HDR Intra-Cavitary Approaches to APBI: Basic Physics and Limitations

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Department of Radiation Oncology

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AAPM, 2010

- Disclosure

Consultant for SenoRx Inc.

Learning Objectives

- To learn about the devices used for intracavitary APBI and their dosimetry
- To learn about planning and define treatment appropriateness based on NSABP B-39/RTOG 0413
- To learn about a number of relevant topics for intracavitary APBI: dose perturbation due to contrast and air, probabilistic aspects of planning and delivery, etc.
- To learn about Quality Assurance methods
- To learn about optimization methods

Outline

- Rationale for APBI
- Devices presentation
- NSABP B39/RTOG 0413
- Interesting topics
- Optimization

Why APBI?

- The underlying assumption is that the risk of ipsilateral breast cancer recurrence resides within proximity to the original tumor site
- Accelerated partial-breast irradiation involves treating a limited volume of tissue, with an increased dose per fraction and a significantly decreased treatment time course.

Available methods

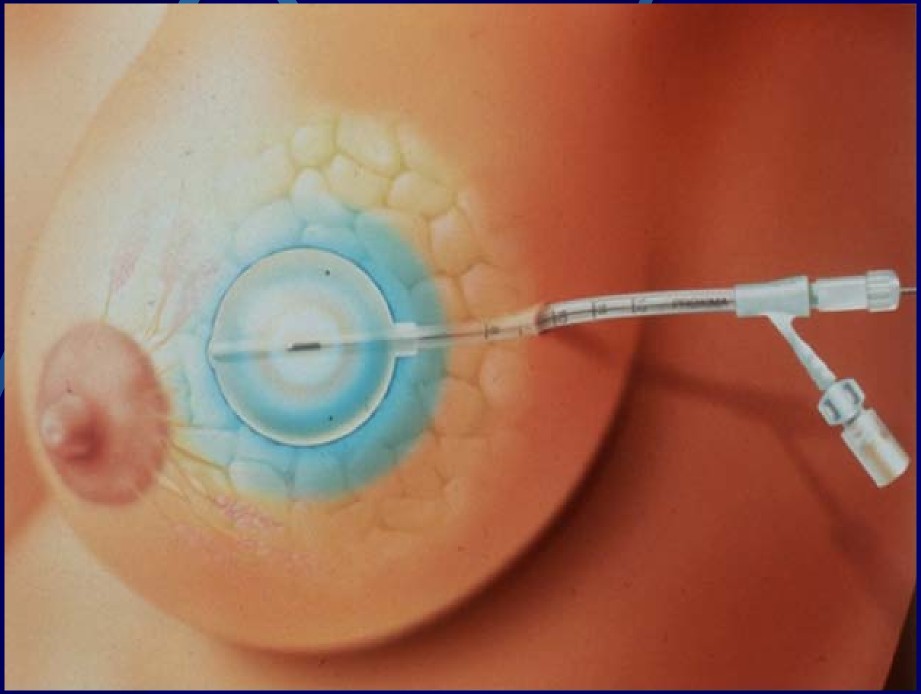
- Interstitial brachytherapy (LDR and HDR)
- Intra-cavitary brachytherapy (HDR)
- Intra-operative brachytherapy (HDR)
- Permanent breast seed implants (LDR)
- 3D conformal EBRT

Intra-cavitary devices

- Balloon based devices:
  - MammoSite
  - Contura
- Strut-based devices:
  - SAVI (Strut Adjusted Volume Implant)
  - Clear-Path

Balloon Catheter
‘MammoSite’

- **MammoSite device (Proxima, Cytyc, Hologic)**
- **Inflatable Balloon Placed In Lumpectomy Cavity**
- **HDR brachytherapy**
  34 Gy in 10 fractions
- ***FDA clearance May 2002***
- ***Since 2002, > 45,000 cases treated***

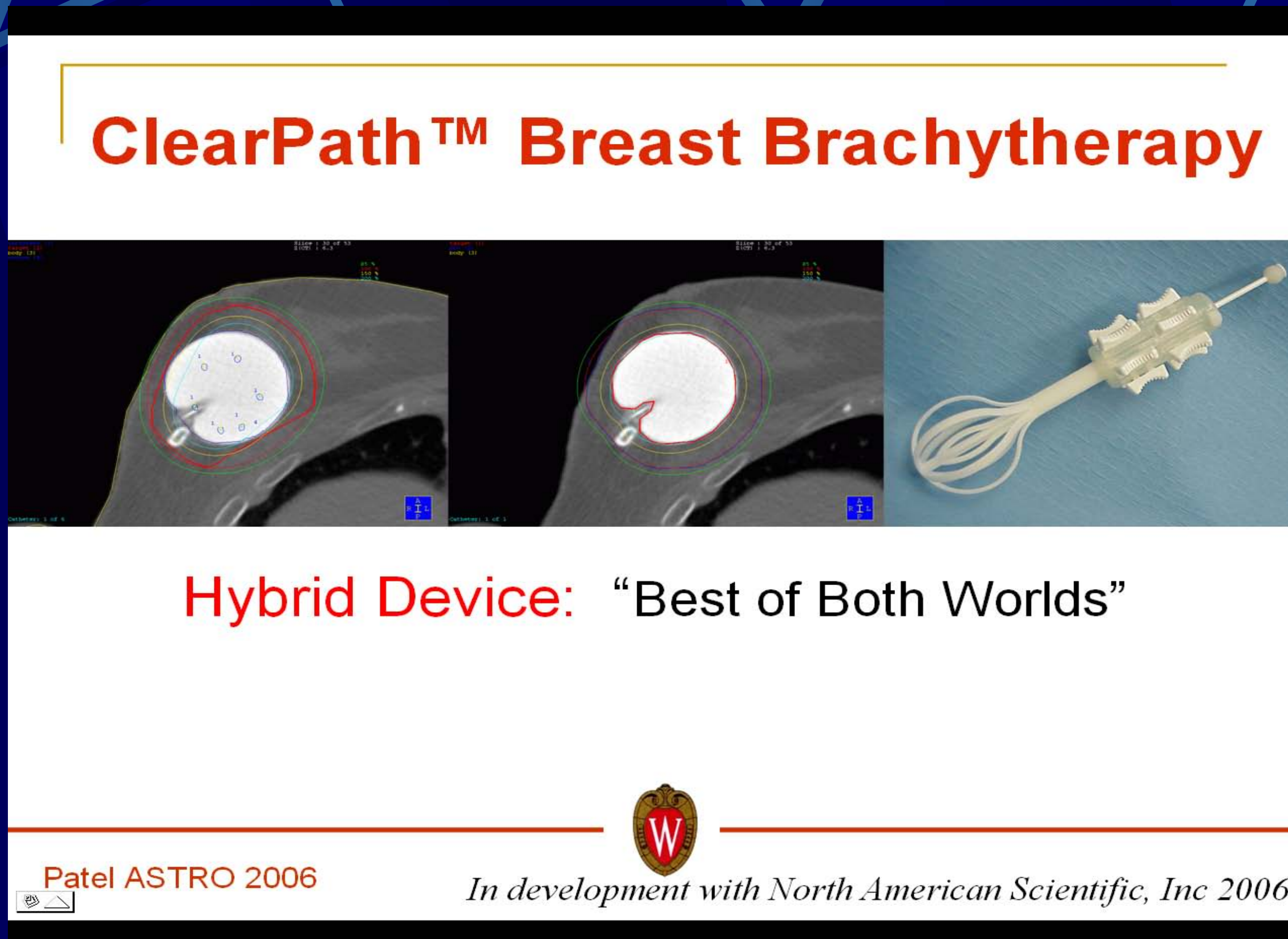


Edmundson GK, Vicini FA, Chen PY, Mitchell C, Martinez AA, Dosimetric characteristics of the MammoSite RTS, a new breast brachytherapy applicator.,

Int J Radiat Oncol Biol Phys. 2002 Mar 15;52(4):1132-9.

Balloon based applicators Contura, MammoSite (ML)

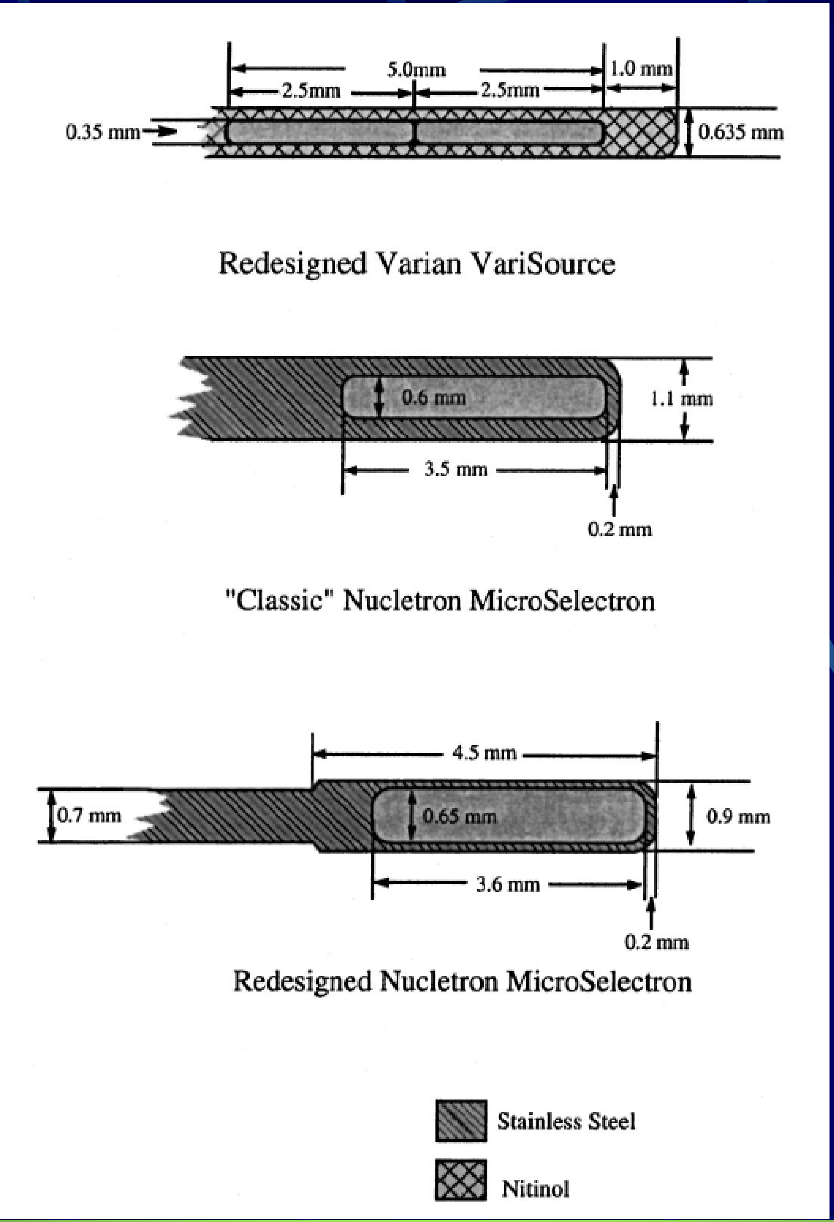
Strut devices



Strut Adjusted Volume Implant Applicator

Iridium 192

- Ir-192 is the most common source for Remote Afterloaders
- Disadvantage: relative short half-life (at least when compared with Co-60 or Cs-137)
- Advantage: low average energy (~.38 Mev, with a range from 0.136 to 1.062MeV) so it is easily shielded requiring just 0.3cm Pb as a half value layer.
- Advantage: high specific activity (450Ci/g) allows the construction of high activity sources (10Ci) of small diameter (0.6-1.1 mm)



Schematic diagram comparing relative dimensions of different Ir-192 sources (from Calibration of new high dose rate 192Ir sources, K. E. Stump, L. A. DeWerd, J. A. Micka, and D. R. Anderson, Department of Medical Physics, University of Wisconsin—Madison, Madison, Wisconsin 53706, Med. Phys. 29 .7., July 2002

Electronic brachytherapy

Axxent®

Electronic Brachytherapy System

Axxent HDR X-ray Source 2.2 Specifications		Part Number
Axxent HDR X-ray Source		S7500
X-ray Tube Diameter	2.25 mm	
Assembly Length	250 mm	
Assembly Diameter	5.4 mm	
X-ray Source Power	15 watts	
Typical Treatment Time	10 min	
Maximum Number of Treatments per X-ray Source	10	
Source Includes	• Integral water cooling sheath • Low-force high-voltage connector • Flexible high-voltage cable	
Nominal Dose Rate	0.6 Gy/min @ 3 cm in water	

Review: three sources

- Both the 169-Ytterbium source and the 192-Iridium source provide comparable coverage for the prescription dose (V100) and minimum dose to 90% of the target (D90).
- The 169-Ytterbium source results in less volume receiving doses of 150% and 200% of the prescription. The 169-Ytterbium source also results in a greater homogeneity (DHI) and lower maximum dose.
- The X-ray source performed worse in all categories.
- The mean %V(90) was 99.6% vs. 99.0%, the mean %V(100) was 96.5% vs. 96.5%, the mean %V(150) was 41.8% vs. 59.4%, the mean %V(200) was 11.3% vs. 32.0% and the mean %V(300) was 0.4% vs. 6.7% for the IBB and KVB methods, respectively.
- The IBB and KVB methods of PBI offer comparable target volume coverage; however, the KVB method is associated with an increased volume of breast tissue in the high-dose regions and a decreased dose to the adjacent normal tissues.

1. Dosimetric comparison of three radiation sources used in balloon-based breast brachytherapy John J. Munro, Ph.D. David C. Medich, Ph.D., Brachytherapy 6 (2007) 77-118
2.. A dosimetric comparison of MammoSite high-dose-rate brachytherapy and Xoft Axxent electronic brachytherapy. Dickler A, Kirk MC, Seif N, Griem K, Dowlatshahi K, Francescatti D, Abrams RA. Brachytherapy. 2007 Apr-Jun;6(2):164-8

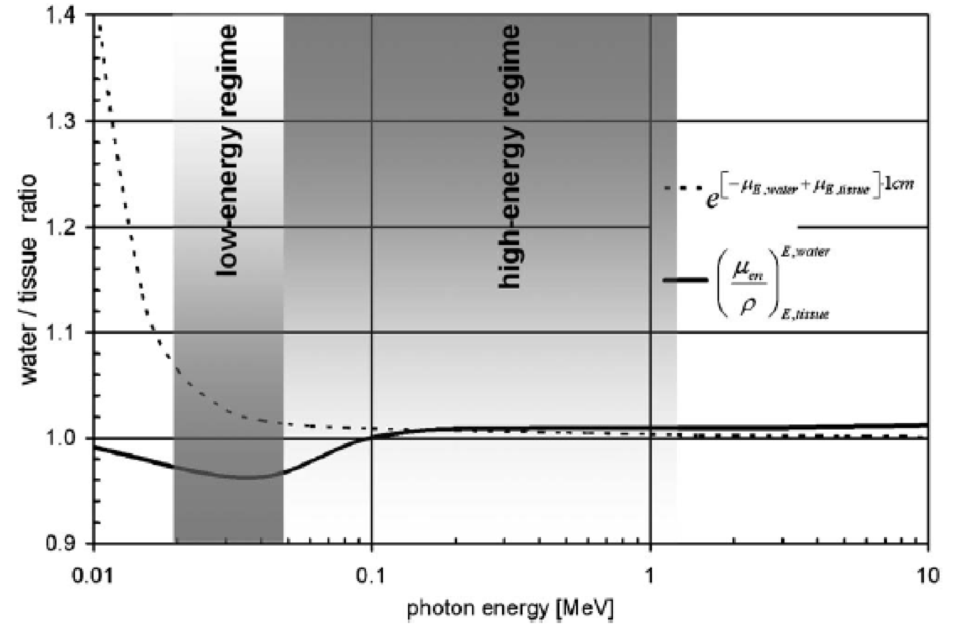


FIG. 3. Effect of phantom medium on absorbed dose and attenuation at $r = 1$ cm as a function of photon energy.

• The mass-energy absorption coefficient as a function of photon energy *E* and atomic number *Z*, may be used to account for differences in absorbed dose between water and tissue. The ratio dips around 50keV due to slightly higher photoelectric cross section of tissue compared to water.
• Similarly, the mass-attenuation coefficient as a function of photon energy E and atomic number *Z* may approximate differences in radiation attenuation between water and tissue.
• Unlike the absorbed dose ratios, the larger mass density of tissue contributes to the increased attenuation. Further, increased attenuation by tissue below 50 keV is caused by the larger photoelectric effect cross section of tissue compared to water.

The evolution of brachytherapy treatment planning. Rivard MJ, Venselaar JL, Beaulieu L. Med Phys. 2009 Jun;36(6):2136-53.

TG-43 vs. MC

- (MammoSite) For the breast patient plan, TG-43 overestimates the target volume receiving the prescribed dose by 4% and the dose to the hottest 0.1 cm^3 of the skin by 9% (*Poon E, Verhaegen F A CT-based analytical dose calculation method for HDR 192Ir brachytherapy. Med Phys. 2009 Sep;36(9):3982-94.)*
- (Multicath) On average, TG-43 overestimates the target coverage by 2% and the dose to the hottest 0.1 cm^3 (D0.1 cc) of the skin by 5%. (*Poon E, Verhaegen F. Development of a scatter correction technique and its application to HDR 192Ir multicatheter breast brachytherapy. Med Phys. 2009 Aug;36(8):3703-13.)*

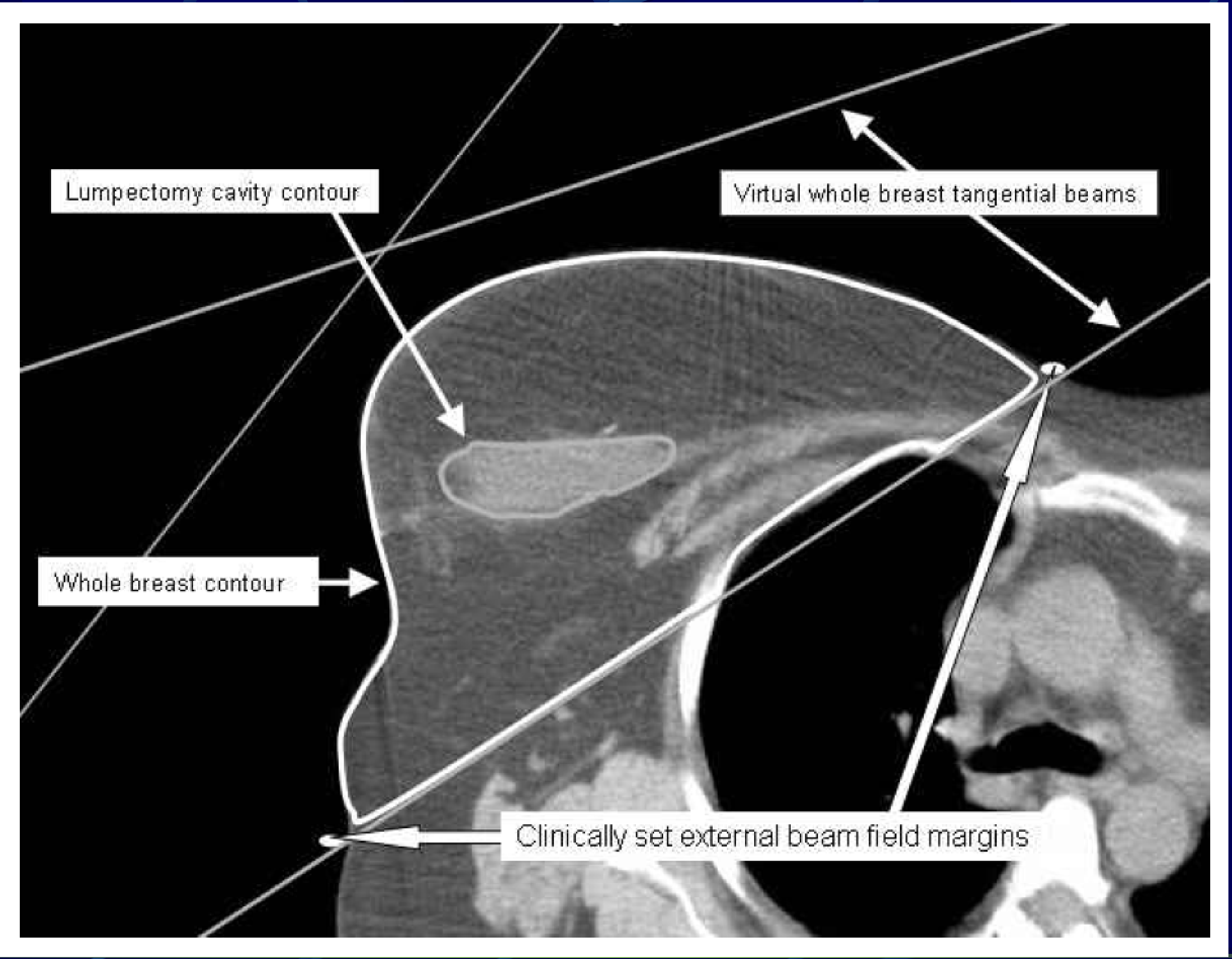
- *The introduction of deterministic Linear Boltzman Transport Equation based methods in the first commercial planning platform Acuros (Varian, Inc.) in brachytherapy*

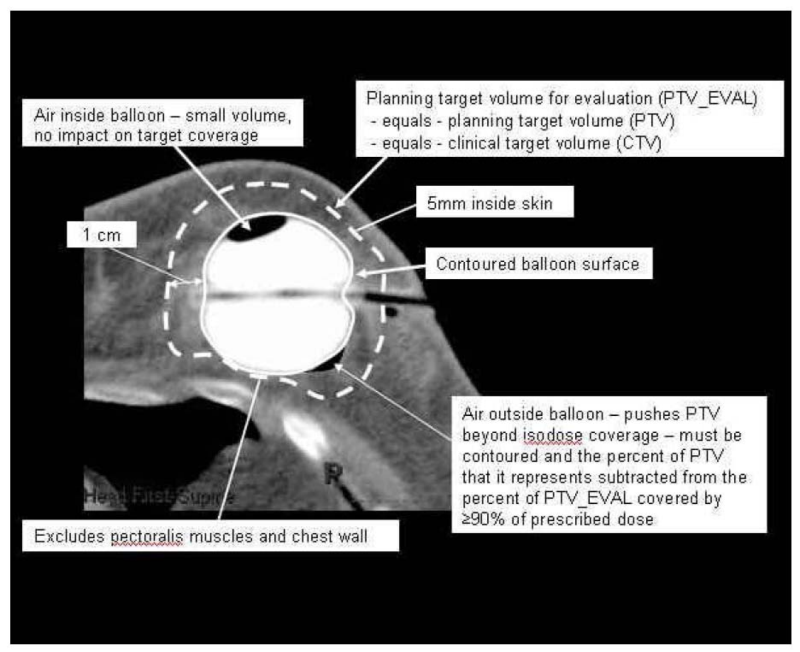
Elements of NSABP B39 / RTOG 0413 protocol

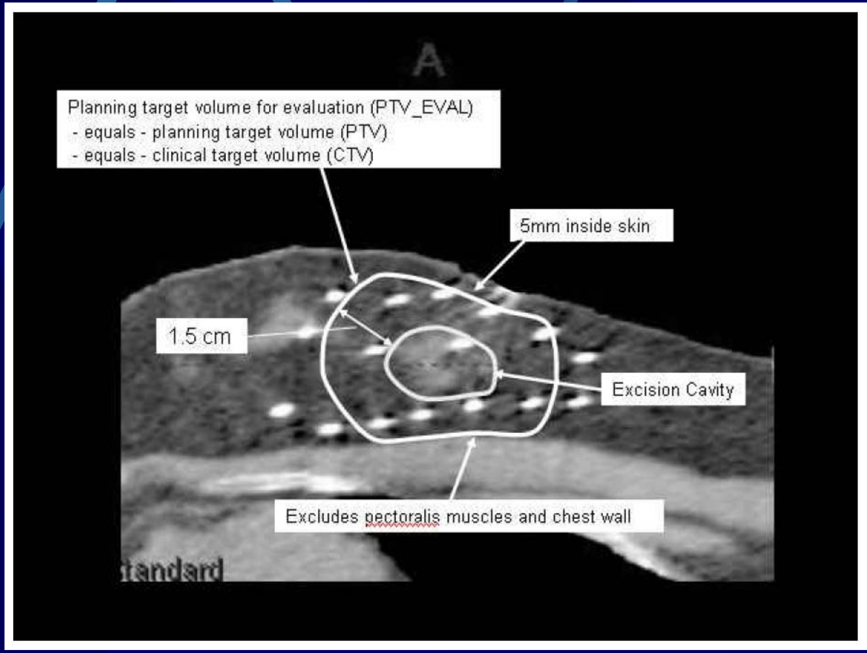
- **Partial Breast Irradiation (PBI) By Multi-catheter Brachytherapy**
- **Partial Breast Irradiation (PBI) By Mammosite® Balloon Catheter**

Target Volumes

- CTV = PTV = PTV_EVAL
- PTV_EVAL = excision cavity + uniform 15mm (10mm for MammoSite) *except:*
  - PTV_EVAL limited to 5mm from the skin surface
  - Chest wall and pectoralis muscles are excluded

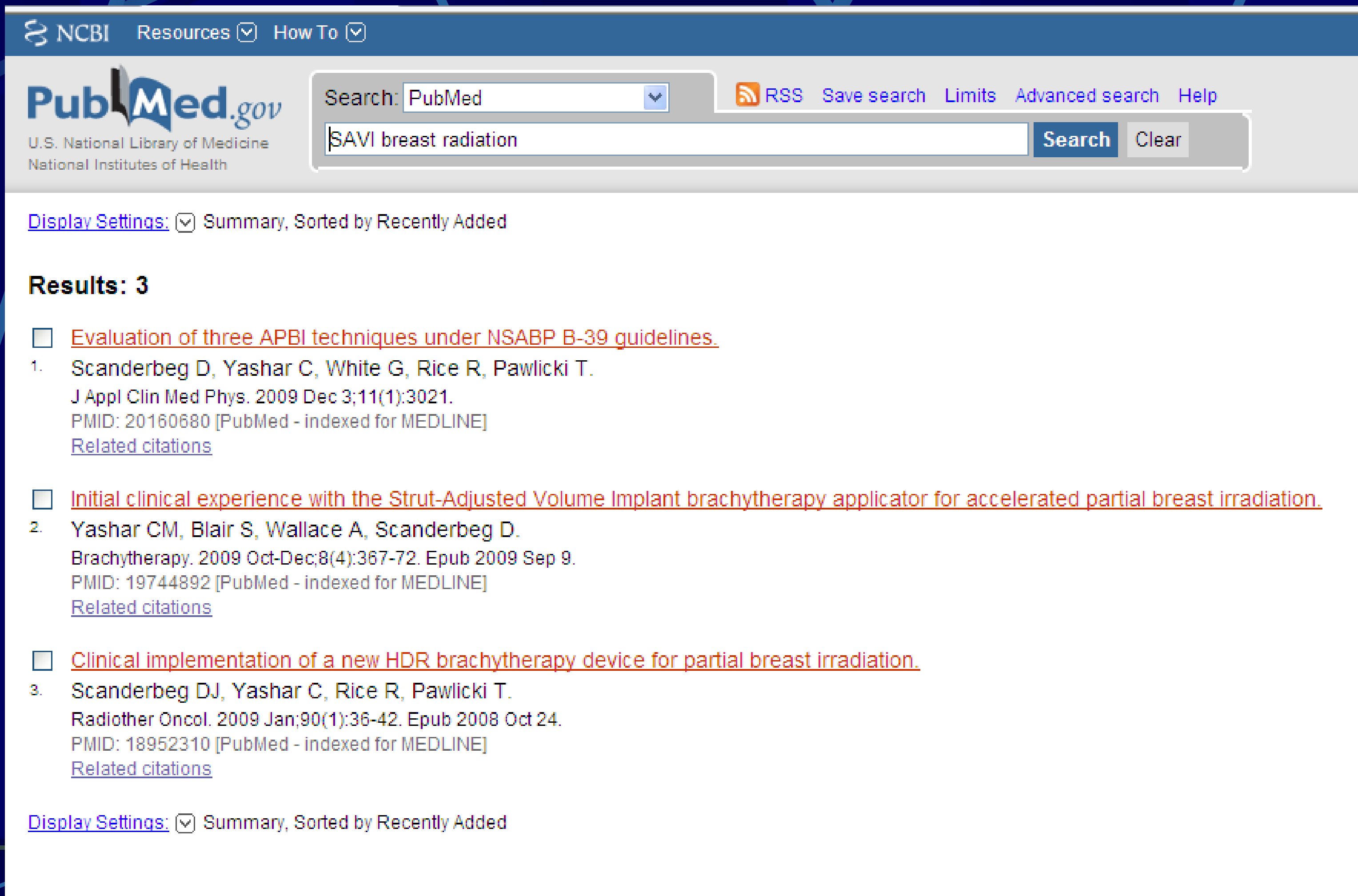

Lumpectomy cavity contour
Virtual whole breast tangential beams
Whole breast contour
Clinically set external beam field margins


Air inside balloon – small volume, no impact on target coverage
Planning target volume for evaluation (PTV_EVAL)
- equals - planning target volume (PTV)
- equals - clinical target volume (CTV)
5mm inside skin
1 cm
Contoured balloon surface
Air outside balloon – pushes PTV beyond isodose coverage – must be contoured and the percent of PTV that it represents subtracted from the percent of PTV_EVAL covered by ≥90% of prescribed dose
Excludes pectoralis muscles and chest wall

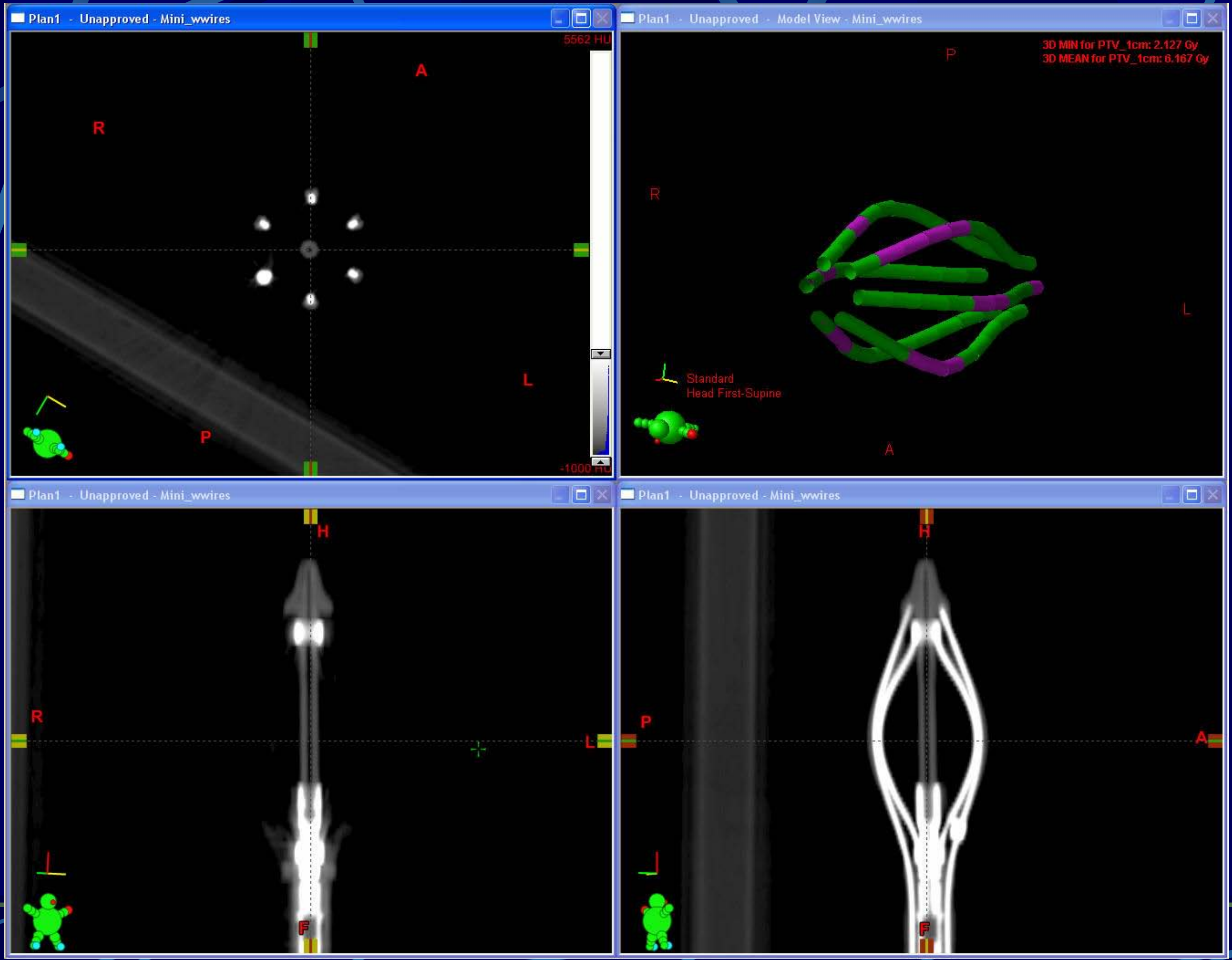

A
Planning target volume for evaluation (PTV_EVAL)
- equals - planning target volume (PTV)
- equals - clinical target volume (CTV)
5mm inside skin
1.5 cm
Excision Cavity
Excludes pectoralis muscles and chest wall

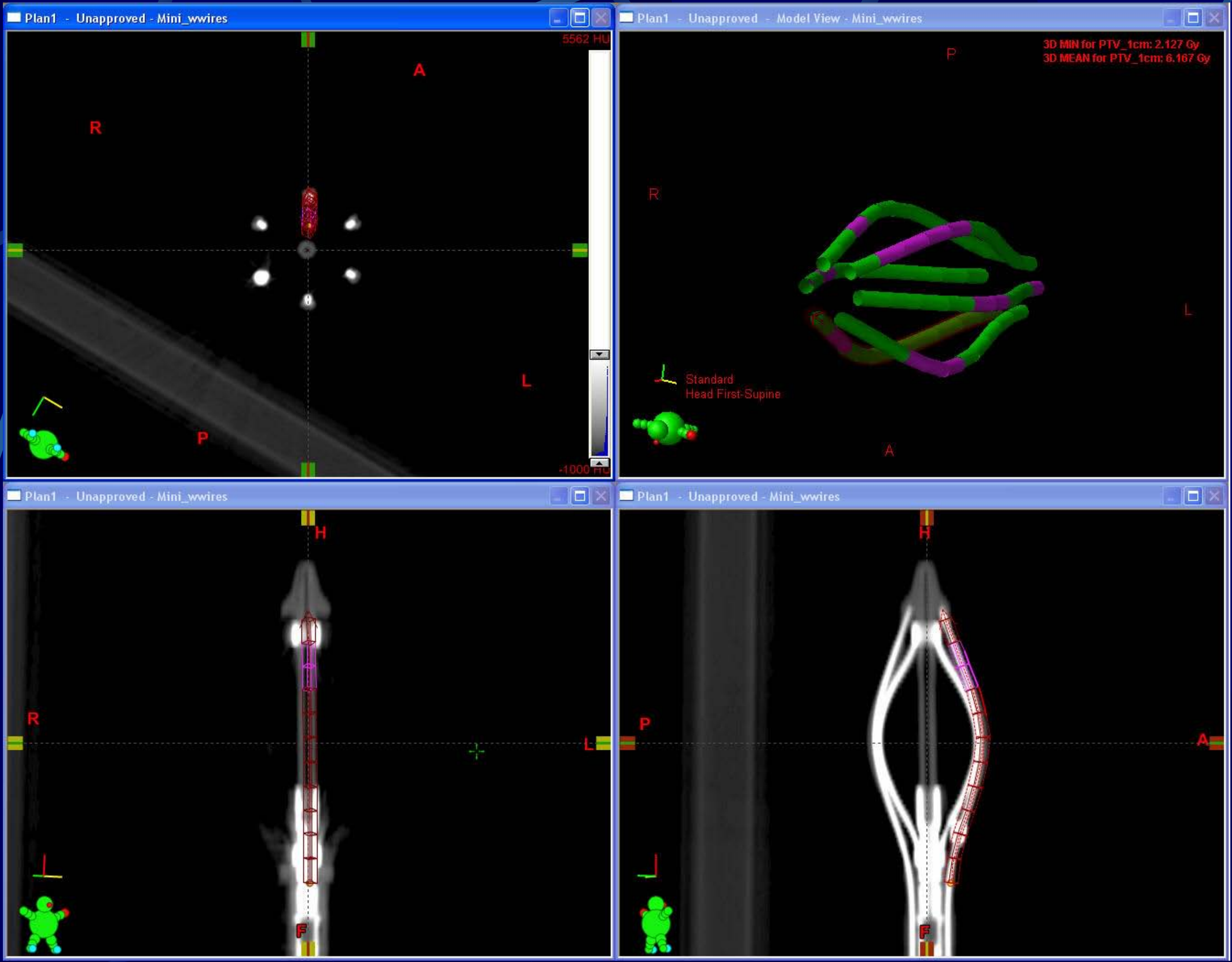
Three models/sizes: 7, 9 and 11 struts available for loading.

SAVI -Strut-Adjusted Volume Implant brachytherapy applicator



"This breast brachytherapy device combines the ease of the single-entry device with the flexibility of IBT while still treating the minimal tissue necessary for APBI. "





Plan1 - Unapproved - Mini_wwires
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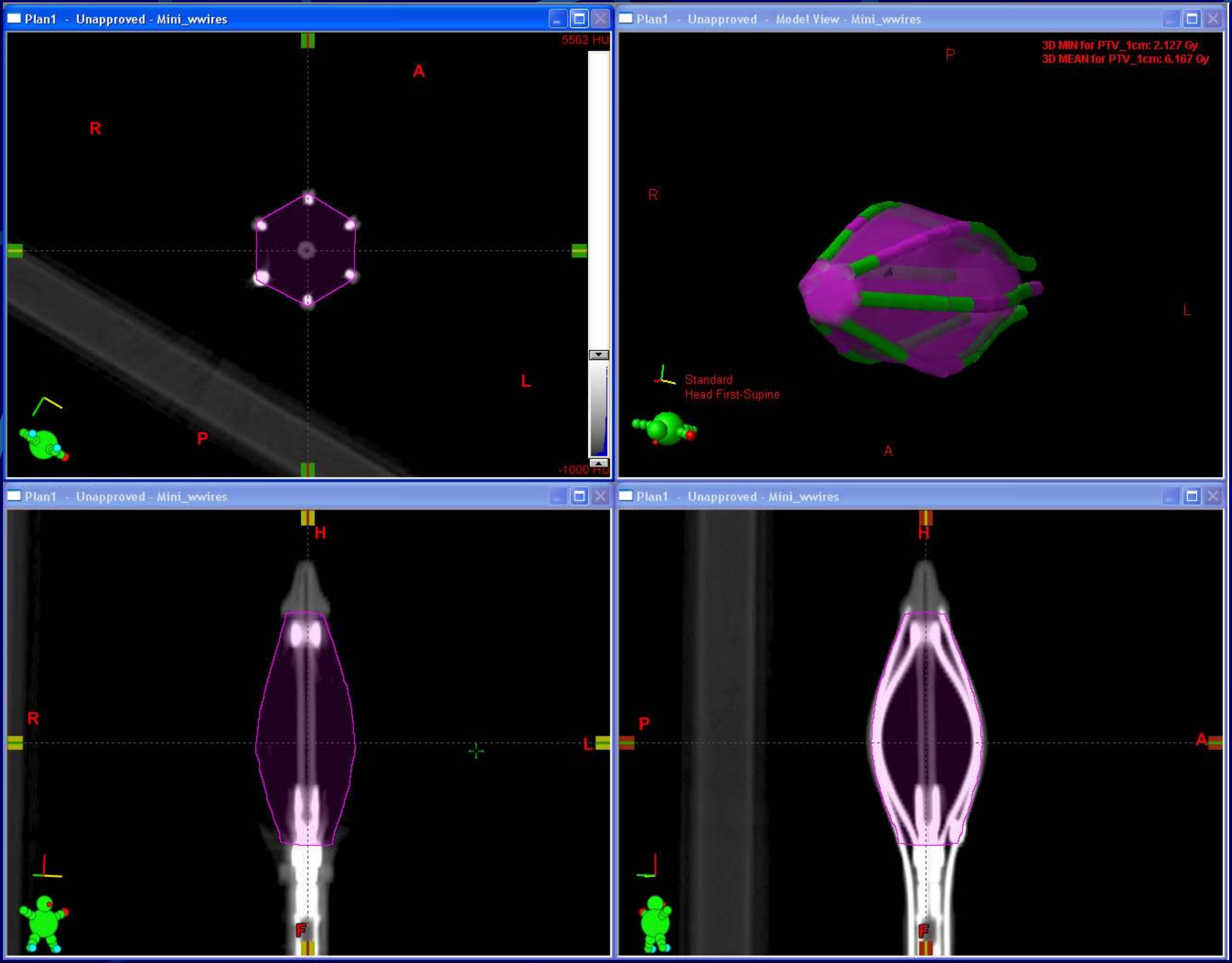
-1000 HU
A
R
L
P
Plan1 - Unapproved - Model View - Mini_wwires
3D MIN for PTV_1cm: 2.127 Gy
3D MEAN for PTV_1cm: 6.167 Gy
P
R
L
A
Standard
Head First-Supine
Plan1 - Unapproved - Mini_wwires
H
R
L
F
Plan1 - Unapproved - Mini_wwires
H
P
A
F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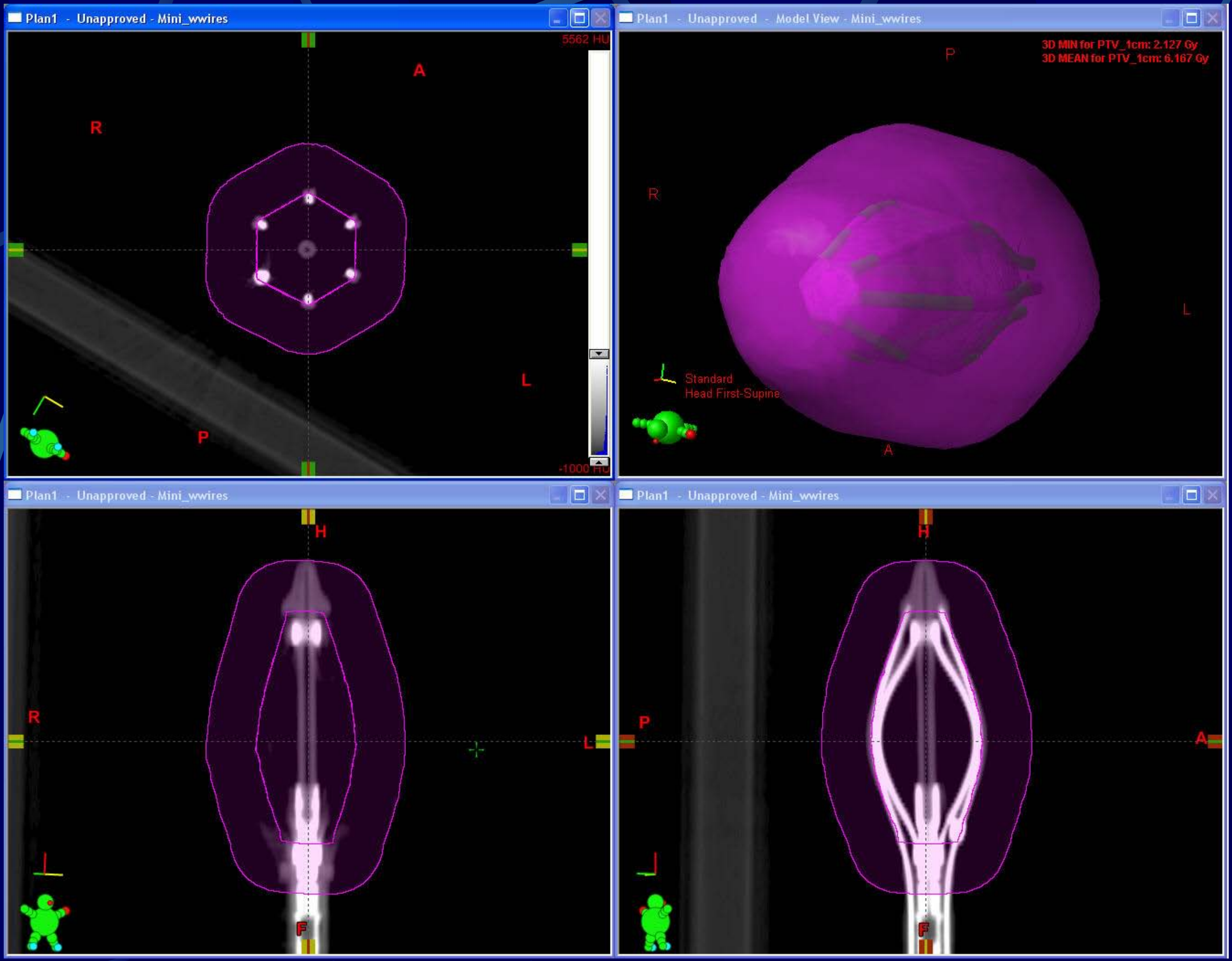
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Head First-Supine
Plan1 - Unapproved - Mini_wwires
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Plan1 - Unapproved - Mini_wwires
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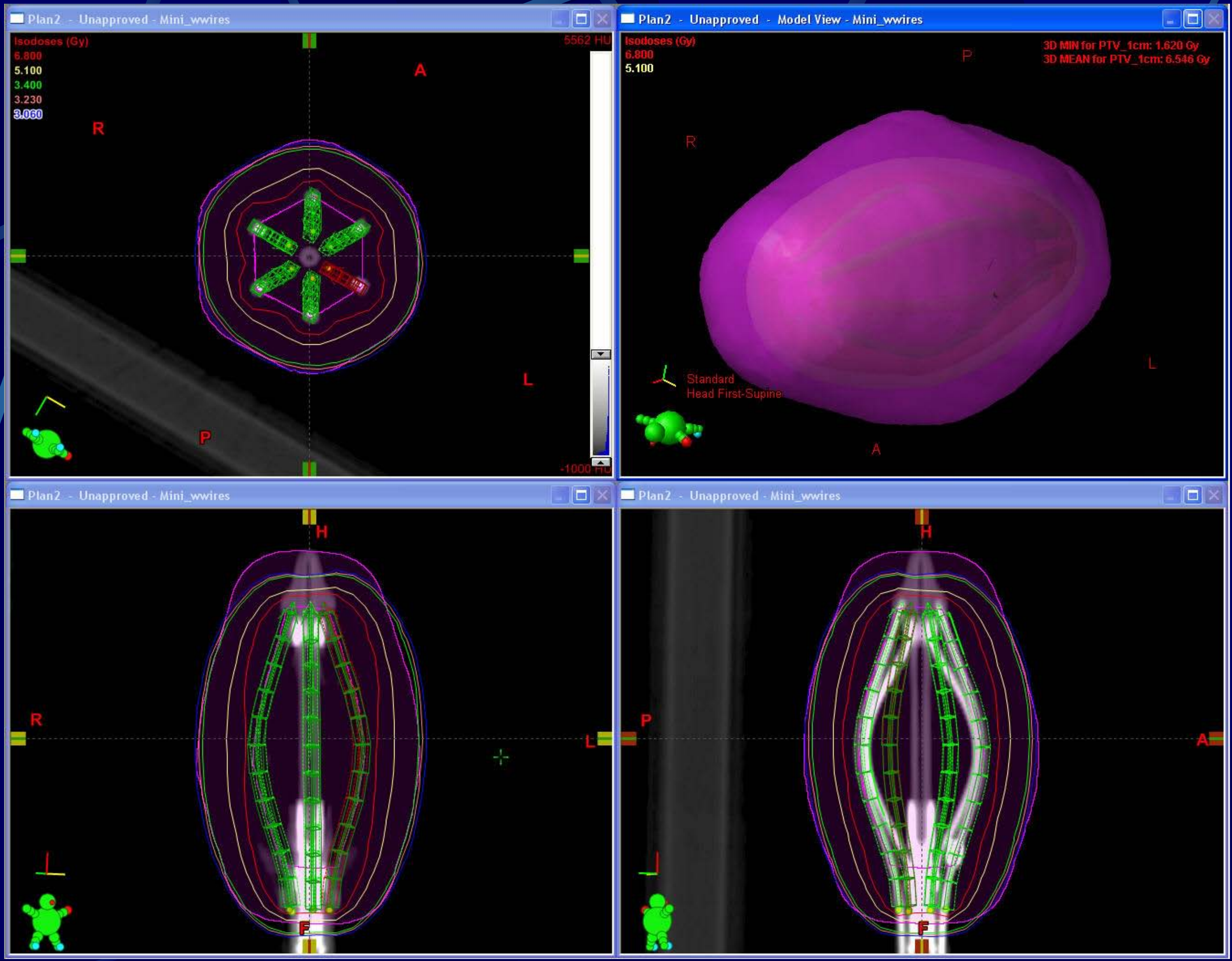
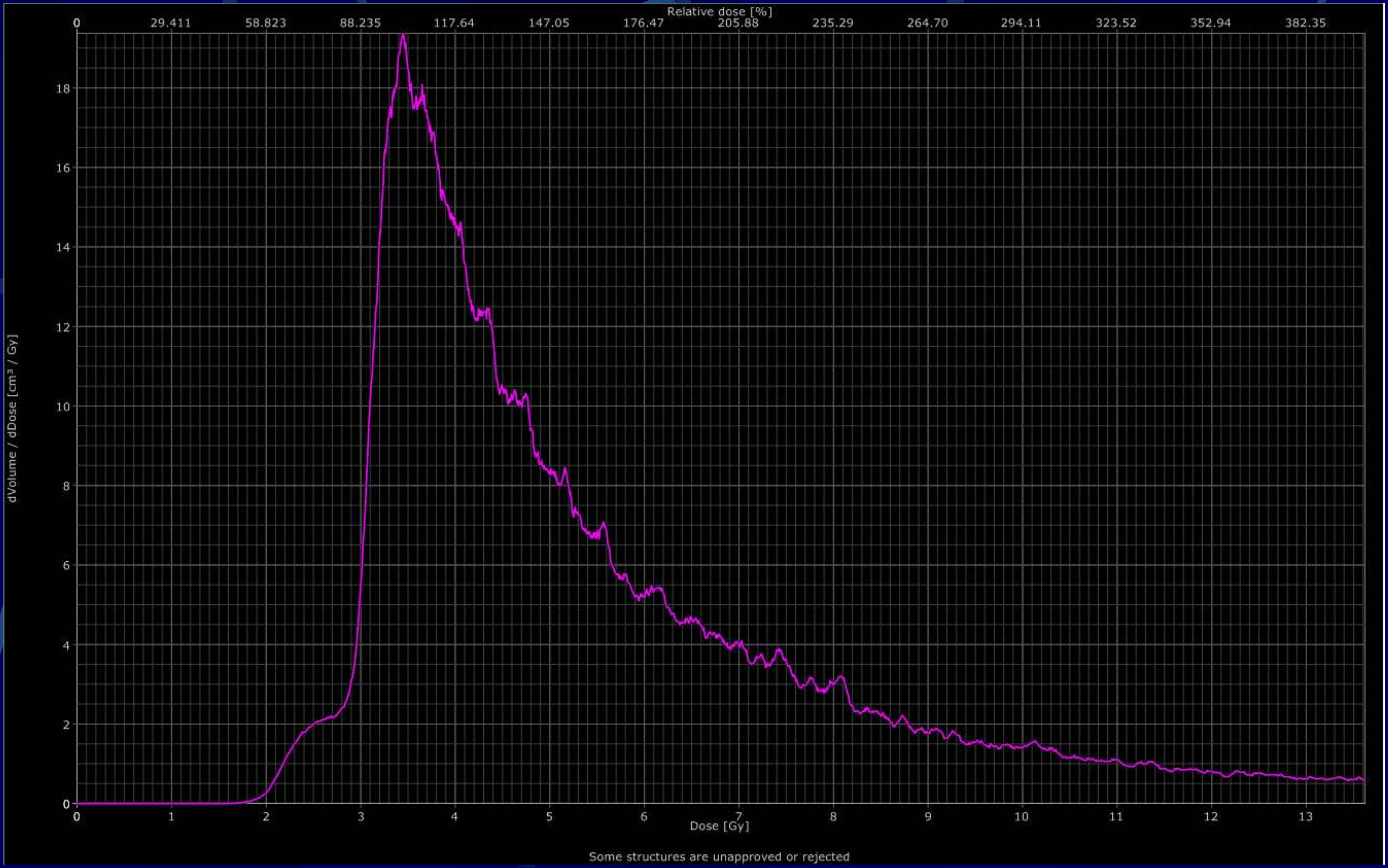
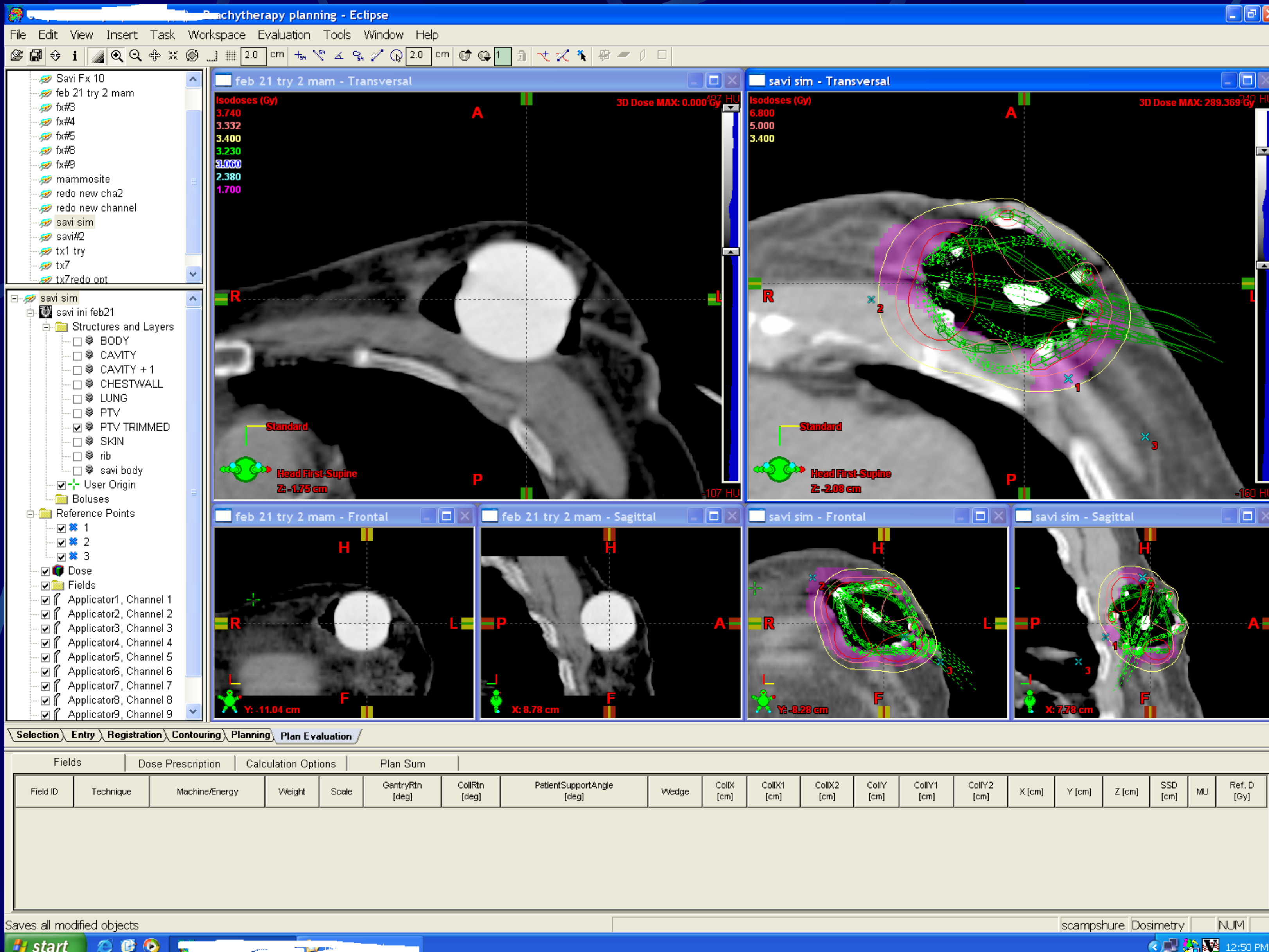


Plan2 - Unapproved - Mini_wwires
Isodoses (Gy)
6.800
5.100
3.400
3.230
3.060
5562 HU
-1000 HU
Plan2 - Unapproved - Model View - Mini_wwires
3D MIN for PTV_1cm: 1.620 Gy
3D MEAN for PTV_1cm: 6.546 Gy
Standard
Head First-Supine
Plan2 - Unapproved - Mini_wwires
Plan2 - Unapproved - Mini_wwires



DDVH shows a long 'hot' tail. Not only do we have tissue receiving 200%PD but also 300%PD and 400%PD.



- courtesy of Rebecca Kitchen M.S.,DABR, Radiation Oncology, Aurora BayCare Medical Center, Green Bay, WI

- courtesy of Rebecca Kitchen M.S.,DABR, Radiation Oncology, Aurora BayCare Medical Center, Green Bay, WI

Interesting topics

- Dose perturbations due to contrast medium and air
- Probabilistic aspects of brachytherapy treatments
- The effect of patient inhomogeneities
- Dose to skin
- Chest wall dose

Dose perturbations due to contrast medium and air

- The radio-opaque iodine-based contrast solution produces dose perturbation up to 6% (for the largest balloon diameter and contrast concentration, relative to a water-filled balloon).
- The dose near the balloon surface may be increased by 0.5% per cm^3 of air.
- Limiting the contrast concentration to 10% would insure less than 3% reduction in the prescription dose, regardless of balloon diameter.

• Dose perturbations due to contrast medium and air in MammoSite treatment: an experimental and Monte Carlo study. Cheng CW, Mitra R, Li XA, Das IJ. Med Phys. 2005 Jul;32(7):2279-87

• Contrast effects on dosimetry of a partial breast irradiation system, Kassas B, Mourtada F, Horton JL, Lane RG. Med Phys. 2004 Jul;31(7):1976-9.

• Dose perturbation induced by radiographic contrast inside brachytherapy balloon applicators. Kirk MC, Hsi WC, Chu JC, Niu H, Hu Z, Bernard D, Dickler A, Nguyen C. Med Phys. 2004 May;31(5):1219-24.

3919 Med. Phys. 37 (8), August 2010

Dosimetric effects of an air cavity for the SAVI™ partial breast irradiation applicator

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(Received 8 July 2009; revised 3 June 2010; accepted for publication 5 June 2010; published 12 July 2010)

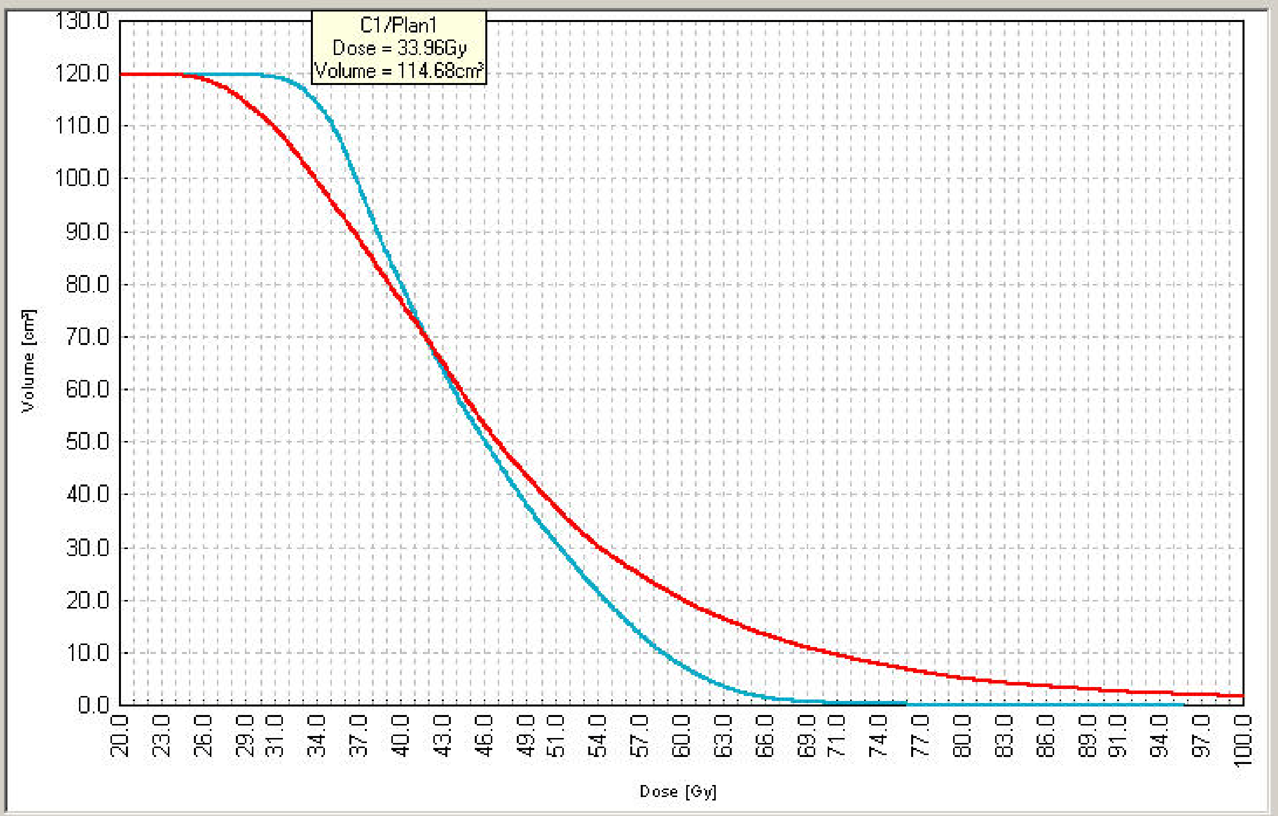
Purpose: To investigate the dosimetric effect of the air inside the SAVI™ partial breast irradiation device.
Methods: The authors have investigated how the air inside the SAVI™ partial breast irradiation device changes the delivered dose from the homogeneously calculated dose. Measurements were made with the device filled with air and water to allow comparison to a homogenous dose calculation done by the treatment planning system. Measurements were made with an ion chamber, TLDs, and film. Monte Carlo (MC) simulations of the experiment were done using the EGSnrc suite. The MC model was validated by comparing the water-filled calculations to those from a commercial treatment planning system.
Results: The magnitude of the dosimetric effect depends on the size of the cavity, the arrangement of sources, and the relative dwell times. For a simple case using only the central catheter of the largest device, MC results indicate that the dose at the prescription point 1 cm away from the air-water boundary is about 9% higher than the homogeneous calculation. Independent measurements in a water phantom with a similar air cavity gave comparable results. MC simulation of a realistic multidwell position plan showed discrepancies of about 5% on average at the prescription point for the largest device.
Conclusions: The dosimetric effect of the air cavity is in the range of 3%–9%. Unless a heterogeneous dose calculation algorithm is used, users should be aware of the possibility of small treatment planning dose errors for this device and make modifications to the treatment delivery, if necessary. © *2010 American Association of Physicists in Medicine.* [DOI: 10.1118/1.3457328]

Errors and uncertainty in delineation, planning and delivery for balloon PBI treatments

- The most probable sources of systematic and random error contributions were identified and the impact on the accuracy of delivered dose studied. They include the effect of:
  - 1. variation in CT resolution and
  - 2. respiratory motion on the accuracy of balloon delineation,
  - 3. contrast concentration on the accuracy of balloon delineation,
  - 4. contouring variability on the accuracy of balloon and planning structure delineation,
  - 5. the variability of applicator tip identification and applicator length,
  - 6. dose matrix sampling on the reported DVH parameters and
  - 7. source position uncertainty.

Histogram

Plan	Structure		Prescr. Dose [Gy]	Treat. [%]	Cov. [%] / [%]	Volume [cm³]	Min [Gy]	Max [Gy]	Mean [Gy]	Modal [Gy]	Median [Gy]	STD
☑ C1/Plan1	PTV		34.0	100.0	100.0 / 99.8	119.7	27.1	95.9	45.3	36.3	43.8	8.54
☑ C1/All_10_fx	PTV				100.0 / 99.8	119.7	22.6	213.8	47.7	44.2	44.3	16.24



Selections...

☑ Grid

Type:

- (•) Cumulative
- ( ) Differential
- ( ) Natural

Dose range [Gy]:

20 to 100

Apply range

Print...

Export...

Close

The effect of patient inhomogeneities

- Treatment planning system software featuring a full TG-43 dose calculation algorithm consider the patient geometry as a homogeneous water medium.
- The comparison of Monte Carlo results and treatment planning system calculations revealed that all percentage isodose contours greater than 60% of the prescribed dose are not affected by the finite breast dimensions or the presence of the lung.
- Treatment planning system calculations overestimate dose in the lung as well as lower isodose contours at points lying both close to the breast or lung surface and relatively away from the implant.

• The effect of patient inhomogeneities in oesophageal 192Ir HDR brachytherapy: a Monte Carlo and analytical dosimetry study. Anagnostopoulos G, Baltas D, Pantelis E, Papagiannis P, Sakelliou L. Phys Med Biol. 2004 Jun 21;49(12):2675-85.

• The effect of finite patient dimensions and tissue inhomogeneities on dosimetry planning of 192Ir HDR breast brachytherapy: a Monte Carlo dose verification study. Pantelis E, Papagiannis P, Karaiskos P, Angelopoulos A, Anagnostopoulos G, Baltas D, Zamboglou N, Sakelliou L. Int J Radiat Oncol Biol Phys. 2005 Apr 1;61(5):1596-602.

The effect of patient finite dimensions

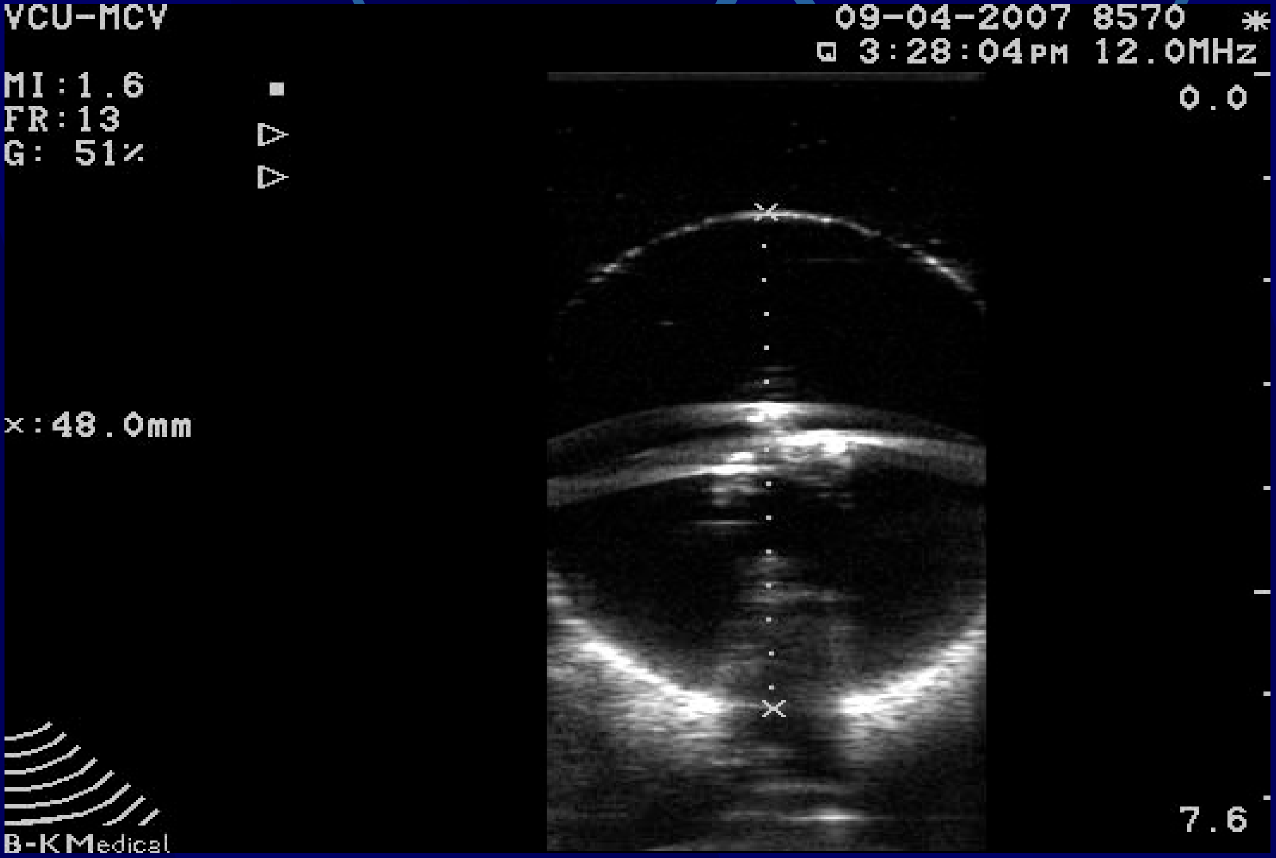
- Most treatment-planning systems currently in use for brachytherapy procedures use water-based dosimetry with no correction for heterogeneity. Therefore, these systems assume that full scatter exists regardless of the amount of tissue beyond the prescription line.
- In fact, the resulting limited scatter could cause an **underdose** to be delivered along the prescription line.

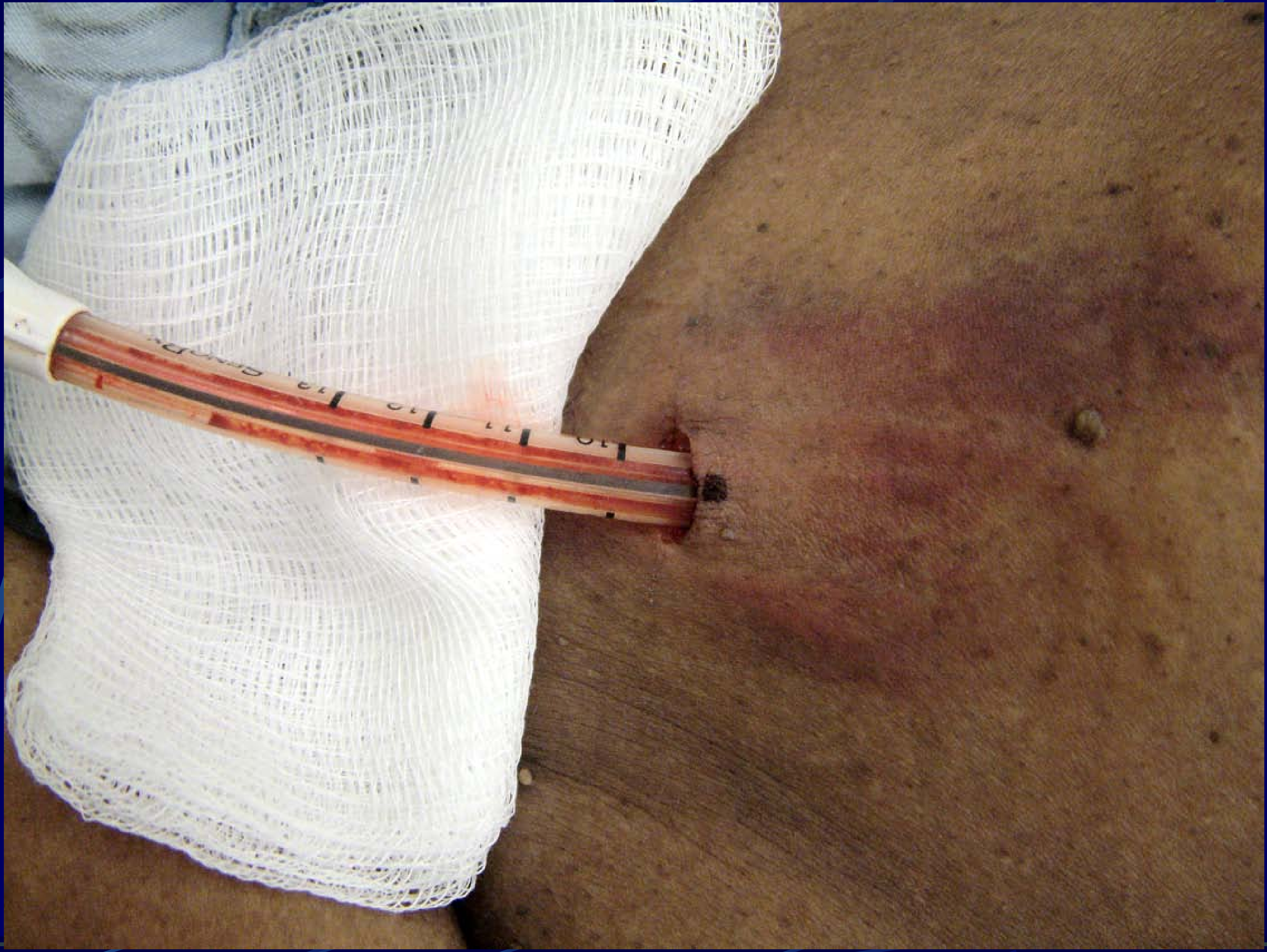
Pre-treatment QA

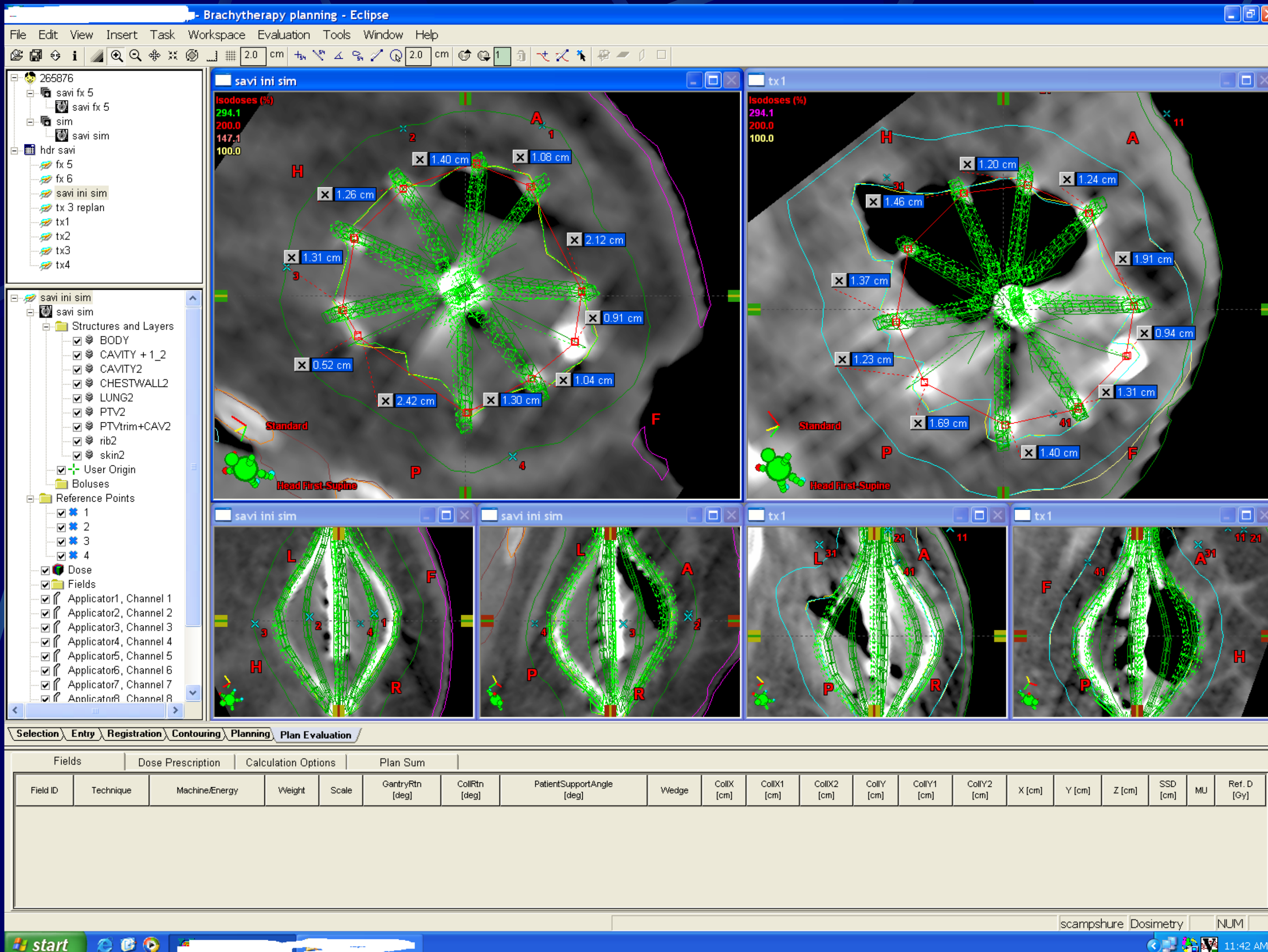
- Balloon Diameter (ultrasound, fluoroscopy, CT)
- Rotation (for the devices that can potentially rotate)
- Catheter and transfer tube length
- Correct identification of treatment lumens and their assignment to the proper afterloader channels

Ultrasound Image of Contura

Central lumen Perpendicular on the Transducer’s Imaging plane





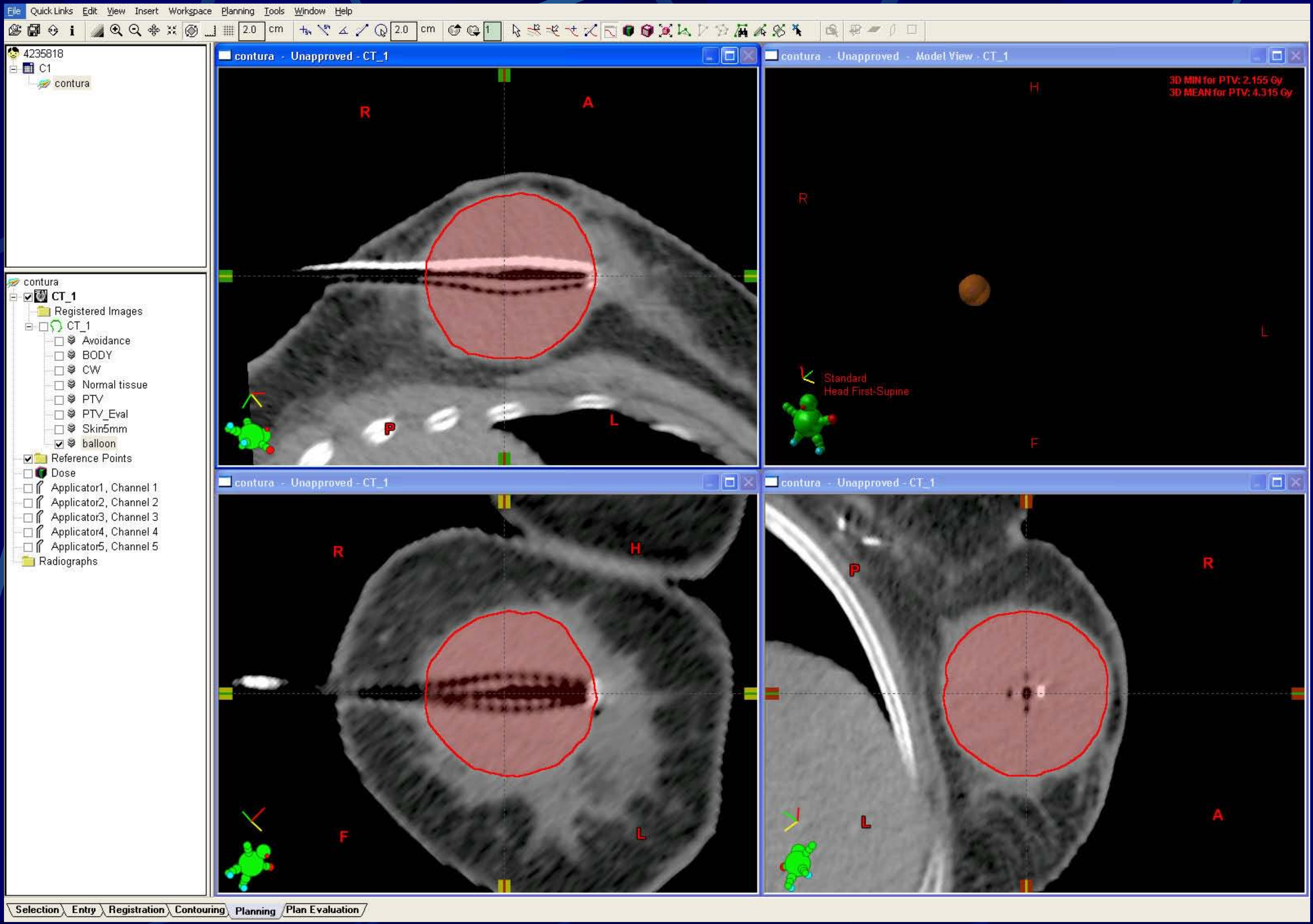


- courtesy of Rebecca Kitchen M.S.,DABR, Radiation Oncology, Aurora BayCare Medical Center, Green Bay, WI

Thank you.

On optimization

- Get to know (and understand) your optimizer.
  If optimization doesn't create 'optimal' plans, something is wrong!
- Use of pseudo-structures
- Constraints (typically Dose-Volume)
- Experiment !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PTV_Eval
Skin5mm
balloon
Reference Points
Dose
Applicator1, Channel 1
Applicator2, Channel 2
Applicator3, Channel 3
Applicator4, Channel 4
Applicator5, Channel 5
Radiographs
contura - Unapproved - CT_1
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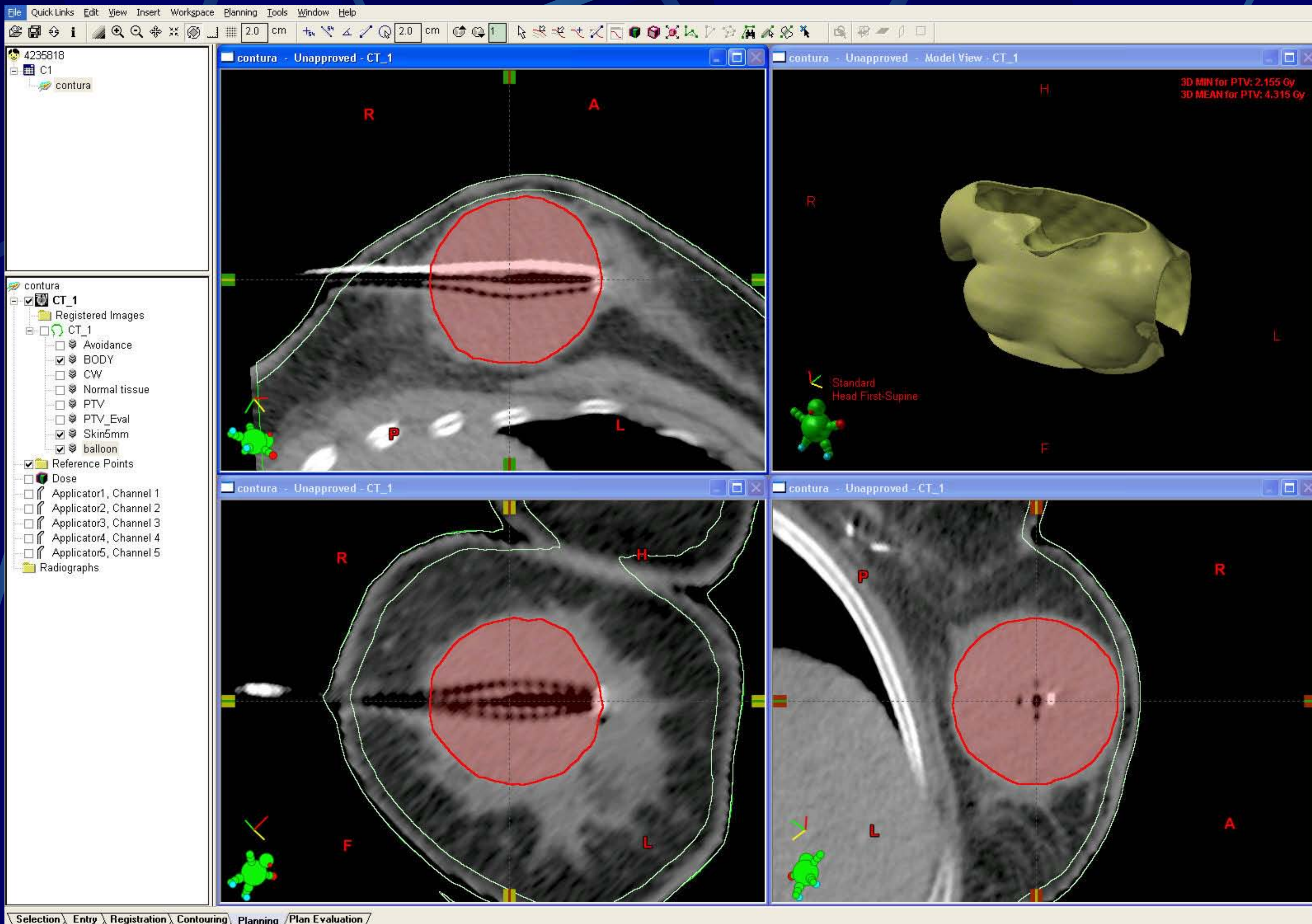

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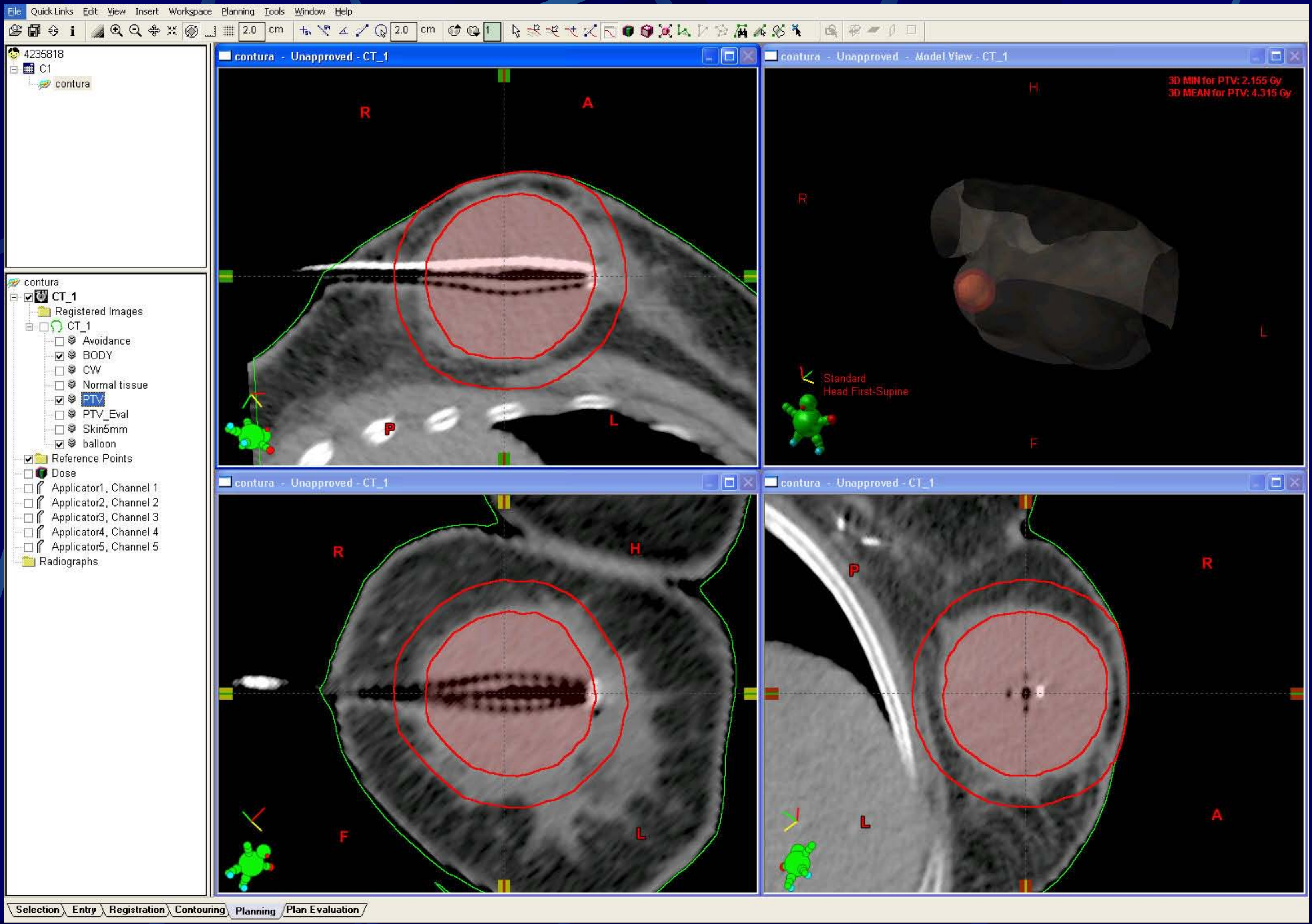

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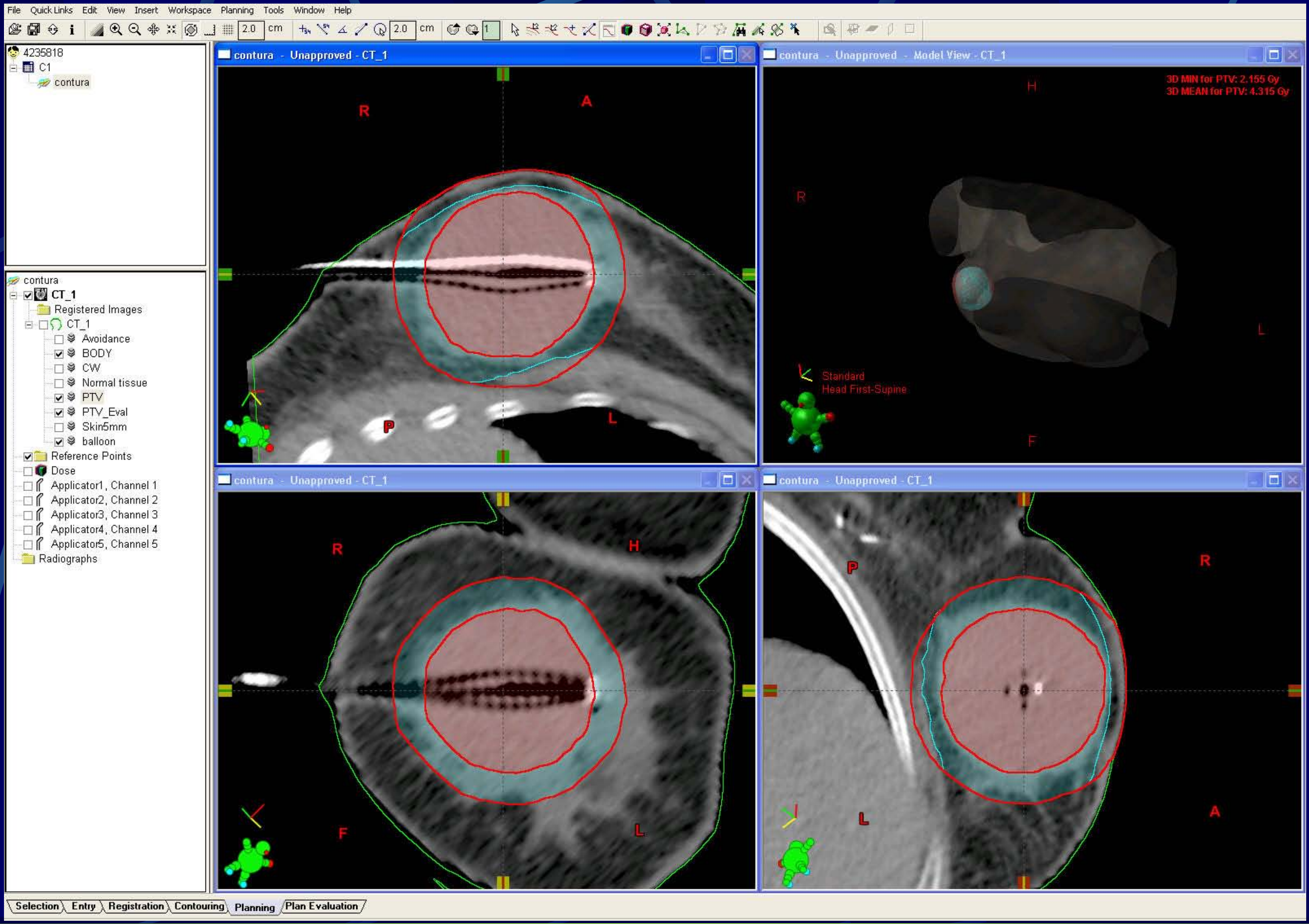
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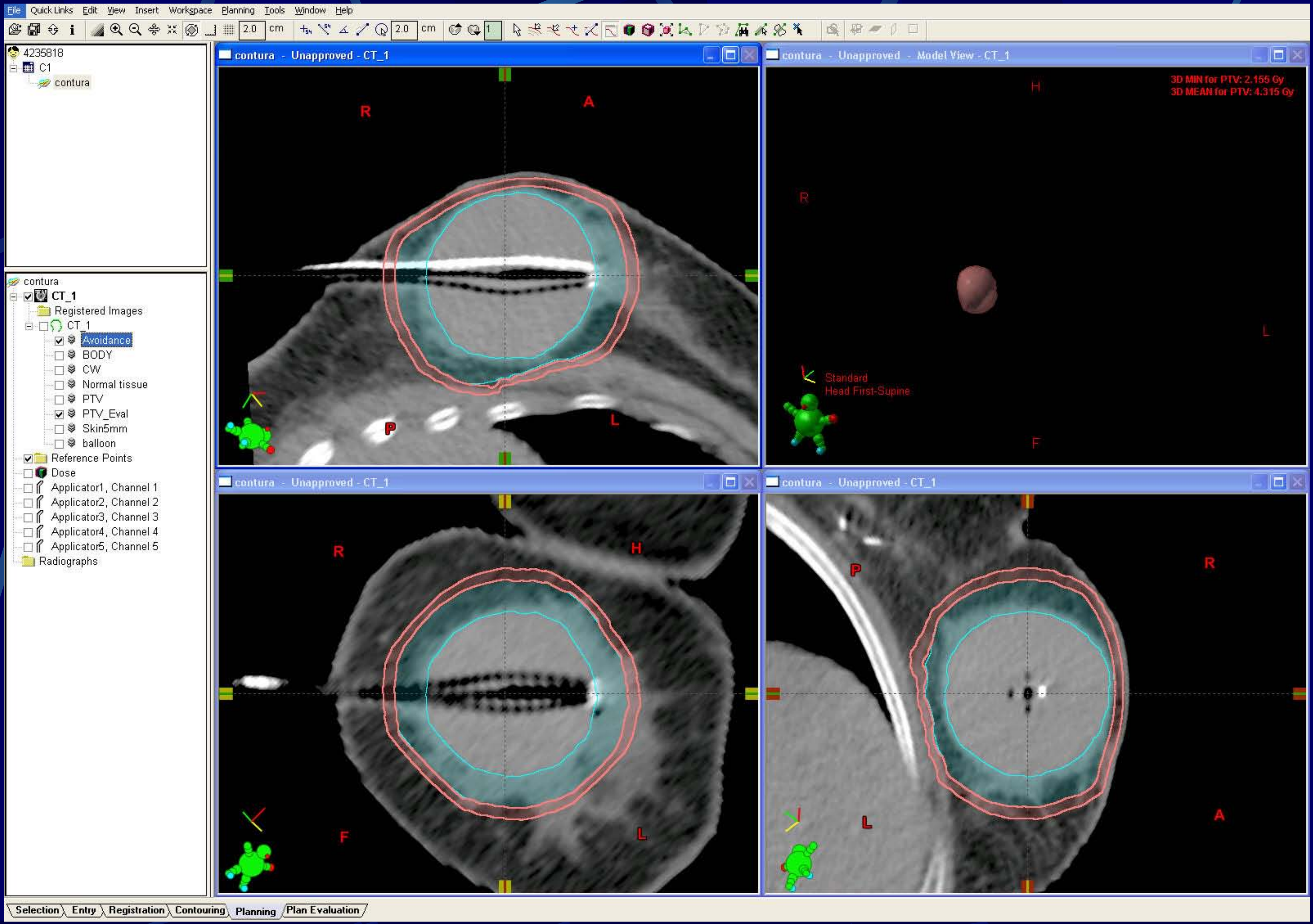
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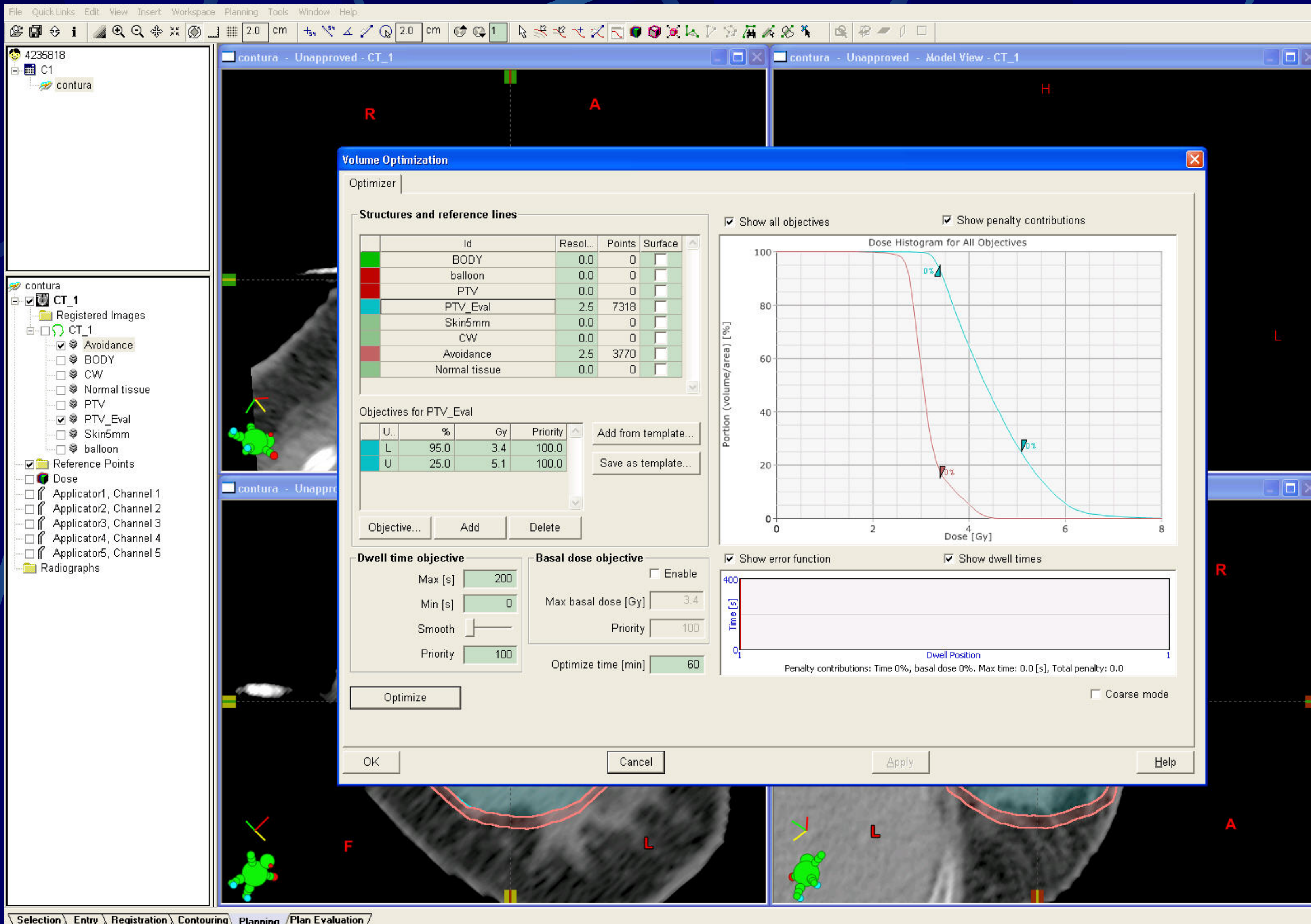
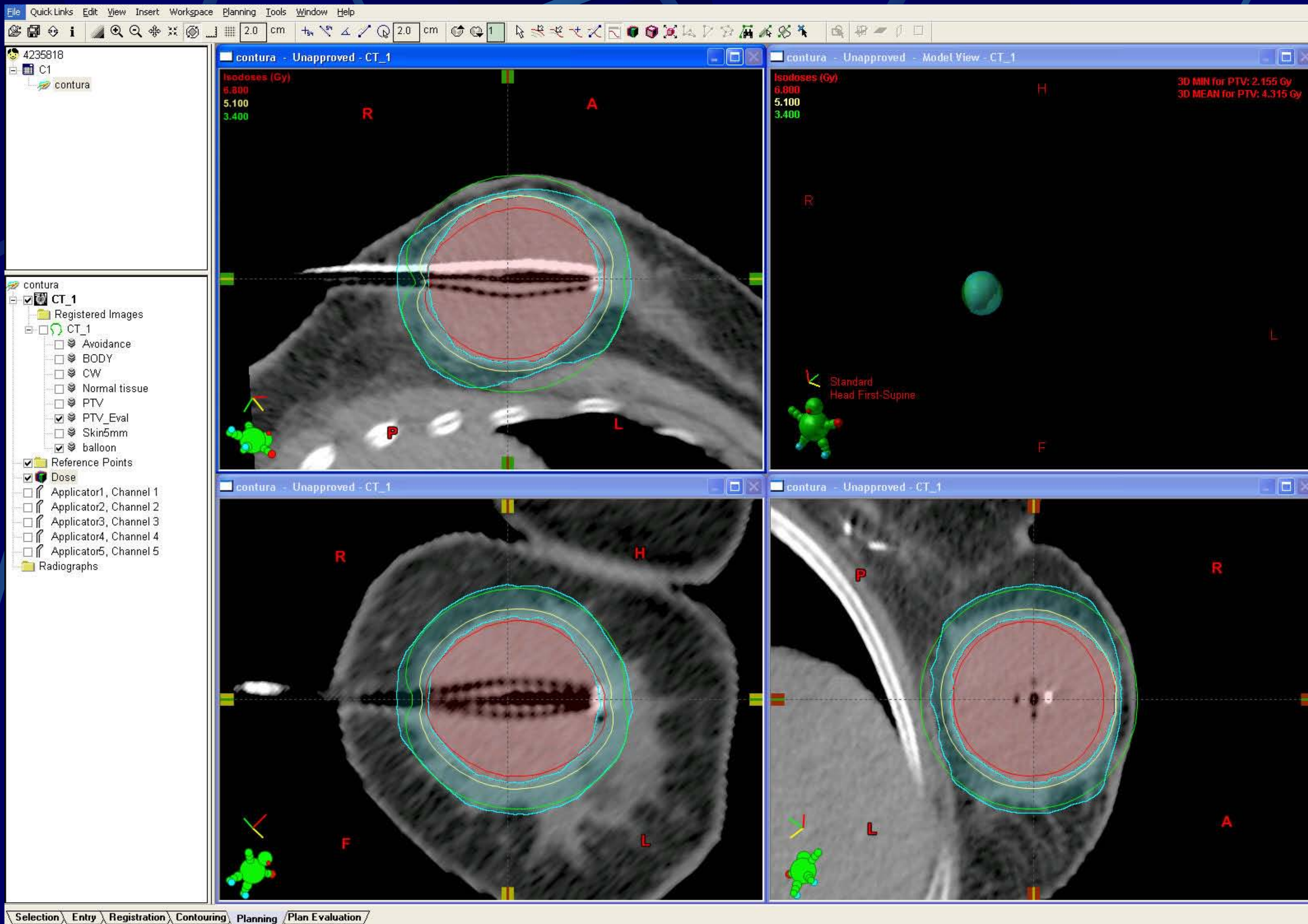
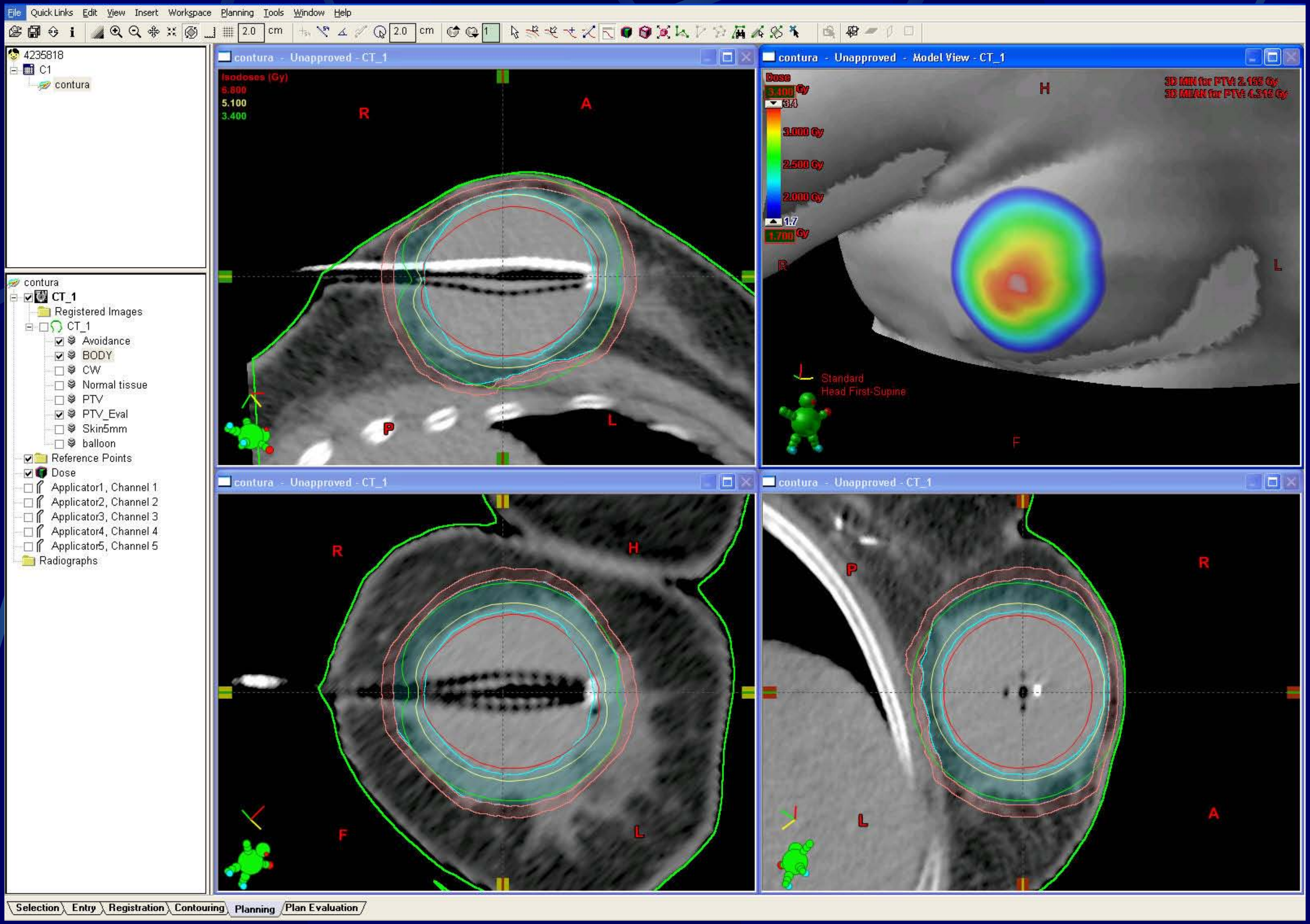
Dose
Applicator1, Channel 1
Applicator2, Channel 2
Applicator3, Channel 3
Applicator4, Channel 4
Applicator5, Channel 5
Radiographs
contura - Unapproved - CT_1
contura - Unapproved - Model View - CT_1
3D MIN for PTV: 2.155 Gy
3D MEAN for PTV: 4.315 Gy
Standard
Head First-Supine
Selection Entry Registration Contouring Planning Plan Evaluation


Volume Optimization
Optimizer
Structures and reference lines
Id Resol... Points Surface
BODY 0.0 0
balloon 0.0 0
PTV 0.0 0
PTV_Eval 2.5 7318
Skin5mm 0.0 0
CW 0.0 0
Avoidance 2.5 3770
Normal tissue 0.0 0
Objectives for PTV_Eval
U.. % Gy Priority
L 95.0 3.4 100.0
U 25.0 5.1 100.0
Add from template...
Save as template...
Objective... Add Delete
Dwell time objective
Max [s] 200
Min [s] 0
Smooth
Priority 100
Basal dose objective
Enable
Max basal dose [Gy] 3.4
Priority 100
Optimize time [min] 60
Optimize
Show all objectives
Show penalty contributions
Dose Histogram for All Objectives
Portion (volume/area) [%]
Dose [Gy]
Show error function
Show dwell times
Time [s]
Dwell Position
Penalty contributions: Time 0%, basal dose 0%. Max time: 0.0 [s], Total penalty: 0.0
Coarse mode
OK Cancel Apply Help
4235818
C1
contura
CT_1
Registered Images
Avoidance
BODY
CW
Normal tissue
PTV
PTV_Eval
Skin5mm
balloon
Reference Points
Dose
Applicator1, Channel 1
Applicator2, Channel 2
Applicator3, Channel 3
Applicator4, Channel 4
Applicator5, Channel 5
Radiographs
contura - Unapproved - CT_1
contura - Unapproved - Model View - CT_1
Selection Entry Registration Contouring Planning Plan Evaluation


File Quick Links Edit View Insert Workspace Planning Tools Window Help
4235818
C1
contura
CT_1
Registered Images
CT_1
Avoidance
BODY
CW
Normal tissue
PTV
PTV_Eval
Skin5mm
balloon
Reference Points
Dose
Applicator1, Channel 1
Applicator2, Channel 2
Applicator3, Channel 3
Applicator4, Channel 4
Applicator5, Channel 5
Radiographs
contura - Unapproved - CT_1
contura - Unapproved - Model View - CT_1
Isodoses (Gy)
6.800
5.100
3.400
3D MIN for PTV: 2.155 Gy
3D MEAN for PTV: 4.315 Gy
Standard
Head First-Supine
Selection
Entry
Registration
Contouring
Planning
Plan Evaluation


File Quick Links Edit View Insert Workspace Planning Tools Window Help
4235818
C1
contura
CT_1
Registered Images
CT_1
Avoidance
BODY
CW
Normal tissue
PTV
PTV_Eval
Skin5mm
balloon
Reference Points
Dose
Applicator1, Channel 1
Applicator2, Channel 2
Applicator3, Channel 3
Applicator4, Channel 4
Applicator5, Channel 5
Radiographs
contura - Unapproved - CT_1
Isodoses (Gy)
6.800
5.100
3.400
contura - Unapproved - Model View - CT_1
Dose
3.000 Gy
2.500 Gy
2.000 Gy
Standard
Head First-Supine
Selection
Entry
Registration
Contouring
Planning
Plan Evaluation

Question 1

Which of the four devices presented do not involve the presence of a balloon?

20%	MammoSite
20%	MammoSite ML
20%	Contura
20%	SAVI
20%	Xoft electronic brachytherapy device

Answer

- Q1 – 4

References

1. Dosimetric characteristics of the MammoSite RTS, a new breast brachytherapy applicator. Edmundson GK, Vicini FA, Chen PY, Mitchell C, Martinez AA. Int J Radiat Oncol Biol Phys. 2002 Mar 15;52(4):1132-9.
2. A Contura catheter offers dosimetric advantages over a MammoSite catheter that increase the applicability of accelerated partial breast irradiation. Wilder RB, Curcio LD, Khanijou RK, Eisner ME, Kakkis JL, Chittenden L, Agustin J, Lizarde J, Mesa AV, Ravera J, Tokita KM. Brachytherapy. 2009 Oct-Dec;8(4):373-8. Epub 2009 Sep 6.
3. Brachytherapy. 2009 Oct-Dec;8(4):367-72. Epub 2009 Sep 9. Initial clinical experience with the Strut-Adjusted Volume Implant brachytherapy applicator for accelerated partial breast irradiation. Yashar CM, Blair S, Wallace A, Scanderbeg D.
4. Nat Clin Pract Oncol. 2009 Mar;6(3):138-42. Epub 2009 Jan 27. Xoft Axxent electronic brachytherapy: a new device for delivering brachytherapy to the breast. Dickler A.

Question 2

The primary purpose of the balloon is:

20%	• to make the target reproducible
20%	• to keep the breast tissue away from the source
20%	• to compress the breast tissue
20%	• to stretch the breast tissue
20%	• to place between source and tissue an tissue 'equivalent' medium

10

Answer

- Q2 – 2

References

1. Dosimetric characteristics of the MammoSite RTS, a new breast brachytherapy applicator. Edmundson GK, Vicini FA, Chen PY, Mitchell C, Martinez AA. Int J Radiat Oncol Biol Phys. 2002 Mar 15;52(4):1132-9.
2. A Contura catheter offers dosimetric advantages over a MammoSite catheter that increase the applicability of accelerated partial breast irradiation. Wilder RB, Curcio LD, Khanijou RK, Eisner ME, Kakkis JL, Chittenden L, Agustin J, Lizarde J, Mesa AV, Ravera J, Tokita KM. Brachytherapy. 2009 Oct-Dec;8(4):373-8. Epub 2009 Sep 6.
3. Brachytherapy. 2009 Oct-Dec;8(4):367-72. Epub 2009 Sep 9. Initial clinical experience with the Strut-Adjusted Volume Implant brachytherapy applicator for accelerated partial breast irradiation. Yashar CM, Blair S, Wallace A, Scanderbeg D.
4. Nat Clin Pract Oncol. 2009 Mar;6(3):138-42. Epub 2009 Jan 27. Xoft Axxent electronic brachytherapy: a new device for delivering brachytherapy to the breast. Dickler A.

Question 3

When TG43 is employed to compute dose for APBI, which device/source is likely to be more affected by the presence of inhomogeneities?

20%	•	MammoSite/ Ir-192
20%	•	MammoSite ML / Ir-192
20%	•	Contura / Ir-192
20%	•	SAVI / Ir-192
20%	•	Xoft electronic brachytherapy (eBx) balloon device/50kV xrays

10

Answer

- Q3 - 5

References:

1. Dosimetric comparison of three radiation sources used in balloon-based breast brachytherapy John J. Munro, Ph.D. David C. Medich, Ph.D., Brachytherapy 6 (2007) 77-118

2. A dosimetric comparison of MammoSite high-dose-rate brachytherapy and Xoft Axxent electronic brachytherapy. Dickler A, Kirk MC, Seif N, Griem K, Dowlatshahi K, Francescatti D, Abrams RA. Brachytherapy. 2007 Apr-Jun;6(2):164-8