

Level of Accuracy Practically Achievable in Radiation Therapy



**David Followill
and RPC staff
August 6, 2013**

Sources of Treatment Uncertainty

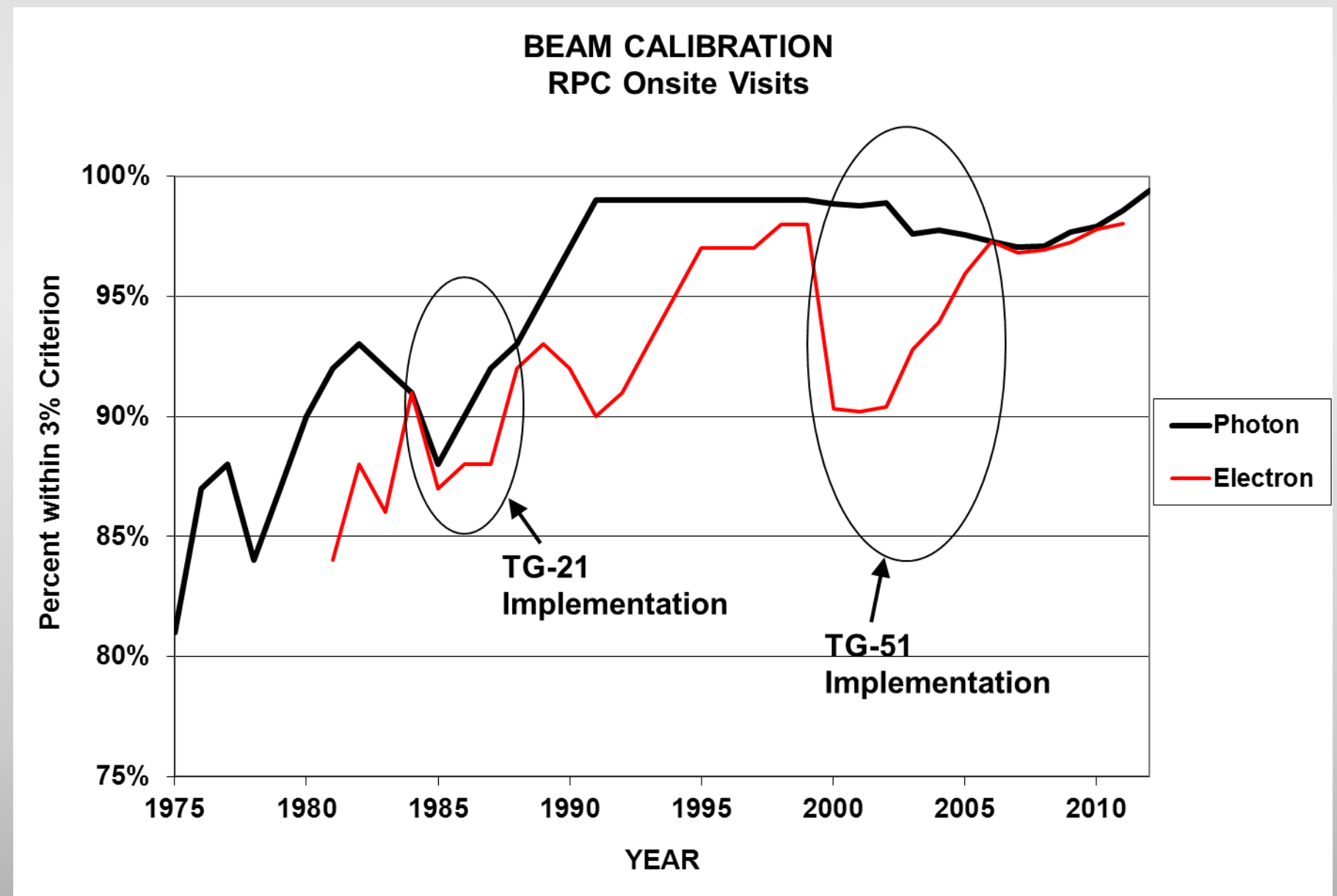
- Machine functioning
- Radiation dose determination
- Patient specific data for treatment planning
- Radiation dose calculation in the patient
- Transfer of treatment plan to treatment machine
- Day to day variation in the treatment (machine/patient motion/set up)

Modern Treatment Units

1. Modern units for a specific make/model/energy have nearly the same dosimetry parameters.
2. RPC measurements based standard data typically within 1-1.5%
3. QA methodology and equipment have come a long way.

However this does not mean we can become lackadaisical in performing our QA

The RPC has spent the last 45 years trying to minimize the uncertainty in radiation dose delivery and improve the accuracy for the clinical trial participating institutions.



In water phantom reference calibrations indicates a spread in the machine output of ~2.5% for 95% of the data since TG-51 was implemented

Contributing factors

1. T & P
2. $N_{d,w}$
3. P_{elec}
4. cables
5. Depth
6. SSD
7. Field size
8. TG-51 factors
9. End effect
10. %dd correction
11. Human error

		REFERENCE CALIBRATION	
		PHOTON	ELECTRON
2000-2006	output 2 std dev.	1.004 ± 0.026	0.991 ± 0.022
2006-2013	output 2 std dev.	1.004 ± 0.026	1.017 ± 0.024

**I KNEW THEY WERE OFF BUT I THOUGHT
IT WOULD ALL AVERAGE OUT.**

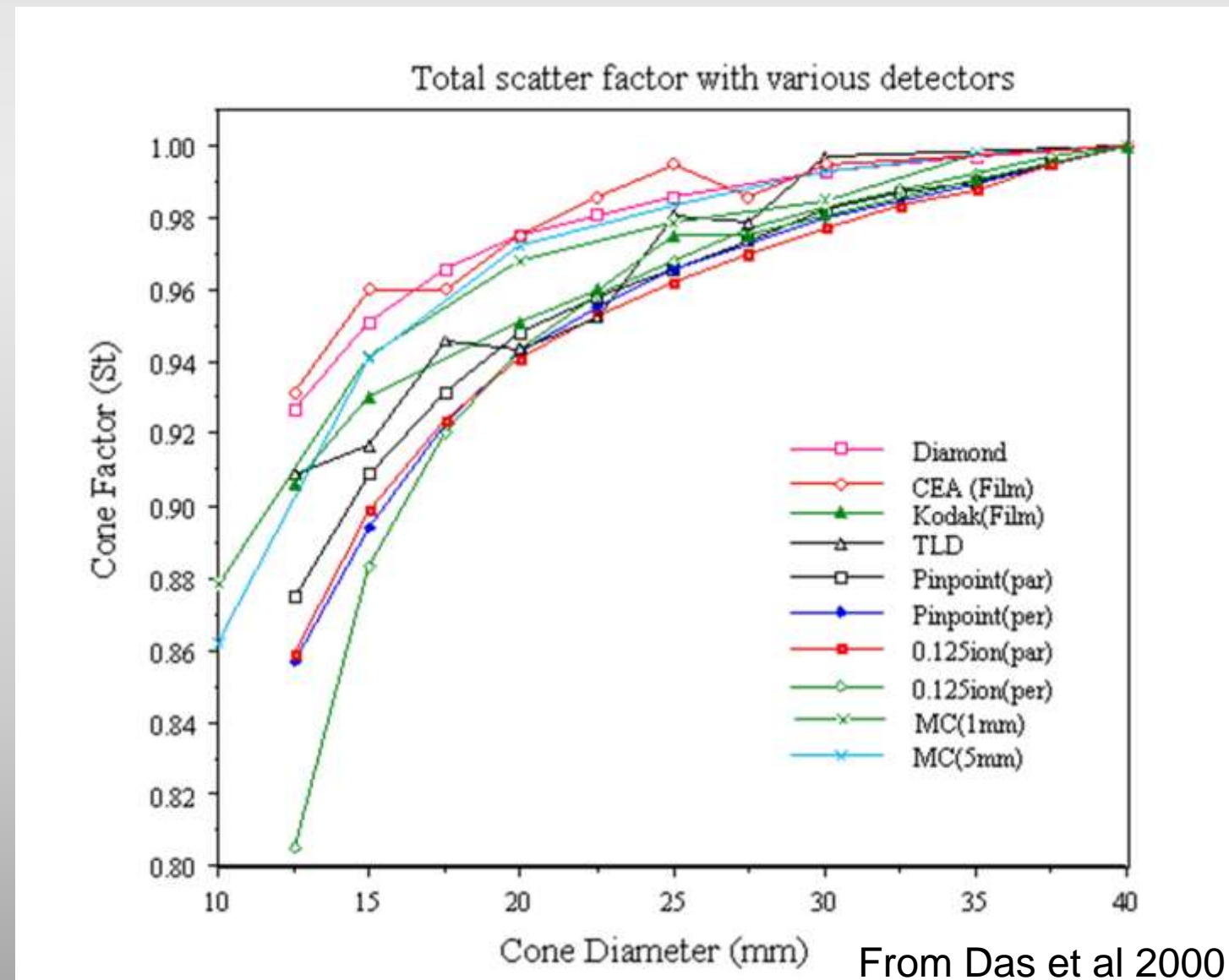
Trilogy			6 MeV			9 MeV			12 MeV		
Parameter	RPC	Inst.	RPC/Inst.	RPC	Inst.	RPC/Inst.	RPC	Inst.	RPC/Inst.		
K _{TP} comparison	1.007	1.002	1.005	1.007	1.002	1.005	1.007	1.002	1.005		
(N _{D,w})(K _e)	5.346	5.336	1.002	5.346	5.336	1.002	5.346	5.336	1.002		
N _{D,w} (inst)	5.336	5.328	1.002	5.336	5.328	1.002	5.336	5.328	1.002		
P _{gr}	1.008	0.987	1.021	-	-	-	1.000	0.998	1.002		
measure depth		1.5			2.0			3.0	me		
%dd(dref)	1/0.960	1/0.979	1.020	-	-	-	1/0.996	1/0.998	1.002		
			1.051			1.009			1.013		
			(1.034)			(1.006)			(1.016)		

Now one of the hottest topics – output factors (OPF)

- Really no problem with OPFs $\geq 4 \times 4 \text{ cm}^2$
 - RPC data show $2\sigma = \sim 1\%$
- What about $< 4 \times 4 \text{ cm}^2$?

Contributing factors

1. Chamber vol.
2. Cables
3. Field size
4. Depth
5. SSD
6. Human error

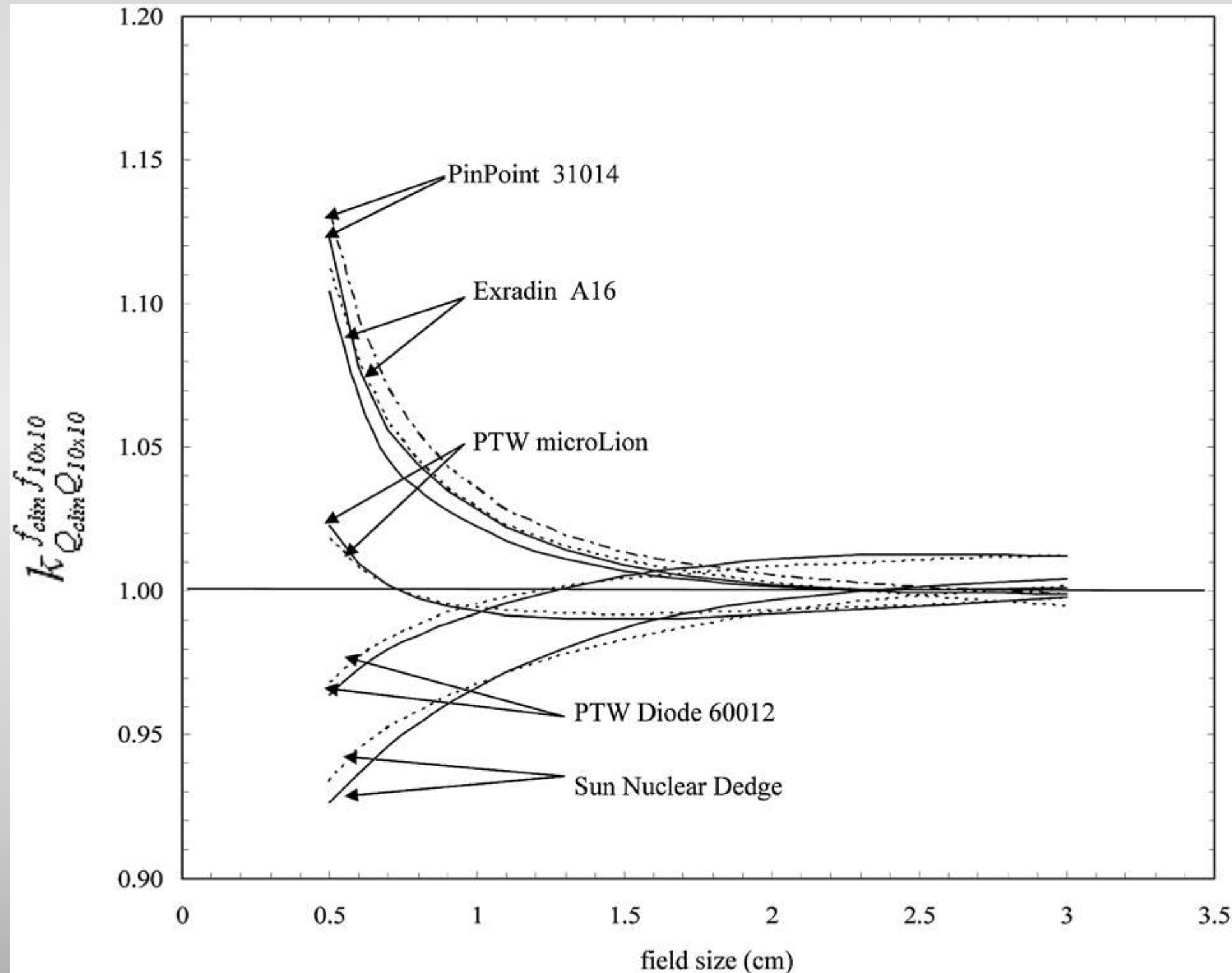


TG-155

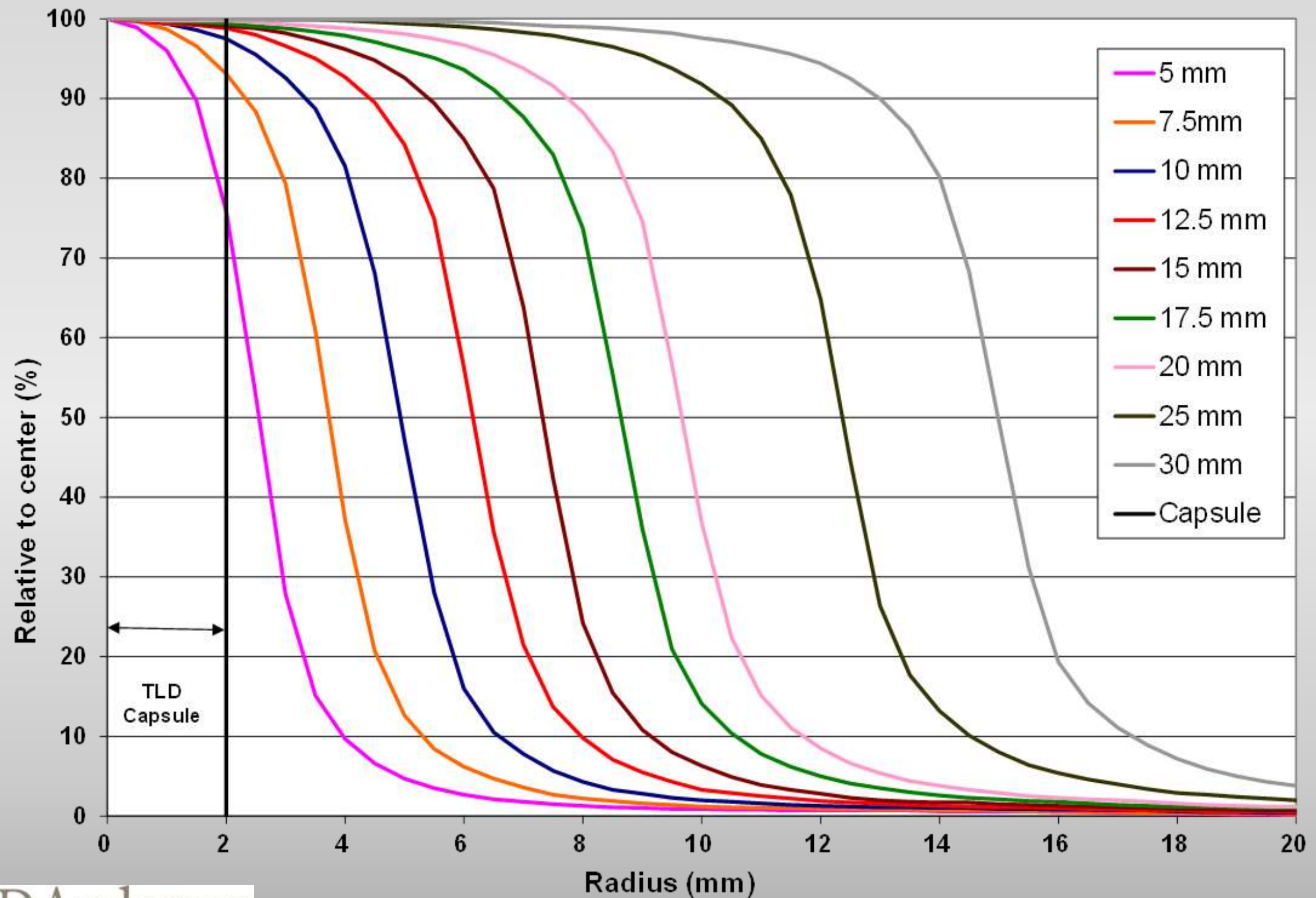
Small Field Dosimetry Corrections

Situation is even worse if you consider using field sizes less than $0.5 \times 0.5 \text{ cm}^2$

Francescon et al
2011 data



The Problem is that our **Nemesis** is very small!



Tables of standard small field factors

TABLE 1. The RPC-measured and institution treatment planning system-calculated small field size dependence output factor values for Varian machines. The values in square brackets and parentheses beneath each energy for each field size value are the average absolute percent differences and standard deviations of the values, respectively. For each energy and field size, the number of measurements (accelerators) is also shown.

Field Size (cm × cm)	Varian 6 MV		Varian 10 MV		Varian 15 MV		Varian 18 MV	
	RPC	Institution	RPC	Institution	RPC	Institution	RPC	Institution
10 × 10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
6 × 6	0.921 (0.013) [0.9%] (n=64)	0.929 (0.004)	0.946 (0.017) [0.7%] (n=9)	0.953 (0.016)	0.951 (0.008) [0.5%] (n=14)	0.950 (0.008)	0.949 (0.011) [0.5%] (n=16)	0.950 (0.014)
4 × 4	0.865 (0.018) [1.3%] (n=64)	0.874 (0.021)	0.900 (0.024) [1.3%] (n=9)	0.912 (0.030)	0.909 (0.013) [1.1%] (n=14)	0.909 (0.017)	0.902 (0.014) [1.1%] (n=16)	0.900 (0.024)
3 × 3	0.828 (0.017) [1.7%] (n=62)	0.841 (0.025)	0.867 (0.020) [1.2%] (n=9)	0.875 (0.025)	0.874 (0.014) [1.3%] (n=12)	0.877 (0.019)	0.861 (0.014) [1.7%] (n=16)	0.856 (0.027)
2 × 2	0.786 (0.019) [2.3%] (n=55)	0.796 (0.031)	0.817 (0.015) [1.8%] (n=11)	0.828 (0.019)	0.803 (0.016) [2.8%] (n=10)	0.813 (0.038)	0.784 (0.015) [3.5%] (n=15)	0.782 (0.034)

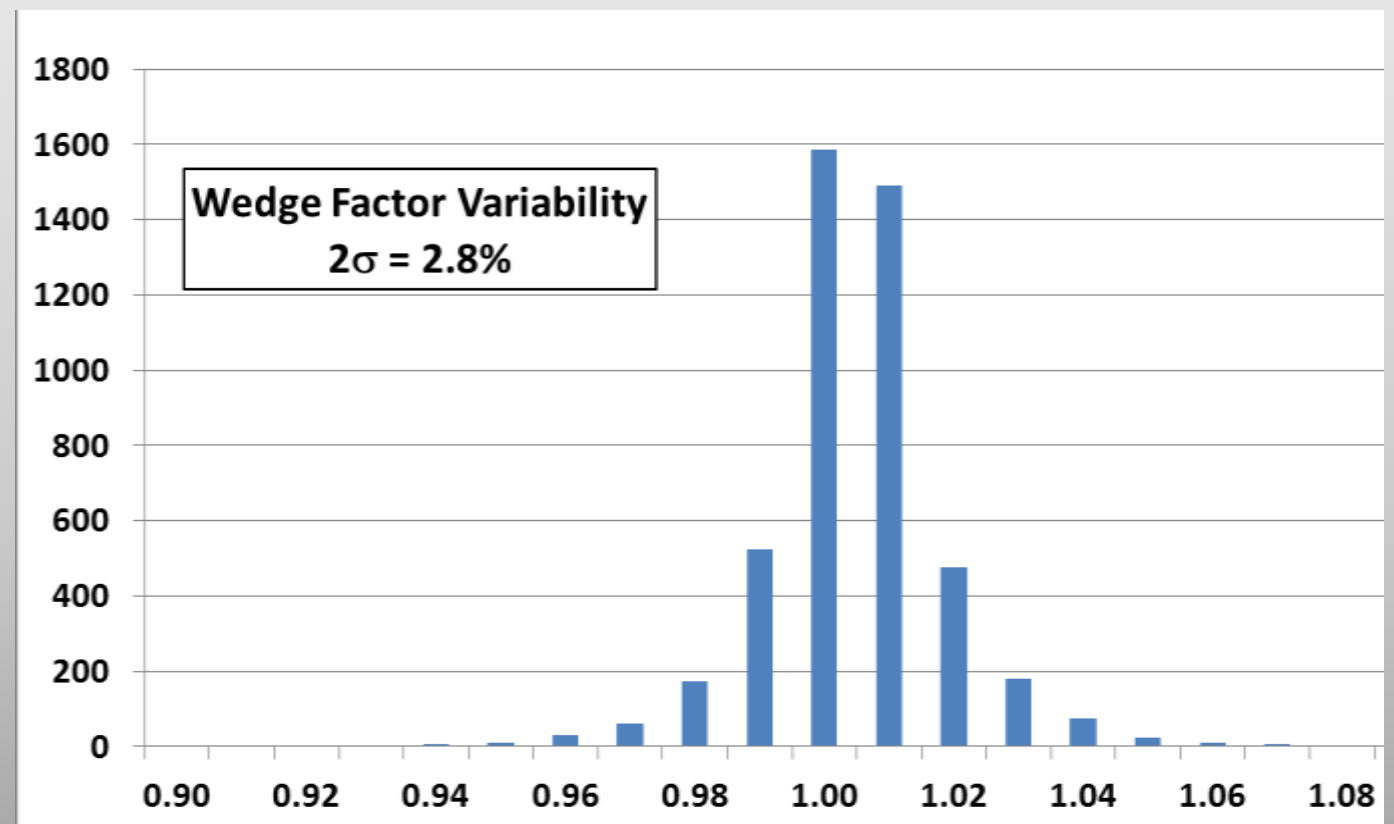
Followill et al 2012

RPC: 0.8 - 2.4%
Institution: 0.4 - 3.8% } It's HARD!

Wedges – Our nemesis yet they should be our friend!

It's not a hard measurement, you just need to take the time to center your chamber accurately (<0.5% rdg change when wedge flipped)

The RPC finds a wedge factor outside our $\pm 2\%$ criterion in a **THIRD** of the sites we visit.



Off Axis Factors can SURPRISE you

Matched machines may have the same dosimetry data but their profiles may be quite different.

Machine A

<u>Position</u>	<u>RPC</u>	<u>Institution</u> ⁺	<u>RPC/Inst.</u>
5 cm left	1.036	1.024	1.01
10 cm left/right	1.060/1.065	1.040	1.02/1.02
10 cm toward/away	1.059/1.064	1.040	1.02/1.02
15 cm left	1.080	1.052	1.03*

OAD	2 σ
5	1.8%
10	2.4%
15	3.2%

Machine B

<u>Position</u>	<u>RPC</u>	<u>Institution</u> ⁺	<u>RPC/Inst.</u>
5 cm left	1.016	1.024	0.99
10 cm left/right	1.018/1.013	1.040	0.98/0.97*
10 cm toward/away	1.019/1.012	1.040	0.98/0.97*
15 cm left	1.016	1.052	0.97*

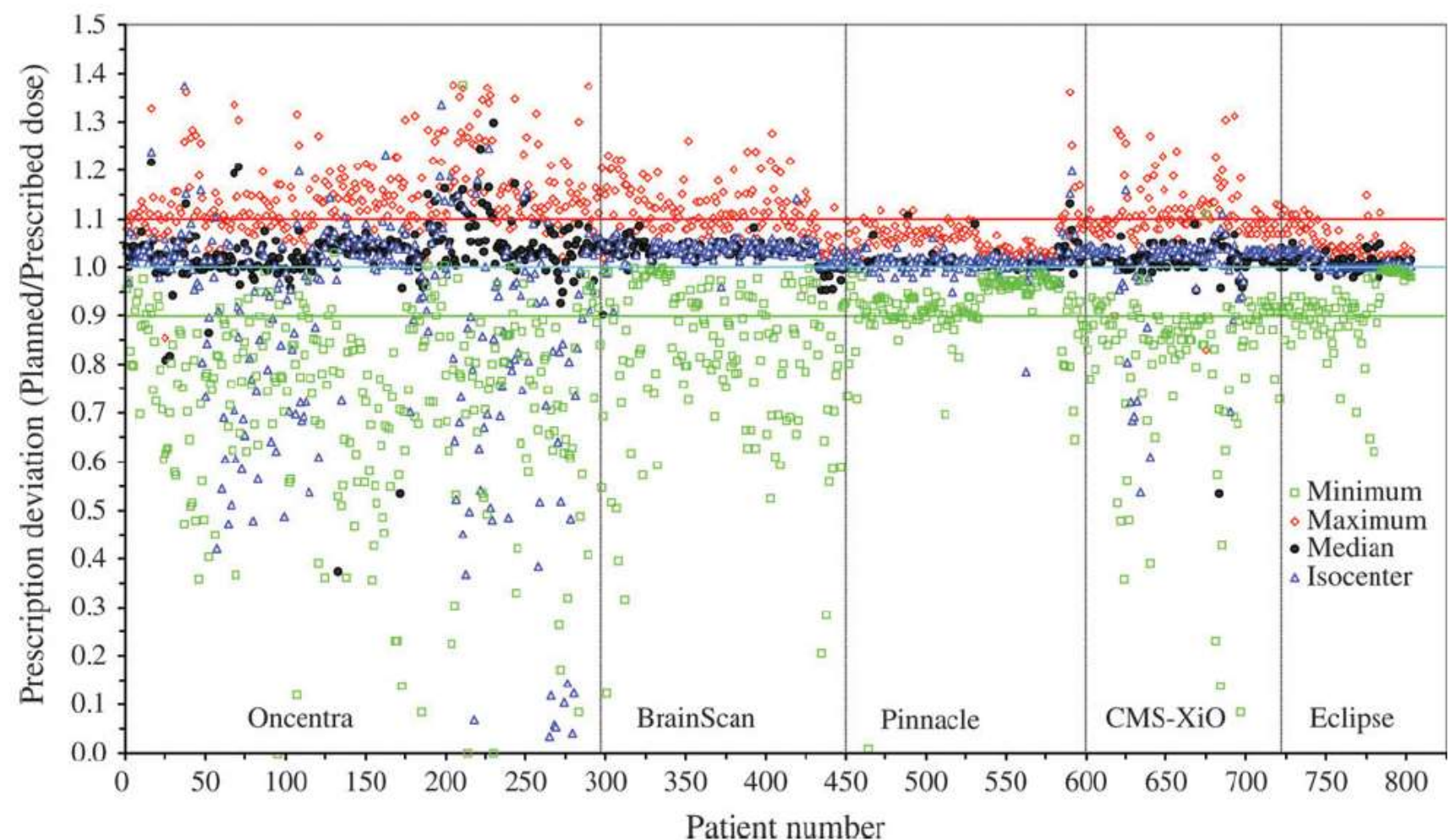
On-Site Dosimetry Review Audit

Discrepancies Discovered (Jan. '05 – April '13)

<u>Discrepancies Regarding:</u>	<u>Number of Institutions Receiving rec. (n = 206)</u>
Review QA Program	152 (74%)
Photon Field Size Dependence	138 (67%)
Wedge Factor (WF)	66 (32%)
Off-axis Factors (OAF)/Beam symmetry	60 (29%)
Electron Calibration	35 (17%)
Photon Depth Dose	33 (16%)
Electron Depth Dose	25 (12%)
Photon Calibration	16 (8%)

Sort of Disturbing to the RT community when Das *et al* published their findings on variations between prescribed and planned doses.

Figure 1. Dosimetric variations between the prescribed and planned doses among 803 patients from five medical institutions with different treatment planning systems. **Vertical lines** separate the data according to treatment planning system (from left to right: Oncentra, BrainScan, Pinnacle, CMS-XiO, Eclipse). The **horizontal line** at 1.0 represents no dose deviation; the **horizontal lines** at 1.1 and 0.9 represent dose deviations of +10% and -10%, respectively, between the planned dose and the prescribed dose.



Das et al 2008

Clinical Trial Patient Case Rapid Review

- Rapid review (pre-treatment review) is designed to evaluate the plan prior to treatment to ensure it meets the protocol prescription specifications.
- 56 IMRT Gyne rapid reviews were performed in 2013 (to date)
 - 22 submitted twice (39%)
 - 6 submitted three times (11%)
 - 2 had to submit 4 times.

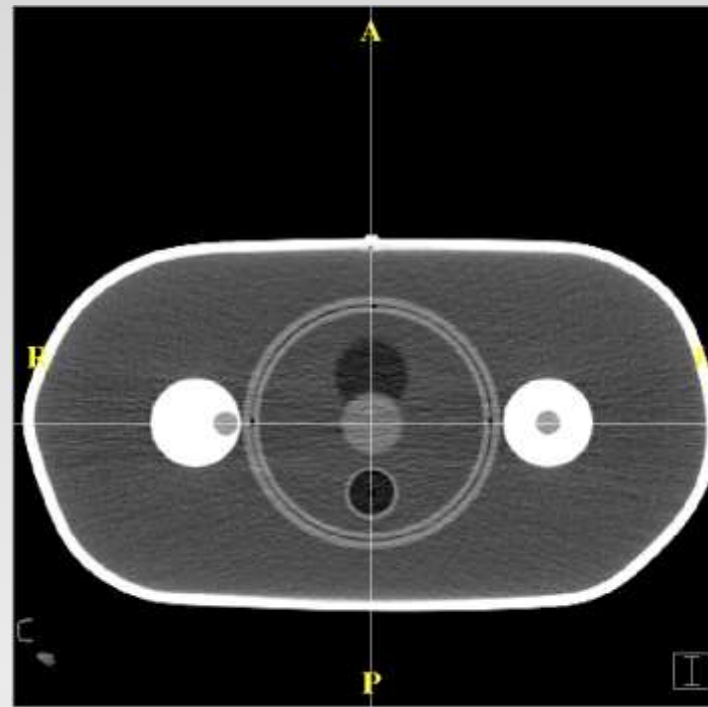
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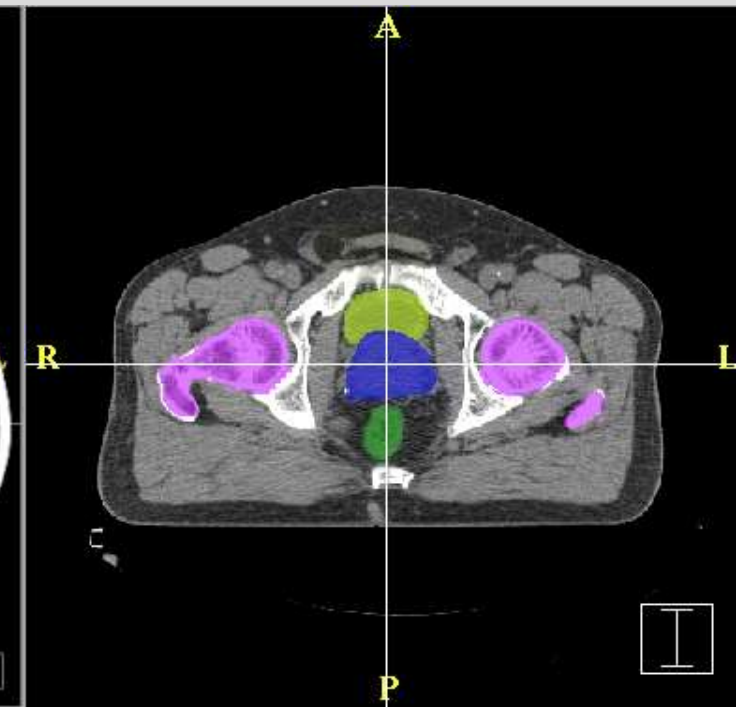
Benefits of RPC Phantoms

- Independent “end to end” audit
 1. Imaging
 2. Planning/dose calculation
 3. Setup
 4. Delivery
- Uniform phantoms and dosimeters
- Standardized analysis
- Uniform pass/fail criteria
- **Allows inst. to inst. comparison**

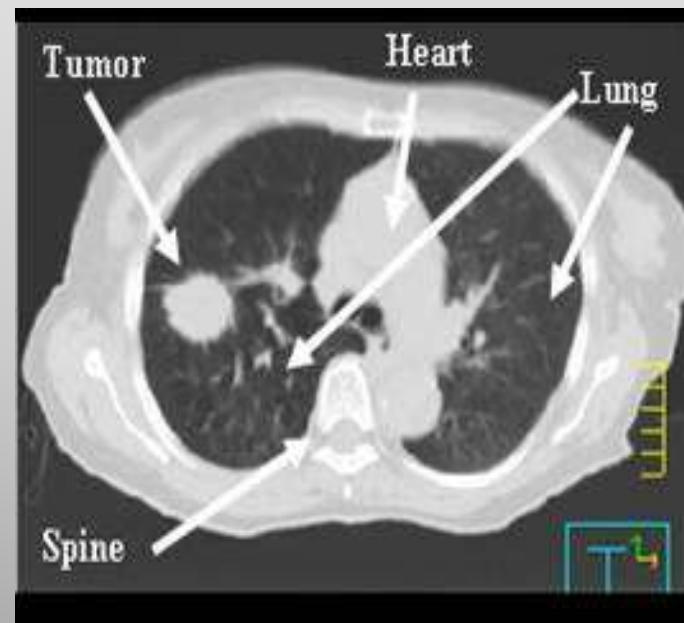
Phantom



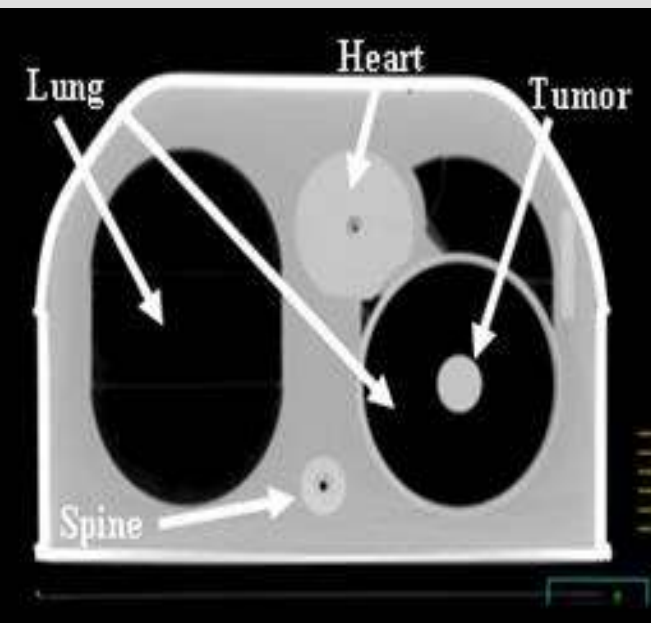
Patient



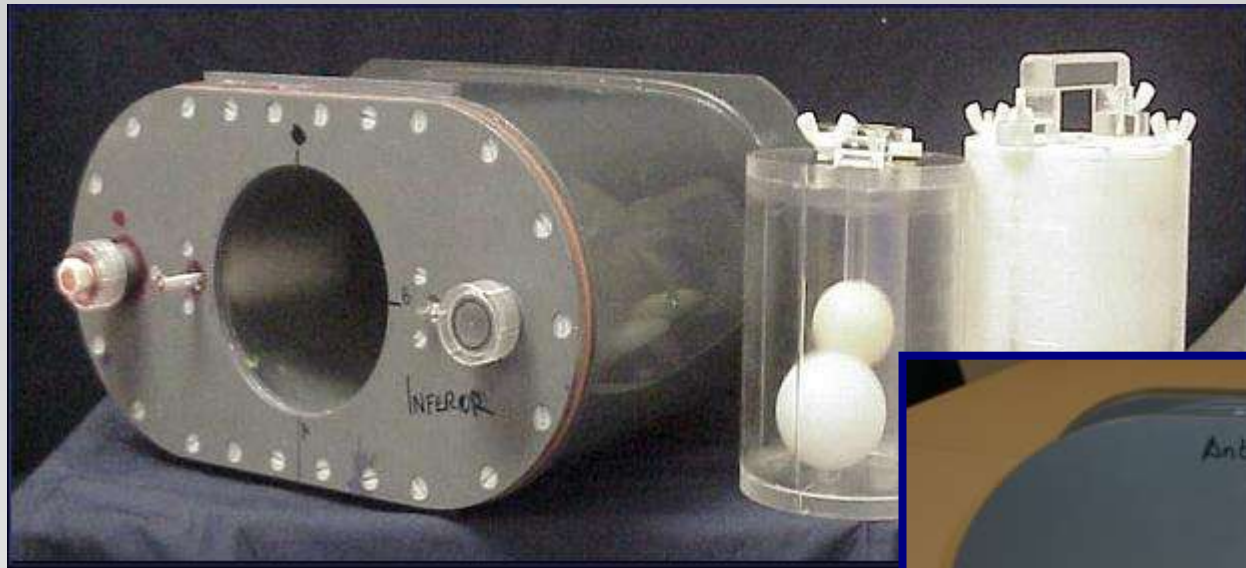
Patient



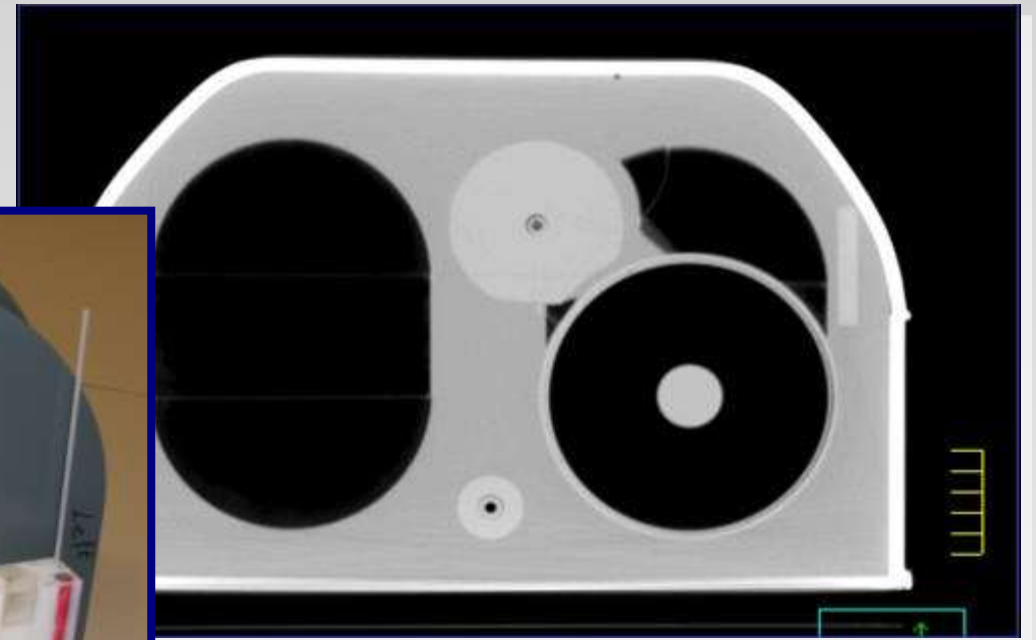
Phantom



RPC Phantoms



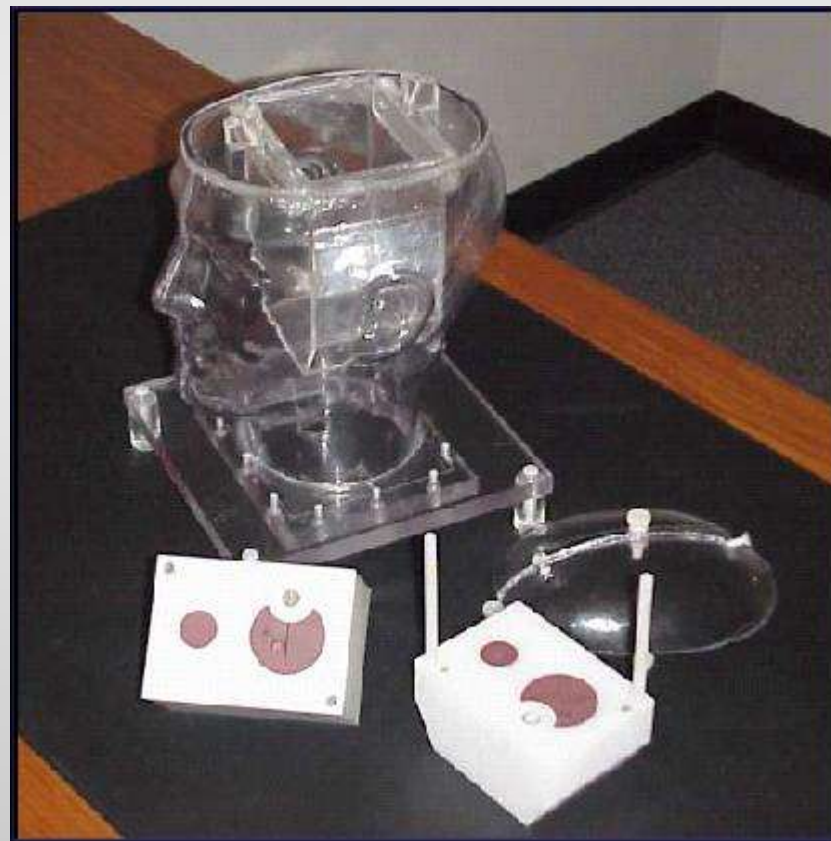
Pelvis (10)



Thorax (10)



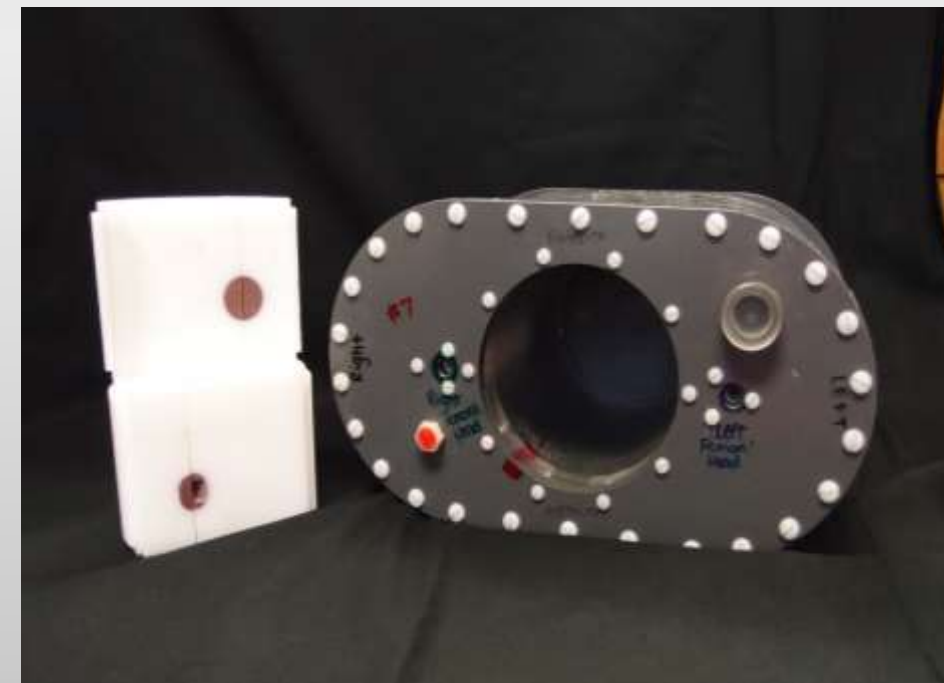
Spine (8)



H&N (30)



SRS Head (10)

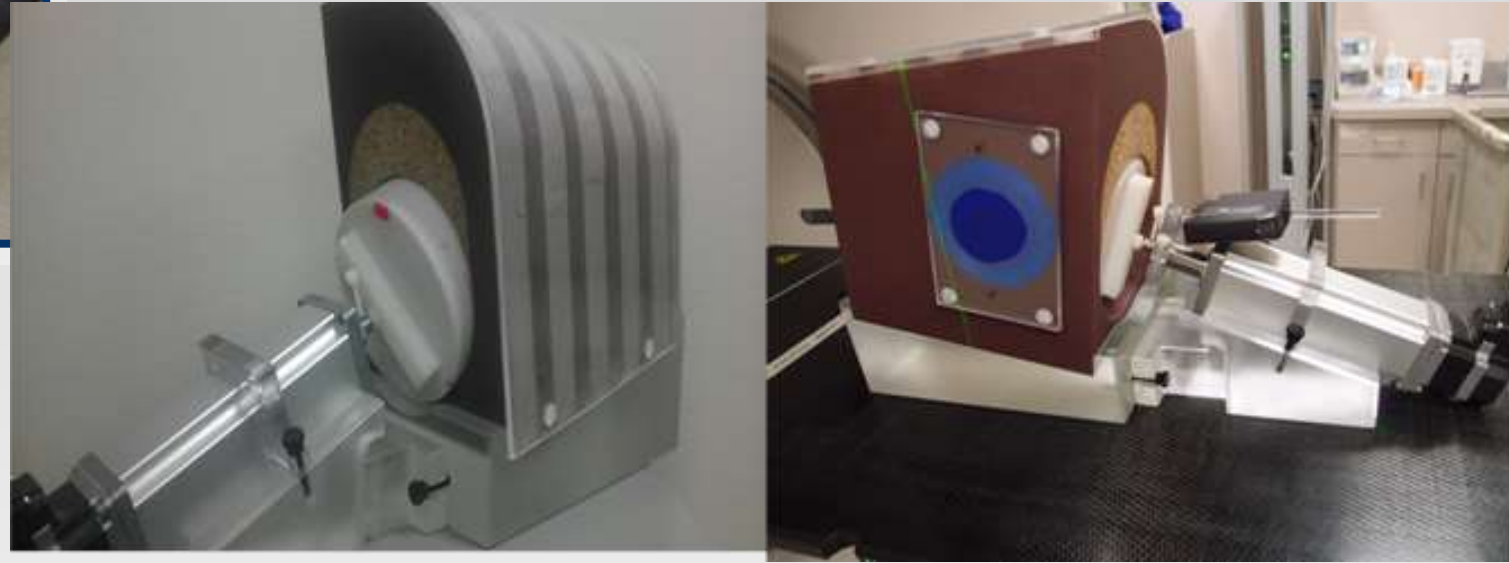


Liver (6)

RPC Phantoms for Protons



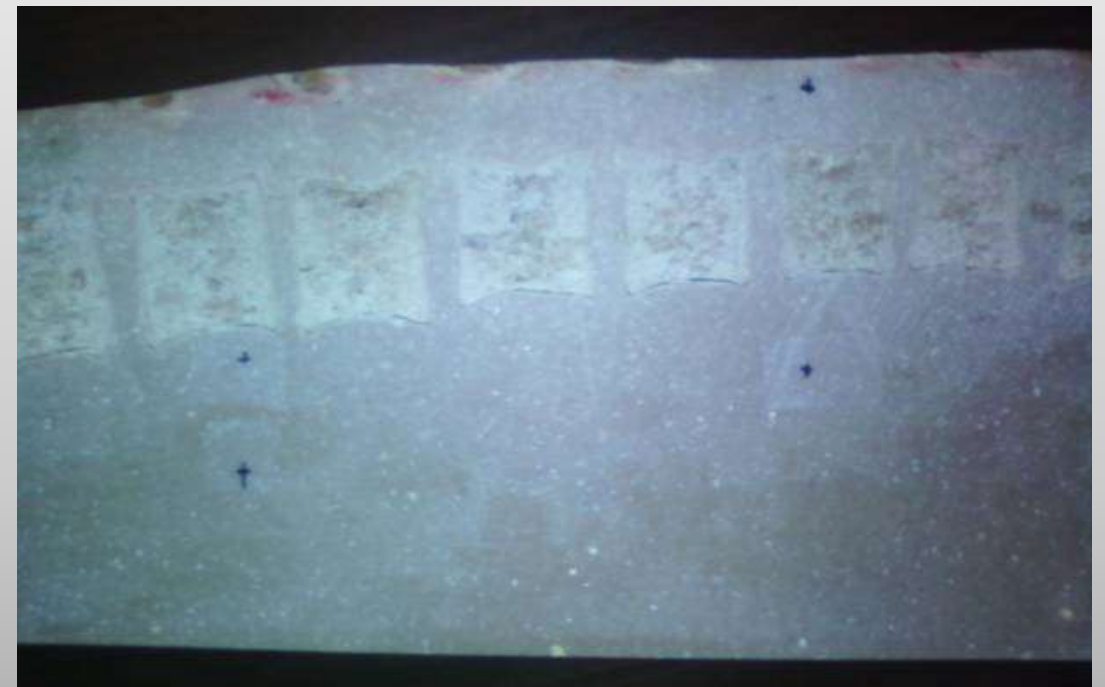
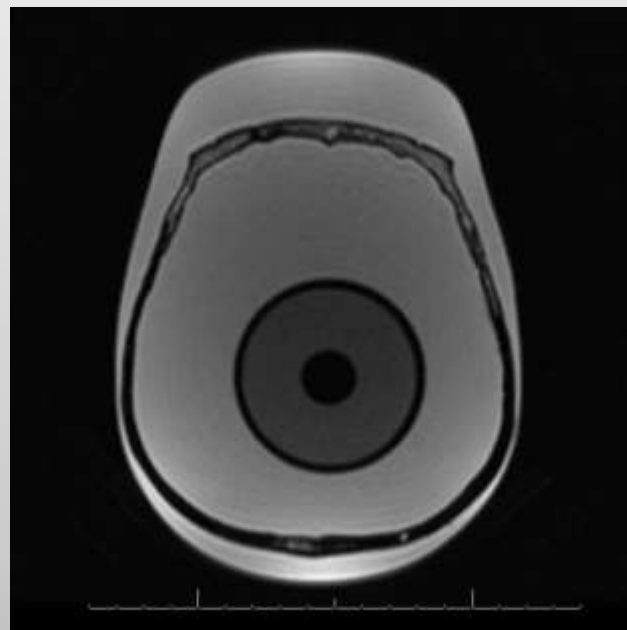
prostate phantom



lung phantom

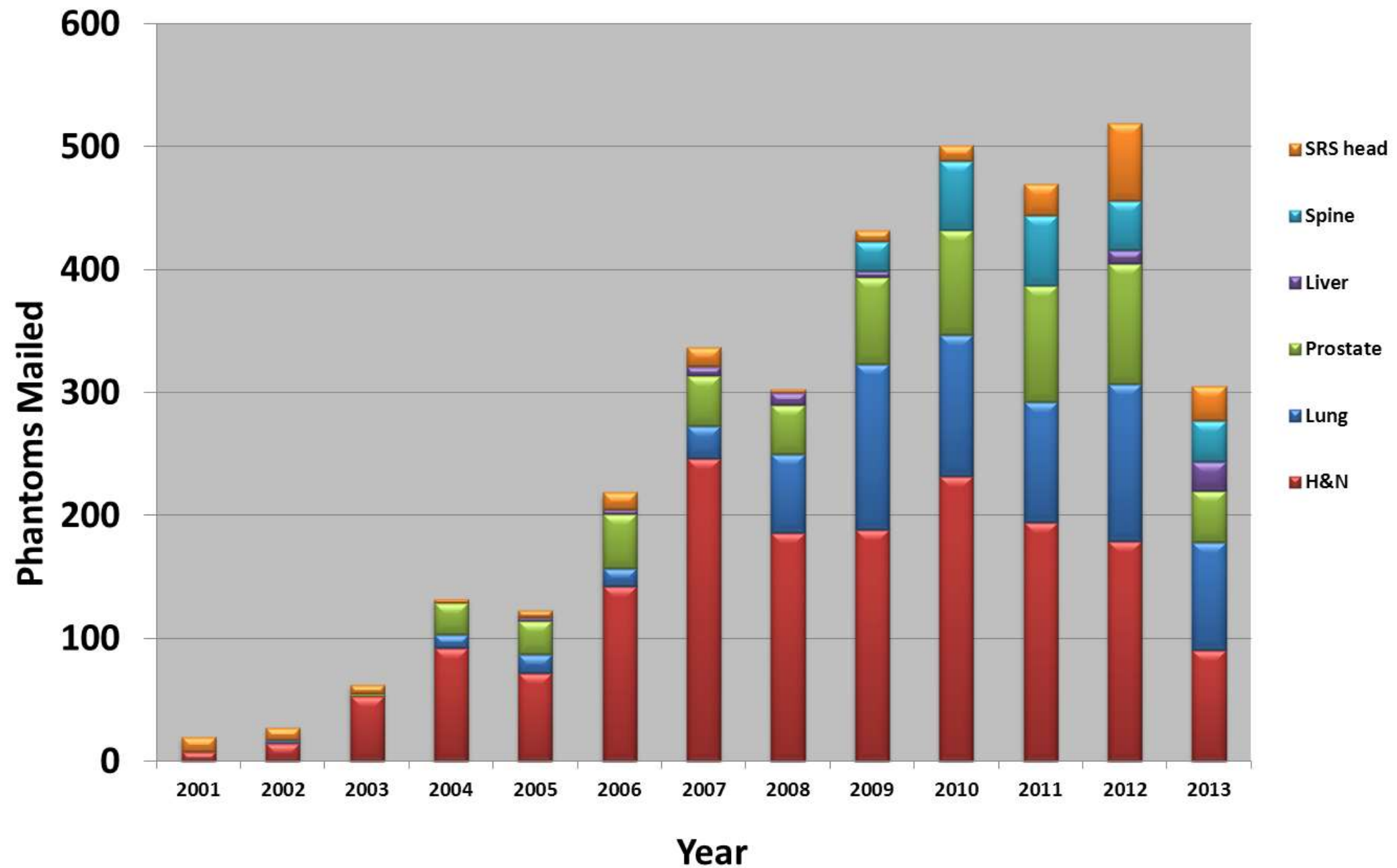


head phantom



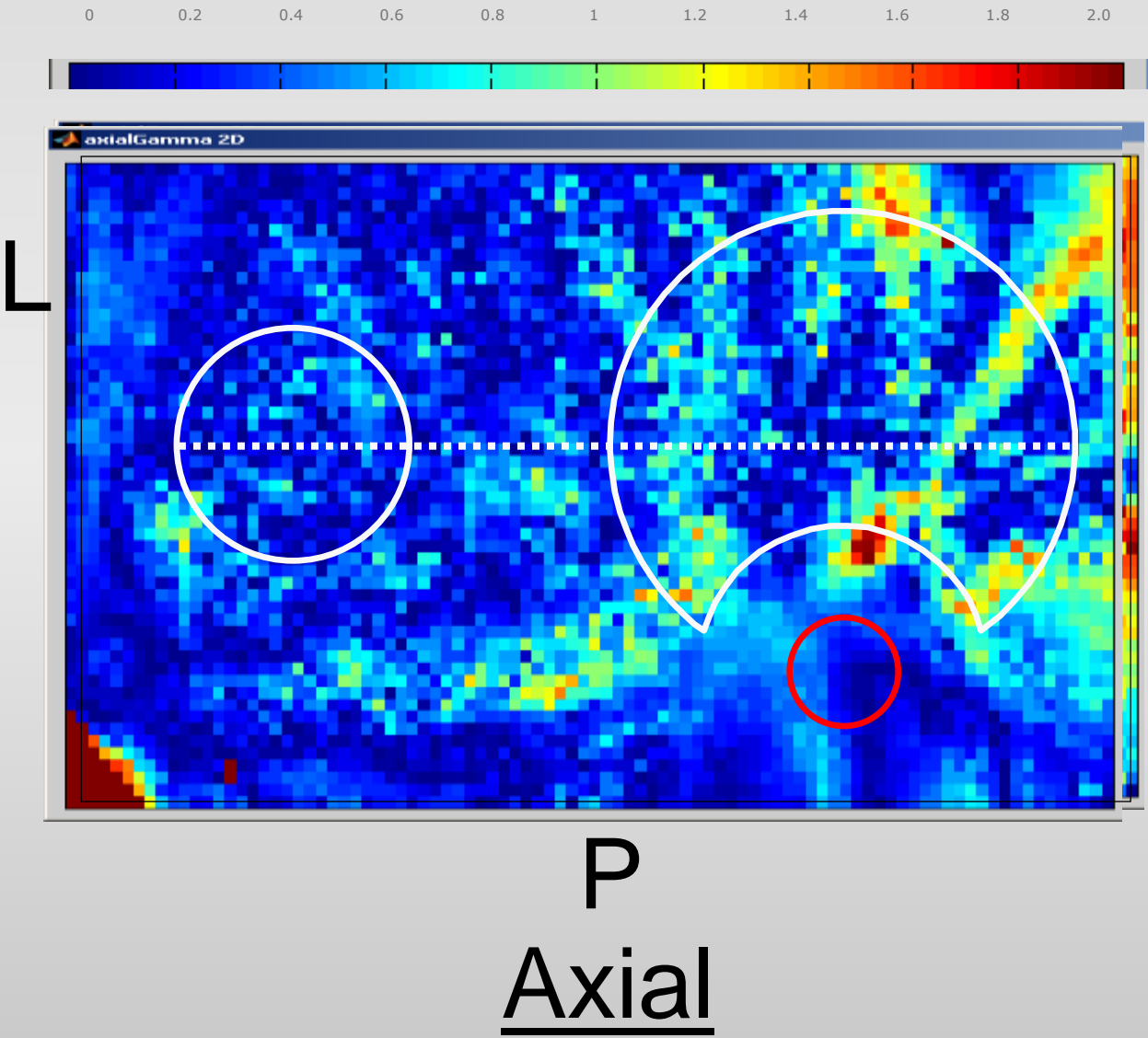
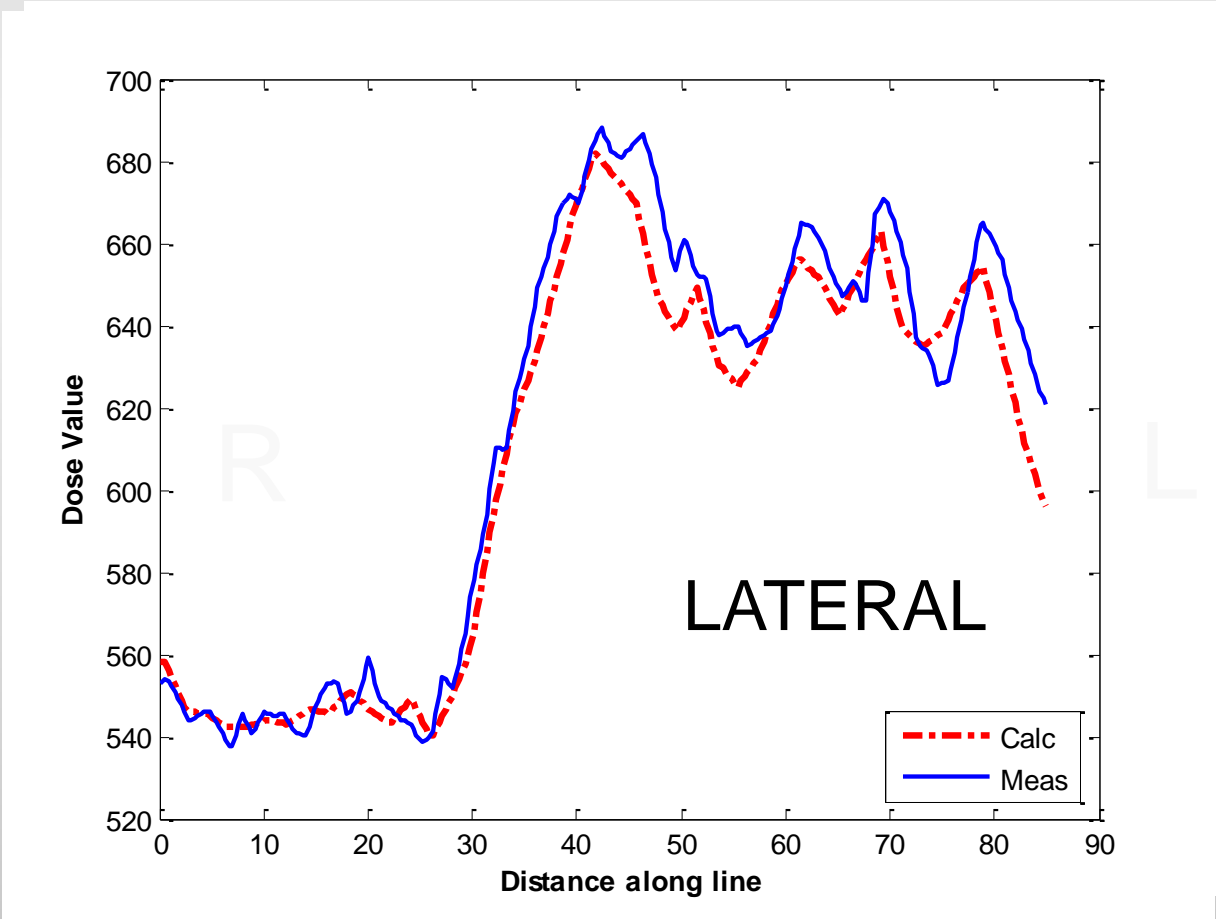
spine phantom

Phantom Irradiations per Year

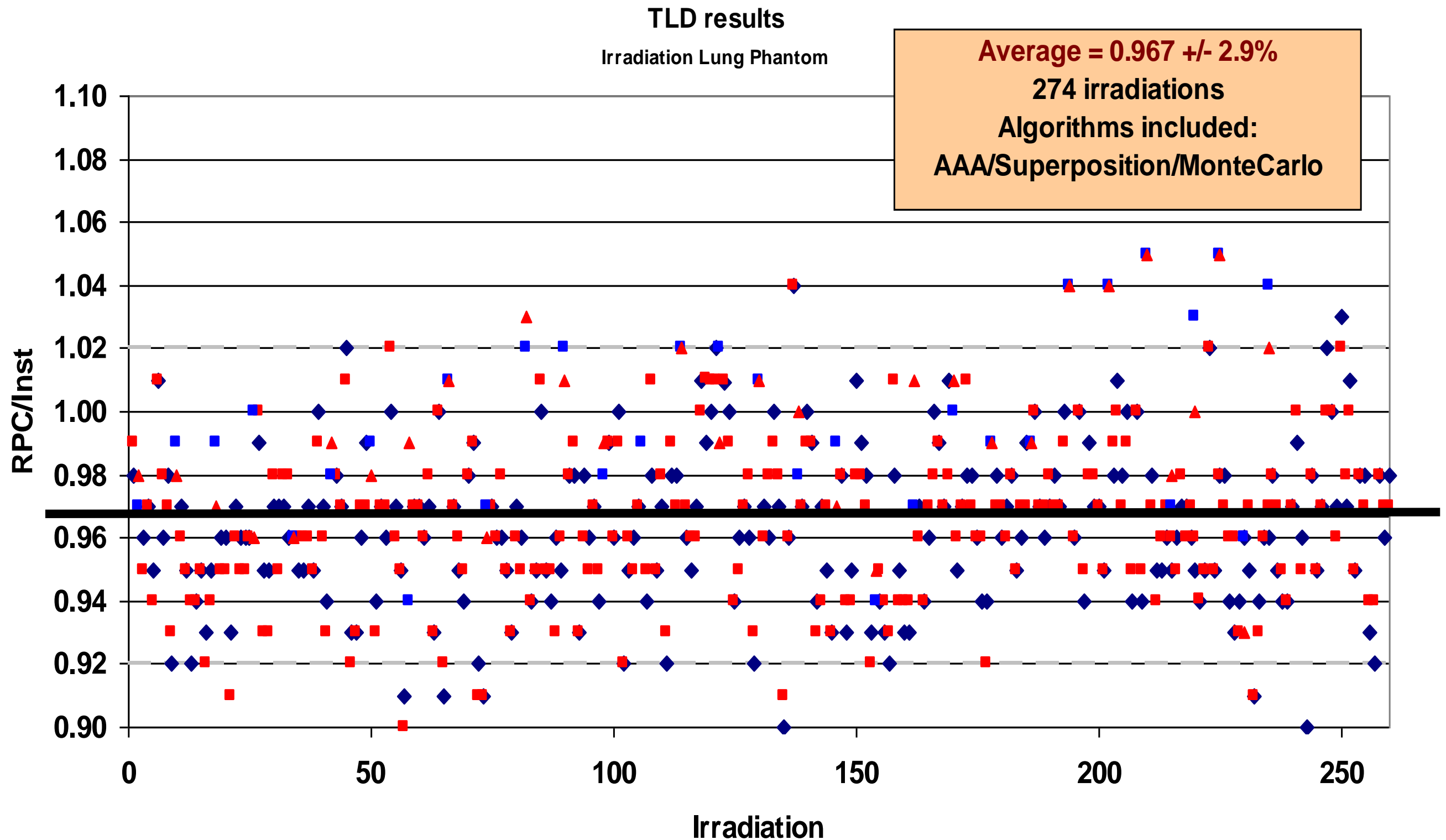


Measurement vs. Monte Carlo

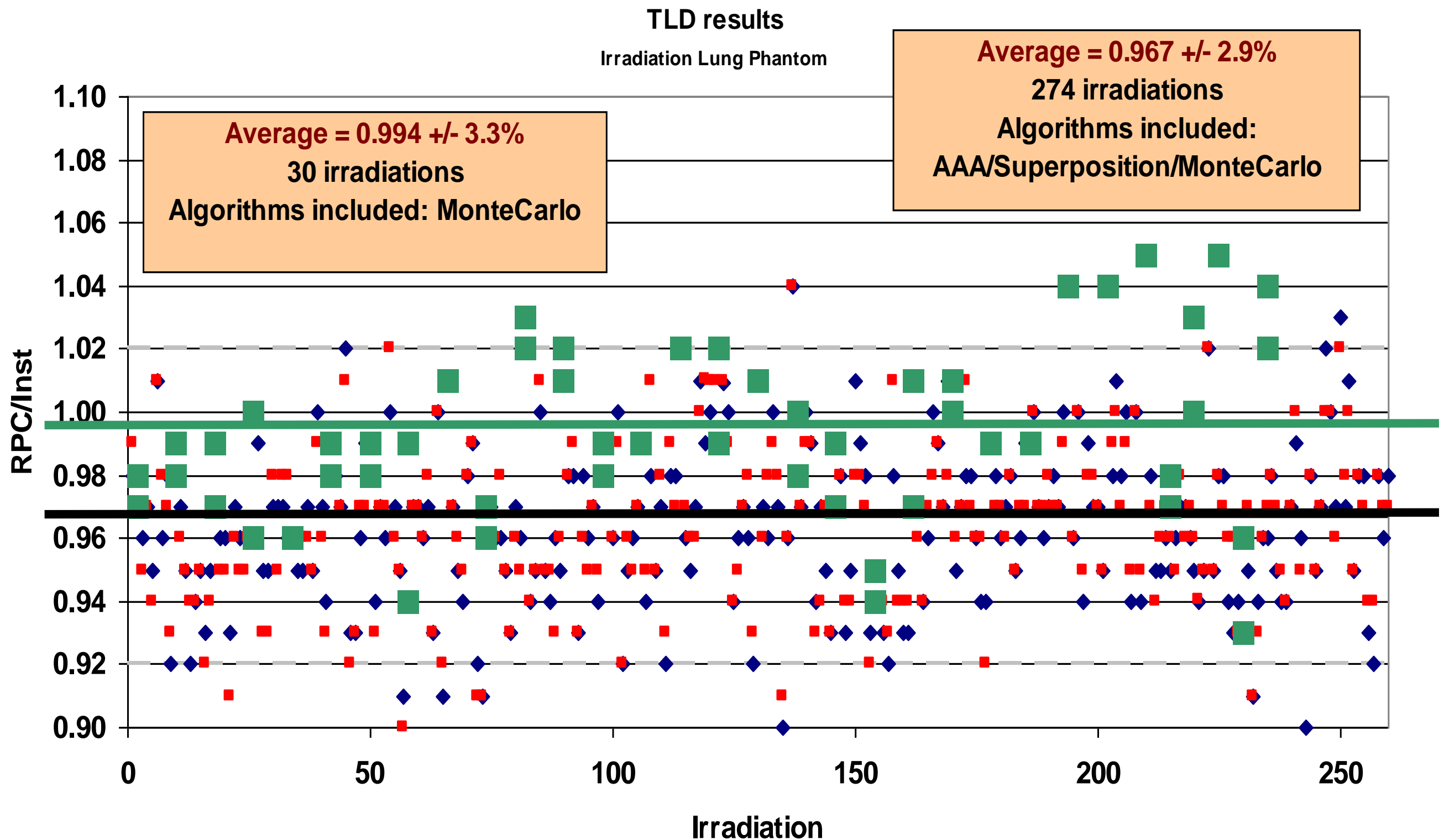
Criteria
3%/2 mm



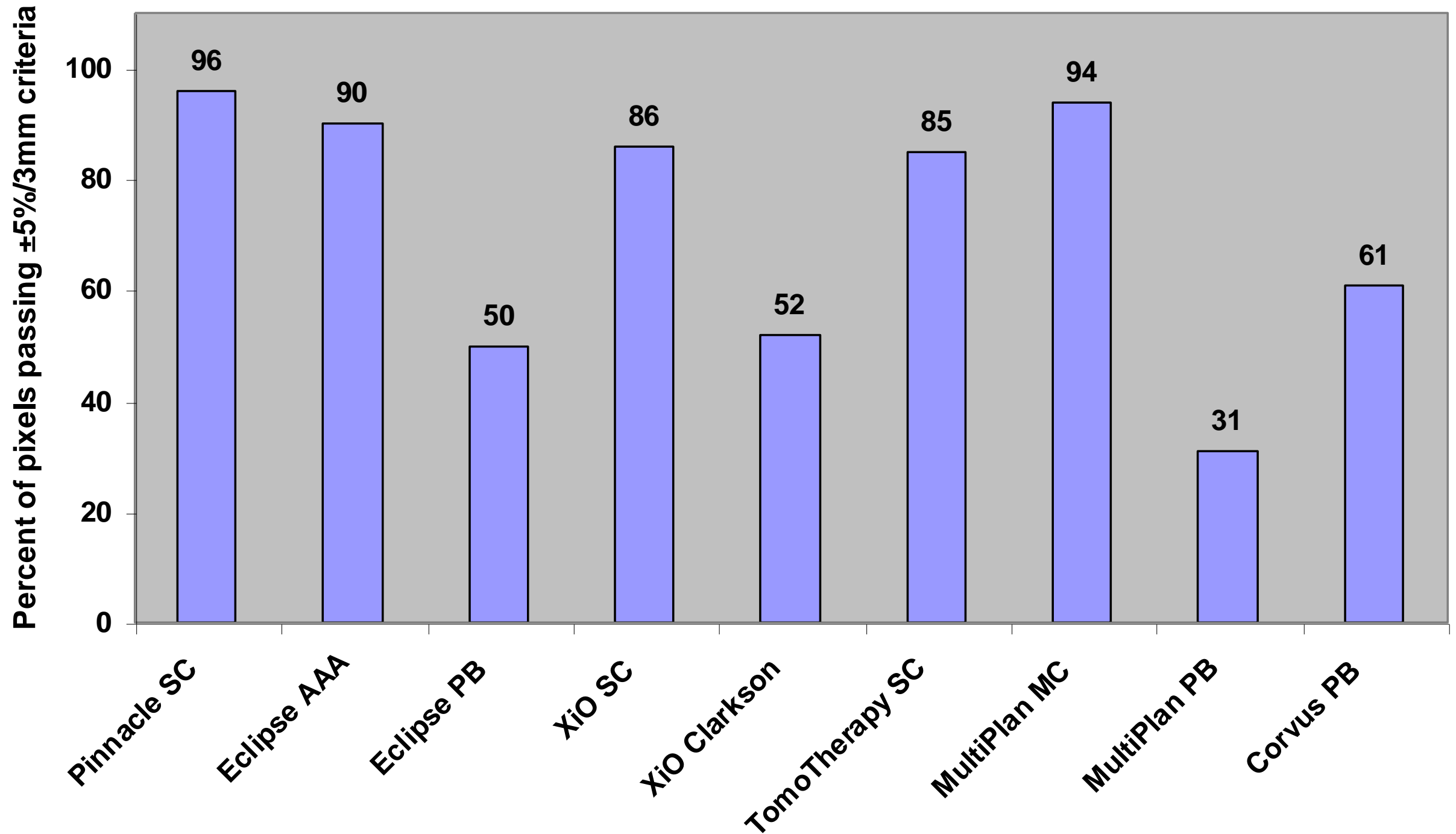
Lung Phantom TLD results



Lung Phantom TLD results



Percent of pixels passing 5%/3mm gamma criteria



Phantom Accomplishments

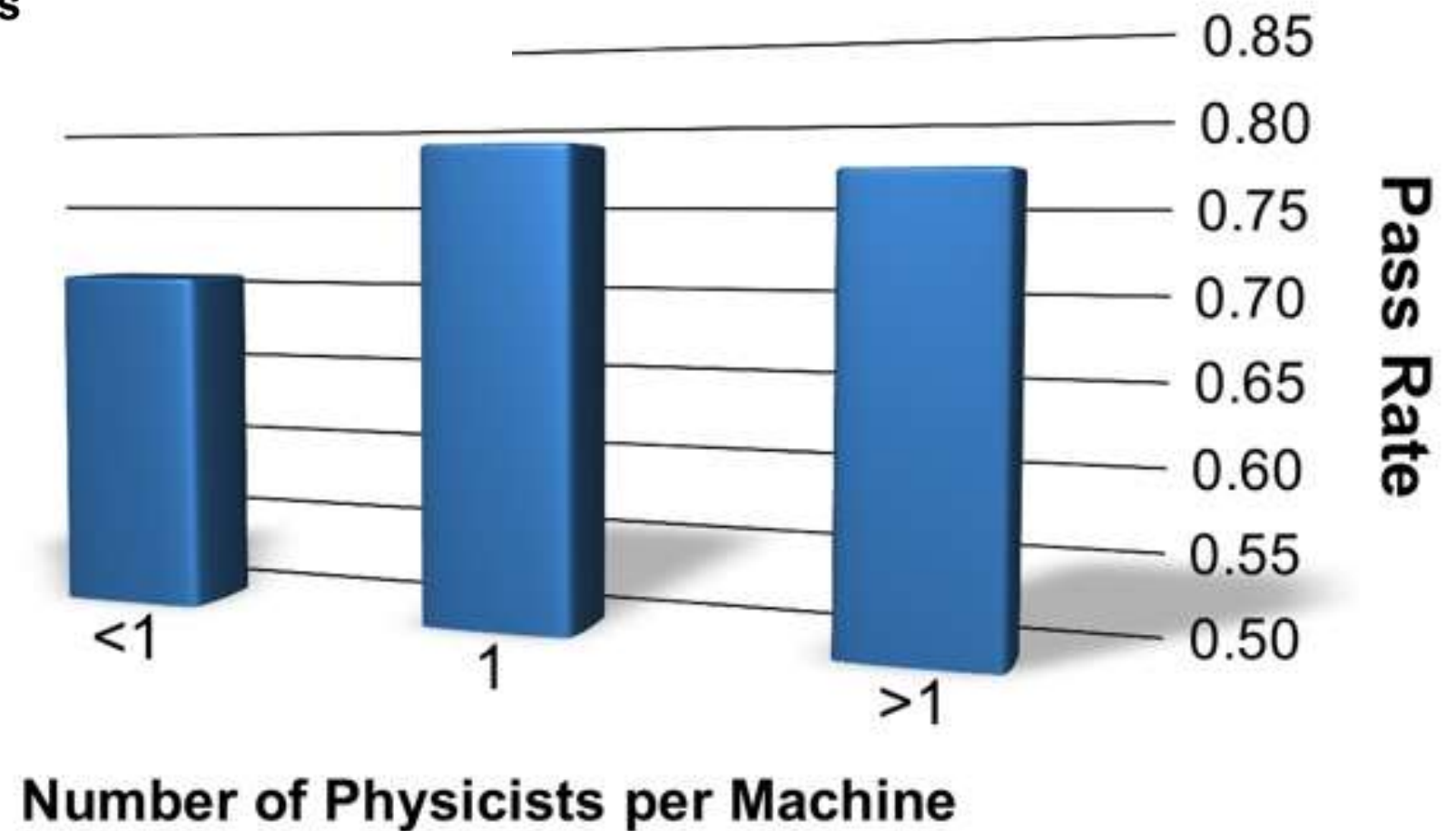
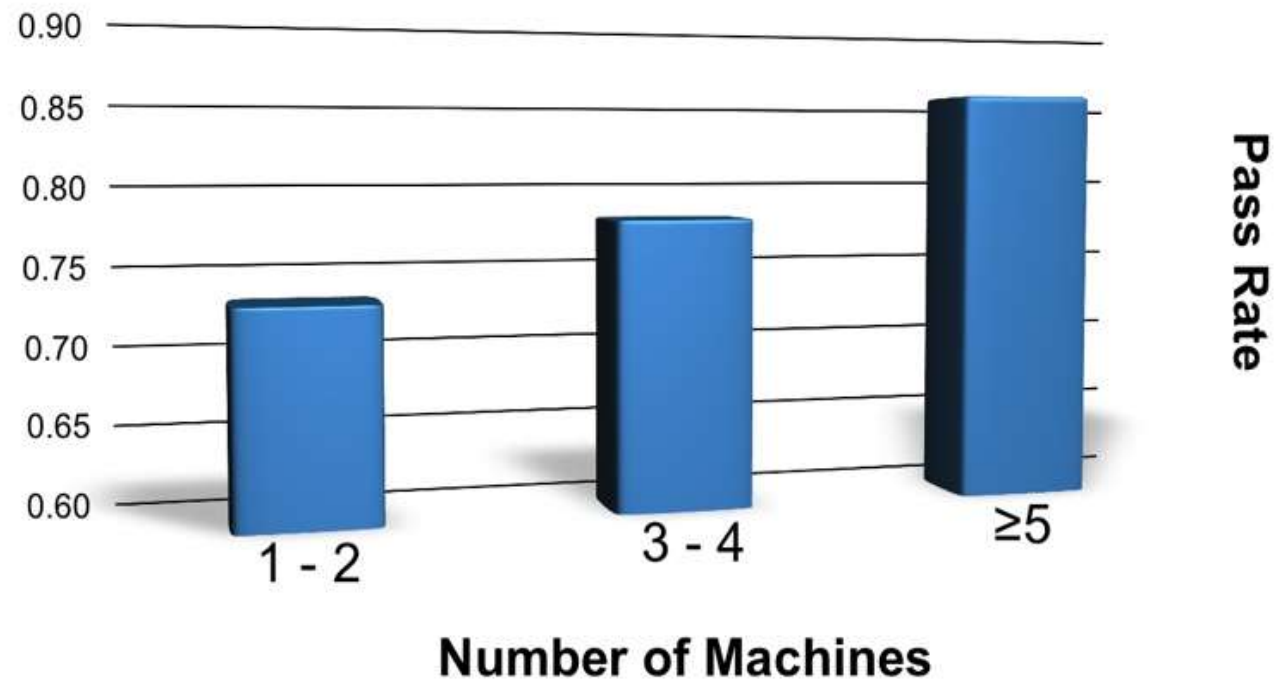
- Setting a standard for IMRT use in national and international clinical trials
- Use of heterogeneity corrections for modern algorithms
- Test ability to hit a moving target(s)
- Provide consistent and independent QA evaluation tool
- Testing proton therapy planning and dose calculations

Phantom Results

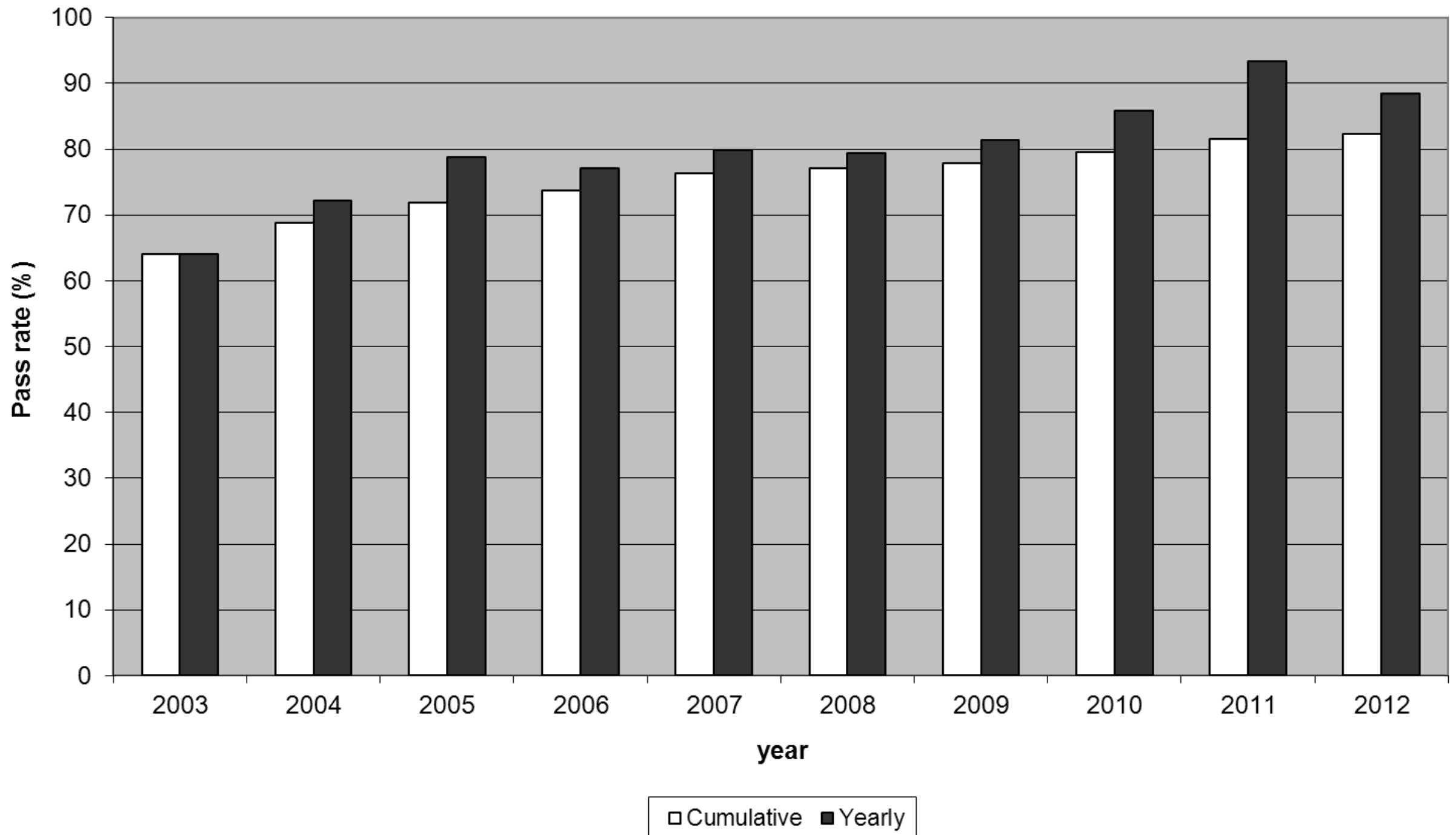
Comparison between institution's plan and delivered dose.

Phantom	H&N	Prostate	Spine	Lung
Irradiations	1368	419	176	664
Pass	1135 (83%)	359 (86%)	119 (68%)	535 (81%)
Fail	233	61	57	129
Criteria	7%/4mm	7%/4mm	5%/3mm	5%/5mm

Phantom Statistics



Progress is being Made!



Use of Advanced Technologies in clinical trials?

TRACKING
TPS

IMRT DOSE PAINTING
HETERO CORRECTION

GATING

SBRT

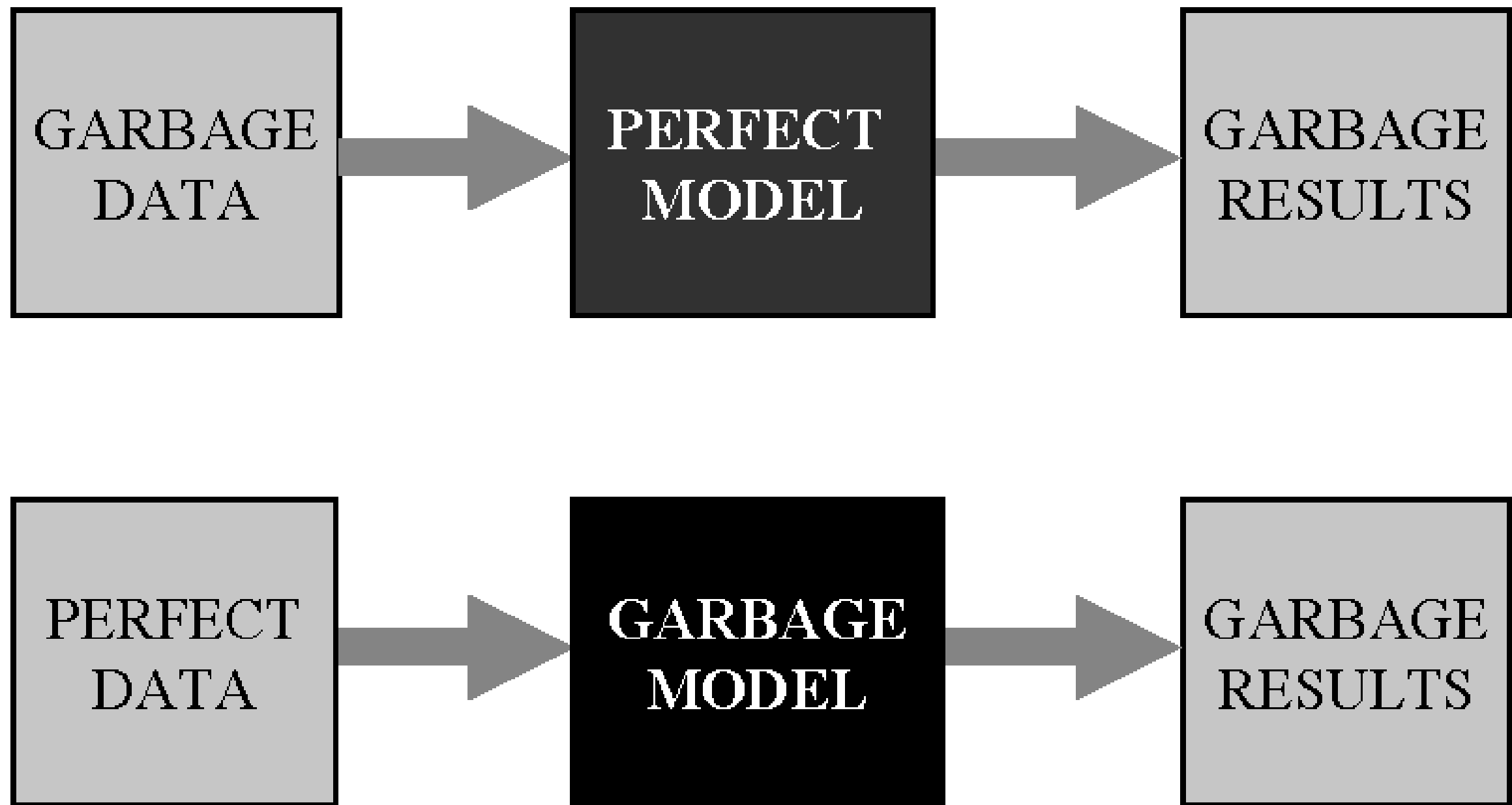


Respiratory
Control

IGRT
KV OR MV



Pay Attention to the Basics as well



Thoughts to Consider

The goal in radiotherapy is to achieve the golden $\pm 5\%$ dose delivery goal for our patients.

Realistically I believe that there are many good RT sites that deliver well within 5%, but there are many that probably, for some patients, are somewhere between 5-10%.

Primary reasons

Human error

Don't understand the complex processes

Don't pay attention to QA results

Resources

Be Willing to Consider an Independent Audit

1. Local physicist at another RT center
2. Physicist at your center/physics group
3. Consulting physicists
4. Former medical physics classmates
5. Radiological Physics Center

Conclusions

1. Take more time and ask questions.
2. Reread the task group report.
3. Read the clinical trial protocol.
4. Be willing to admit you were wrong and learn from your mistakes.
5. Place more responsibility on manufacturers to implement more accurate systems.
6. MLC QA!
7. Use only the most recent heterogeneity correction algorithms (preferably Monte Carlo or Acuros XB).
8. Small field dosimetry – caution, how small can we really go?
9. Implement IGRT for heaven's sake.
10. Be inquisitive, don't just believe others at face value.