International Comparison of Varian LINAC Commissioning Data for a Common Independent Monitor Unit Calculator

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Purpose

- (1) To compare the commissioning data from 10 different Varian high energy LINACs installed in North America.
  - Profile comparisons
  - PDD's
  - Open output and Wedge factors
  - Horns vs PDD comparison

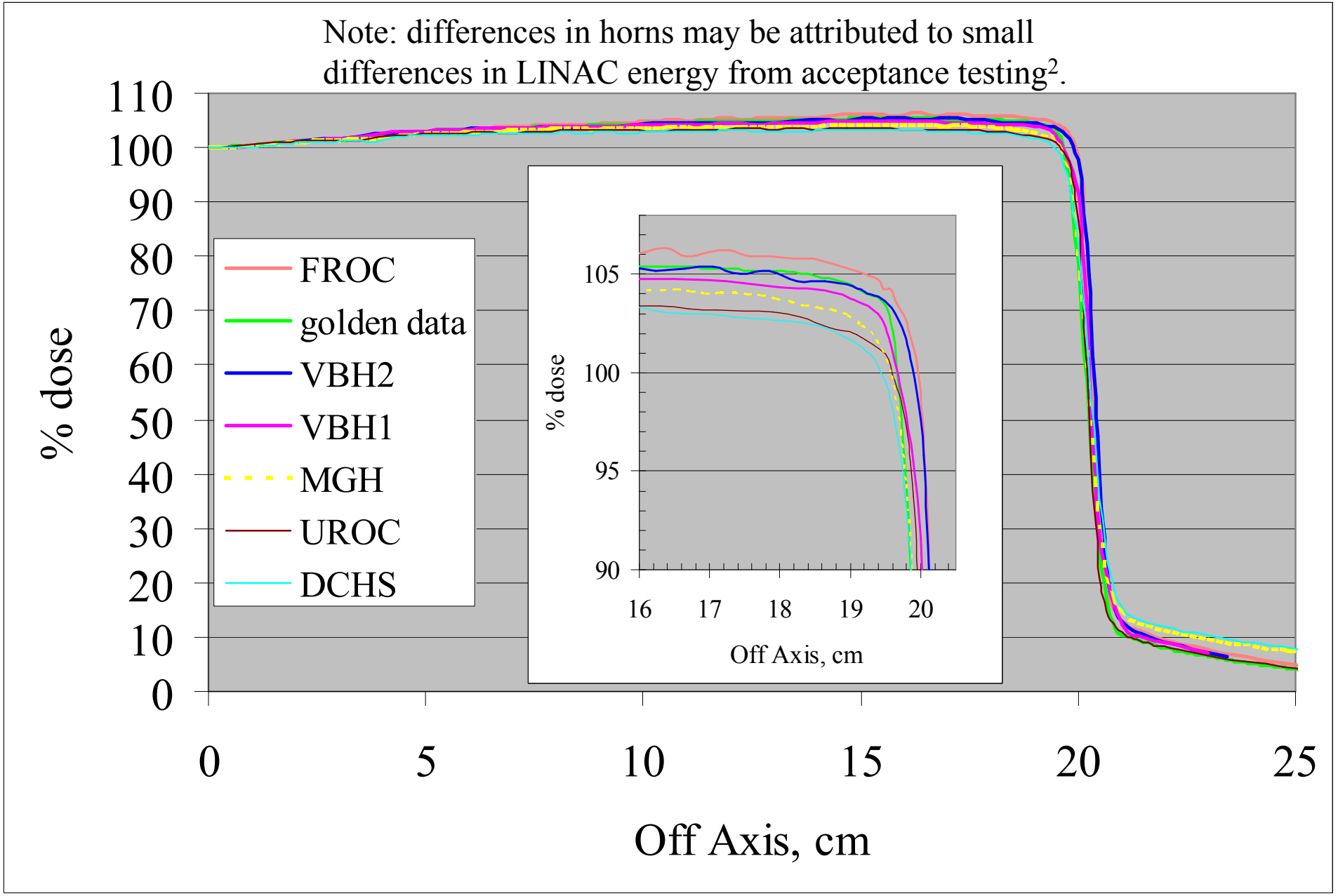
(2) To illustrate the need for proper documentation of methods used in data collection, and

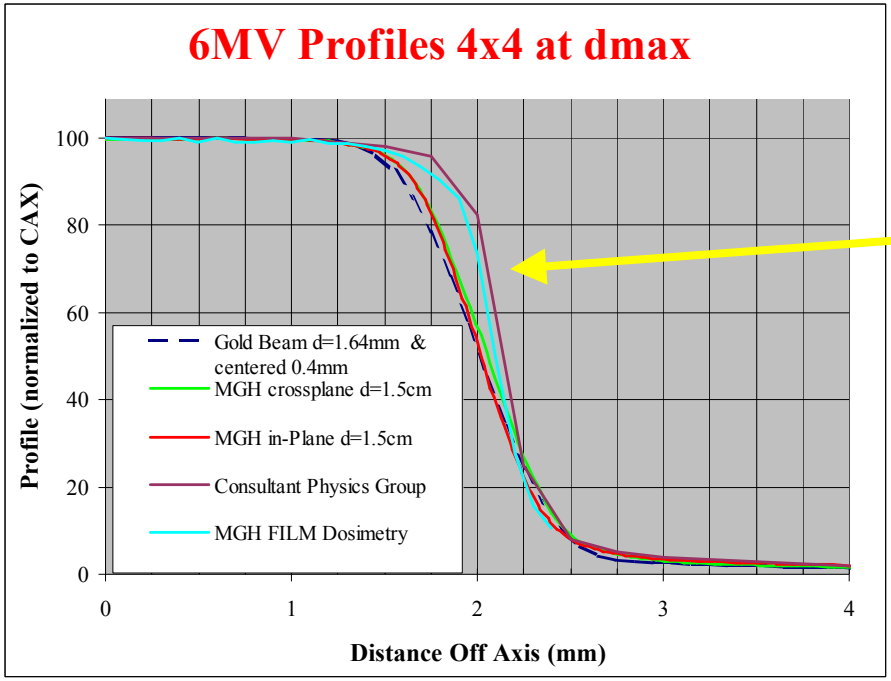
- (3) To demonstrate a simple independent Monitor Unit calculator that is based on data from institutions other than the one the patient plan is created under.

Data Collection Sites and Scanning Equipment

- London Regional Cancer Center (LRCC), London, Ontario Canada (RFA-300; RK cylindrical ion chamber)
- Stony Brook Medical Center (SB), Stony Brook, NY (Wellhofer)
- Vassar Brothers Medical Center (VBH1 and VBH2),Poughkeepsie, NY (RFA-Plus; RK 0105 ion chamber)
- Fishkill Radiation Oncology Center (FROC), Fishkill, NY (RFA-Plus; RK cylindrical ion chamber)
- Ulster Radiation Oncology Center (UROC), Kingston, NY (RFA-Plus; RK cylindrical ion chamber)
- Marquette General Hospital (MGH), Marquette, MI (PTW-MP3; TN 31002 cylindrical ion chamber)
- Dickinson County Health System (DCHS), Iron Mountain, MI (PTW-MP3; TN 31002 cylindrical ion chamber)
- Inova Alexandria Hospital Cancer Center, Alexandria, VA (RFA-Plus, RK chamber)
- Hershey Medical Center (HMC), Hershey, PA (Blue Phantom, CC-13 chamber)
- Varian Golden Beam Data Set (GBD) (Wellhofer)
- BJR-11 report

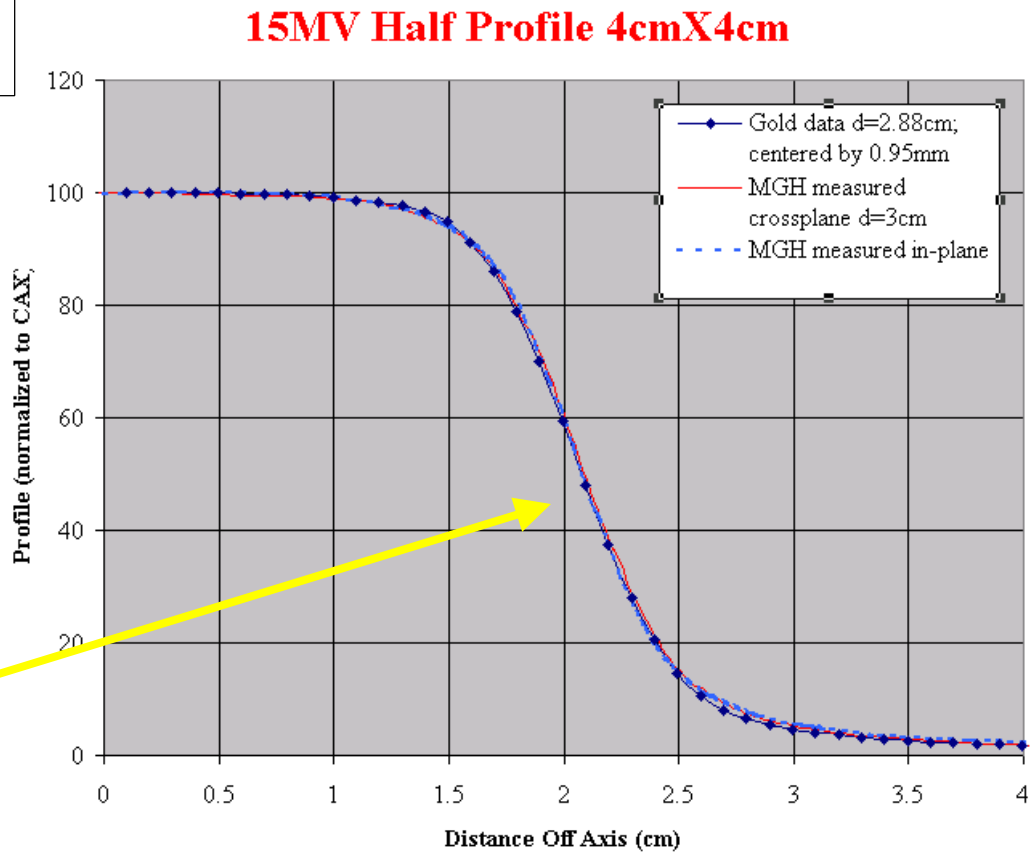
6MV 40cmx40cm Half Profiles





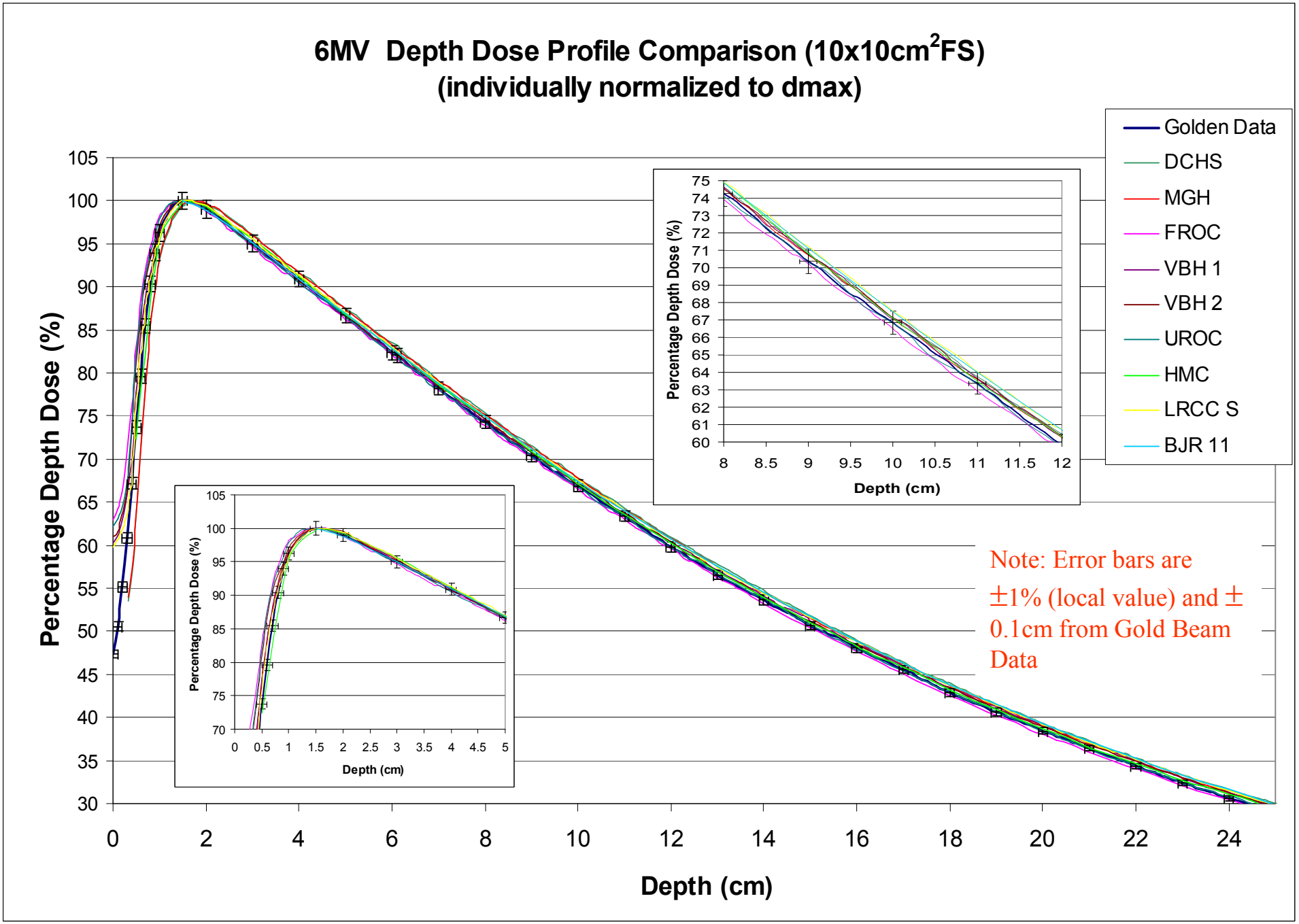
4cmx4cm Profile comparisons

Results: Film dosimetry reveals a steeper penumbra than ion chambers which have a volume averaging effect[1]. Data for your TPS should be collected per the manufacturer's recommendation.

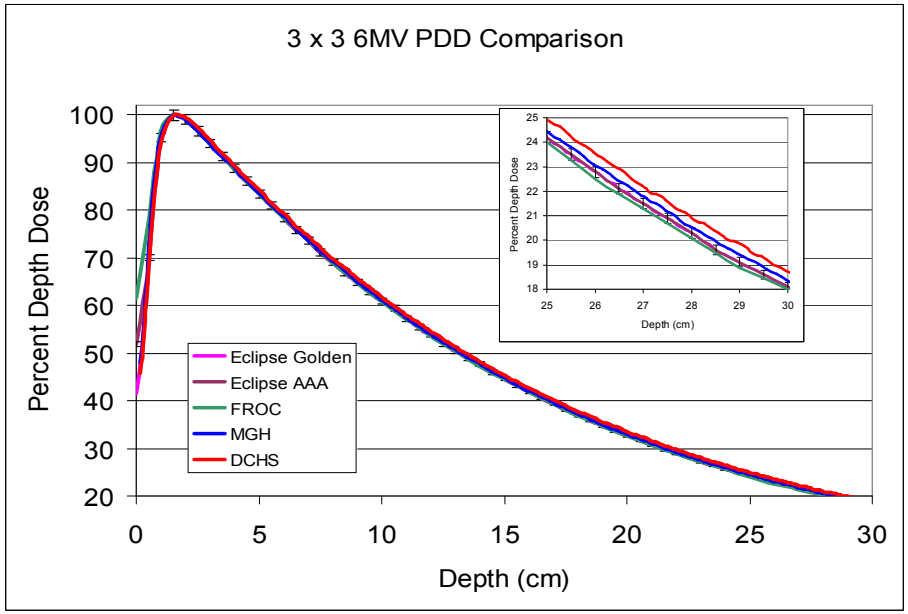


Results: Varian gold beam data is reproducible only if measured under the same conditions (small ion chamber).

Note: Varian gold beam profiles were centered.

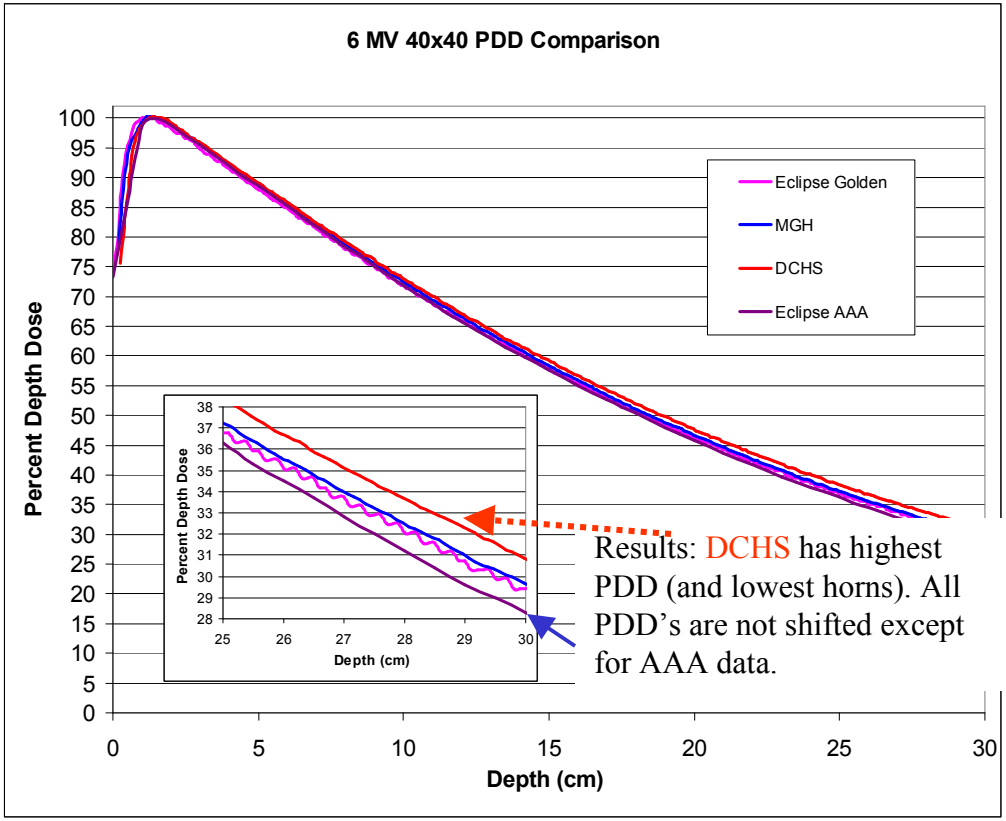

6MV Depth Dose Profile Comparison (10x10cm2FS)
(individually normalized to dmax)
Percentage Depth Dose (%)
Depth (cm)
Golden Data
DCHS
MGH
FROC
VBH 1
VBH 2
UROC
HMC
LRCC S
BJR 11
Note: Error bars are ±1% (local value) and ± 0.1cm from Gold Beam Data

PDD comparison 3x3 and 40x40

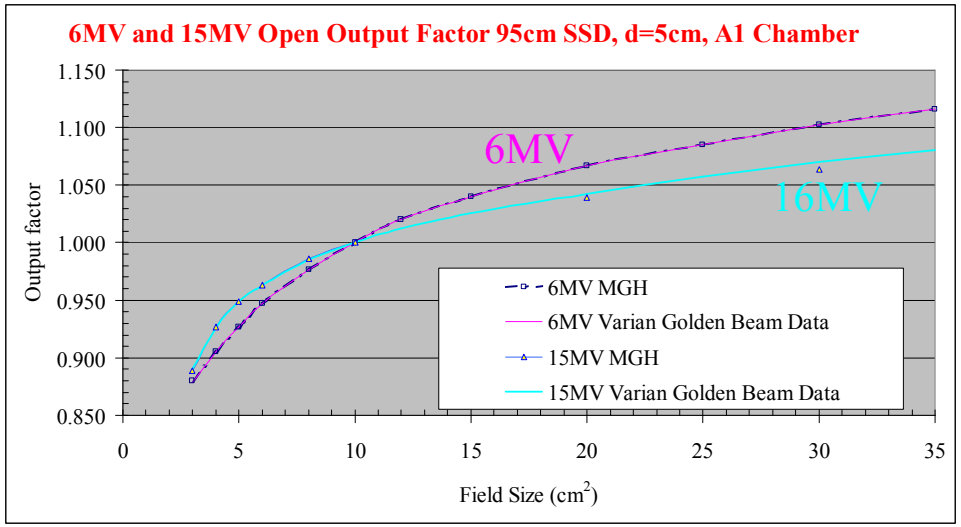


Results: Unlike TG-106[1], our PDD curves only show large discrepancies (± 1%) for very large field sizes at depths >20 cm and not for smaller field sizes. This phenomena may be attributed to actual energy differences[2] between LINACs.

Note: For comparison, all PDD data are presented with no shift, except for the Eclipse AAA data. The Eclipse AAA is the same as the GBD but shifted by 2mm.

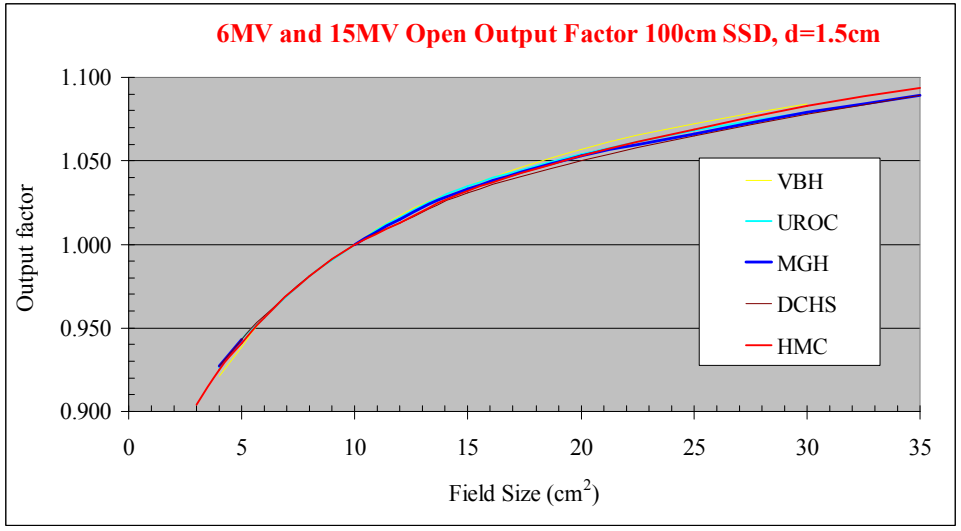


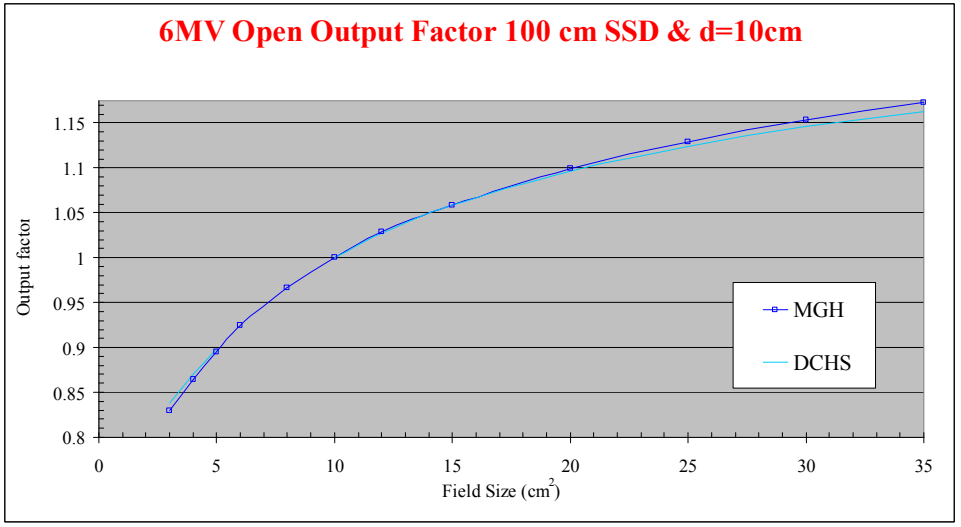
Open Field Output Factors measured under the same and different conditions



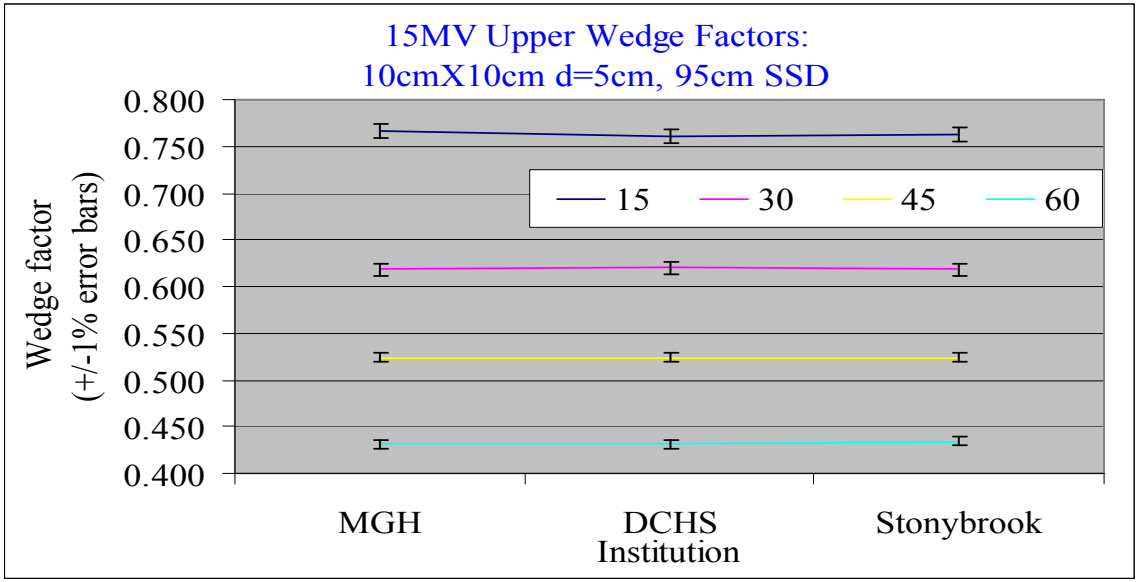
Results: Output Factor comparisons can only be made if measurement conditions are the same. Maximum difference between institutions measured at the same SSD and depth was ±0.5% (bottom left and right).

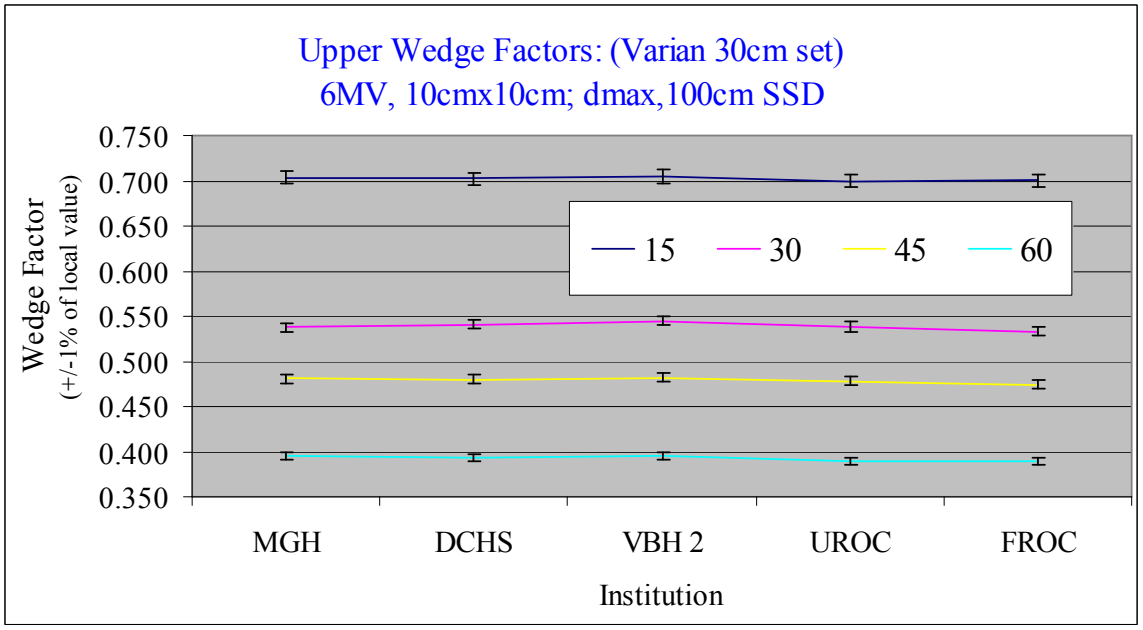
Note: that Golden Beam data was reproducible to ± 0.1% (top left hand figure).





Wedge Factor Comparison





Results: Wedge factors from different institutions are the similar only if measured using identical setup geometry.

Summary: When compared with identical measurement geometry, wedge factors for wedges of the same model were found to be within a maximum spread of approximately ± 1.1%.

Thus, a common independent MU calculator can be used at any of the cancer centers evaluated, since all of the beam data are within ± 1%.

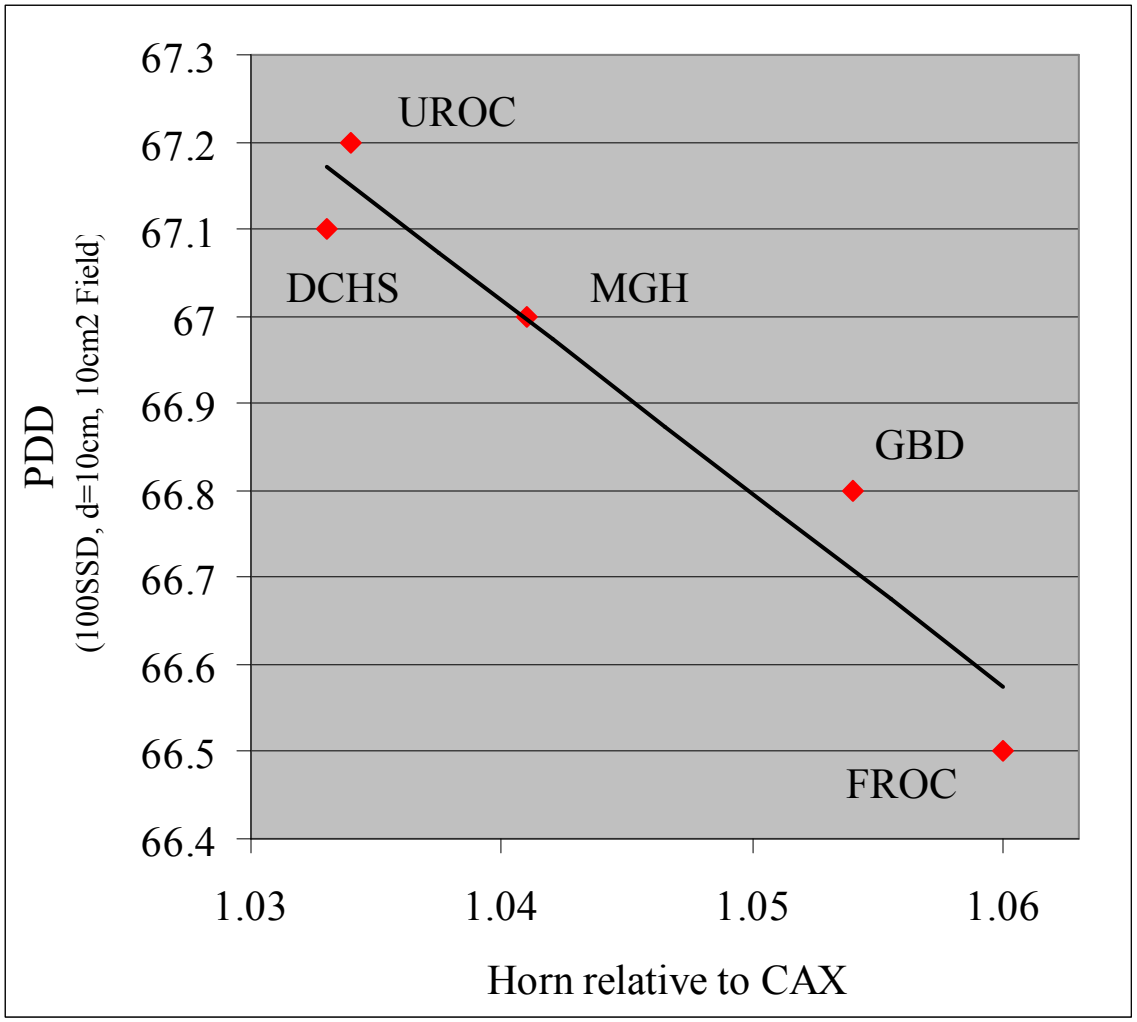
Results of Data Comparison

- PDD from 10 different sources (no shift) were found to be within ± 1% or ± 1mm
- Wedge factors from different LINACs measured under same conditions are within ± 1%.
- Open output factors are within ± 0.1% of the golden data from Varian
- Must use mini/micro ion chamber for small Fields <5cm for output measurements
- Output and wedge factors at measured at different SSD's and depths cannot be compared (within 4%)

Common Errors To Look Out For in Data collection

- Water scanning is tedious work, taking many days and often assigned to inexperienced Jr. physicist with minimal training of what is important
- Common documentation errors during scanning are:
  - Incorrect Energy, field size, SSD, Depth, detector type
  - PDD having shifts in the detector or not
  - Profiles that are smoothed+centered+ symmerterized are not equal to profiles that are smoothed, then symmertized+centered
  - In-plane mixed with cross plane
  - Transposing digits e.g.1.189 vs 1.198 during manual data entry
  - This made it difficult for us to cross compare all data from the various cancer centers
- Water tank not level, squared or sag in table turn table as a function of time due to weight
- Tank not leveled, and parallax effects for short physicists

Relationship Between Horns and PDD



Results: our data show a similar trend as reported by Constantinou et al[2]:

The softer the beam energy, the larger the horns. The softer the beam, the faster the PDD drops off.

This issue is very important when *accepting* a new machine or attempting to "twin" machines. Horns are more sensitive to slight energy changes than PDD, so make sure your horns match at dmax!

Note: Graph data used unshifted PDDs that were normalized to d=1.5cm

Ideal Independent MU calculator

- *Use data from a different cancer center* or not from your treatment planning system
  - Must be same LINAC model
  - Must be calibrated in same fashion
- Thus a *patient being treated at any cancer center* should result in the *similar MU's* (assuming same treatment parameters)
- We have done this using Excel
- All data were collected independently by different physicists
- RESULTS are <3% difference for over 6000 patients

- If your second check calculator uses the same data is in your TPS, all that you are doing is confirming the TPS algorithm/calculation has not been corrupted. If you wedge factor is wrong in the TPS, then the second check calculator is also wrong…garbage in garbage out.
- What ever system you use, it should be able to independently reveal all sources of error including electronic or hand charting.

Our Independent MU calculator

Photon 15MV MU Calculation/Verification (v.31)

	Patient Label Here					
Patient name	Test Patient			Rx =	180	cGy
beam description	1A AP	2A PA	3A RAO	4A RPO	5A Lt LAT	
dose per fraction	22.8	11.5	39.2	36.0	70.4	
% isoline selected	100	100	100	100	100	
SSD over norm pt (w/ bolus)	85.0	87.5	82.0	83.0	81.4	
geometric depth of norm pt	15.0	12.5	18.0	17.0	18.6	
equivalent depth of norm pt	13.1	13.4	11.1	11.3	12.5	
collimator width, X jaw	15.4	15.8	10.5	13.6	11.2	
collimator length, Y jaw	12.7	12.7	12.7	12.7	13.0	
blocked width from DRR	13.0	14.0	8.0	11.0	8.0	
blocked length from DRR	12.0	12.0	12.0	11.0	11.0	
Off axis distance to norm pt						
tray factor at dmax	1.000	1.000	1.000	1.000	1.000	
wedge angle	30 Out	45 Right	none	45 left	30 Left	
Wedge factor at dmax	0.677	0.516	1.000	0.516	0.677	
Wedge hardening factor	1.000	1.000	1.000	1.000	1.000	
Other factor (default is 1.0)	1.000	1.000	1.000	1.000	1.000	
TX Planning MUs	38	26	43	75	117	
MU w/o Heterogeneity	40.6	25.0	52.5	89.9	142.4	
SAD MU w/ Heterogeneity	**39**	**26**	**43**	**77**	**119**	
SSD MU w/ Heterogeneity	**39**	**26**	**43**	**77**	**120**	
Differnce from Tx Plan	within 2MU	within 2MU	0.3%	2.3%	1.8%	
Physics/Dosimetry signature/date						

Independent MU Calculator in Microsoft Excel:

User enters basic parameters for each field and the system uses a series of lookup and interpolation[3] tables to calculate MU's using both a standard SSD and standard SAD hand calculation[4].

Data used in our 2nd Check calculators

6MV calculator	15MV calculator	18MV calculator
PDD is from VBH1	PDD is from Varian GBD	PDD is from FROC
TMR from LRCC	TMR from SB	TMR from FROC
ROF from LRCC	ROF from Varian GBD	ROF from GBD

6MV Percentage Depth Dose Table (100 cm SSD)

Ionization depth curves since no shift in ion chamber (RK) — VBH Linac 1, Measured November 2000;

depth, cm w FS cmxcm	3.0	5	10	15	20	25	30	35	40
0.0	61.6	59.75	63	66.73	70.13	72.71	75.44	77.55	78.84
0.5	78.3	76.9	80	82.8	85.1	86.9	88.3	89.8	90.7
1.0	96.5	95.7	96.6	97.6	98.2	98.6	98.8	99.3	99.4
1.5	100.0	100	100	100	100	100	100	100	100
2.0	99.1	99.3	99.1	99	98.9	98.6	98.7	98.9	98.8
2.5	96.5	97.1	97.2	97.1	97.1	97	97	97.2	97.1
3.0	93.9	95.2	95.2	95.1	95.3	95.1	95.3	95.6	95.4
3.5	91.4	92.6	93	93.2	93.3	93.3	93.5	93.7	93.7
4.0	88.7	90.3	91	91.5	91.6	91.4	91.7	92.1	92.1

MUcheck (2) / MUcheck / TMR2 / PDD1 / **PDD** / Sc / Sp / TMR / ROF / WF

Note: each energy is in one Excel file, and needs and an interpolation file.
Tolerance <3% to several TPS (Eclipse, Xio, Theraplan, Renderplan,)

CL2100C/D 6X TMR TABLE and NPSF — London Regional Cancer Center (1996)

taken from TMR database and made into subset for TTC

Final 6X TMR table smoothed in origion by 5 point adjacent average in depth direction and by "hand" in field size direction for depths (0-7

note: only 5 entries changed by over 0.5% and all for less than dmax (see %diff table)

Field Size (cm)

d	3	4	5	6	7	8	10	12	15	20	25	30	35	40
0	0.559	0.565	0.567	0.577	0.582	0.585	0.607	0.616	0.637	0.670	0.697	0.720	0.736	0.751
0.5	0.740	0.743	0.745	0.752	0.752	0.755	0.777	0.779	0.791	0.816	0.833	0.853	0.865	0.874
1	0.944	0.945	0.945	0.948	0.948	0.949	0.956	0.957	0.961	0.969	0.974	0.978	0.979	0.979
1.5	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1.005	1.006	1.005	1.005	1.005	1.005	1.003	1.003	1.001	1.000	1.001	0.999	0.999	0.999
2.5	0.992	0.995	0.995	0.995	0.996	0.996	0.995	0.994	0.994	0.994	0.993	0.993	0.993	0.993
3	0.975	0.979	0.980	0.983	0.983	0.984	0.983	0.984	0.984	0.985	0.985	0.984	0.985	0.986
3.5	0.956	0.963	0.965	0.968	0.969	0.970	0.971	0.972	0.973	0.974	0.976	0.976	0.976	0.977
4	0.938	0.946	0.949	0.953	0.955	0.956	0.958	0.960	0.961	0.964	0.966	0.967	0.967	0.968
5	0.900	0.910	0.916	0.921	0.925	0.928	0.932	0.934	0.938	0.944	0.947	0.947	0.948	0.949
6	0.864	0.874	0.882	0.888	0.894	0.898	0.905	0.909	0.914	0.921	0.925	0.928	0.928	0.931

MUcheck (2) / MUcheck / TMR2 / PDD1 / PDD / Sc / Sp / **TMR** / ROF

CL2100C/D 6X OUTPUT FACTORS

LRCC — RDF @dmax for rectangular fields - Combination of Dec 4 and 5 data (1996)

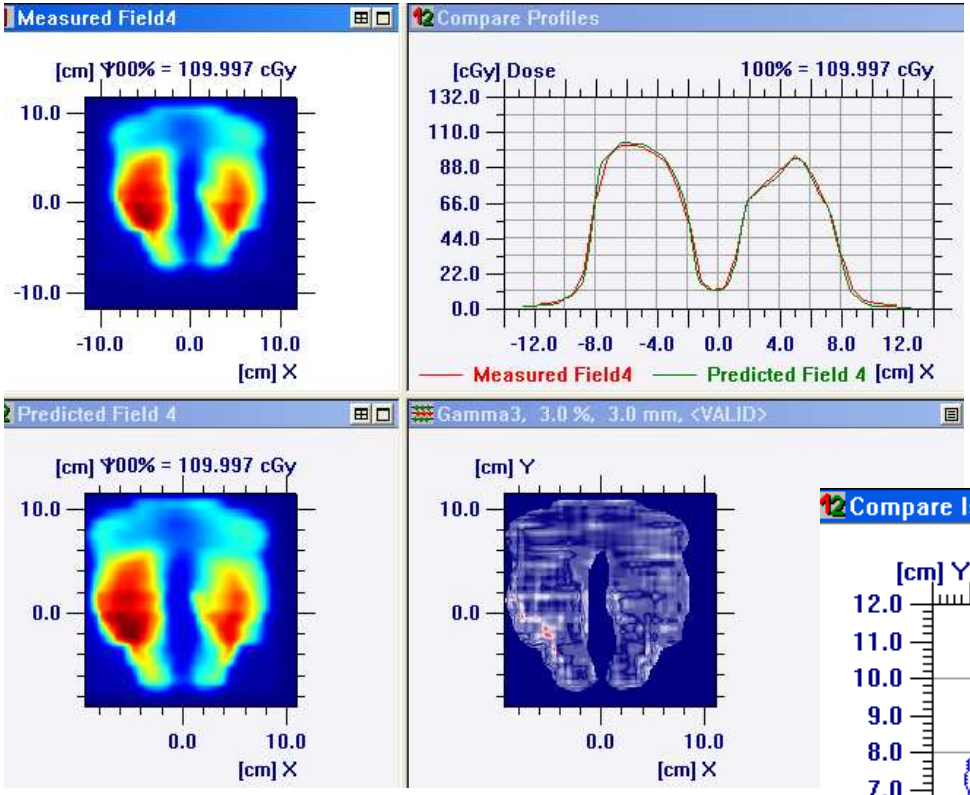
Y-jaw (cm)

	4	5	6	7	8	10	12	15	20	25	30	35	40
4	**0.925**	0.934	0.941	0.947	0.953	0.959	0.966	0.971	0.976	0.980	0.983	0.986	0.990
5	0.932	**0.942**	0.950	0.957	0.962	0.971	0.976	0.983	0.991	0.996	0.999	1.002	1.005
6	0.936	0.947	**0.956**	0.964	0.970	0.979	0.987	0.993	1.002	1.007	1.012	1.015	1.018
7	0.939	0.953	0.962	**0.969**	0.976	0.986	0.994	1.002	1.011	1.017	1.022	1.026	1.029
8	0.942	0.957	0.966	0.975	**0.980**	0.991	0.999	1.009	1.019	1.025	1.030	1.035	1.038
10	0.947	0.963	0.972	0.981	0.988	**1.000**	1.010	1.020	1.032	1.038	1.044	1.048	1.052
12	0.949	0.965	0.976	0.986	0.994	1.006	**1.015**	1.026	1.039	1.045	1.051	1.056	1.060
15	0.953	0.969	0.981	0.990	0.999	1.013	1.023	**1.034**	1.048	1.055	1.062	1.066	1.071
20	0.956	0.973	0.985	0.995	1.004	1.019	1.030	1.042	**1.057**	1.066	1.073	1.079	1.084
25	0.958	0.975	0.987	0.998	1.007	1.022	1.034	1.048	1.063	**1.072**	1.080	1.087	1.092
30	0.959	0.976	0.990	1.000	1.010	1.026	1.037	1.052	1.068	1.078	**1.086**	1.093	1.098
35	0.961	0.976	0.990	1.001	1.011	1.027	1.039	1.054	1.070	1.081	1.089	**1.097**	1.102
40	0.961	0.979	0.991	1.002	1.012	1.028	1.040	1.055	1.072	1.082	1.091	1.099	**1.104**

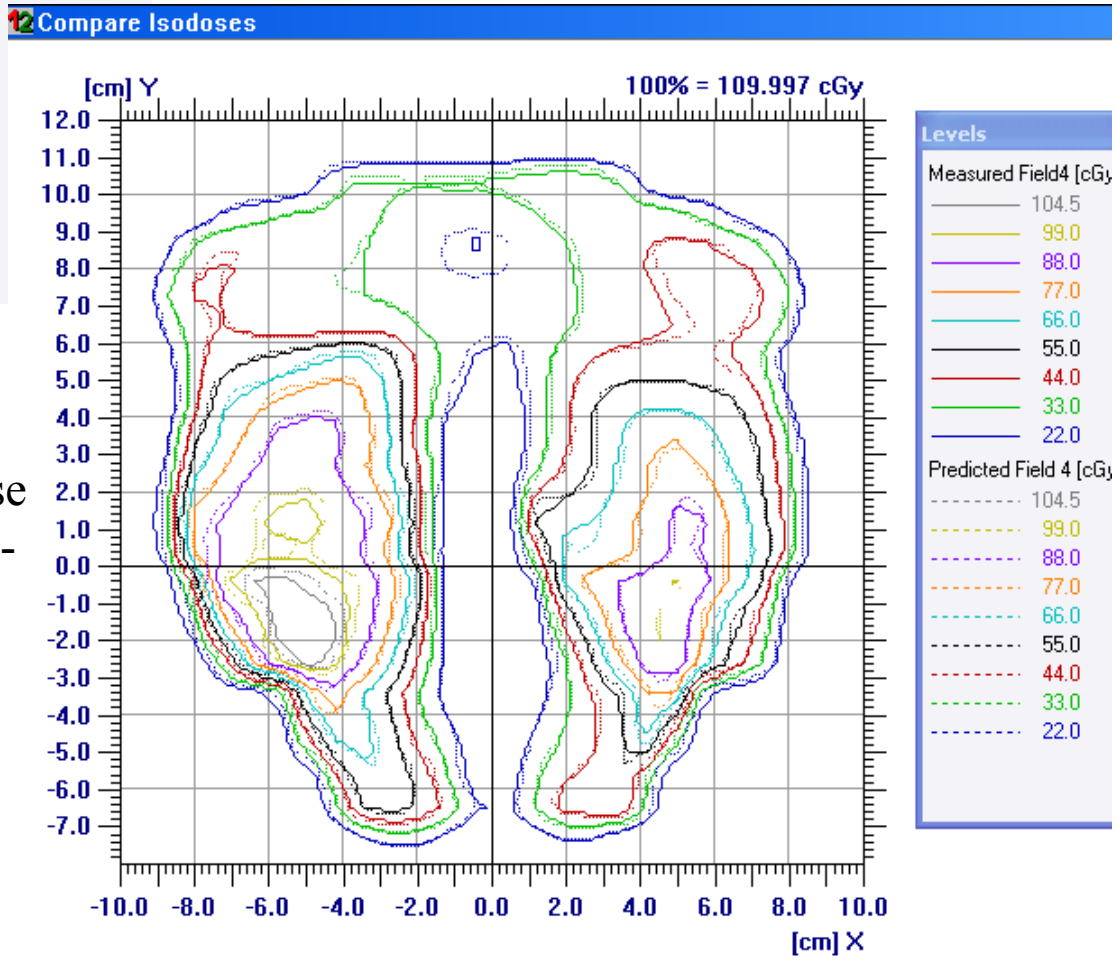
MUcheck / TMR2 / PDD1 / PDD / Sc / Sp / TMR / **ROF** / WF / WF-off axis / OA

Conclusions

- Linac data can be compared only if collected under similar conditions. Measurements from different sites can often not be compared due to poor documentation.
- Varian high energy LINACs (2100c. 2100c/d, 2100ex, iX, Triology) generally have similar profiles, PDD's, output factors, and wedge factors
  - Varian golden beam data can be reproduced using a small ion chamber
- A true *independent* monitor unit calculator should have data that is different from your TPS.
  - It is best to use data from a different cancer center (or possibly GBD)
  - This cross comparison will reveal any errors entered into your TPS
  - E.g. an incorrect wedge factor or dose rate table in your TPS cannot be caught if your independent check uses the same factor
- Commissioning reports of what was done, equipment used, why and how data was entered to the TPS, and what tests were used to confirm the TPS output need to be clearly written so that any subsequent physicist can understand the history of the system.
  - Solo Physics practices with limited experience in commissioning should seek advice from reputable consultant groups



Proof : is always from comparing Measurements versus Predicted



RESULTS: Measured versus predicted of single AP field of Head and Neck Plan. Predicted used Eclipse TPS with Varian Gold beam data pre-installed for AAA. Measured was on 2100c/d s/n 1032 with 80 leaf Mark series MLC. IBA Matrixx IMRT QA device used: (99% pass at 3mm/3% gamma criteria)

References

1) "Accelerator beam data commissioning equipment and procedures: Report of the TG-106 of the Therapy Physics Committee of the AAPM", Das et al, Med. Phys. Pg 4186-4215, 35(9) September 2008.

2) "Reduction of the 'horns' observed on the beam profiles of a 6-MV linear accelerator", Chris. Constantinou and E.S. Sternick, Med. Phys. Pg 840-842 11(6) Nov./Dec. 1984.

3) Interpolation.xla shareware for Microsoft Excel from Fred Ernst fcernst@earthlink.net

4) Monitor Unit Calculations for External Photon and Electron Beams, J.P.Gibbons, *Advanced Medical Publishing* 2000 pg.6

Off topic: To shift PDD or not shift for TPS

• It is best that, in your cancer center, you pick one method and stick to that method. The last step in TG-51 is to divide by your clinical PDD.

• This last step self-corrects your TPS so that the patient gets the correct dose at depth 10cm.

Example of what is happening in terms of dose to the patient:
clinical D10 PDD not shifted=0.668
clinical D10 PDD shifted 2mm= 0.661

TG51 using NOT shifted PDD=> output at dmax is 66.8cGy/MU
TG51 using shifted PDD=> output at dmax is 66.1cGy/MU

TPS MU's with NOT shifted data (100cGy, 10x10, d=10cm, 100SSD)=>149.7MU's
TPS MU's with shifted data (100cGy, 10x10, d=10cm, 100SSD)=>151.3MU's

Bottom line, patient gets 100cGy to depth 10cm
(even though MU's are different by 1%)

Extra slide

Reproduced from Figure 1c of TG-106 :
Depth dose depends on detector for large field size