Comparison of Two Phantoms for End-to-End SRS/SBRT Testing

Vikren Sarkar, Ph.D.

Associate Professor

University of Utah Huntsman Cancer Center

Disclosure

- Travel and Speaker Honorarium from Sun Nuclear Corp.

Overview

- Comparing the two phantoms on different aspects of end-to-end testing
- Lessons Learned and Tips/Tricks for using the phantoms
- The “joys” of micro chambers (time permitting)

QA for SRS/SBRT

- The nature of SRS/SBRT requires very high accuracy both on the planning end and on the delivery end.
- Much has been written about the special requirements for characterizing beams used for stereotactic treatments.
- A large body of literature also exists on how to test various aspects of the SRS/SBRT treatment chain.

QA for SRS/SBRT

- The end-to-end (E2E) test is the only test that can tell us the whole story about our accuracy.
- This is why the E2E test should be done regularly (recommendation of TG101).
- Is there a phantom that would allow us to do this efficiently?

What would constitute an ideal phantom?

- Easy to set up.
- Reproducible setup.
- Allows user to do a full E2E.

Current Commercial Solutions

- Non-anthropomorphic
  - The Lucy 3D QA Phantom (Standard Imaging)
  - StereoPHAN (Sun Nuclear)
- Anthropomorphic
  - STEEV (CIRS)
  - Max-HD (IMT)

Lucy

StereoPHAN

STEEV

www.medicaldevicedepot.com

Max-HD

www.gammagurus.com

The Two Candidates

- Lucy 3D QA & StereoPHAN
  - Both are non-anthropomorphic
  - Both are precision-milled
  - Both are modular
  - Both are meant to be used for E2E testing
  - Lucy has been in the market for a very long time while StereoPHAN is newer.
  - Do they fit the “ideal phantom” characteristics?

Ease of Setup

Lucy

1. Disassembly required to change inserts
2. Smooth clear surface
3. Roughly 5 mins to change insert and reposition using lasers

StereoPHAN

1. No disassembly required to change insert
2. Matte surface
3. Roughly 2 mins to change insert and reposition using lasers

Once a user gets familiar with the phantoms, they are both easy to use and are basically equivalent.

An ideal phantom?

- ✓ Easy to set up.
  - Reproducible setup.
  - Allows user to do a full E2E.

Repositioning Reliability Test

- We did reproducibility testing using a modified Winston-Lutz-type test - planned radiation field offset from geometric center of film insert.

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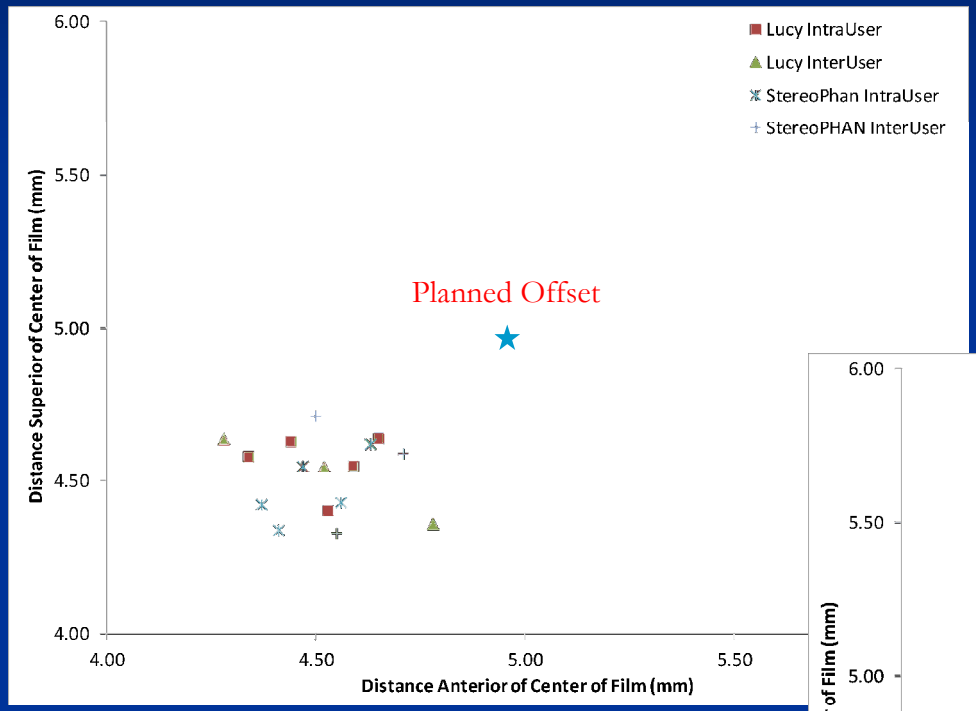
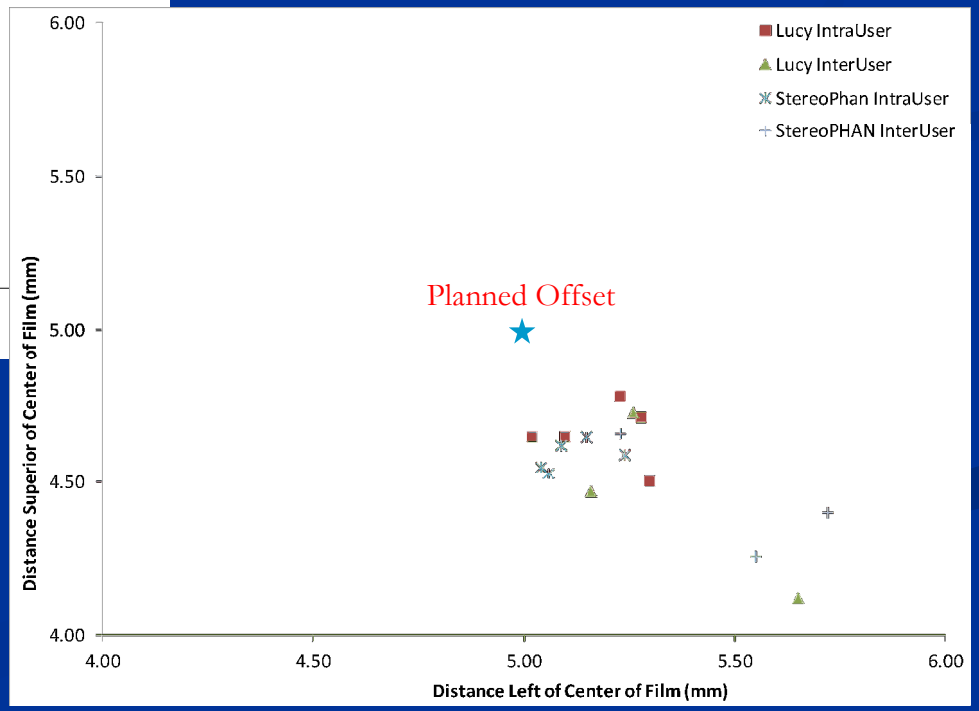
Repositioning Reliability Test

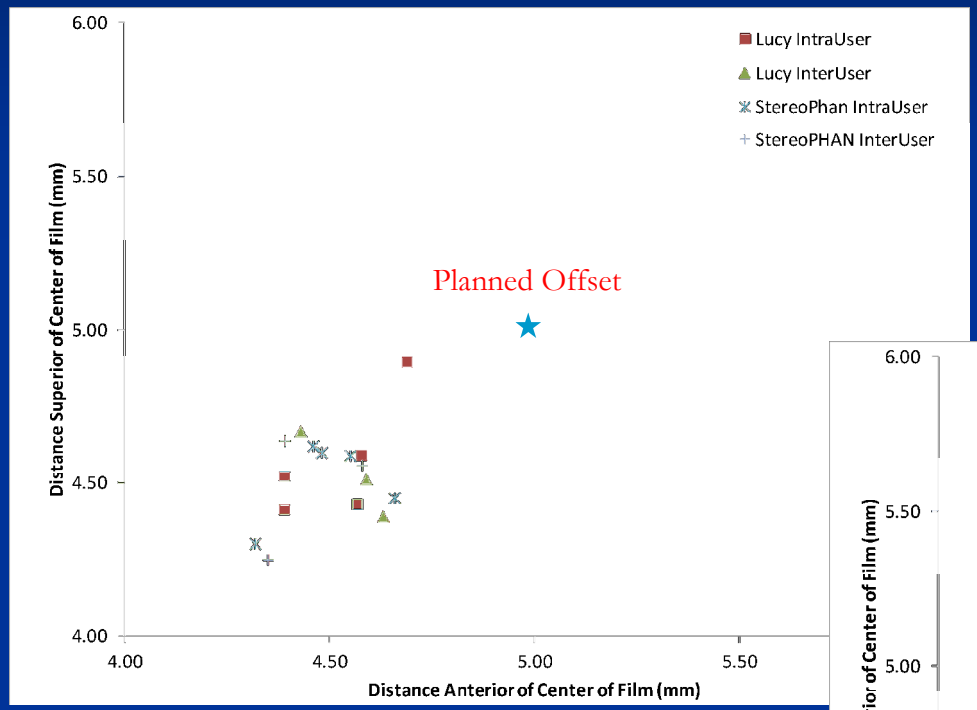
- We did reproducibility testing using a modified Winston-Lutz-type test - planned radiation field offset from geometric center of film insert.
- The test was repeated 5 times by a single user (intra-user) and then by three different users (inter-user).
- Done in 3 clinical scenarios:
  1. Framed (Brainlab) with no IGRT
  2. Frameless with ExacTrac IGRT
  3. Frameless with kV Conebeam CT IGRT

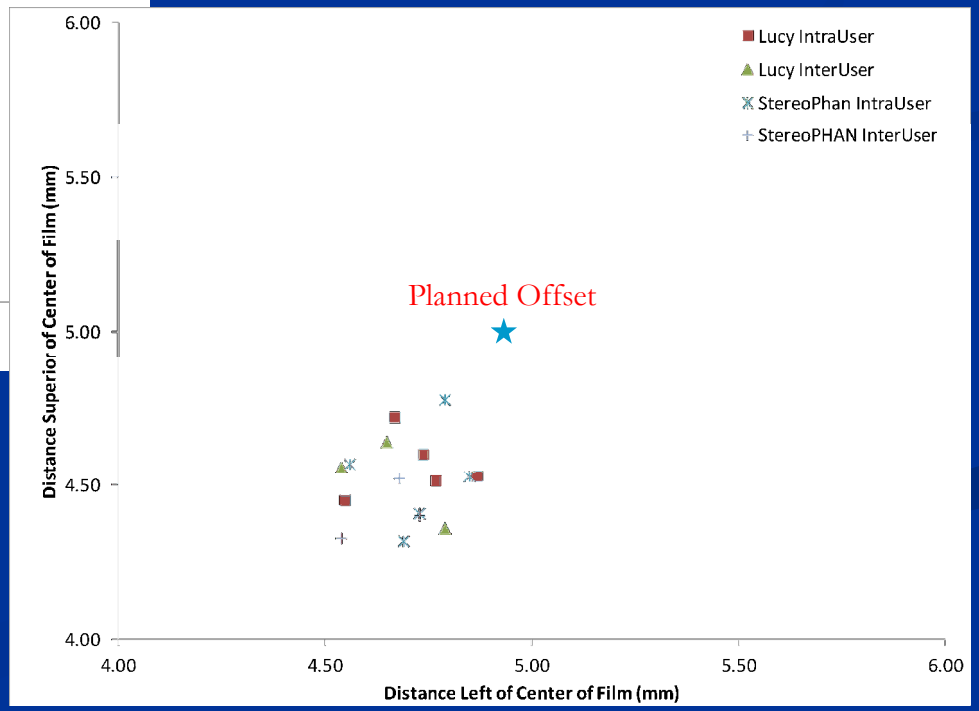
Repositioning Reliability Test Framed, No IGRT



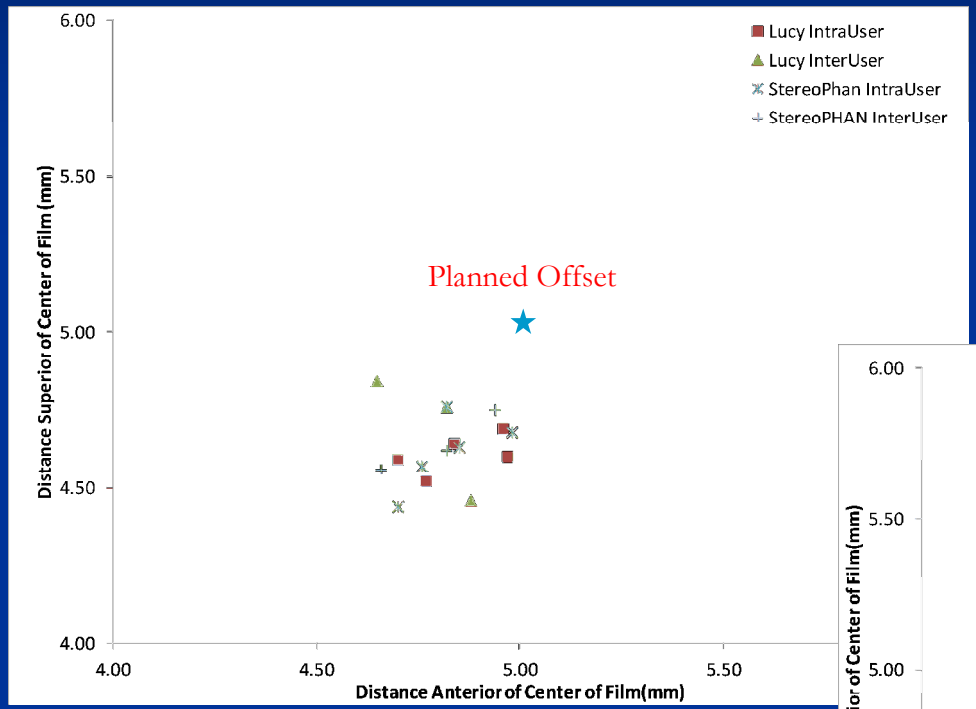


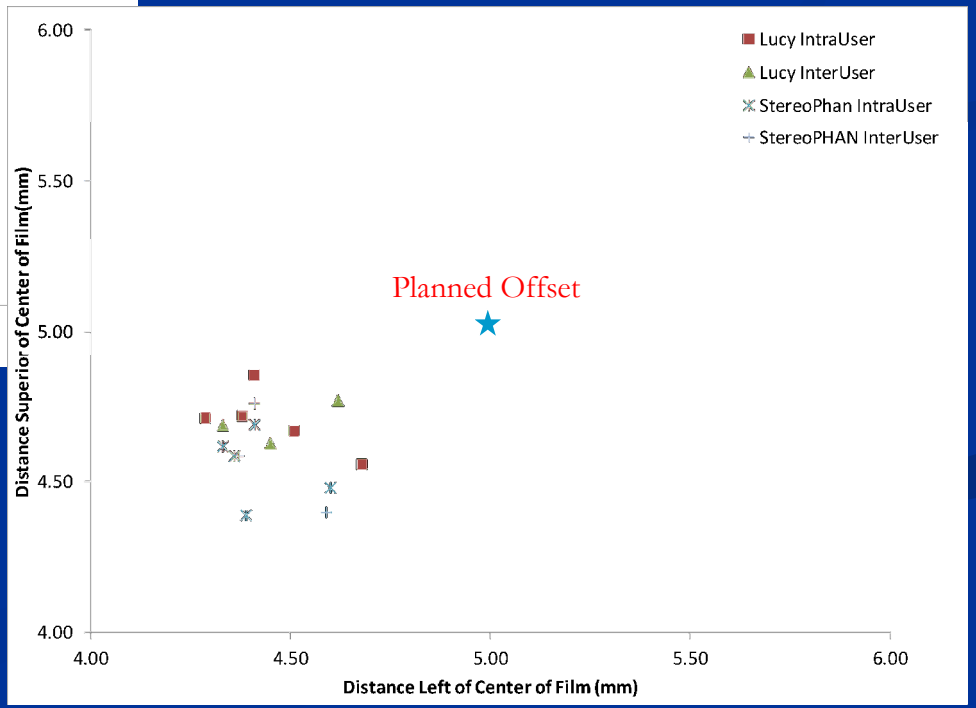
Repositioning Reliability Test Frameless, ExacTrac IGRT





Repositioning Reliability Test Frameless, Conebeam CT IGRT





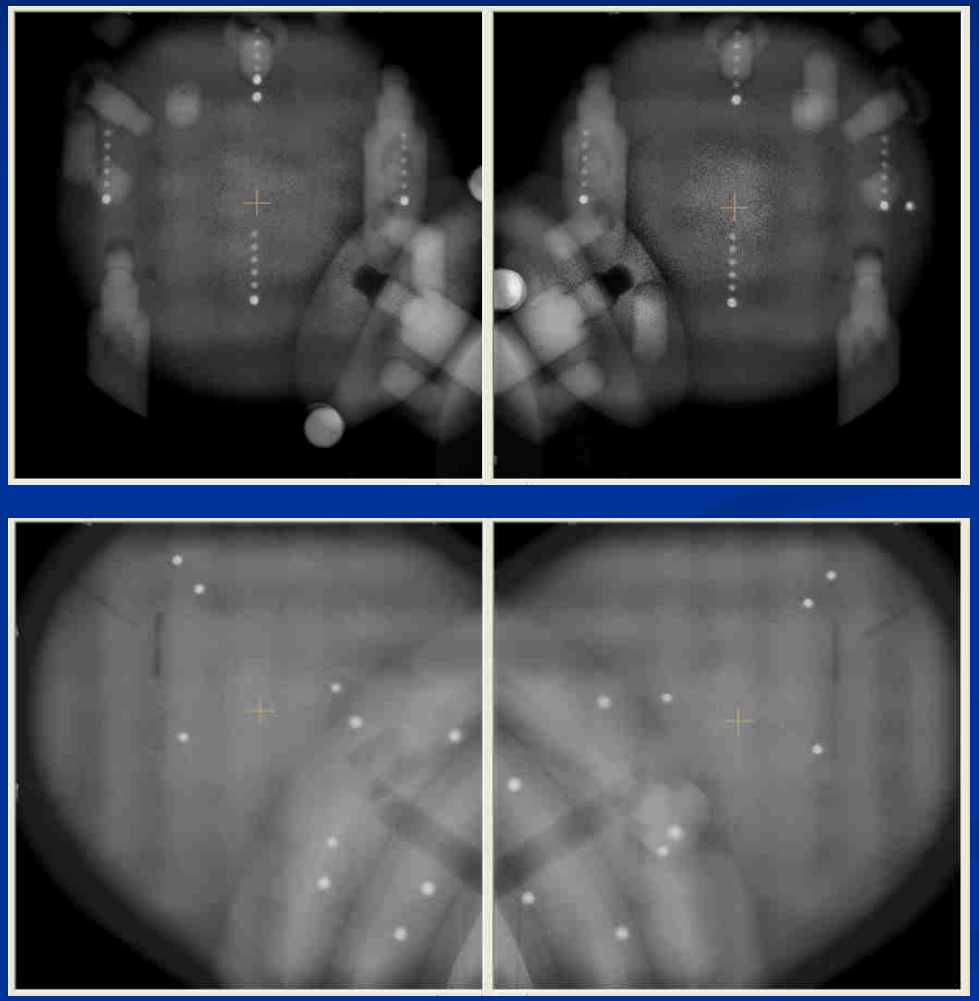
Repositioning Reliability Test Result Summary & Conclusion

- Very tight clustering of results shows reproducibility.
- Results being close to expected value shows accuracy.
- Both phantoms were deemed equivalent as far as repositioning reliability
  - … but there were some lessons learned along the way

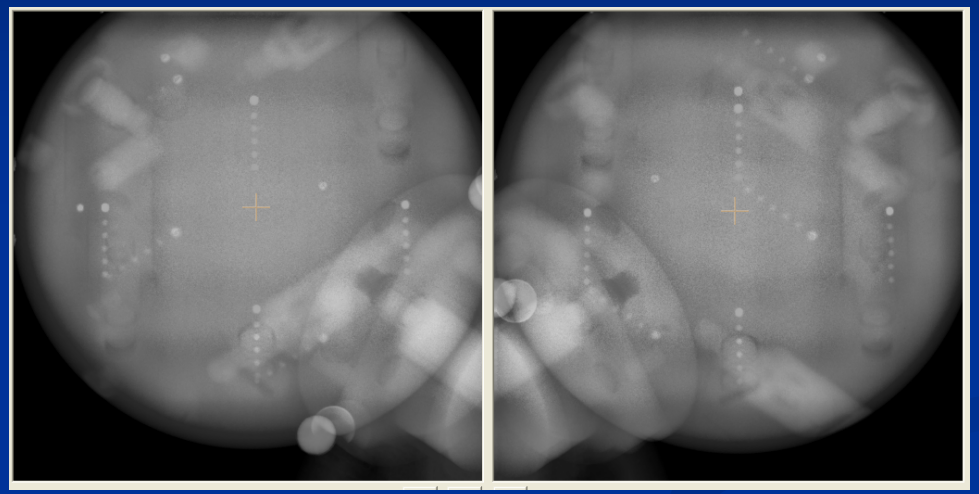
Lessons learned

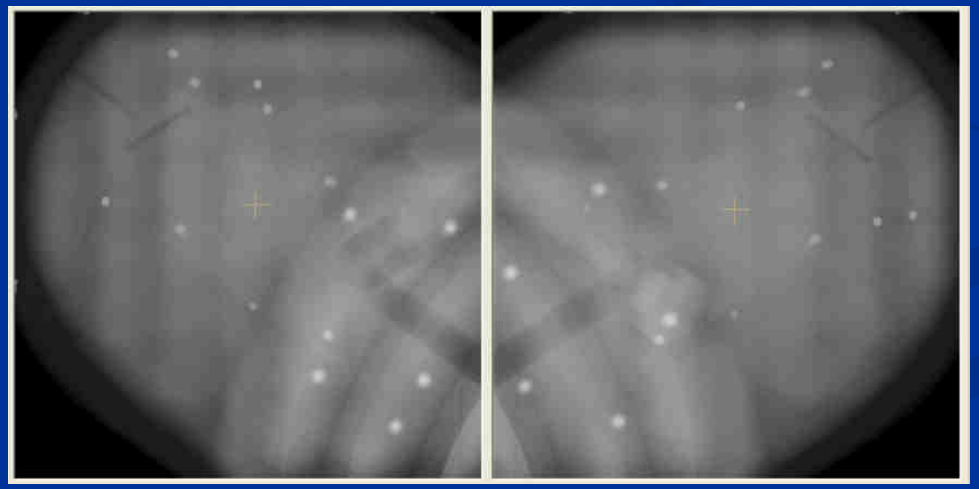
- Both phantoms made of uniform material with very few elements to provide image contrast.
- It therefore makes it imperative that the reference CT scan used for IGRT be obtained in the exact geometry in which the phantom is being imaged.

Reference CT in correct geometry



Reference CT in incorrect geometry





An ideal phantom?

- ✓ Easy to set up.
- ✓ Reproducible setup.
  - Allows user to do a full E2E.

Phantom End to End Testing

- In the clinic, we would use the full workflow to do our end to end test.
- For a direct comparison, since the phantoms have different geometries, we broke this part down in two parts
  - CT/MRI Fusion
  - A phantom “Plan Validation” test based on a clinical plan

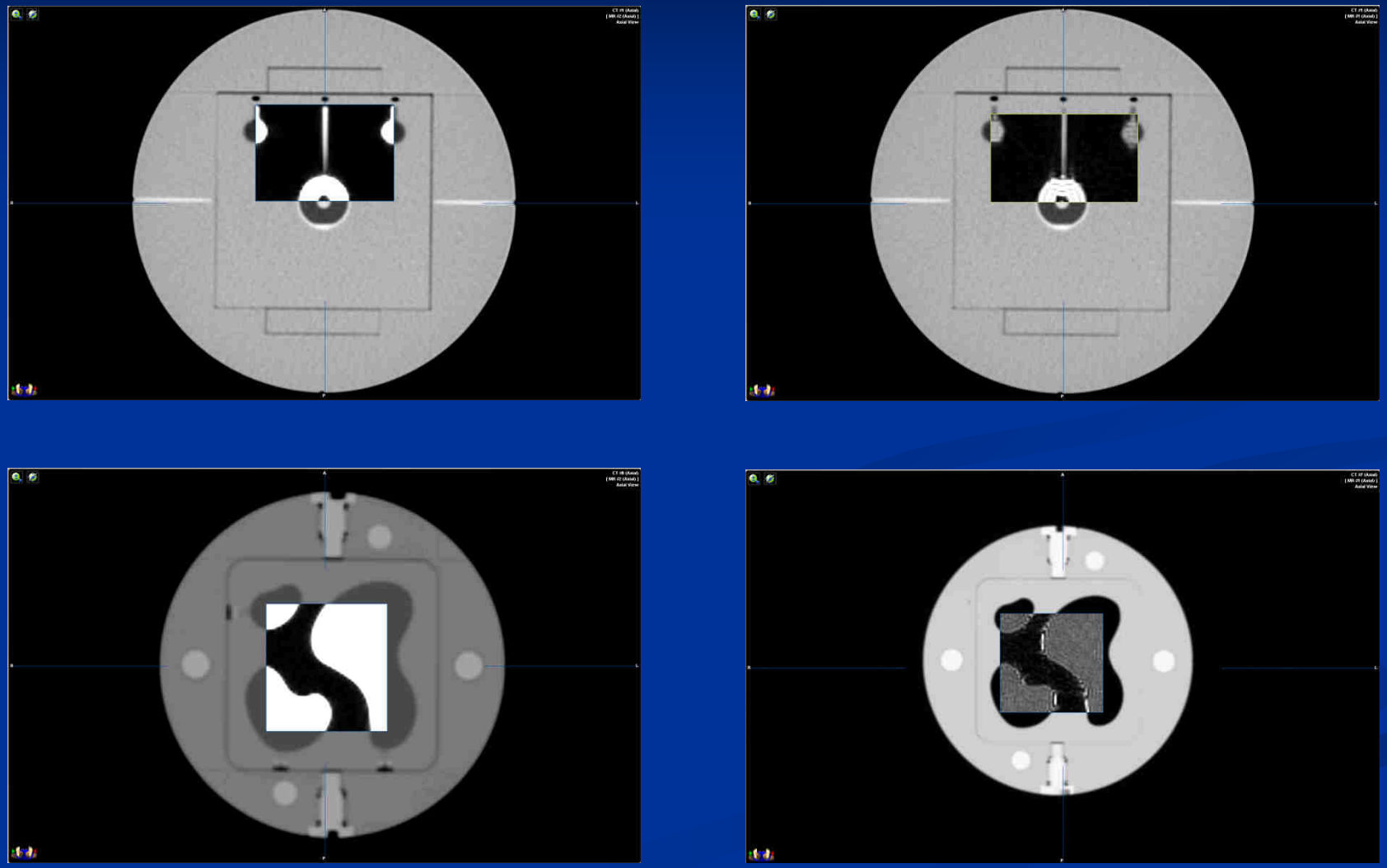
CT/MR Fusion

- Both phantoms provide inserts with objects of known volumes that can be imaged in both an MRI and CT scanner.
- This allows us to check for two properties:
  - How each modality will affect the contoured volumes.
  - How much distortion is being introduced from the MR process.

Volume Check

	Lucy								
	CT			MRI - SPGR (T1)			MRI - T2		
	Actual Volume (cc)	Contoured Volume (cc)	Difference (%)	Actual Volume (cc)	Contoured Volume (cc)	Difference (%)	Actual Volume (cc)	Contoured Volume (cc)	Difference (%)
	1.70	1.75	3%	1.70	1.81	6%	1.70	1.94	14%
	5.25	5.31	1%	5.25	5.422	3%	5.25	5.69	8%
	12.25	12.11	-1%	12.25	12.76	4%	12.25	13.63	11%
Average			1%			5%			11%
	StereoPHAN								
	CT			MRI - SPGR (T1)			MRI - T2		
	Actual Volume (cc)	Contoured Volume (cc)	Difference (%)	Actual Volume (cc)	Contoured Volume (cc)	Difference (%)	Actual Volume (cc)	Contoured Volume (cc)	Difference (%)
	0.52	0.52	0%	0.52	0.55	5%	0.52	0.58	11%
	0.52	0.54	3%	0.52	0.56	7%	0.52	0.57	8%
	3.90	3.77	-3%	3.90	4.00	3%	3.90	4.19	8%
Average			0%			5%			9%

Evaluation of MRI Distortion



Evaluation of MRI Distortion

- Another way to do this is by using a grid-like insert that can be imaged and show distortions as non-straight lines.
  - Available with Lucy but not StereoPHAN.

End to End – Plan Validation

- Done on a Novalis Classic with a 9-field IMRT plan (Rx = 5 Gy/fraction)
  - Framed using no IGRT
  - Frameless using ExacTrac for IGRT
- Repeated on a TrueBeam using a 2-arc VMAT plan (Rx = 5 Gy/fraction)
  - Frameless using kV CBCT for IGRT

Plan Validation Results

				Ion Chamber Results				Film Analysis Results
Phantom	Framed/ Frameless	IGRT Type	Plan Type	Plan Dose (Gy)	Average Measured Dose (Gy)	Difference from Planned Dose (%)	Difference between Phantoms (%)	Average Gamma (2%,2mm)
Lucy	Framed	None	9 Field IMRT	5.40	5.38	-0.4%	0.6%	90.0
StereoPHAN	Framed	None	9 Field IMRT	5.22	5.23	0.2%		88.1
Lucy	Frameless	ExacTrac	9 Field IMRT	5.40	5.33	-1.4%	0.1%	84.5
StereoPHAN	Frameless	ExacTrac	9 Field IMRT	5.22	5.15	-1.3%		83.4
Lucy	Frameless	kV CBCT	2 Arc VMAT	5.72	5.78	1.0%	0.4%	98.0
StereoPHAN	Frameless	kV CBCT	2 Arc VMAT	5.59	5.63	0.6%		96.9

An ideal phantom?

- ✓ Easy to set up.
- ✓ Reproducible setup.
- ✓ Allows user to do a full E2E.

Would you like fries with that?

- Lucy offers the following other functionality:
  1. Insert allowing stack of films for a pseudo-3D dose distribution.
  2. MRI Distortion Insert.
  3. Electron Density Insert.
  4. Dosimetry Insert for TLD or MOSFET.
  5. 3D Volumetric Target Dosimetry Kit.
- SterePHAN offers:
  1. Cyberknife-specific modules.
  2. 3-Film stack
  3. Ability to use SRS MapCHECK™
- Non-equivalent functionality was not tested.

Conclusion

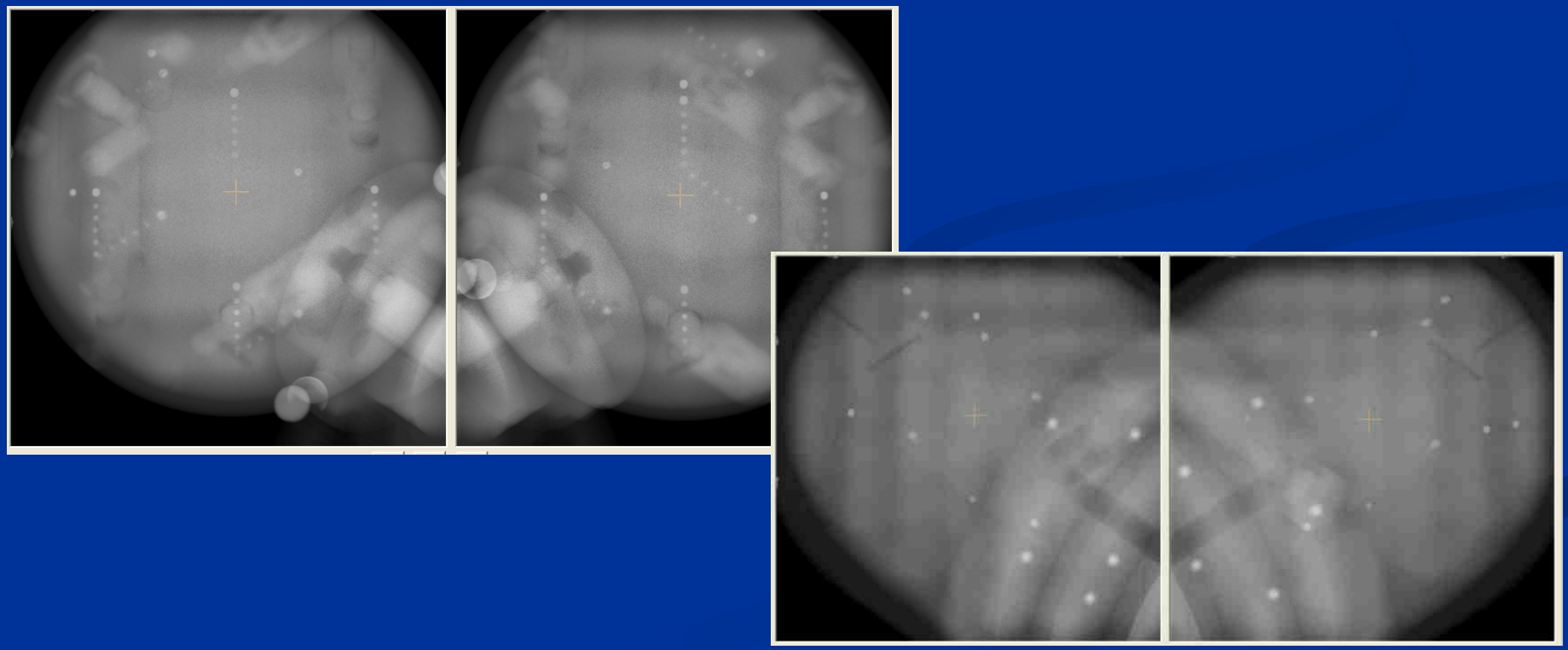
- The results from both phantoms were equivalent for all tests performed.

Publication

Sarkar V, Huang L, Huang J, Szegedi M, Rassiah-Szegedi P, Zhao H, Salter (2016), Head to Head Comparison of Two Commercial Phantoms Used for SRS QA . *Journal of Radiosurgery & SBRT*

Lessons Learned

- Scan the phantom in the same geometry as you intend to use it.



Lessons Learned

- Orientation can turn out to be a show stopper. Mark your inserts and always use the same orientation.

Lessons Learned

- If you will use a film insert, use the registration pins to guide you in your analysis.

Lessons Learned

- For "absolute" dose measurements with a micro-chamber, do not use a 10x10 cm^2 field as reference.
  - These tend to have a rather large stem effect associated with it.
  - Use a smaller field size (say 3x3 cm^2)
- Speaking of micro-chambers…

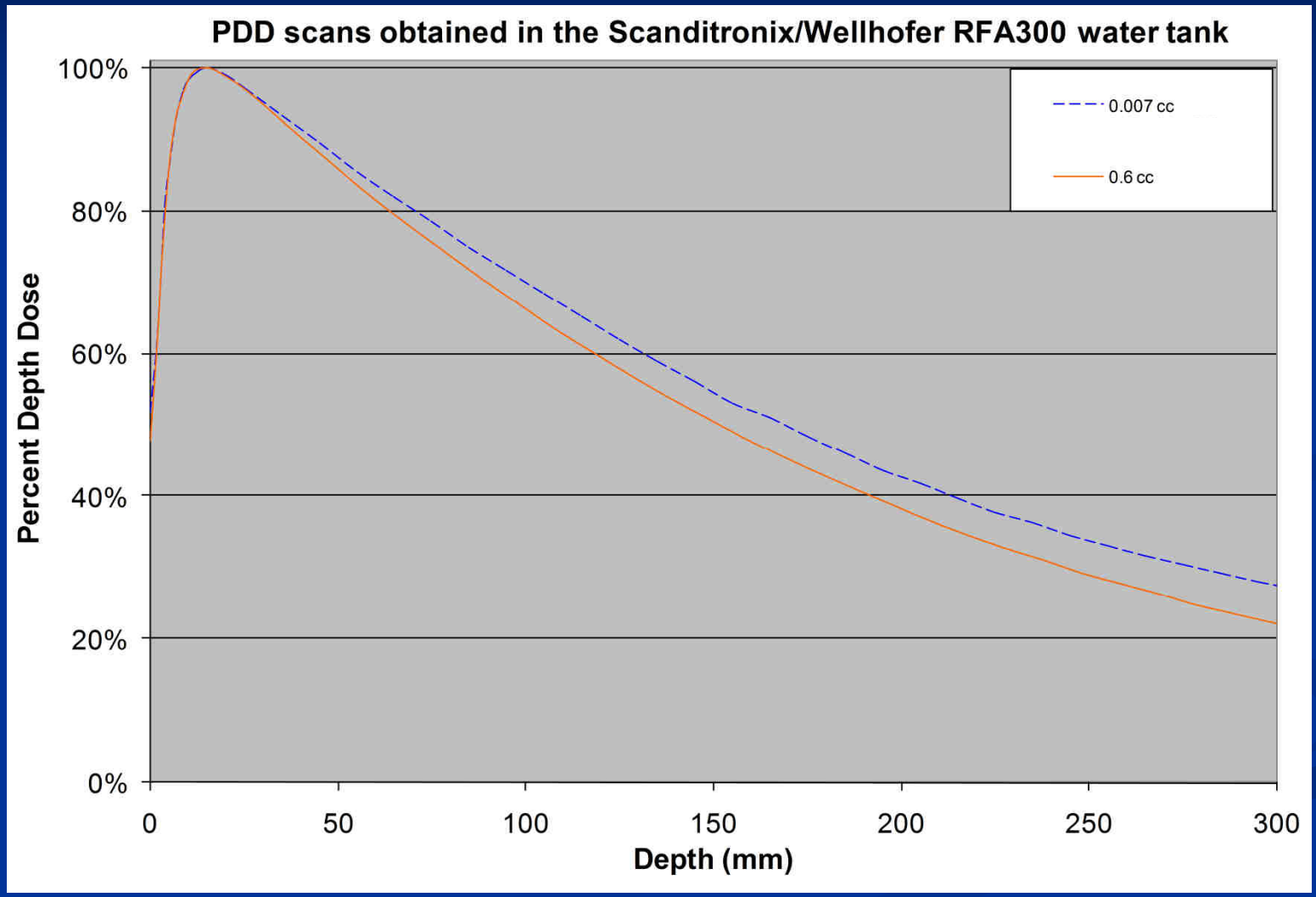
Background

- Commissioning of a new algorithm required new water scans to be obtained.
- Since very small fields would be involved, a micro-chamber (A16) was used to obtain all of the scans.
- The first set of scans obtained looked normal
  - d_{max}, trend with field size, trend with depth etc…

Background

- All was well…
  - until the 10x10, 100 SSD scan was compared to the analogous one obtained the previous month during the TG-51 calibration using a Farmer chamber.

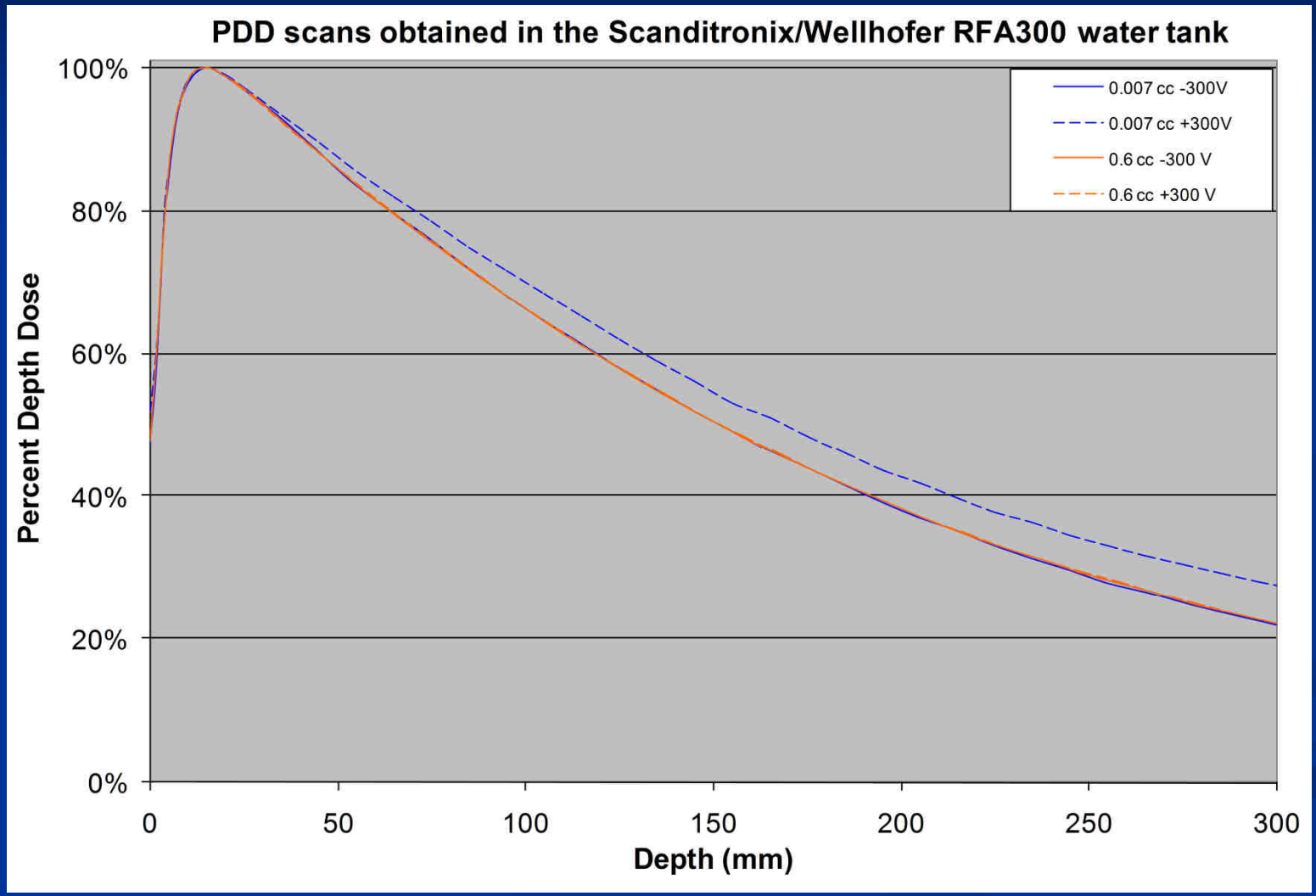
Background


PDD scans obtained in the Scanditronix/Wellhofer RFA300 water tank
Percent Depth Dose
100%
80%
60%
40%
20%
0%
0
50
100
150
200
250
300
Depth (mm)
0.007 cc
0.6 cc

Background

- The scans were repeated using both chambers and found to be reproducible.
- The A16 scan had been done with a +300V
  - Historically, we have always had our chambers calibrated at this bias.
- So we decided to switch biases and see the effect.

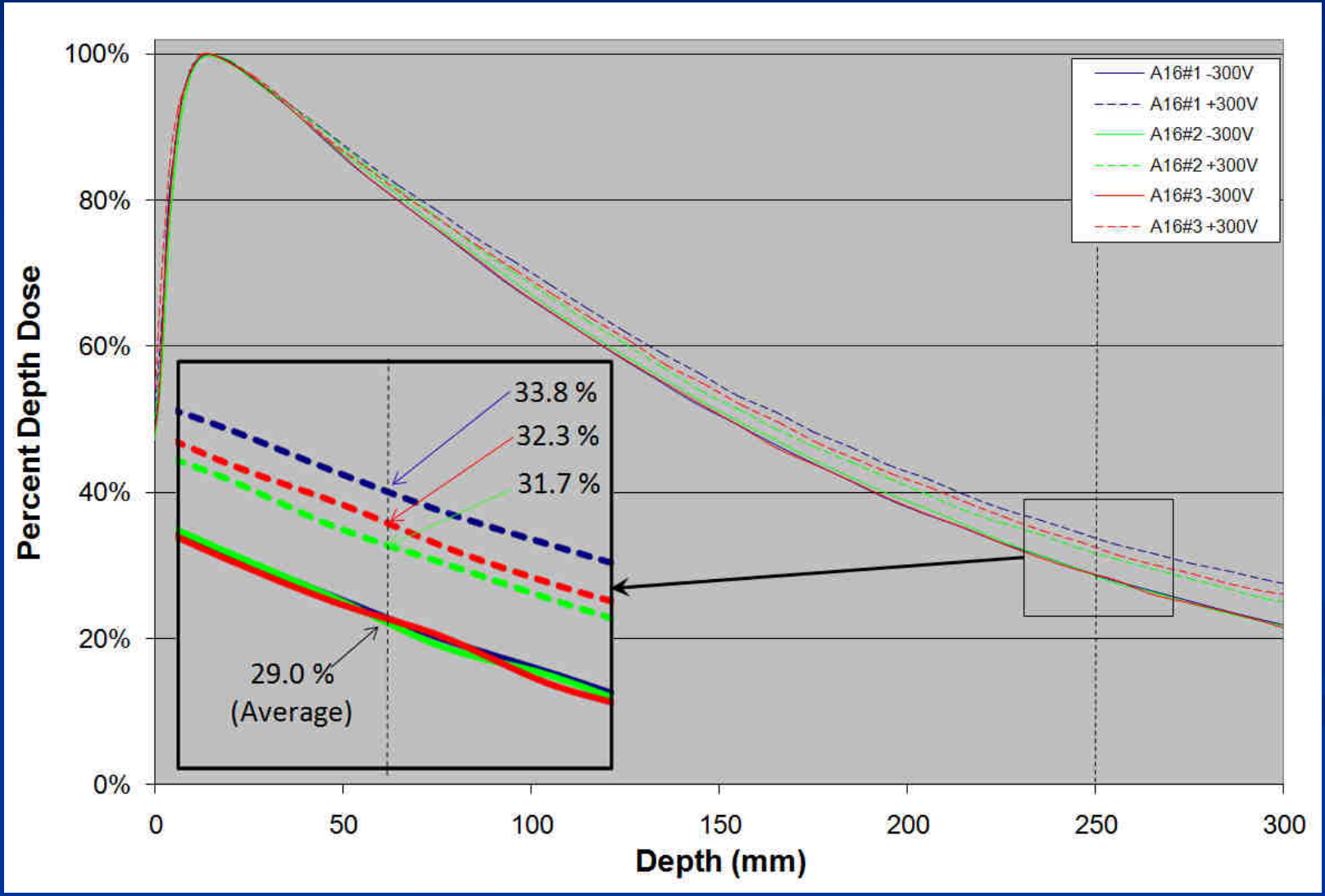
Background


PDD scans obtained in the Scanditronix/Wellhofer RFA300 water tank
Percent Depth Dose
100%
80%
60%
40%
20%
0%
0
50
100
150
200
250
300
Depth (mm)
0.007 cc -300V
0.007 cc +300V
0.6 cc -300 V
0.6 cc +300 V

Questions

- Is it related to
  - Our A16 chamber?
    - Repeat with multiple A16 with our water tank – phone a friend
  - Chamber size?
    - Repeat with multiple chambers and same water tank – we have plenty
  - Our water tank/chamber combination?
    - Repeat with multiple water tanks (same chamber) – phone a friend

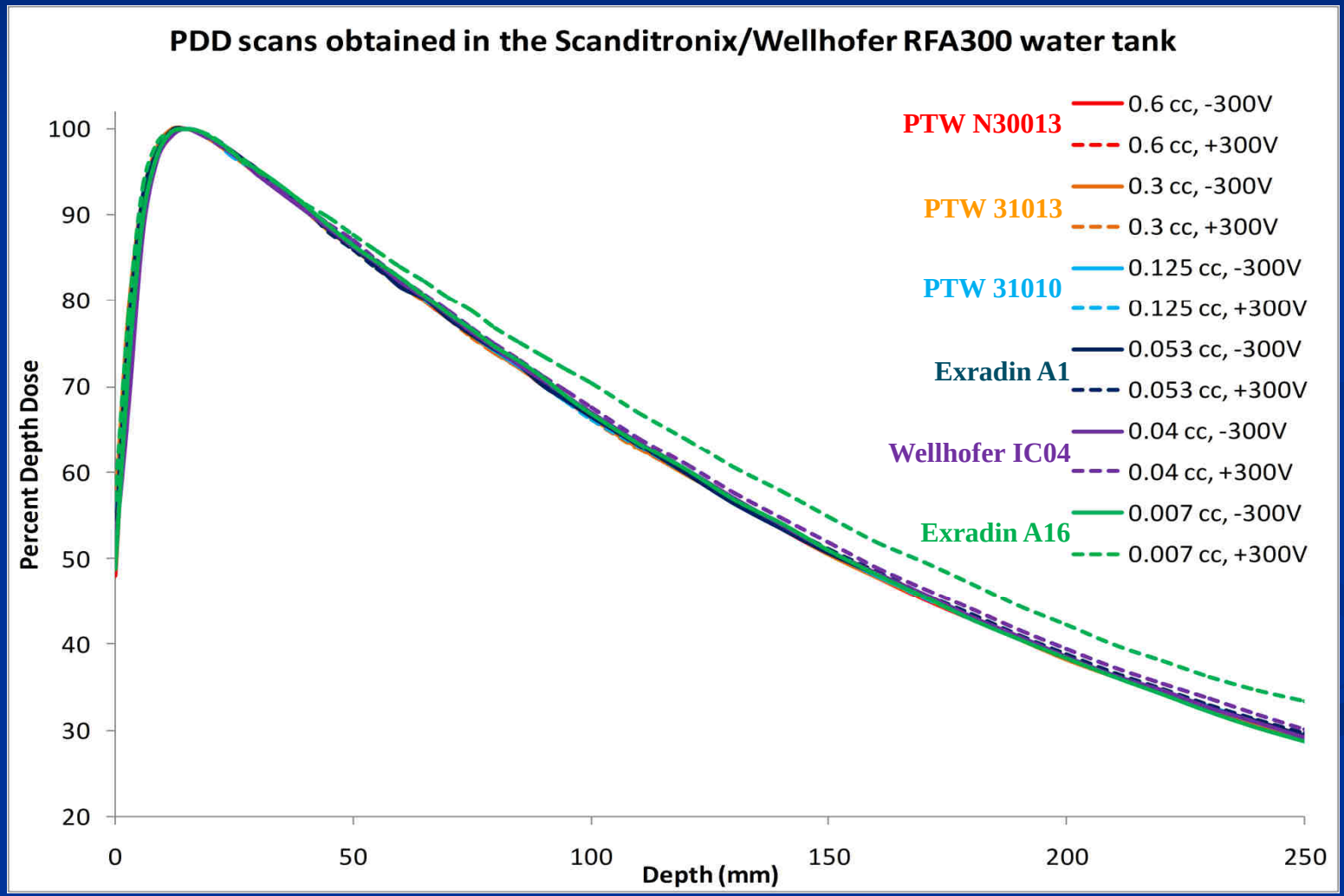
Multiple versions of same chamber model (A16)



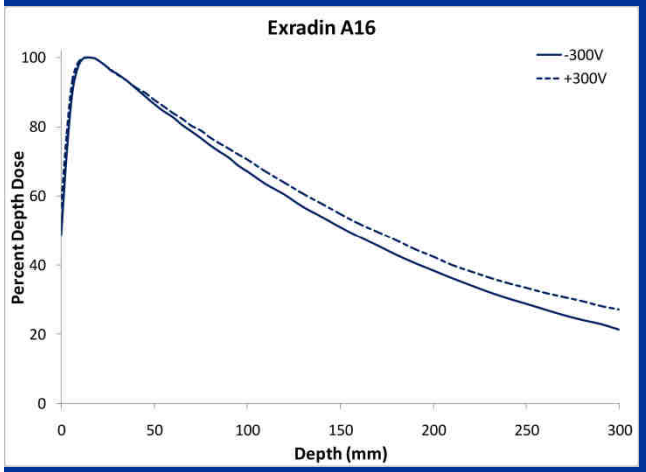
Questions

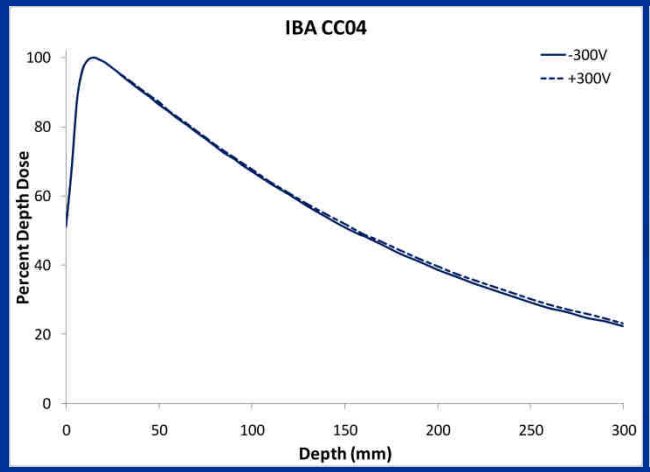
- Is it related to
  - Our A16 chamber? No
    - Repeat with multiple A16 with our water
  - Chamber size?
    - Repeat with multiple chambers and same water tank
  - Our water tank/chamber combination?
    - Repeat with multiple water tanks (same chamber)

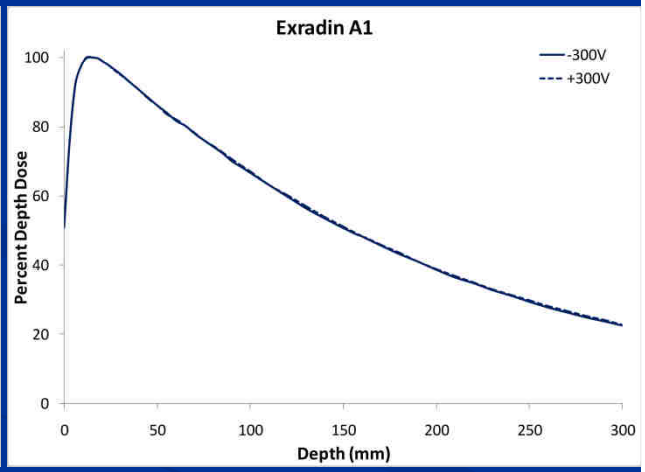
Scanning with chambers of differing active volumes



Scanning with chambers of differing active volumes







Questions

- Is it related to
  - Our A16 chamber? No
    - Repeat with multiple A16 with our water tank – Get the contact list working for us.
  - Chamber size? Yes. Due to large P_{pol}?
    - Repeat with multiple chambers and same water tank
  - Our water tank/chamber combination?
    - Repeat with multiple water tanks (same chamber)

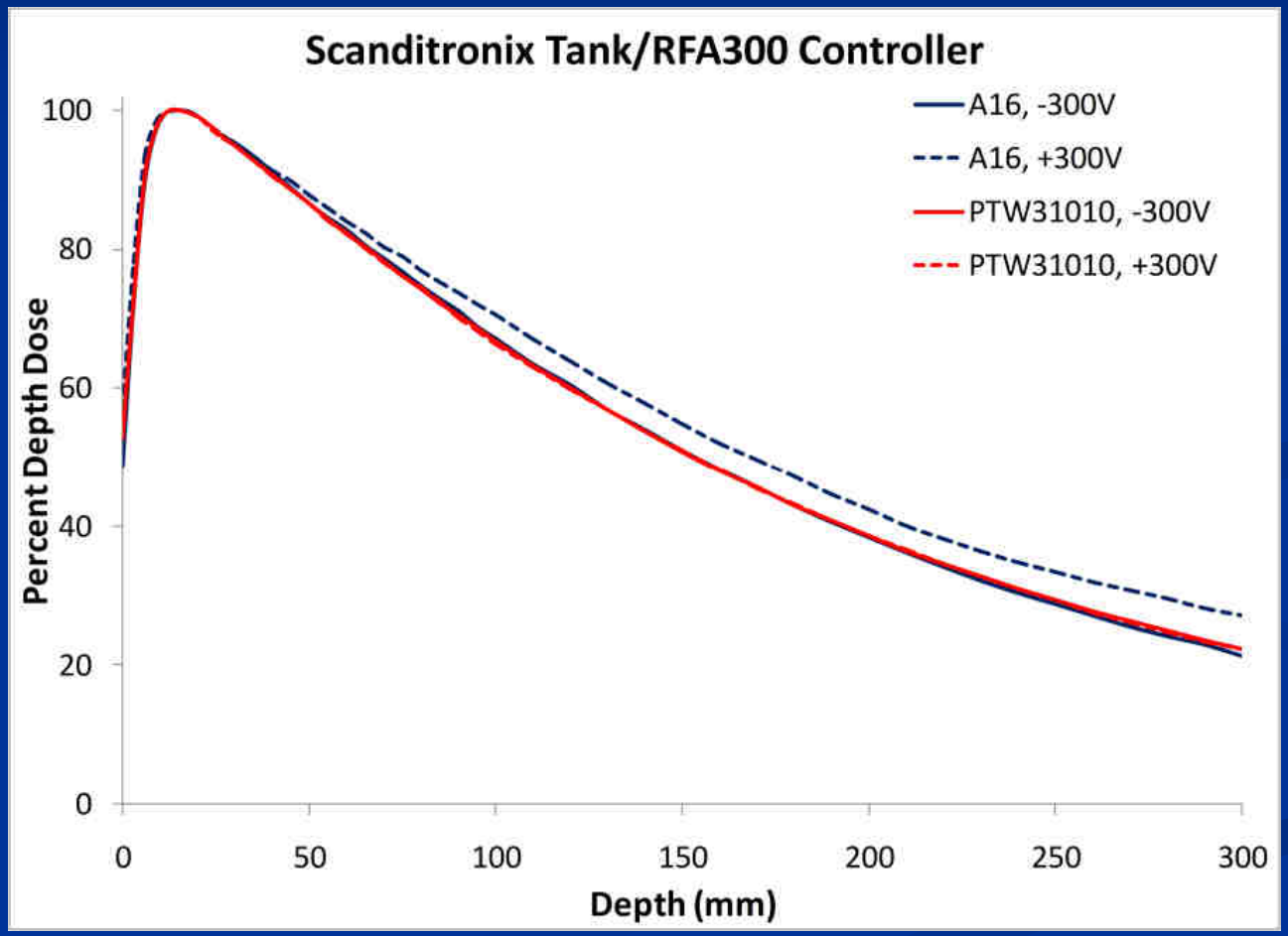
Unusually large P_{pol}?

Chamber	Ppol
A16 #1	1.009091
A16 #2	1.011544
CC04	1.010345
A1	1.006695
PTW 31010	1.00655
PTW 31013	1.000325
PTW N30013	1.000162

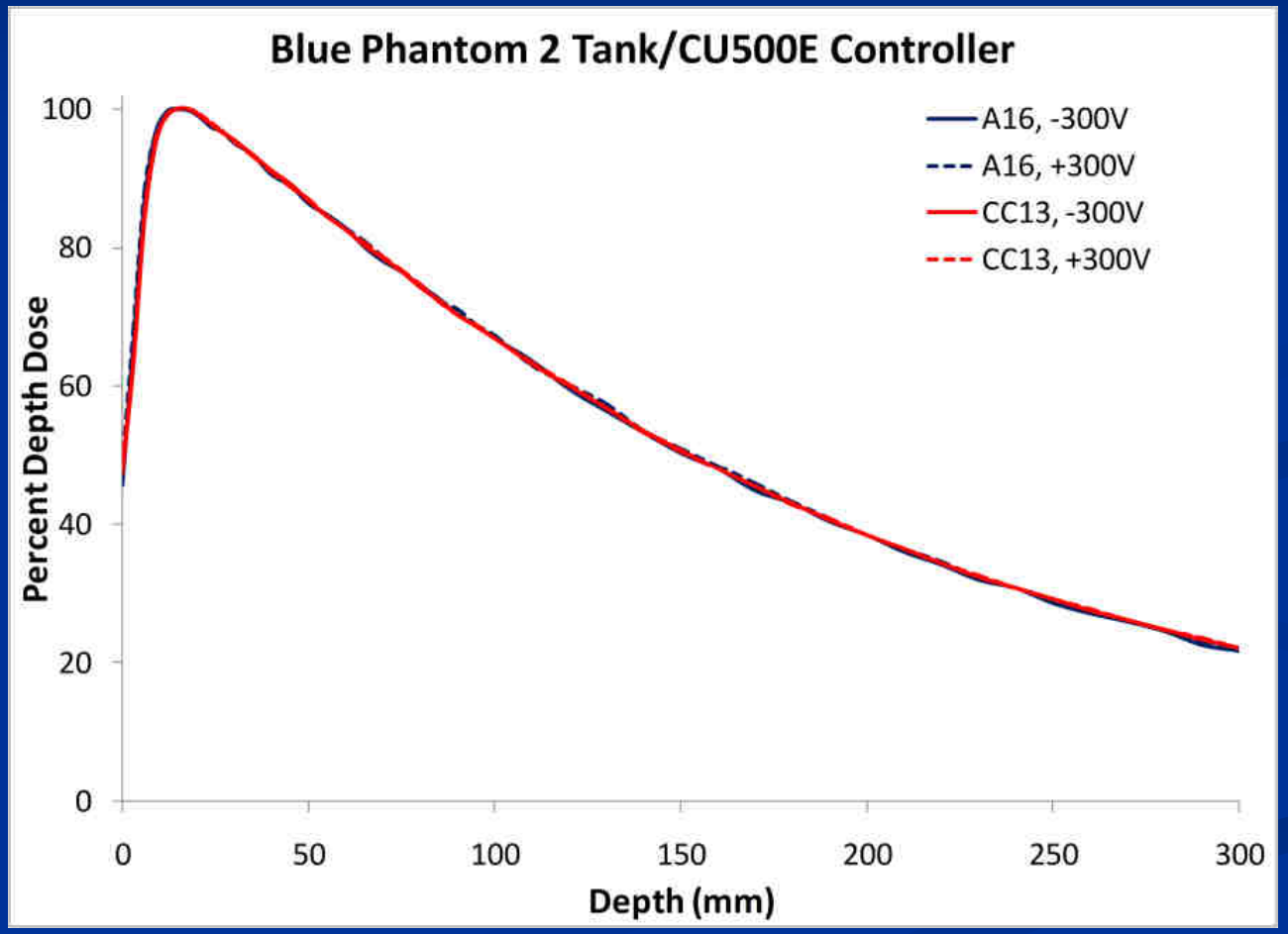
Questions

- Is it related to
  - Our A16 chamber? No
    - Repeat with multiple A16 with our water tank – Get the contact list working for us.
  - Chamber size? Yes. ~~Due to large P_{pol}?~~
    - Repeat with multiple chambers and same water tank
  - Our water tank/chamber combination?
    - Repeat with multiple water tanks (same chamber)

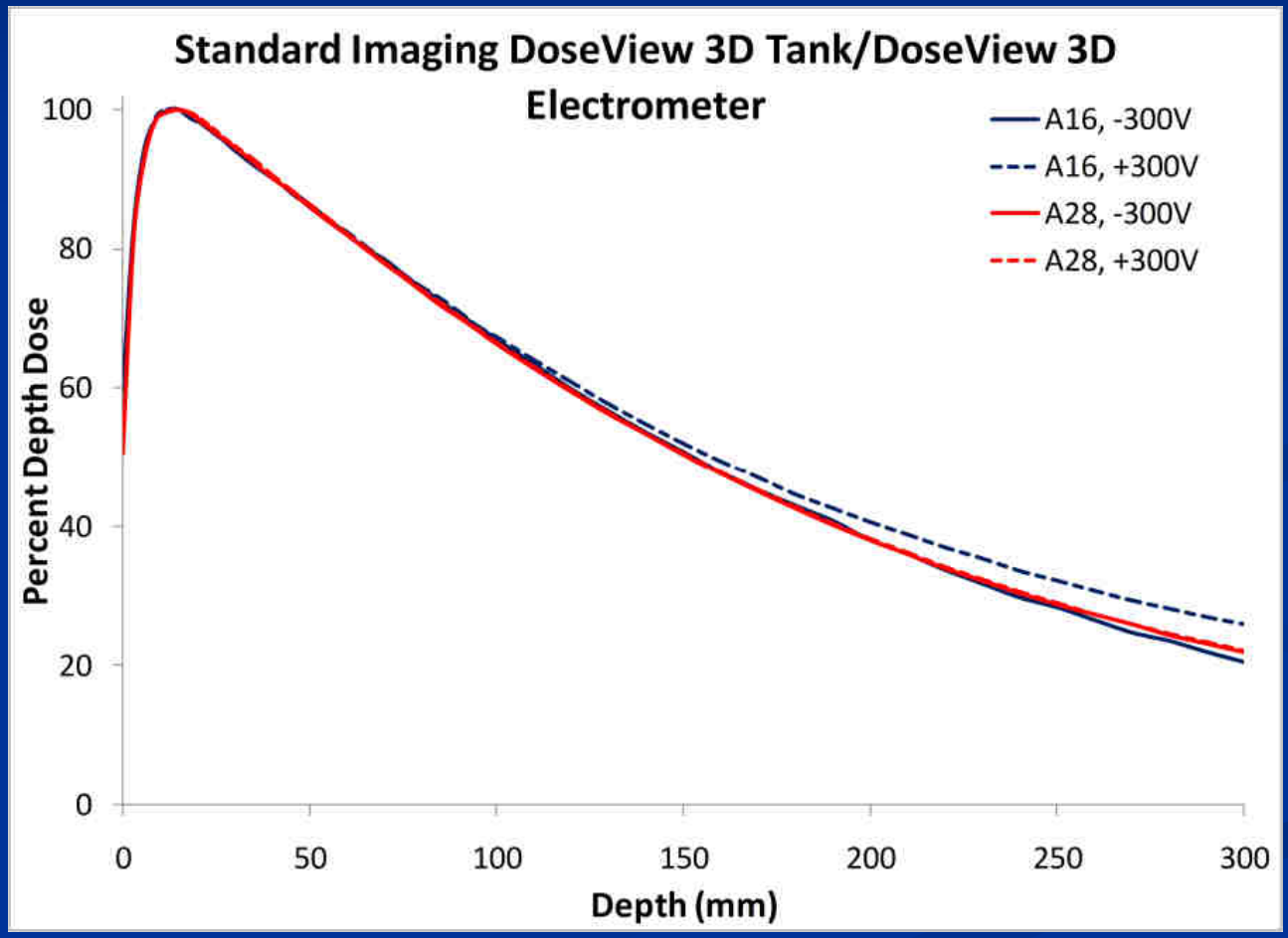
Using with multiple scanner systems



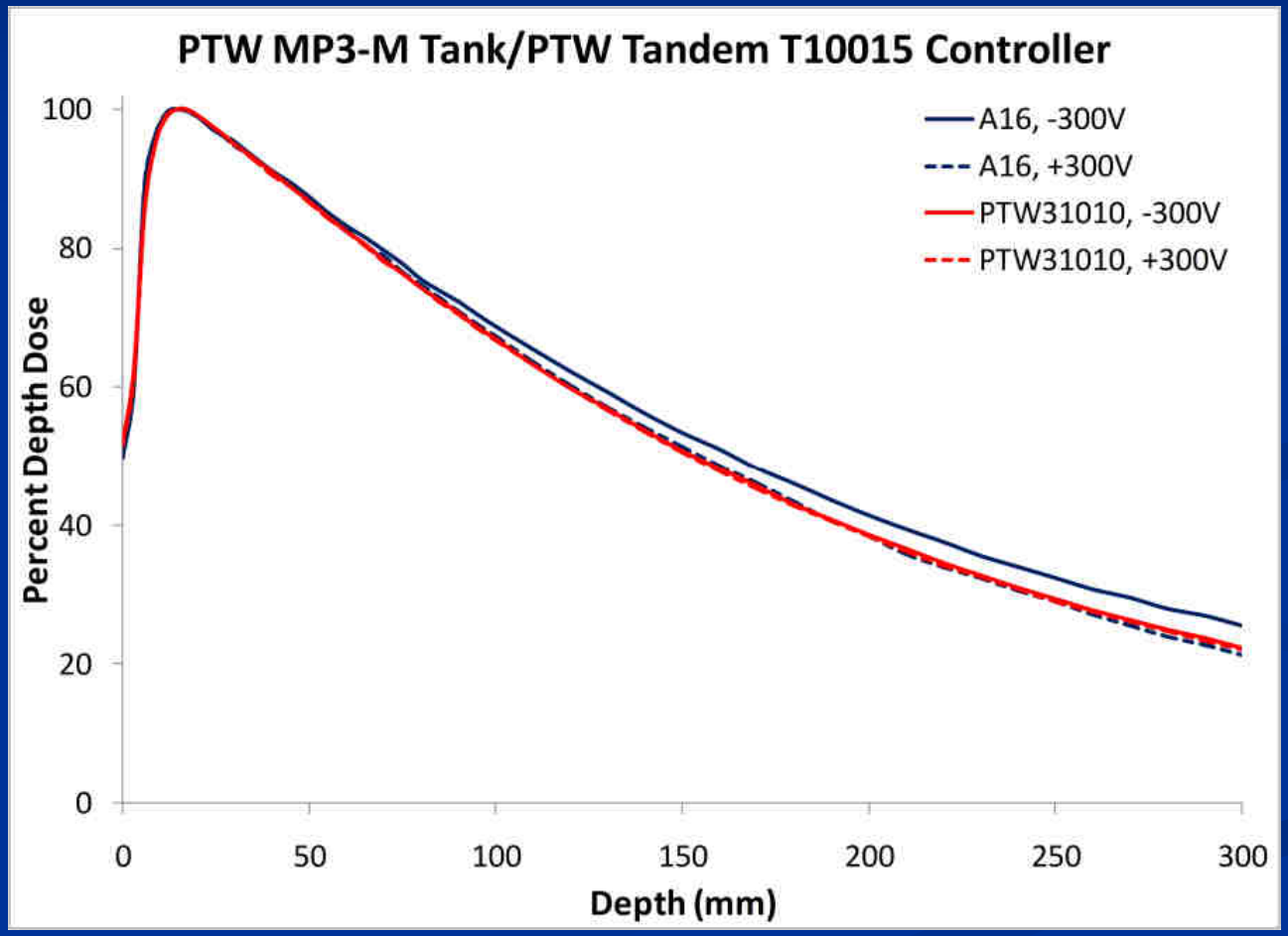
Using with multiple scanner systems



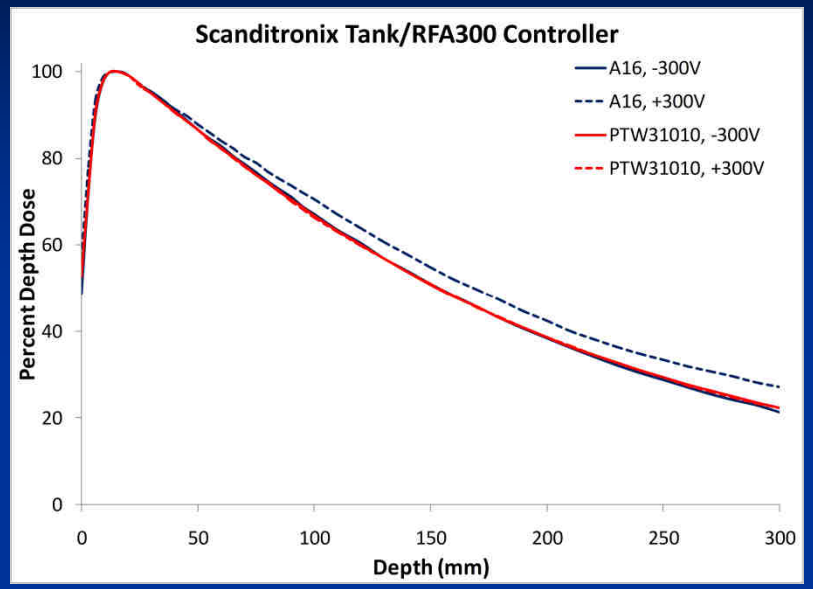
Using with multiple scanner systems

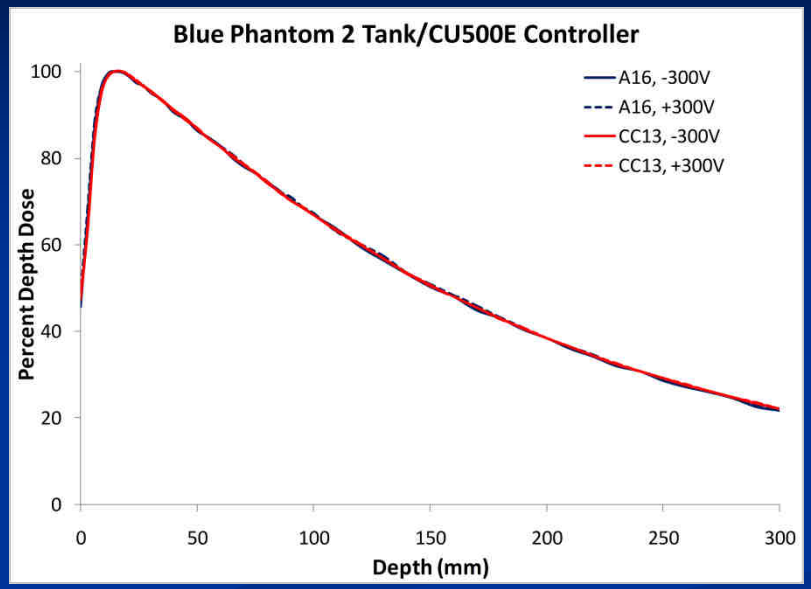


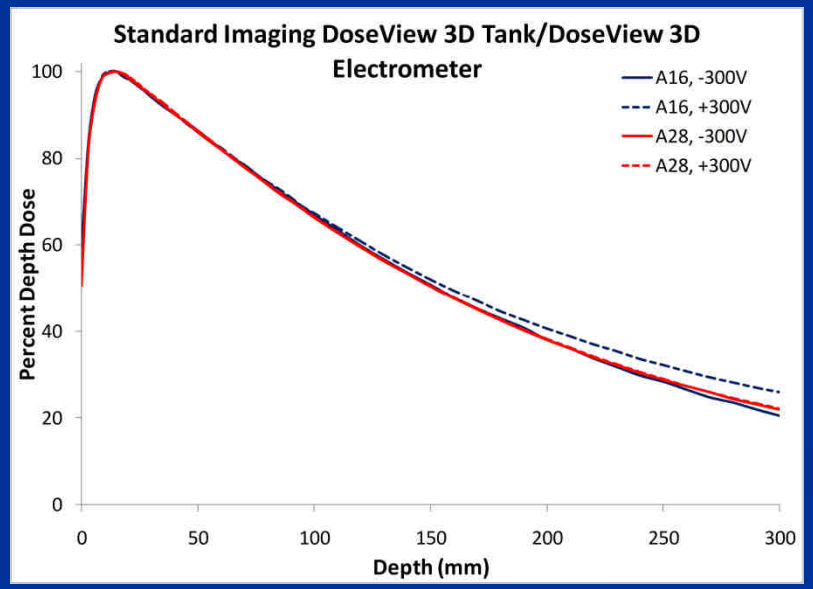
Using with multiple scanner systems

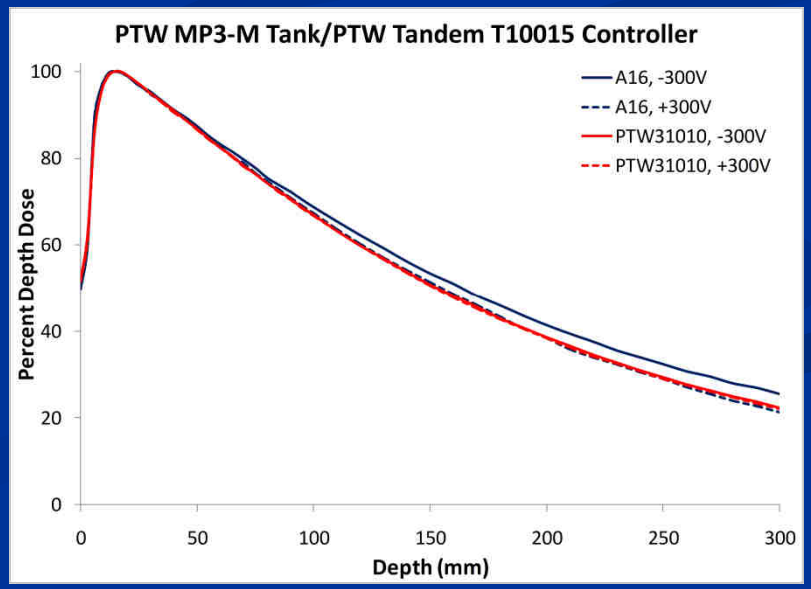


Using with multiple scanner systems









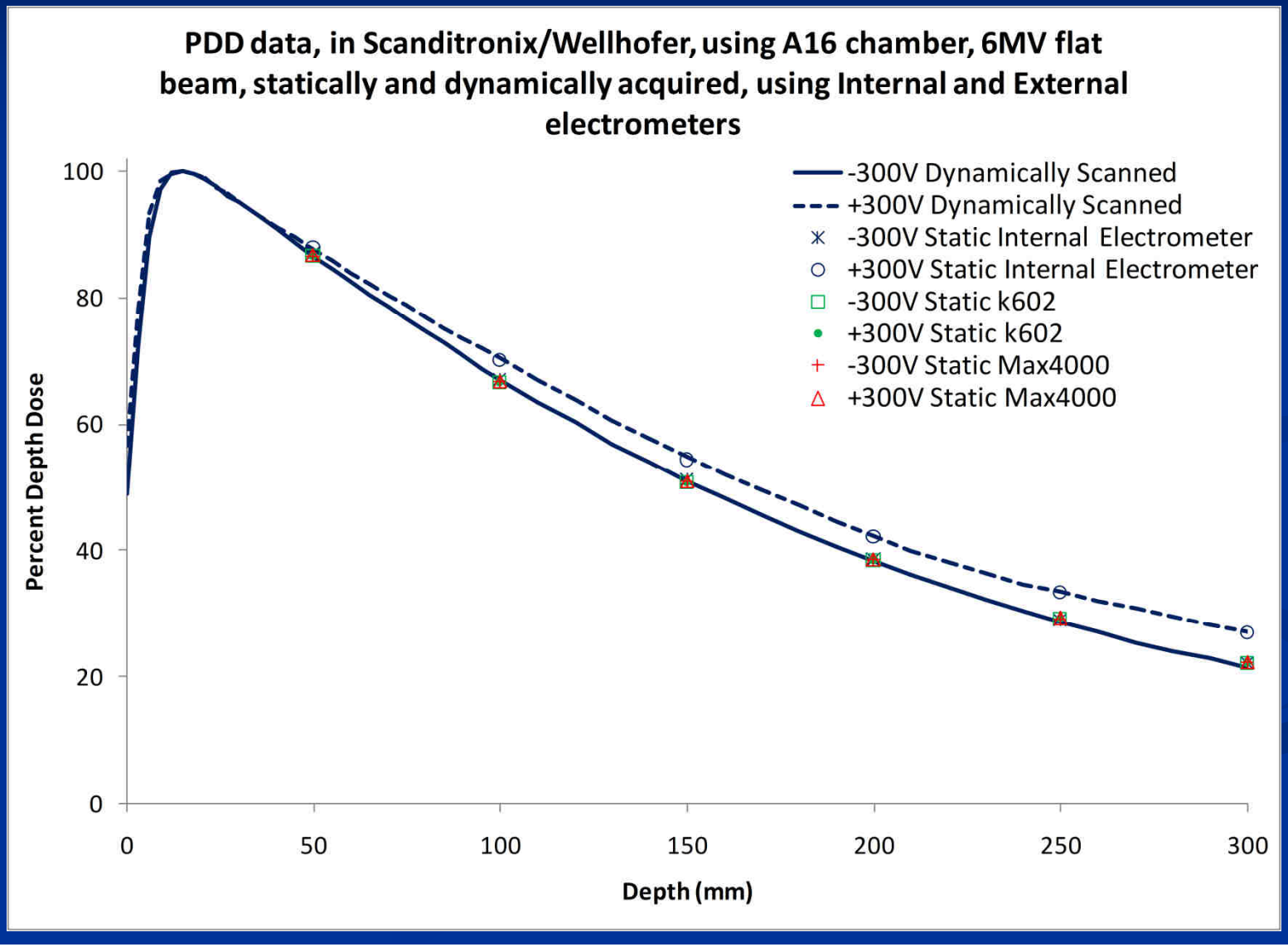
Questions

- Is it related to
  - Our A16 chamber? No
    - Repeat with multiple A16 with our water tank – Get the contact list working for us.
  - Chamber size? Yes
    - Repeat with multiple chambers and same water tank
  - Our water tank/chamber combination? Yes
    - Repeat with multiple water tanks (same chamber)

Updated Questions

- Is it related to
  - Our A16 chamber? No
  - Chamber size? Yes
  - Our water tank/chamber combination? Yes
  - Our process in general?
    - Is this related to the scanning process? How about sampling the PDDs instead of dynamically acquiring them?

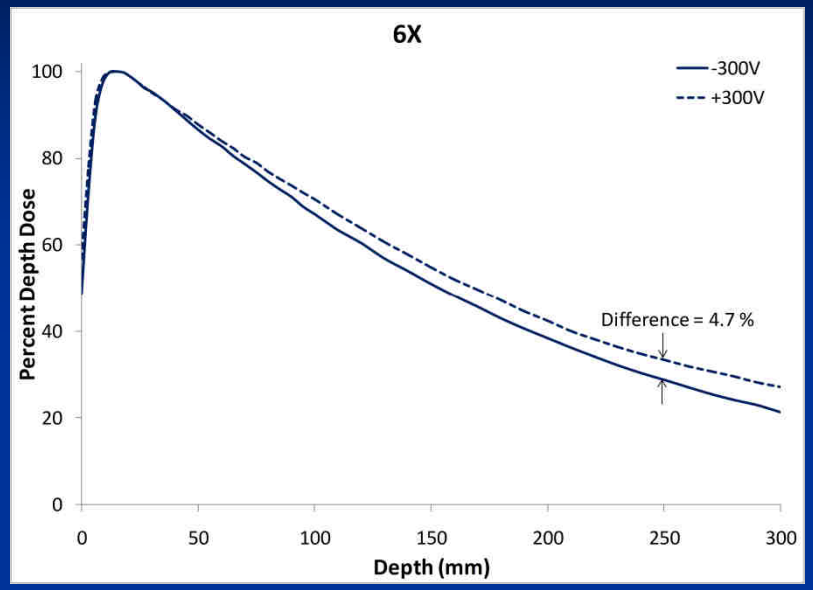
Sampling the PDD with internal and external electrometer

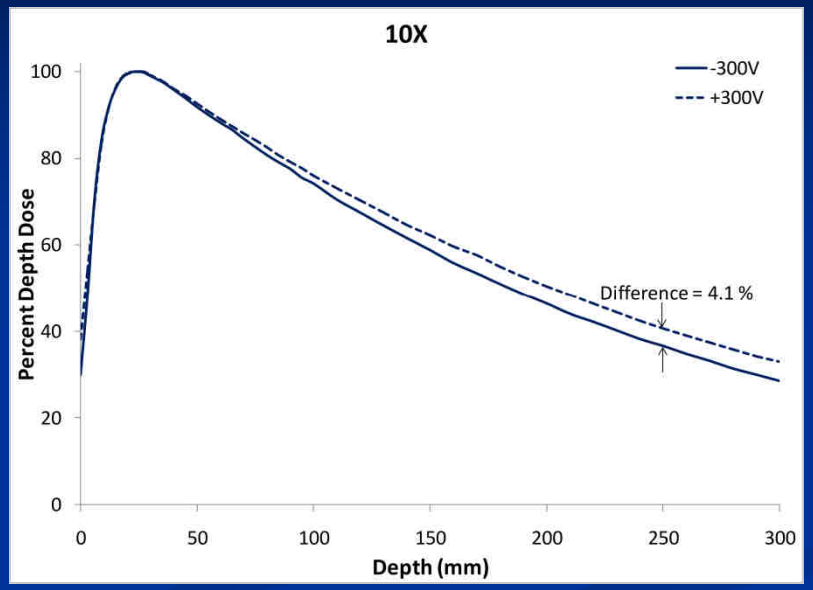


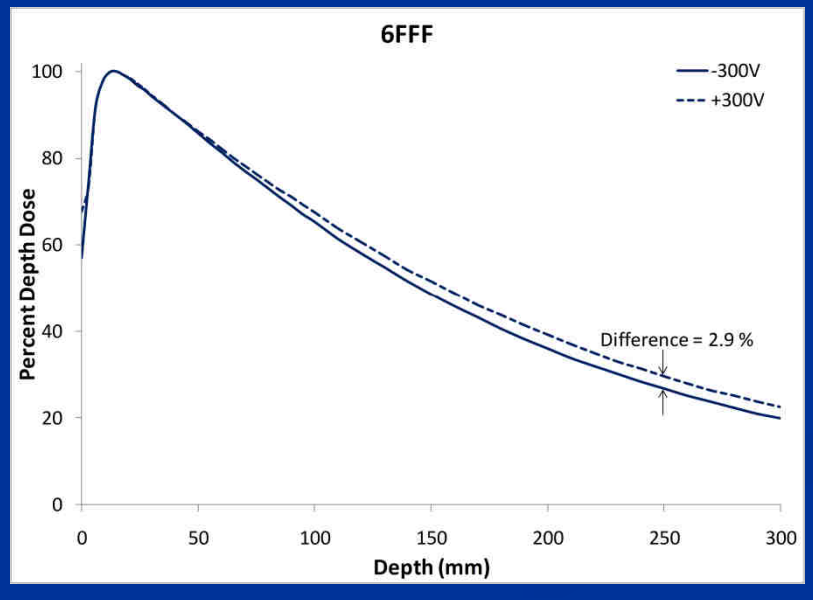
More questions

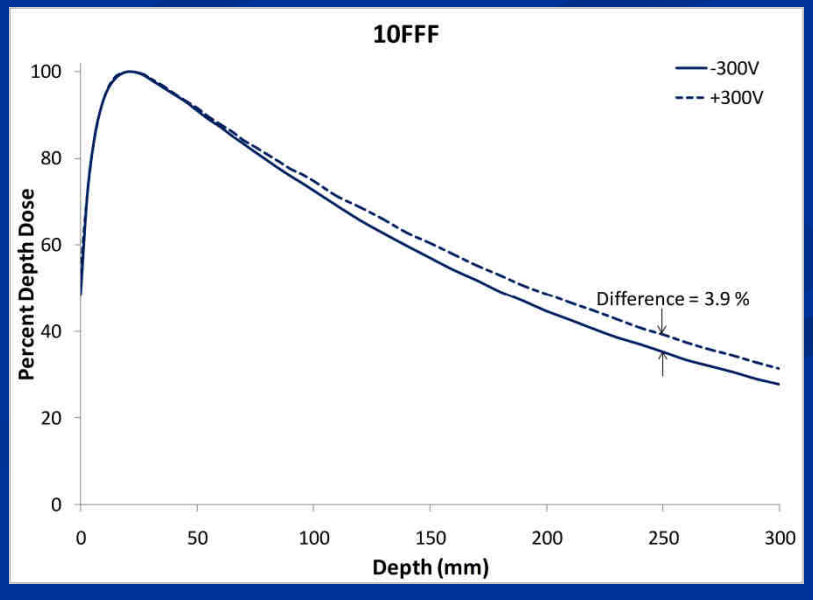
- Is this effect observed with
  - All energies?
  - Profiles as well as PDDs?
- Is the effect related to
  - Electronic noise in the system?
  - Charge vs Current?

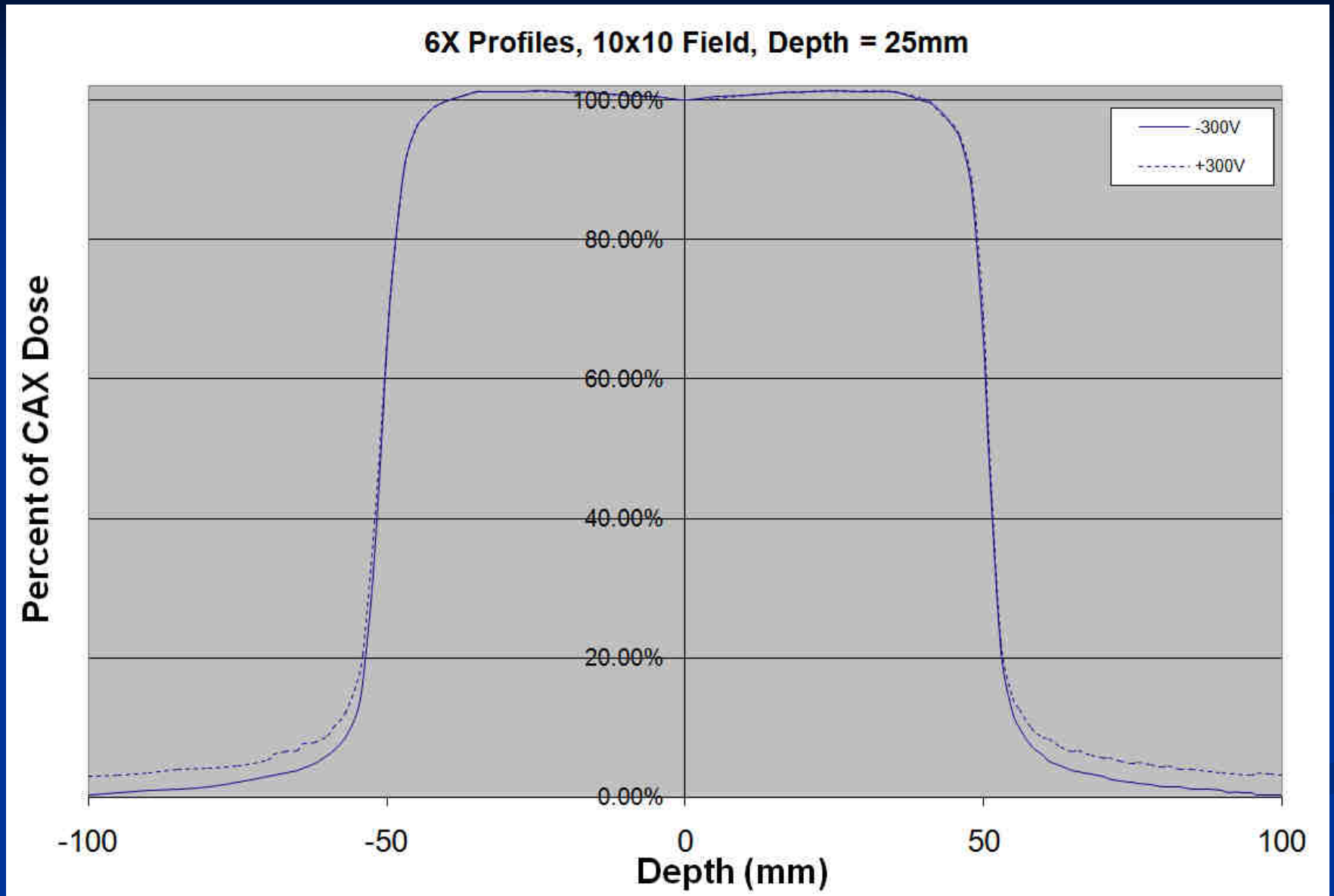
PDDs using different energies










6X Profiles, 10x10 Field, Depth = 25mm
Percent of CAX Dose
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
-300V
+300V
-100
-50
0
50
100
Depth (mm)

More questions

- Is this effect observed with
  - All energies? Yes
  - Profiles as well as PDDs? Yes
- Is the effect related to
  - Electronic noise in the system?
  - Charge vs Current?

Electronic Noise

- Using raw ADC signal levels from the water tank software (OmniPro)
  - There is some noise seen as the motors are run and no beam is turned on – of the order of 1% of signal at 30 cm.
- The same is observed when using an external electrometer (CNMC K602) to measure currents.

More questions

- Is this effect observed with
  - All energies? Yes
  - Profiles as well as PDDs? Yes
- Is the effect related to
  - Electronic noise in the system? Does not seems so
  - Charge vs Current?

Charge vs Current

Measurement Technique	Tank ADC units		External Electrometer Current (pA)		External Electrometer Charge (nC)	
Bias (V)	PDD_{20}	PDD_{25}	PDD_{20}	PDD_{25}	PDD_{20}	PDD_{25}
-300	37.4%	28.7%	37.6%	28.8%	37.5%	28.6%
300	41.5%	32.4%	37.7%	28.9%	37.4%	28.8%

More questions

- Is this effect observed with
  - All energies? Yes
  - Profiles as well as PDDs? Yes
- Is the effect related to
  - Electronic noise in the system? Does not seems so
  - Charge vs Current? Same results – at least for static measurements with an independent electrometer

What we learned

- The effect
  - Causes non-trivial over-estimation of the PDD when a very small chamber is used under specific conditions.
  - Is reproducible for multiple versions of the same chamber.
  - Is seen with at least three scanner systems.
  - Seems to go away when an external electrometer is used.
  - Does not always occur at the same bias.

What we learned

- The effect
  - Does not seem to be solely due to larger than normal P_{pol} in some chambers.
  - Is seen with different energies and the tail of profiles (lower signal levels).
  - Does not seem to be relatable to noise in the scanning system.
  - Does not seem to be related to measuring current vs charge.

Our conclusion

- We do not have a definite explanation for why the effect occurs.
- We know the effect exists and can lead to commissioning errors.
  - Due to the rather insidious presentation of the error.
- We have a **clinical recommendation**:
  - Anyone using a micro chamber during scanning should check their scans against one obtained using a larger chamber to determine which bias to use.

Result Dissemination

- Published in JACMP in 2015
  - **Sarkar V**, Wang B, Zhao H, Lynch B, James JA, McCullough KT, Salter BJ (2015). Percent depth-dose distribution discrepancies from very small volume ion chambers. *J Appl Clin Med Phys*, *16*(2), 5230

Questions