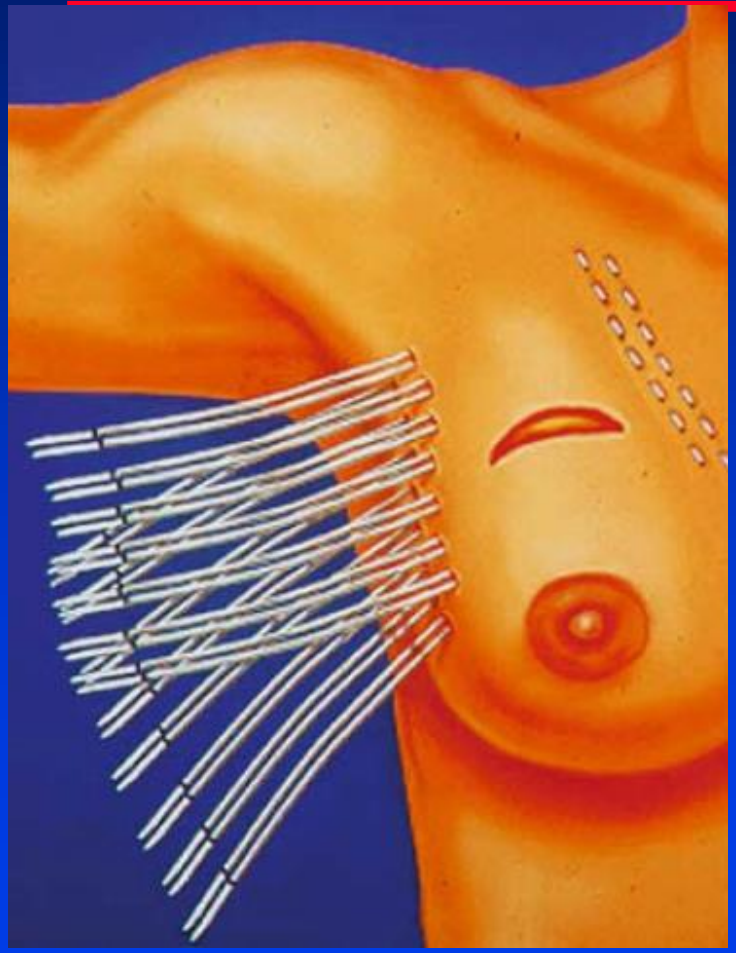
1. needles are inserted interstitially into the breast using a template with either LDR or HDR, or

2. an applicator is inserted into the cavity and expanded so as to make the cavity roughly spherical and an HDR is source is stepped through the applicator

Template for interstitial needle technique



Interstitial needle technique



Applicator method: MammoSite

There are two types: a single lumen (shown) and multiple lumens

Njeh *et al. Radiation Oncology* 2010 **5**:90

Applicator method: Contura

The Contura has a balloon to displace and shape the tissue central lumen and four expandable lumens, all of which can carry the HDR source

Njeh *et al. Radiation Oncology* 2010 **5**:90

Applicator method: Savi

The expandable struts (lumens) displace the tissue and carry the HDR source

Njeh *et al. Radiation Oncology* 2010 **5**:90

Applicator method: ClearPath

ClearPath has outside struts (lumens) to displace the tissue and inner lumens to carry the HDR source

The pink cover is used between fractions to protect the applicator and for cosmetic purposes

Njeh *et al. Radiation Oncology* 2010 **5**:90

Typical APBI brachytherapy doses when used as monotherapy

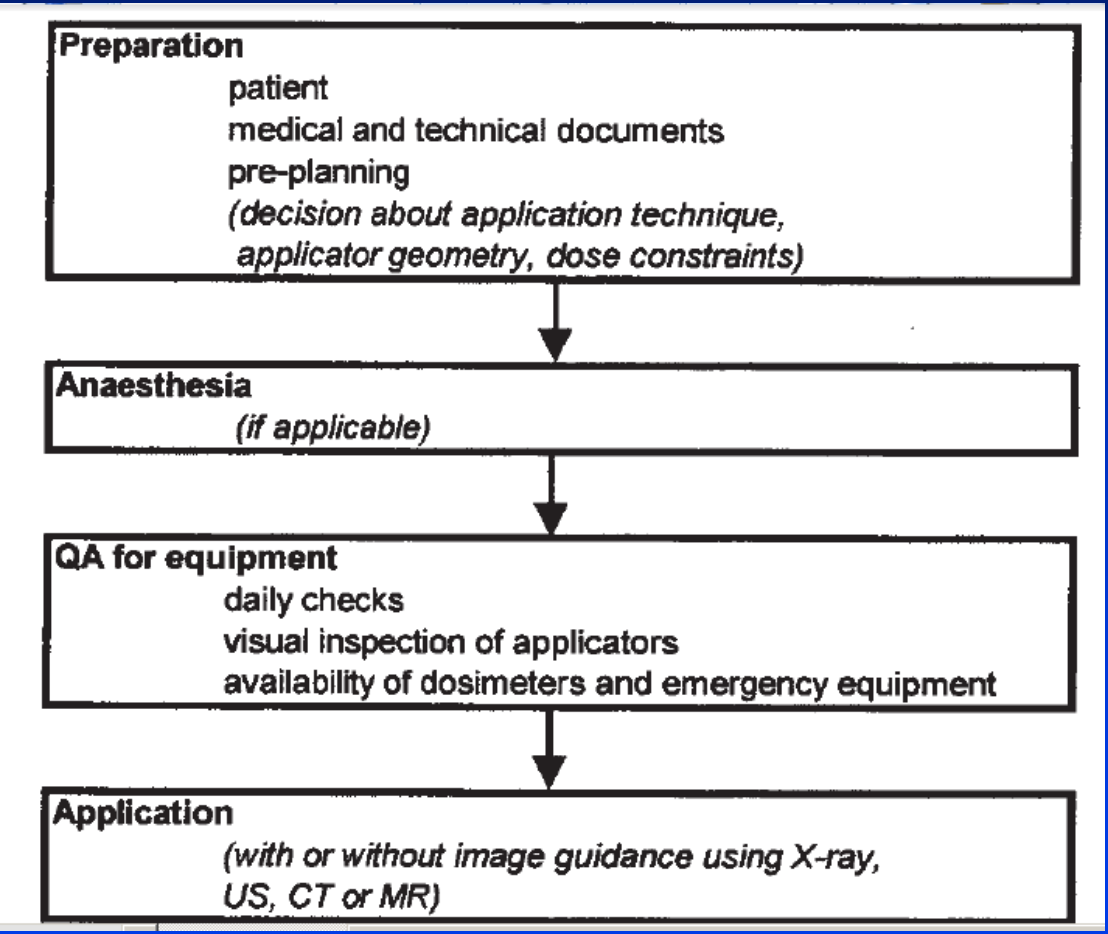
- LDR: 45-50 Gy at about 0.5 Gy/h
- HDR: 34 Gy at 1.0 cm outside the cavity wall in 10 fractions

Imaging for brachytherapy

IMAGE ASSISTED PROVISIONAL TREATMENT PLANNING (treatment simulation and provisional dose calculation) conventional radiography, sectional imaging: MR, CT, US, PET
IMAGE GUIDED APPLICATION Radiography, MR, CT, US, endoscopy with or without on-line treatment planning
IMAGE ASSISTED DEFINITIVE TREATMENT PLANNING Imaging after application for definitive treatment planning (Radiography, US, CT, MR)
IMAGE ASSISTED QUALITY CONTROL OF DOSE DELIVERY Imaging for quality control during or after brachytherapy Radiography, CT, MR

Gerbaulet et al, 2002

General flow scheme for a brachytherapy procedure: preparation and application



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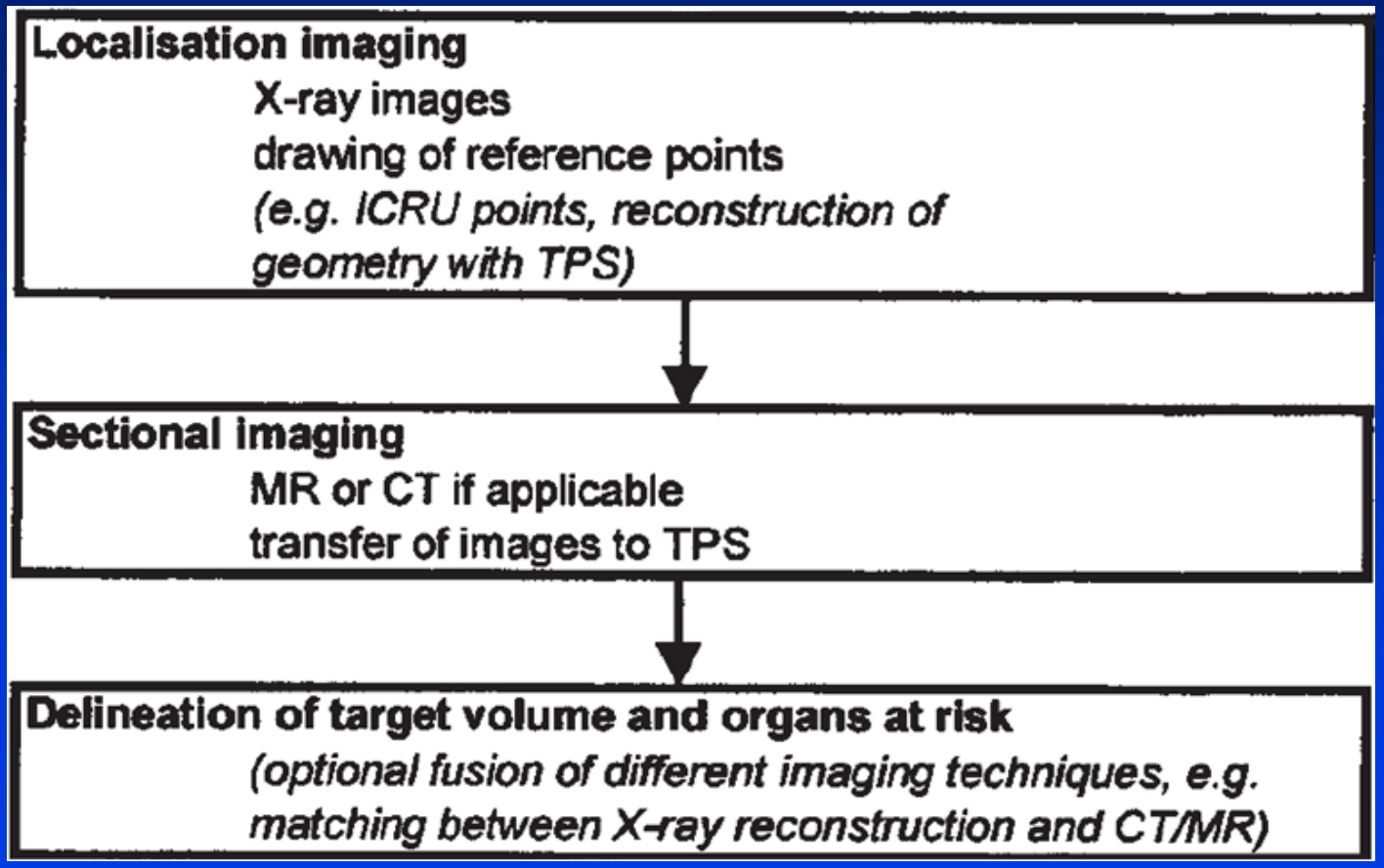
Flow scheme for brachytherapy imaging for treatment planning



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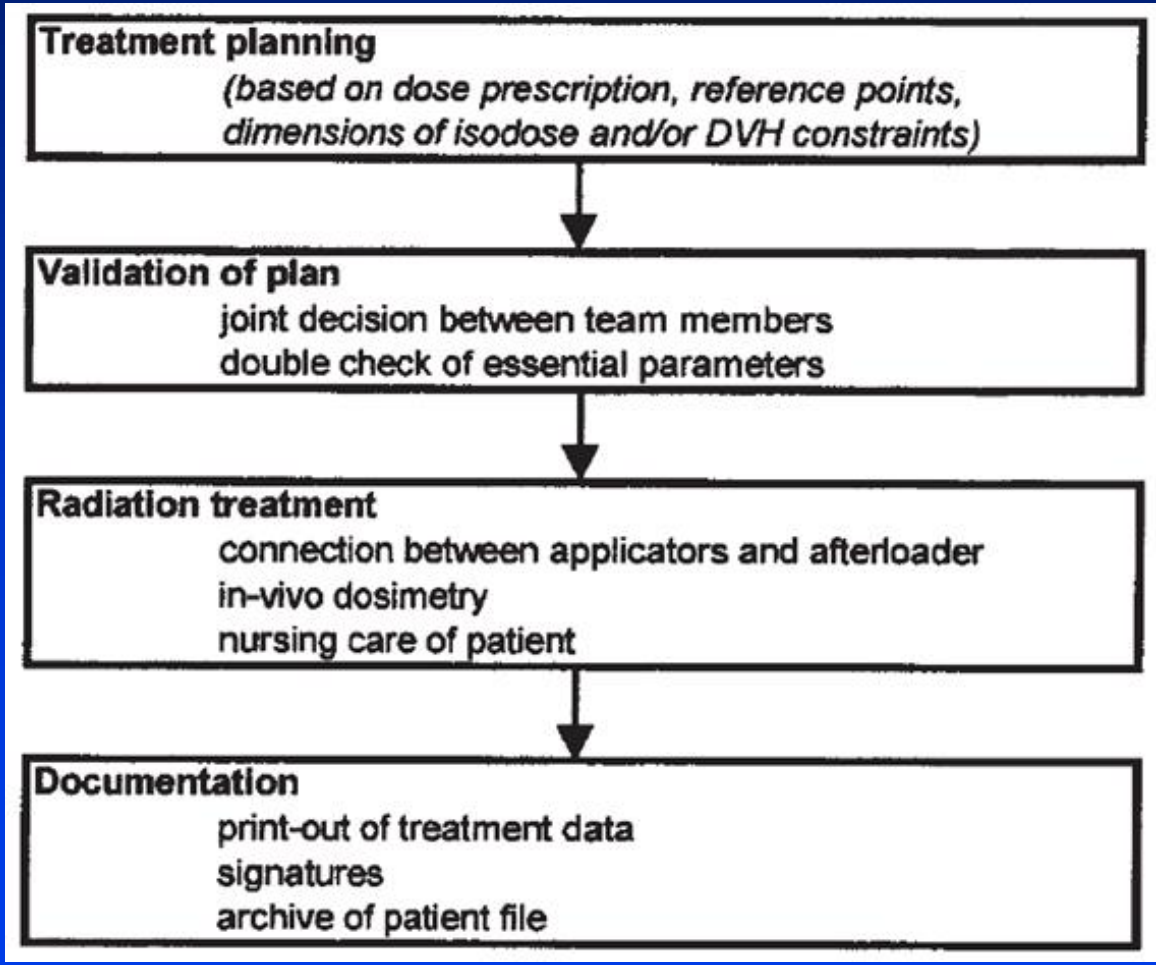
General flow scheme for a brachytherapy procedure: planning and treatment



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ICRU Report 89

Volume 13 No 1–2 2013

ISSN 1473-6691 (print)
ISSN 1472-3422 (online)

Journal of the ICRU

ICRU REPORT 89

Prescribing, Recording, and Reporting Brachytherapy for Cancer of the Cervix

ICRU 89 recommended prescribing, recording, and reporting levels

- Level 1: minimum requirements that should be followed by all centers, for all patients, and represents the minimum standard of treatment
- Level 2: advanced standards of dose planning and treatment that allows a more comprehensive and standardized exchange of information between centers and based on a more complete set of parameters

Example: Level 1 dose and delivery reporting for cervix brachytherapy

Dose reporting:

- TRAK
- Point A dose
- Recto-vaginal reference-point dose
- $D_{0.1cm^3}$ and D_{2cm^3} for the bladder and rectum

Dose delivery pattern:

- Absorbed-dose rate/dose per fraction
- Number of fractions
- Time between fractions
- (Pulse number, size, time, if PDR)
- Overall treatment time
- Total EQD2 dose

Source and dose calculation:

- Radionuclide and source model
- Source strength
- Dose-calculation algorithm

Level 2: additional dose and delivery reporting

Dose reporting for defined volumes:

- $D_{98\,\%}$, $D_{90\,\%}$, $D_{50\,\%}$ for the CTV_{HR}
- ($D_{98\,\%}$, $D_{90\,\%}$ for the CTV_{IR} if used for prescription)
- $D_{98\,\%}$ for GTV_{res}
- $D_{98\,\%}$ for pathological lymph nodes

Dose reporting OARs:

- Bladder reference point dose
- $D_{0.1cm^3}$, D_{2cm^3} for sigmoid[a]
- D_{2cm^3} bowel
- Intermediate- and low-dose parameters in bladder, rectum, sigmoid, bowel
  (*e.g.*, $V_{15\,Gy}$, $V_{25\,Gy}$, $V_{35\,Gy}$, $V_{45\,Gy}$ or $D_{98\,\%}$, $D_{50\,\%}$, $D_{2\,\%}$)
- Vaginal point doses at level of sources (lateral at 5 mm)[a]
- Lower- and mid-vagina doses (PIBS, PIBS $\pm$ 2 cm)[a]

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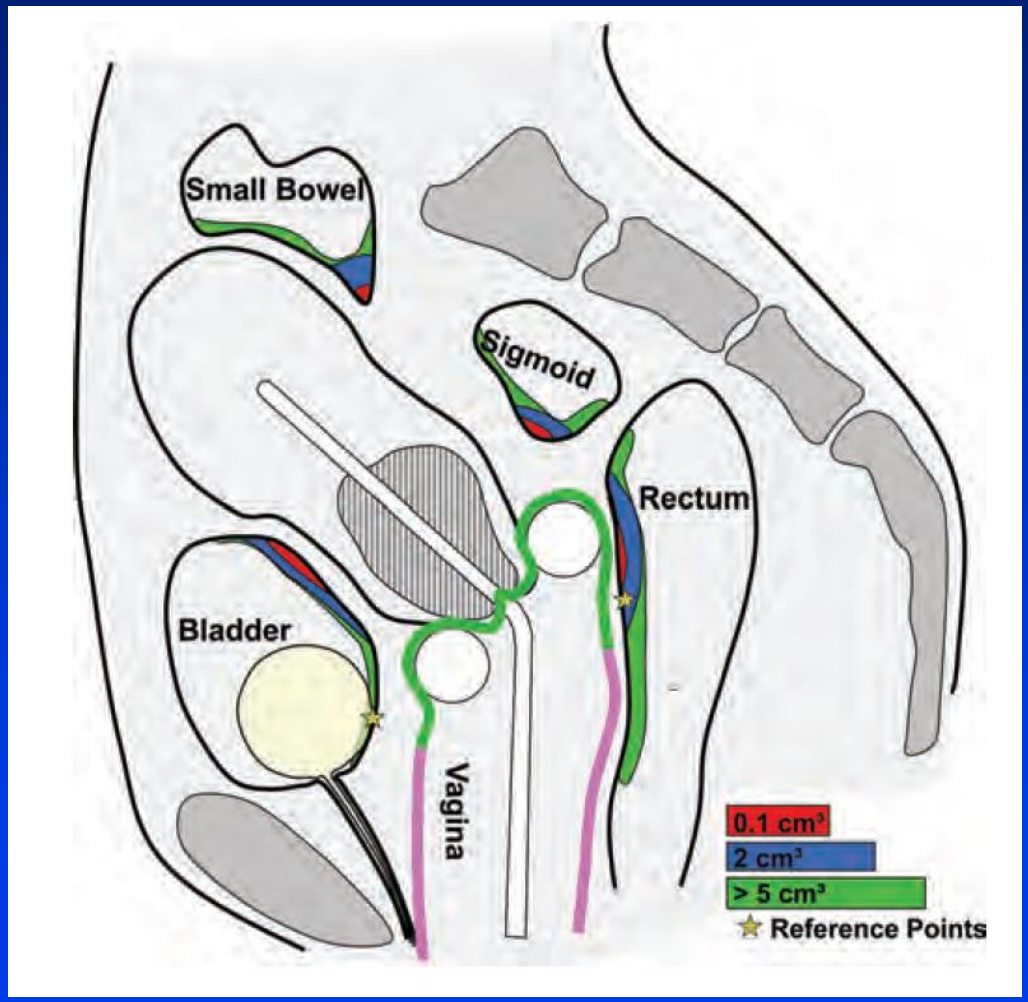
[a]Surrogate points for volumetric vaginal dose assessment.

Tissues imaged and planned in 3-D



Brachytherapy quality assurance

- Quality assurance program is needed to assure:
  - *safety of the patient, the public, and the staff*
  - *positional accuracy*
  - *temporal accuracy*
  - *dose delivery accuracy*

ESTRO Brachytherapy QA Guidelines

AAPM Report No. 59:
Code of practice for brachytherapy physics

RECOMMENDED QUALITY ASSURANCE PROGRAM FOR BRACHYTHERAPY EQUIPMENT

A. Manual afterloading brachytherapy
B. Remote afterloading brachytherapy devices
    1. Daily remote afterloader QA protocol
    2. Quarterly remote afterloader QA protocol
    3. Acceptance testing and annual remote afterloader QA
C. Quality assurance for treatment planning and evaluation systems

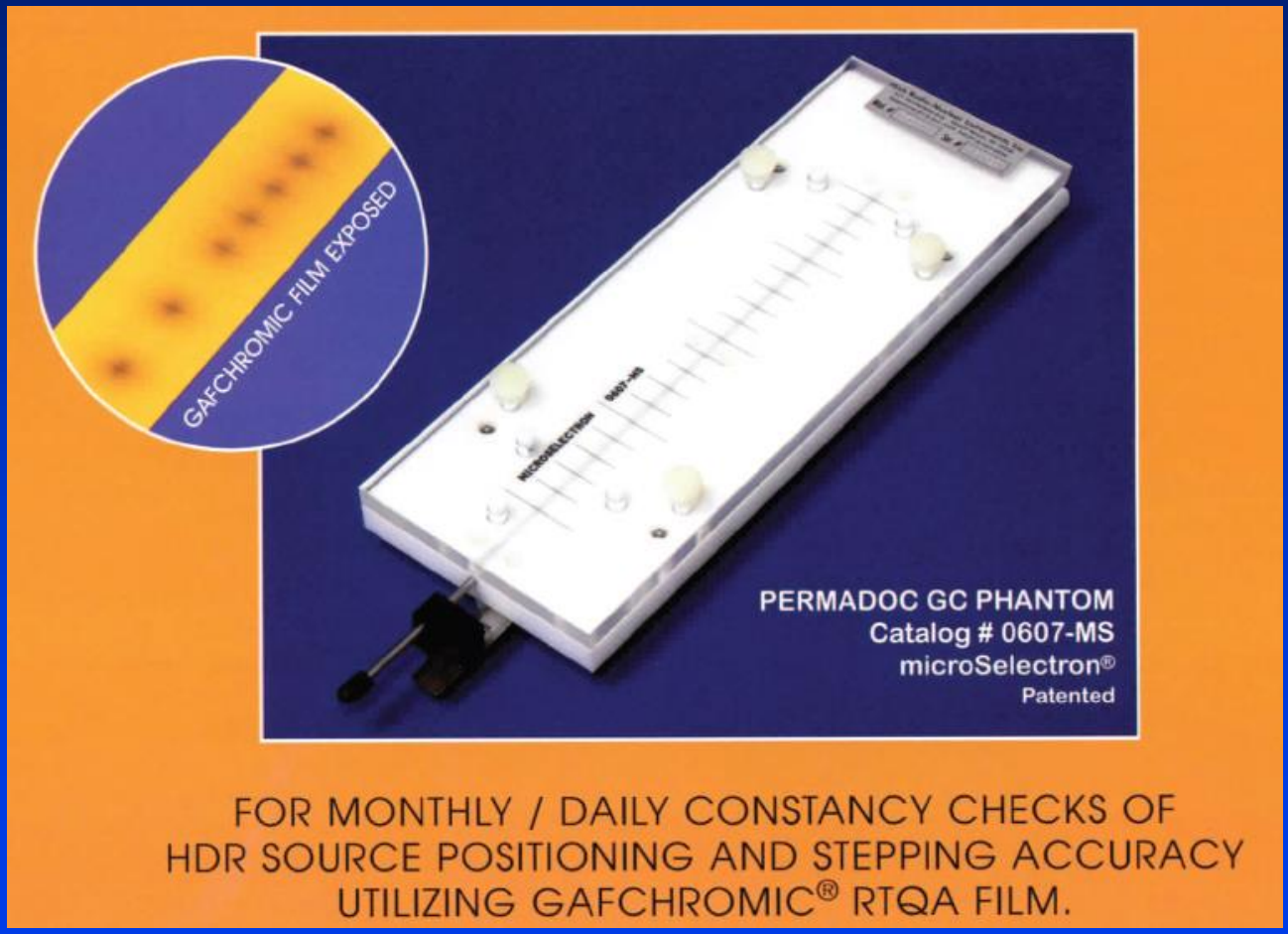
Safety of the patient, the public, and the staff

- Error avoidance
  - *clear prescriptions, equipment testing, patient identification, etc.*
- Emergency procedures
  - *training staff, availability of equipment, etc.*
- Radiation safety
  - *room shielding, control of sources, monitoring devices, interlocks, etc.*

Positional accuracy

- Machine programming parameters
  - *accurate transfer of positional data from treatment planning system to treatment machine*
  - *correct lengths, positions, channel numbers*
- Correct location of applicators, catheters, etc.
  - *for each patient treatment*
- Correct location of sources
  - *for each patient treatment*

Typical source positioning accuracy QA phantom



Temporal accuracy

- LDR
  - *need to assure that treatment is terminated once the prescribed dose is delivered*
- *Remote afterloading (LDR, PDR and HDR)*
  - *timer and dwell time accuracy*
  - *magnitude of transit dose*
  - *accurate transfer of temporal data from treatment planning system to treatment machine*

Dose delivery accuracy

- Physical aspects
  - *source strength calibration, accurate data in treatment planning computer, accurate decay correction, account for effect of applicator attenuation, etc.*
- Clinical aspects
  - *accuracy of anatomical data and transfer of that data to the treatment planning system*
  - *accuracy of planning system, optimization, etc.*

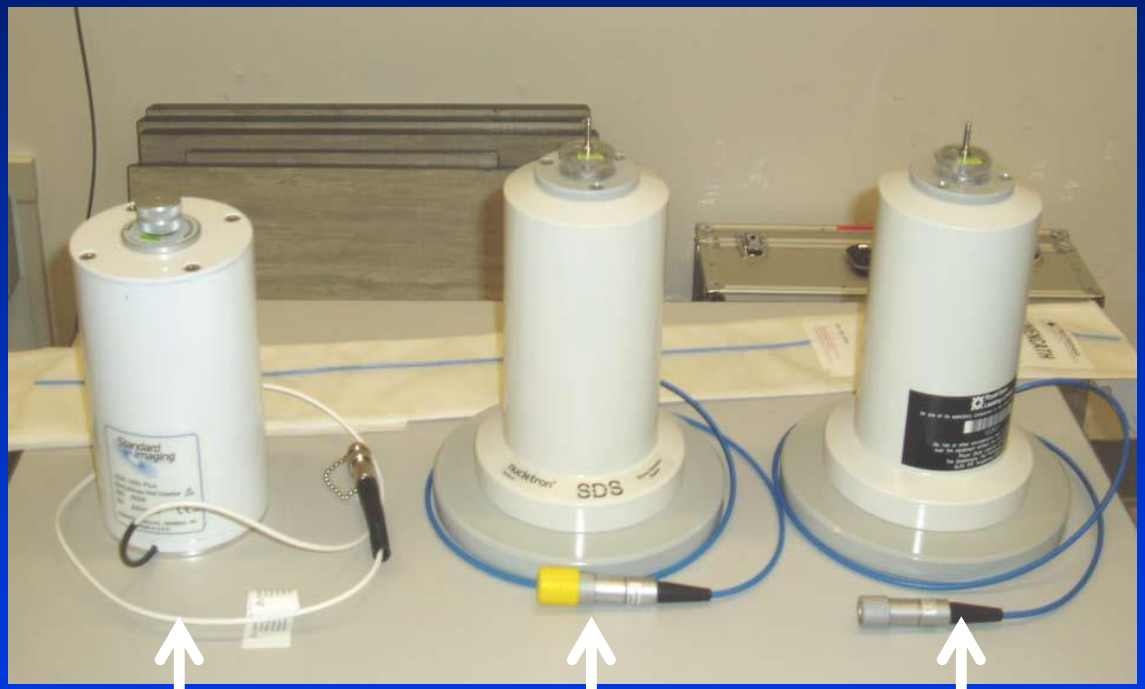
Source strength calibration

- Primary standards laboratories have developed advanced methods to calibrate different sources
- These are typically well beyond the scope of most users who need to check source strengths in-house

Source strength verification by the user

This is typically done using a well-type ionization chamber that has been calibrated by the primary standards laboratory or at a secondary standards lab using a method traceable to that at the primary lab

Typical well-type ionization chambers



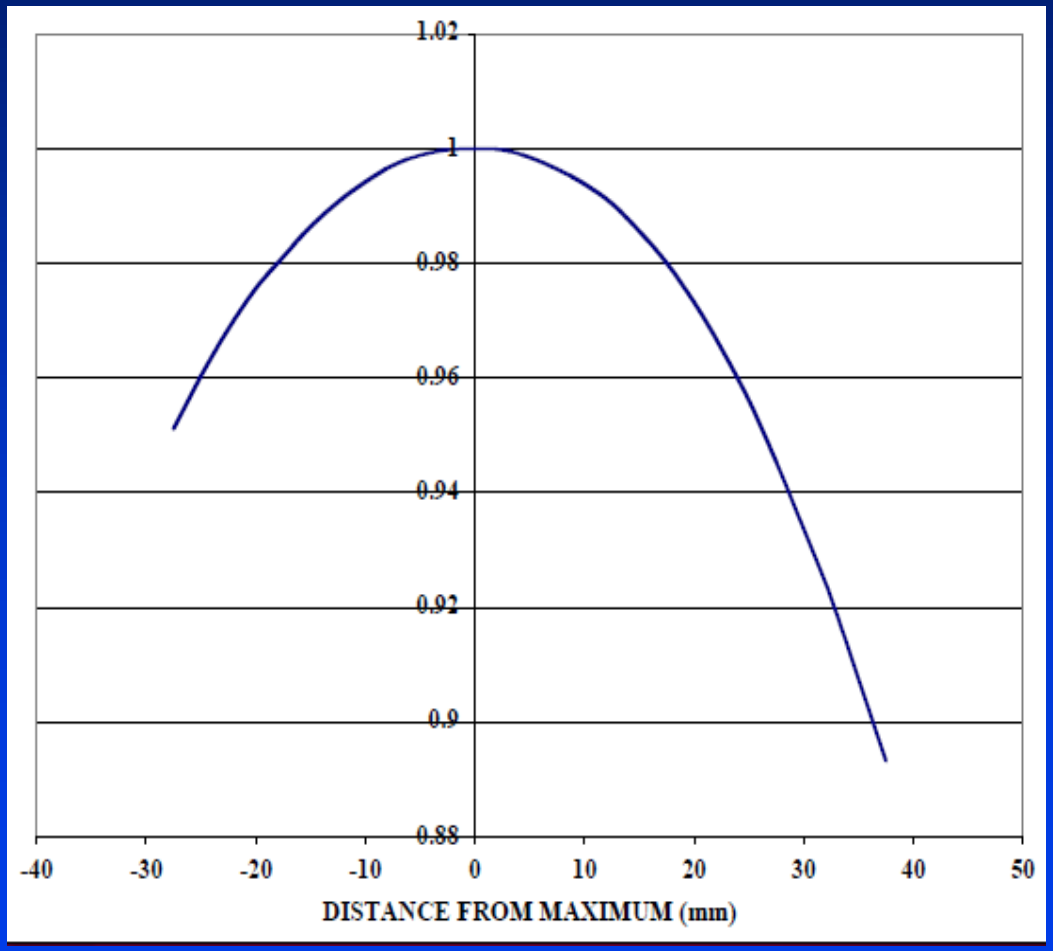
Standard Imaging Nucletron PTW

Data supplied by the calibration lab

- Sweet spot location
- Air kerma strength calibration factor for the chamber
- Source used for the calibration
- Irradiation conditions
- Traceability to national calibration lab

Sweet spot location

The location of the sweet spot on the central axis of the chamber is determined by moving a single source and taking multiple readings



Pre-treatment brachytherapy QA for each patient

- Check for completeness of printed information
- Check for consistency of plan with treatment prescription
- Double check of data by independent second person
- If possible perform (simple) manual calculation of treatment time
- Signing of document before treatment starts by physician and physicist

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Summary

- Classical systems little used today except for the Manchester System for cervix cancer
- Computerized planning now used with advanced imaging
- QA program for delivery and planning equipment, input and output data, essential to assure safety and accuracy