Commissioning of

Varian TrueBEAM

with

Flattening Filter Free – FFF Design

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Traditionally, radiation beam profiles are made to be “flat” for the ease of and dose computations and treatment planning.

Since the introduction and the successful implantation of IMRT delivery technology, the need for linear accelerators to produce a “flat” radiation beam has become un-important; so long as the beam profiles are stable and reproducible in the short term (daily or from moment to moment) and long term (yearly).

Hence, High Intensity Mode (HIM) or Flattening Filter Free (FFF) X-ray beams are introduced.

Of course, it is ideal if these “FFF” X-ray beams are proven to be consistent and reproducible from machines to machines, as well.

There are already many publications dealing with the topic of FFF X-ray beams, including many Monte Carlo modeling of these X-ray beams. However, because these FFF X-ray beams are new to the clinical environment, there is much to be studied and analyzed.

The intend of the presentation is NOT to provide answers but to open discussion topics, to address areas of concerns, and to spring future investigations.

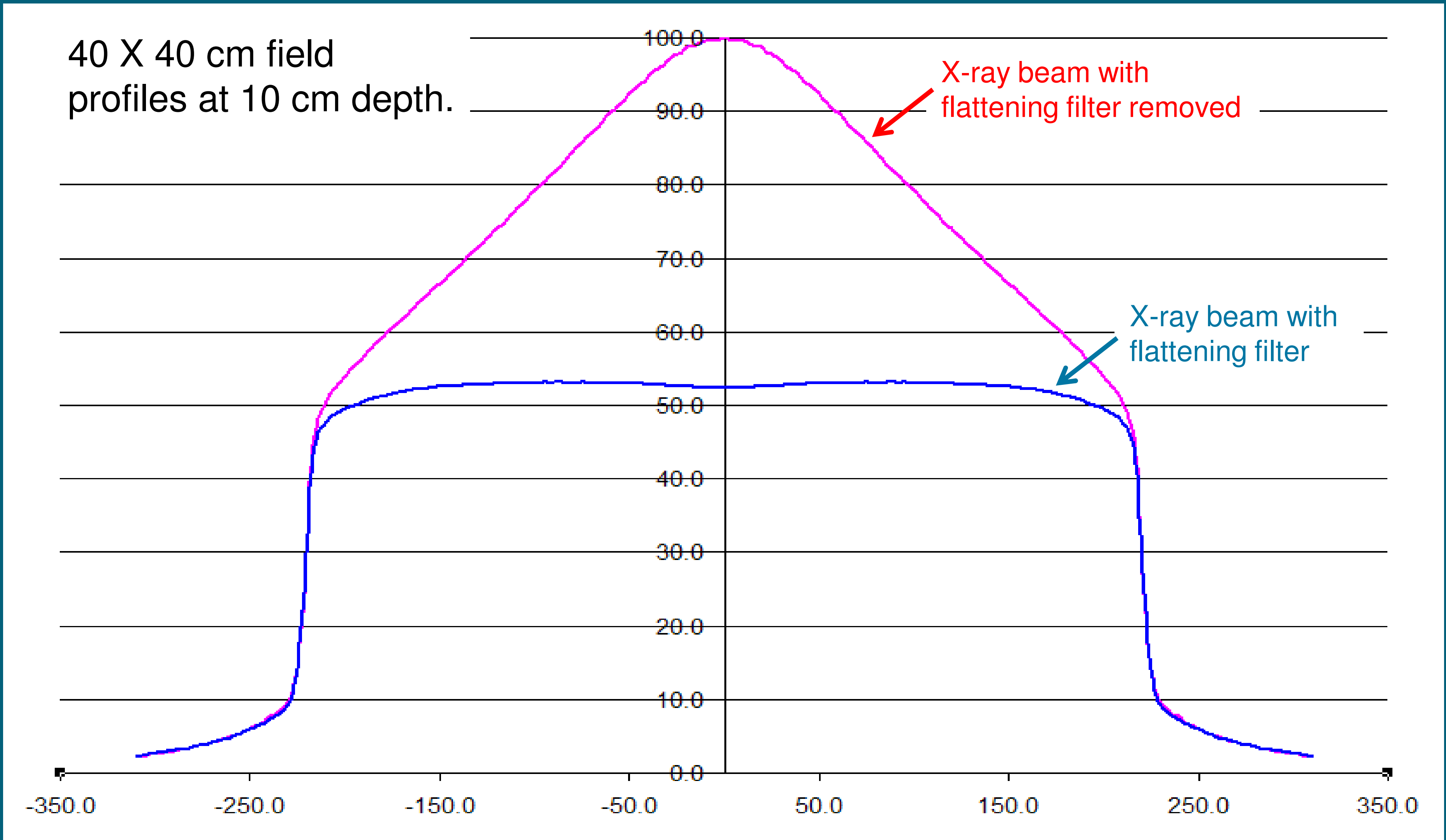
This presentation will address these topics about FFF X-ray beams:

(A) Production
(B) Dosimetric properties (PDD and Profiles)
(C) Parameters and quantification of the flattening filter free beam
(D) Typical clinical applications
(E) Samples of treatment plans with IMRT / RapidArc
(F) Clinical benefits and radiation protection benefits

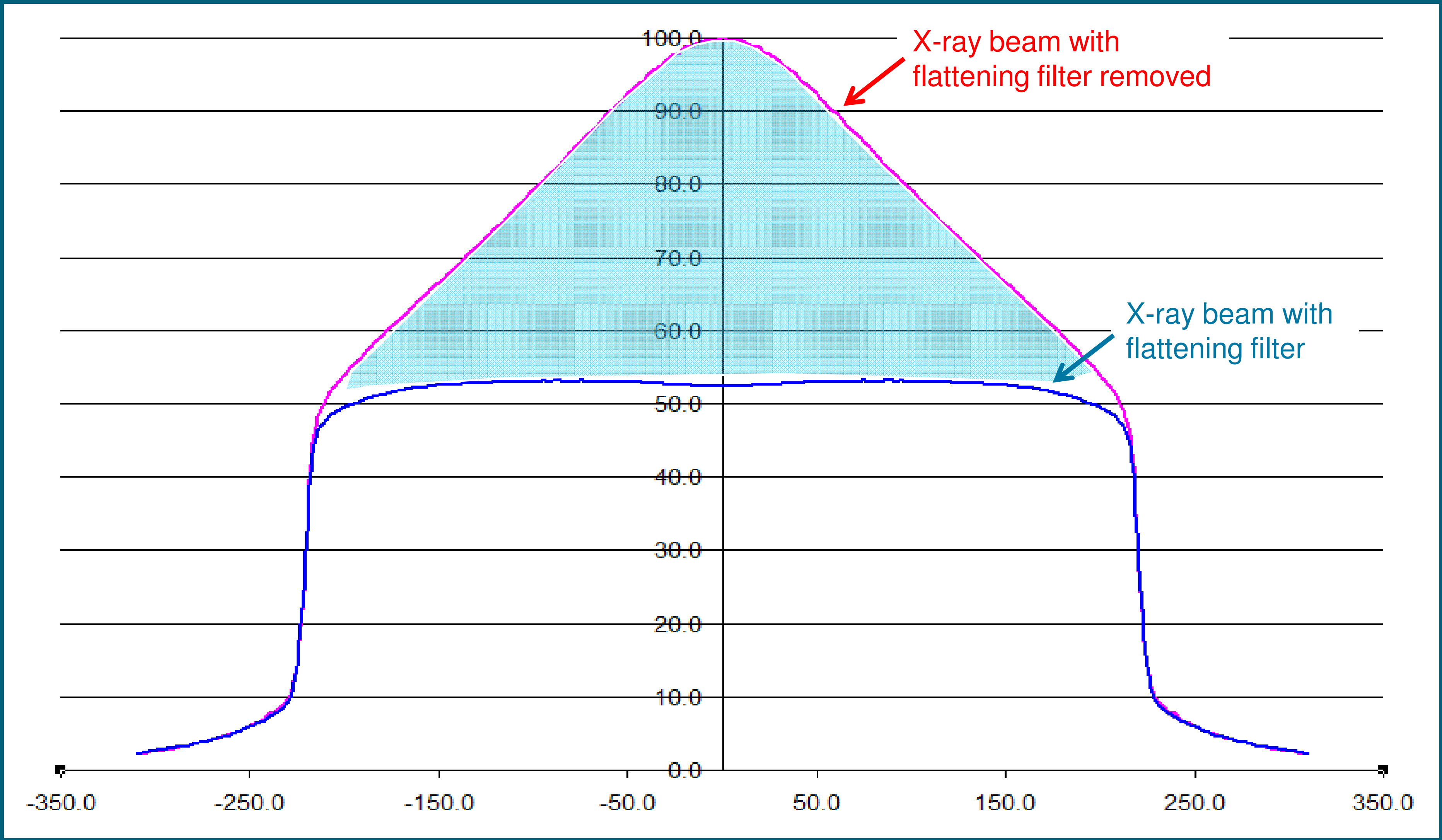
First, let us discuss:

(A) Production
(B) Dosimetric properties (PDD and Profiles)
(C) Parameters and quantification of the flattening filter free beam
(D) Typical clinical applications
(E) Samples of treatment plans with IMRT / RapidArc
(F) Clinical benefits and radiation protection benefits

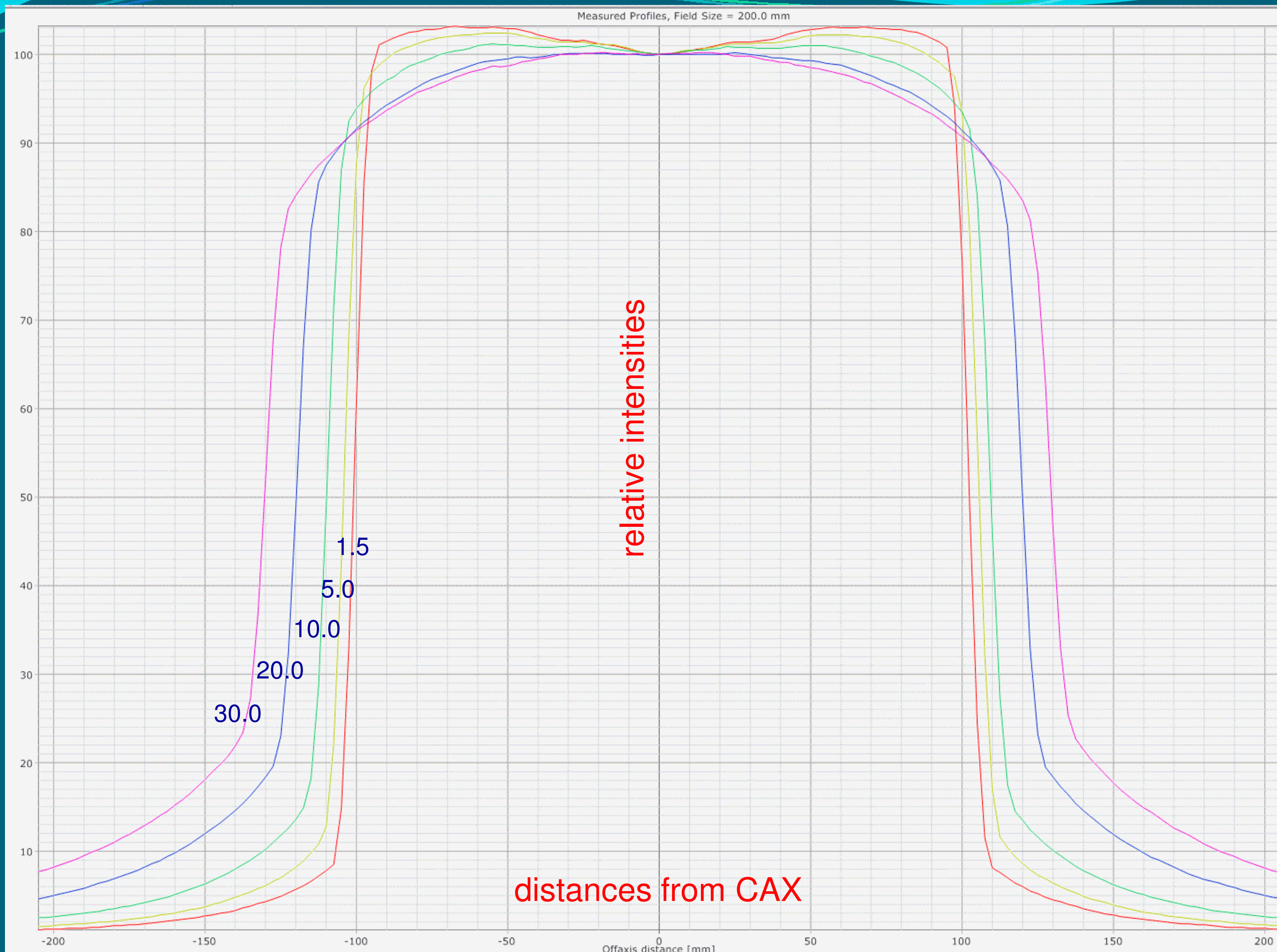
FFF X-ray profile graphed against the flat (conventional) beam profile. RED is the Flattening Filter Free beam profile, BLUE is the flattened (conventional) beam profile. These two profiles are normalized to the physical field edge.



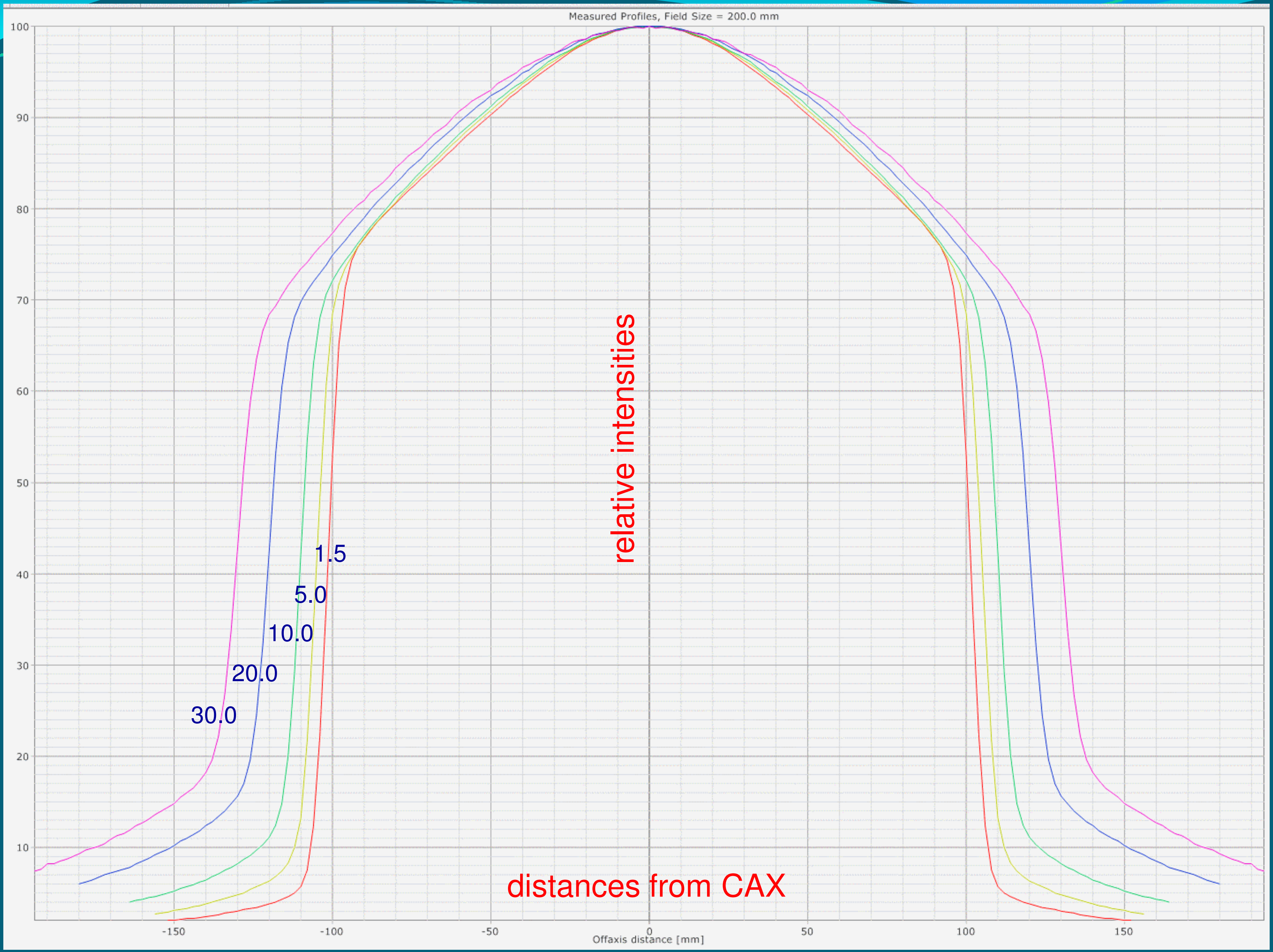
Flattened X-ray profile is generated by attenuating the raw beam with a flattening filter. The High Intensity Mode (flattening filter free mode) is achieved by removing the flattening filter from the X-ray beam path. Thus the intensity is increased (by nearly 200%) near the central axis with an un-flat (conical shaped) beam profile.



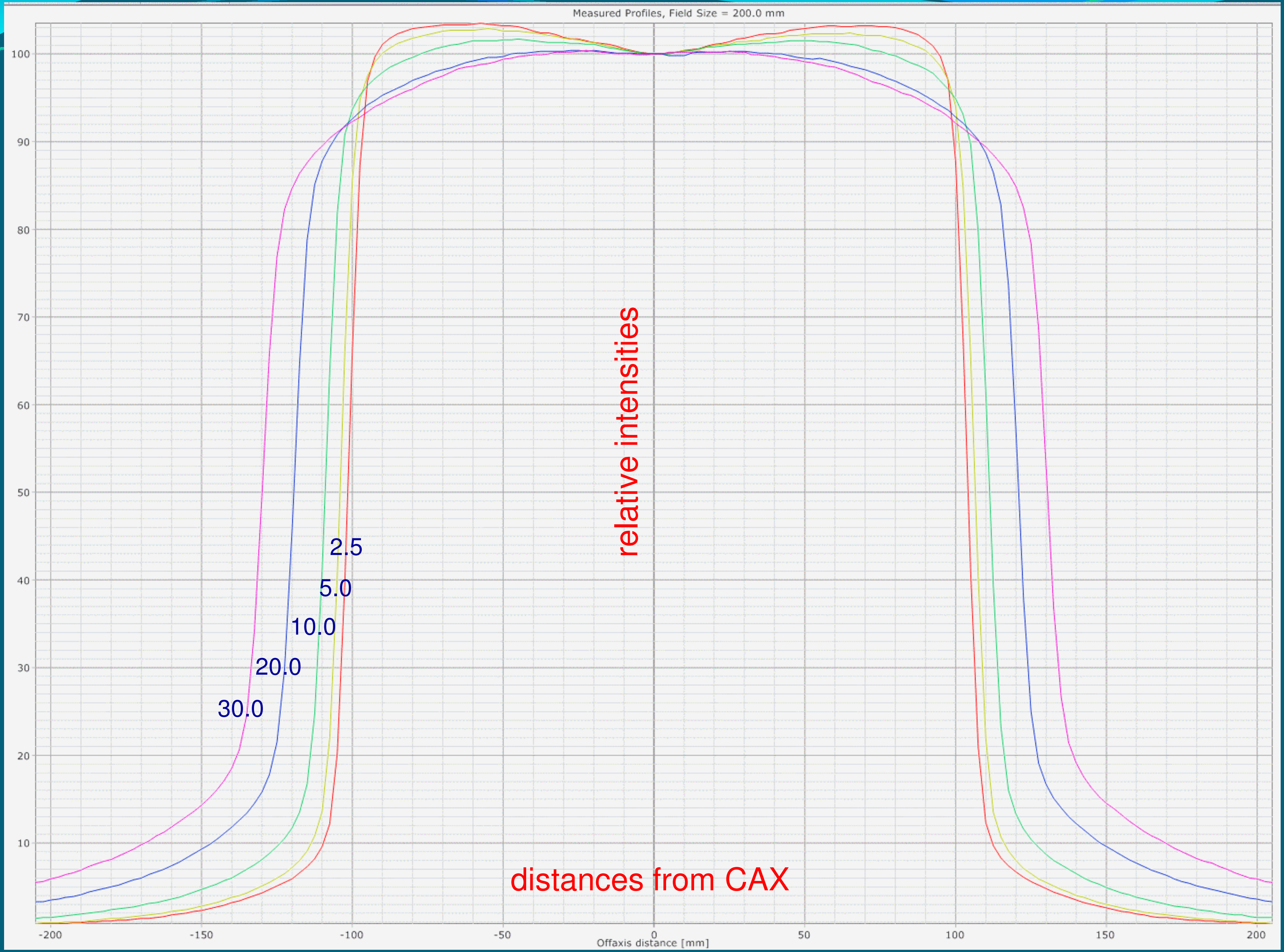
To set the viewing perspective, these are profiles from a conventional 20X20, 6 MV X-ray



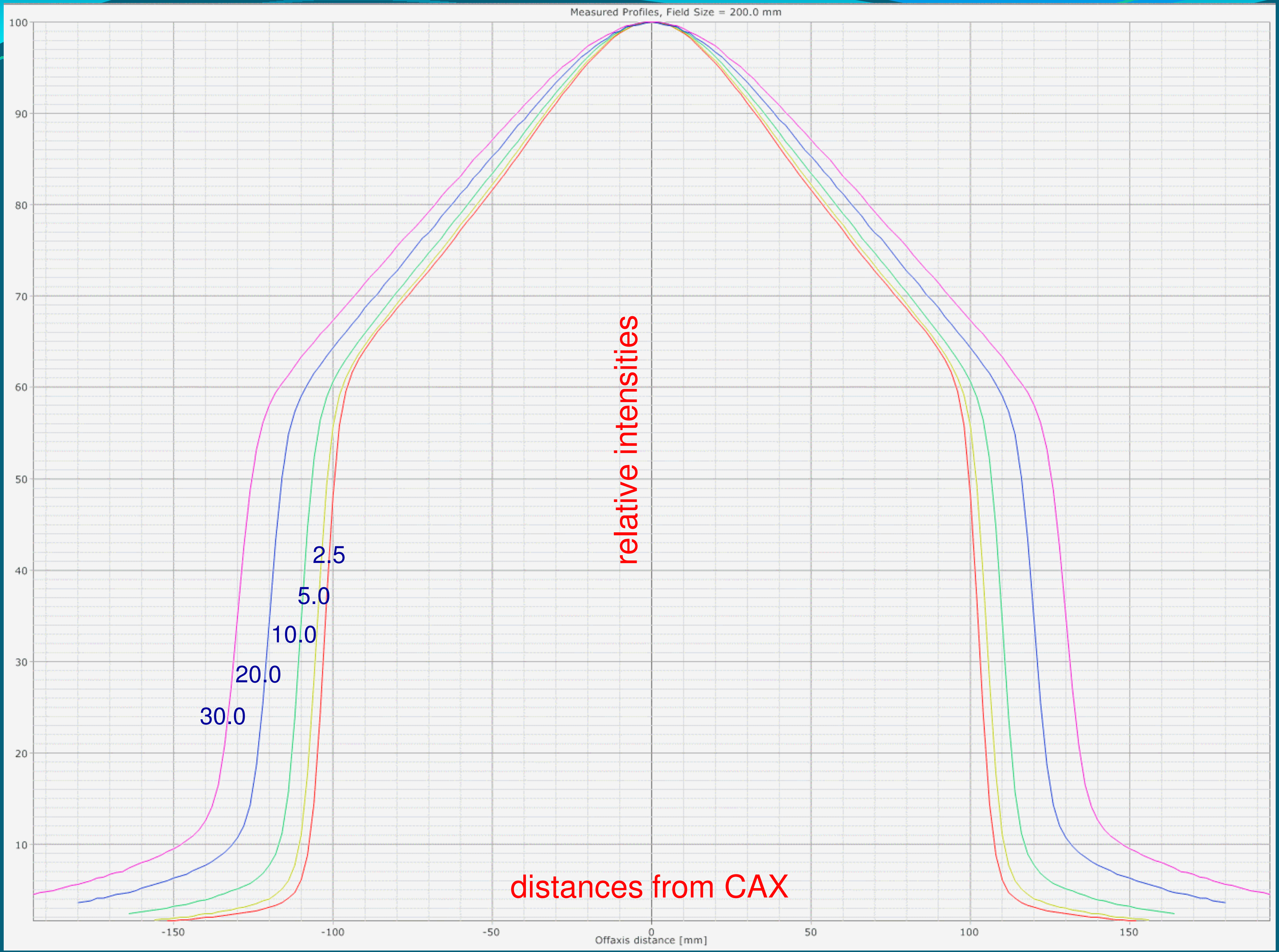
There are profiles from an HIM (FFF) 20X20, 6 MV X-ray



These are profiles from a conventional 20X20, 10 MV X-ray



There are profiles from an FFF 20X20, 10 MV X-ray



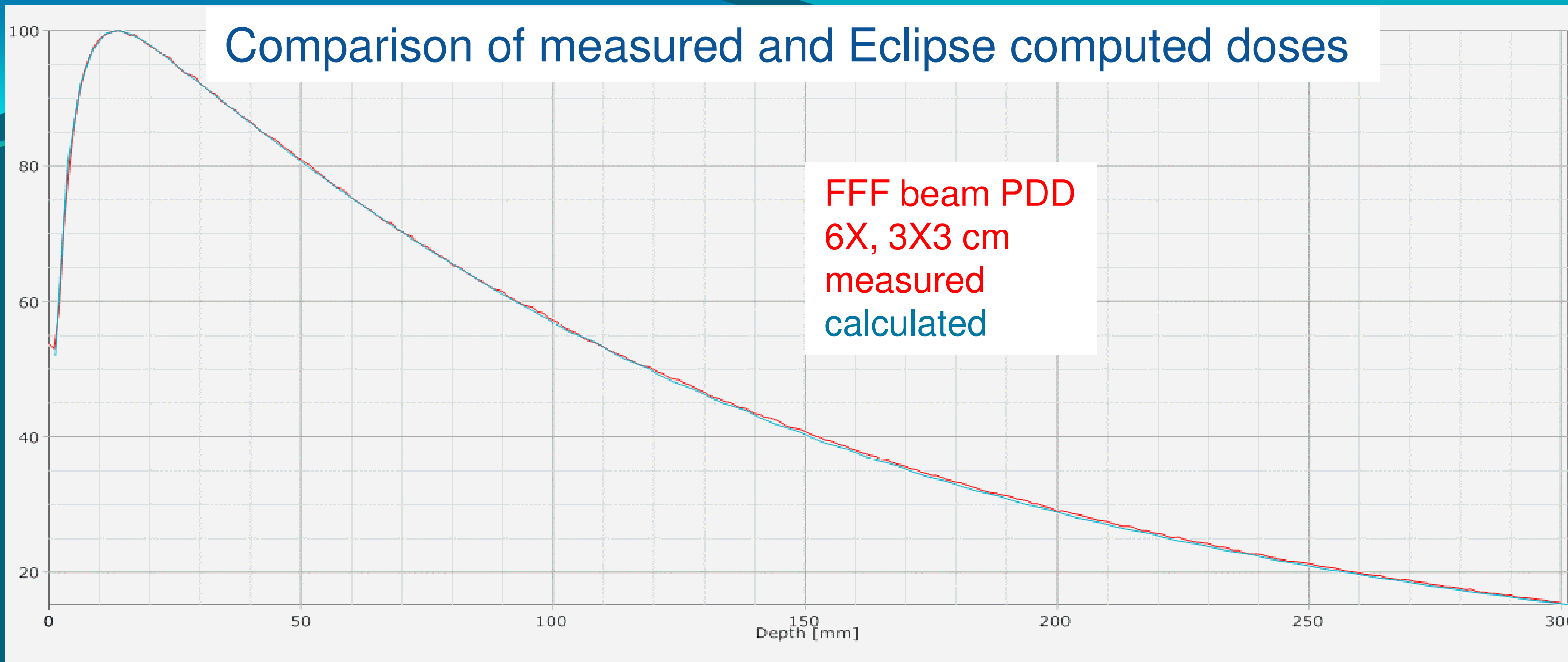
BEAM MODEL VALIDATIONS:

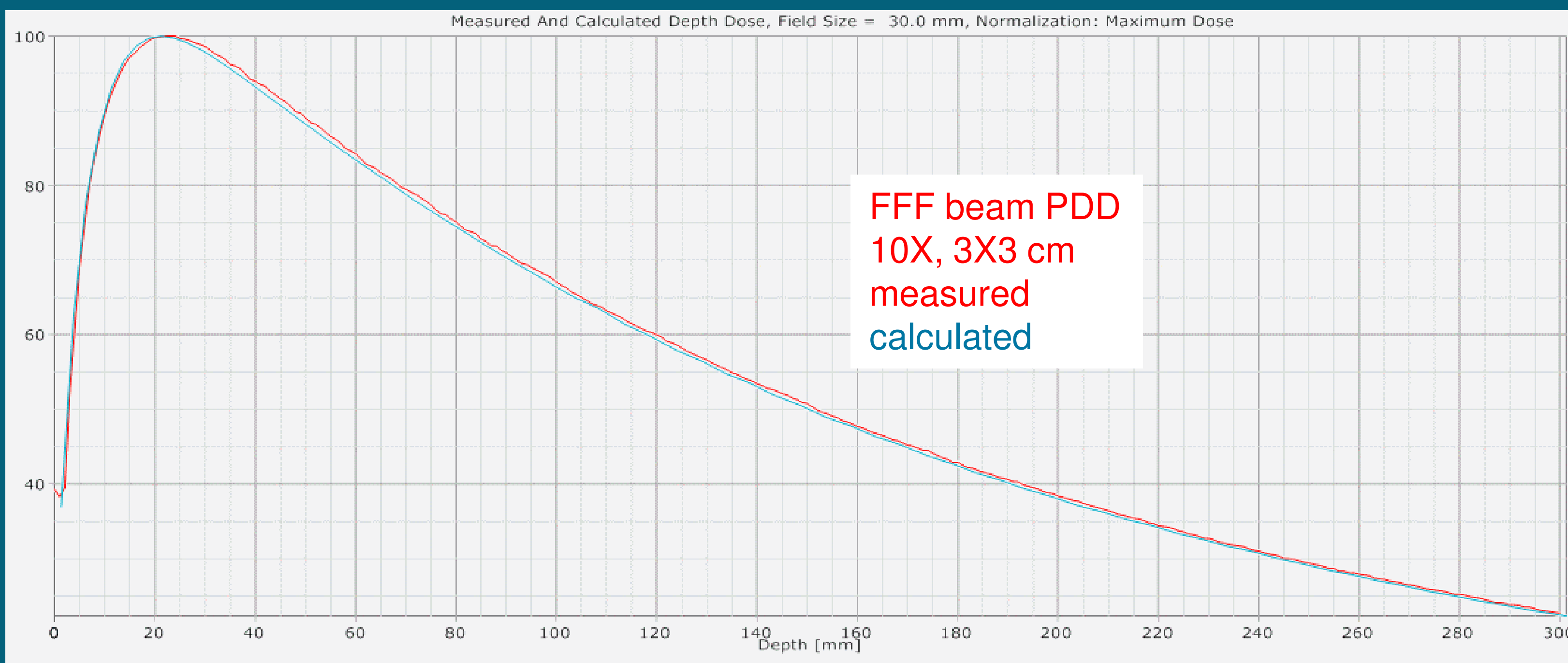
After entering the beam data into a treatment planning computer, Eclipse, one must compare measured and computed data from treatment computer. Often, this important step is either forgotten or skipped by physicists.

This is the final step in commissioning task.

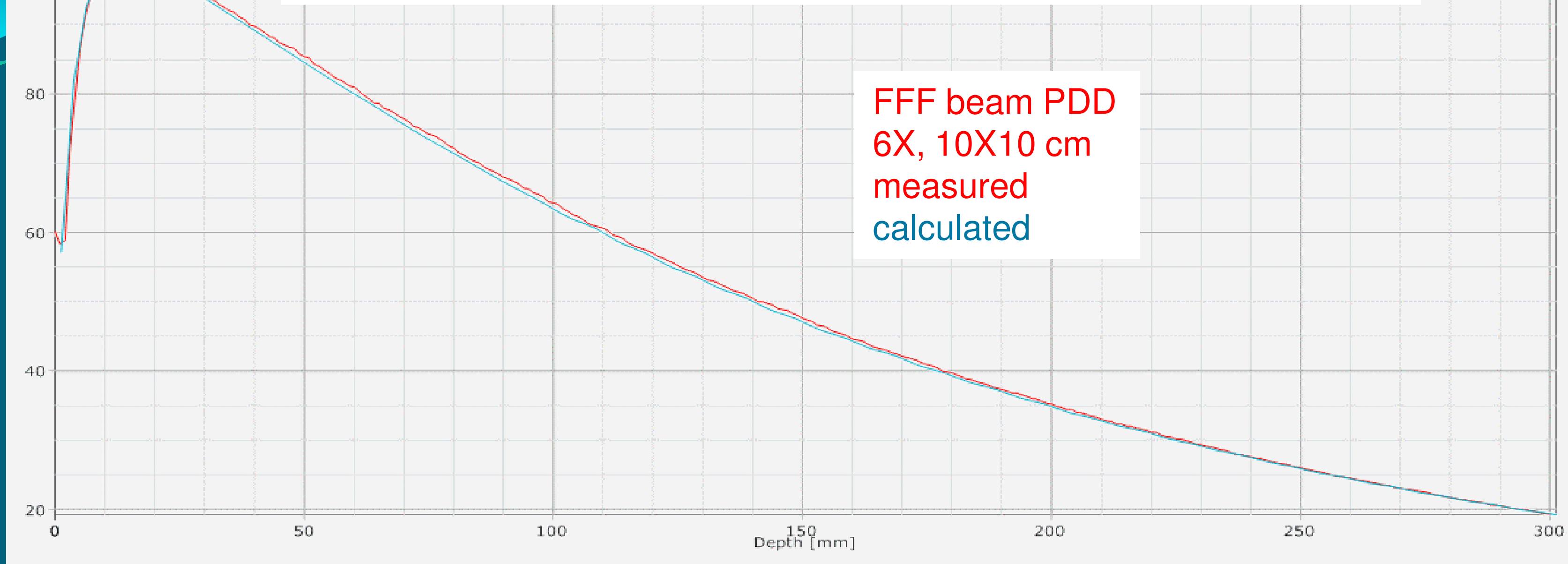
First, measured and computed *percentage depth doses* (PDDs) will be compared.

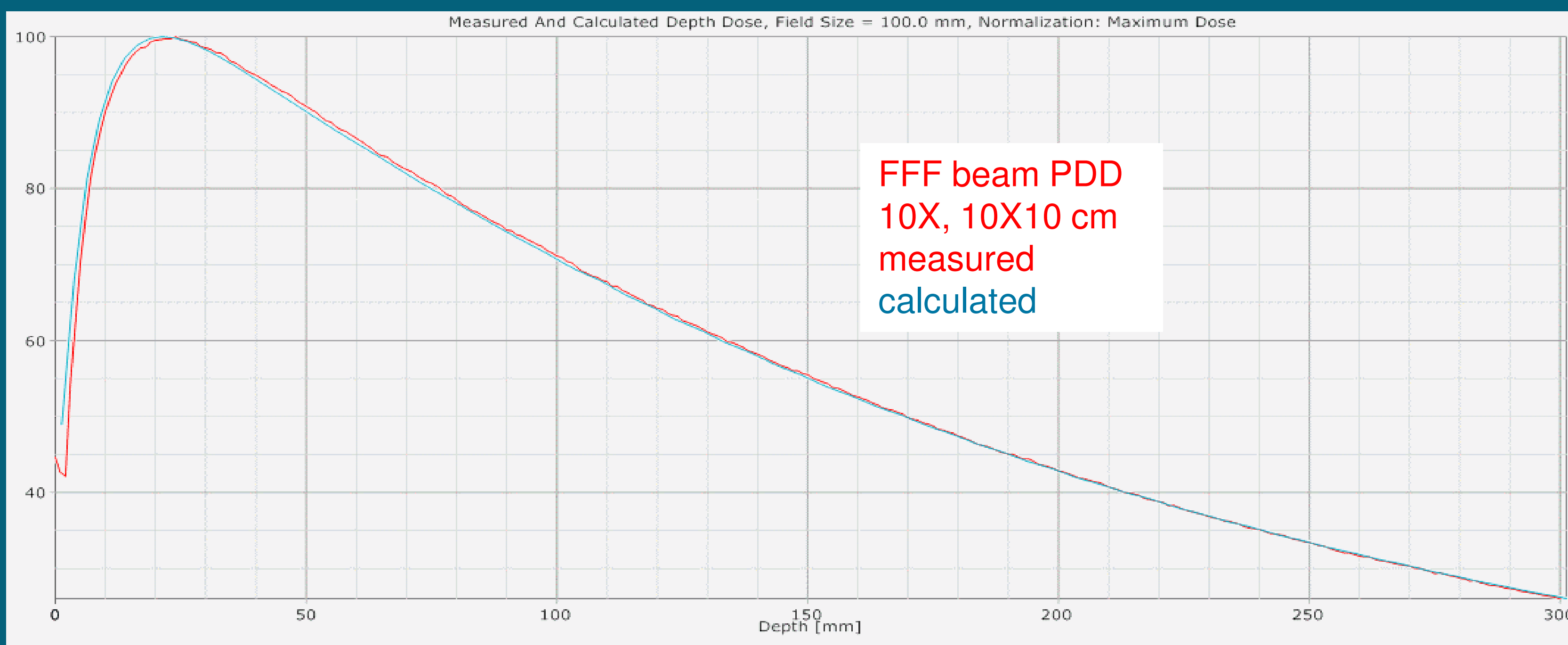
Comparison of measured and Eclipse computed doses



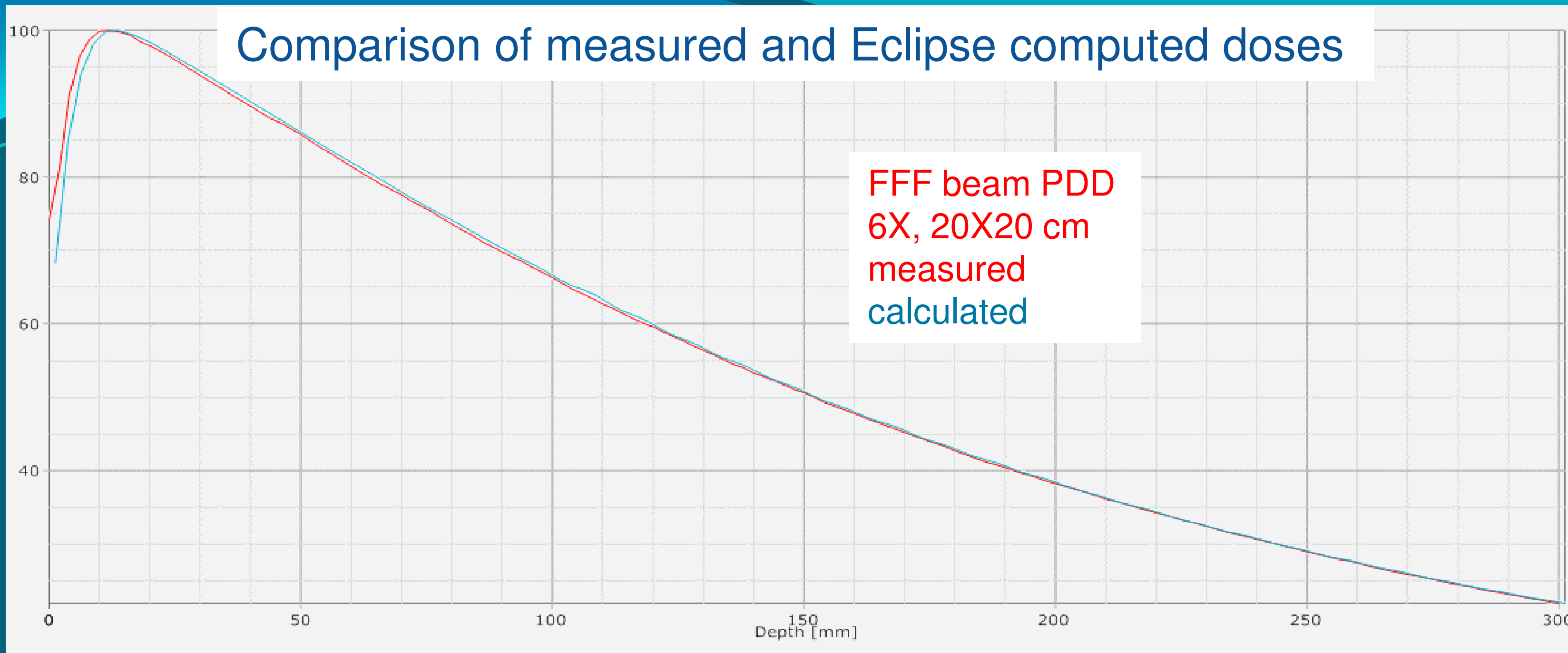


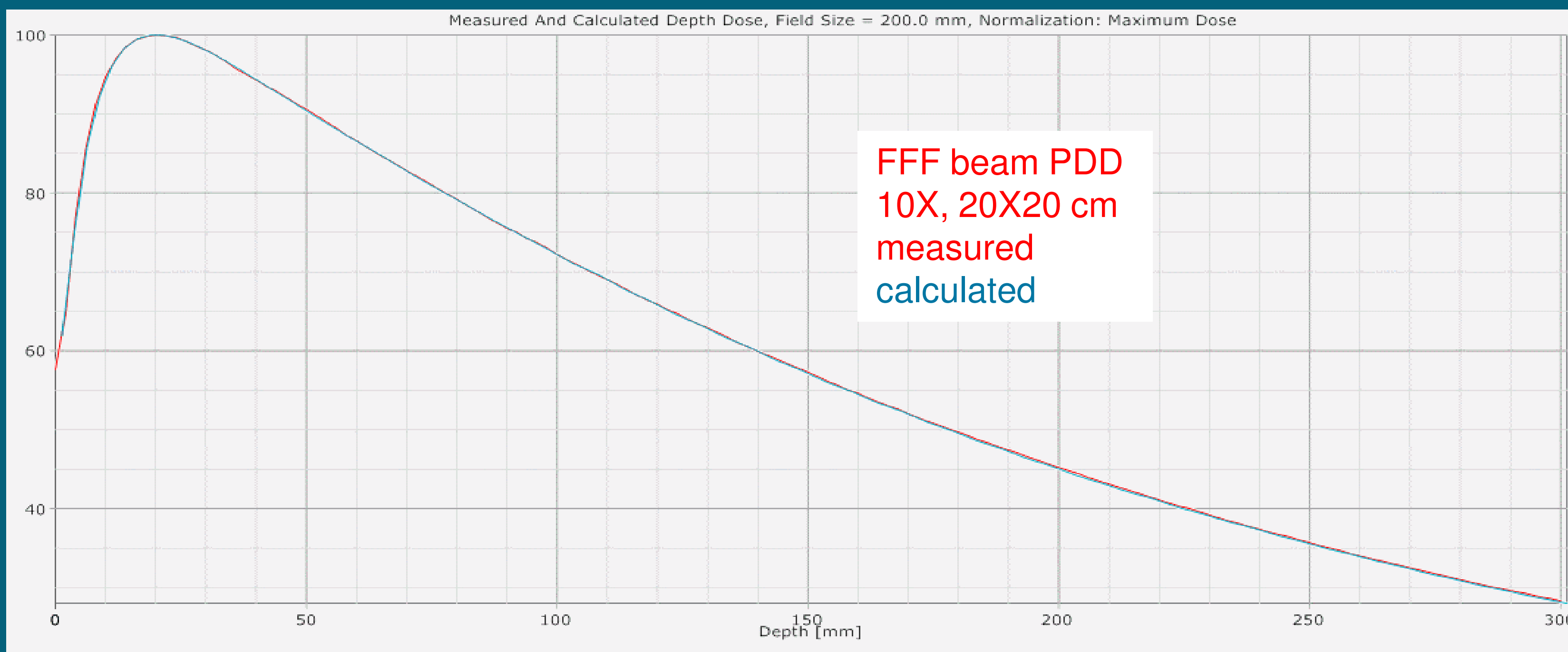
Comparison of measured and Eclipse computed doses



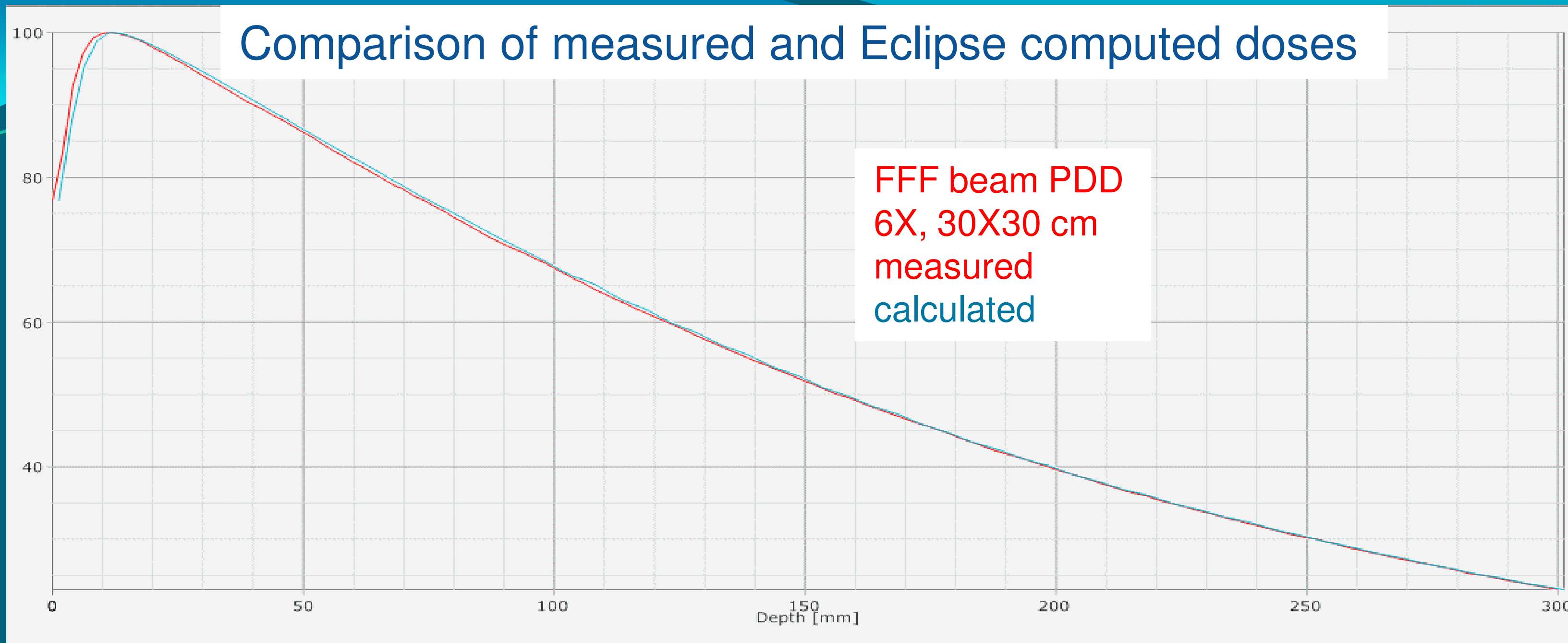


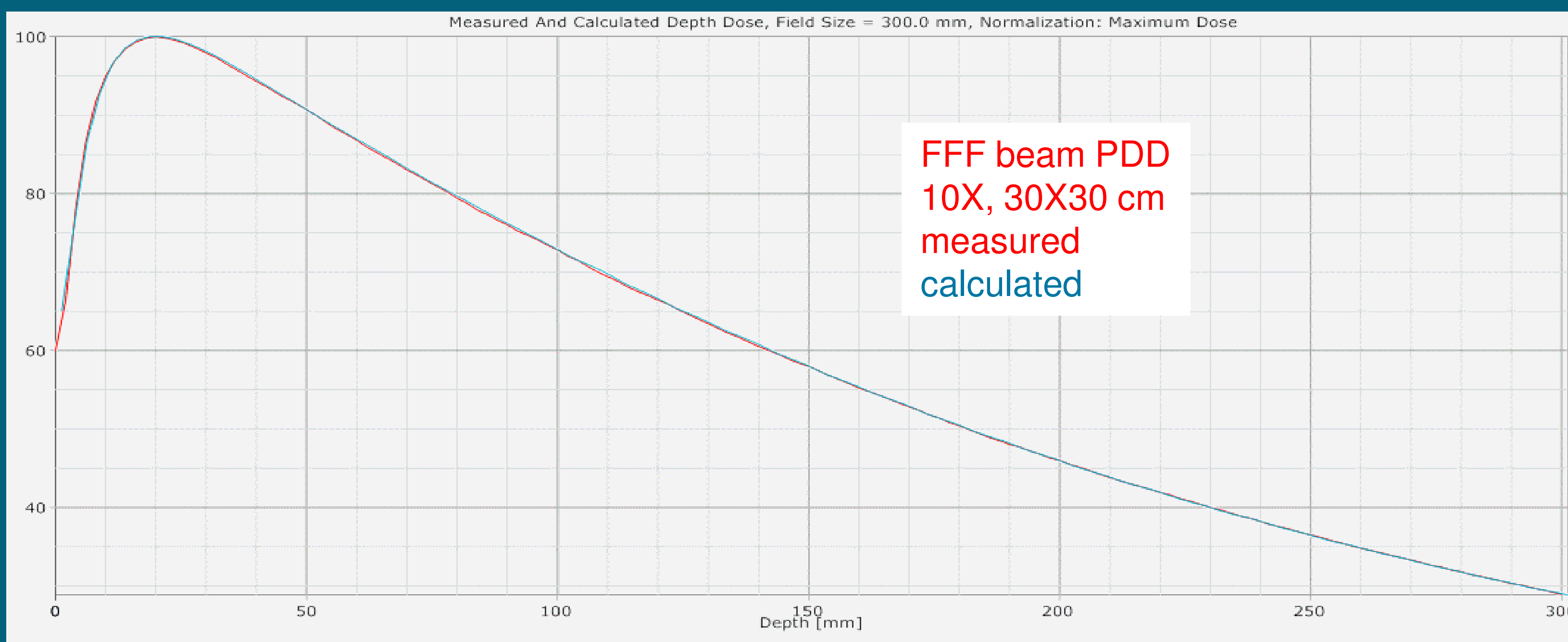
Comparison of measured and Eclipse computed doses





Comparison of measured and Eclipse computed doses



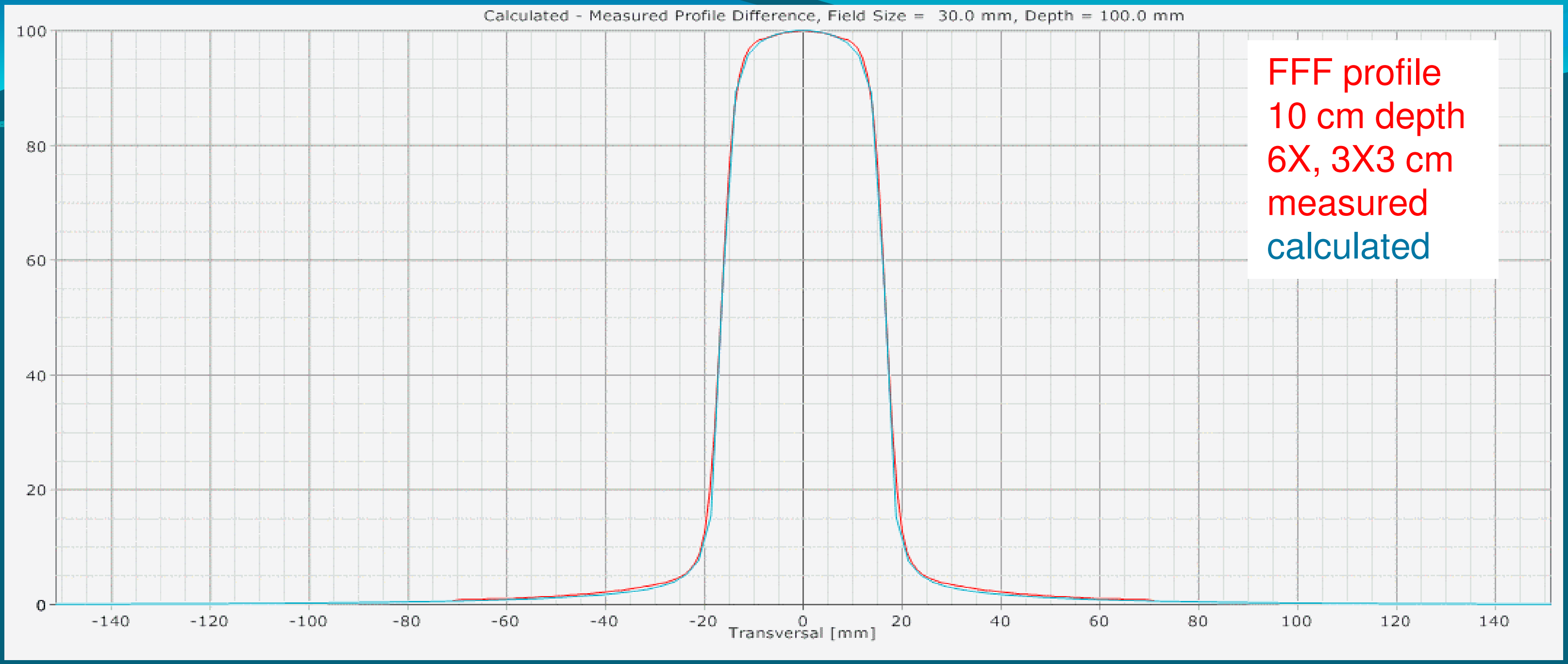


BEAM MODEL VALIDATIONS:

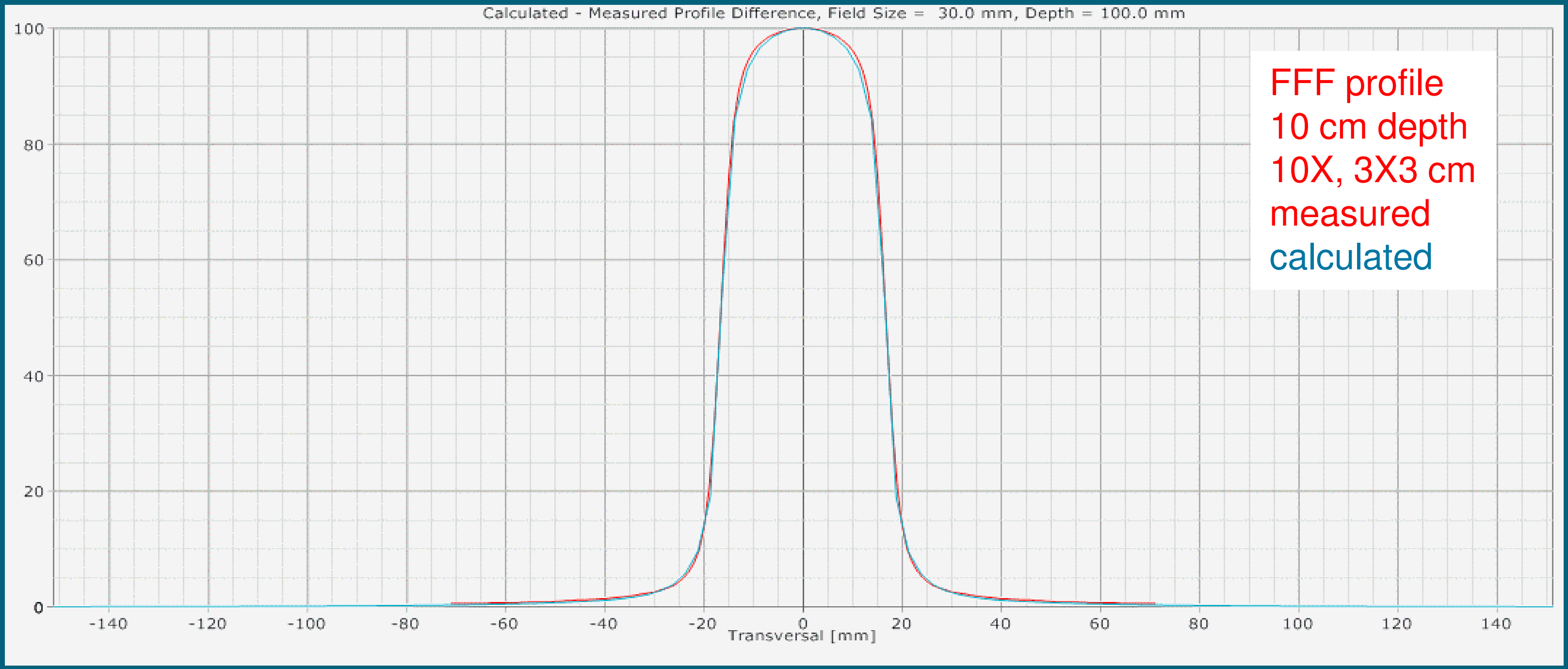
After entering the beam data into a treatment planning computer, Eclipse, one must compare measured and computed data from treatment computer. Often, this important step is either forgotten or skipped by physicists.

This is the final step in commissioning task.

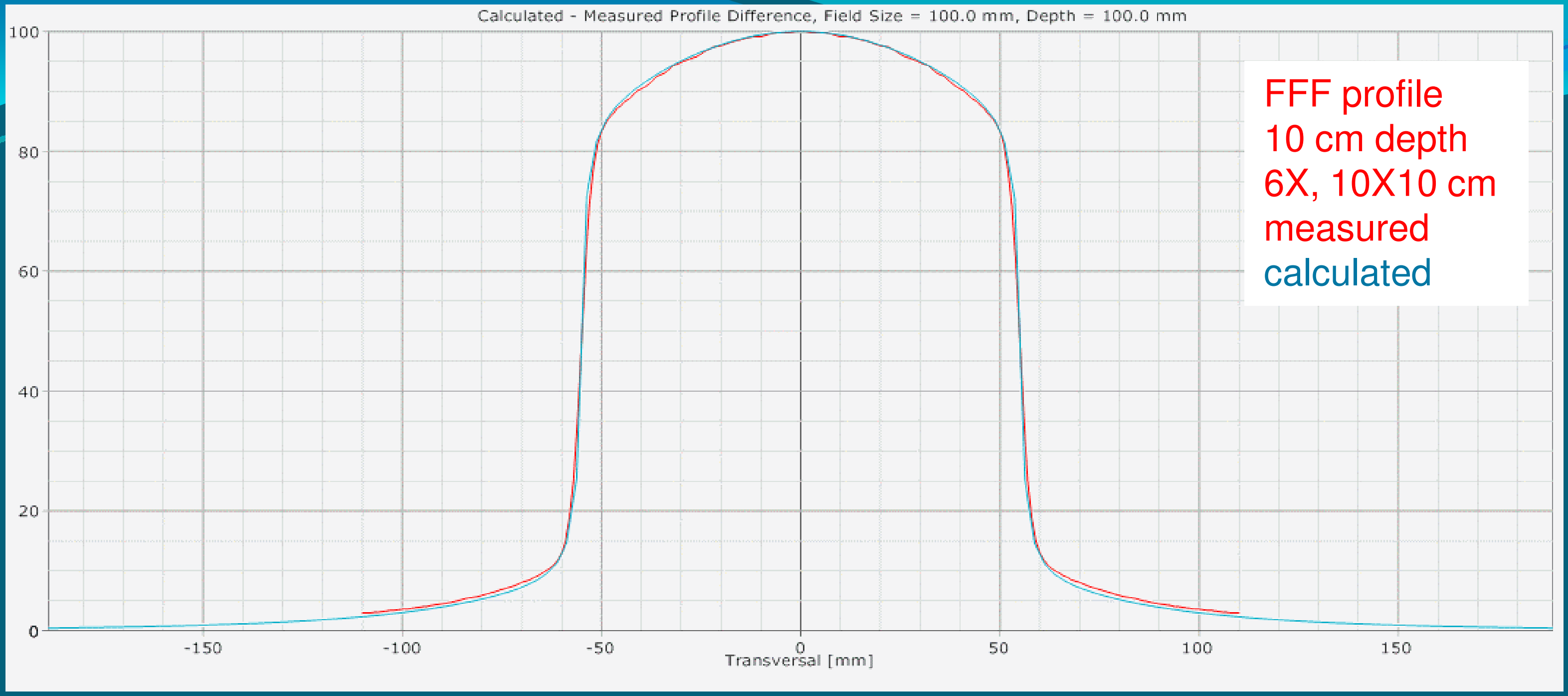
Next, measured and computed *beam profiles* (at 10 cm depth) will be compared.

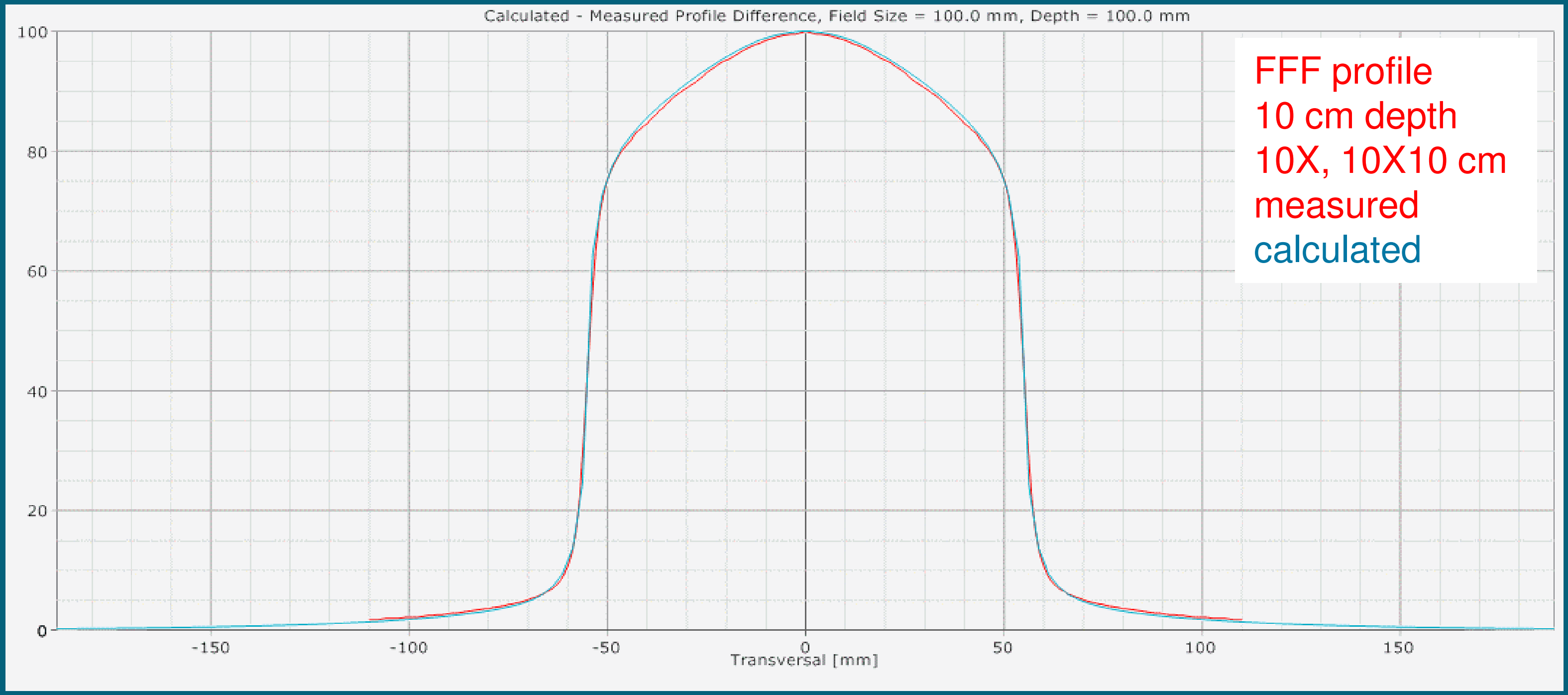


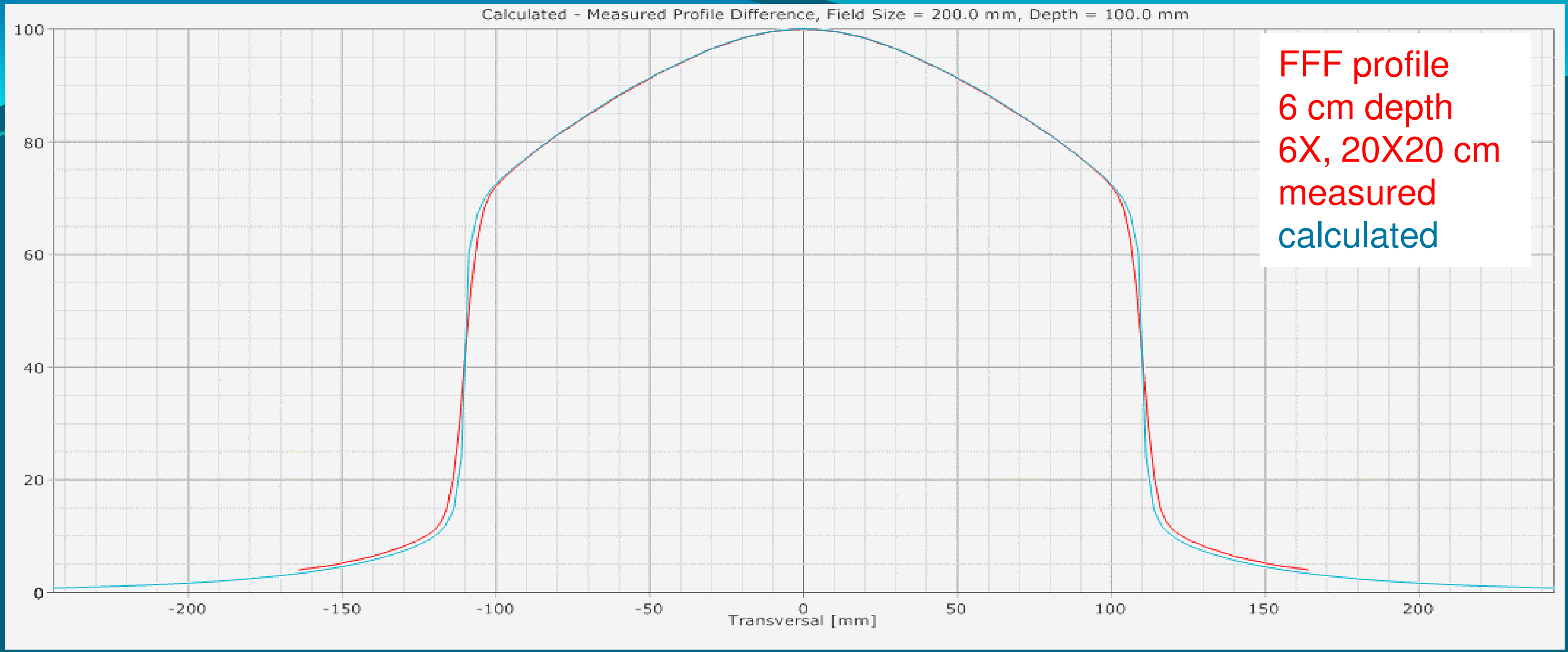
Calculated - Measured Profile Difference, Field Size = 30.0 mm, Depth = 100.0 mm
FFF profile
10 cm depth
6X, 3X3 cm
measured
calculated
100
80
60
40
20
0
-140
-120
-100
-80
-60
-40
-20
0
20
40
60
80
100
120
140
Transversal [mm]



Calculated - Measured Profile Difference, Field Size = 30.0 mm, Depth = 100.0 mm
FFF profile
10 cm depth
10X, 3X3 cm
measured
calculated
100
80
60
40
20
0
-140
-120
-100
-80
-60
-40
-20
0
20
40
60
80
100
120
140
Transversal [mm]


Calculated - Measured Profile Difference, Field Size = 100.0 mm, Depth = 100.0 mm
100
80
60
40
20
0
-150
-100
-50
0
50
100
150
Transversal [mm]
FFF profile
10 cm depth
6X, 10X10 cm
measured
calculated


Calculated - Measured Profile Difference, Field Size = 100.0 mm, Depth = 100.0 mm
100
80
60
40
20
0
-150
-100
-50
0
50
100
150
Transversal [mm]
FFF profile
10 cm depth
10X, 10X10 cm
measured
calculated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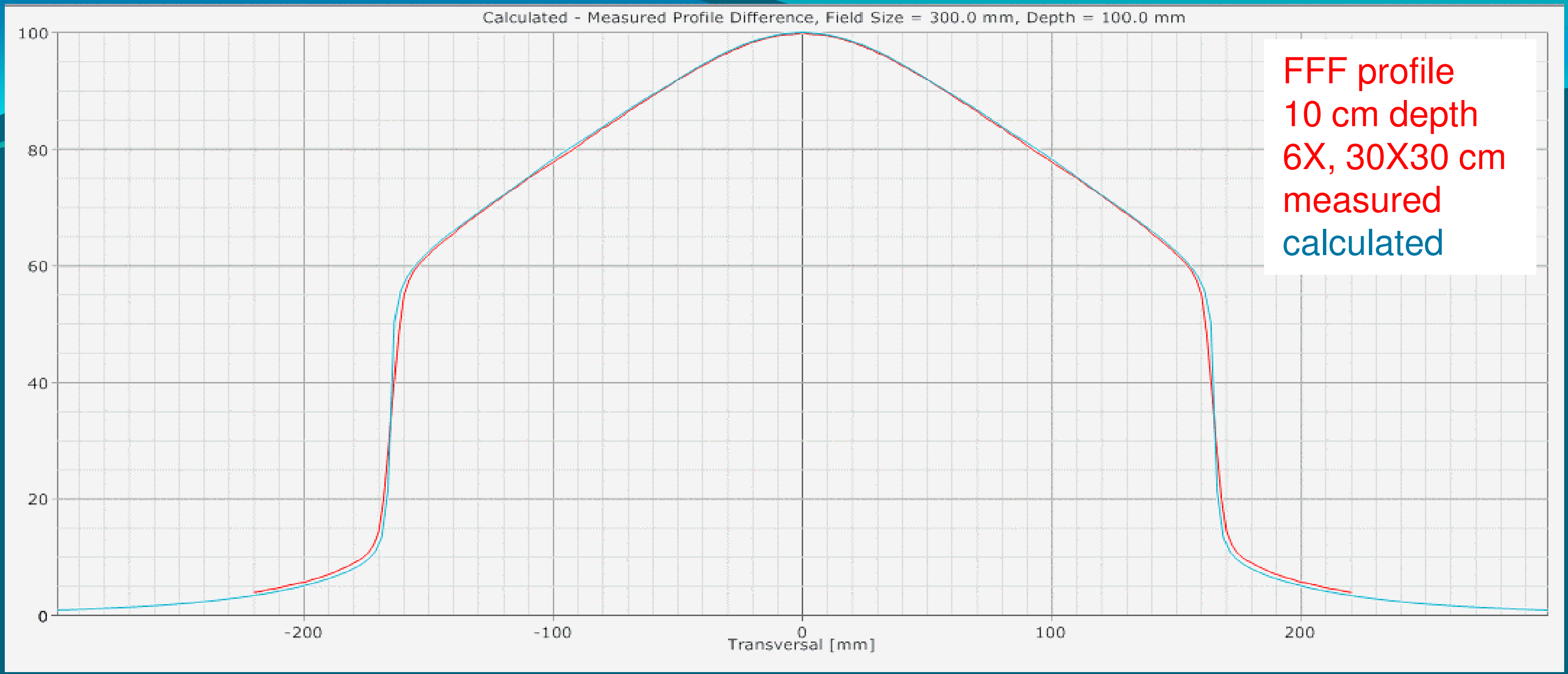
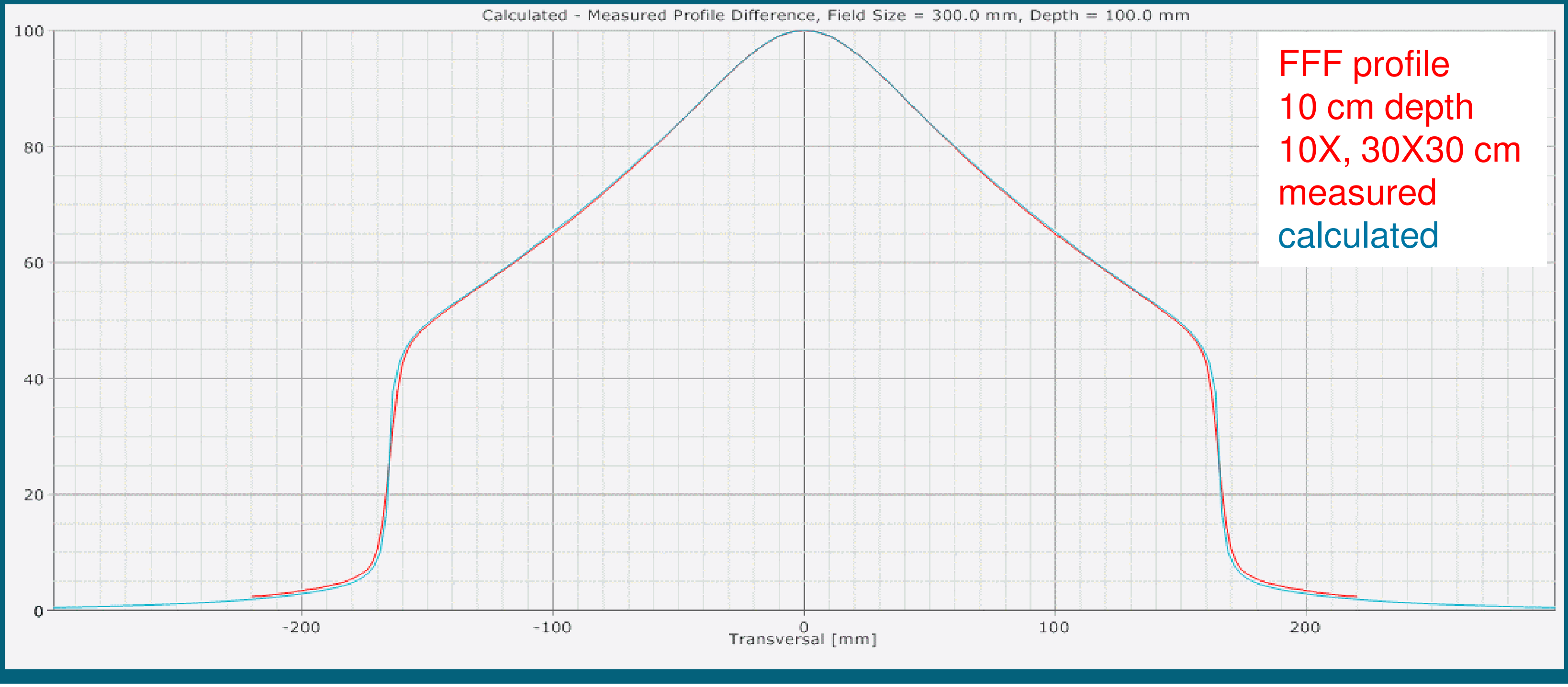
100
80
60
40
20
0
-200
-150
-100
-50
0
50
100
150
200
Transversal [mm]
FFF profile
6 cm depth
6X, 20X20 cm
measured
calculated


Calculated - Measured Profile Difference, Field Size = 200.0 mm, Depth = 100.0 mm
100
80
60
40
20
0
-200
-150
-100
-50
0
50
100
150
200
Transversal [mm]
FFF profile
10 cm depth
10X, 20X20 cm
measured
calculated


Calculated - Measured Profile Difference, Field Size = 300.0 mm, Depth = 100.0 mm
FFF profile
10 cm depth
6X, 30X30 cm
measured
calculated
Transversal [mm]
100
80
60
40
20
0
-200
-100
0
100
200


Calculated - Measured Profile Difference, Field Size = 300.0 mm, Depth = 100.0 mm
FFF profile
10 cm depth
10X, 30X30 cm
measured
calculated
Transversal [mm]
100
80
60
40
20
0
-200
-100
0
100
200

Final step => check the Eclipse output against measurements taken on the linac: output factors, PDD, TMR conversion, wedge profiles, wedge factors, e-beam cone factors, e-beam PDD, and so on. Typically, it is a 10-hour measurement session. This is the final check in commissioning task to discover data entry (human) errors, if any. Surprisingly, this important step is often not done.

6MV X-Rays (AAA beam model)

AAA Beam Model (6 MV X-ray)

Output factors

100 cm SSD field sizes	Measured values	Eclipse values	percent difference
4 X 4	1.077	1.072	0.5%
8 X 8	1.018	1.014	0.4%
10 X 10	1.000	1.000	---
15 X 15	0.970	0.970	0.0%
20 X 20	0.953	0.948	0.5%
25 X 25	0.941	0.936	0.6%
30 X 30	0.932	0.926	0.6%

Percentage Depth Doses

100 cm SSD field 4 X 4	Measured data	Eclipse values	Percent difference
depth 1.6 cm	1.000	1.000	---
depth 5.0 cm	0.845	0.839	0.6%
depth 10.0 cm	0.623	0.618	0.5%
depth 20.0 cm	0.339	0.334	0.5%

100 cm SSD field 8 X 8	Measured data	Eclipse values	Percent difference
depth 1.6 cm	1.000	1.000	---

depth 5.0 cm	0.863	0.858	0.5%
depth 10.0 cm	0.658	0.653	0.5%
depth 20.0 cm	0.371	0.370	0.1%

100 cm SSD field 10 X 10	Measured data	Eclipse values	Percent difference
depth 1.6 cm	1.000	1.000	---
depth 5.0 cm	0.868	0.864	0.4%
depth 10.0 cm	0.669	0.667	0.2%
depth 20.0 cm	0.384	0.385	-0.1%

Percentage Depth Doses

100 cm SSD field 15 X 15	Measured data	Eclipse values	Percent difference
depth 1.6 cm	1.000	1.000	---
depth 5.0 cm	0.873	0.871	0.2%
depth 10.0 cm	0.687	0.687	0.0%
depth 20.0 cm	0.408	0.410	-0.2%

100 cm SSD field 20 X 20	Measured data	Eclipse values	Percent difference
depth 1.6 cm	1.000	1.000	---
depth 5.0 cm	0.877	0.875	0.2%
depth 10.0 cm	0.698	0.698	0.0%
depth 20.0 cm	0.424	0.424	0.0%

100 cm SSD field 25 X 25	Measured data	Eclipse values	Percent difference
depth 1.6 cm	1.000	1.000	---

If this final step is not completed, (human) errors could result in errors in data entry into TPS; and these (systemic) errors may not be discovered for many years.

Physical wedges

Wedge factors (at 5 cm depth)			
95 cm SSD wedge angle	Measured values	Eclipse values	percent difference
15W	1.408	1.408	0.0%
30W	1.813	1.813	0.0%
45W	2.035	2.035	0.0%
60W	2.476	2.476	0.0%

Off axis at +5 cm (at 5 cm depth)			
95 cm SSD wedge angle	Measured values	Eclipse values	percent difference
15W	0.930	0.931	-0.1%
30W	0.865	0.866	-0.1%
45W	0.808	0.818	-1.3%
60W	0.698	0.702	-0.5%

Off axis at -5 cm (at 5 cm depth)			
95 cm SSD wedge angle	Measured values	Eclipse values	percent difference
15W	1.066	1.070	-0.4%
30W	1.141	1.141	0.0%
45W	1.239	1.248	-0.7%
60W	1.510	1.518	-0.5%

Enhanced dynamic wedge factors

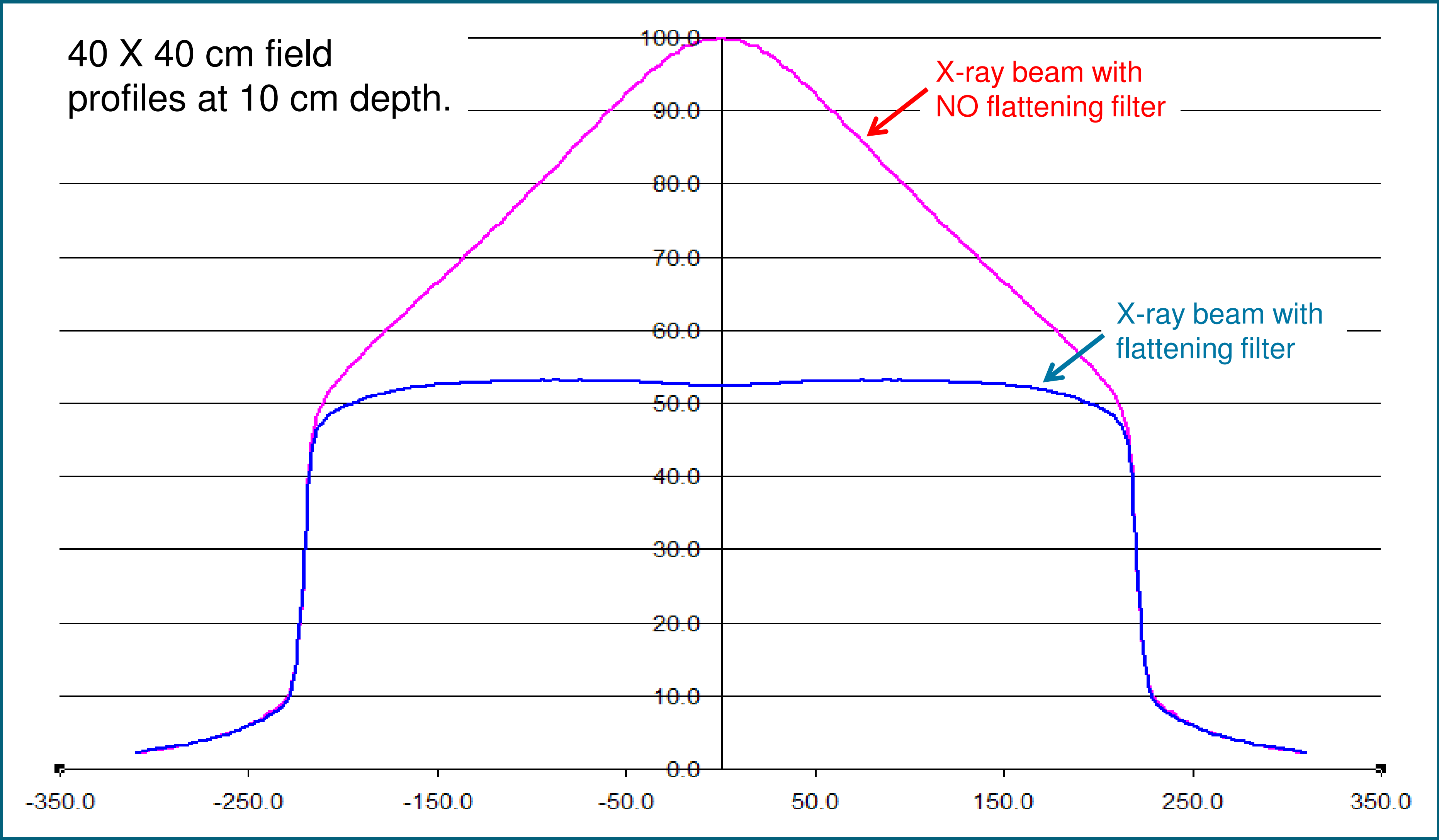
Enhanced dynamic wedge factors			
95 cm SSD wedge angle	Measured values	Eclipse values	percent difference
EDW 10	1.144	1.142	0.2%
EDW 15	1.219	1.215	0.3%
EDW 20	1.297	1.293	0.3%
EDW 25	1.380	1.375	0.4%
EDW 30	1.470	1.464	0.4%
EDW 45	1.811	1.804	0.4%
EDW 60	2.400	2.391	0.4%

Enhanced dynamic wedge factors

Off axis at +5 cm (at 5 cm depth)			
95 cm SSD wedge angle	Measured values	Eclipse values	percent difference
EDW 10	1.074	1.076	-0.2%
EDW 15	1.105	1.106	-0.1%
EDW 20	1.138	1.138	0.0%
EDW 25	1.173	1.172	0.1%
EDW 30	1.210	1.209	0.1%
EDW 45	1.352	1.349	0.2%
EDW 60	1.597	1.591	0.4%

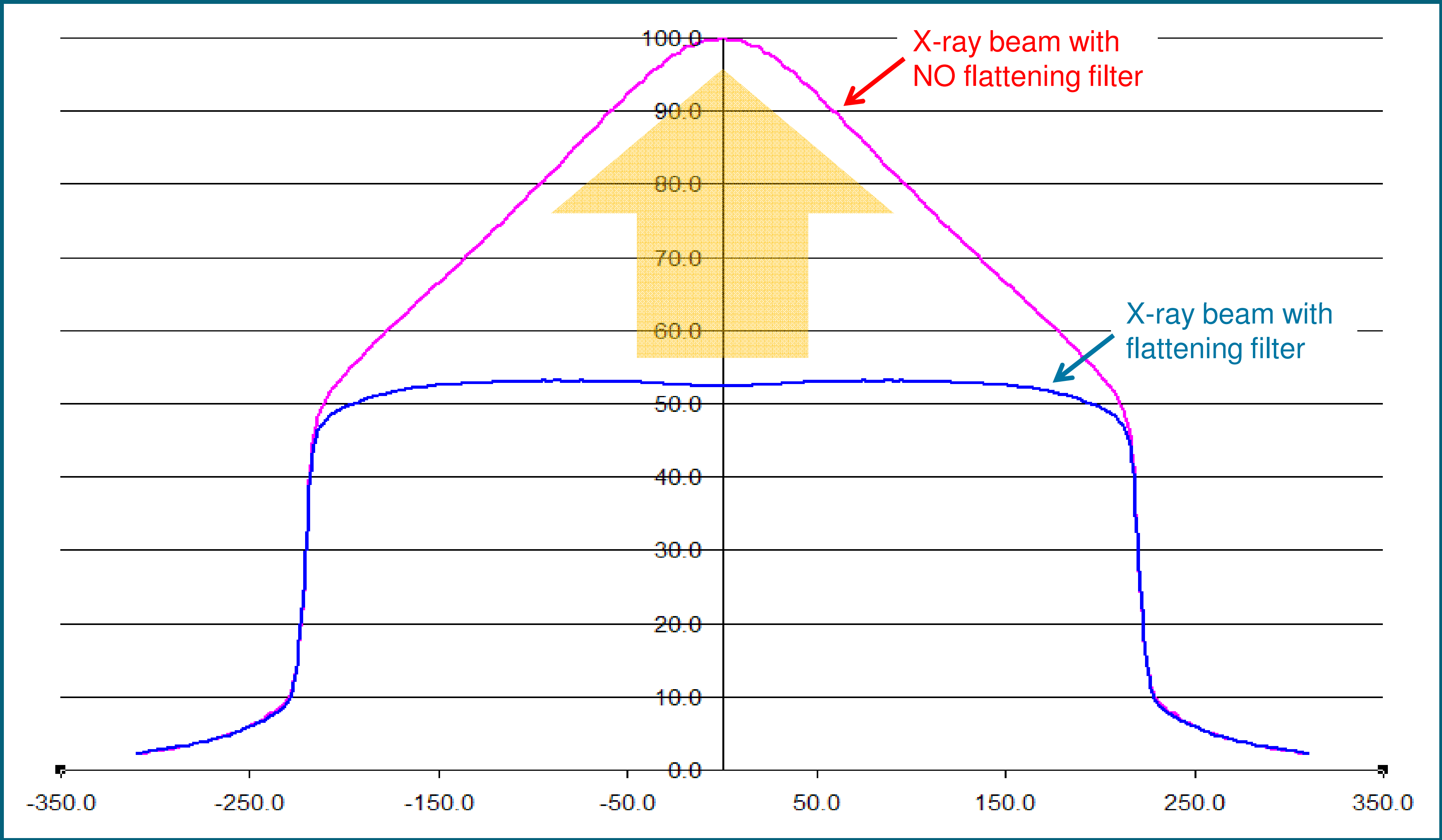
Off axis at -5 cm (at 5 cm depth)

FFF X-ray profile graphed against the flat (conventional) beam profile. RED is the Flattening Filter Free beam profile, BLUE is the flattened (conventional) beam profile. These two profiles are normalized to the physical field edge.

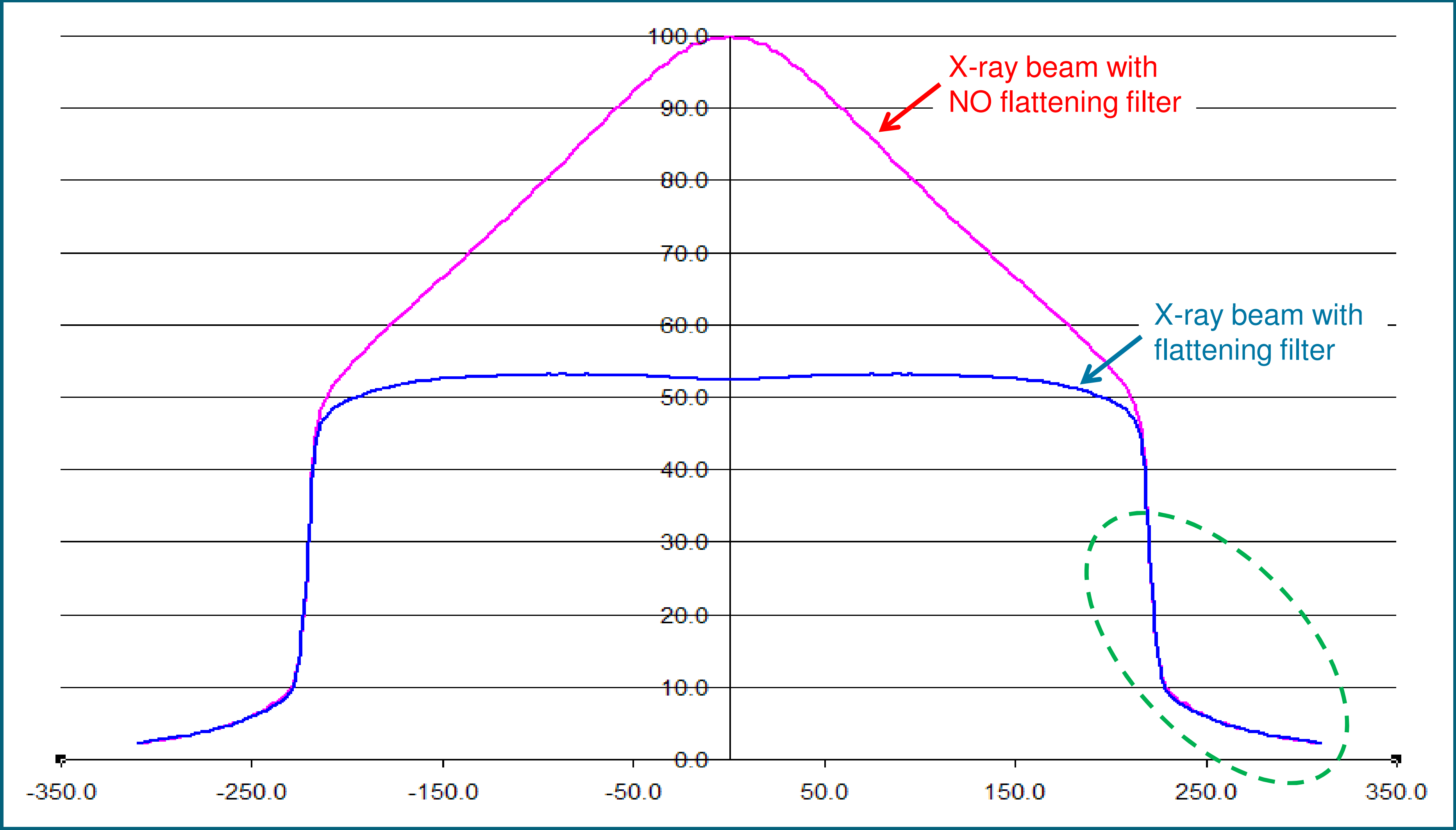


By removing the flattening filter, these beam parameters are affected:

- Beam profile
- Effective beam energy
- Dose rate
- Head leakage (more efficient use of photons)
- Neutron production (more efficient use of photons)
- Beam steering and feed back



If one normalizes these 2 profile curves properly, there is no difference at the penumbra or “off-field” radiation between FFF and flattened (conventional) beam profiles.

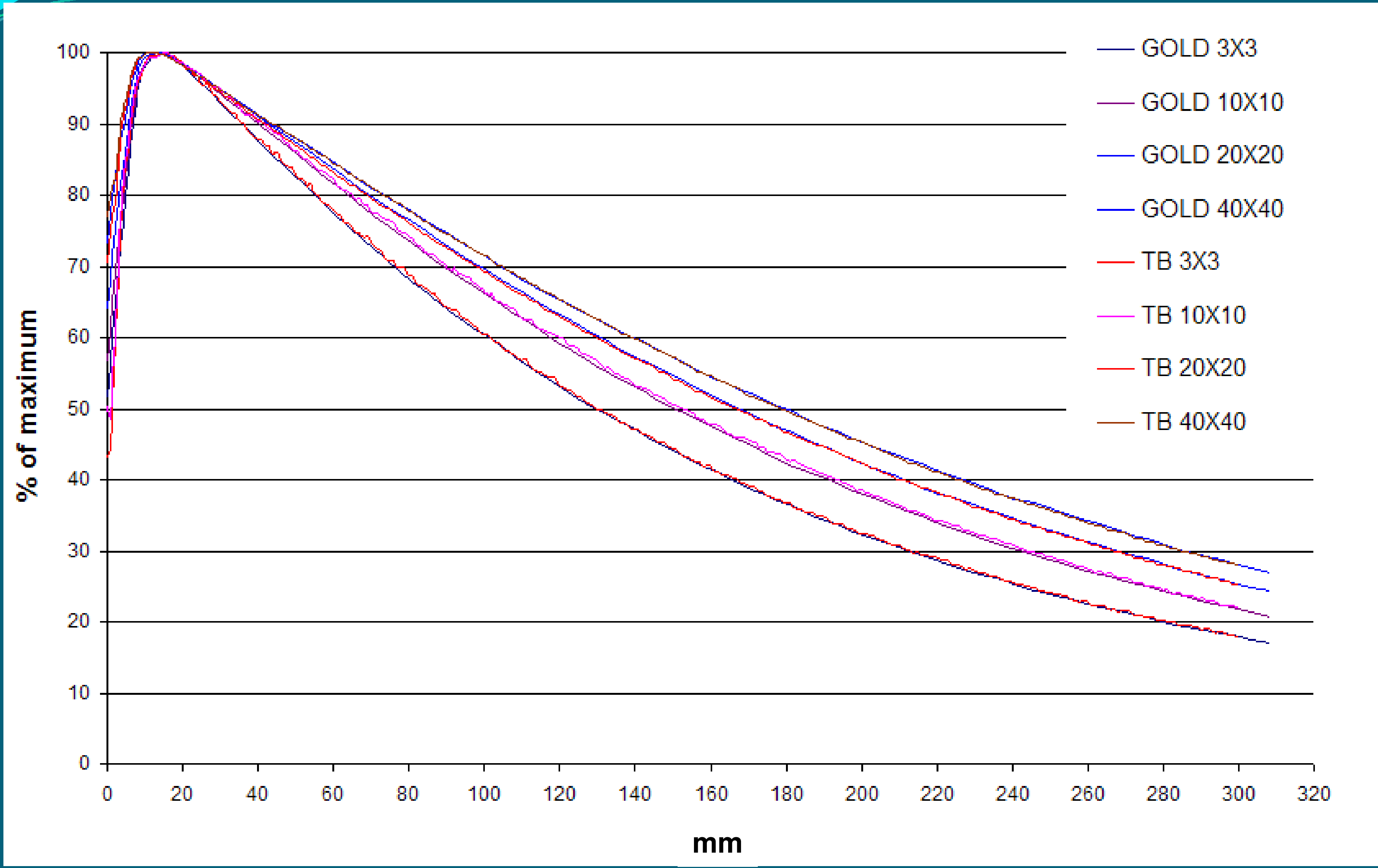


Percentage Depth Dose and Profile comparisons

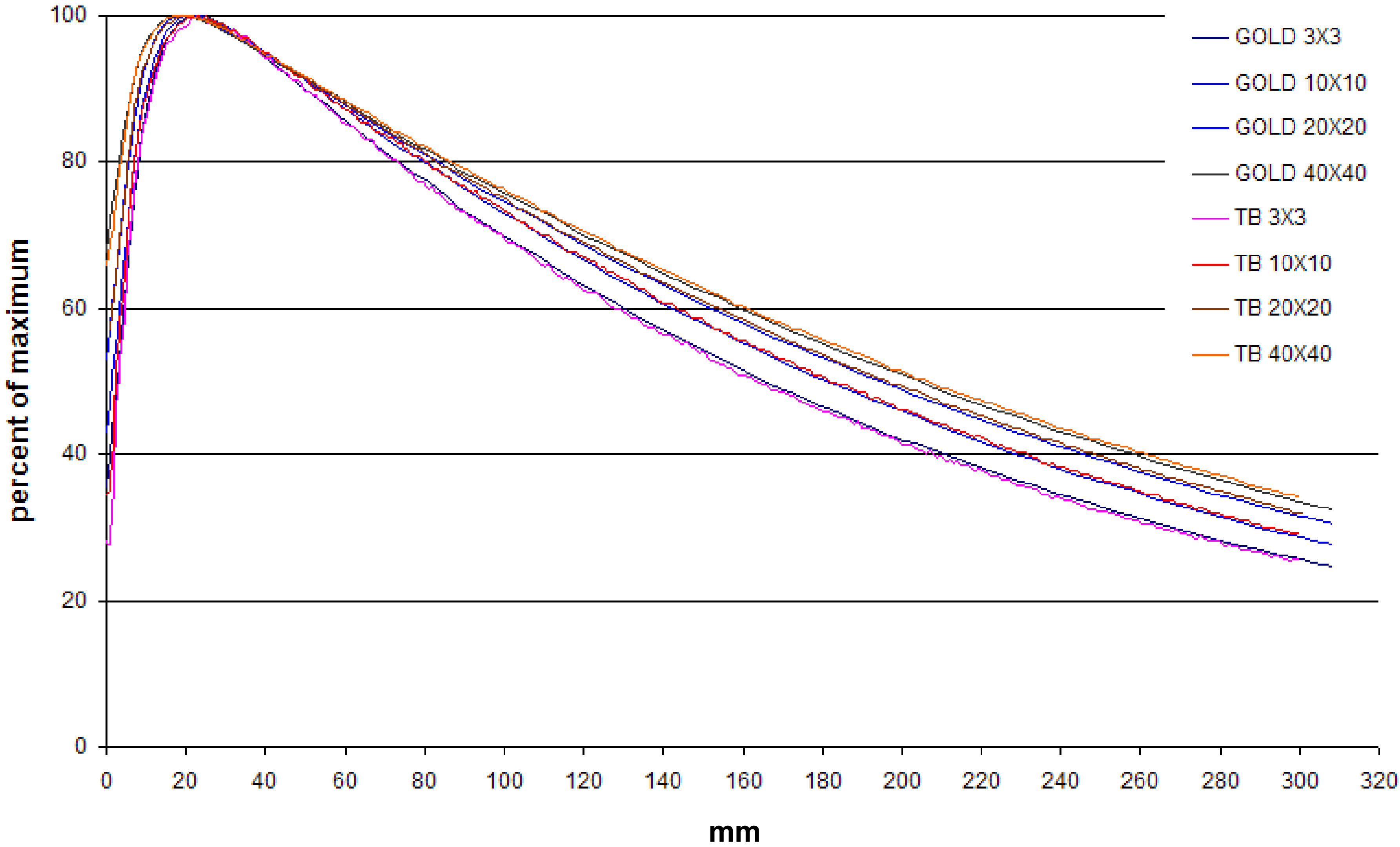
between

scanned data (SN 1008) and ***Gold Beam*** data

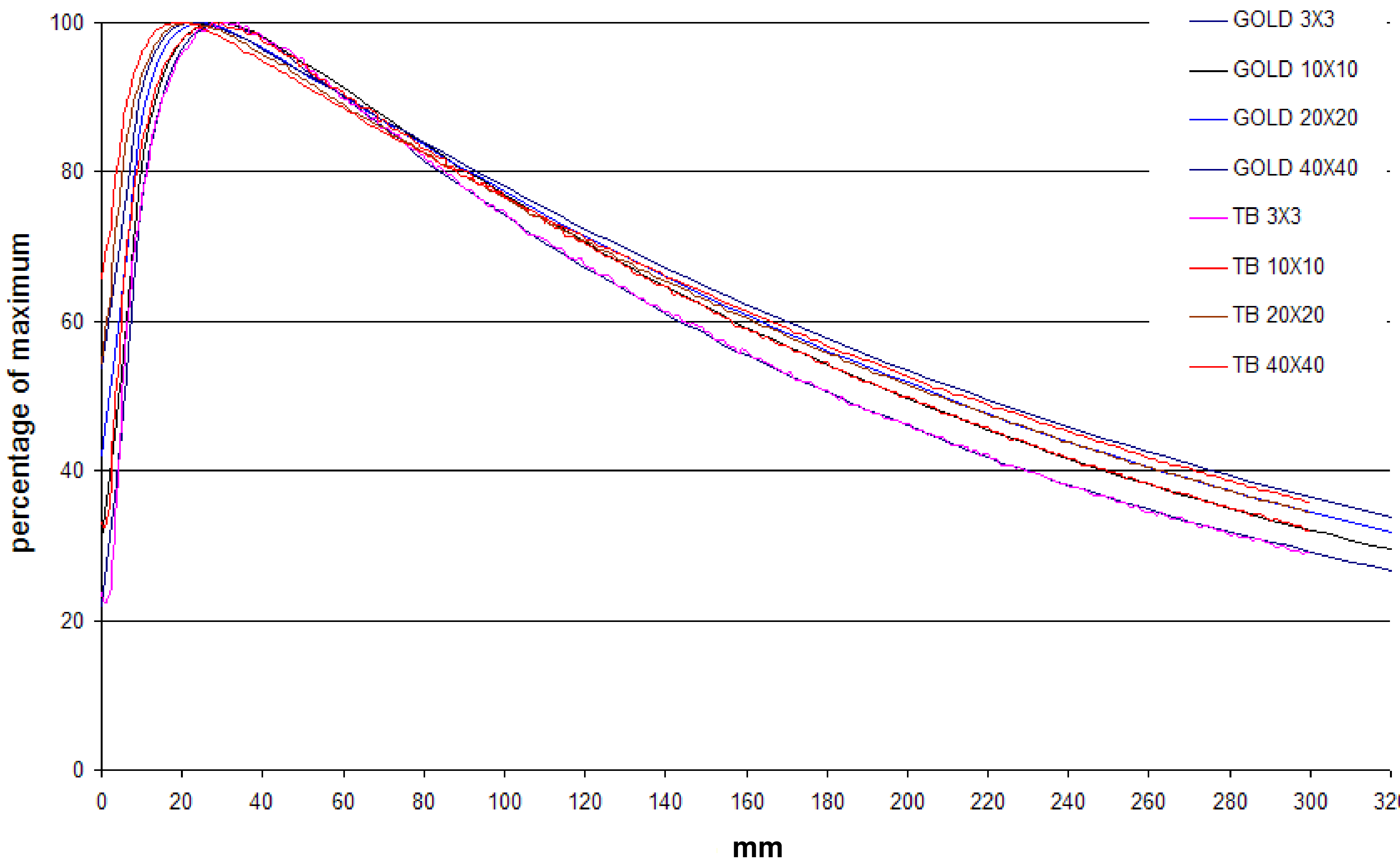
Comparison of GOLD BEAM and TrueBEAM 6X PDD data



Comparison of GOLD BEAM and TrueBEAM 10X PDD data



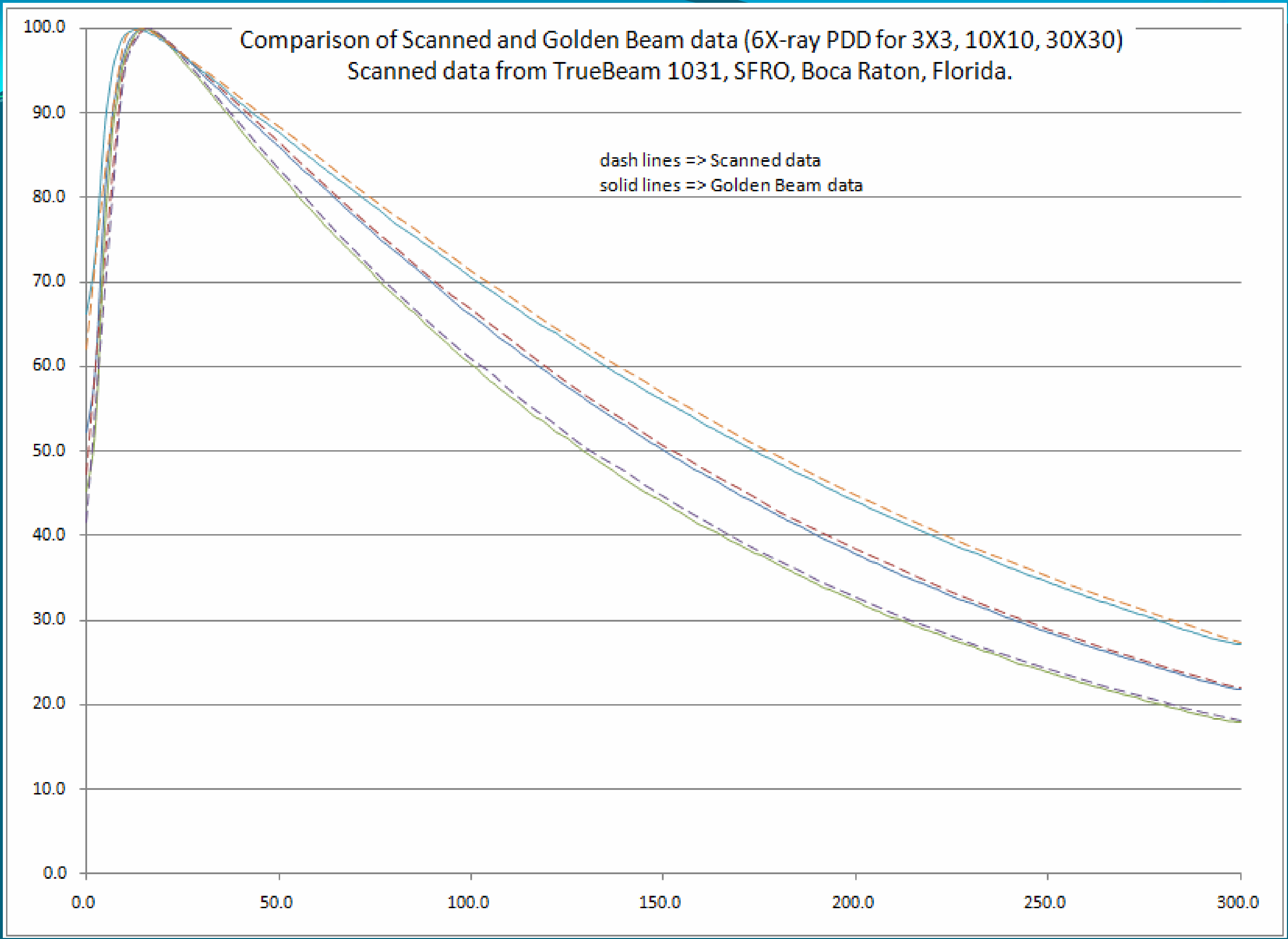
Comparison of GOLD BEAM and TrueBEAM 15X PDD data



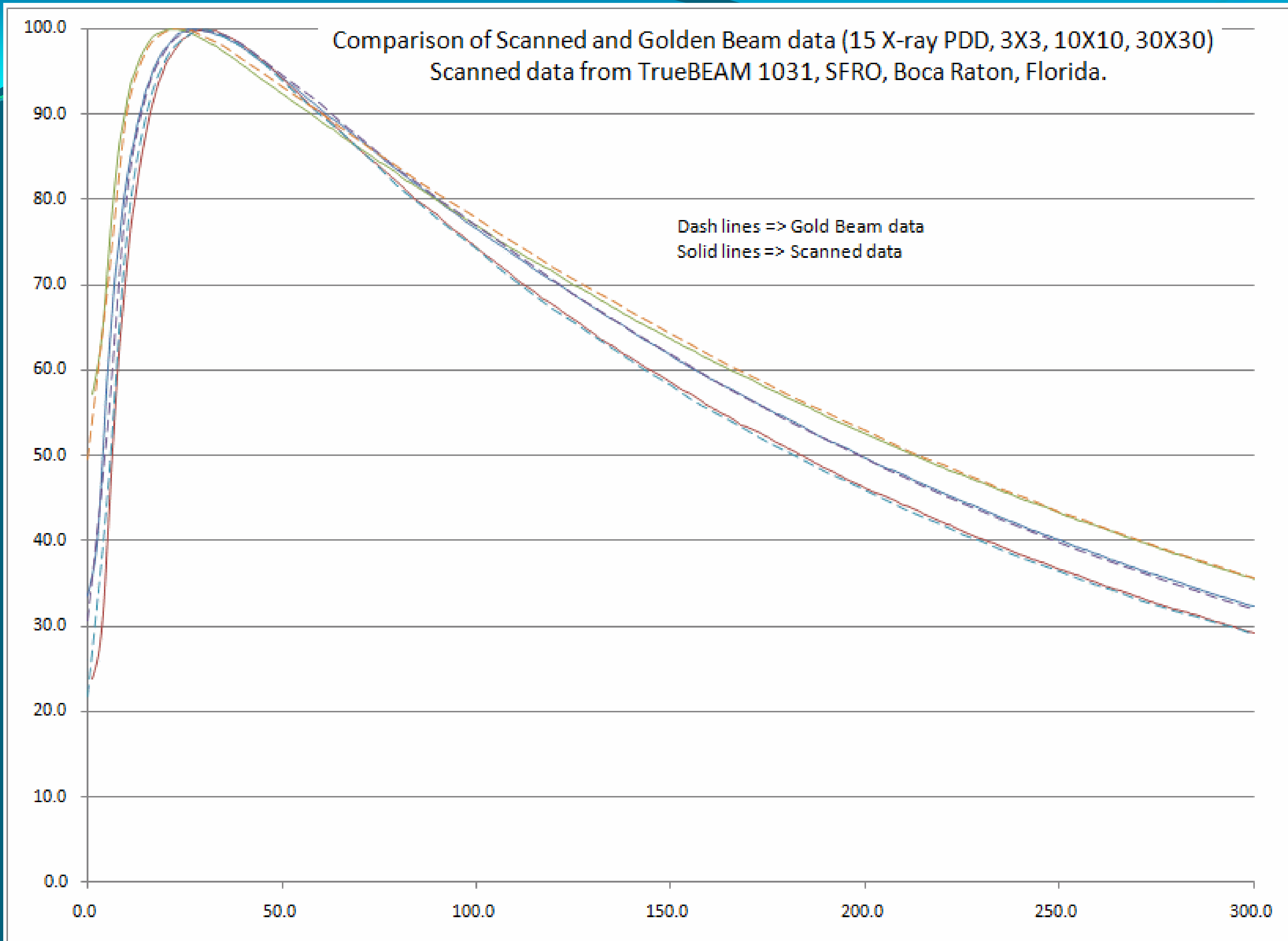
Percentage Depth Dose and Profile comparisons

between

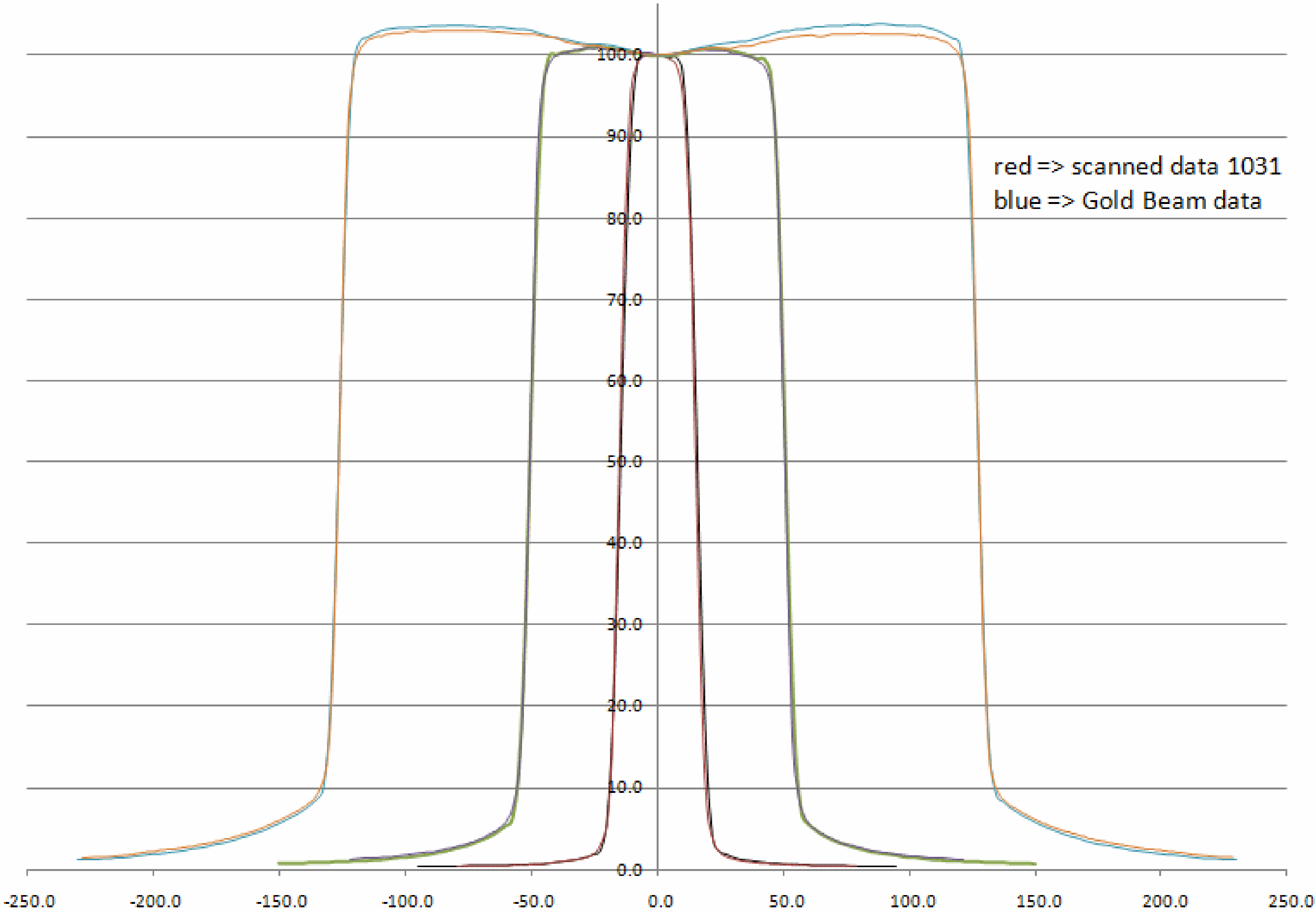
scanned data (SN 1031) and ***Gold Beam*** data

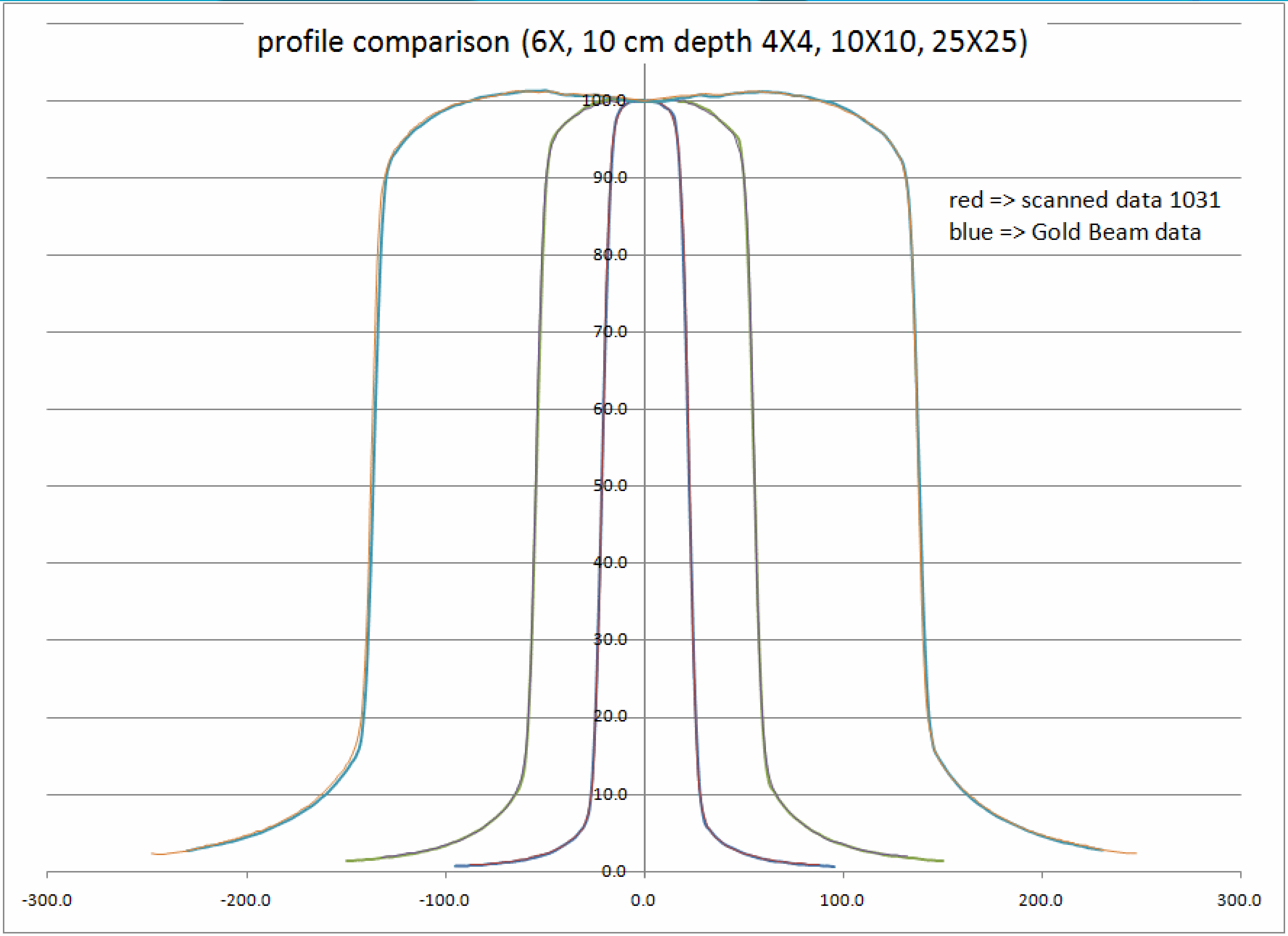


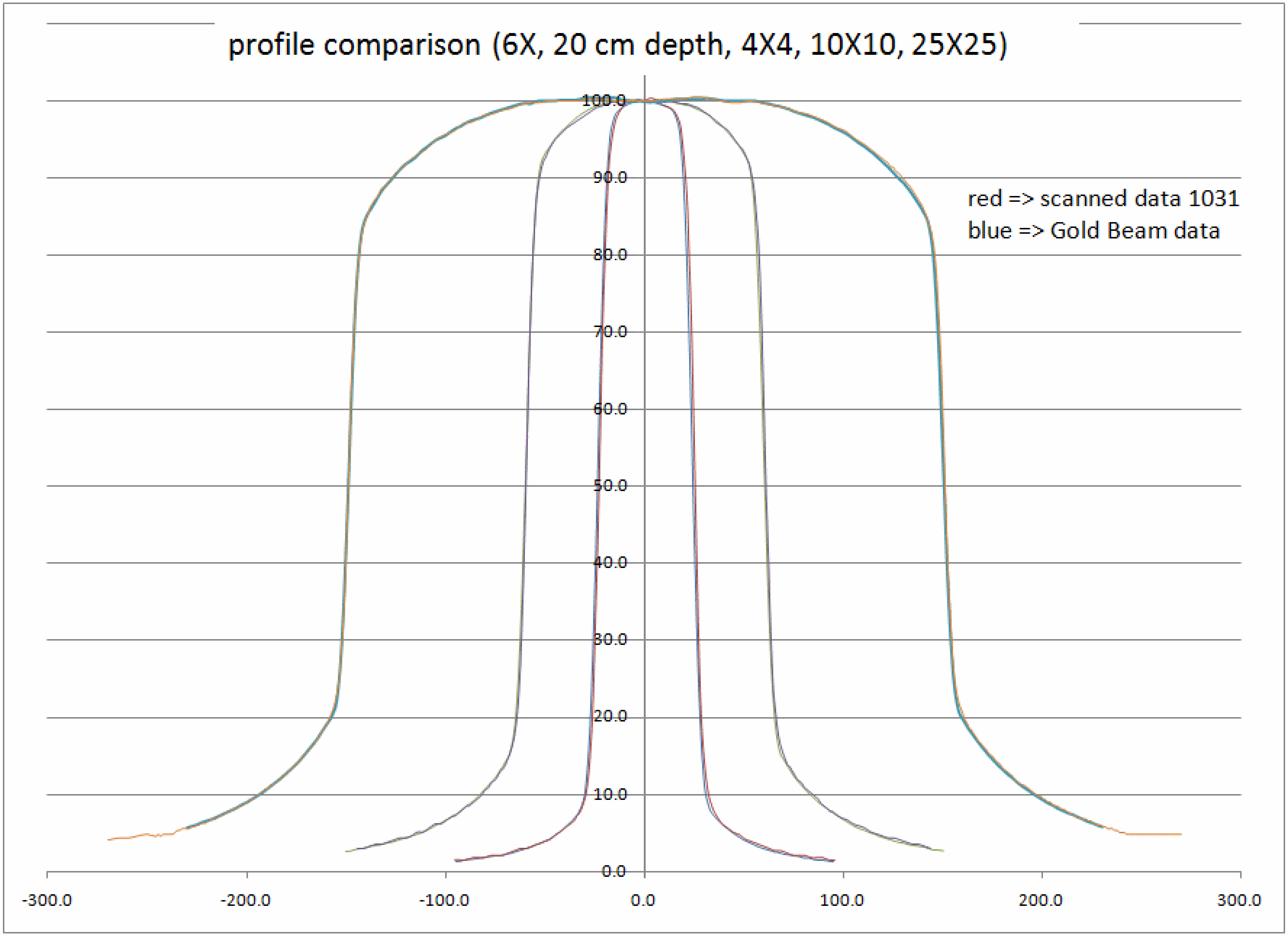
Comparison of Scanned and Golden Beam data (6X-ray PDD for 3X3, 10X10, 30X30)
Scanned data from TrueBeam 1031, SFRO, Boca Raton, Florida.
dash lines => Scanned data
solid lines => Golden Beam data
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.0
50.0
100.0
150.0
200.0
250.0
300.0


Comparison of Scanned and Golden Beam data (15 X-ray PDD, 3X3, 10X10, 30X30)
Scanned data from TrueBEAM 1031, SFRO, Boca Raton, Florida.
Dash lines => Gold Beam data
Solid lines => Scanned data
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.0
50.0
100.0
150.0
200.0
250.0
300.0

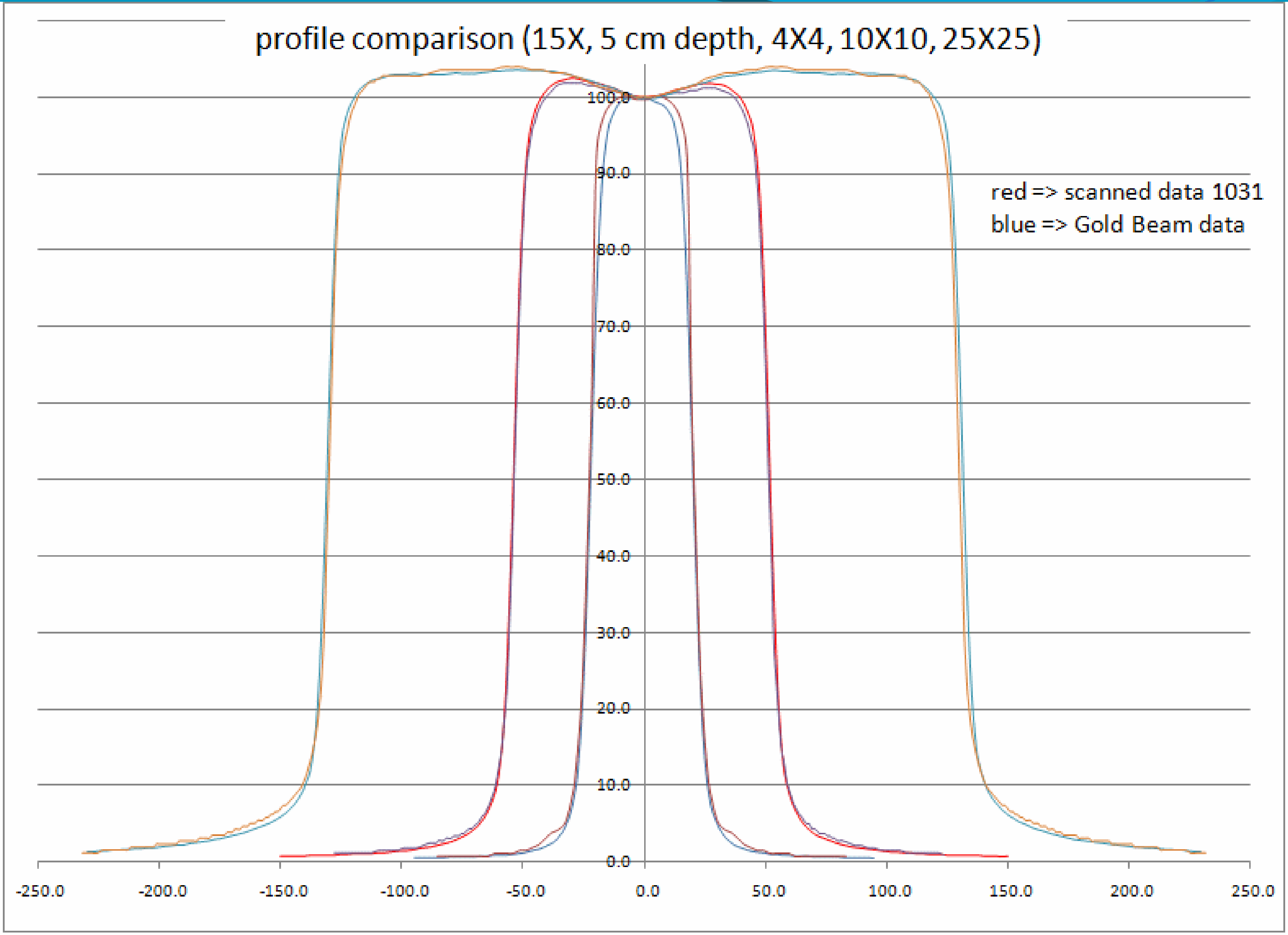
profile comparison (6X, Dmax, 4X4, 10X10, 25X25)

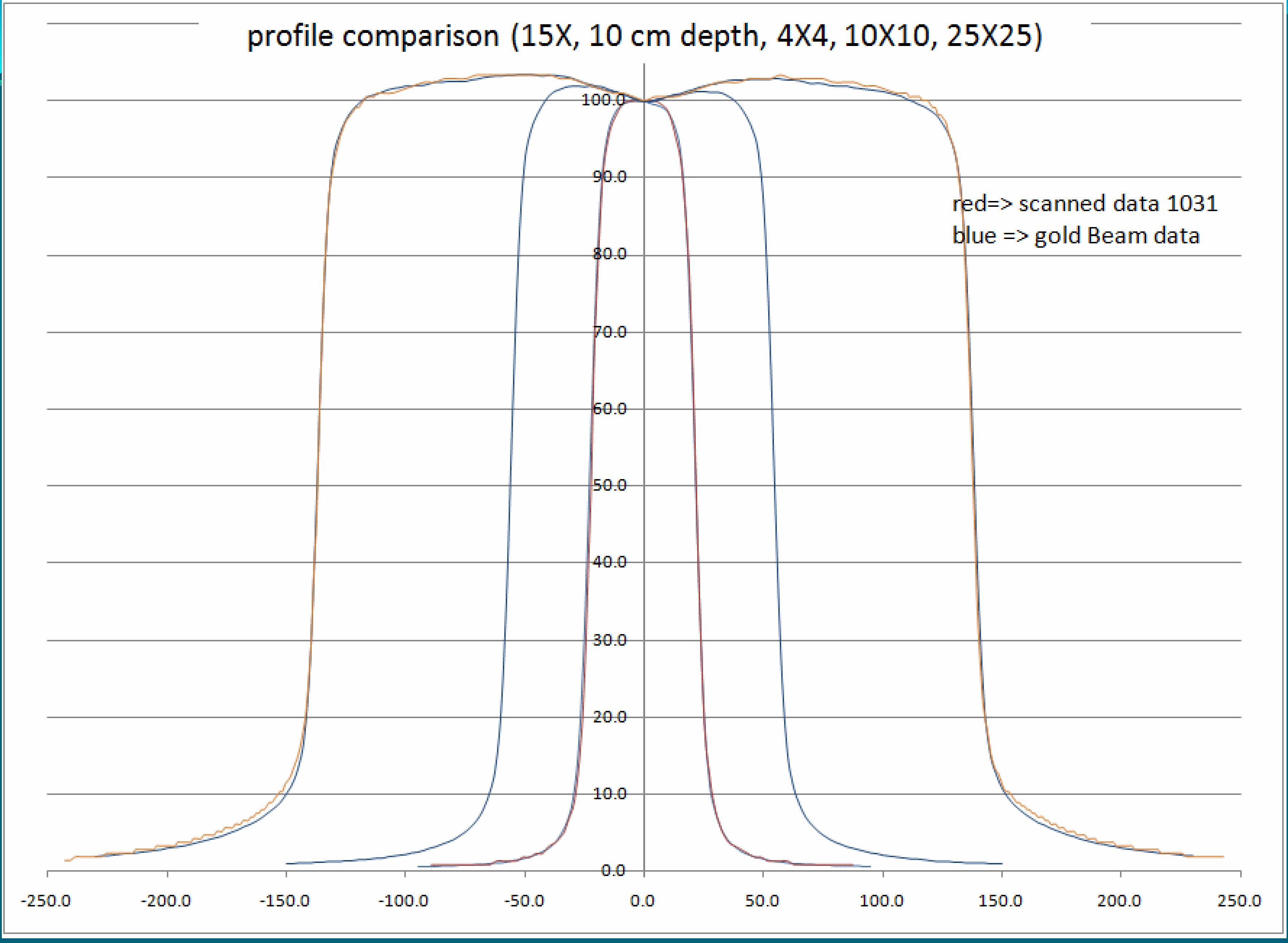



profile comparison (6X, 10 cm depth 4X4, 10X10, 25X25)
red => scanned data 1031
blue => Gold Beam data
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-300.0
-200.0
-100.0
0.0
100.0
200.0
300.0

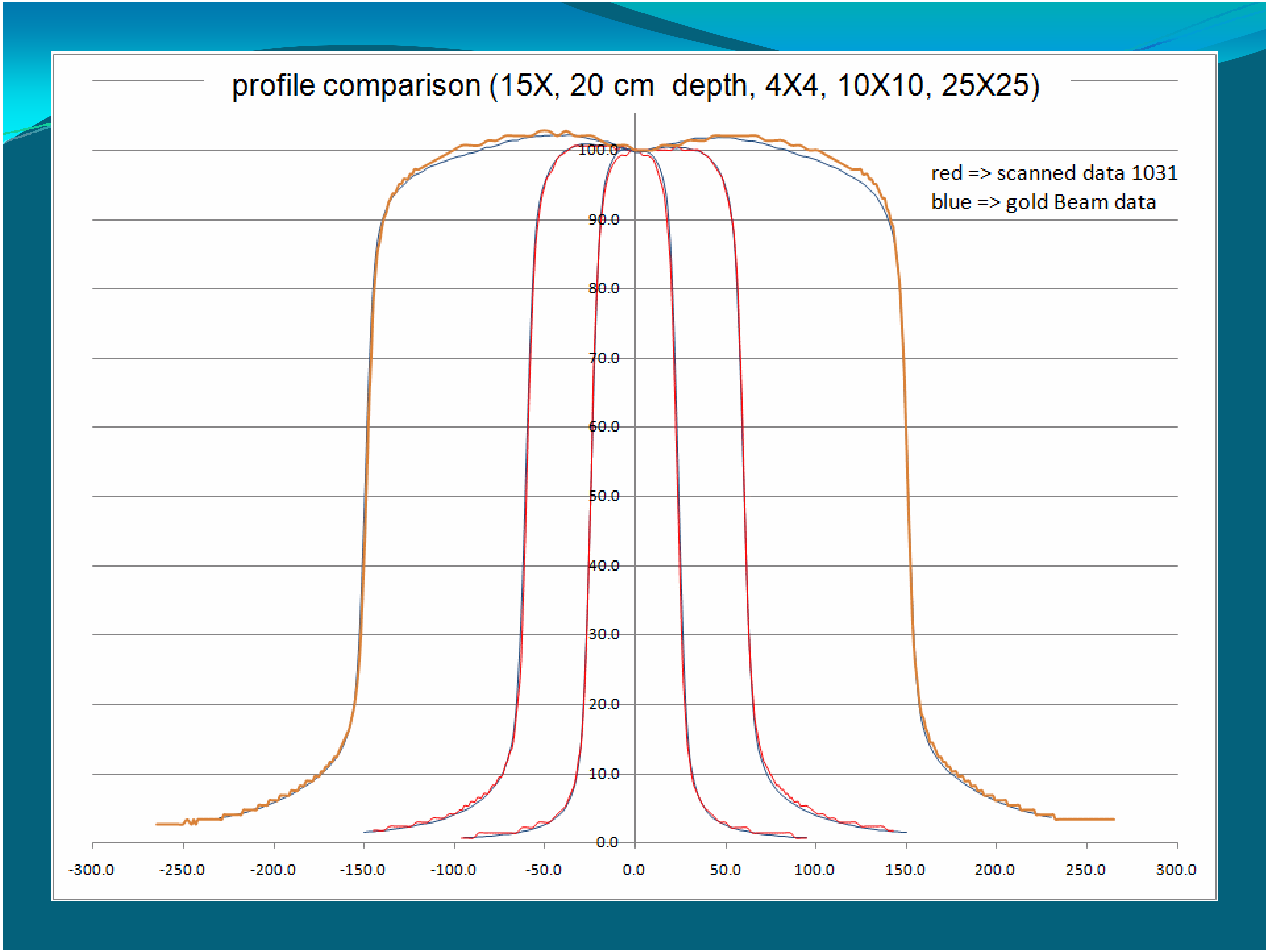


profile comparison (6X, 20 cm depth, 4X4, 10X10, 25X25)
red => scanned data 1031
blue => Gold Beam data
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-300.0
-200.0
-100.0
0.0
100.0
200.0
300.0

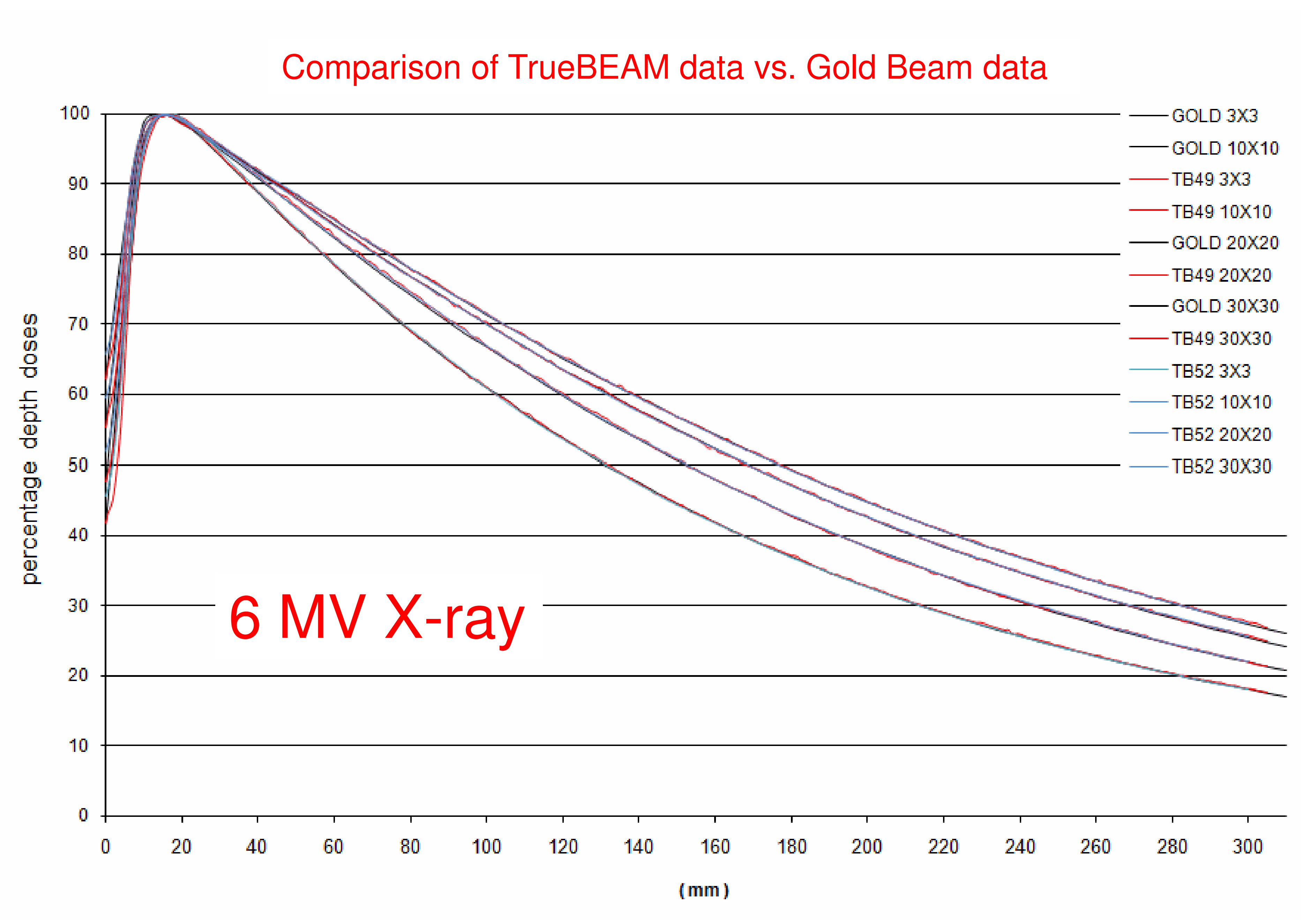

profile comparison (15X, 5 cm depth, 4X4, 10X10, 25X25)
red => scanned data 1031
blue => Gold Beam data
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-250.0
-200.0
-150.0
-100.0
-50.0
0.0
50.0
100.0
150.0
200.0
250.0

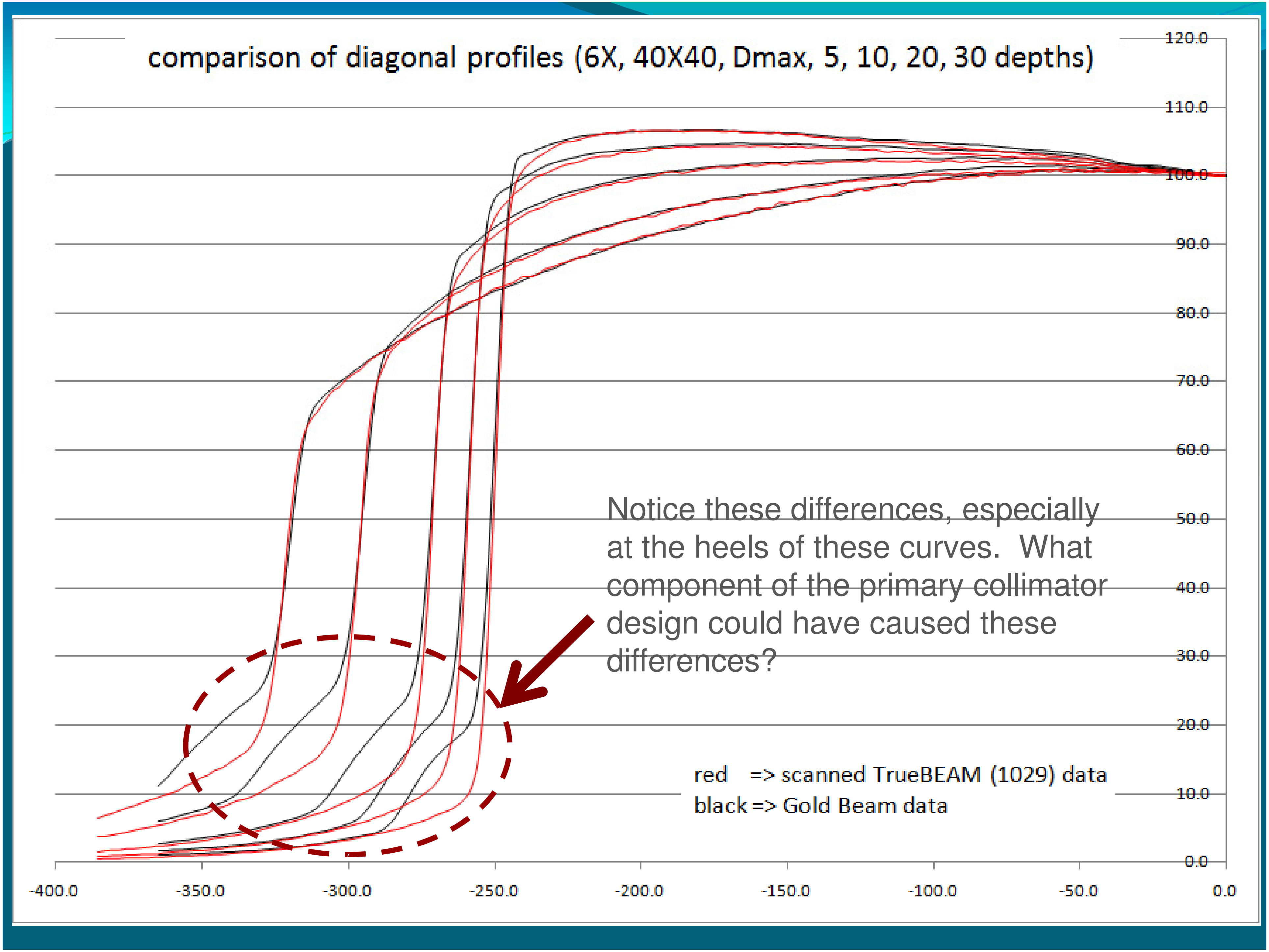


profile comparison (15X, 10 cm depth, 4X4, 10X10, 25X25)
red=> scanned data 1031
blue => gold Beam data
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-250.0
-200.0
-150.0
-100.0
-50.0
0.0
50.0
100.0
150.0
200.0
250.0



profile comparison (15X, 20 cm depth, 4X4, 10X10, 25X25)
red => scanned data 1031
blue => gold Beam data
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-300.0
-250.0
-200.0
-150.0
-100.0
-50.0
0.0
50.0
100.0
150.0
200.0
250.0
300.0

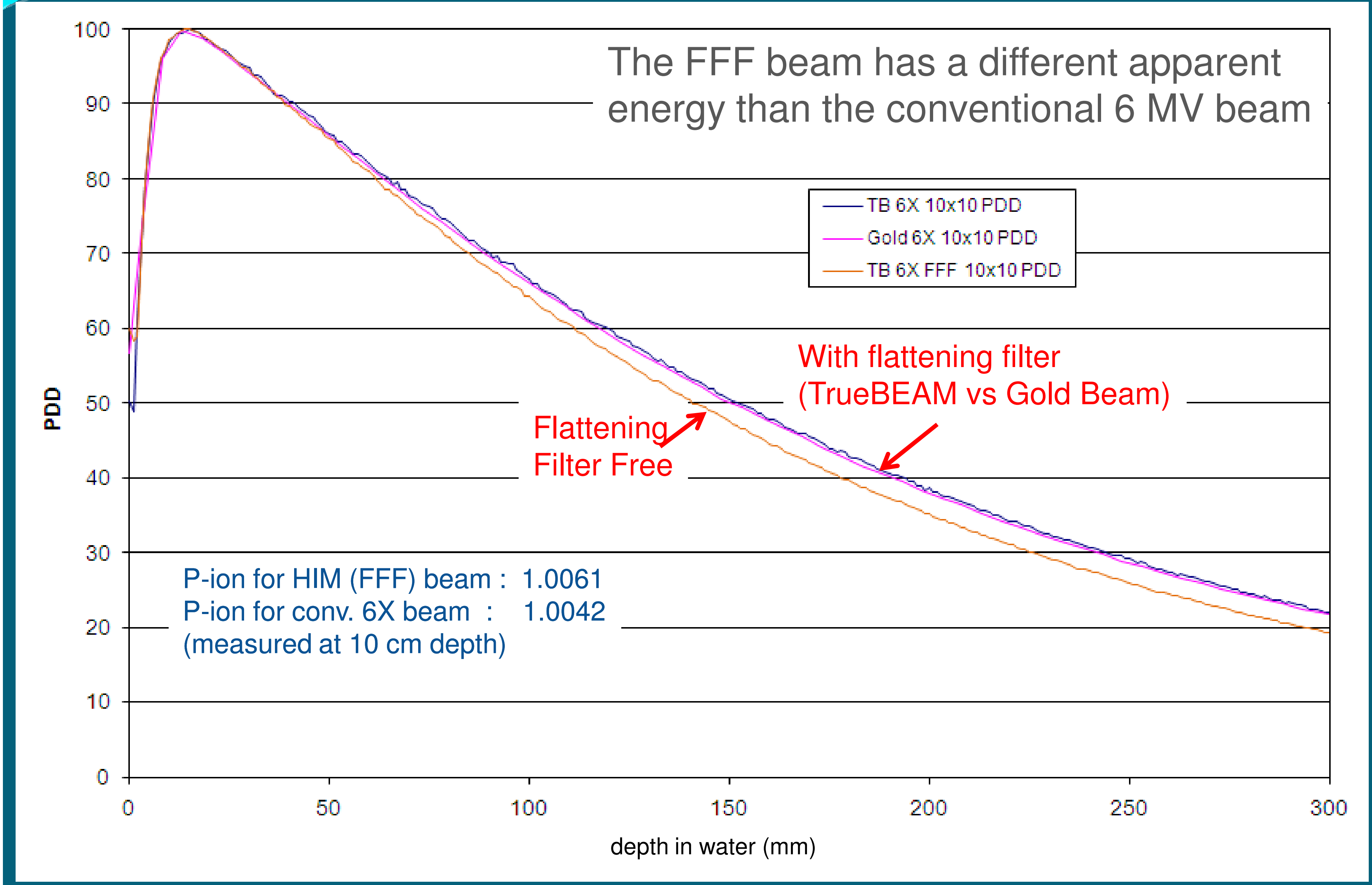

Comparison of TrueBEAM data vs. Gold Beam data
percentage depth doses
(mm)
6 MV X-ray
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
GOLD 3X3
GOLD 10X10
TB49 3X3
TB49 10X10
GOLD 20X20
TB49 20X20
GOLD 30X30
TB49 30X30
TB52 3X3
TB52 10X10
TB52 20X20
TB52 30X30



comparison of diagonal profiles (6X, 40X40, Dmax, 5, 10, 20, 30 depths)
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-400.0
-350.0
-300.0
-250.0
-200.0
-150.0
-100.0
-50.0
0.0
Notice these differences, especially at the heels of these curves. What component of the primary collimator design could have caused these differences?
red => scanned TrueBEAM (1029) data
black => Gold Beam data

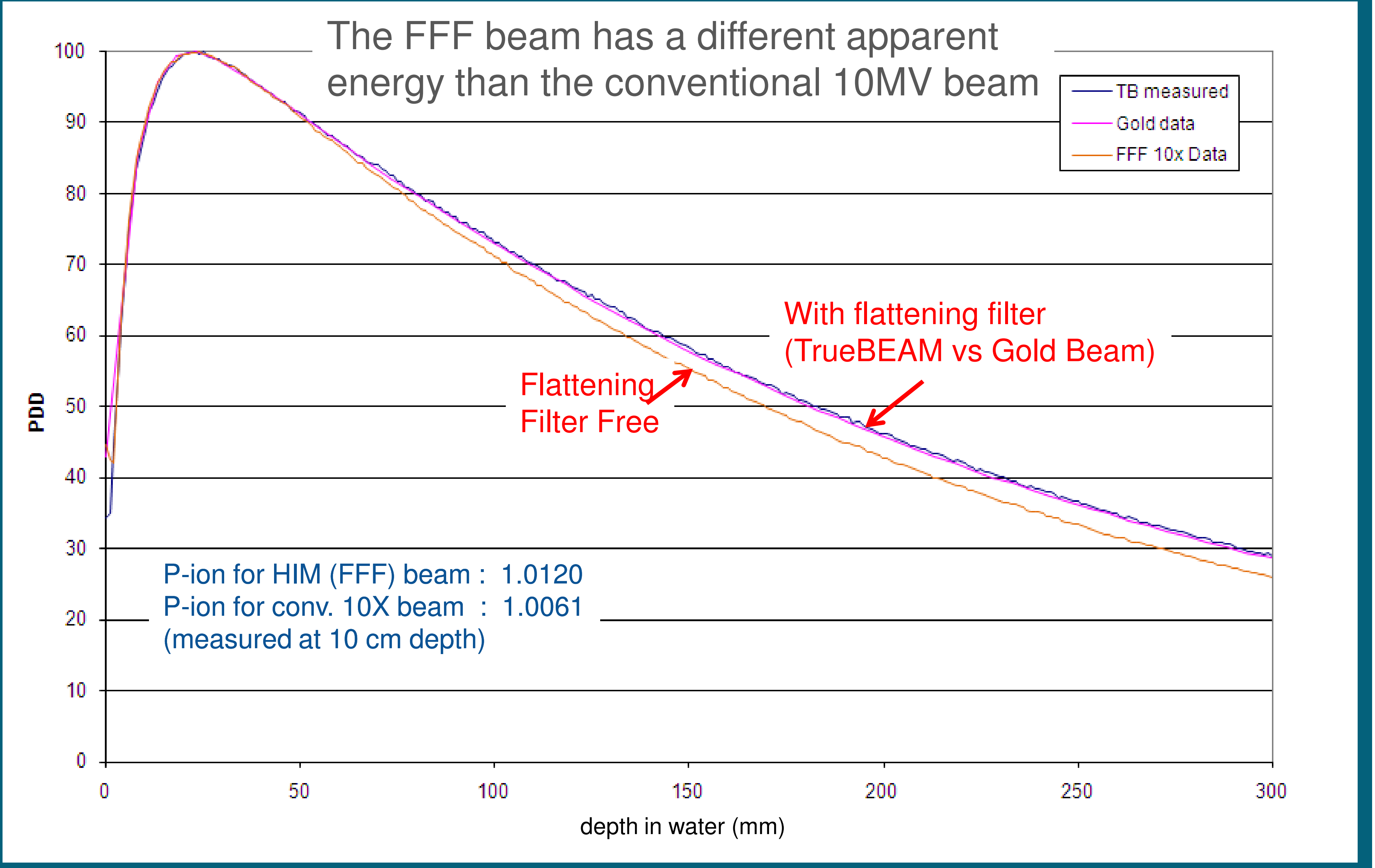
Comparison of Percentage Depth Doses (with and without flattening filter)

The “6X” beam without the flattening filter has a lower apparent energy



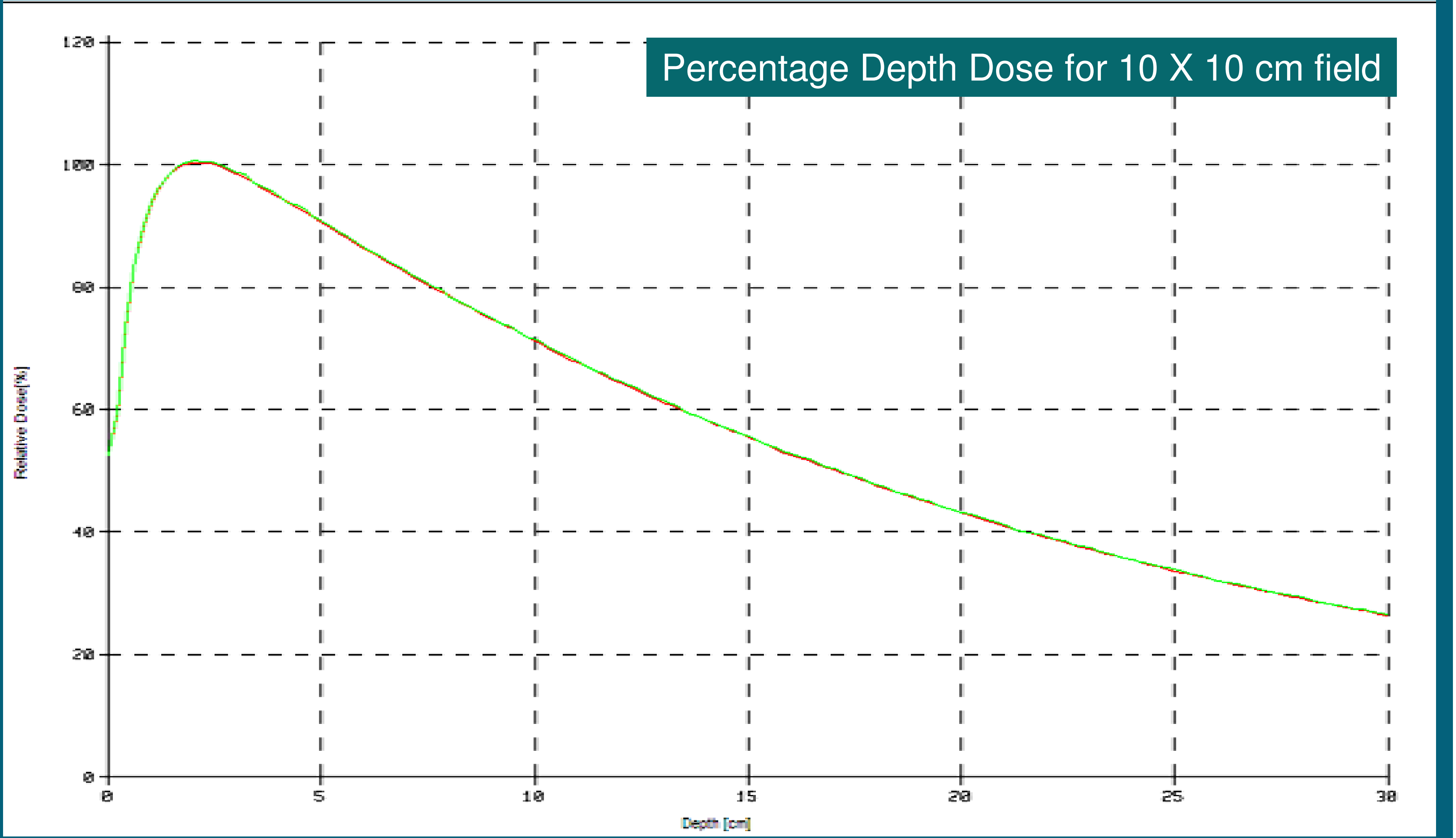
Comparison of Percentage Depth Doses (with and without flattening filter)

The “10X” beam without the flattening filter has a lower apparent energy



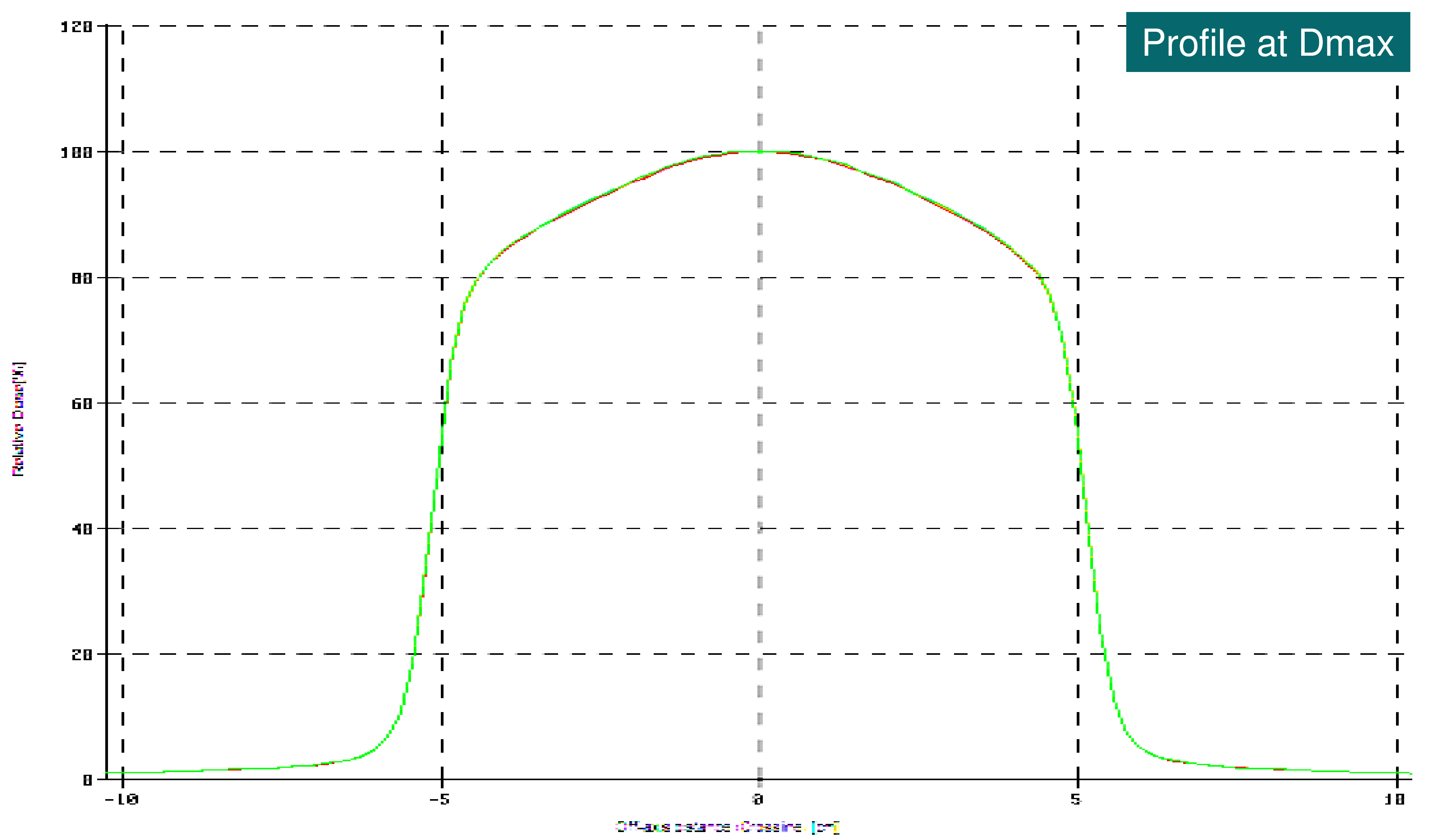
Because of the dose per beam pulse is the same regardless of the nominal dose rates, one would not expect to find differences between different dose rate settings.

This is a comparison of 400 and 2400 MU/minute for 10 MV FFF X-ray
(Wellhofer 3-D tank with CC-13 - 0.13 cc scanning chamber, 300-volt bias)



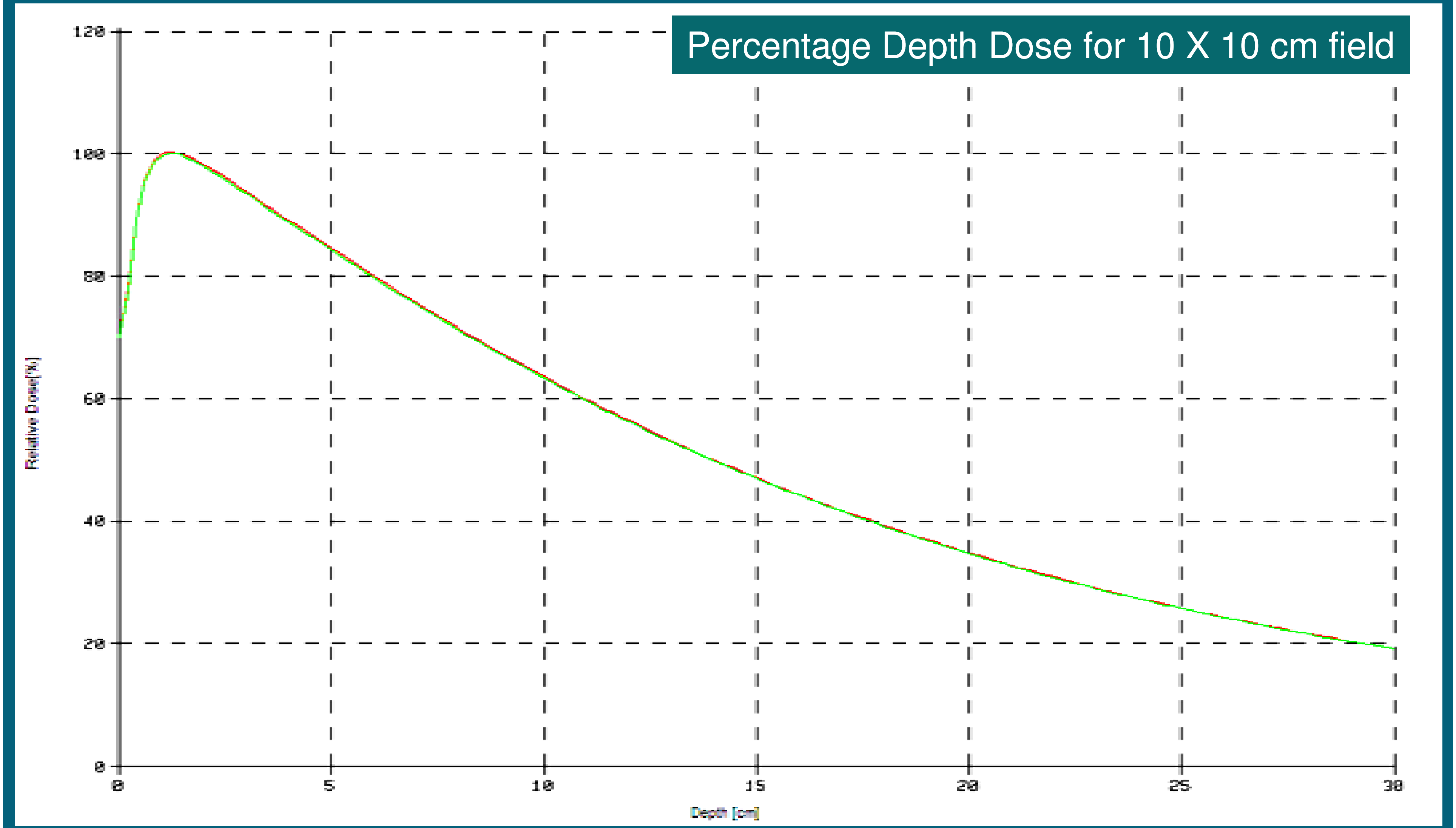
This is a comparison of 400 and 2400 MU/minute for 10 MV FFF X-ray
There is no difference between these 2 curves.

(Wellhofer 3-D tank with CC-13 - 0.13 cc scanning chamber, 300-volt bias)



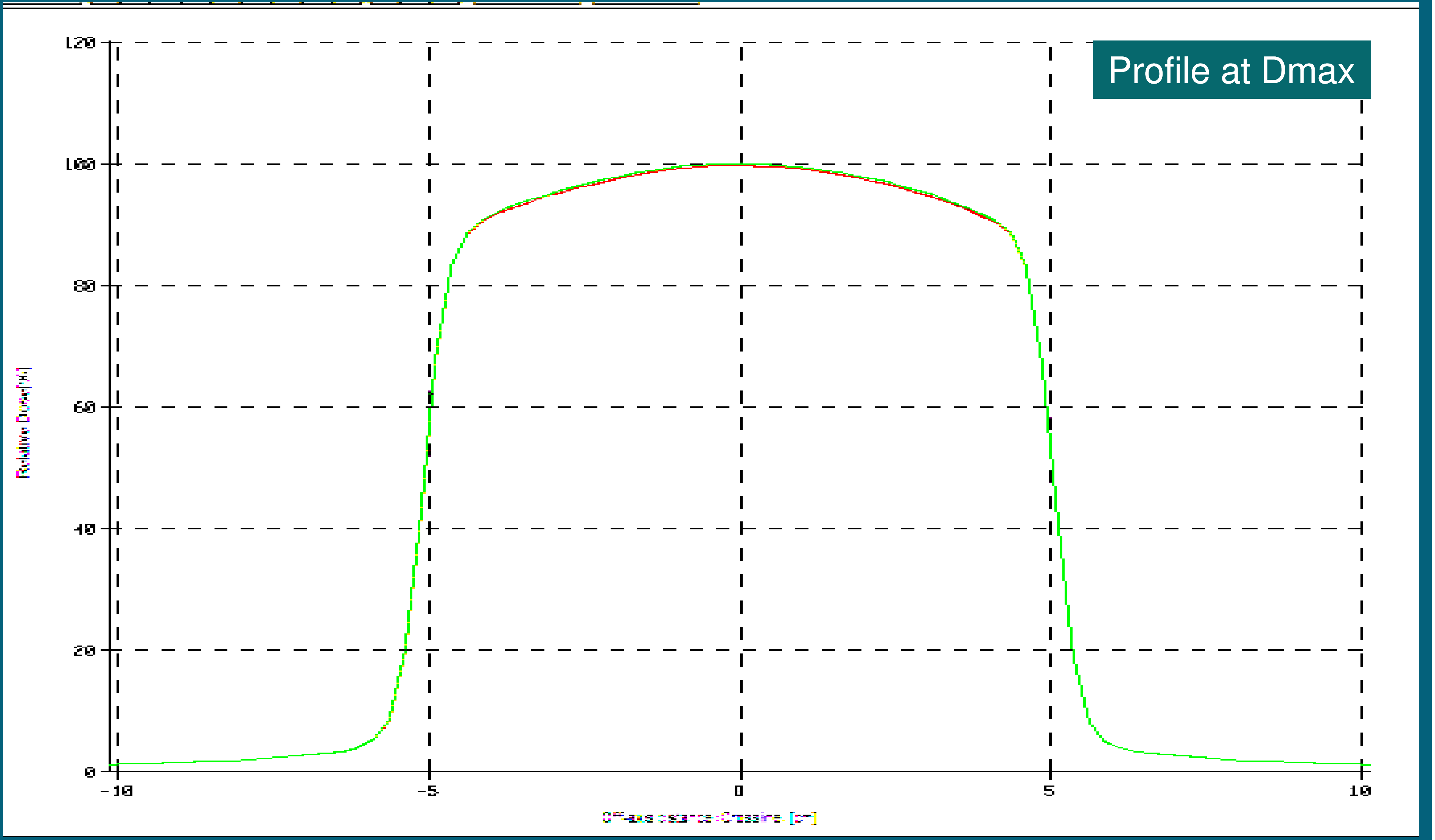
Comparison of 400 and 1400 MU/minute for 6 MV X-ray
There is no difference between these 2 profile curves.

(The dose per beam pulse is the same regardless of the dose rate selections)



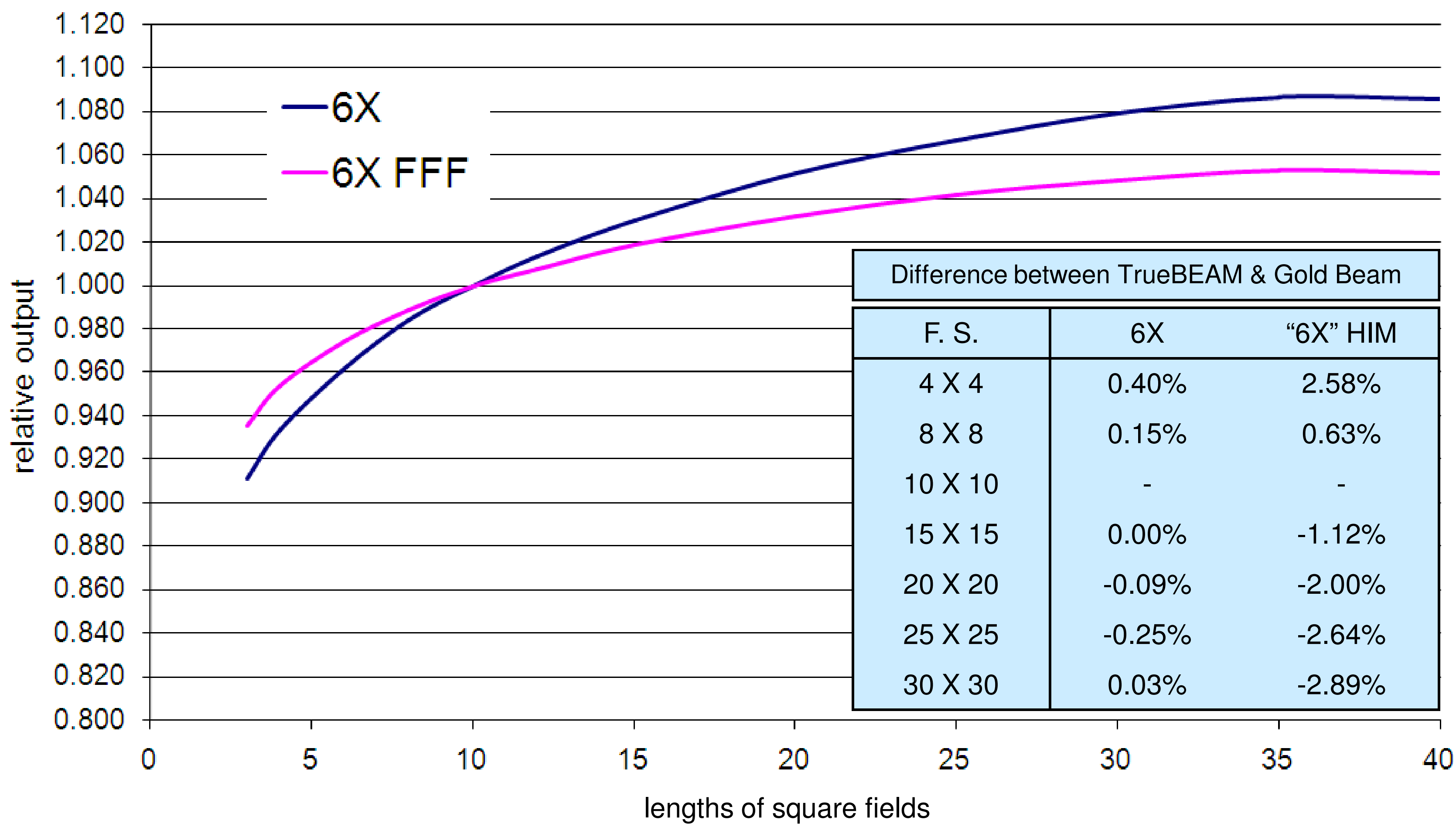
Comparison of 400 and 1400 MU/minute for 6 MV X-ray
There is no difference between these 2 profile curves.

(The dose per beam pulse is the same regardless of the dose rate selections)



Output factors for 6X, 6X (FFF) in 400 MU/minute

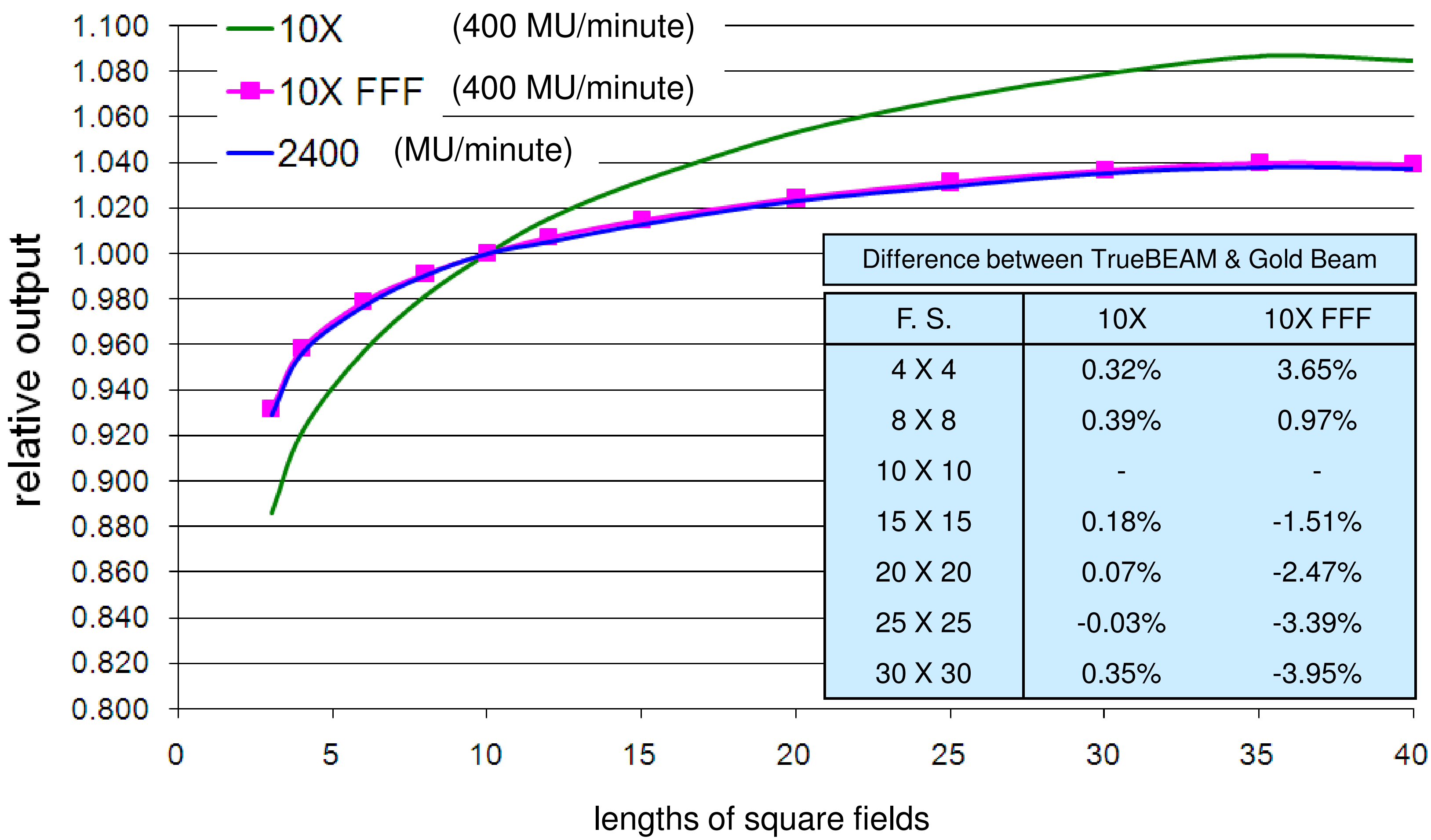
(0.6 cc. Farmer chamber, 300 volt bias)



Difference between TrueBEAM & Gold Beam

F. S.	6X	"6X" HIM
4 X 4	0.40%	2.58%
8 X 8	0.15%	0.63%
10 X 10	-	-
15 X 15	0.00%	-1.12%
20 X 20	-0.09%	-2.00%
25 X 25	-0.25%	-2.64%
30 X 30	0.03%	-2.89%

Output factors for 10X, 10X (FFF) in 400 and 2400 MU/minute



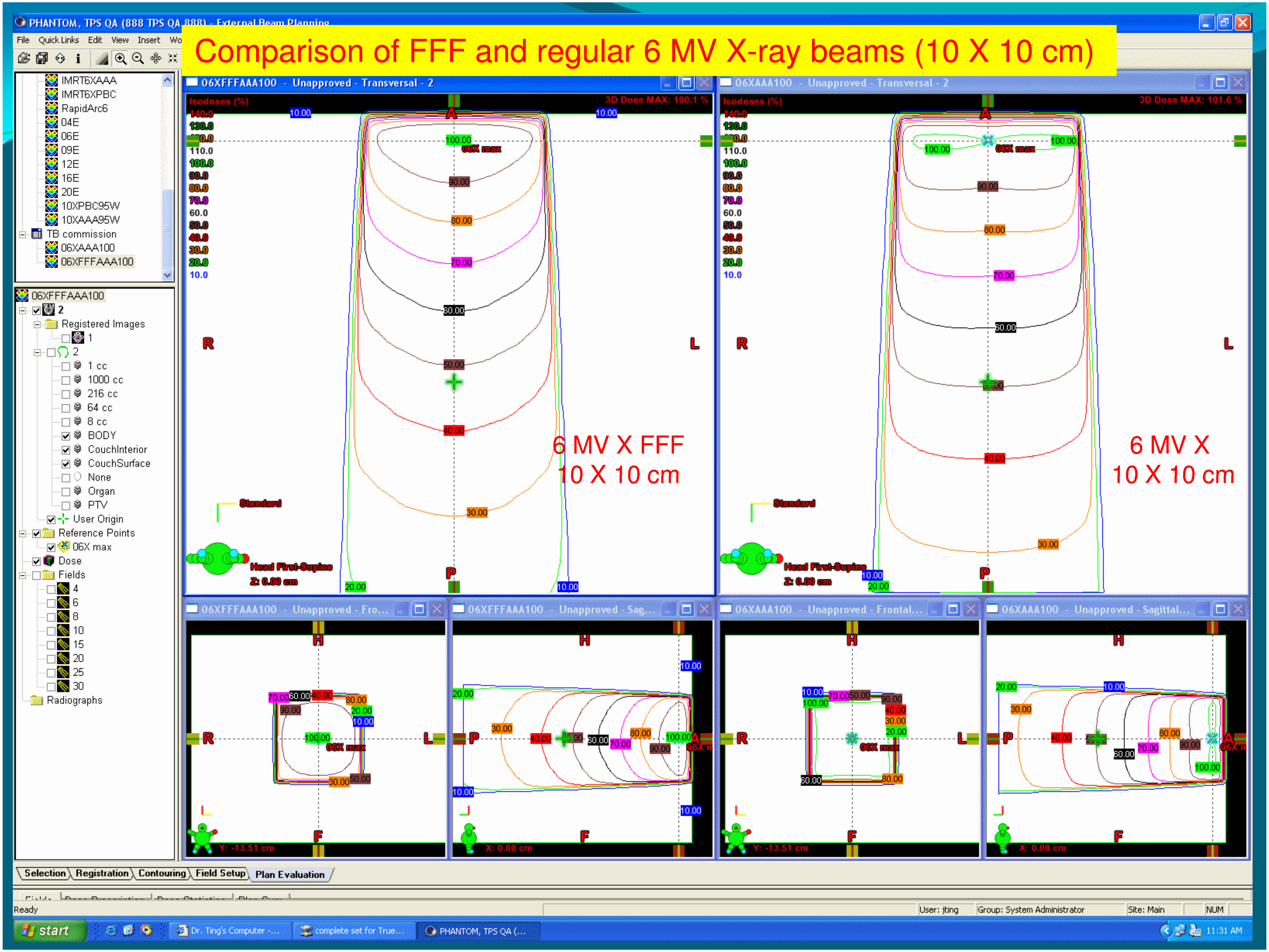
Difference between TrueBEAM & Gold Beam

F. S.	10X	10X FFF
4 X 4	0.32%	3.65%
8 X 8	0.39%	0.97%
10 X 10	-	-
15 X 15	0.18%	-1.51%
20 X 20	0.07%	-2.47%
25 X 25	-0.03%	-3.39%
30 X 30	0.35%	-3.95%

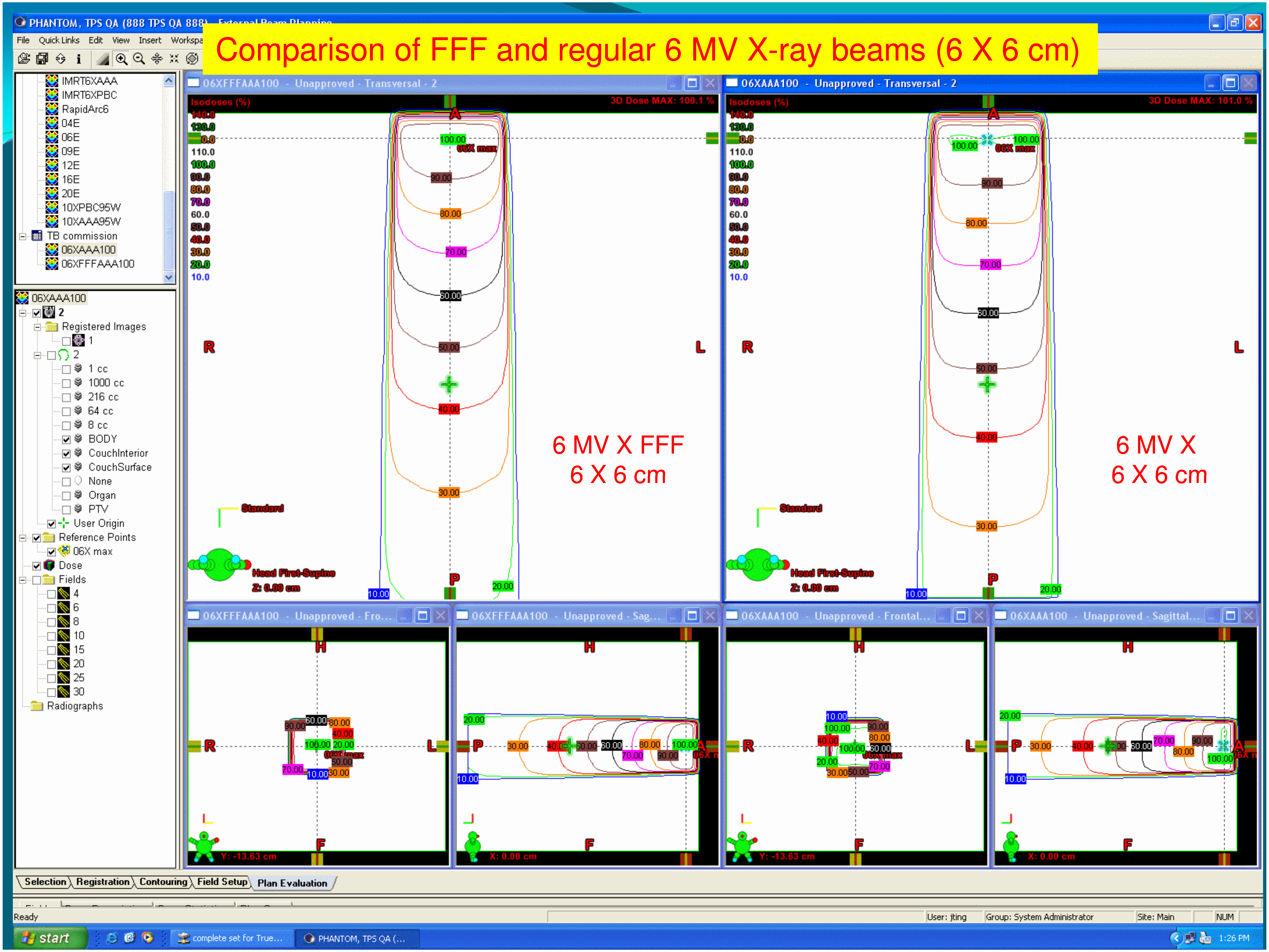
Output factors for all available X-ray modalities

square field sizes	6X	"6X" HIM	10X	"10X" HIM	"10X" HIM	15X
	400 MU/min	400 MU/min	400 MU/min	400 MU/min	2400 MU/min	400 MU/min
3	0.911	0.936	0.886	0.931	0.929	0.872
4	0.933	0.954	0.922	0.958	0.956	0.913
6	0.961	0.974	0.957	0.979	0.977	0.953
8	0.984	0.989	0.981	0.991	0.990	0.980
10	1.000	1.000	1.000	1.000	1.000	1.000
12	1.014	1.007	1.016	1.007	1.005	1.016
15	1.030	1.018	1.032	1.015	1.013	1.034
20	1.052	1.032	1.053	1.024	1.023	1.058
25	1.067	1.042	1.068	1.031	1.029	1.074
30	1.079	1.048	1.079	1.037	1.035	1.087
35	1.087	1.053	1.087	1.040	1.038	1.094
40	1.086	1.051	1.085	1.039	1.037	1.092

Comparison of FFF and regular 6 MV X-ray beams (10 X 10 cm)

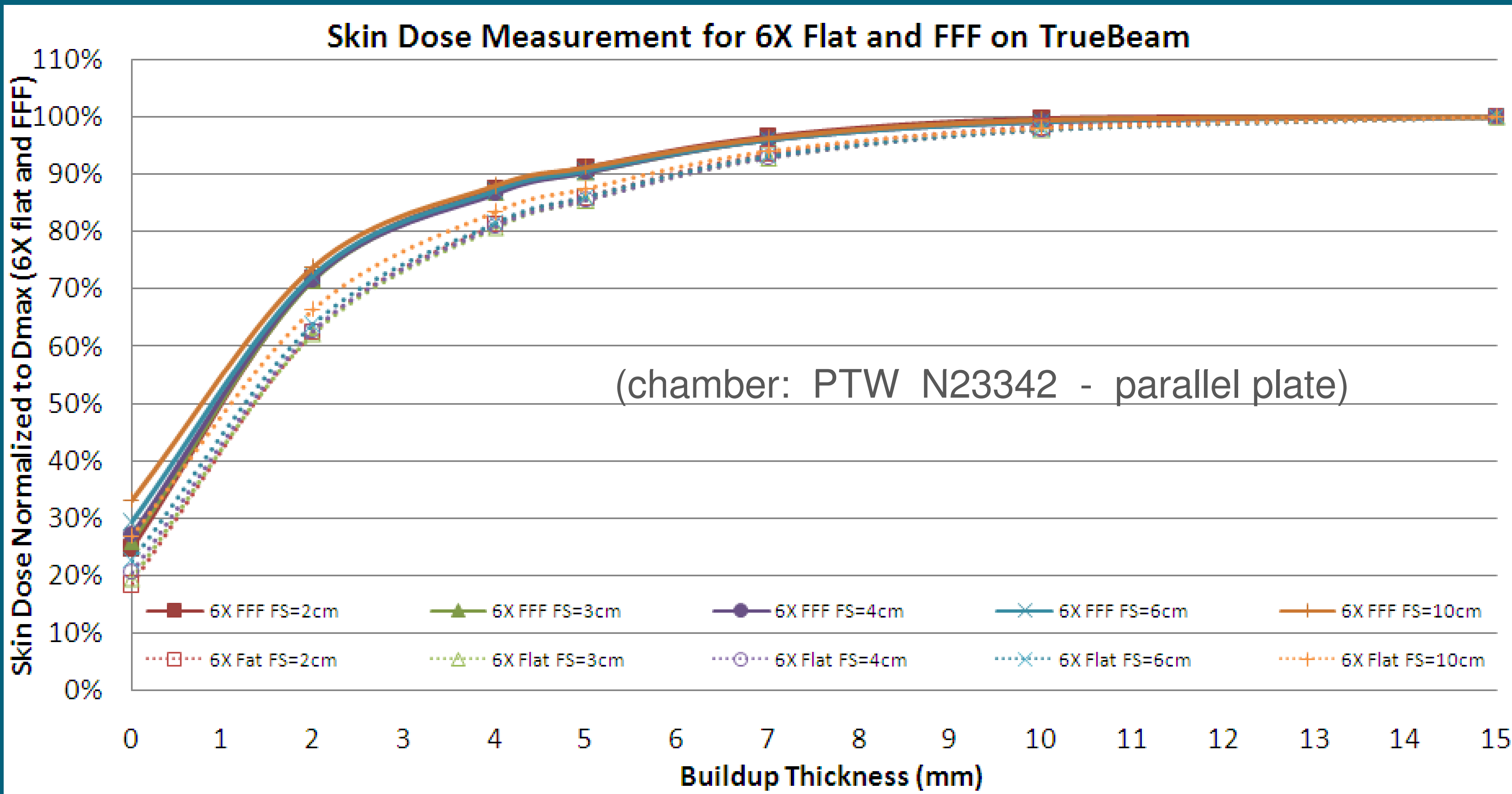


Comparison of FFF and regular 6 MV X-ray beams (6 X 6 cm)



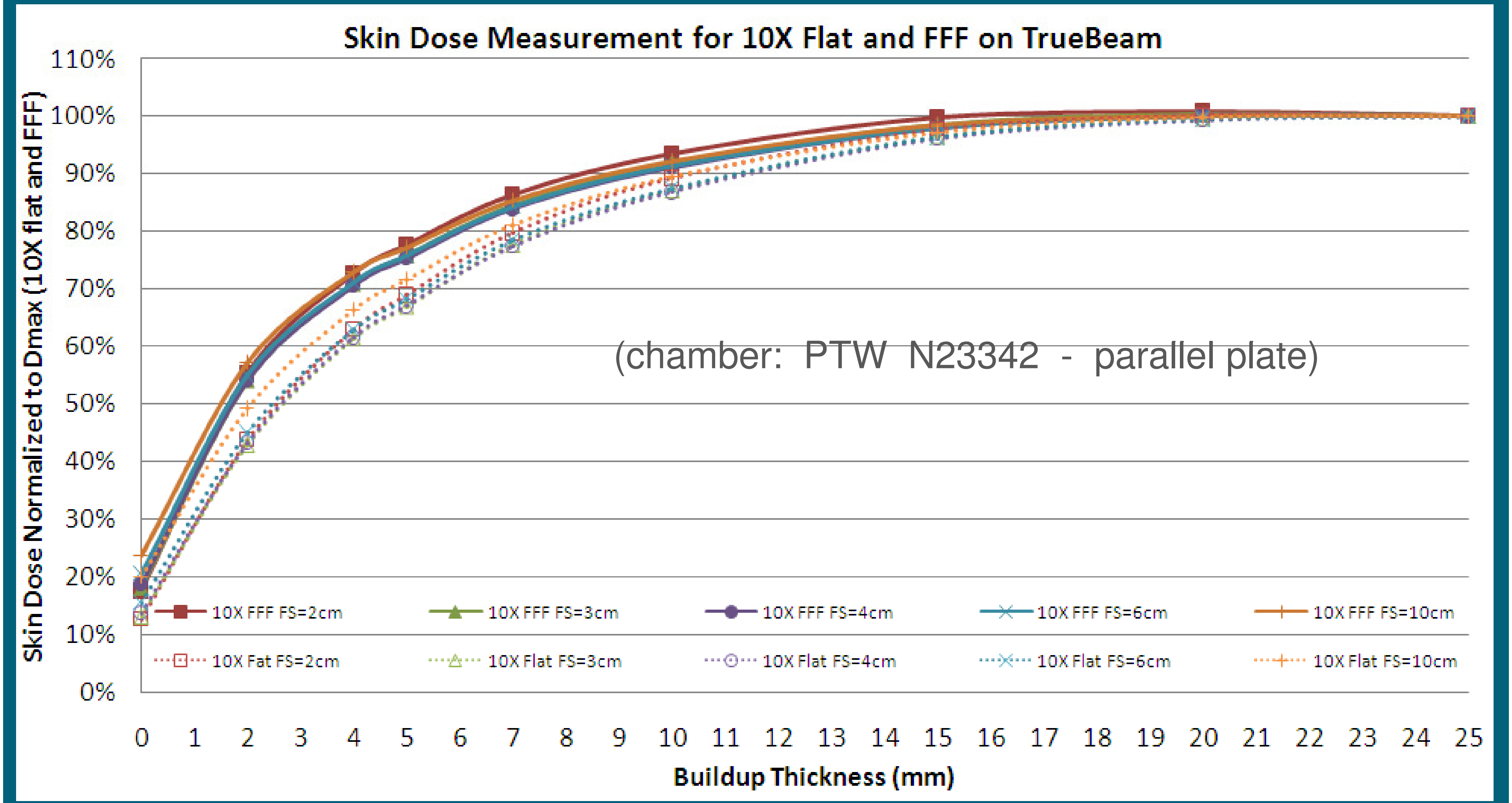
6X surface Dose Measurements

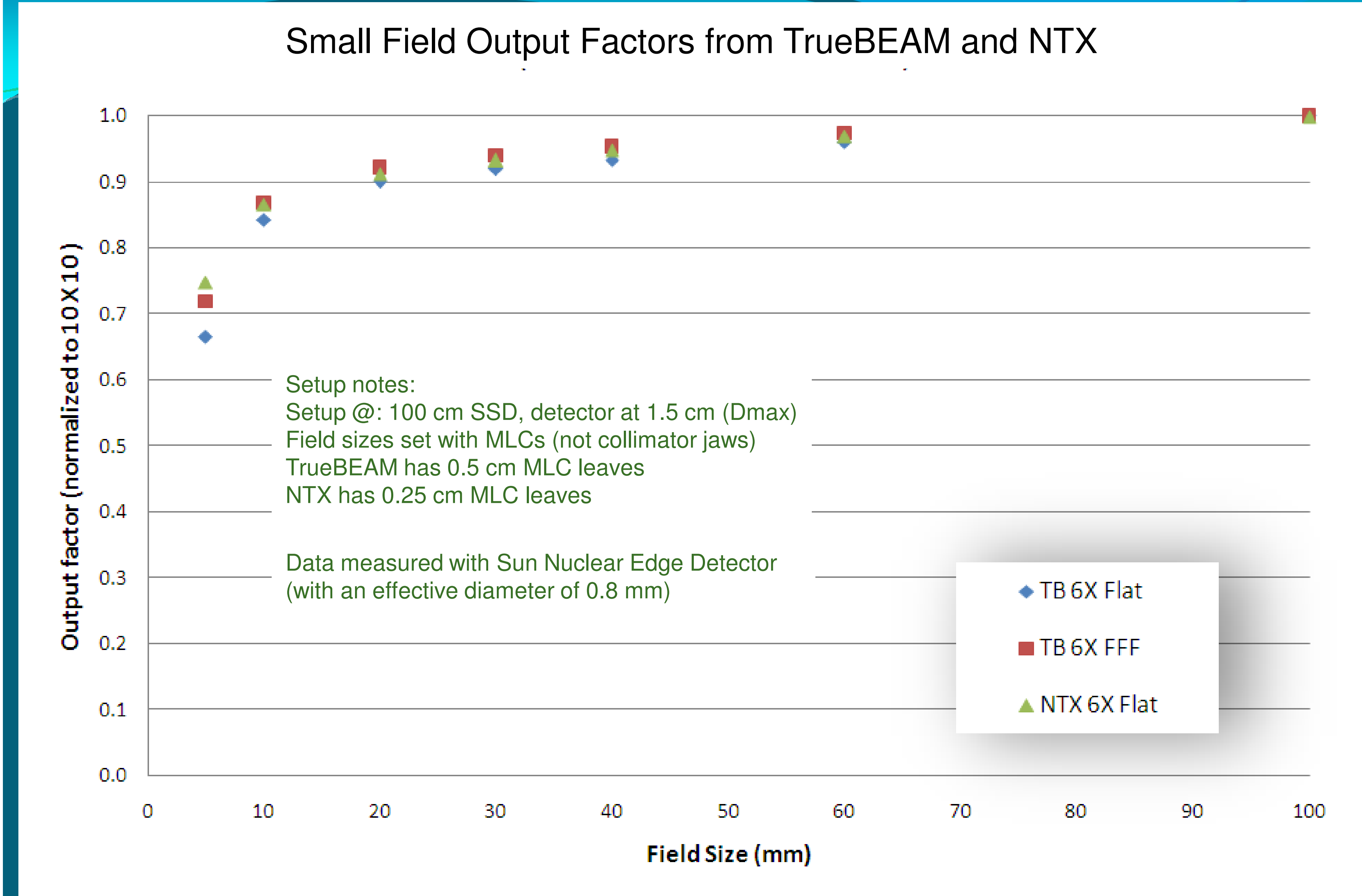
(chamber: PTW N23342 parallel plate)



10X surface Dose Measurements

(chamber: PTW N23342 parallel plate)

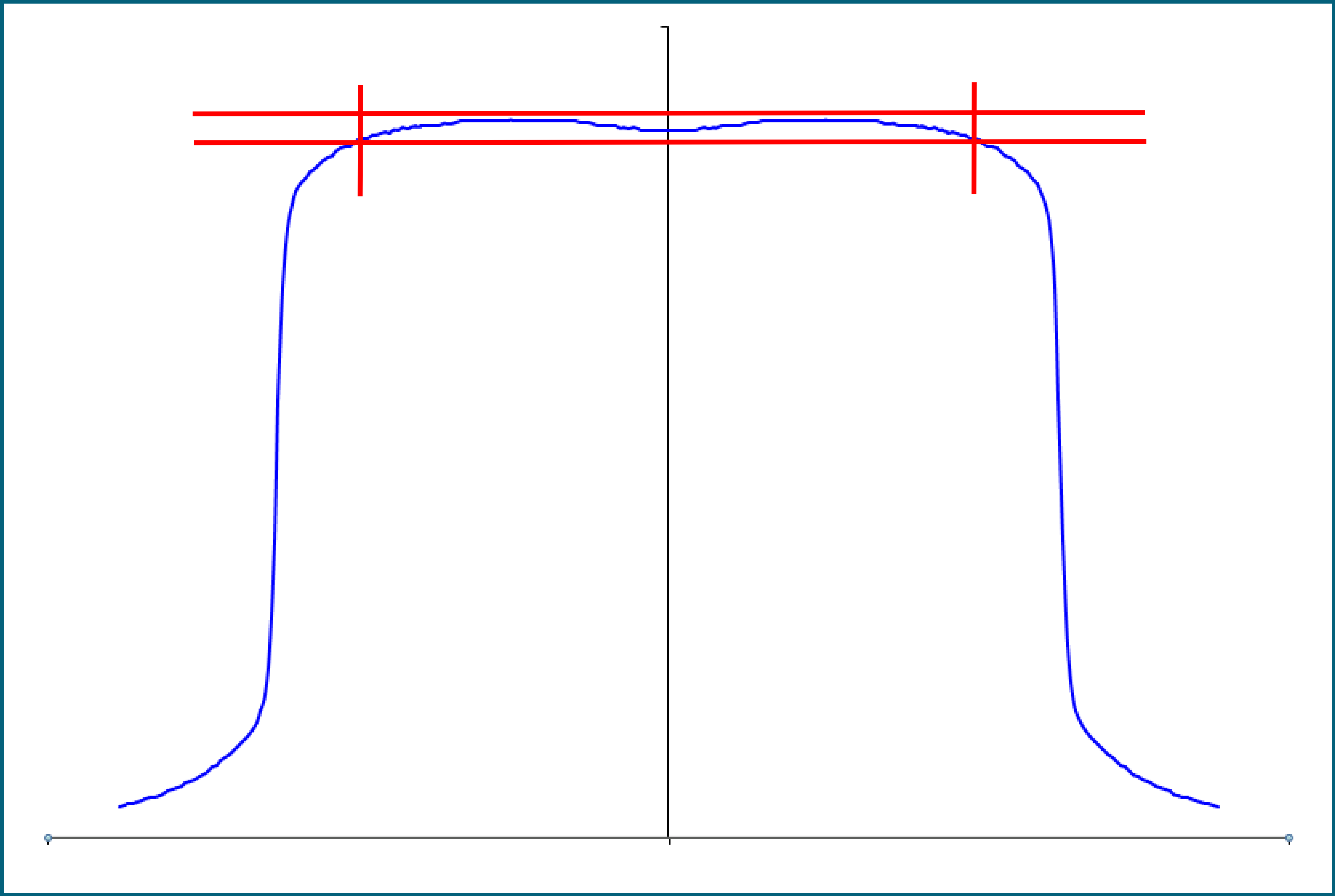



Small Field Output Factors from TrueBEAM and NTX
Output factor (normalized to 10X10)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
70
80
90
100
Field Size (mm)
Setup notes:
Setup @: 100 cm SSD, detector at 1.5 cm (Dmax)
Field sizes set with MLCs (not collimator jaws)
TrueBEAM has 0.5 cm MLC leaves
NTX has 0.25 cm MLC leaves
Data measured with Sun Nuclear Edge Detector
(with an effective diameter of 0.8 mm)
TB 6X Flat
TB 6X FFF
NTX 6X Flat

This presentation will address these topics about FFF X-ray beams:

(A) Production
(B) Dosimetric properties (PDD and Profiles)
(C) Parameters and quantification of the flattening filter free beam
(D) Typical clinical applications
(E) Samples of treatment plans with IMRT / RapidArc
(F) Clinical benefits and radiation protection benefits

To provide a common denominator for comparison and specification of an X-ray beam, parameters must be established. In a conventional X-ray (with flattening filter) beam profile, one can specify the flatness and symmetry with a set of well established definitions.



Radiation Oncology Physics:
A Handbook for Teachers and Students

E.B. Podgorsak
Technical Editor

With respect to HIM (FFF) beams, the 80% of beam width is a misleading number and should not be applied to these beams.

6.9.1. Beam flatness

The beam flatness F is assessed by finding the maximum D_{max} and minimum D_{min} dose point values on the beam profile within the central 80% of the beam width and then using the relationship:

$$F = 100 \times \frac{D_{max} - D_{min}}{D_{max} + D_{min}} \quad (6.64)$$

Standard linac specifications generally require that F be less than 3% when measured in a water phantom at a depth of 10 cm and an SSD of 100 cm for the largest field size available (usually 40 × 40 cm^2).

Compliance with the flatness specifications at a depth of 10 cm in water results in 'over-flattening' at z_{max}, which manifests itself in the form of 'horns' in the profile, and in 'under-flattening', which progressively worsens as the depth z increases from 10 cm to larger depths beyond 10 cm, as evident from the profiles for the 30 × 30 cm^2 field in Fig. 6.17. The typical limitation on beam horns in the z_{max} profile is 5% for a 40 × 40 cm^2 field at SSD = 100 cm. The over-flattening and under-flattening of the beam profiles is caused by the lower beam effective energies in off-axis directions compared with those in the central axis direction.

6.9.2. Beam symmetry

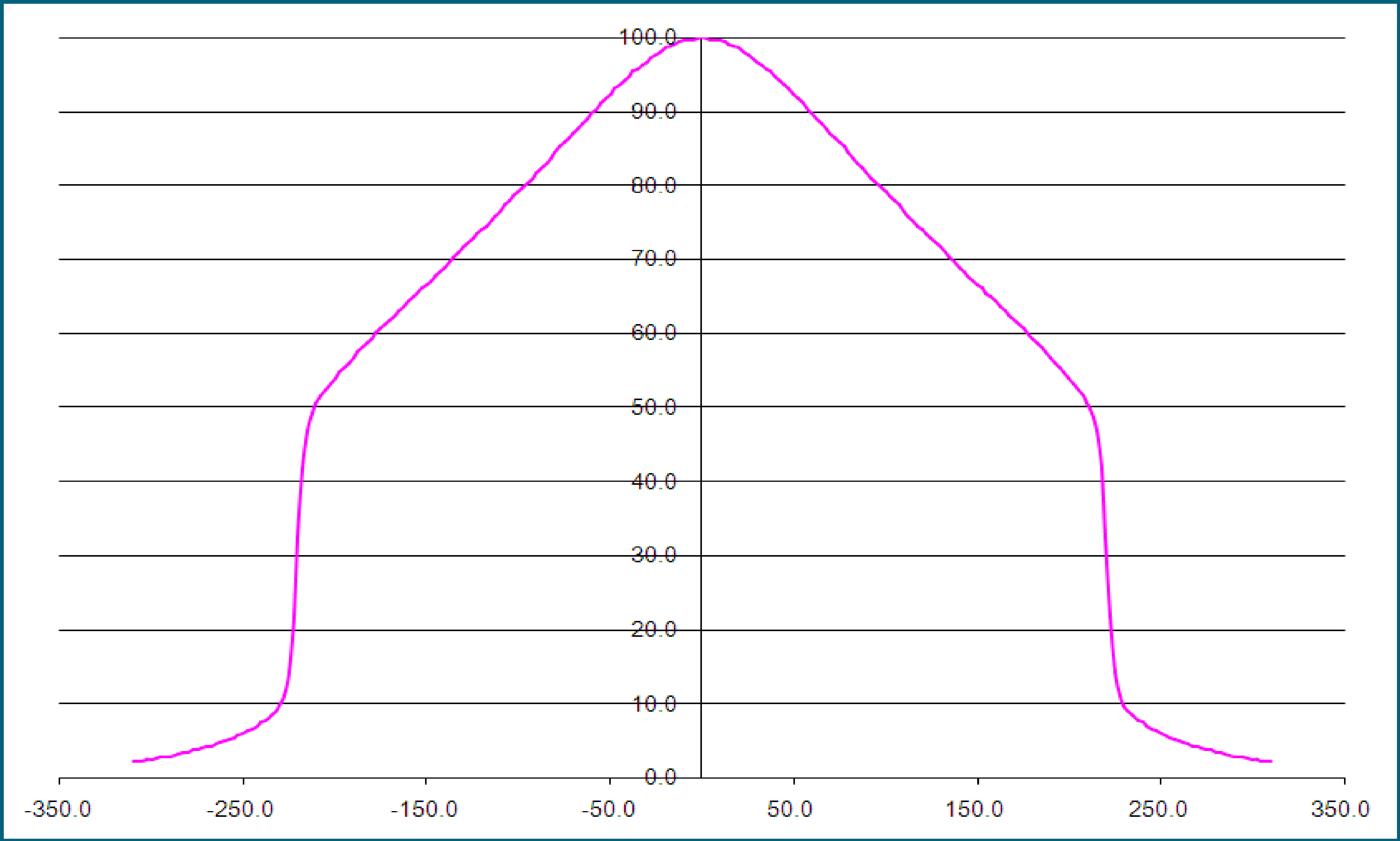
The beam symmetry S is usually determined at z_{max}, which represents the most sensitive depth for assessment of this beam uniformity parameter. A typical symmetry specification is that any two dose points on a beam profile, equidistant from the central axis point, are within 2% of each other. Alternately, areas under the z_{max} beam profile on each side (left and right) of the central axis extending to the 50% dose level (normalized to 100% at the central axis point) are determined and S is then calculated from:

$$S = 100 \times \frac{\text{area}_{\text{left}} - \text{area}_{\text{right}}}{\text{area}_{\text{left}} + \text{area}_{\text{right}}} \tag{6.65}$$

The areas under the z_{max} profiles can often be determined using an automatic option on the water tank scanning device (3-D isodose plotter). Alternatively, using a planimeter or even counting squares on graph paper with a hard copy of the profile are practical options.

With respect to FFF beams, the 50% level is a misleading number and should not be applied to these beams.

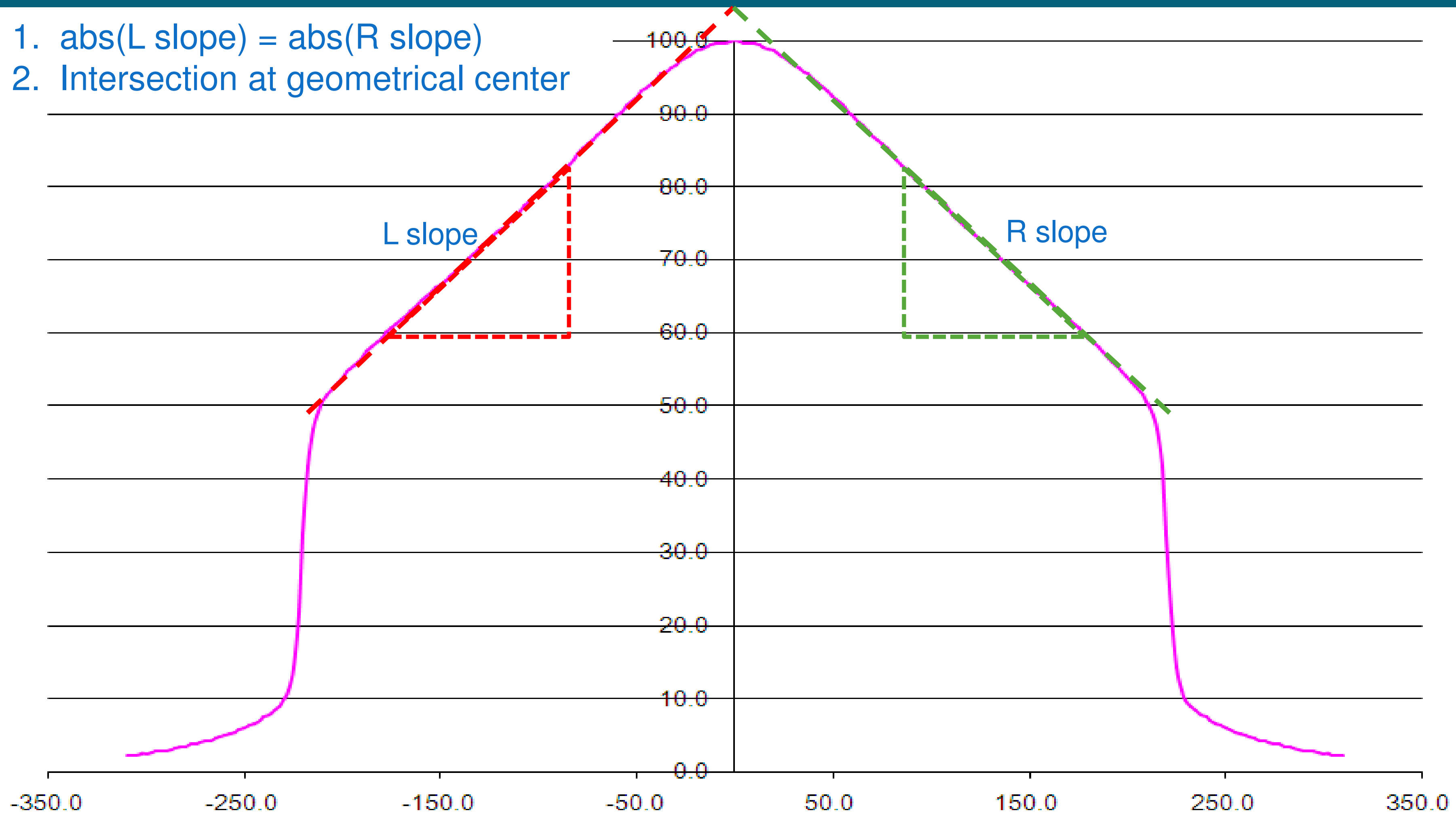
In a high intensity mode (FFF) X-ray (without flattening filter) beam profile, one needs to find a set of new definitions for such beam profiles. The purpose is to set standard criteria for initial acceptance and routine quality assurance, such as: daily, monthly, and yearly QA checks.

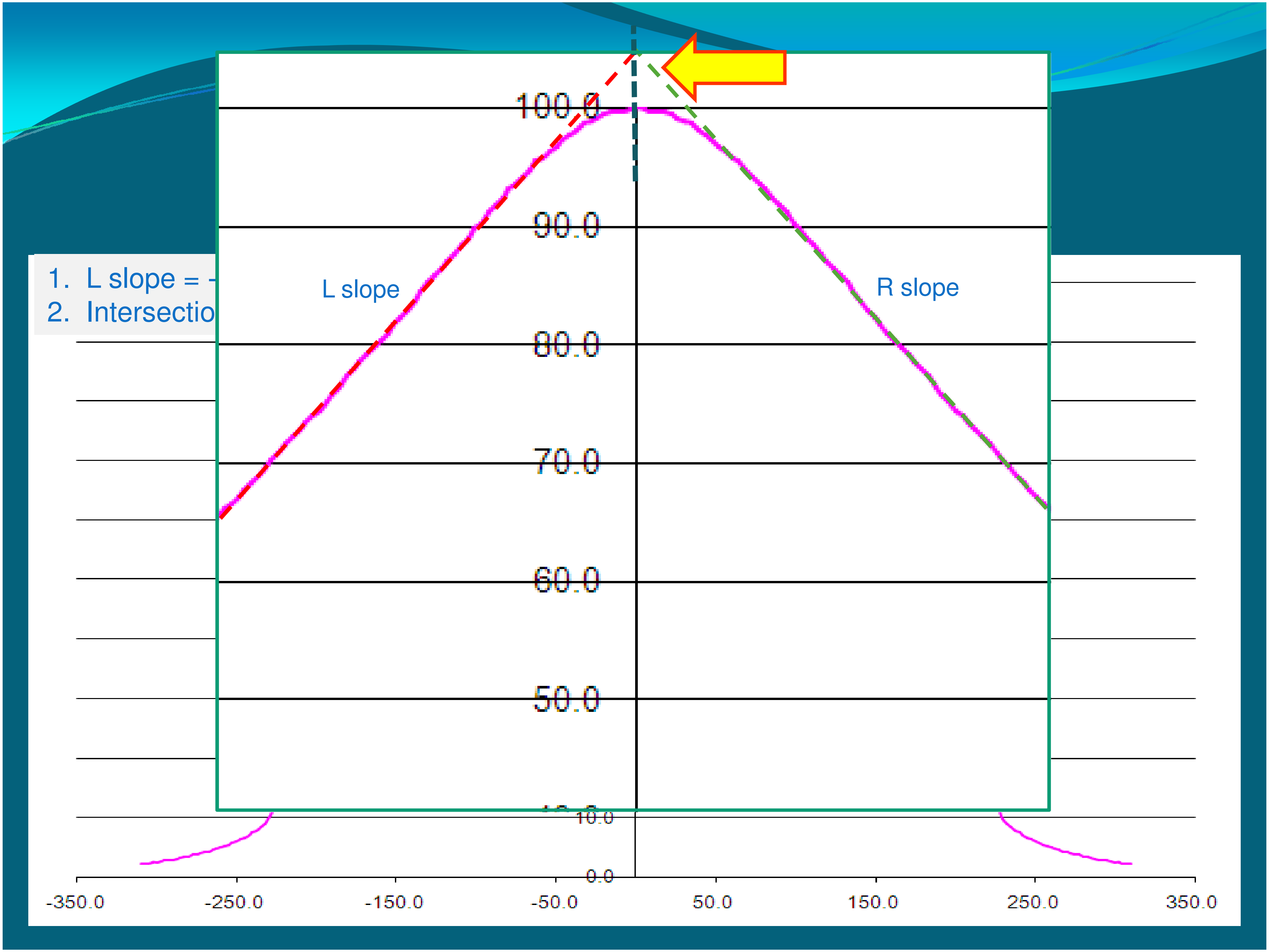


This set of new parameters must be able to describe the profile characteristics under a variety of conditions and must be simple to use (for example: no computer algorithms required).

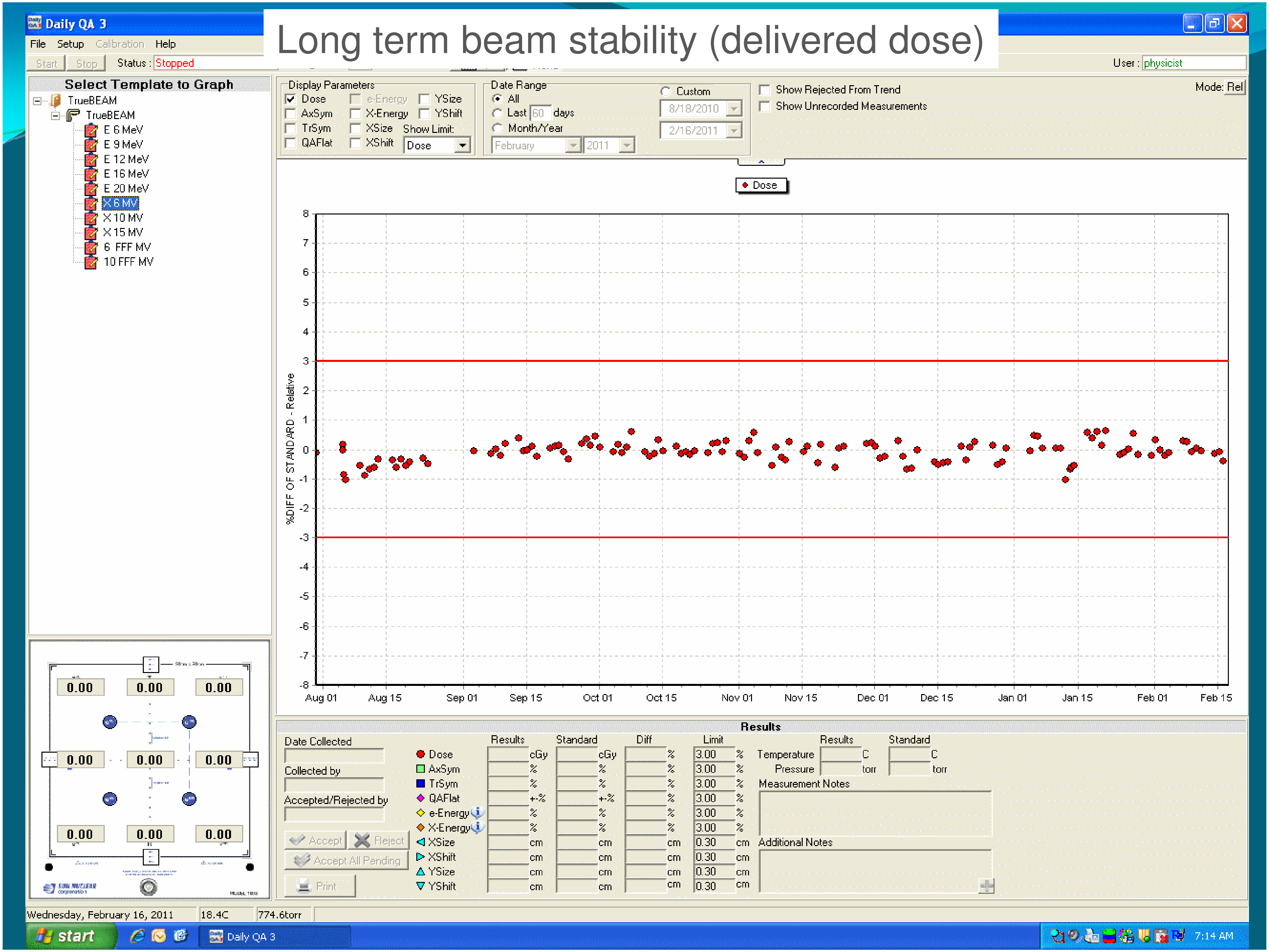
We propose the use of two slopes (left - red and right - green) and the intersection of these two extrapolated lines.

1. abs(L slope) = abs(R slope)
2. Intersection at geometrical center

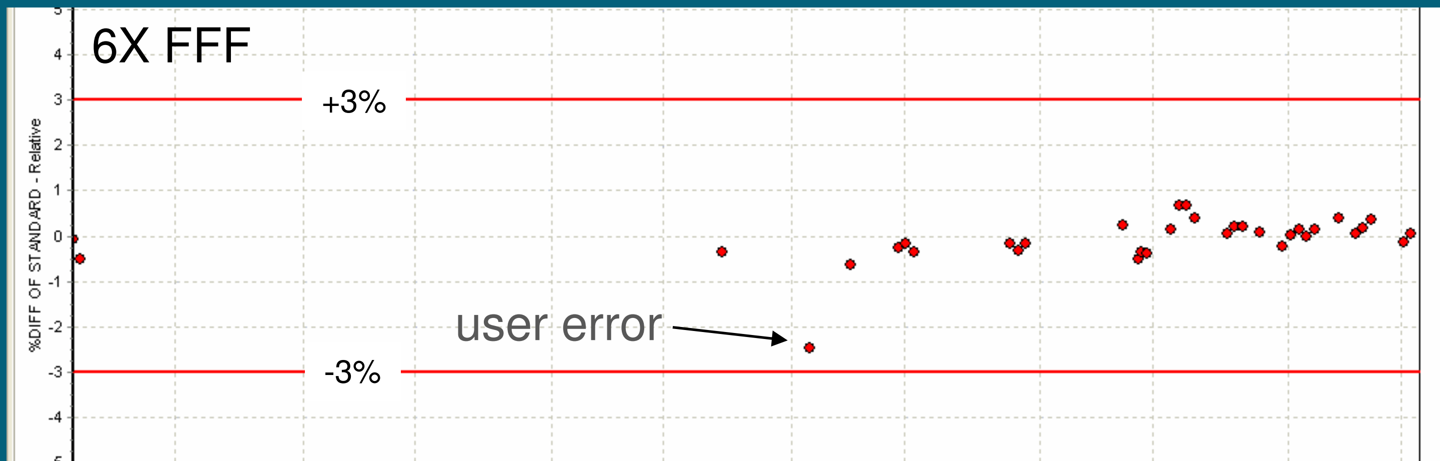



1. L slope = -
2. Intersectio
L slope
R slope
100.0
90.0
80.0
70.0
60.0
50.0
10.0
0.0
-350.0
-250.0
-150.0
-50.0
50.0
150.0
250.0
350.0

Long term beam stability (delivered dose)

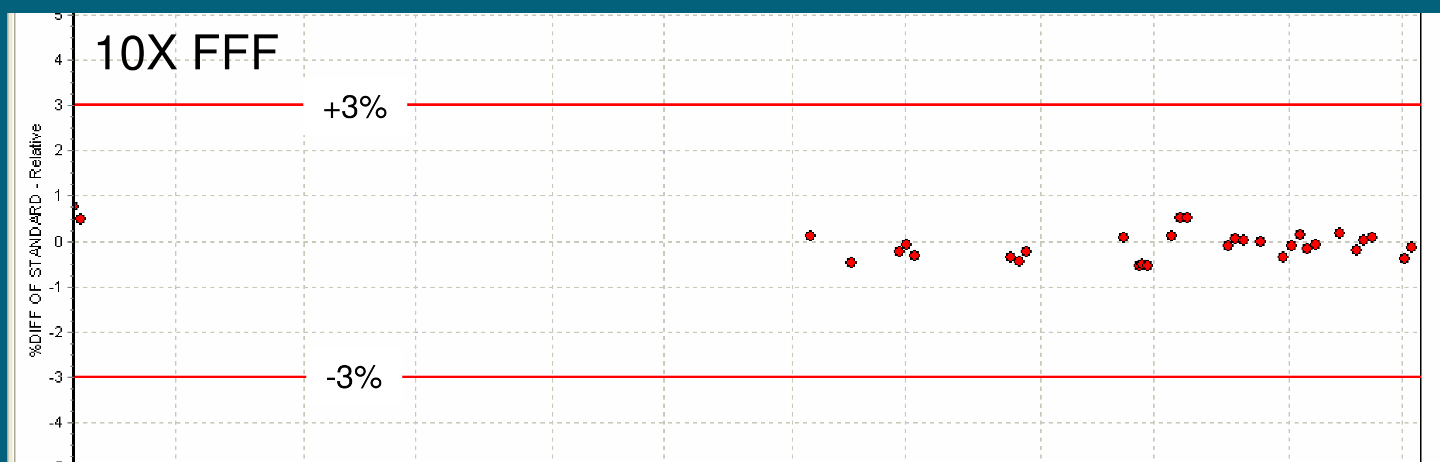


Long term beam stability (delivered dose)

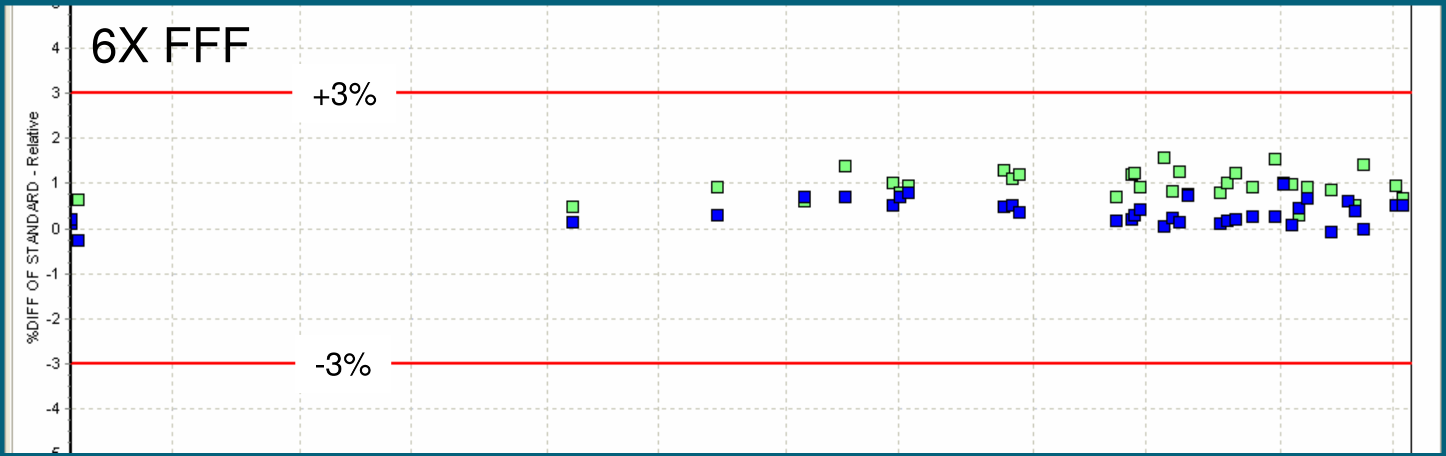


August 1, 2010

Feb 15, 2011

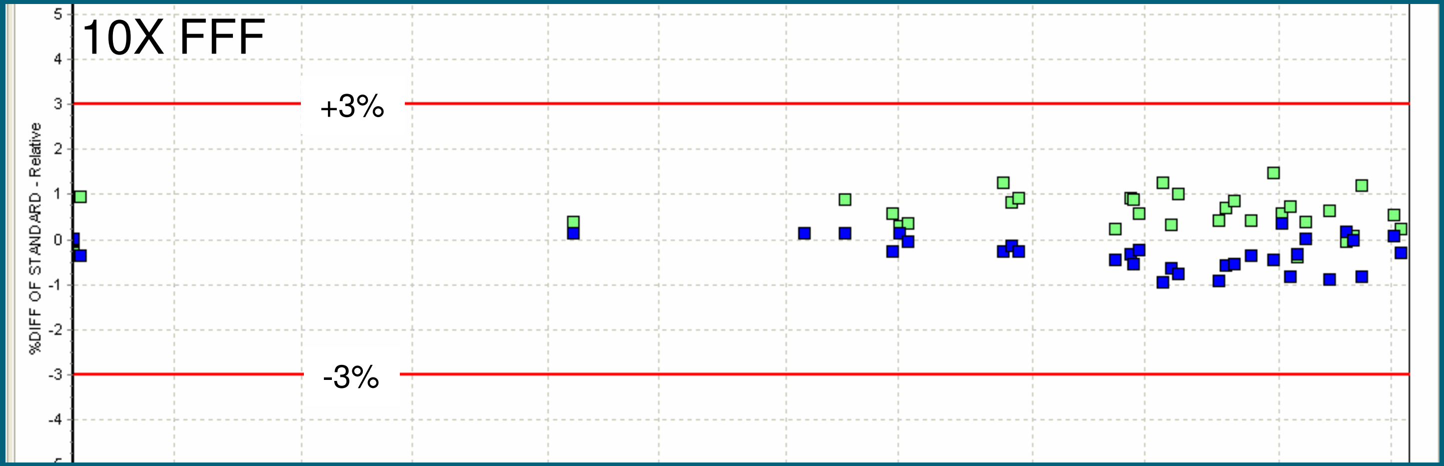


Long term beam stability symmetry / “flatness”

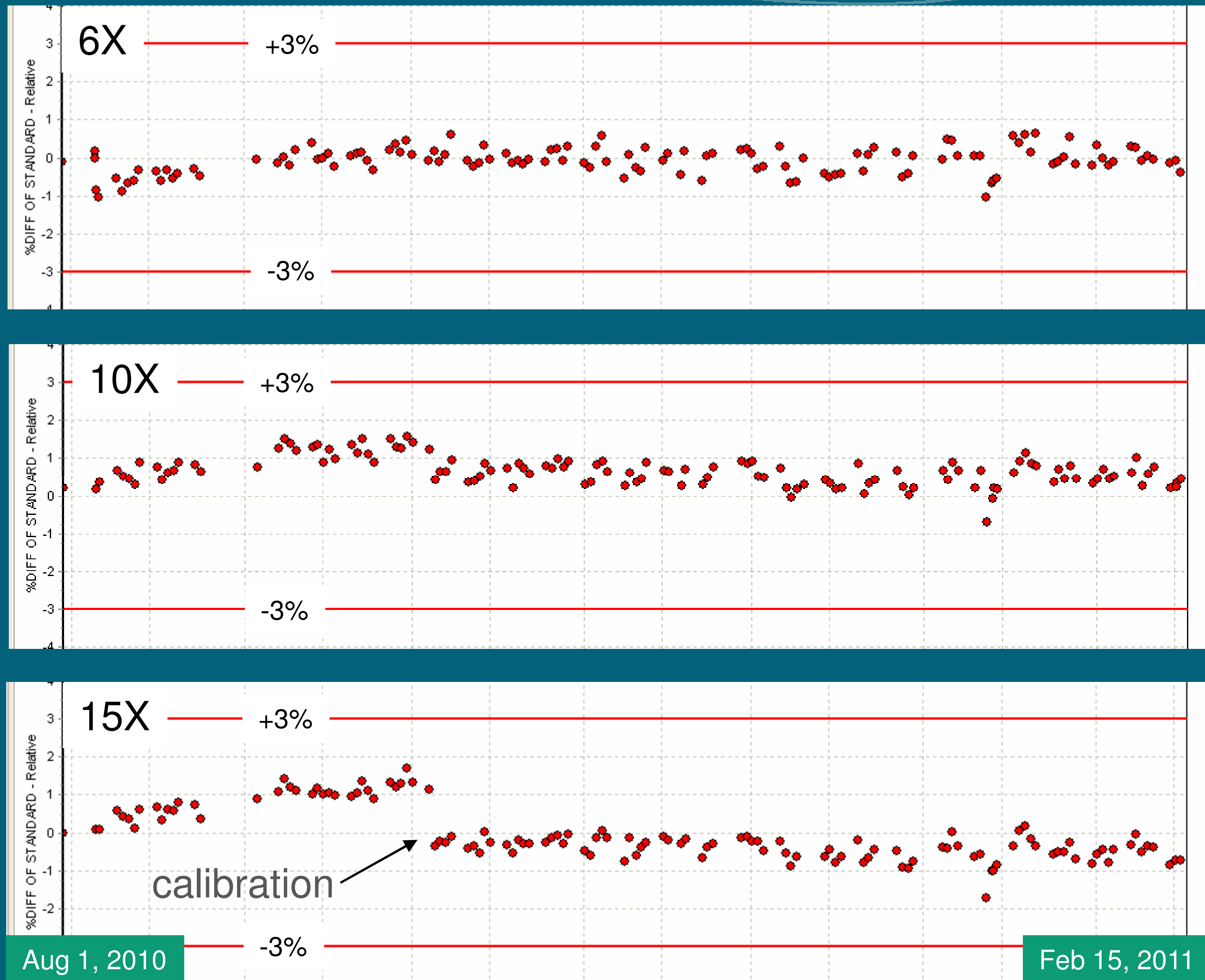


August 1, 2010

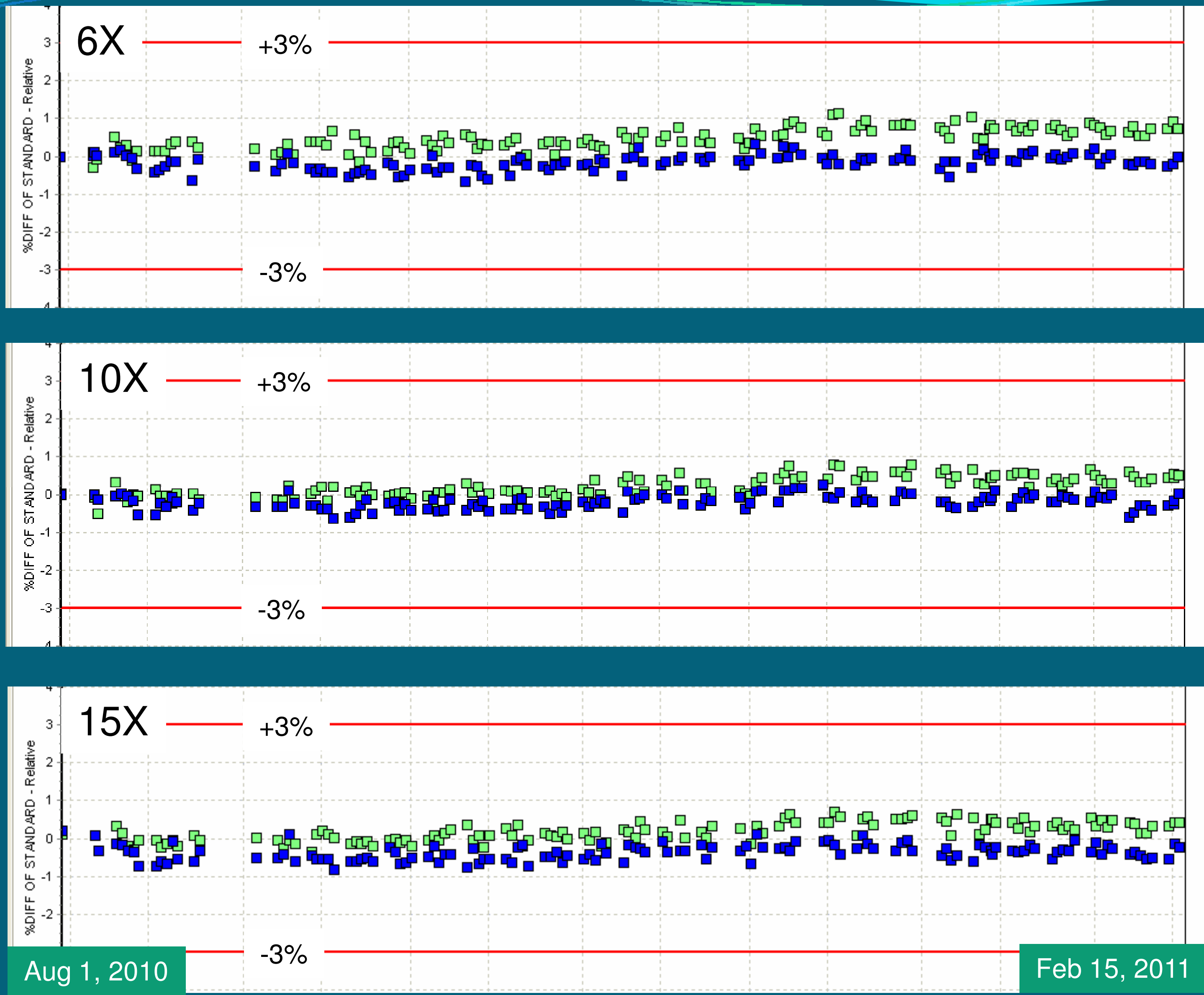
Feb 15, 2011



Long term beam stability (delivered dose)



Long term beam stability symmetry / “flatness”



This presentation will address these topics about FFF X-ray beams:

(A) Production
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(E) Samples of treatment plans with IMRT / RapidArc
(F) Clinical benefits and radiation protection benefits

Four clinical cases, comparing HIM and conventional deliveries, are presented here. All cases presented are optimized using identical optimization parameters for FFF and conventional 6X beams.

SITE # 1 A, B, & C

SBRT lung

dose 10 Gy X 5
A & B mode VMAT (RapidArc 2 arcs)
C mode 9-field IMRT
A MUs (FFF) 3944 / (6X) 5180
B MUs (FFF) 2870 / (6X) 2590
C MUs (FFF) 4330 / (6X) 4101
daily CBCT localization
note clinician and physicist at treatment console for every fraction during XRT.

SITE # 2

Prostate (initial 45 Gy)

1.8 Gy X 25
9-field IMRT with dynamic MLC
MUs (FFF) 1869 / (6X) 1129
kV X-ray with implanted markers

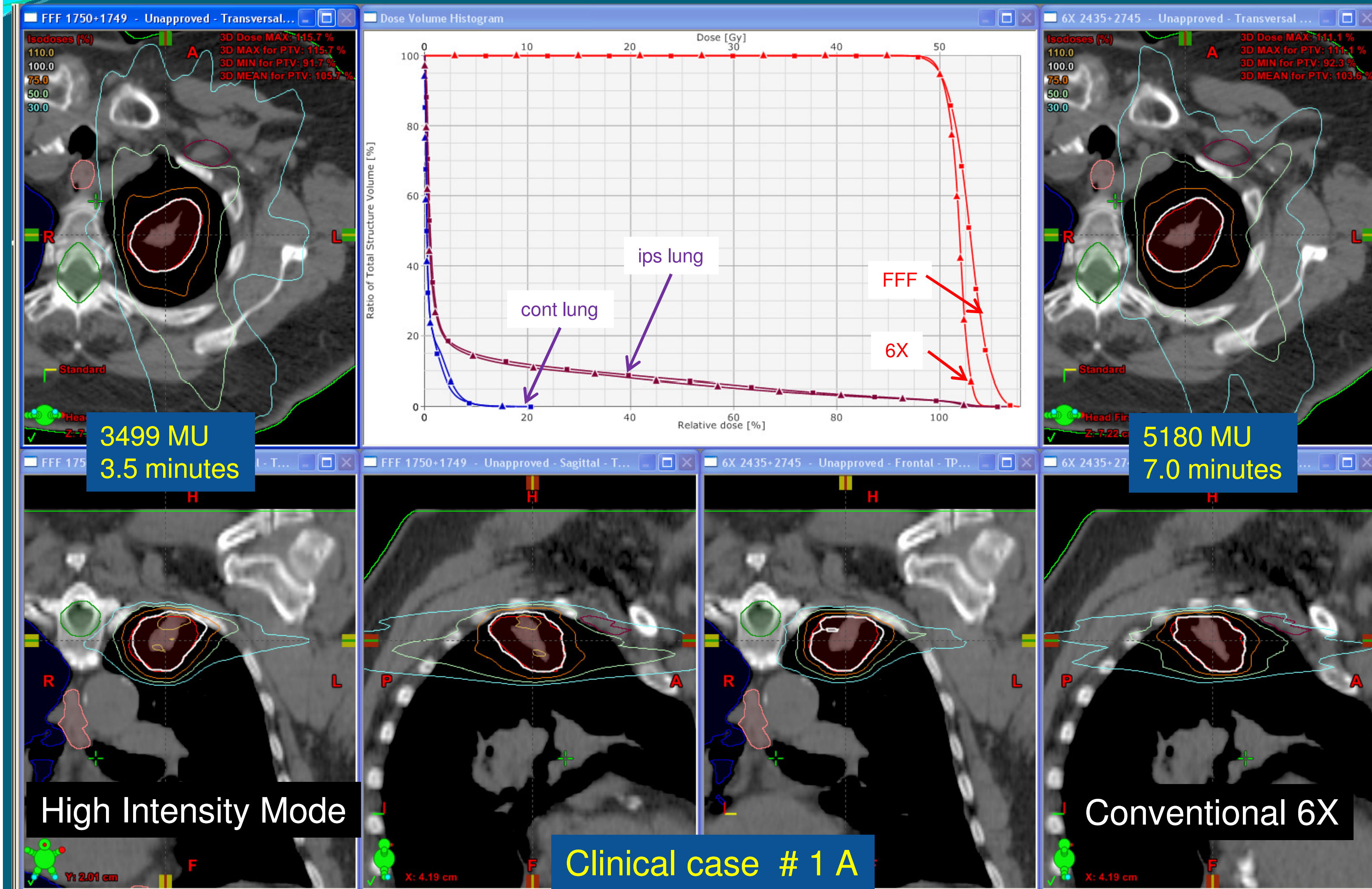
SITE # 3

Head-Neck (initial 50.0 Gy)

2.0 Gy X 25
9-field IMRT with dynamic MLC
MUs (FFF) 2486 / (6X) 1650
Daily CBCT image matching

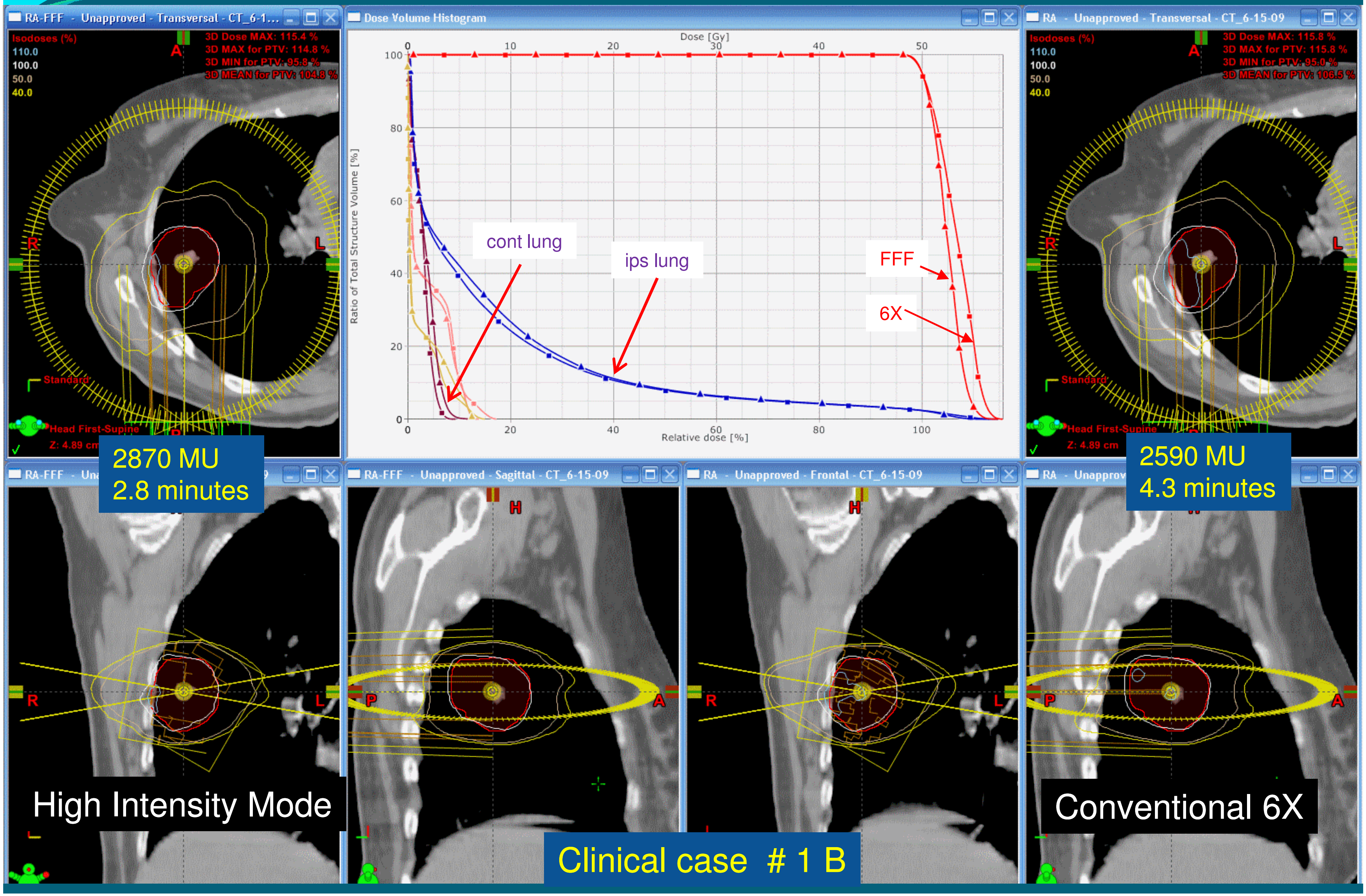
Dosimetric comparison of FFF and conventional (6X) deliveries for an SBRT of a lung lesion (10 Gy X 5) treated with VMAT.

(These two plans are similar, except the hot spot (inside the PTV) for the HIM is larger than the 6X)



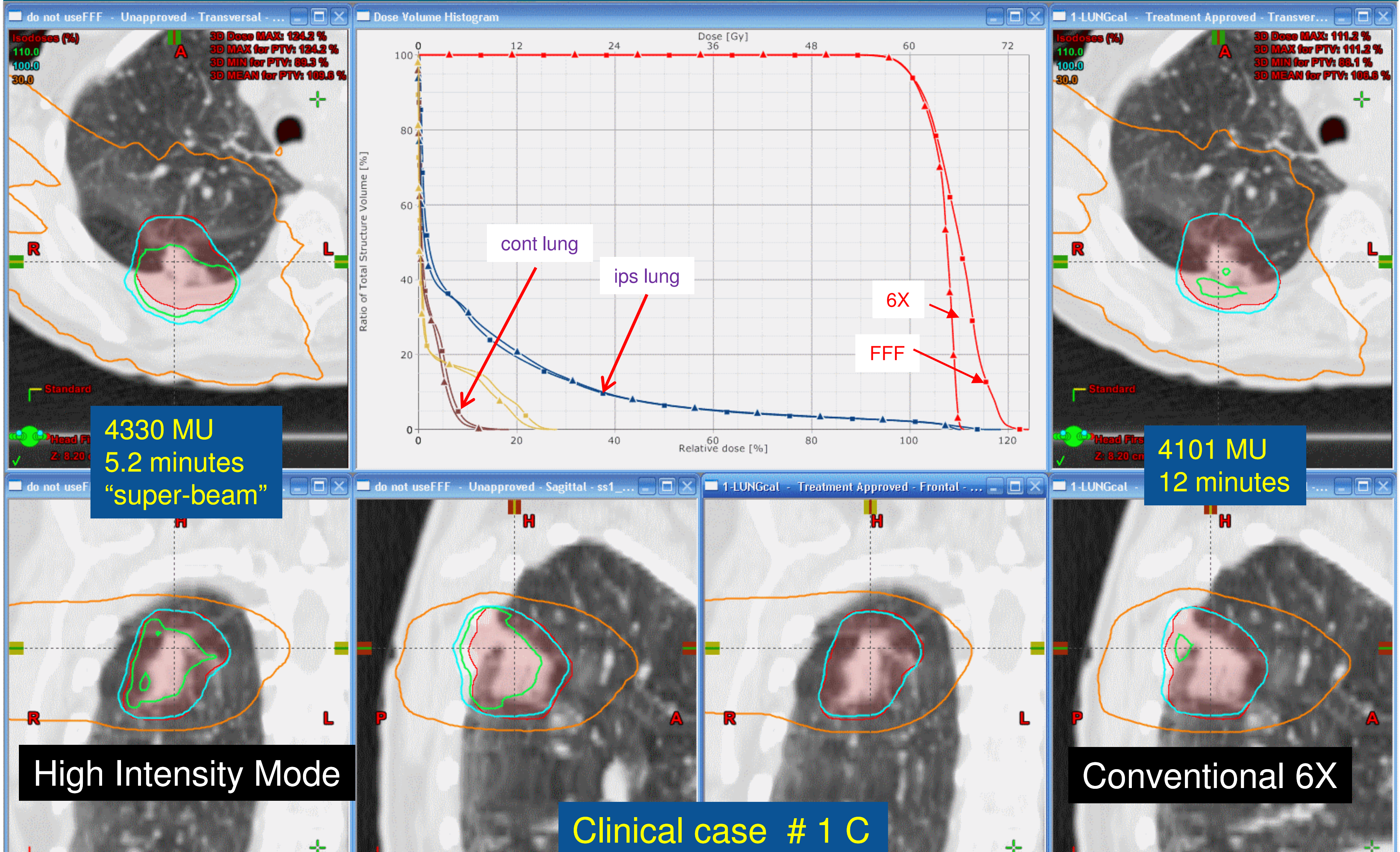
Second example: Dosimetric comparison of FFF and conventional (6X) deliveries for an SBRT of a lung lesion (10 Gy X 5) treated with VMAT.

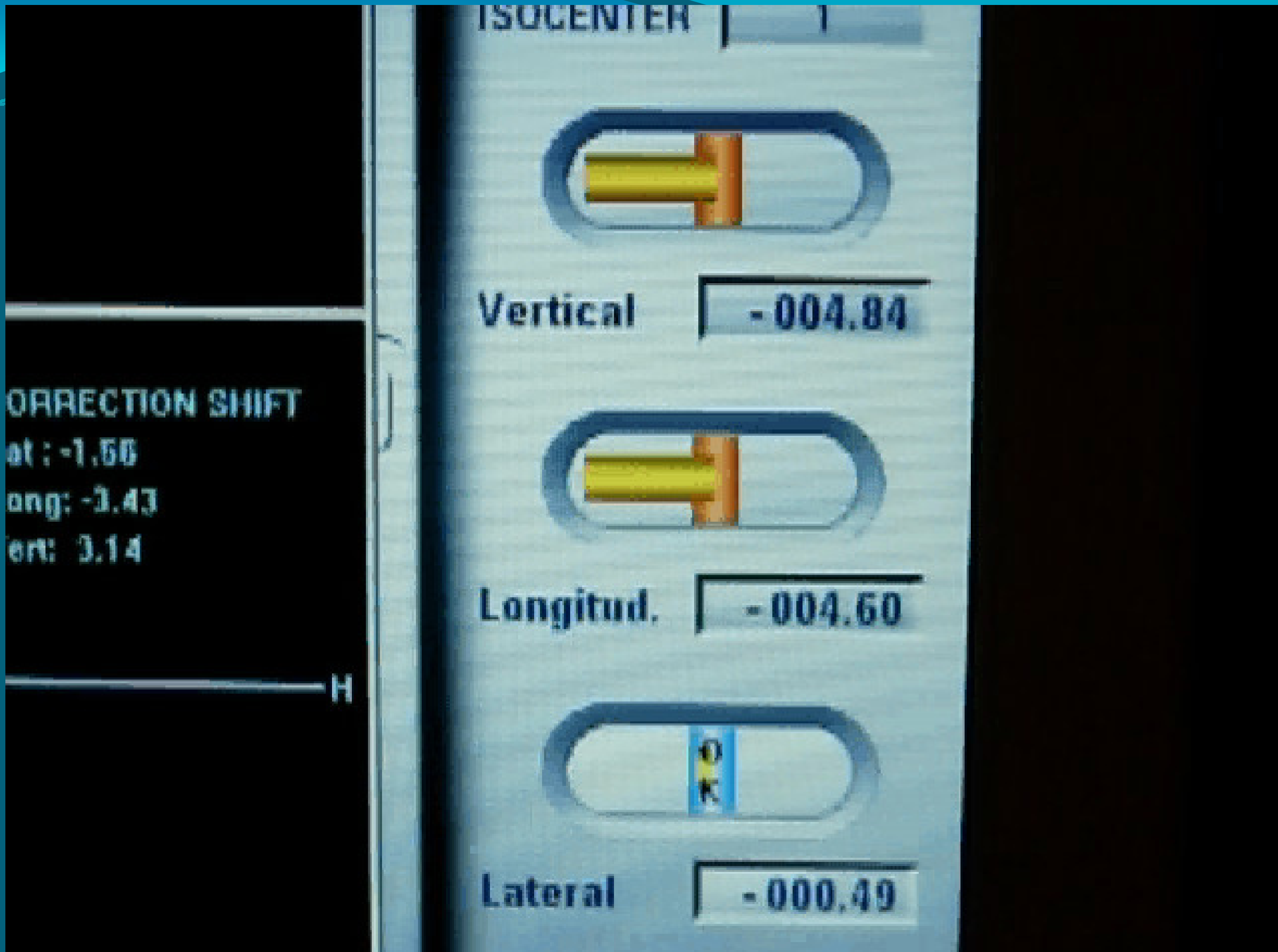
(These two plans are similar, except the hot spot (inside the PTV) for the HIM is LESS than the 6X)



Third example: Dosimetric comparison of FFF and conventional (6X) deliveries for an SBRT (10 Gy X 5) treated with IMRT with *breath-hold*.

(Again, these 2 plans are similar, except the hot spot (inside the PTV) for is HIGHER and the hot spot volume is larger than the 6X. But the MUs for both plans are nearly the same).

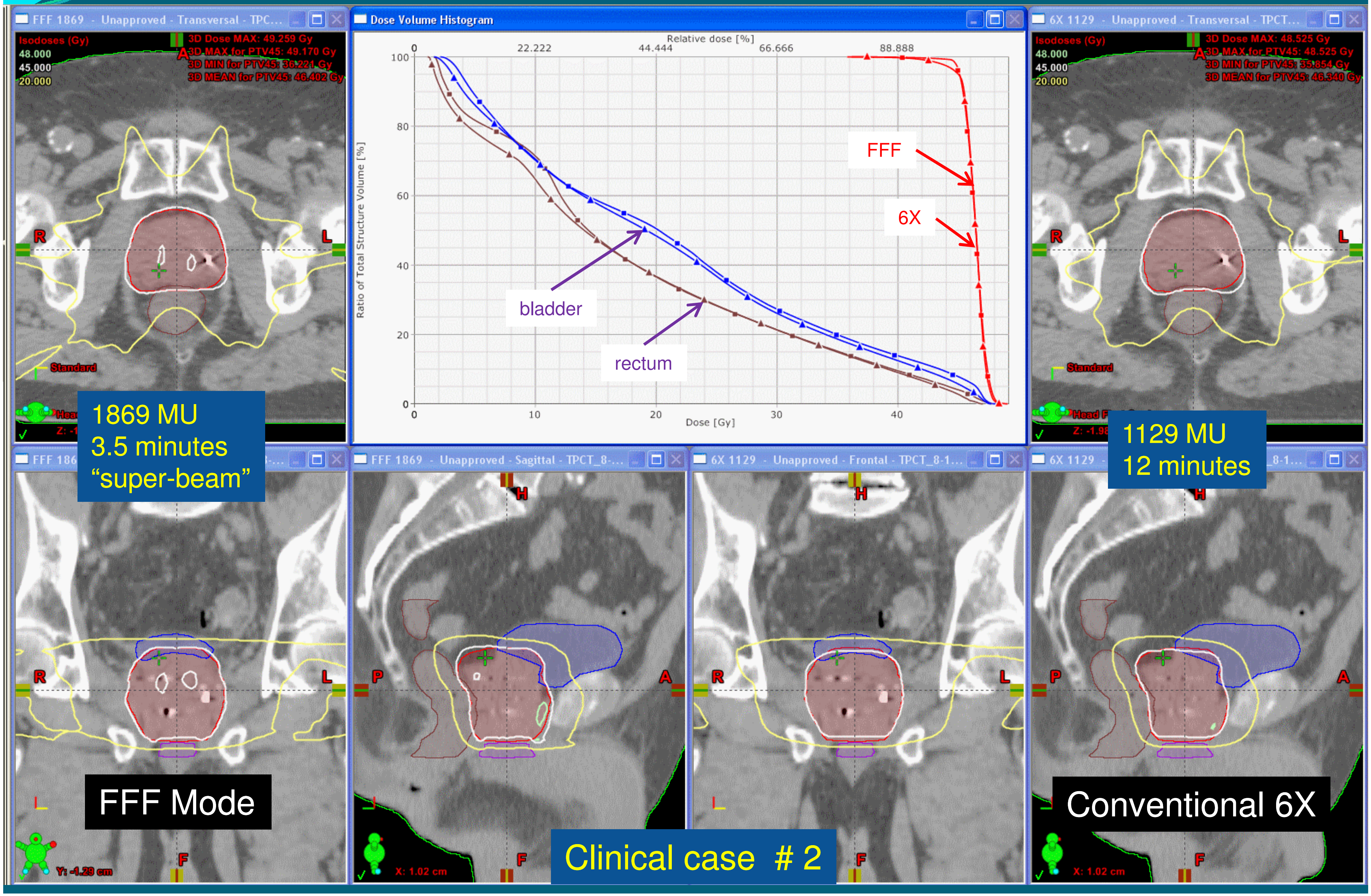


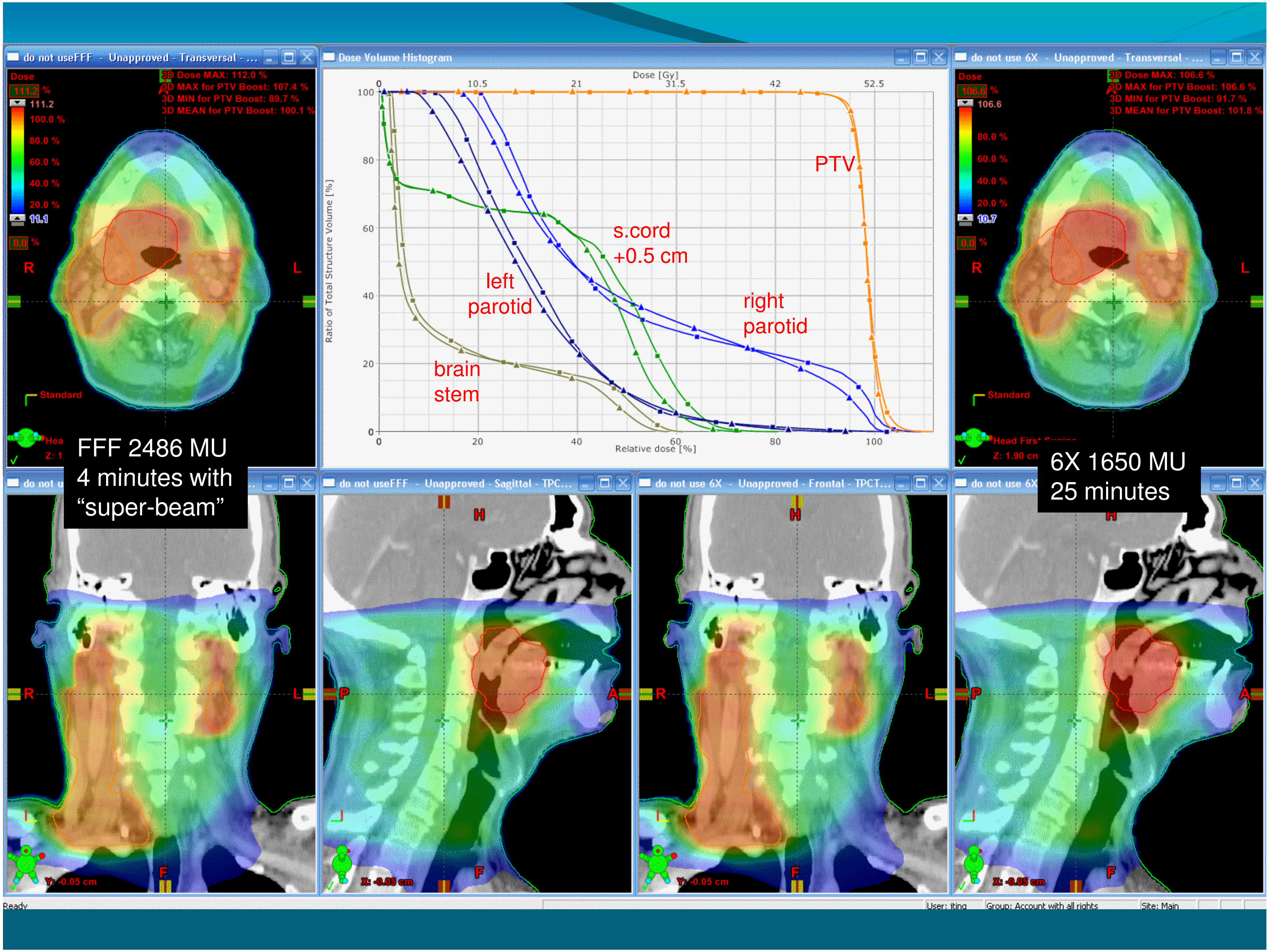


Example of a breath-hold treatment session.
Note: With practice, most patient can hold breath repeatly without problems and we monitor patient motion with IR.

Dosimetric comparison of HIM (FFF) and conventional (6X) deliveries for a prostate treatment (initial XRT prostate+BSV, 1.8 Gy X 25) with IMRT.

(These two plans are similar, except the PTV shoulder for the HIM (FFF) is better than the 6X)



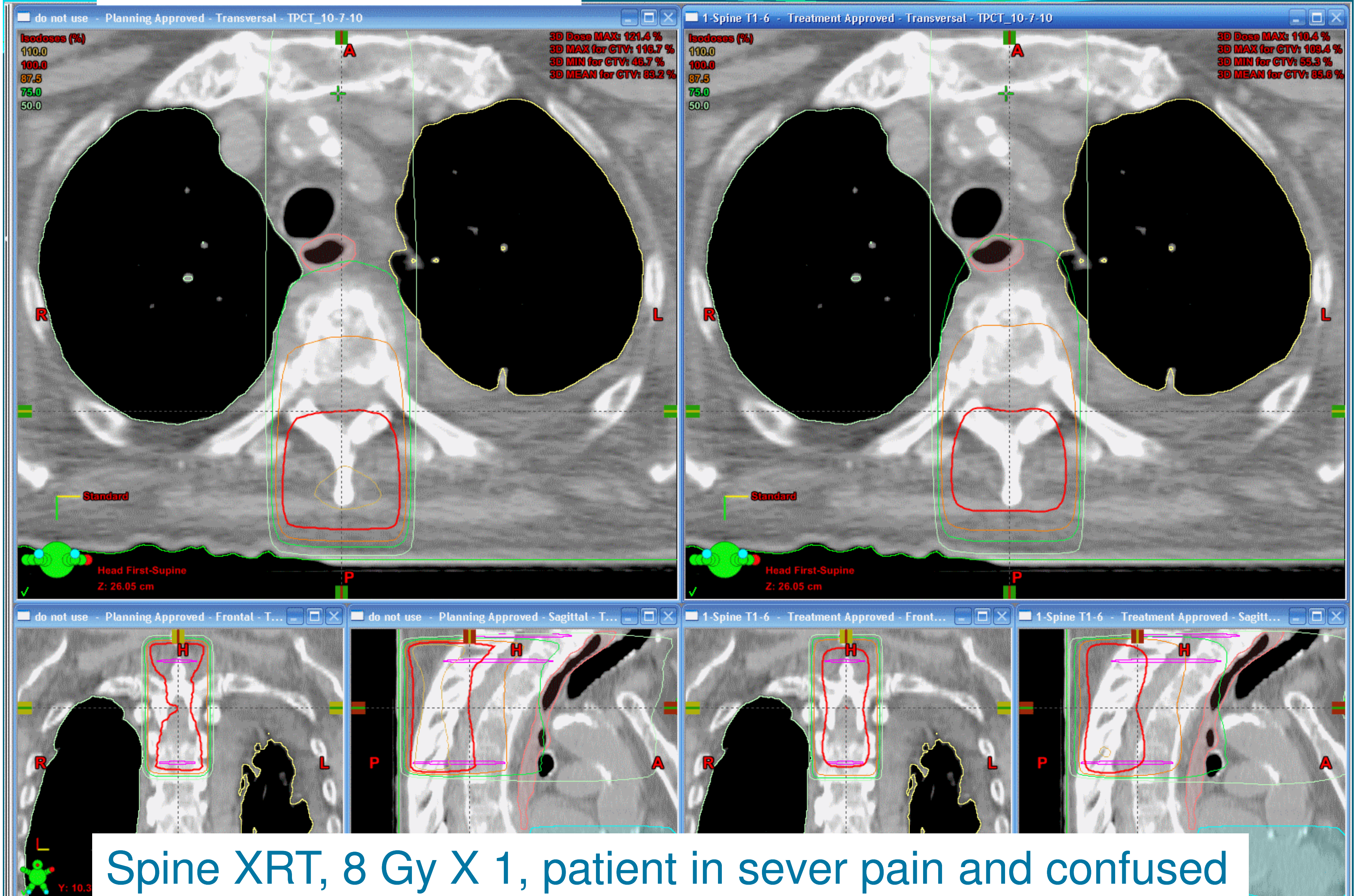

do not useFFF - Unapproved - Transversal - ...
Dose
111.2 %
111.2
100.0 %
80.0 %
60.0 %
40.0 %
20.0 %
11.1
0.0 %
3D Dose MAX: 112.0 %
3D MAX for PTV Boost: 107.4 %
3D MIN for PTV Boost: 89.7 %
3D MEAN for PTV Boost: 100.1 %
R
L
Standard
Dose Volume Histogram
Dose [Gy]
0
10.5
21
31.5
42
52.5
Ratio of Total Structure Volume [%]
Relative dose [%]
PTV
s.cord
+0.5 cm
left
parotid
right
parotid
brain
stem
do not use 6X - Unapproved - Transversal - ...
106.6 %
106.6
10.7
3D Dose MAX: 106.6 %
3D MAX for PTV Boost: 106.6 %
3D MIN for PTV Boost: 91.7 %
3D MEAN for PTV Boost: 101.8 %
FFF 2486 MU
4 minutes with
“super-beam”
6X 1650 MU
25 minutes
do not useFFF - Unapproved - Sagittal - TPC...
do not use 6X - Unapproved - Frontal - TPCT...
H
F
P
A
Y: -0.05 cm
X: -0.05 cm
Ready
User: iting
Group: Account with all rights
Site: Main

Can one use the High Intensity Mode (FFF) in a simple PA spine treatments ?

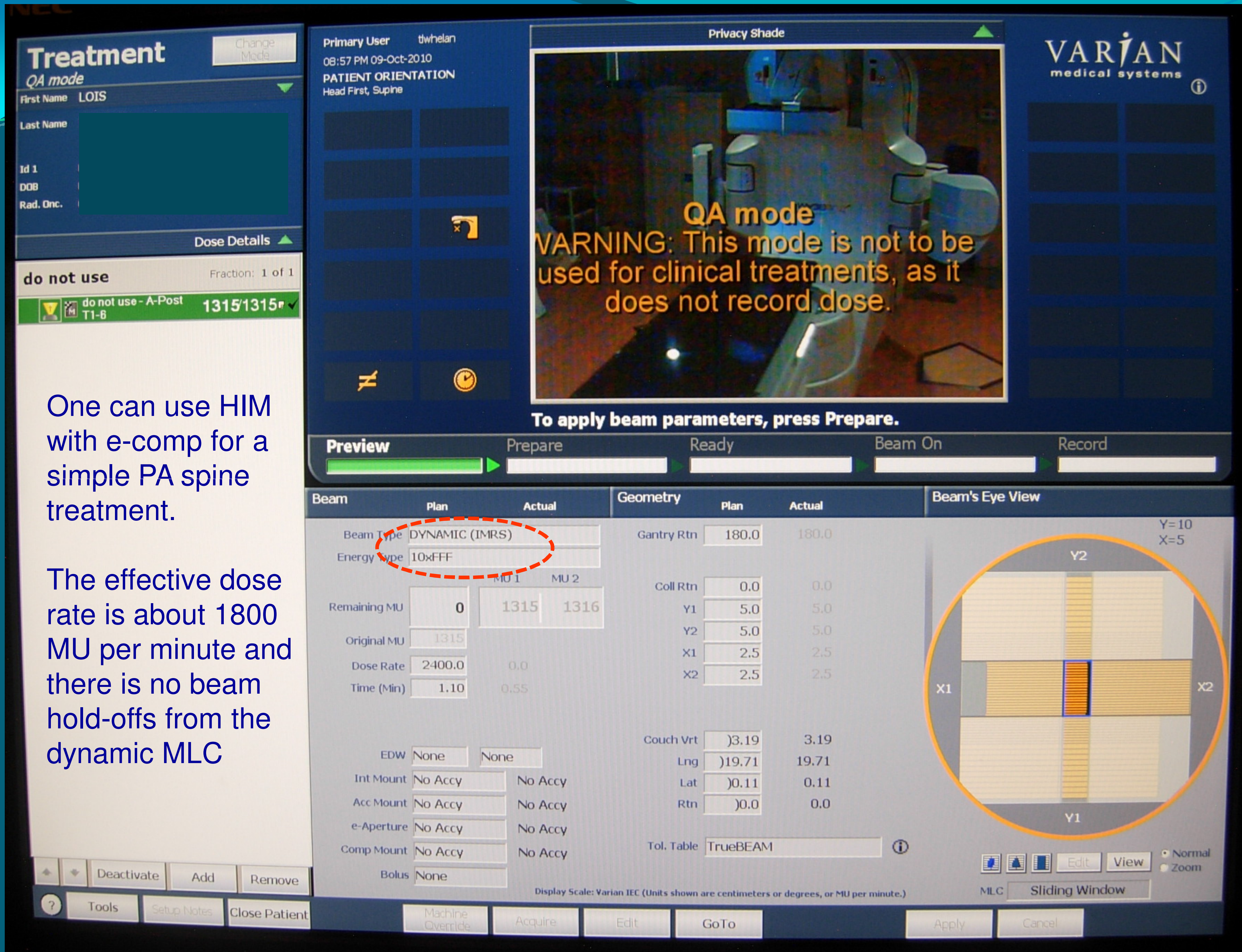
Would there be any benefits to patients ?

“10X” FFF , 1315 MU, with e-comp
2400 MU/minute (45 seconds)

15X, 789 MU, open field
600 MU/minute (80 seconds)

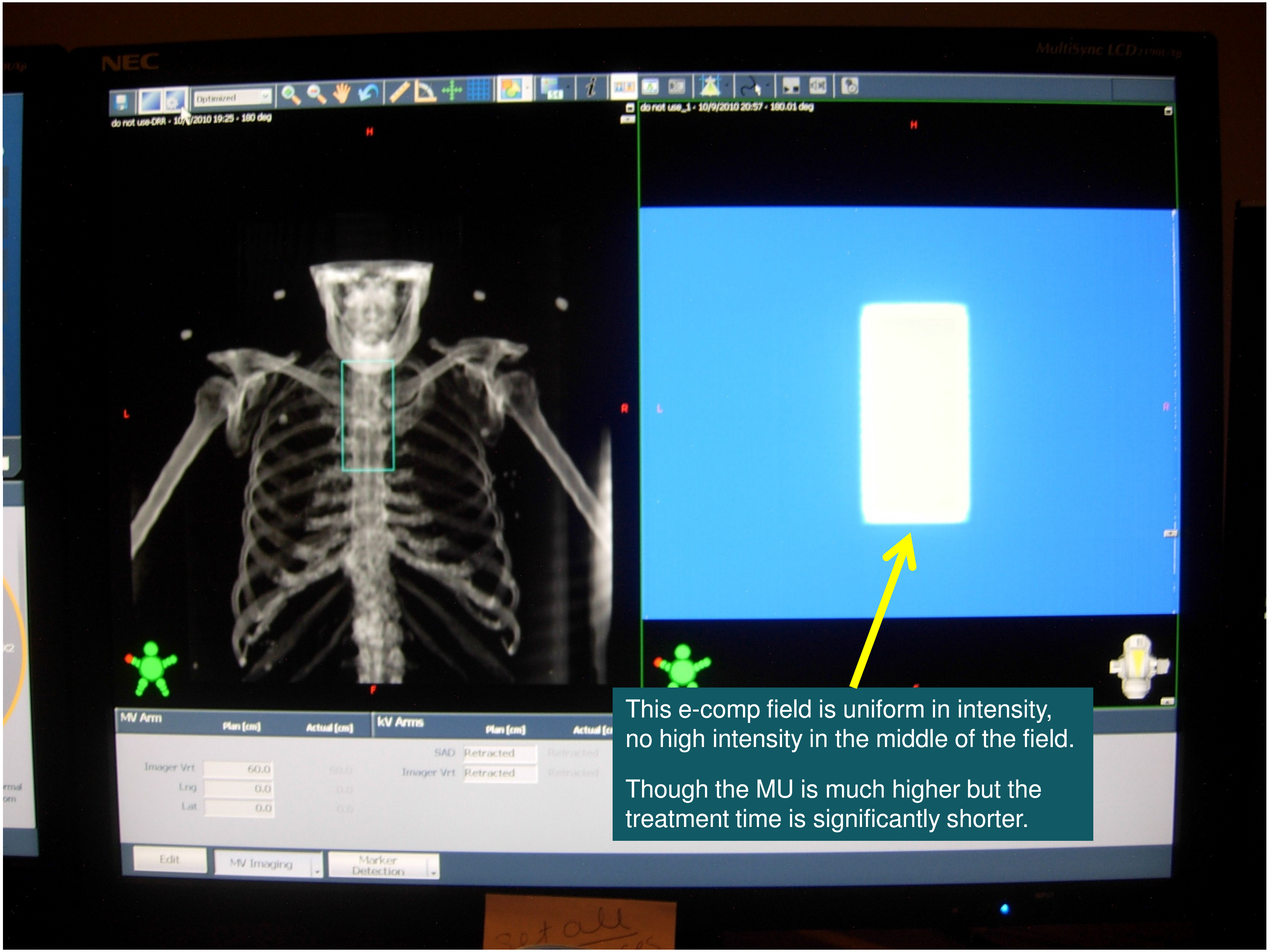


Spine XRT, 8 Gy X 1, patient in sever pain and confused



One can use HIM with e-comp for a simple PA spine treatment.

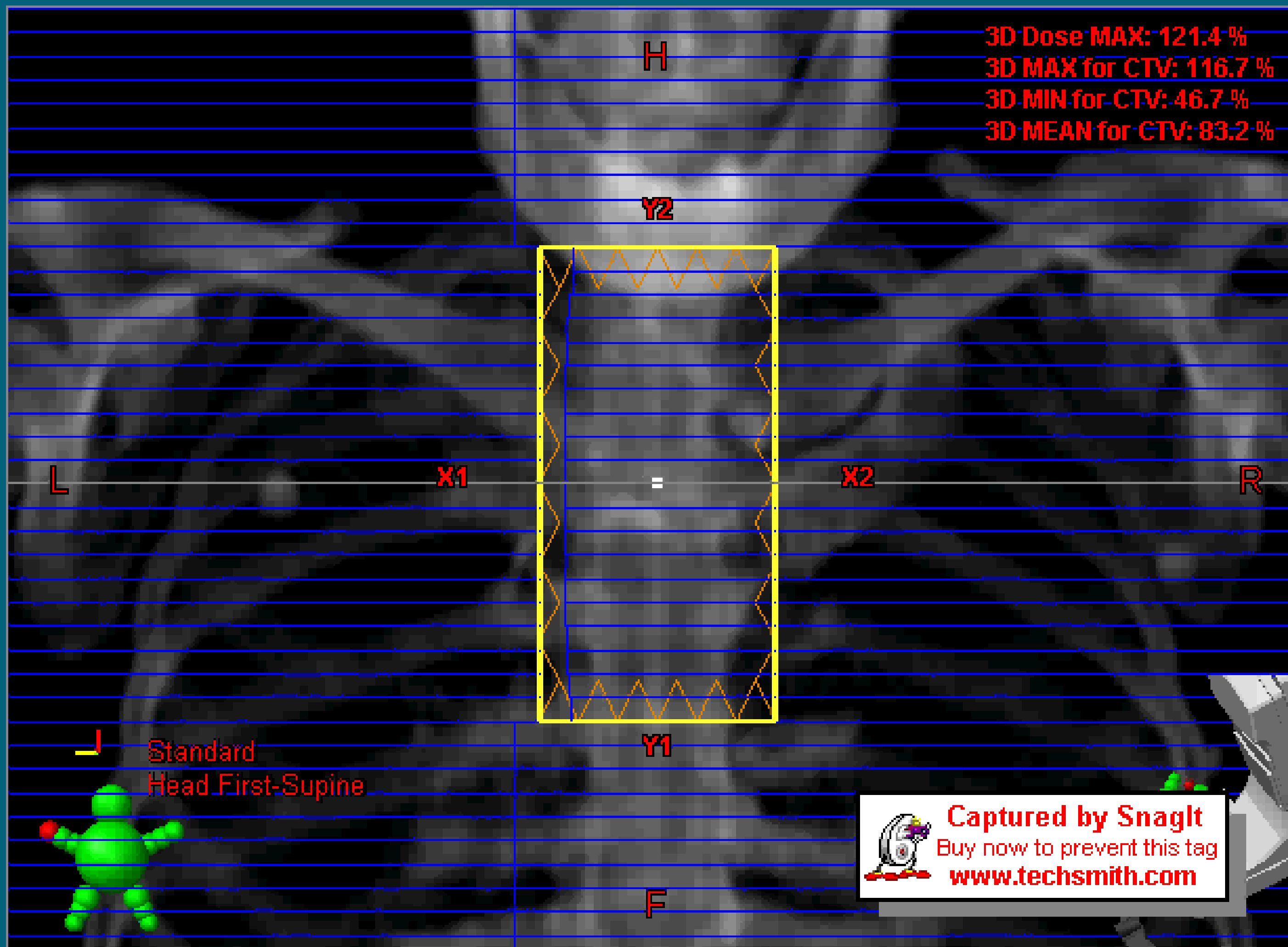
The effective dose rate is about 1800 MU per minute and there is no beam hold-offs from the dynamic MLC



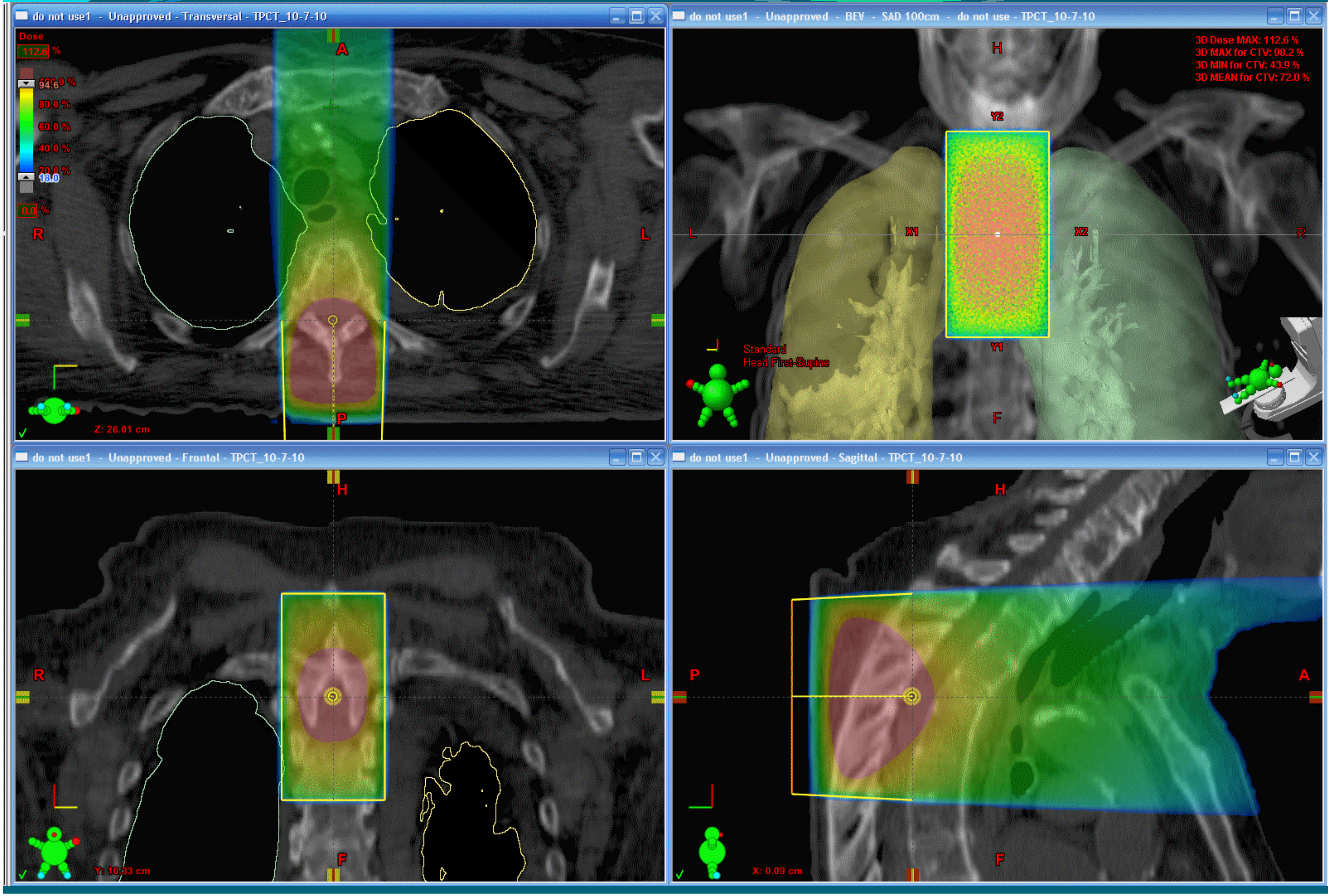
This e-comp field is uniform in intensity, no high intensity in the middle of the field.

Though the MU is much higher but the treatment time is significantly shorter.

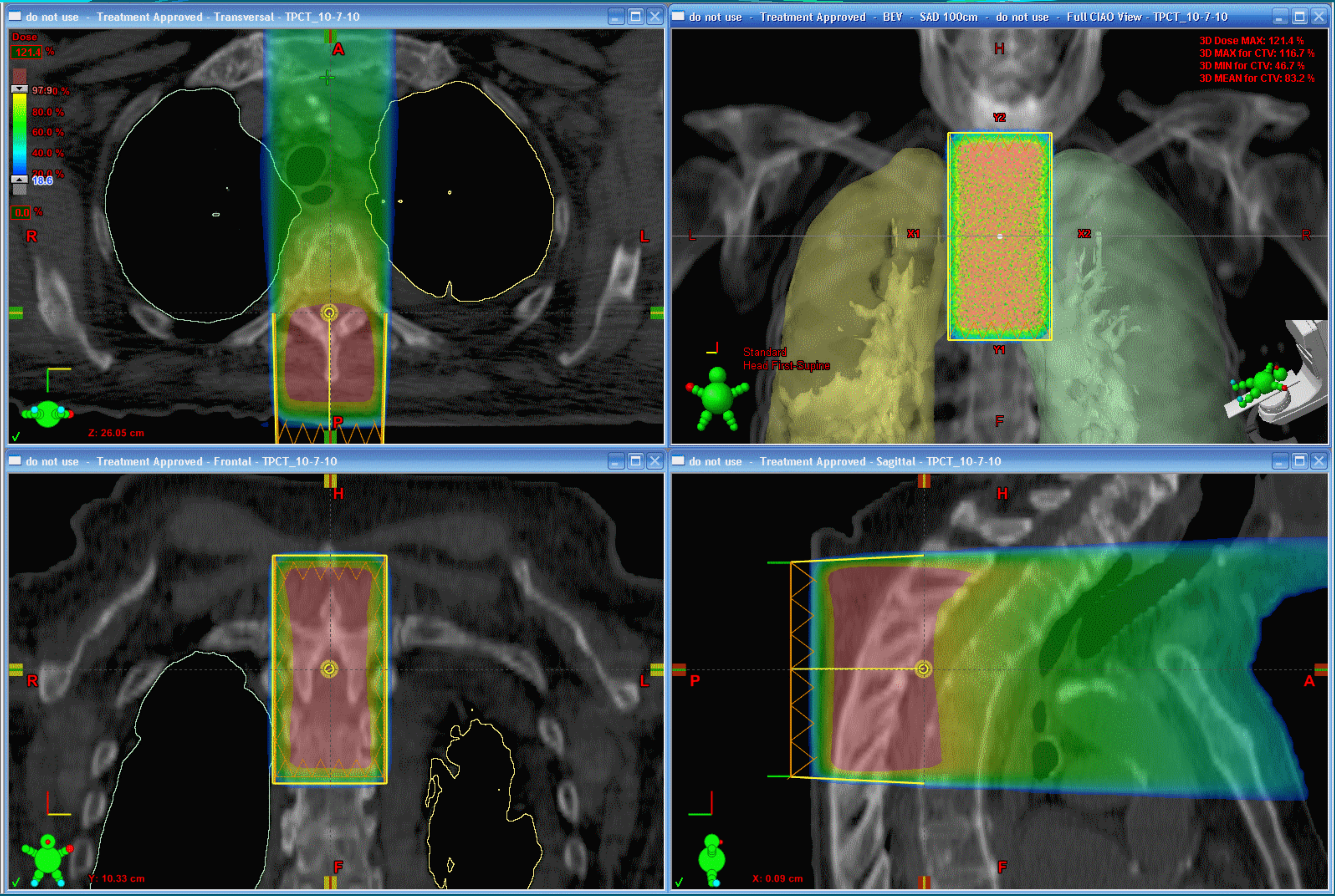
This movie loop shows the dynamic MLC movement as an electronic tissue compensator. But, in this instance, the dynamic MLC serves the purpose of "flattening filter" to reduce the beam intensity in the middle of the treatment field.



This high intensity mode (FFF) field has no d-MLC compensation and it is non-uniform in intensity, high intensity in the middle of the field



This high intensity mode treatment field (FFF) has d-MLC compensation and it is uniform in intensity, and there is no high intensity in the middle of the field.



Though the “*Stated Dose Rate*” (maximum MU / minute) is 1400 or 2400, the “*Effective Dose Rate*” during an IMRT or a RapidArc treatment can be very different.

The “*Effective Dose Rate*” is heavily influenced by MLC movements and/or GANTRY movements. In the case of RapidArc (VMAT) deliveries, it is a combination of both.

A simple calculation about "effective dose rate" when using FFF:

GANTRY

Maximum GANTRY speed: 1.0 revolution / sec (1.0 RPM).

If the arc angle is 210 degrees, it takes 35 seconds for the gantry to travel this 210-degree arc.

If the FFF dose rate is 1400 MU / min., it takes 43 seconds to deliver 1000 MU.

Thus, if 1000 MU is required for a RapidArc (VMAT) field and the arc travel is 210 degrees, there will be ***no delay*** of dose rate caused by the MLC travel (43 second > 35 second).

If 700 MU (30 seconds) is required for the same field and the gantry travel is 1.0 RPM, there ***WILL BE delays*** of dose rate caused by the MLC travel (30 second < 43 second).

(816)

And, calculation about “effective dose rate” when using FFF:

MLC

Maximum MLC speed: 2.0 cm / sec.

If the maximum travel (X-jaw opening) is 10 cm, it takes 5 seconds for the leaf to travel this 10 cm span.

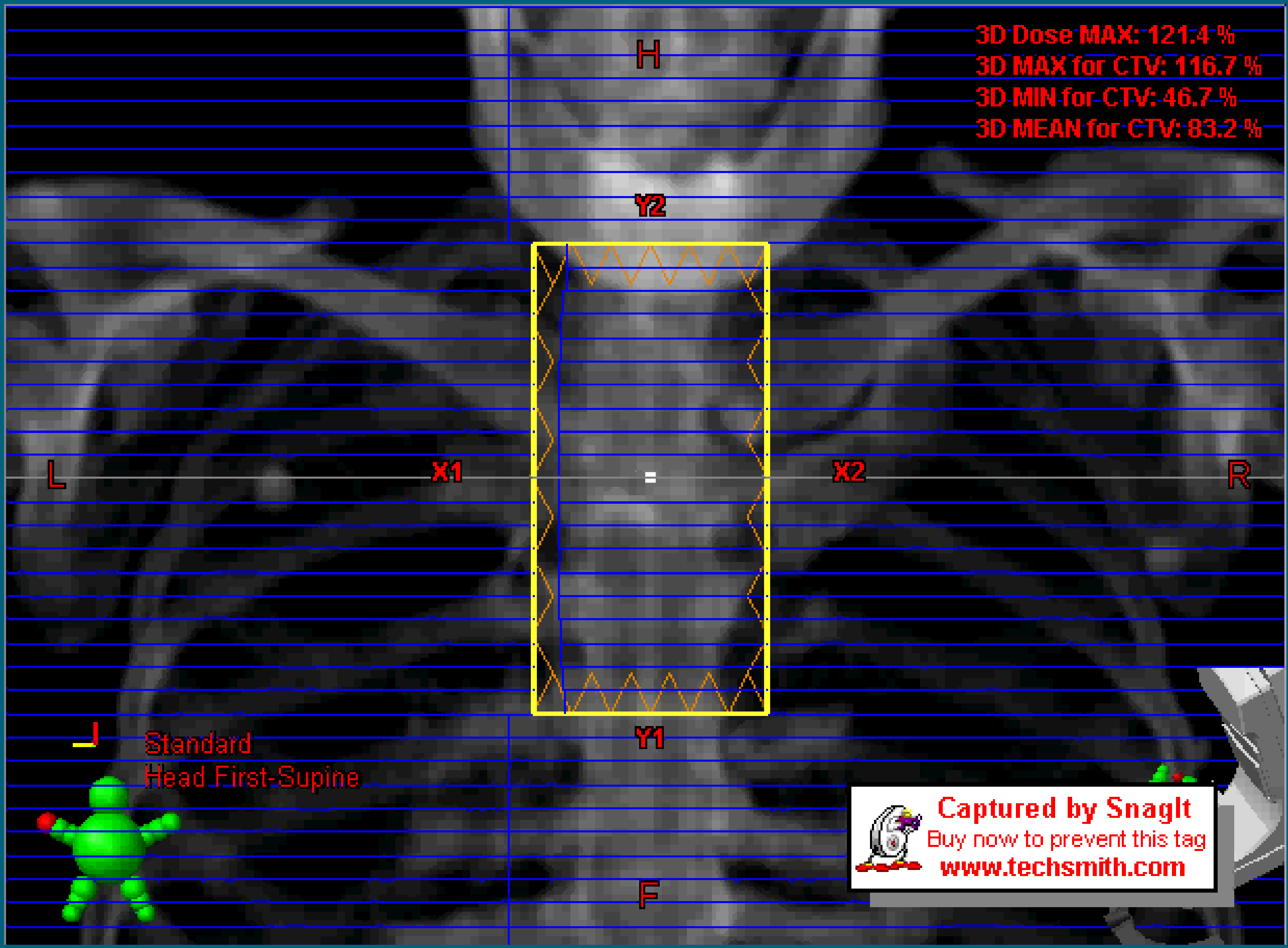
If the FFF dose rate is 1400 MU / min., it takes 8.6 seconds to deliver 200 MU.

Thus, if 200 MU is required for a field and the MLC travel is 10 cm, there will be ***no delay*** of dose rate caused by the MLC travel (8.6 second > 5.0 second).

If 100 MU (4.3 seconds) is required for the same field and the MLC travel is 10 cm, there ***WILL BE delays*** of dose rate caused by the MLC travel (4.3 second < 5.0 second).

Actually, it is not so simple because not all MUs are available for leaf movements. Therefore, computation of “effective dose rate” from FFF beam before actual treatment (or QA session) is difficult.

For example, in this electronic tissue compensator field, the dynamic MLC serves the purpose of “flattening filter” to reduce the intensity in the center of the tfield andonly a very small portion of the MUs are available for MLC movements.



Based upon our preliminary studies, we found:

- Treatment plans generated with HIM (FFF) or conventional X-ray beam are quite similar based on coverage of PTVs, DVHs, and dose maximum evaluations.
- There is no clear cut differences for PTV coverage or organ sparing. There is no clear indication which mode would have a better dosimetric advantage over another.
- Some small variations are observed between patients and plans but no conclusions could be derived at this time. More clinical studies / investigations are needed.

Based upon our preliminary studies, we found (continued):

- In some instances, MUs are higher for one and, in other instances, MUs are higher for the other. Furthermore, the differences in MUs could be very large, as shown in previous clinical examples.
- Hypothesis to be tested: MUs will be comparatively less if the effective field size (not the collimator setting) is smaller than 6 cm X 6 cm.
- We found that the "beam-on" time is definitely shorter. This has clear clinical implications in organ motion and patient movement management.

High Intensity Mode delivery has clear implications in organ motion and patient movement management :

- “Beam-on” time is shorter for SBRT deliveries (typically 3000 to 4000 MUs)
- And, because of the lengthy treatment with conventional treatment beam, often it is advisable to take kV X-rays to confirm patient / target positions during an SBRT session. With HIM, the treatment time is significantly reduced and the need for kV re-localization could become un-necessary.

High Intensity Mode delivery has clear implications in organ motion and patient movement management (continued):

- "Breath-hold" technique is now easier to be implemented and it can be prescribed for more patients.
- Over-all treatment time required for "Respiratory Gating" could be much shorter because a larger proportion of radiation dose can be delivered during the "beam-on" cycle. Or, within a given duty cycle, many more MUs could be delivered.
- If the "beam-on" time is much shorter during VMAT deliveries, it could reduces the patient motion during treatment and improves patient comfort (typically reduced from 3 +/- to 1.5 +/- minutes) This is of great significance because the need to interrupt a VMAT delivery to take re-confirmation kV X-rays can be eliminated.

Finally, there are still other benefits brought about by the HIM (FFF) X-ray beams:

(A)Production
(B)Dosimetric properties (PDD and Profiles)
(C)Parameters and quantification of the flattening filter free beam
(D)Typical clinical applications
(E)Samples of treatment plans with IMRT / RapidArc
(F)Clinical benefits and radiation protection benefits

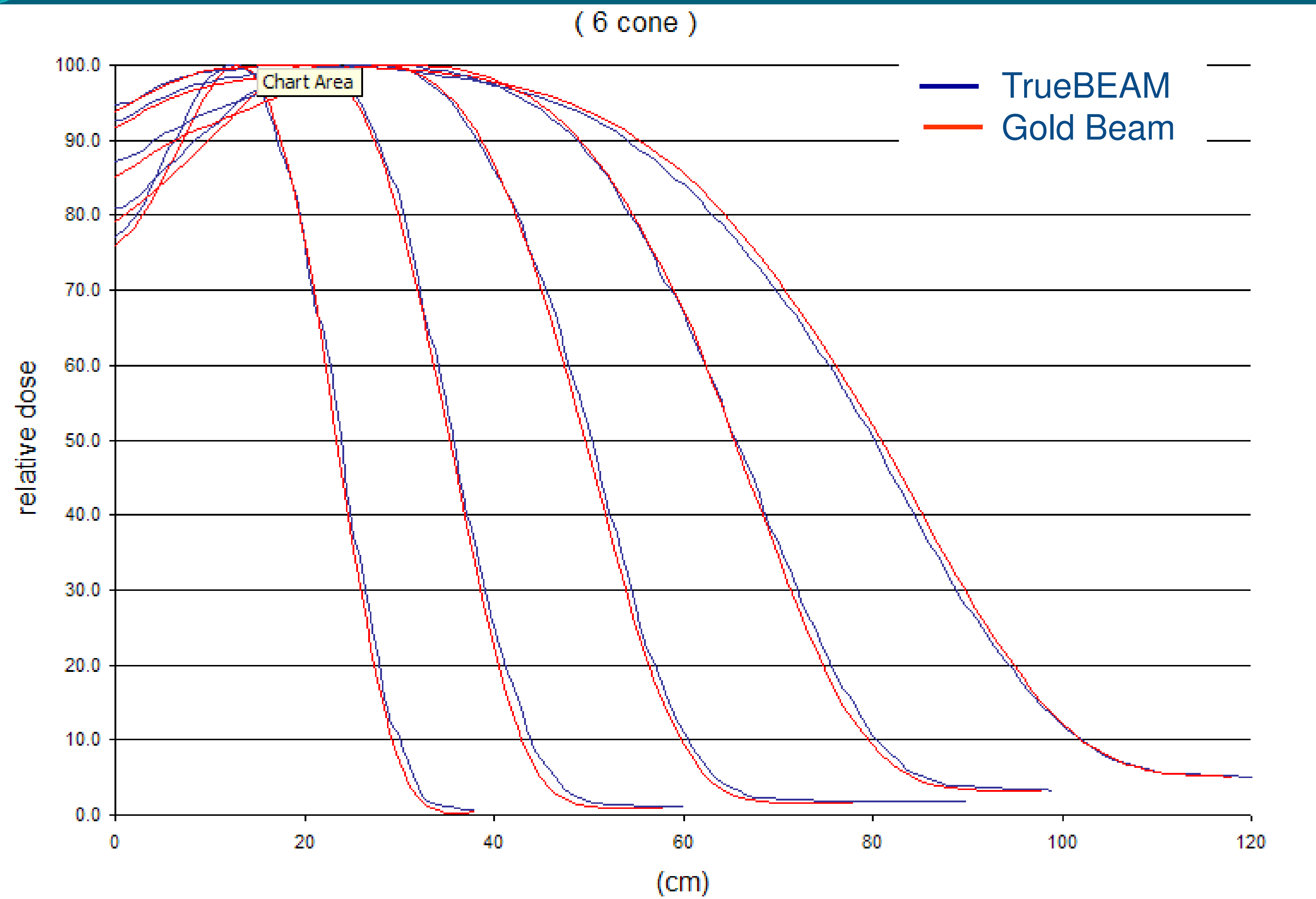
Because of the more efficient use of photons from the accelerator guide, the High Intensity Mode (FFF) has these benefits in radiation protection design (though it is not practical to design a treatment room based on the High Intensity Mode operation at this time).

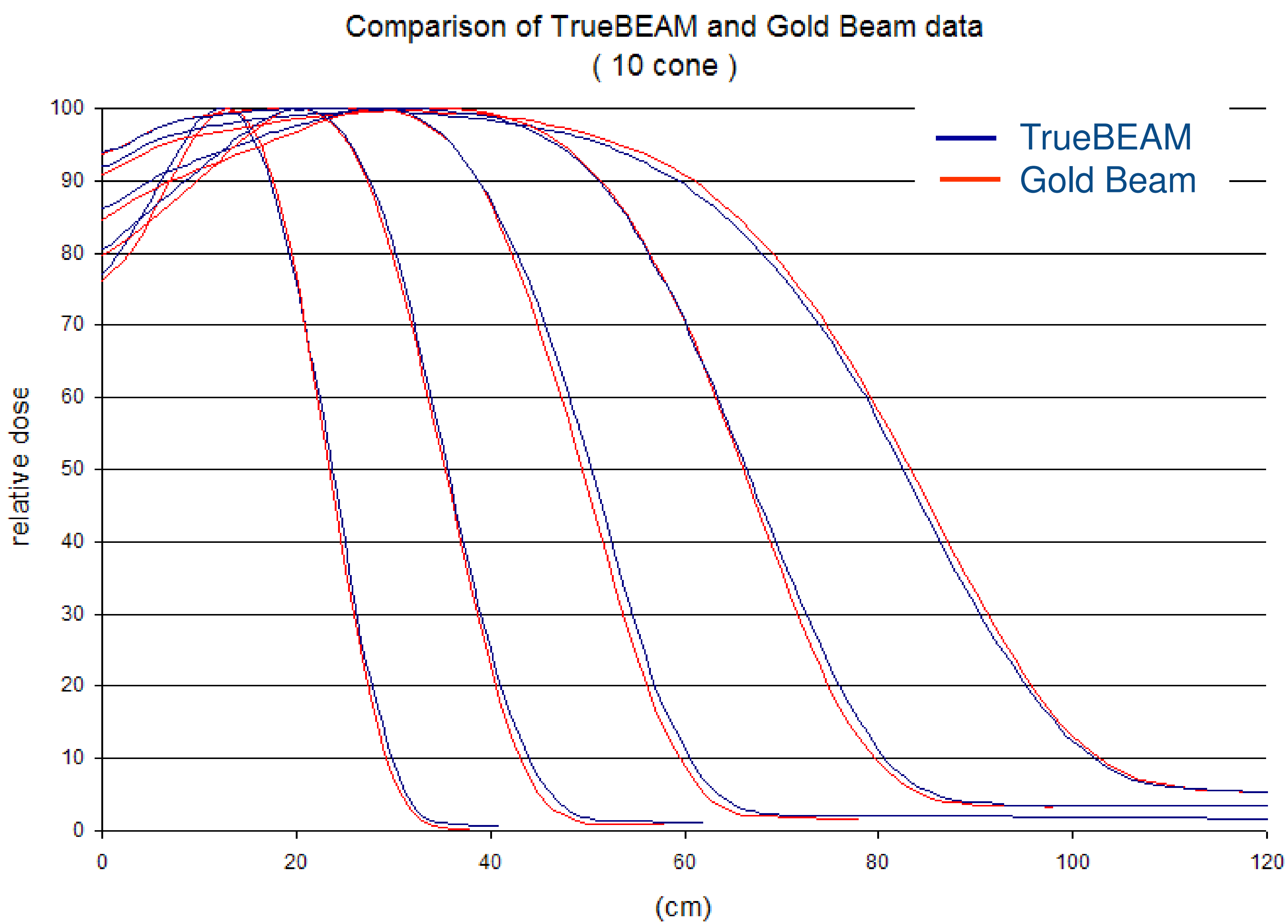
(A) Less head leakage by definition (mR per cGy at the isocenter).

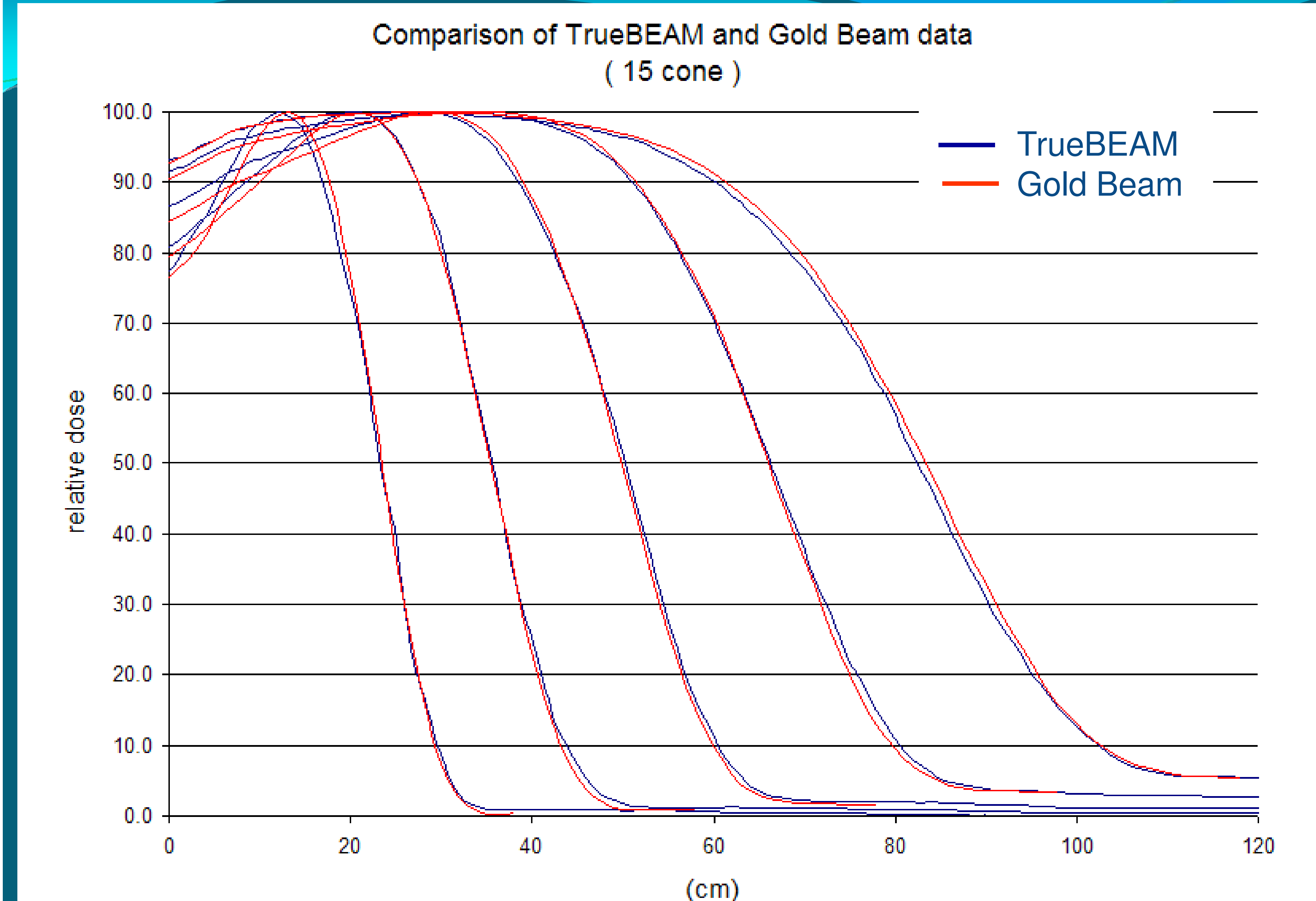
(B) Less neutron production by definition (mREM per cGy at the isocenter).

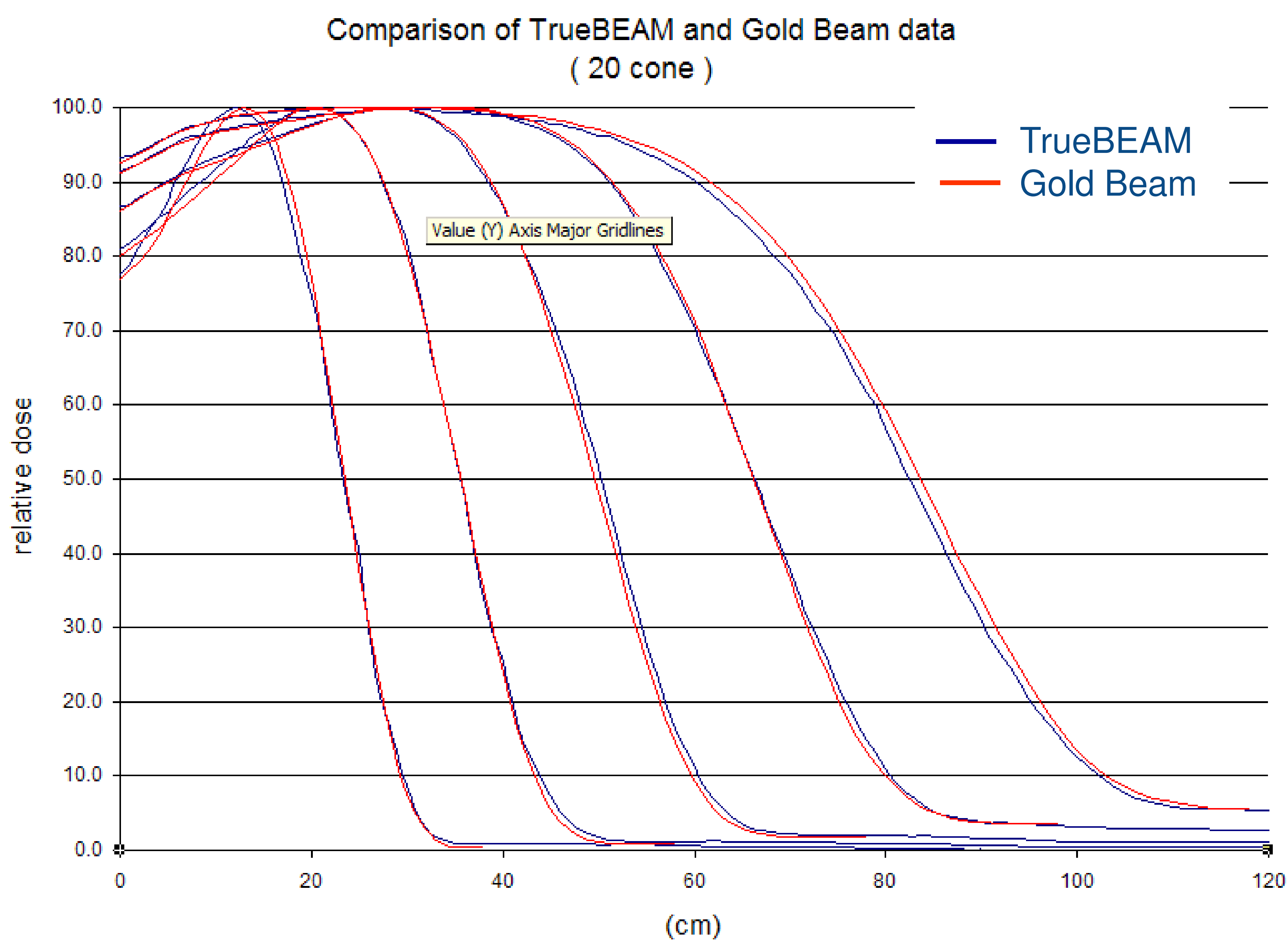
(C) There are more photons from the accelerator guide hitting the clinical target (more efficient use of the electrons in an accelerator guide).

For those curious minds in the audience:
This is a comparison of GOLD BEAM and TrueBEAM electron data

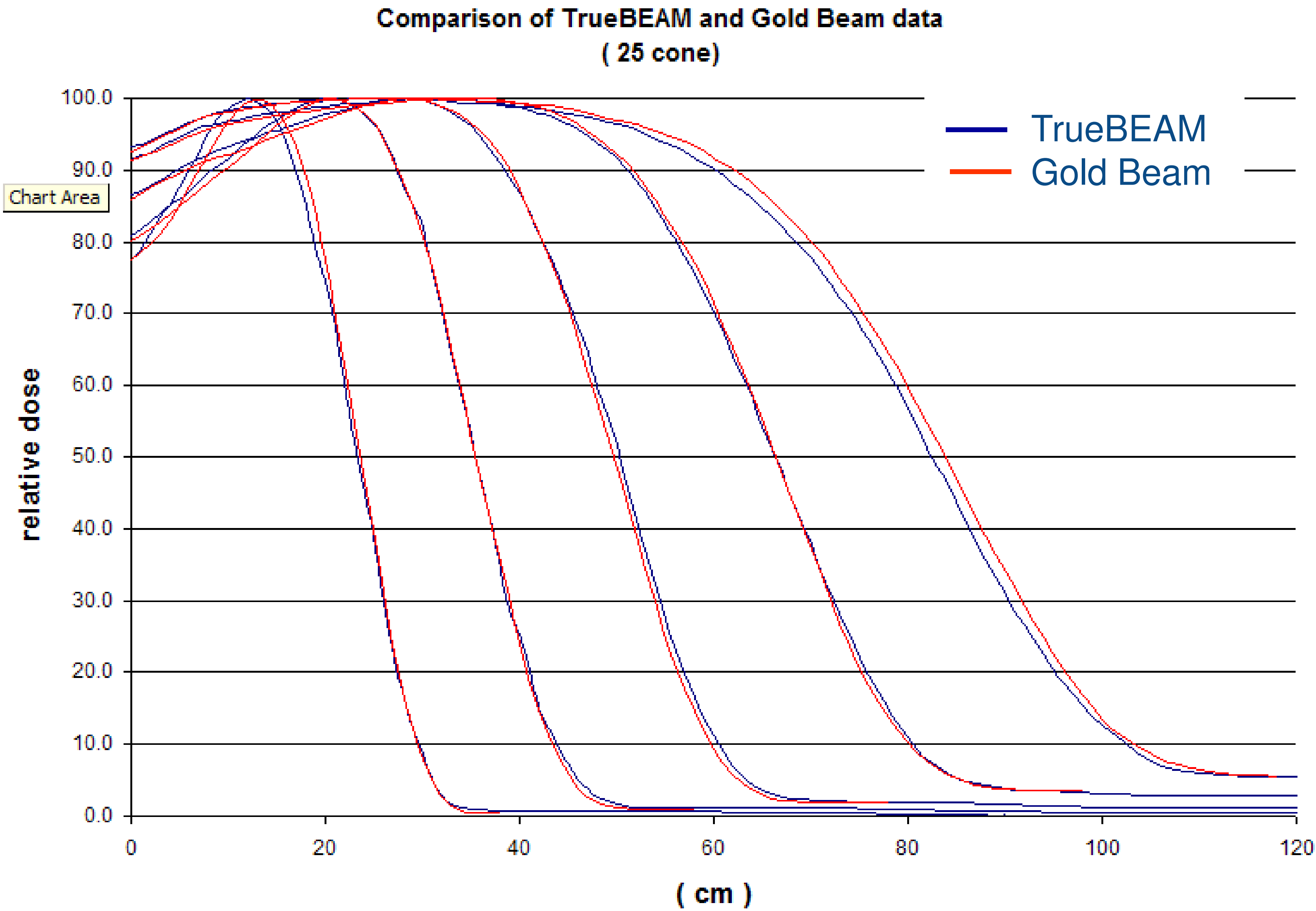



Comparison of TrueBEAM and Gold Beam data
(10 cone)
relative dose
(cm)
TrueBEAM
Gold Beam
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
120


Comparison of TrueBEAM and Gold Beam data
(15 cone)
relative dose
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
20
40
60
80
100
120
(cm)
TrueBEAM
Gold Beam



Comparison of TrueBEAM and Gold Beam data
(20 cone)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
relative dose
0
20
40
60
80
100
120
(cm)
TrueBEAM
Gold Beam
Value (Y) Axis Major Gridlines



Comparison of TrueBEAM and Gold Beam data
(25 cone)
relative dose
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
20
40
60
80
100
120
(cm)
TrueBEAM
Gold Beam
Chart Area

Thank you