Radiation Oncology

Residency Lectures

in Physics

HDR Brachytherapy

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Radiation Therapy: Brachytherapy vs. Teletherapy

Teletherapy describes "at a distance" (*tele-*) treatment

Teletherapy radiation machines locate an external radiation source at a large distance, 50 cm to 100 cm or more, from the tissue to be treated.

Brachytherapy

denotes "short" distance (*brachy-*) treatment

Brachytherapy source or sources are placed in or immediately adjacent to the tissue to be treated

Types of Brachytherapy

1. Interstitial
2. Intracavitary
3. Intraluminal
4. Surface molds (plaques)

How are brachy sources introduced?

1. Manual Loading
2. Afterloading
3. Remote Afterloading

LDR (low dose rate): 0.4 to 1 Gy/hr

MDR (medium dose rate): 1 to 60 Gy/hr

HDR (high dose rate): >60 Gy/hr

LDR

Advantages

- 100 years of experience
- doses/effects well established
- therapeutic ratio* possibly superior to HDR

Disadvantages of LDR

- inpatient hospital stay
- radiation exposure to staff and visitors
- Morbidity due to extended bedrest
- large number of sources in inventory

HDR

Advantages

•Optimization of dose distribution

•Reduced risk of morbidity due to immobilization

•No radiation dose to family/caregivers

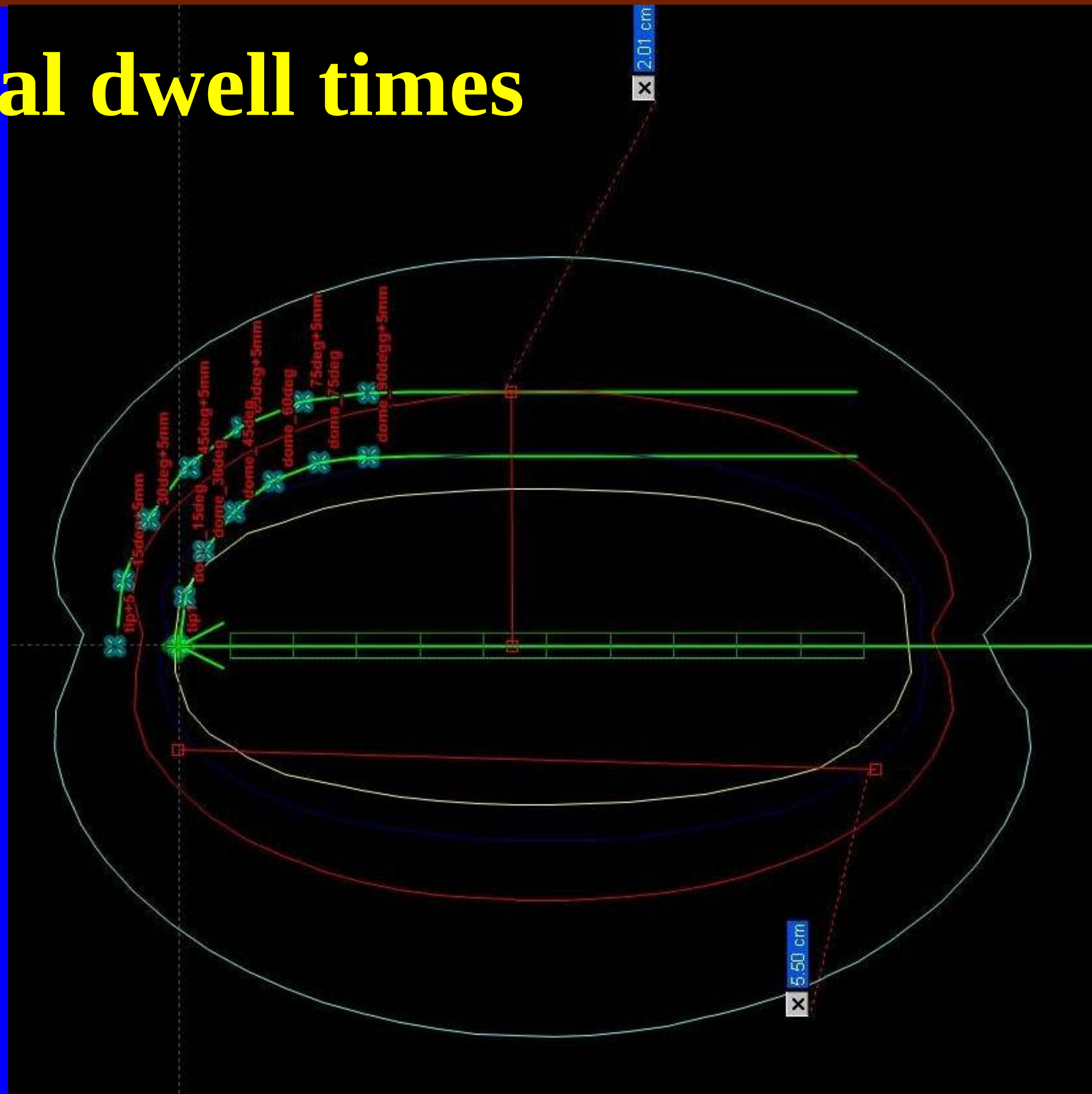
Only one source in inventory

Disadvantages of HDR

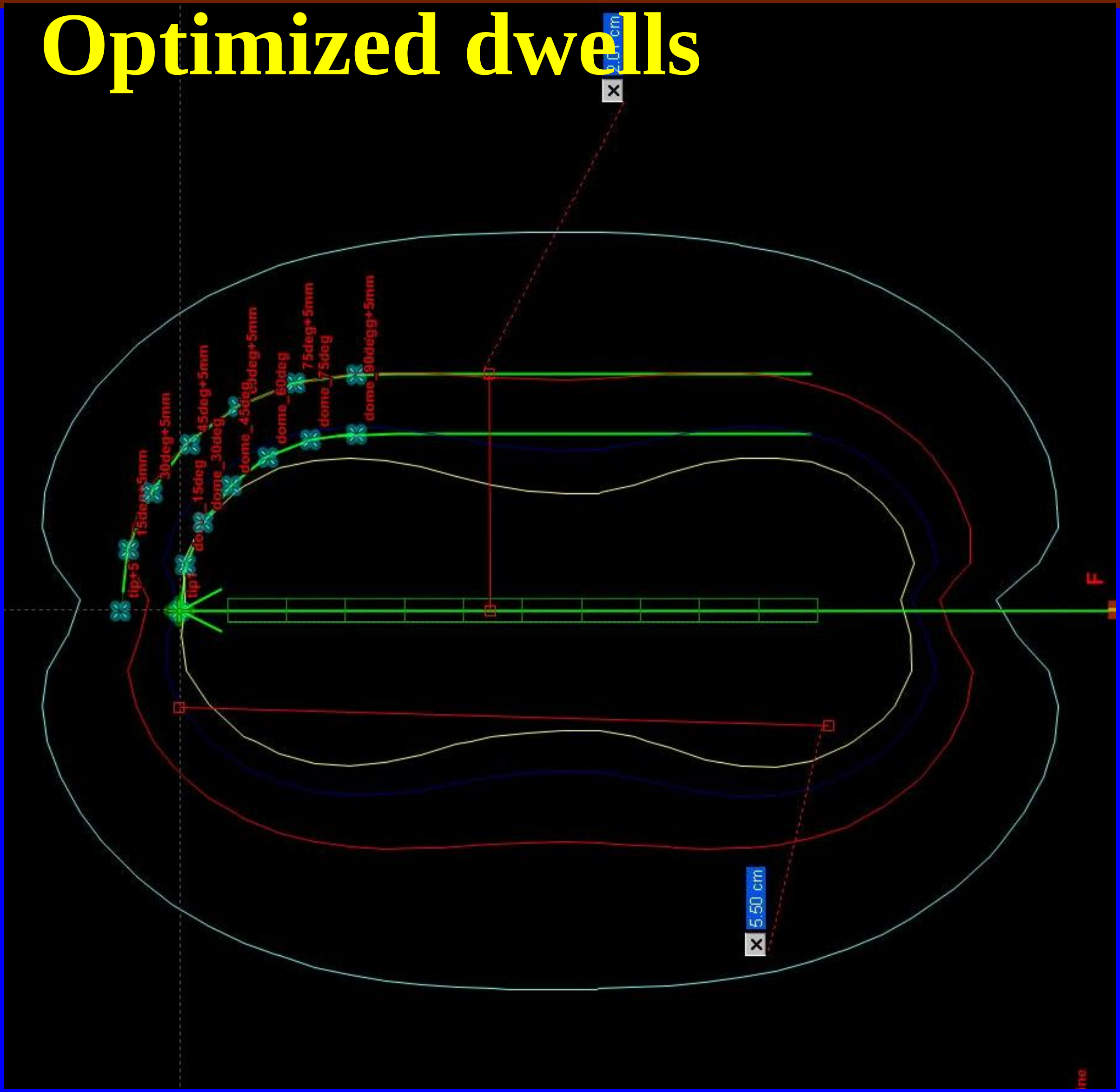
- Fractionated treatments (typically 3-10)
- Doses not as well established as LDR
- (?) Increased late effects compared to LDR(?)

The primary advantage of HDR is the possibility of dose optimization using a stepping-source technology as opposed to the static sources of LDR.

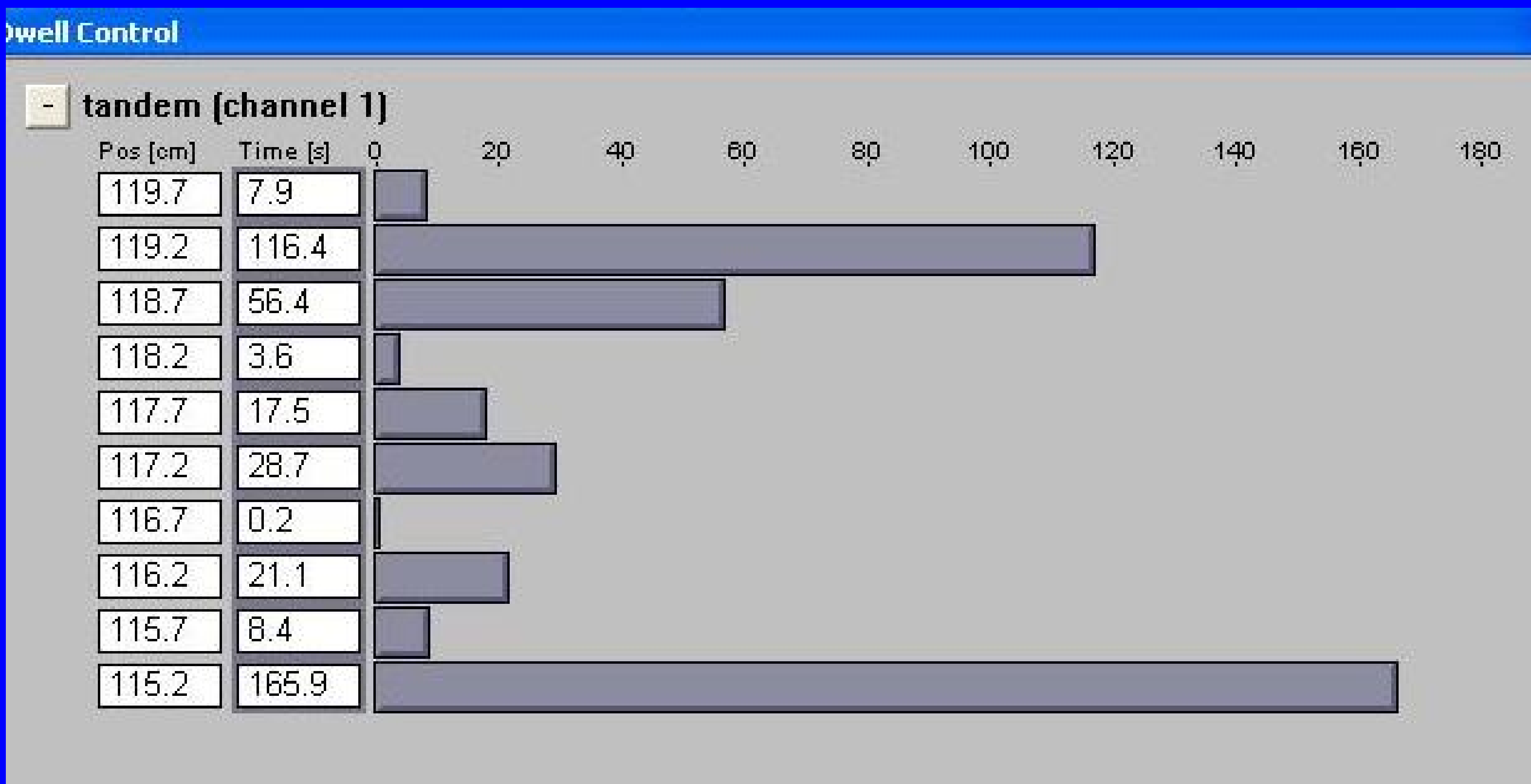
Equal dwell times



Optimized dwells



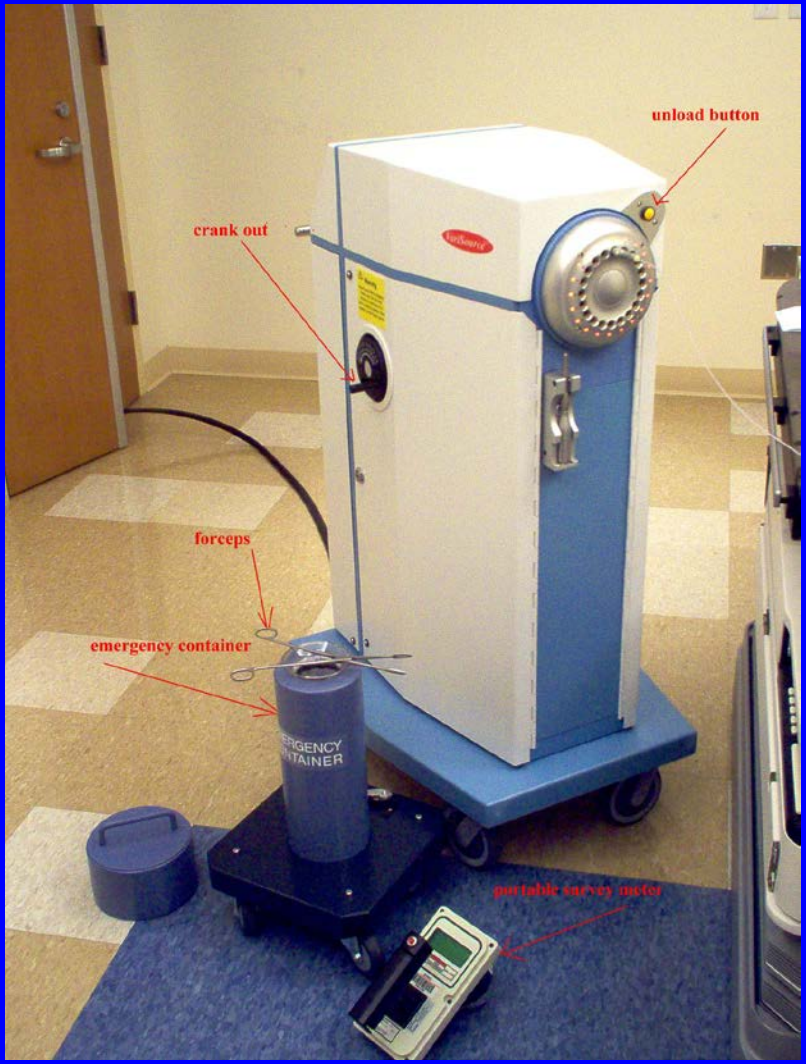
Optimized dwell times




ESC

SELECTRON
nucletron
printer
length
time
position
active
spacer
cancel
alarm
normal mode
special mode

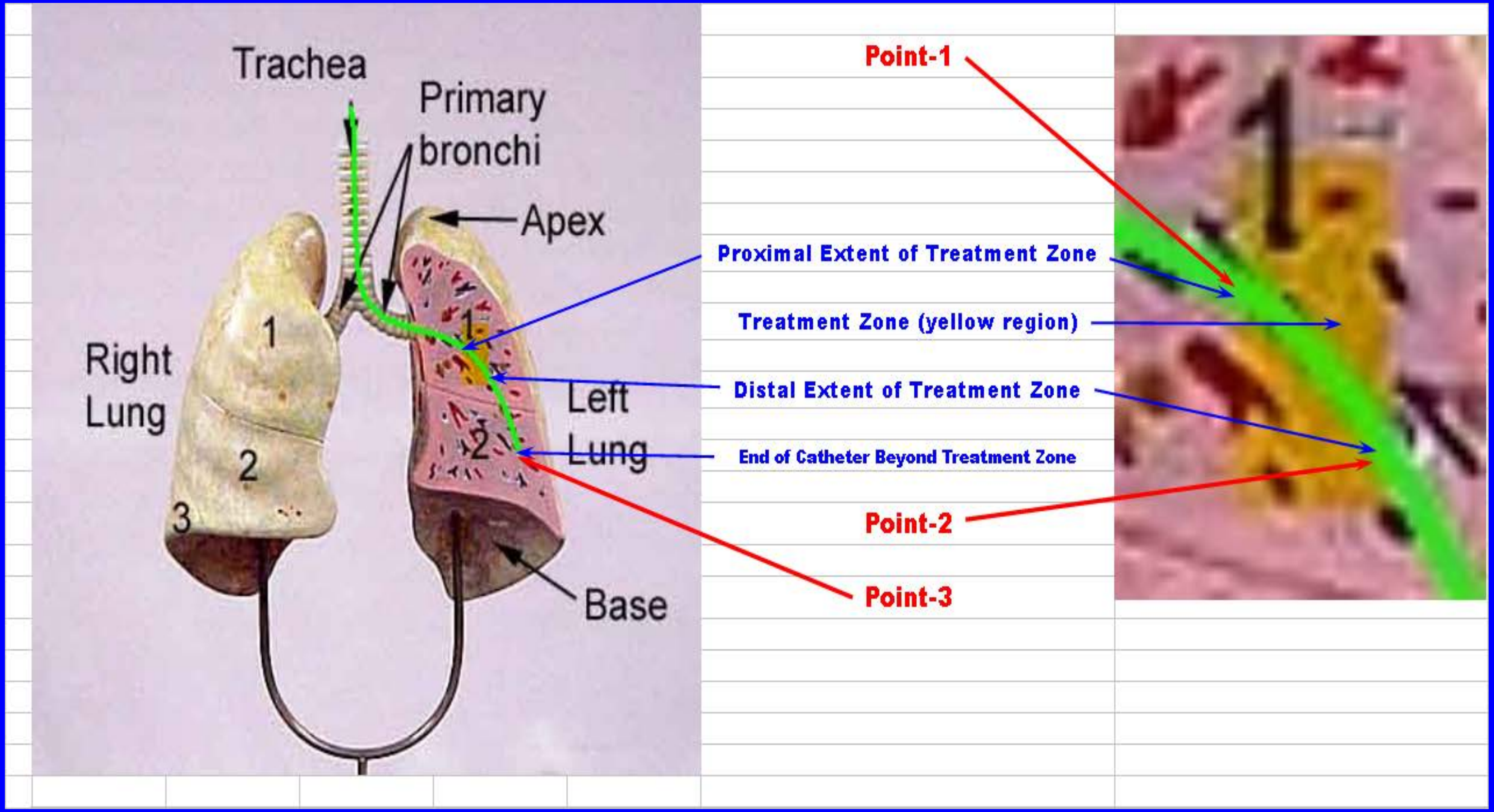
Varisource VS200



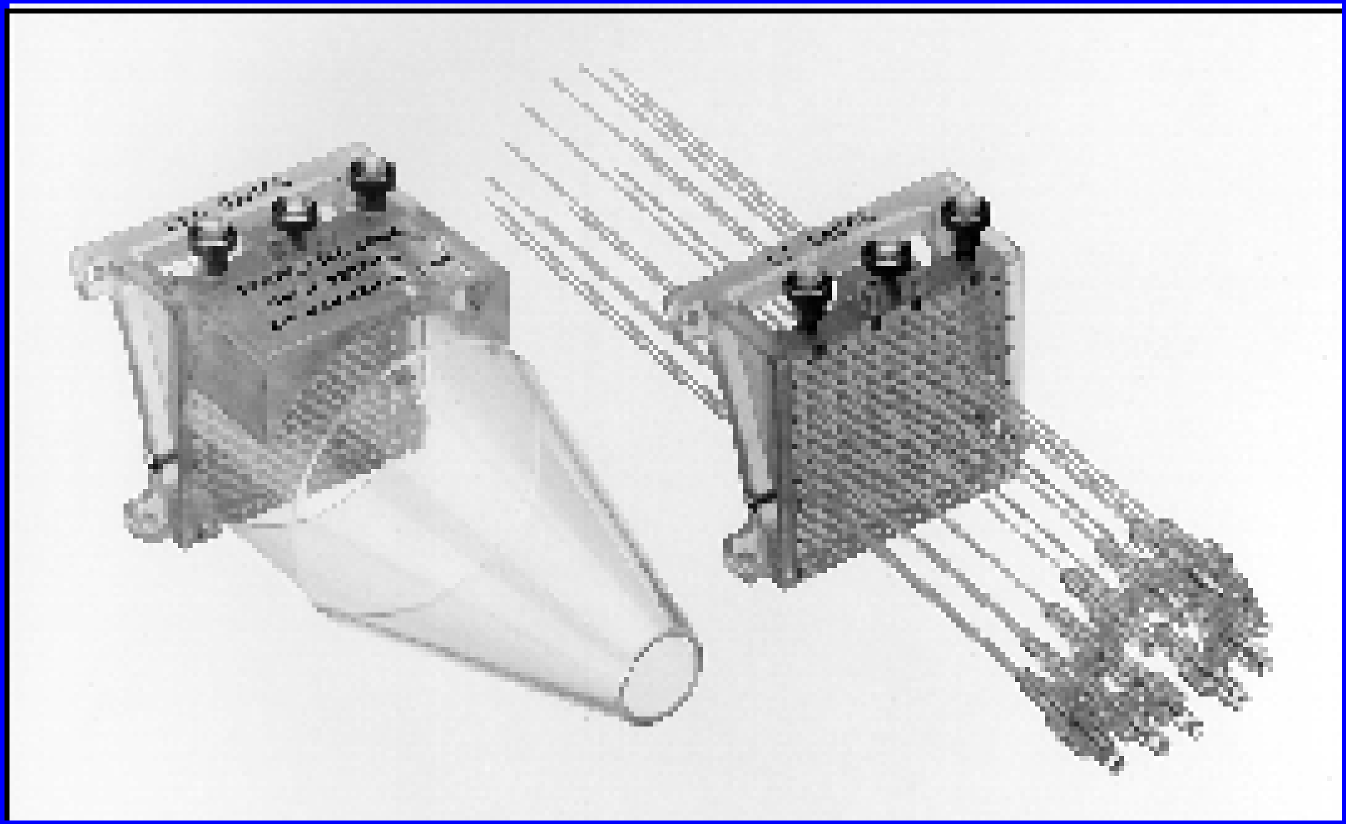
Popular HDR Procedures

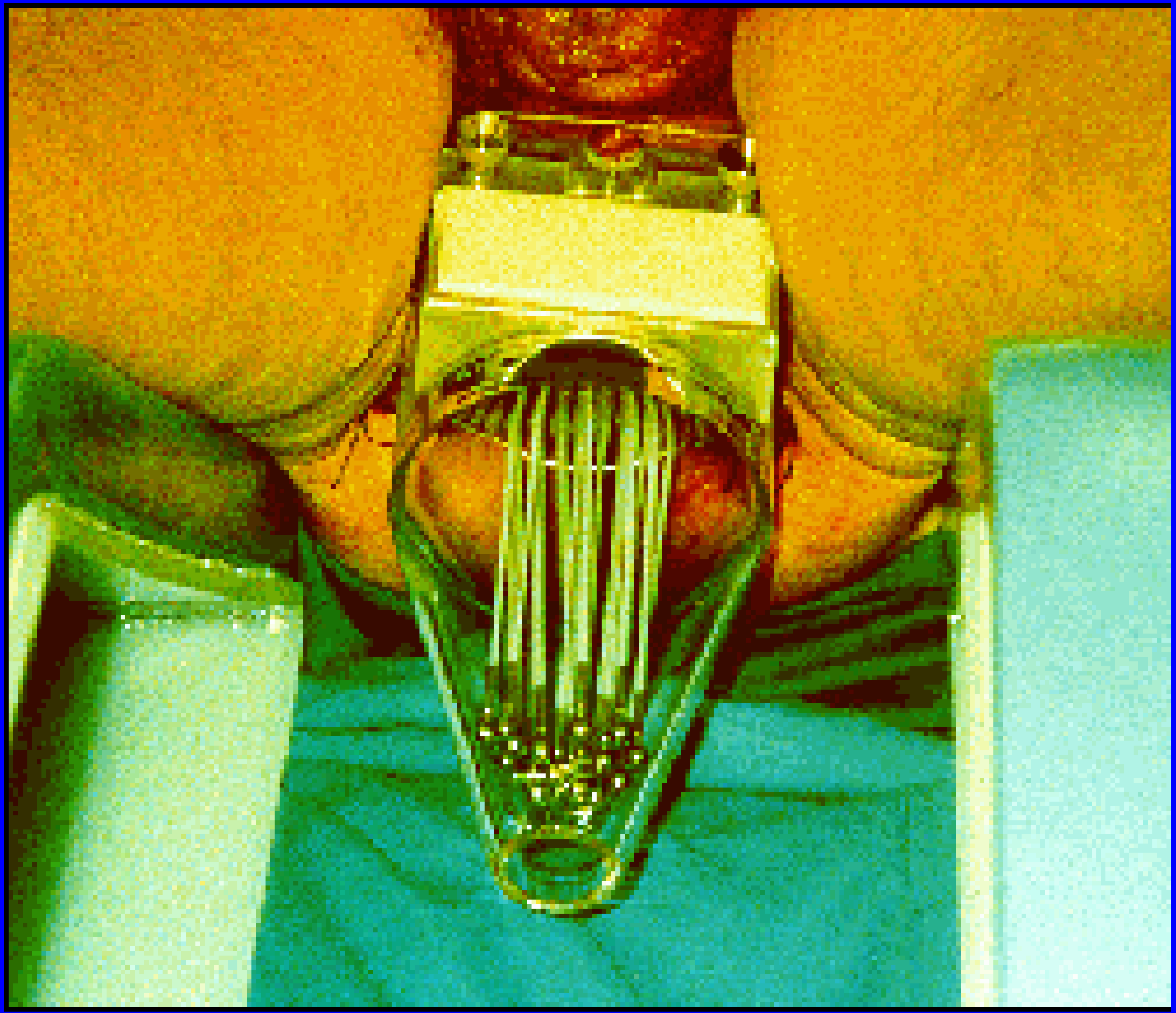
1. Endobronchial
2. Prostate
3. Gyn; SF and vaginal cylinder, template
4. Breast template
5. MammoSite

Endobronchial HDR



Mick HDR template





beyond a peripheral flexiguide. This approach had the effect of creating a treatment volume that was based upon: (1) the TRUS prostate and seminal vesicle anatomy; (2) the clinical and radiological determination of the extent of disease; (3)

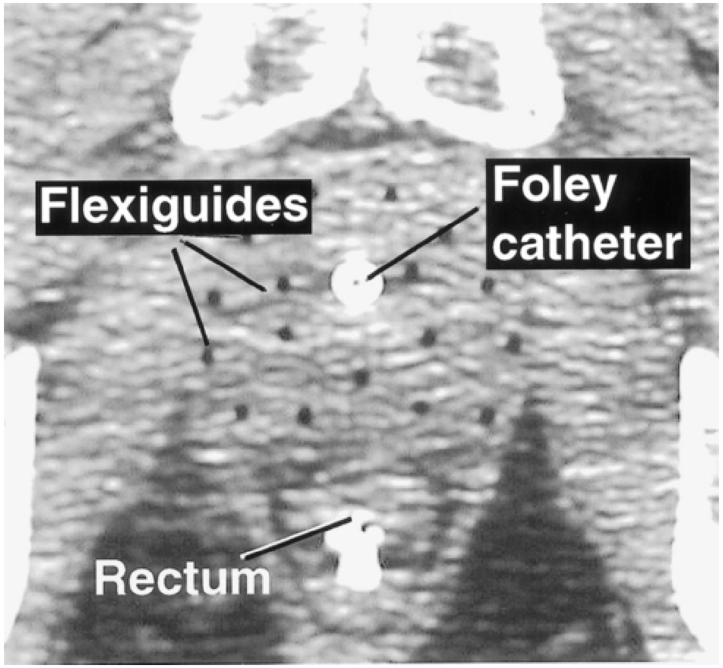


Fig. 8. CT showing 17 flexiguides, urethra and rectal contrast. Note the position of catheter #15 is displaced posterior from central row to form the 'central' flexiguide in the posterior plane of the implant.

disease (Fig. 9). This has been verified by duplicating the dosimetry using Nucletron's 3D PLATO software and evaluating the 100% isodose 'cloud' for complete coverage of the target volume.

After the dose was calculated, further refinement in the dosimetry was achieved by manual dwell time adjustment. We observed the uniformity of doses to the prostate and the maximum doses delivered to various patient (normal tissue) points. When prostate doses required refinement or patients points exceeded the allowable levels, the dosimetrist used the 'dose verification to a point' option to evaluate which

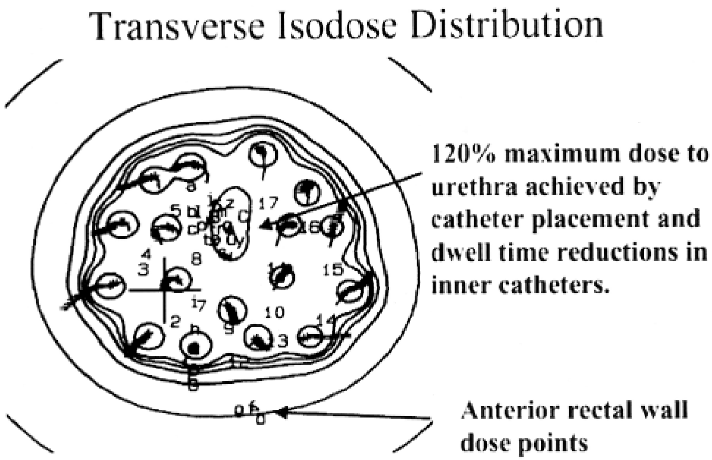


Fig. 9. Transverse representation of isodosimetry of the mid implant.

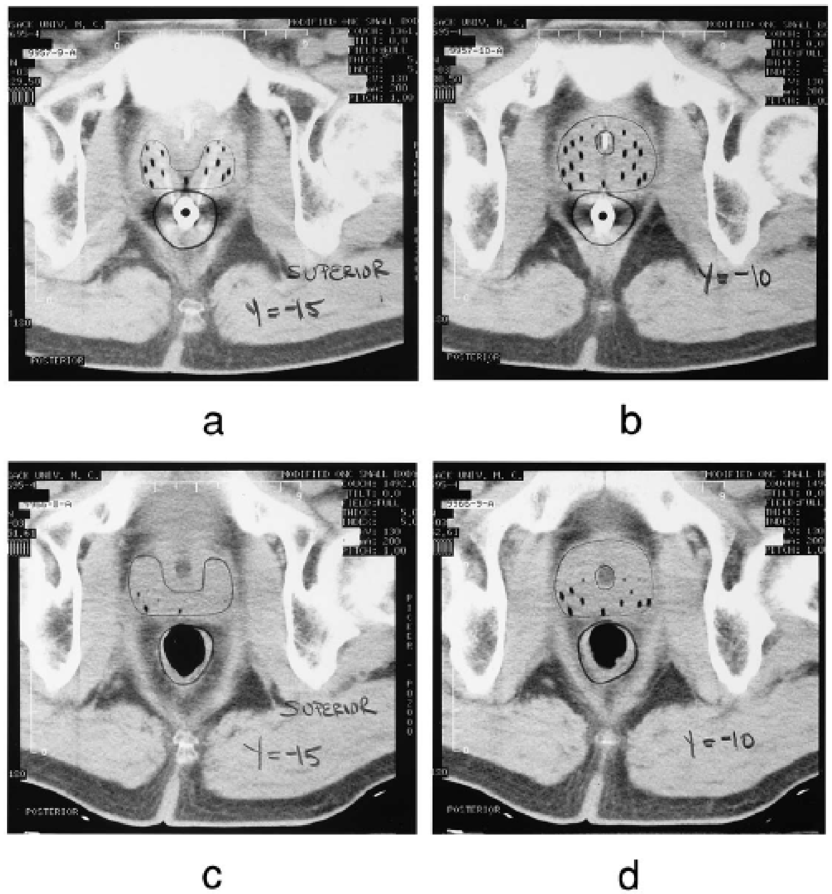
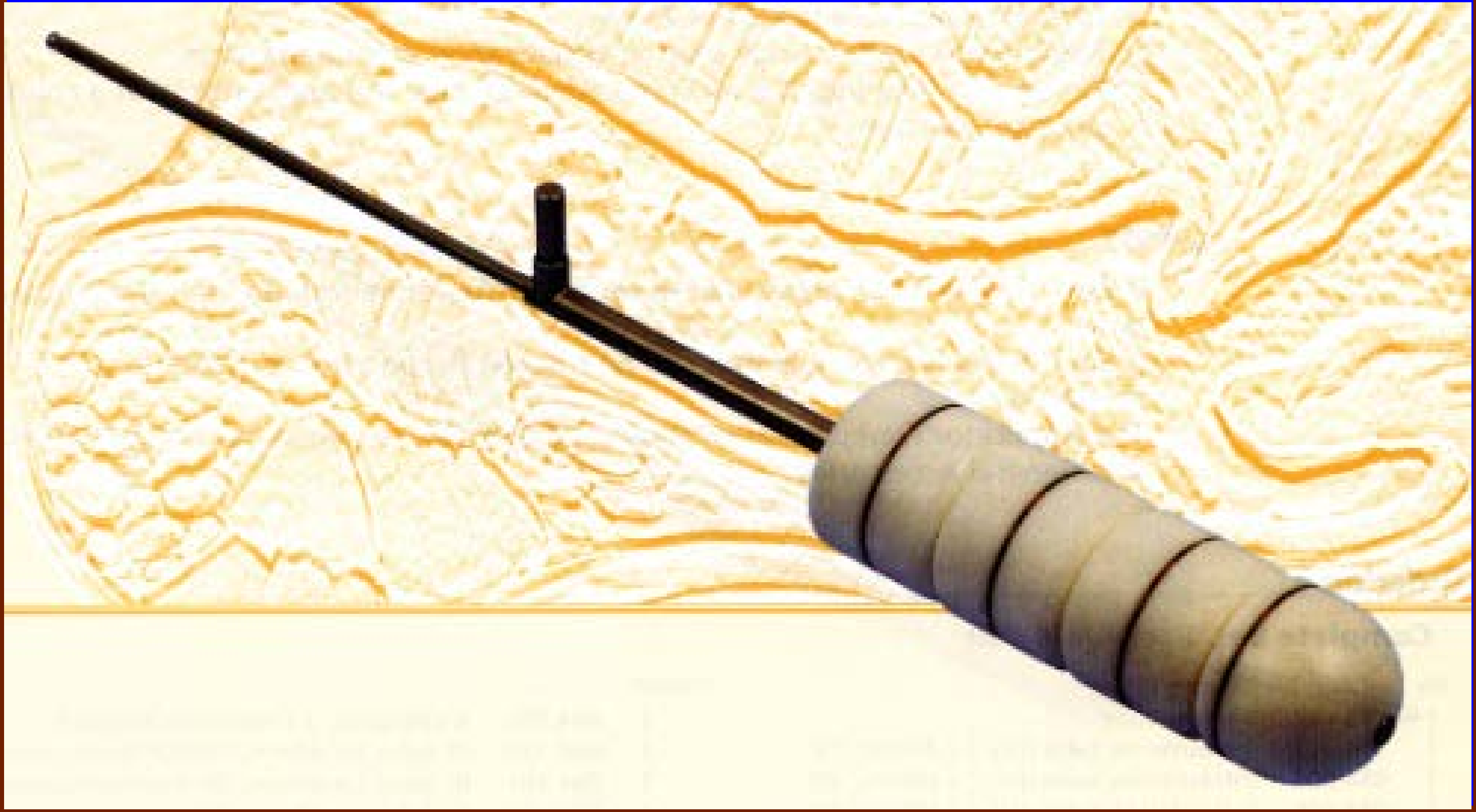


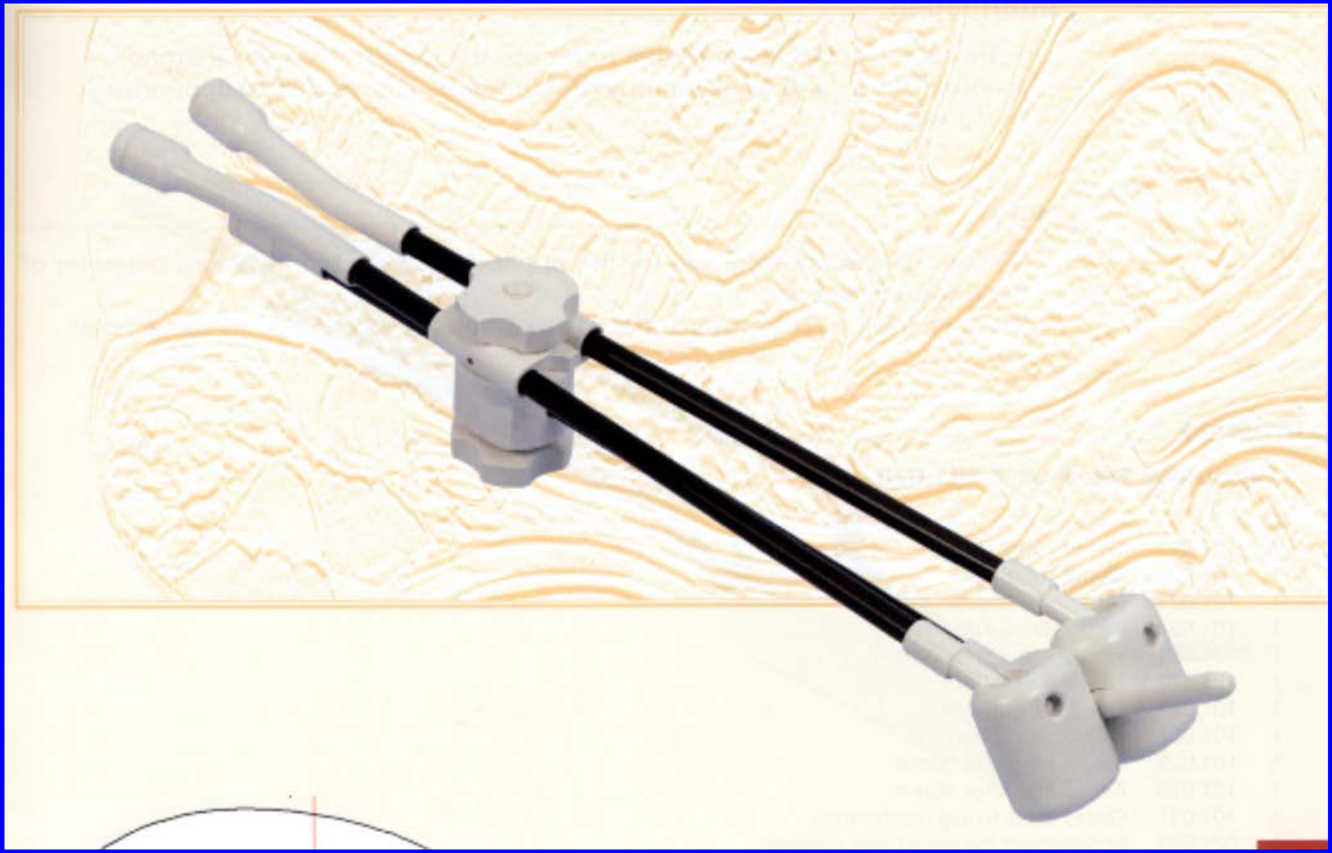
Fig. 3. Serial CT cuts of prostate base demonstrating caudal displacement of catheters. (a,b) Initial CT scans. (c,d) Second CT scans.

Vaginal cylinder for HDR

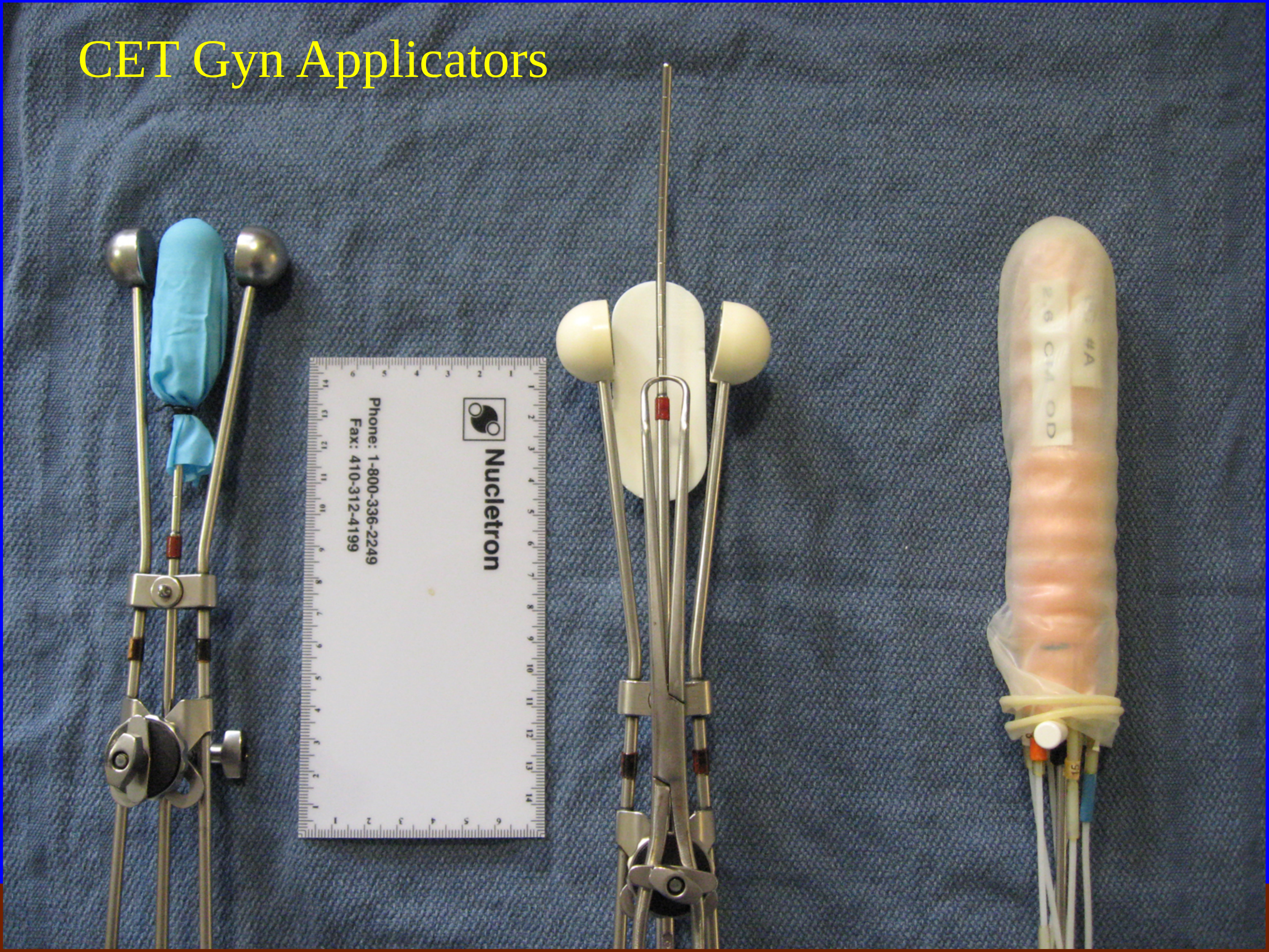


Demanes-Rodrigues Applicator for HDR

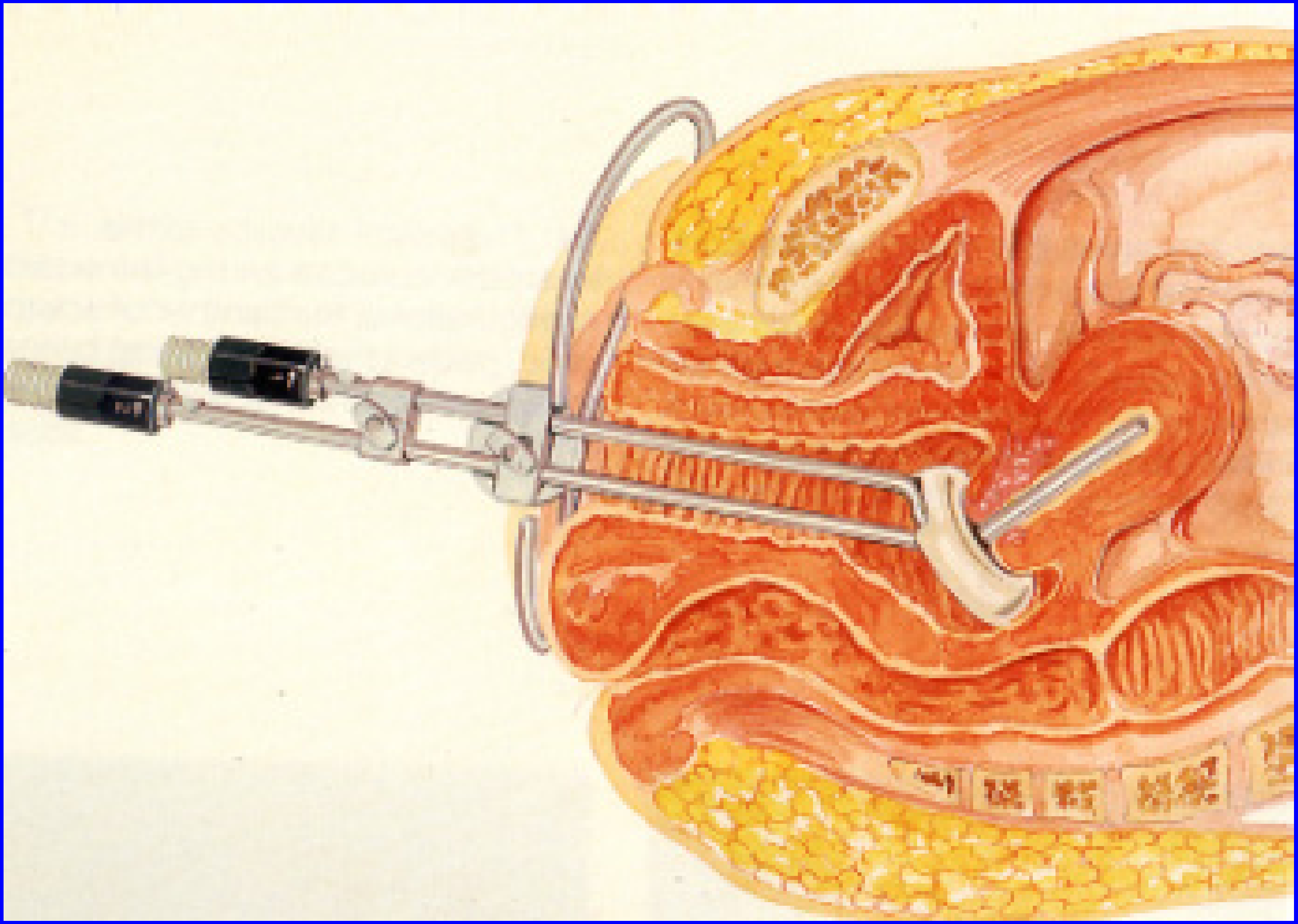
CT/MRI compatible FSD applicator for HDR



CET Gyn Applicators



Ring applicator



Smit sleeve
for fractionated HDR treatments

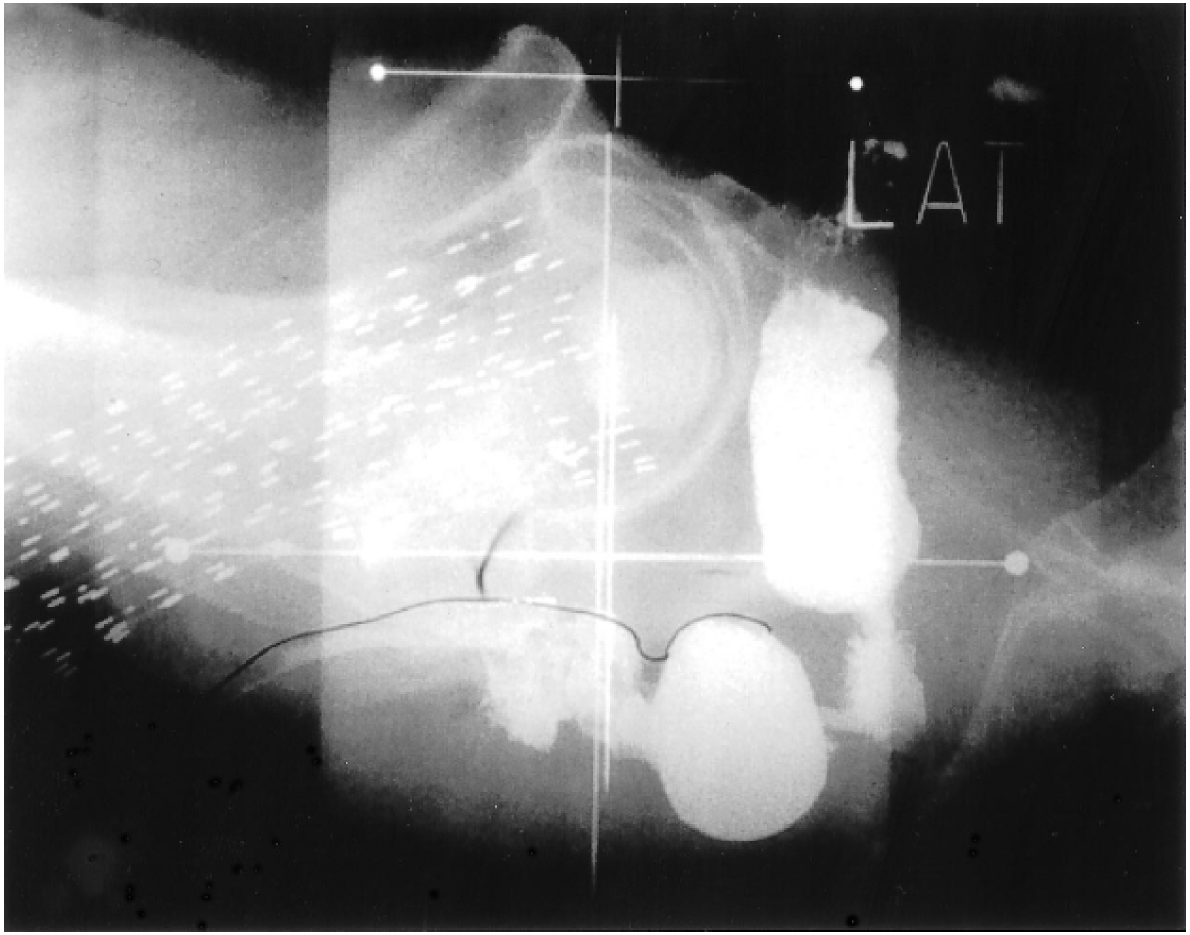
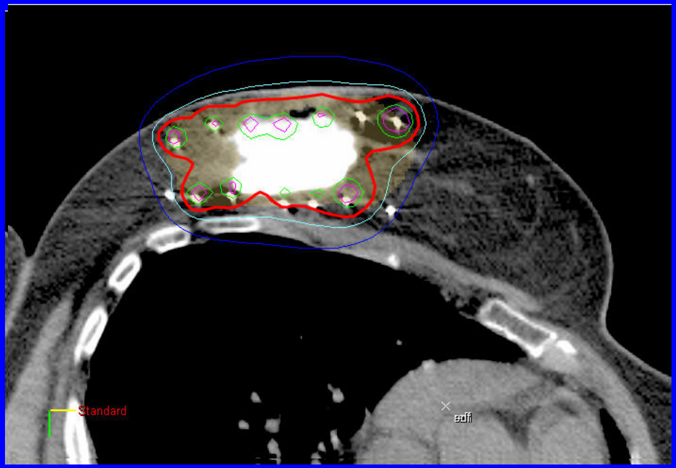


Fig. 7. Lateral simulation radiograph, showing tungsten 'dummy' ribbons, Foley catheter and rectal barium.

Breast Irradiation Technique

Interstitial Multi-Catheter

- Treats lumpectomy margin
- Effective in properly selected patients
- Can be challenging technically[1]
- Optimal results require extensive operator and institutional experience[1]

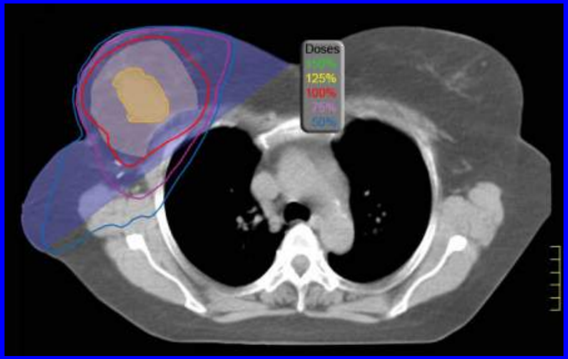


[1]Shah N, Tenenholz T, Arthur D, DiPetrillo T, et al. MammoSite and Interstitial Brachytherapy for Accelerated Partial Breast Irradiation. *Cancer.* 101: 727-734; 2004.

Investigational PBI Technique

3D CRT

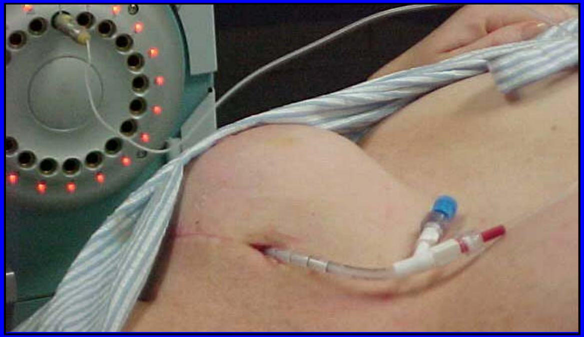
- 3 - 5 non-coplanar beams
- No IMRT or bolus allowed
- No beams direct towards critical structures
- PTV = 2.5cm margin + 0.5cm margin for penumbra
- 3.85 Gy/fx, 10 fx, BID (38.5 Gy total dose)

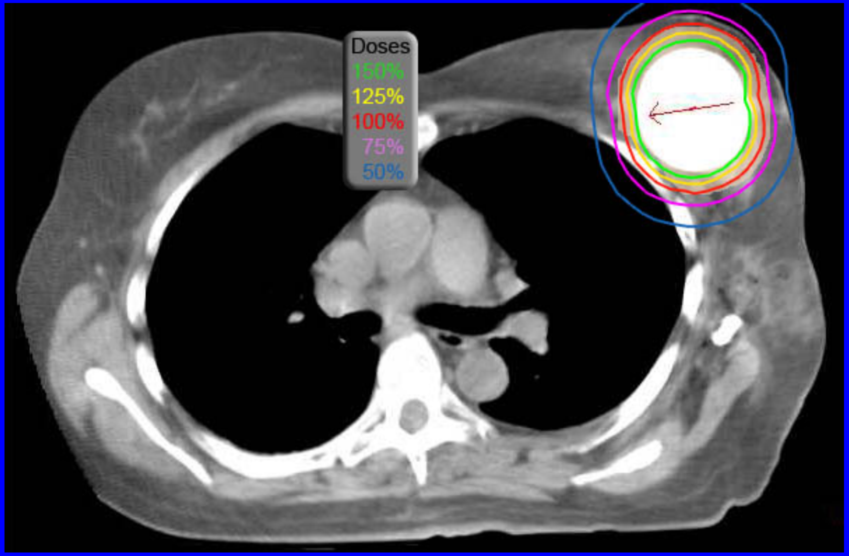


Breast Irradiation Technique

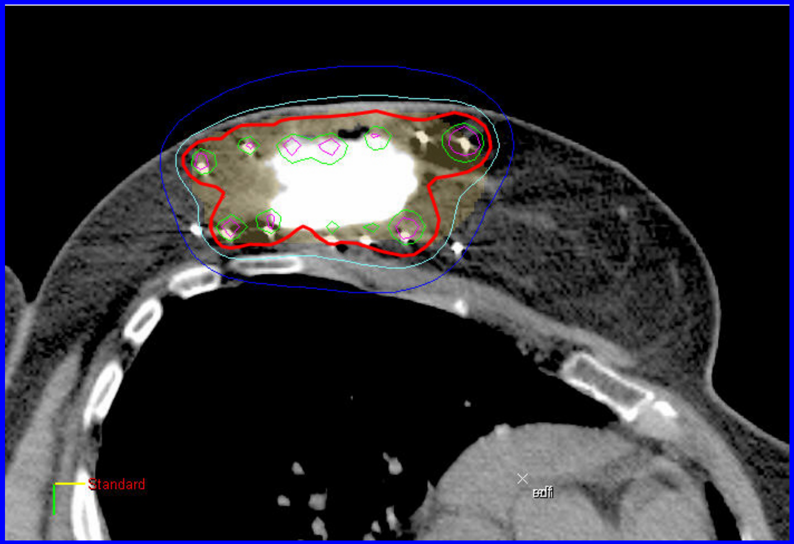
MammoSite

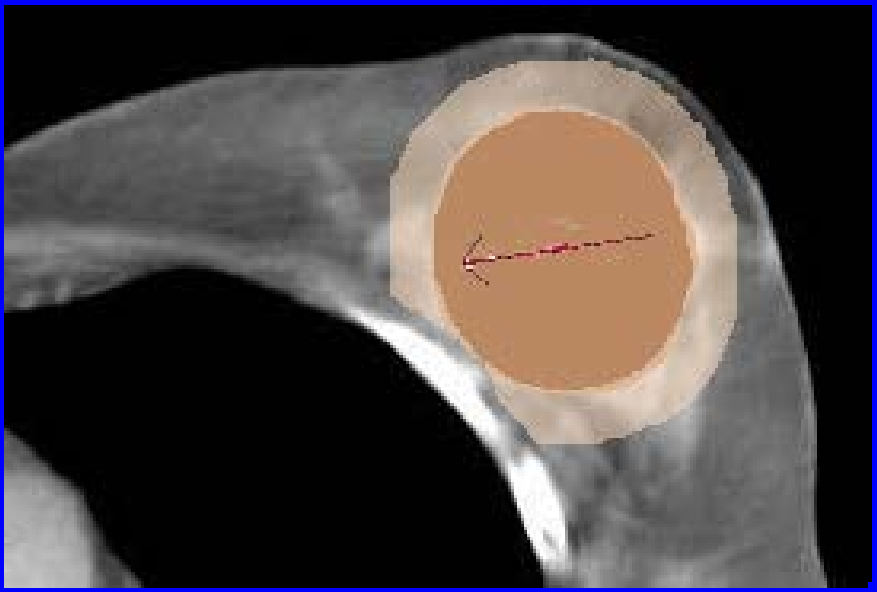
- Distends cavity
- Very conformal
- Prescription limited by doses to skin and balloon surface





Treatment Volumes: Multiple Catheter / MammoSite® RTS



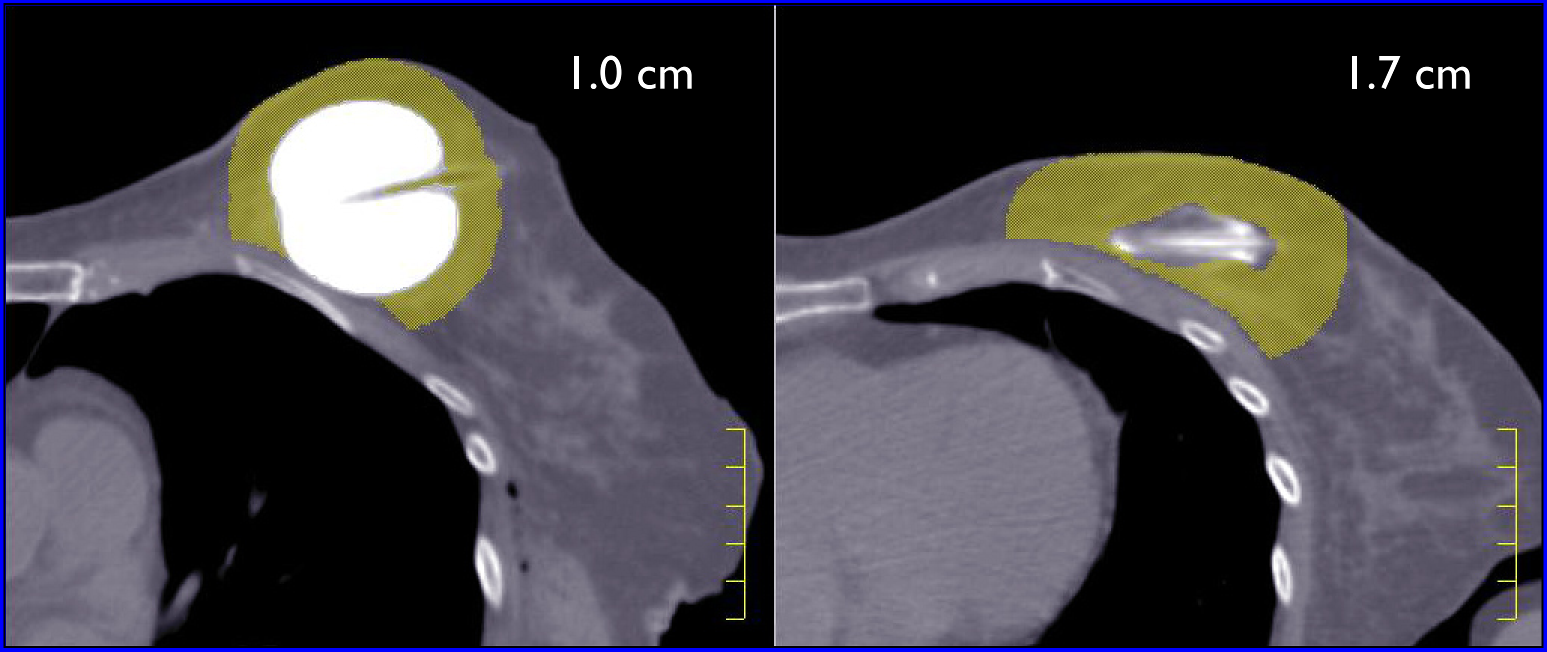


Treatment Volume of mulitcatheter implant: a 2 cm margin around the lumpectomy cavity, excluding the chestwall and 0.5 cm of tissue below the skin.

Treatment Volume of MammoSite: a 1 cm margin around the balloon surface, excluding the chestwall and balloon volume.

Effective Depth of Treatment[1,2]

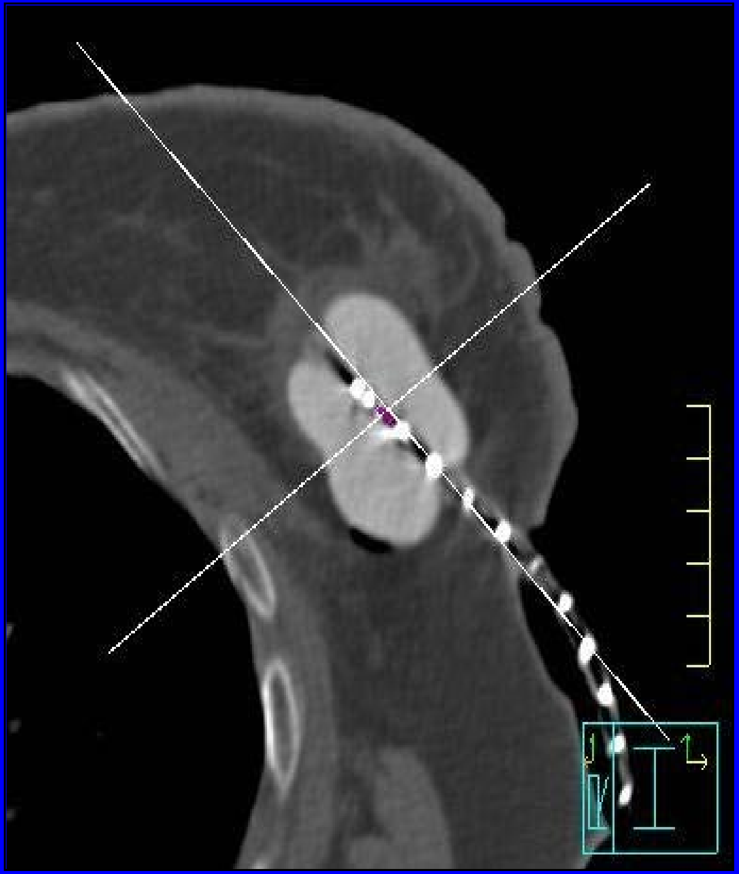
- Before, after deflation
- Shaded volumes are equal



[1]Edmundson GK, Vicini FA, Chen PY, Mitchell C, Martinez AA. Dosimetric Characteristics of the MammoSite RTS, A New Breast Brachytherapy Applicator. *Int. J. Radiation Oncology Biol. Phys.* 52: 1132-1139; 2002
[2]Dickler A, Kirk M, Choo M, et al: Treatment Volume and Dose Optimization of MammoSite Breast Brachytherapy Applicator. *Int J Radiat Oncol Biol Phys* 59: 469-474, 2004.

Not Appropriate for Treatment

- Significant balloon distortion due to inappropriate cavity selection

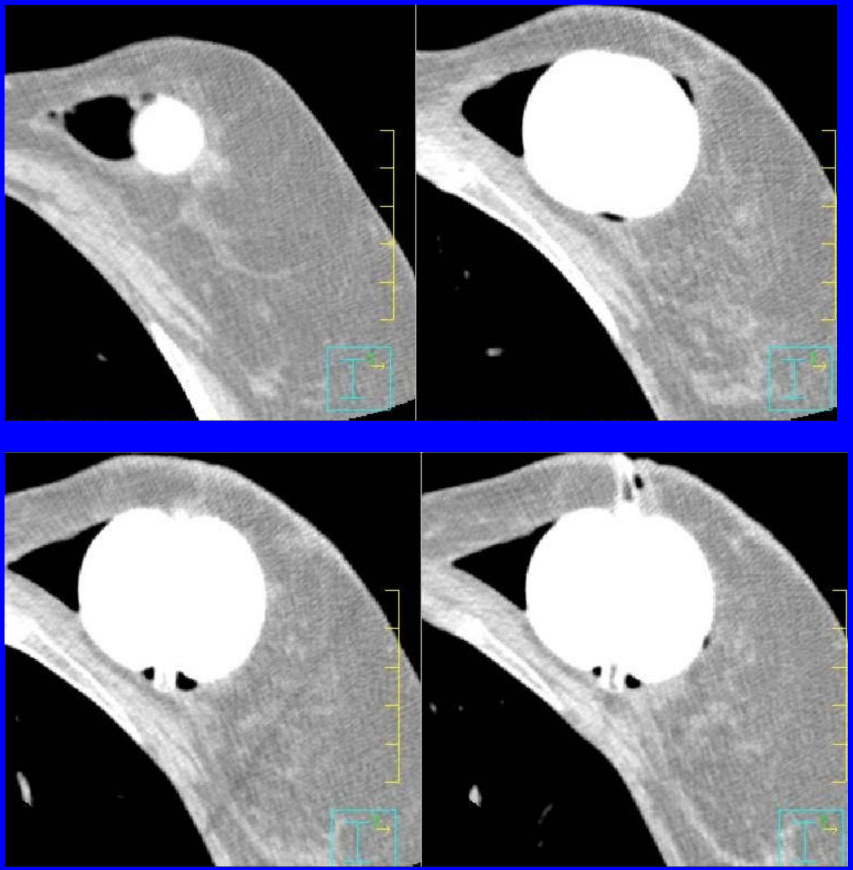


Appropriateness for Treatment: Balloon to Skin Spacing

Skin reaction due to minimal skin spacing

Appropriateness for Treatment: Tissue/Balloon Conformance

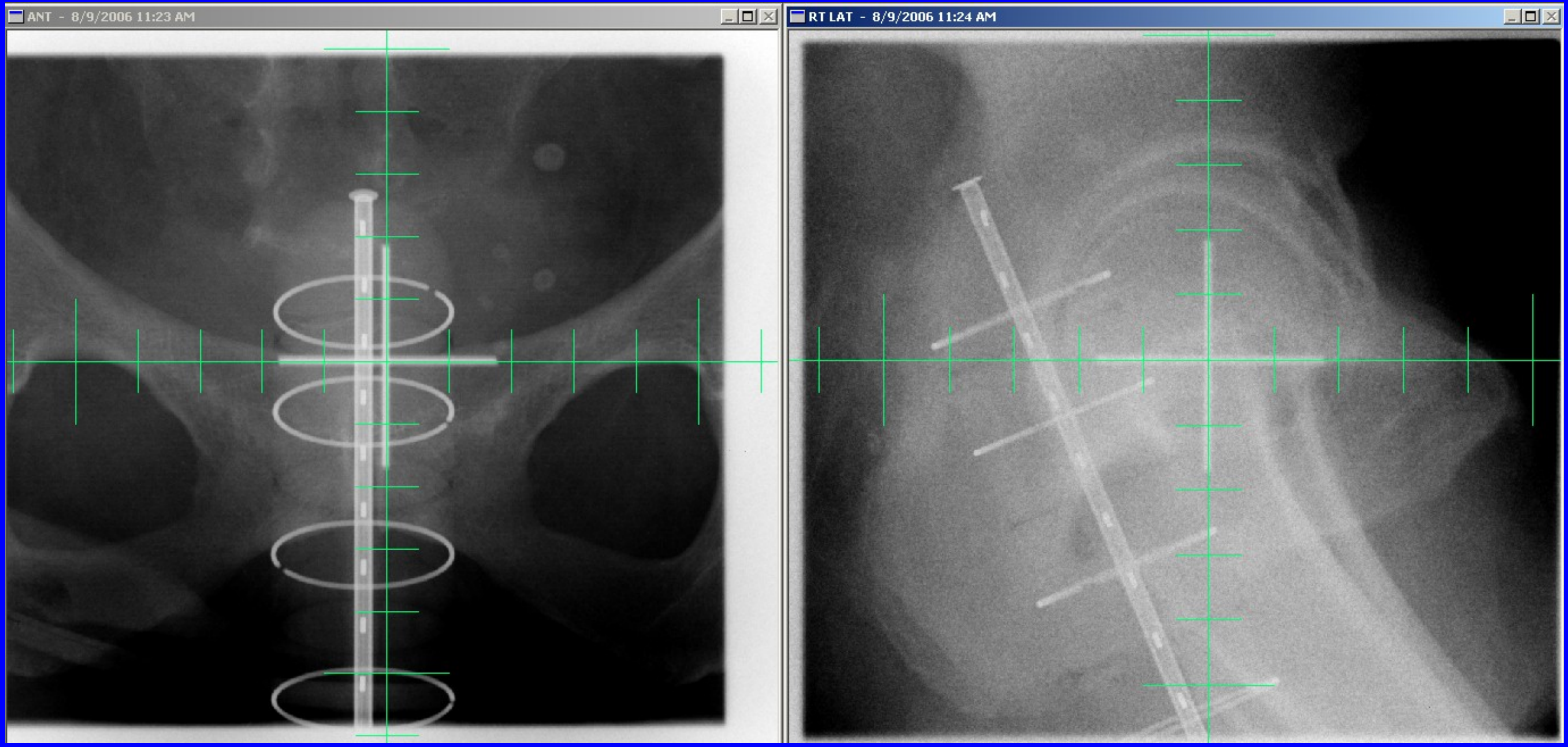
Poor conformance – Unrecoverable air gap



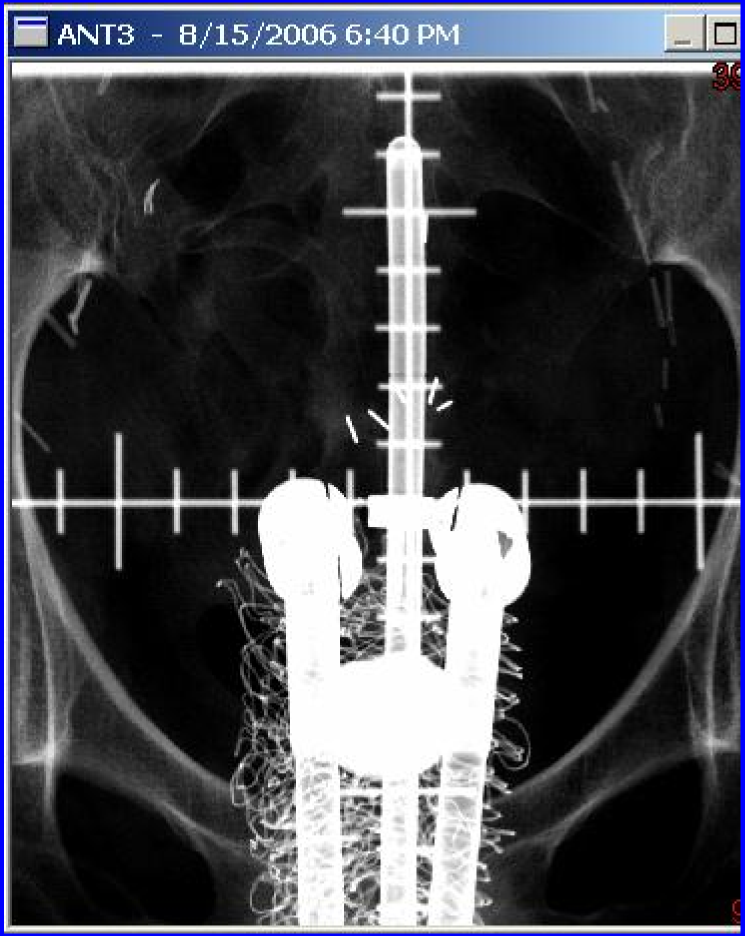
Source Localization Methods

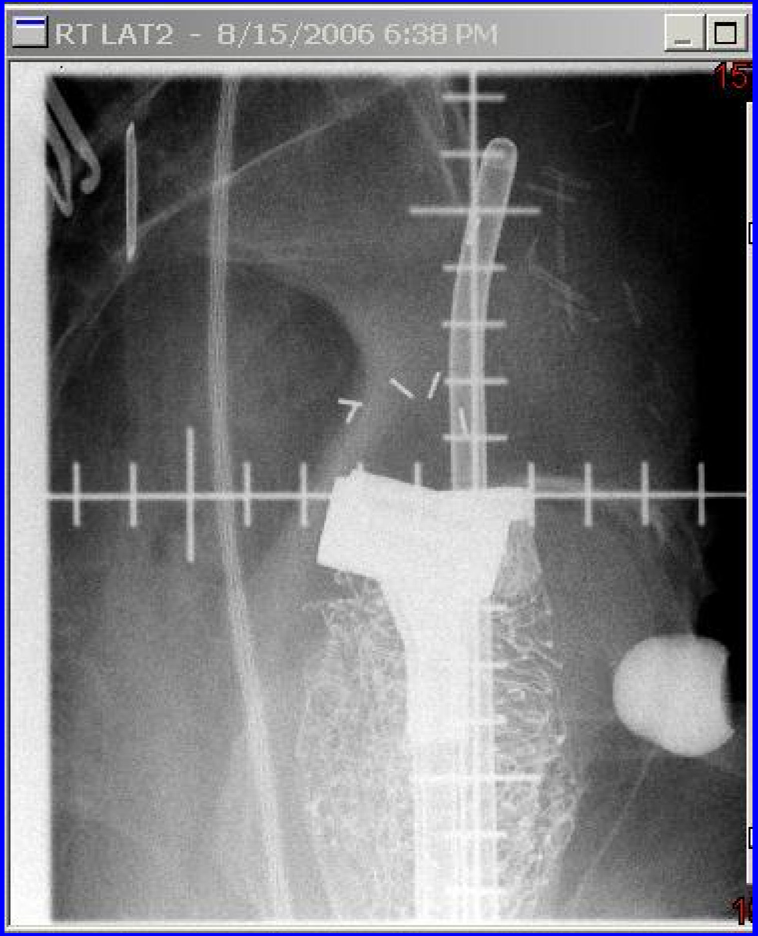
1. Orthogonal “films”
2. Stereo shift “films”
3. Isocentric variable angle “films”
4. Localization jig (frame)
5. CT localization

Orthogonal films



Orthogonal films





MODALITY

HDR

AFTERLOADER

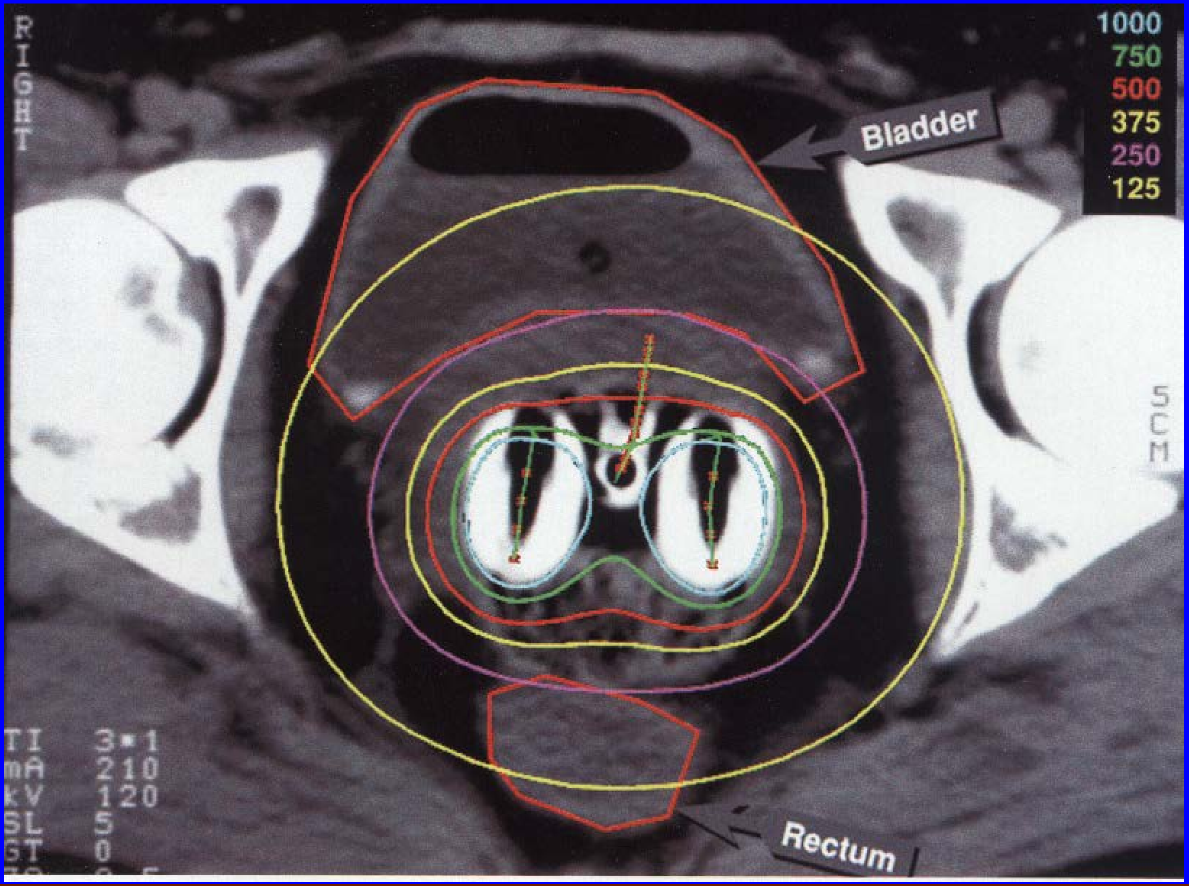
VS 200

VS ID

Reconstruction Jig

- can be used when isocentric films at a known angle may be difficult to obtain
- particularly well-suited for use with a C-arm radiography unit to obtain films in an operating room environment
- available in a choice of two widths (50 and 65 cm), depending on the aperture of the C-arm being used

Tranverse CT through colpostats



Specific Activity

of a radioactive material is defined as the activity per gram of the material. The maximum specific activity is straightforward to calculate:

Avagadro's Number N_A is the number of atoms in a gram-atomic-weight, i.e. the number of atoms in 226 grams of Ra-226. It is numerically equal to 6.022×10^{23} . Λ is the decay constant in sec^{-1} and A is the atomic weight in grams. The specific activity then equals:

$$\Lambda N_A / A$$

Specific Activity of Radium

0.975 Ci/g

Units of Activity

Becquerel, Bq 1 sec^{-1}

Curie, Ci 3.7×10^{10} sec^{-1}

Properties of Brachytherapy Isotopes

Radionuclide	Half-life	Photon energy MeV	Exposure Rate Constant Rcm2/Mci-hr	Specific Activity Ci/g
Ra-226	1600 yr	0.047-2.45 (0.83 avg)	8.25	0.989
Co-60	5.27 yr	1.17,1.33	13.07	1135.069
Cs-137	30 yr	0.662	3.26	86.994
Ir-192	74 days	0.136-1.06 (0.38 avg)	4.6	9191.574
Yb-169	32 days	0.093 avg		24170.939

Using the exposure rate constant to calculate environmental exposure from sealed brachytherapy sources: example Ir-192

$$4.6\ R\text{-}cm^{2}\text{-}mCi^{-1}\text{-}hr^{-1}$$

Consider a 10 Ci source at a distance of 20 cm.

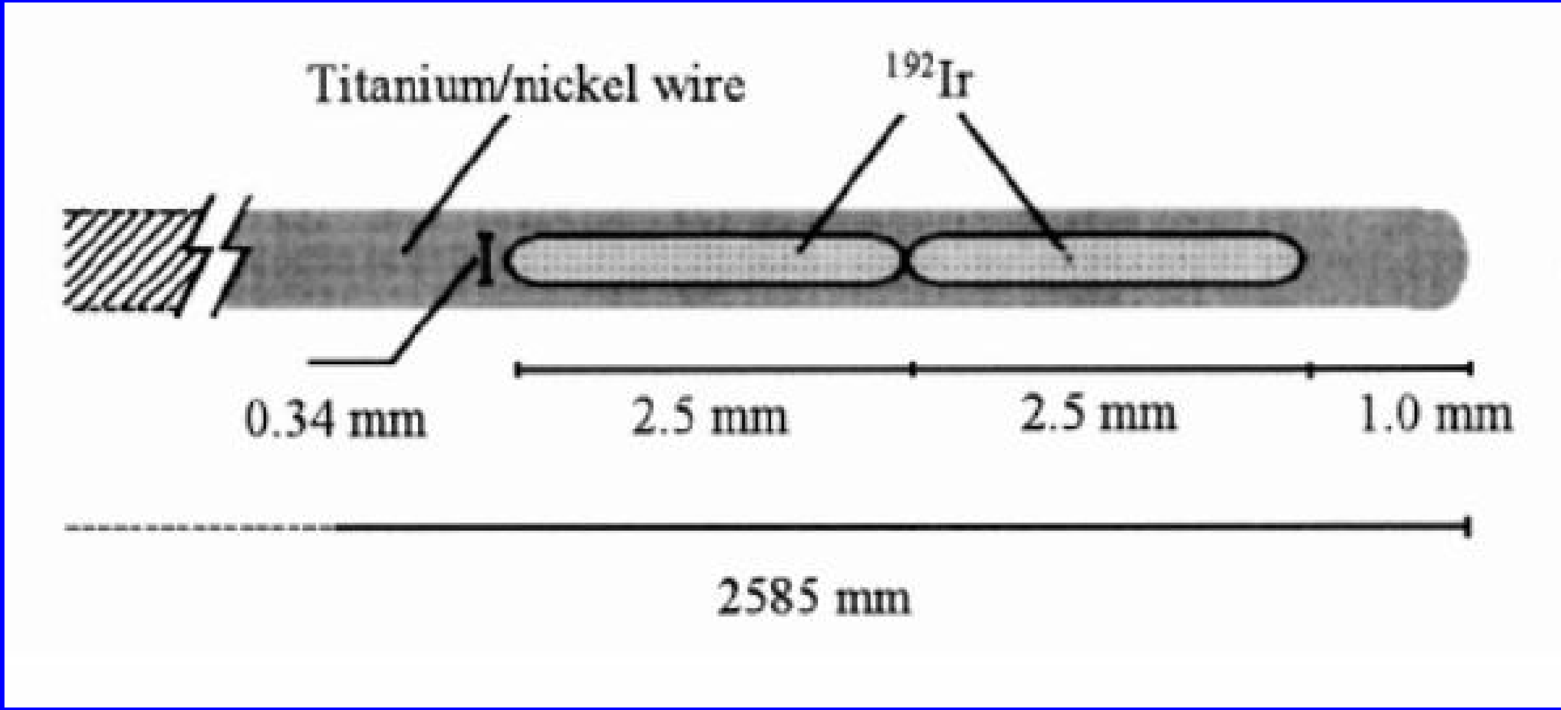
Consider a 10 Ci source at a distance of 20 cm.

$$\left(\frac{4.6 Rcm^2 * 10^4 mCi}{mCihr * 20^2 cm^2} \right) = 115 Rhr^{-1}$$

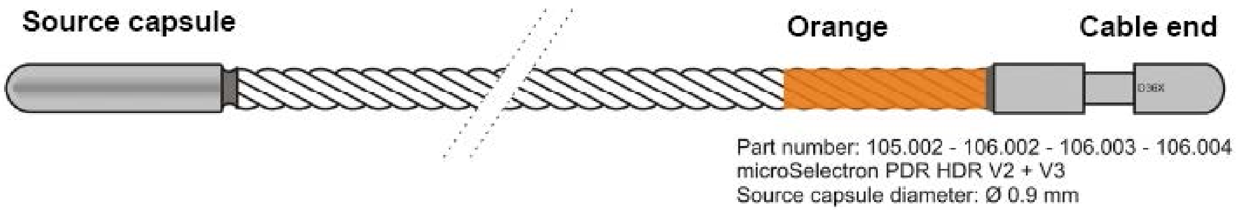
$$\left(\frac{4.6 Rcm^2 * 10^4 mCi}{mCihr * 20^2 cm^2} \right) = 115 Rhr$$

Remember TDS: *time, distance, shielding*

Varian HDR Source



microSelectron HDR V2 + V3							
Part number	Source material	Source strength	Source capsule diameter	Source capsule length	Cable Length	Tail color	Serial Number
105.002	Solid Ir-192	10.0 Ci / 370.0 GBq	Ø 0.9 mm	4.5 mm	2022 mm	Orange	D36XNNNN



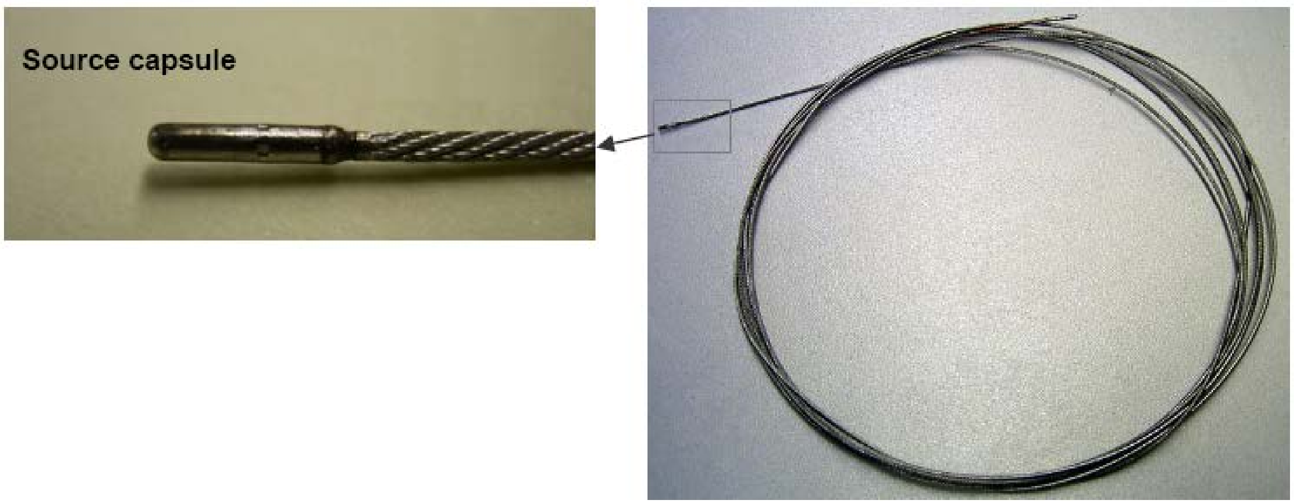


Figure 2: Source cable: microSelectron HDR V2 + V3

^{169}Ytterbium Low Energy Gamma Source for High Dose Rate Brachytherapy

Physical Characteristics

^{169}Ytterbium Physical Properties

Half Life:	30.2 days
$E_{\gamma\text{-avg}}$:	93 keV
Decay Mode:	Electron Capture (100%)
Production Mode:	Thermal neutron activation
	Fast neutron activation

TABLE I. Structural details and geometries of the investigated ^{192}Ir HDR sources. All dimensions are in cm.

Source type	Active core			Encapsulation		Outer diameter
	Material	Length	Diameter	Material	Thickness	
microSelectron (old design)	Ir	0.35	0.0600	Stainless steel	0.0250	0.110
microSelectron (new design)	Ir	0.36	0.0650	Stainless steel	0.0125	0.090
VariSource (old design)	Ir	1.00	0.0340	Ti/Ni	0.0125	0.059
VariSource (new design)	Ir	0.50	0.0340	Ti/Ni	0.0125	0.059
Buchler	Ir	0.13	0.1000	Stainless steel	0.0200	0.160[a]
Seed (Best Medical)	Pt/Ir	0.3	0.0100	Stainless steel	0.0200	0.050
AngioRad™	Ir	3	0.0127	Ti/Ni	0.0070	0.035[b]

[a]An air gap of 0.01 cm exists between the active core and encapsulation.
[b]An air gap of 0.004 15 cm exists between the active core and encapsulation.

HDR Program

Licensing: Site selection, Shielding, Writing Procedures, Commissioning, Training and Re-Training

HDR QA

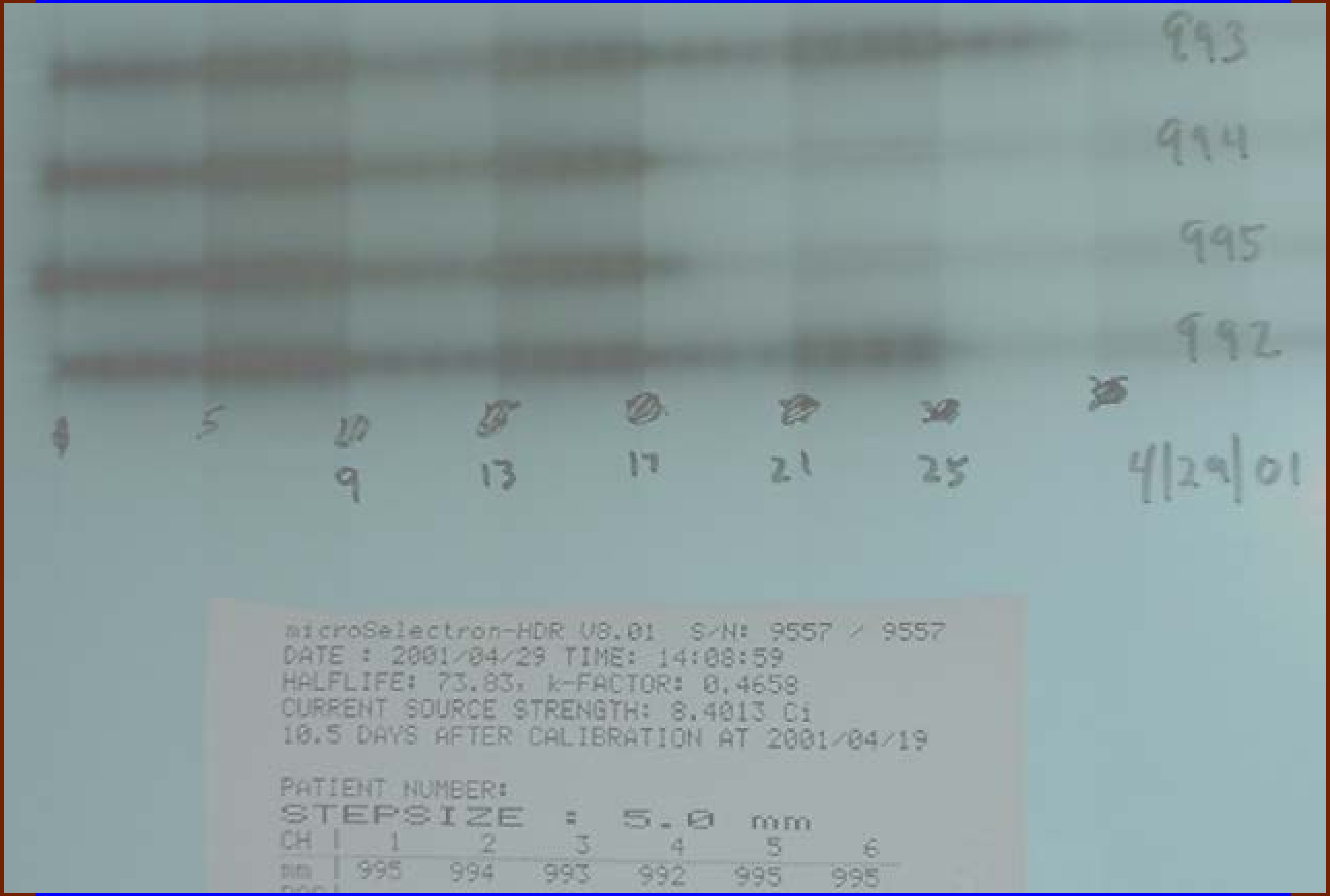
Periodic QA: Monthly and Daily

Pre- and PostTreatment QA

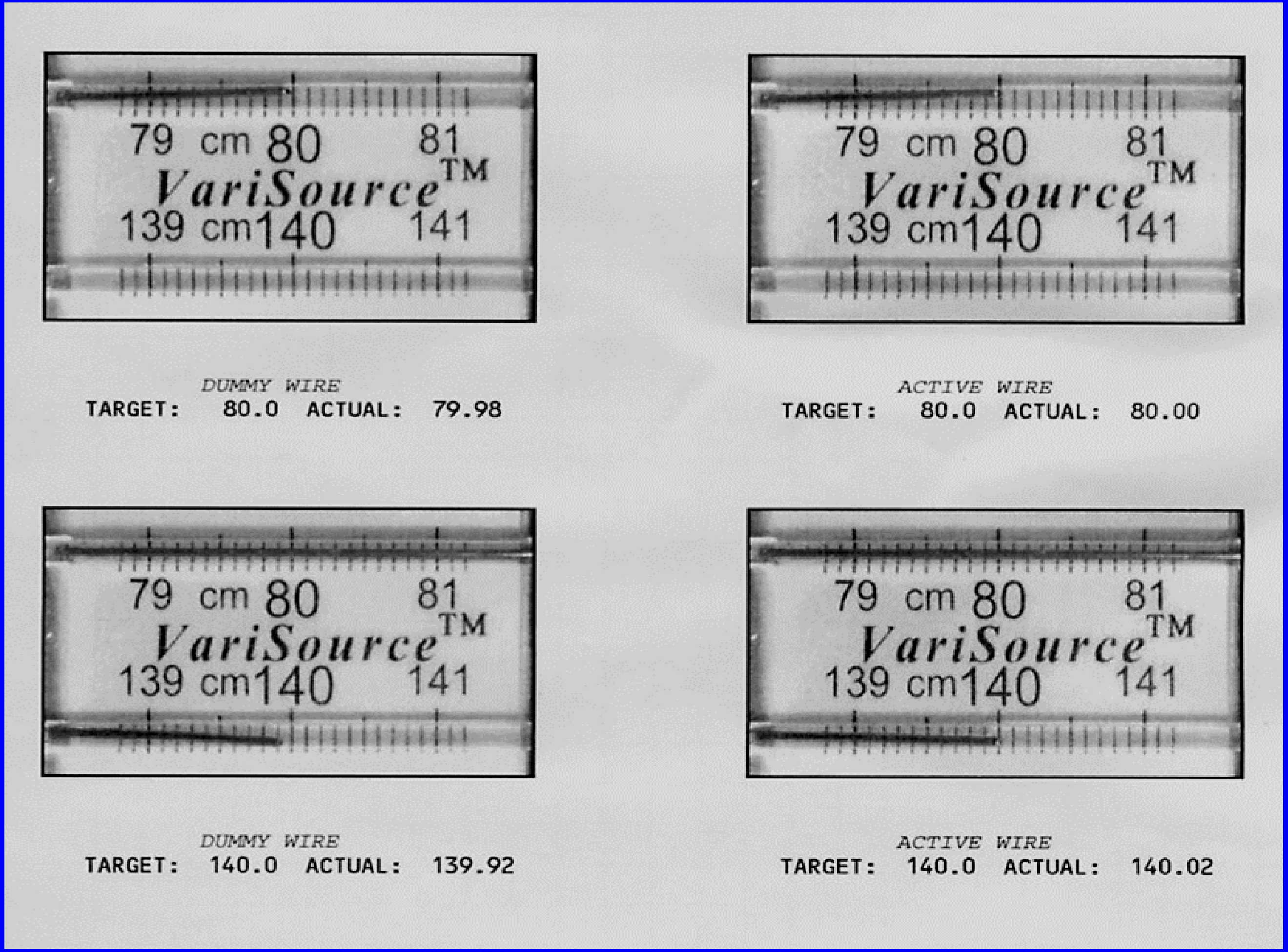
Periodic QA

(may be at source change, monthly or daily)

1. Positional Accuracy within 1 mm
2. Emergency preparedness (includes posted procedures, equipment and survey meters
3. Interlock tests (interrupts, door, etc.)
4. Condition of apparatus (missing lights, etc.?)
5. Source activity (monthly calibration check; daily: indicated vs. decay chart)


993
994
995
992
5
9
13
17
21
25
4|29|01
microSelectron-HDR V8.01 S/N: 9557 / 9557
DATE : 2001/04/29 TIME: 14:08:59
HALFLIFE: 73.83, k-FACTOR: 0.4658
CURRENT SOURCE STRENGTH: 8.4013 Ci
10.5 DAYS AFTER CALIBRATION AT 2001/04/19
PATIENT NUMBER:
STEPSIZE : 5.0 mm
CH | 1 2 3 4 5 6
mm | 995 994 993 992 995 995

Varian Position Test – 1 mm accuracy required



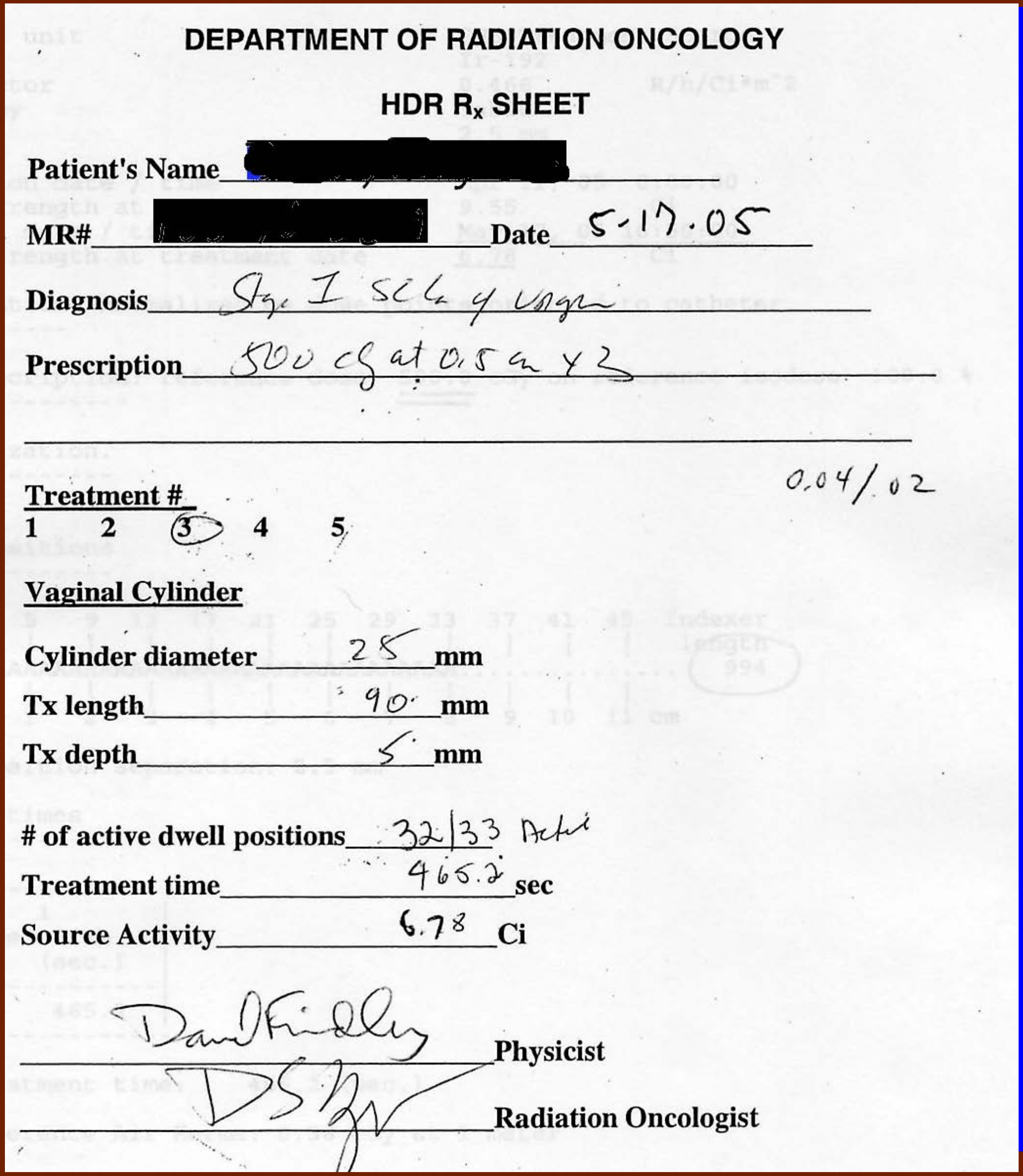
Calibration of HDR Source Using a Well Ionization Chamber

Treatment QA

Pre treatment: Patient Identity; Independent check of treatment plan; signed written directive; verification of treatment parameters (catheter length; channel-catheter correspondence; and treatment dwell times) ; verify presence of emergency equipment and pre-treatment radiation survey of patient

Post treatment: verify execution of written directive or document deviations; document post-treatment radiation survey of the patient

Written Directive



DEPARTMENT OF RADIATION ONCOLOGY

HDR R_x SHEET

Patient's Name [redacted]

MR# [redacted] **Date** 5-17-05

Diagnosis Stg. I SCCa of vagina

Prescription 500 cGy at 0.5 cm x 3

0.04/.02

Treatment #

1 2 (3) 4 5

Vaginal Cylinder

Cylinder diameter 25 **mm**

Tx length 90 **mm**

Tx depth 5 **mm**

# of active dwell positions 32/33 Active

Treatment time 465.2 **sec**

Source Activity 6.78 **Ci**

Physicist

Radiation Oncologist

Radiation survey of the patient

Emergency Procedures

When the active source does not retract into the safe

1. **Attempt to activate back-up motor**

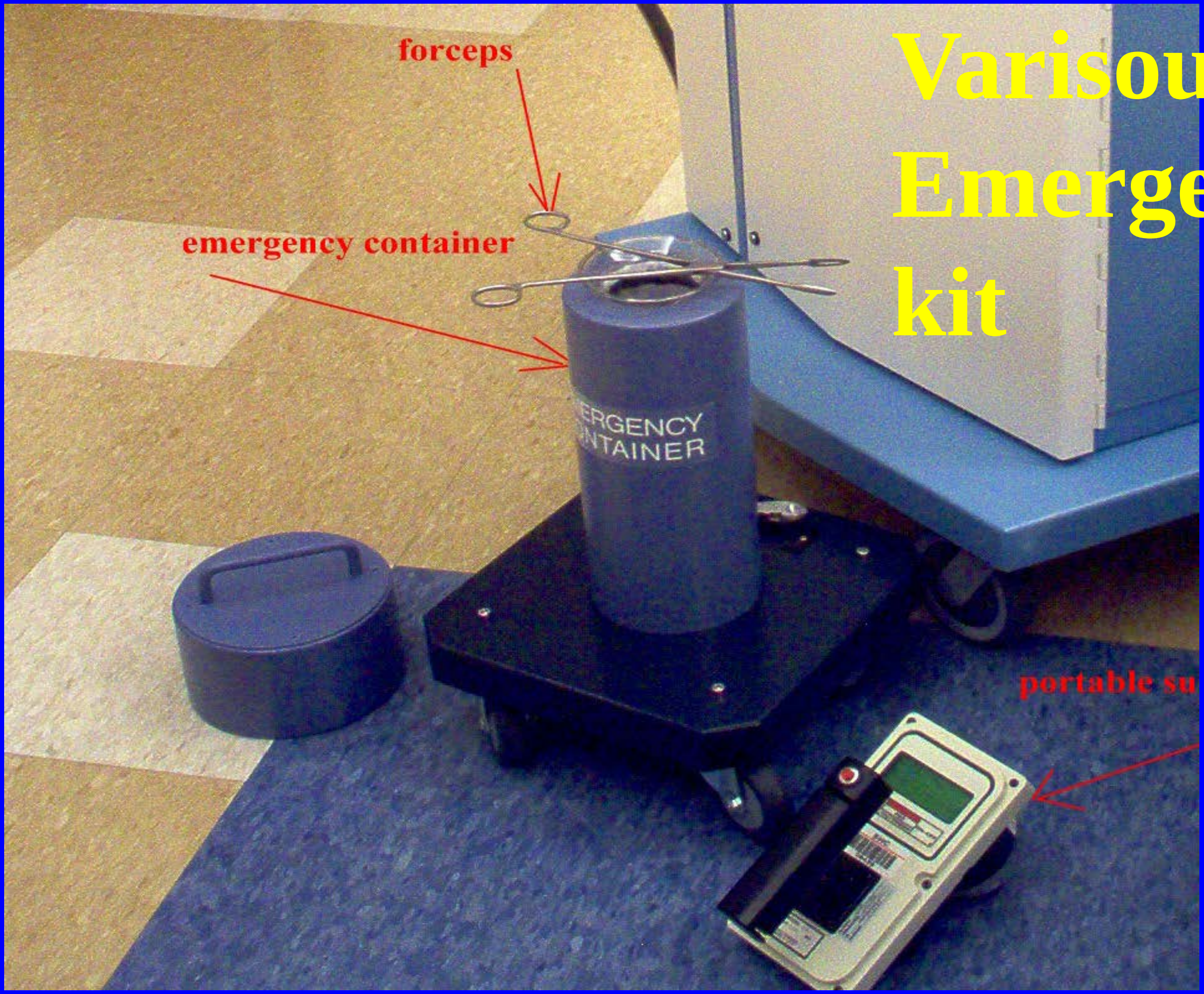
2. **Identify the active catheter if possible**

3. **Remove either the active catheter or the entire Applicator and place it into the emergency container**

4. **Maintain a closed system (take care on disconnecting!)**

5. **Remove the patient from the treatment room and survey**

Varisource Emergency kit



Indiana, PA, iridium-192 incident

An 82-year-old woman was diagnosed with anal cancer and treated with high dose rate brachytherapy at Indiana Regional Cancer Center, Indiana, Pennsylvania, on 16 November 1992. High-intensity 192Ir brachytherapy was begun, but the source was not retracted afterwards and remained in place for 4 days until it dislodged. Hospital staff ignored warning signals, believing that safety equipment was giving a false alarm, and the source was not discovered until it was transferred to a medical incinerator. The patient died 5 days after the exposure [1, 5, 6].