Linac Acceptance Testing and Commissioning

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Acceptance Testing

- Why?
- Assure the accelerator performs according to specifications
  - As stated or claimed by the manufacturer
  - As agreed to by specifications before purchase
  - Be sure we understand the equipment
  - Avoid surprises after implementation


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Steps in Acceptance Testing

1. Configuration 2. Options 3. Equipment needed 4. Protection survey 5. Mechanical tests	6. Radiation isocenter test 7. Beam characteristics 8. Dosimetry 9. Dynamic therapy

Configuration

- Did I get what I asked for?
- Is everything present?

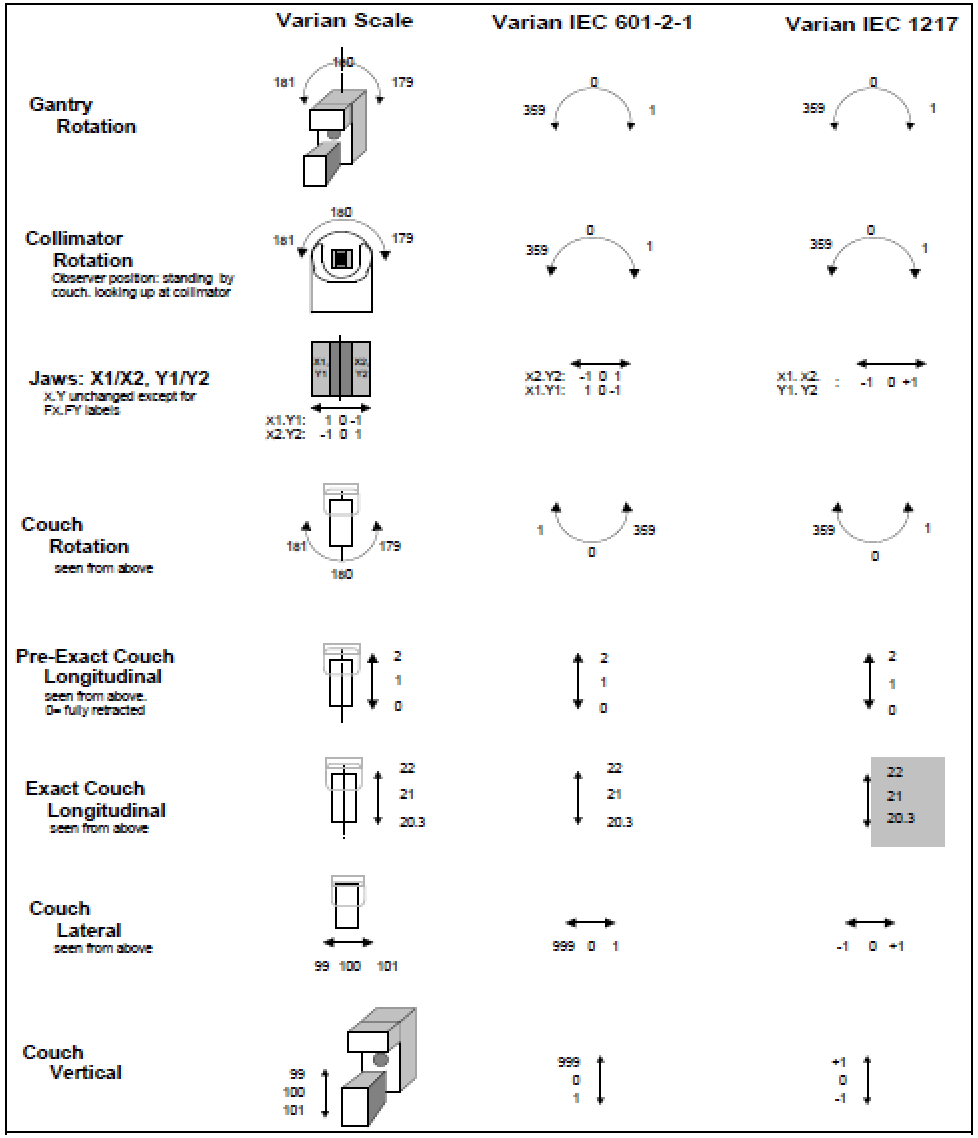
- Not just linac!!!

Also accessories: patient immobilization devices …

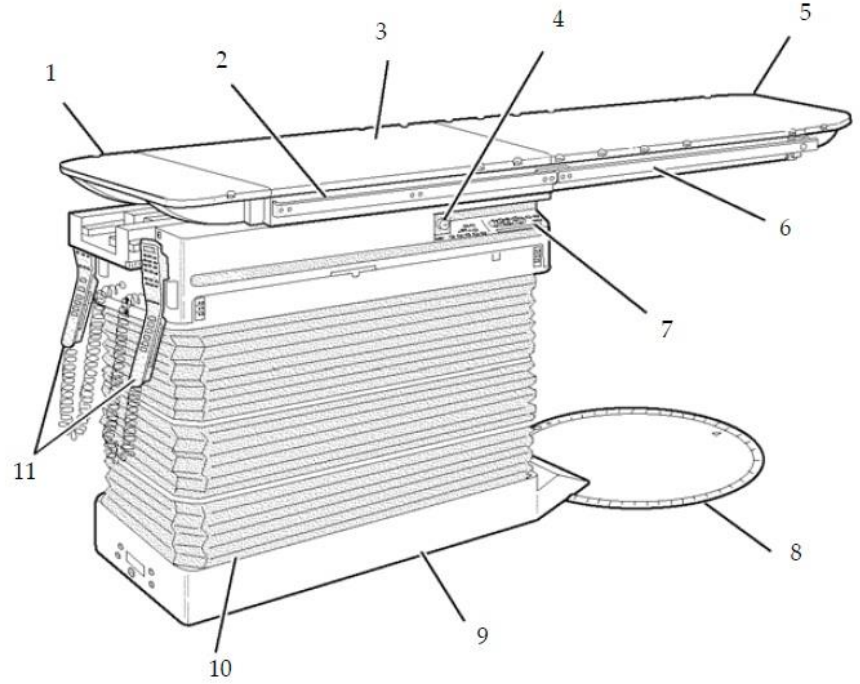
Options

- Are the optional items included?
  - High dose rate capabilities
  - Electron applicators
  - Special couch top
  - Room decoration?

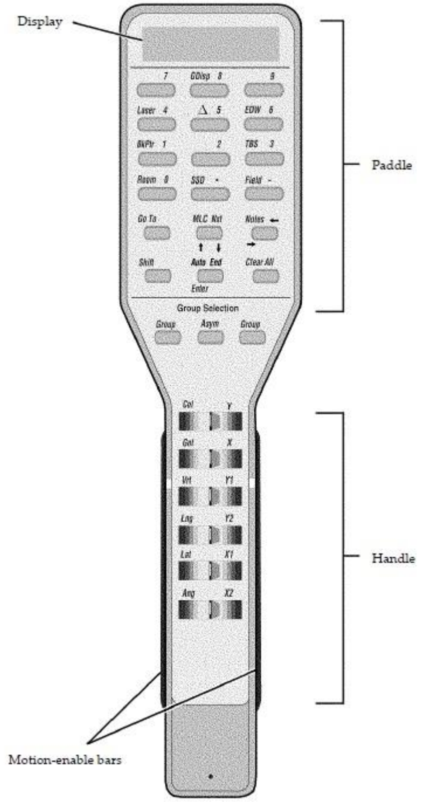
Scale convention



Get familiar with the linac and accessories



1 Foot extension
2 Fixed accessory rail
3 Couch top
4 EMERGENCY OFF button
5 Head-end hook
6 Removable accessory rail
7 Side panel controls
8 Turntable
9 Lift base
10 Bellows
11 Hand pendants



Equipment needed

- What equipment do I have to have to do the acceptance testing?
  - Must I have it or will manufacturer provide it?
  - If I have my own equipment, can I use it?

Typical equipment

- Spirit level
- Water phantom (x2 at least)
- Dosimetry scanning system
- Scanning (waterproof) ion chambers
- Vernier caliper?
- Tape measure
- Graph paper (mm, not inches or log)
- Film (either gafchromic or need a developer)
- Electrometer and ion chamber
- Densitometer

Protection Survey

- Do not endanger staff and public during acceptance testing

Protection Survey

- Evaluate doses and doserates under testing conditions (usually not the normal conditions)
  - Maximum field size (40 x 40 cm → diagonal = 56.6 cm)
  - Maximum dose rate
  - Various gantry angles
  - Primary beam (walls and roof)
  - Scatter (with phantom)

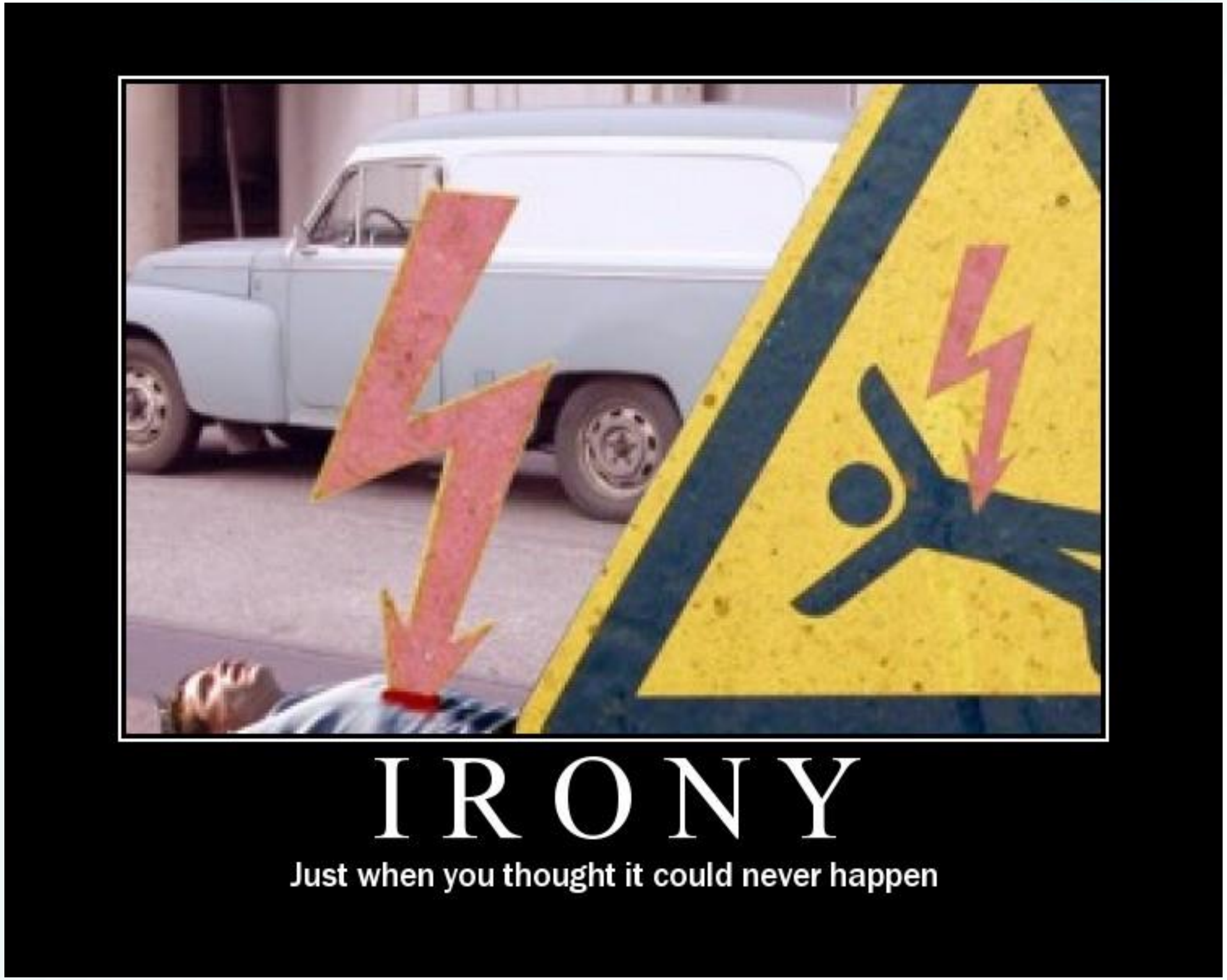
Radiation Area Survey

- Adjacent working areas, waiting rooms, roof…
- Interlocks
- Warning systems (beam-on lights, signage)

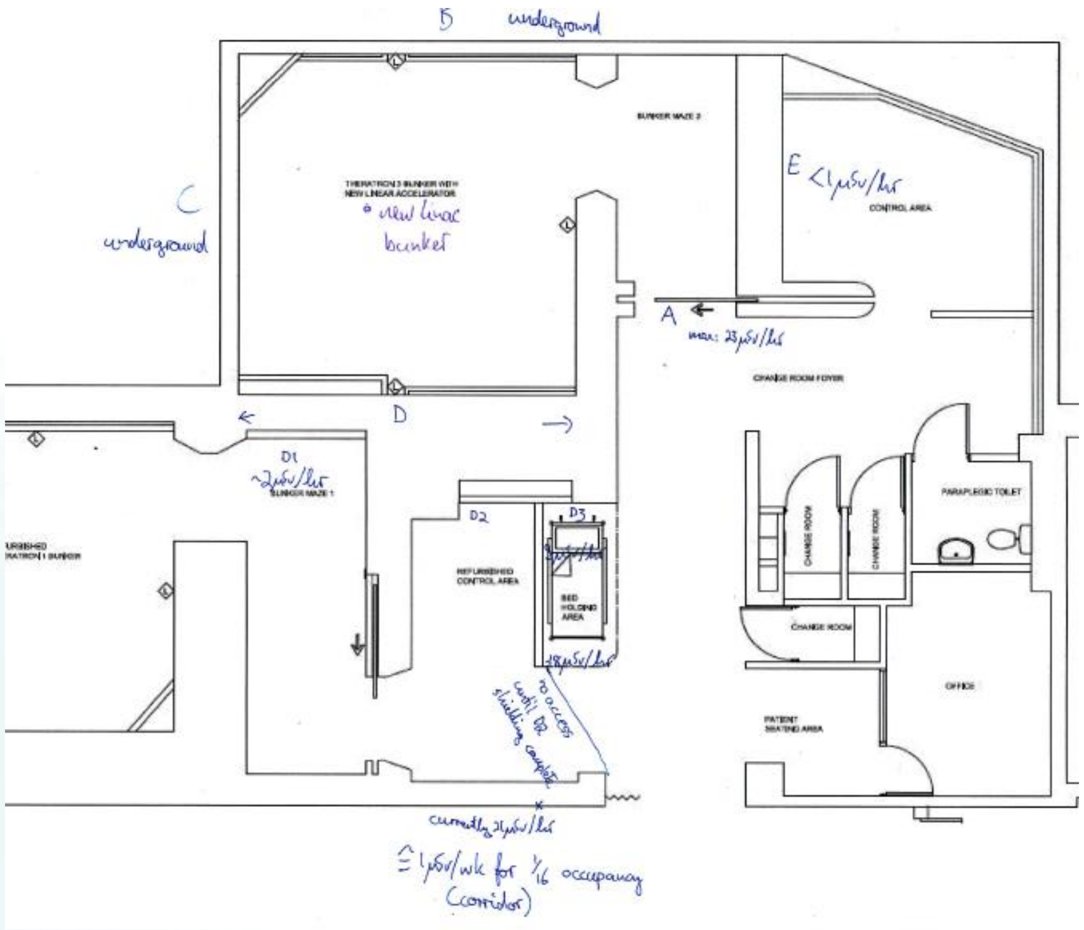
Radiation Protection

- Head leakage? (probably manufacturer)
- Neutrons?
- Collimator transmission? Jaw transmission?

- Beamstopper transmission if applicable


IRONY
Just when you thought it could never happen

Survey



B underground
BUNKER MAZE 2
THERATRON 3 BUNKER WITH NEW LINEAR ACCELERATOR
new linac bunker
C underground
E <1μSv/hr
CONTROL AREA
A
max: 23μSv/hr
CHANGE ROOM FOYER
D
D1
~2μSv/hr
BUNKER MAZE 1
D2
D3
REFURBISHED CONTROL AREA
BED HOLDING AREA
18μSv/hr
no access until D2 shielding complete
currently 21μSv/hr
≅1μSv/wk for 1/16 occupancy (corridor)
PARAPLEGIC TOILET
CHANGE ROOM
CHANGE ROOM
CHANGE ROOM
OFFICE
PATIENT SEATING AREA

Survey

Please attach a diagram or plan of the appropriate enclosure indicating the corresponding position on premises (e.g. A, B, etc):

Highest photon energy = 6 MV; Largest collimator opening = 40 x 40 cm²; Dose rate used during measurements ($\dot{D}$)= 600 MU/min ~~Gy/h~~; Total weekly workload (W) at isocentre = 600 Gy/week

Position on premises	Measurement (R) = (μSv/h)	Calculation of weekly dose at a point = R x WUT/ D = ….. μSv/week
A Entrance gate	23 μSv/hr (max) (γ)	57,5 μSv/wk (full occupancy)
B Outside wall } underground	/ (γ)	
C Outside wall	(γ)	
D Outside wall	D1: 2μSv/hr D2: * D3: 18μSv/hr (γ)	max (excl D2): 45 μSv/wk
E Outside wall / Control Panel	< 1 μSv/hr (γ)	< 2,5 μSv/week
~~E Control panel (not indicated)~~	(γ)	
G Up direction (not indicated)	on roof: 3μSv/hr max at generator: 45μSv/hr (γ)	2μSv/wk with occupancy 1/16
H Skyshine (not indicated)	/ (γ)	
~~A Entrance gate~~	(n)	
*D2: drawings were incorrect,	extra shielding currently being	added, access blocked

4. RADIATION SAFETY OF THE PREMISES; ↗ see note on D2

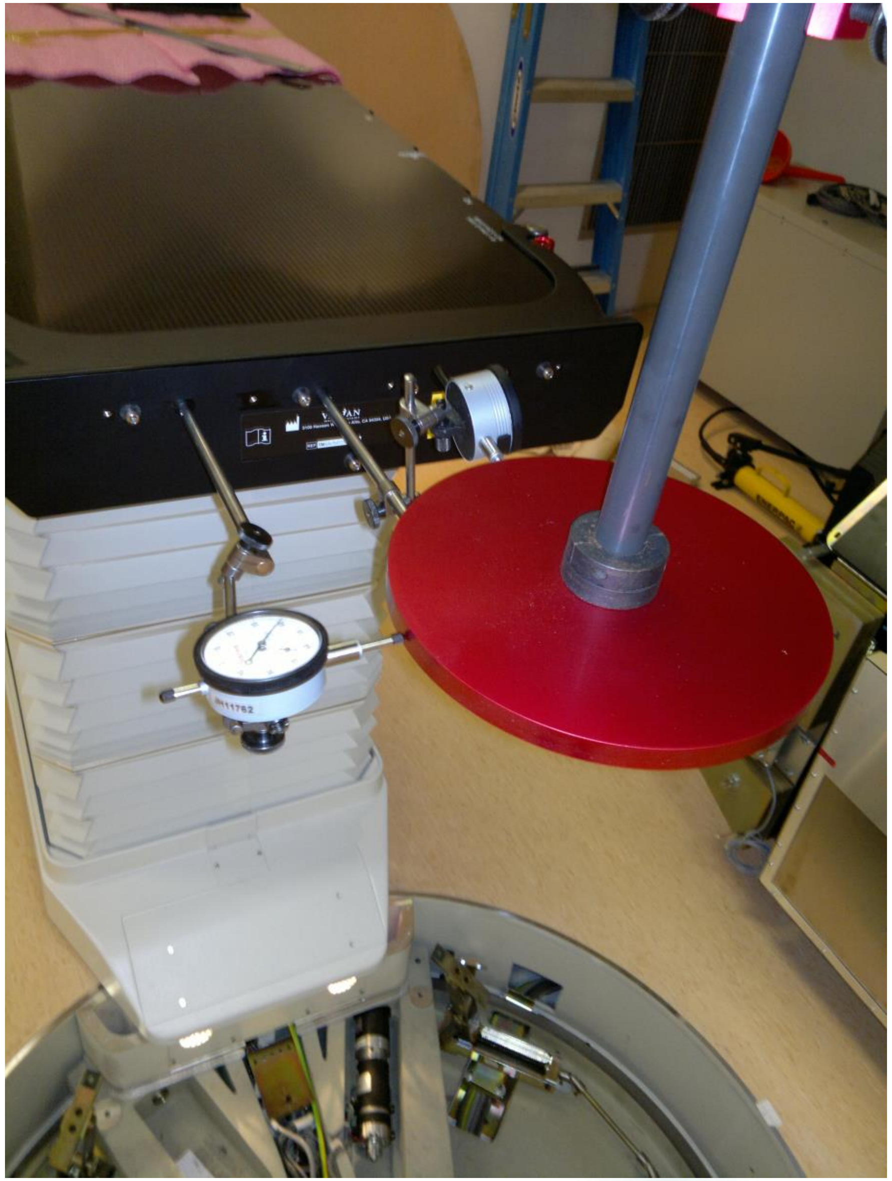
Yes ✓	No	N/A	Radiation levels ≤ **20 μSv/week** for all uncontrolled areas and members of the public?
Yes ✓	No	N/A	Radiation levels ≤ **100 μSv/week** for radiation workers?

Mechanical Tests

- Isocenter tolerance
  - Mechanical
  - Light field
  - Radiation field

Isocenter

- Mechanical
  - Collimator, gantry, couch



Light field

- Graph paper very useful here…

- Field size – actual vs displayed
- Are the crosshairs at the isocenter? Do they move during rotation?
- Distance from jaw edge to crosshairs

Angle readout calibration

- Collimator, gantry, couch

Digital: ±0.5°

Mechanical ±1°

Couch calibration

- Vertical, lateral, longitudinal (± 2 mm)
- Couch rotation

  Digital: ±0.5°

  Mechanical ±1°

- Couch sag

Optical Distance Indicator (ODI)

- ODI vs front pointer

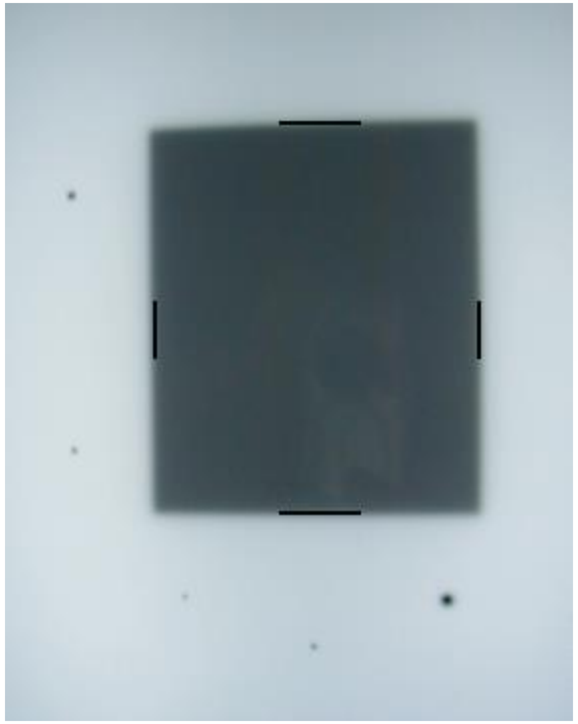
±1mm @ 100 cm

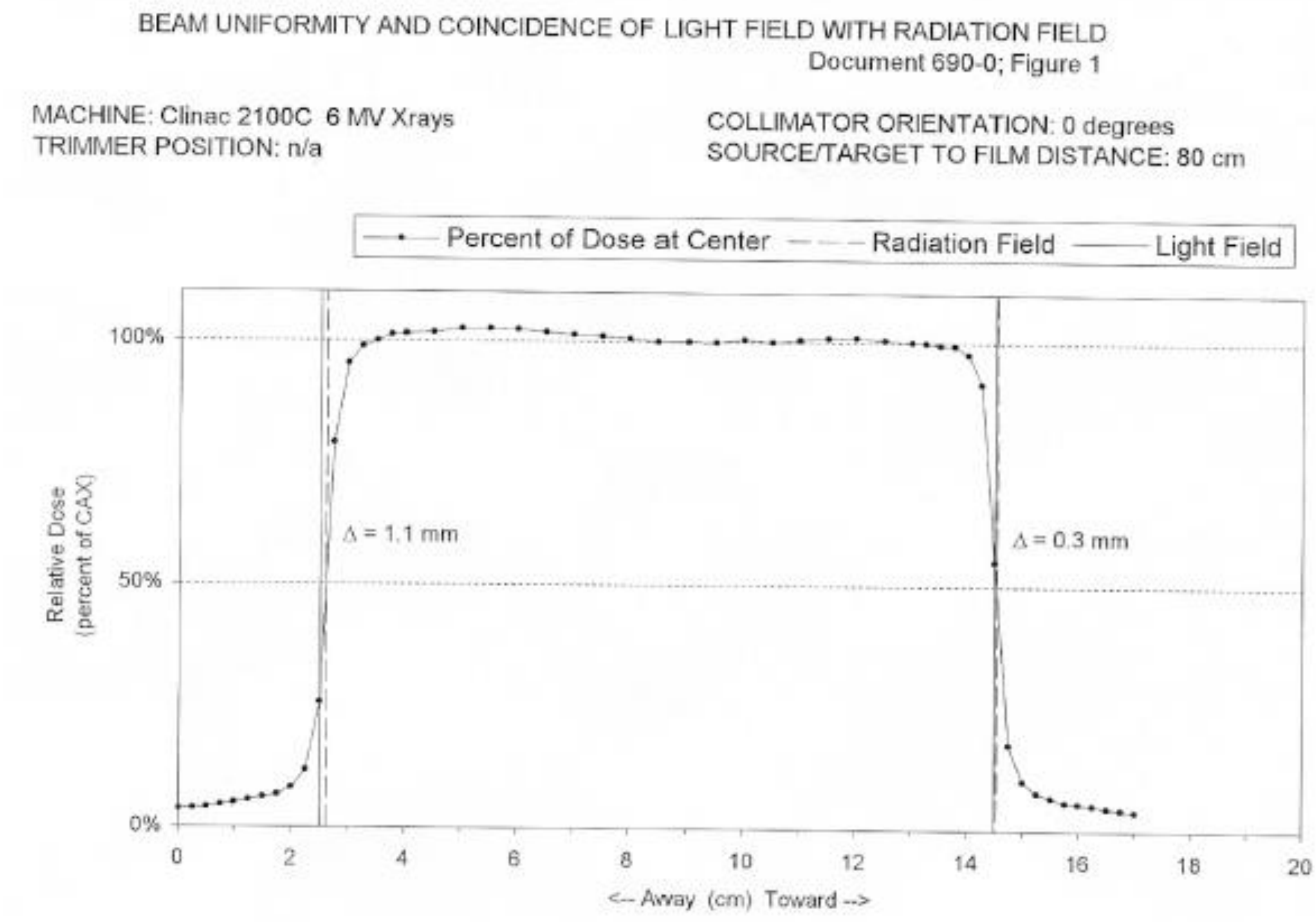
±3mm @ 80 and 130 cm

Light vs radiation field alignment

- Mark lightfield on film (not always easy)
- Irradiate, but not too much
- Compare light-rad coincidence
  ± 2 mm

This is where a densitometer is useful – scan film to find 50 % isodose

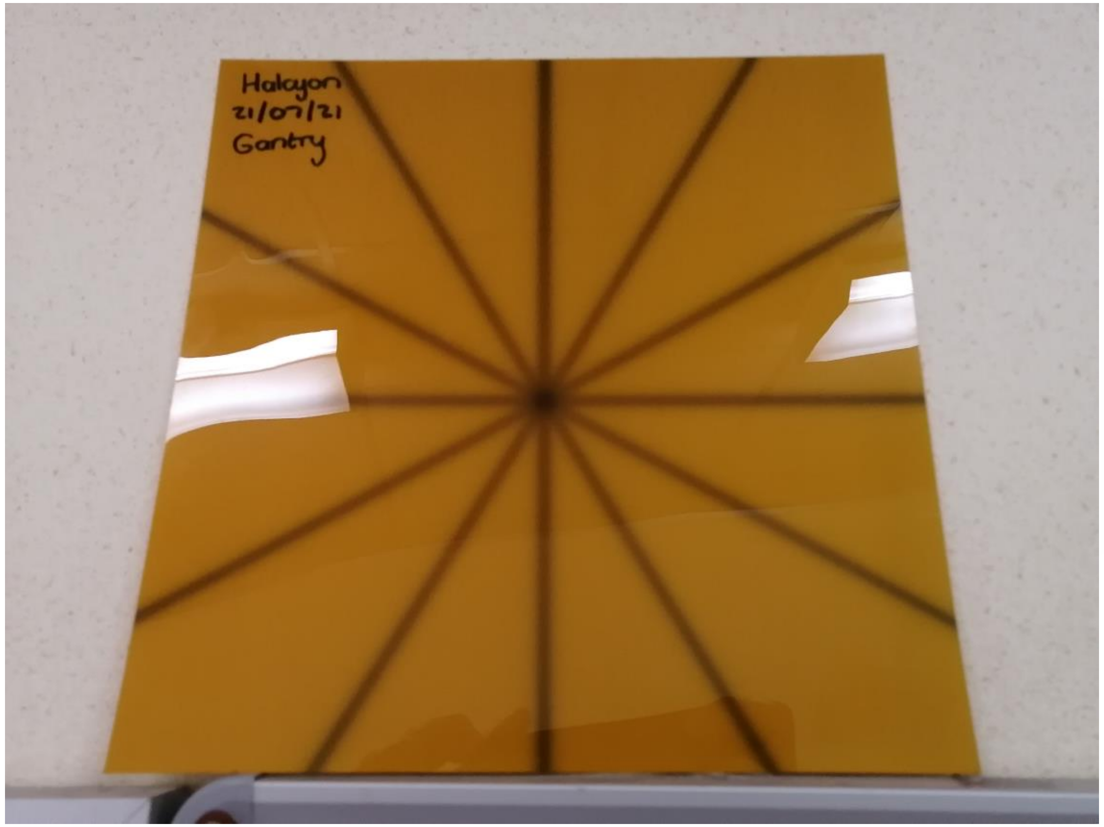




BEAM UNIFORMITY AND COINCIDENCE OF LIGHT FIELD WITH RADIATION FIELD
Document 690-0; Figure 1
MACHINE: Clinac 2100C 6 MV Xrays
TRIMMER POSITION: n/a
COLLIMATOR ORIENTATION: 0 degrees
SOURCE/TARGET TO FILM DISTANCE: 80 cm
Percent of Dose at Center
Radiation Field
Light Field
100%
50%
0%
Relative Dose
(percent of CAX)
Δ = 1.1 mm
Δ = 0.3 mm
0
2
4
6
8
10
12
14
16
18
20
<-- Away (cm) Toward -->

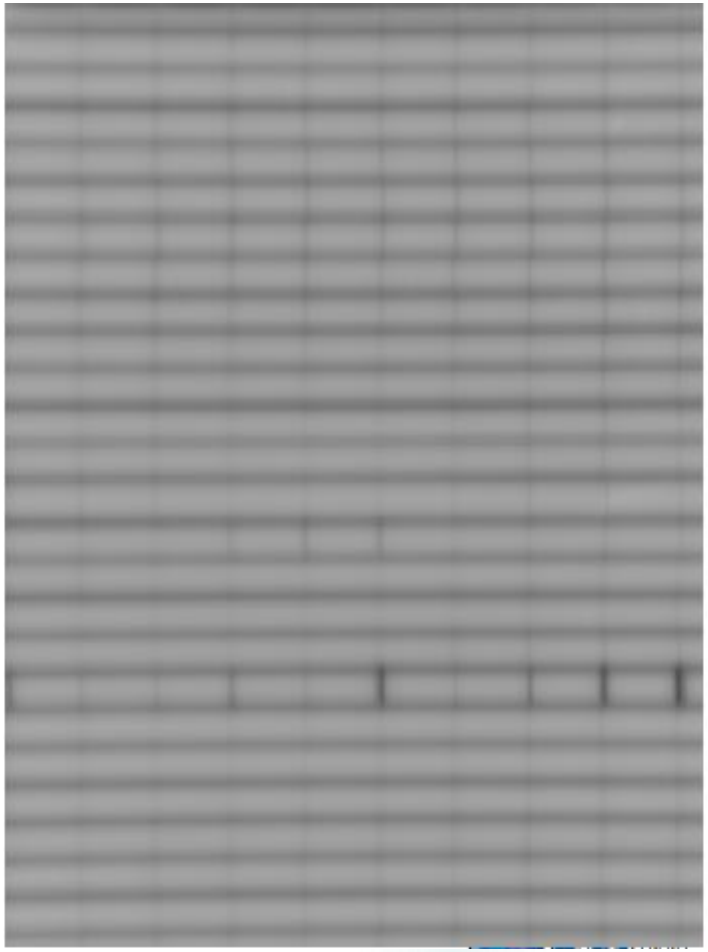
Spoke shots

- Collimator spoke shot
- Gantry spoke shot



MLC calibration

- Picket fence test or similar



Dosimetry

- Beam characteristics determined by scanning

- Tank level and aligned!
- Correct for effective point of measurement of selected scanning chamber!
- Correct field size

Beam energy

- Often specified as a percentage depth dose

Energy	d_{max}	var.	$\%dd_{10}$	var.
4	1.2cm	±0.15cm	63.0%	2%
6	1.6cm	±0.15cm	67.0%	1%
10	2.4cm	±0.15cm	74.0%	1%
15	2.9cm	±0.15cm	77.0%	1%
18	3.3cm	±0.15cm	80.0%	1%

Electron energy

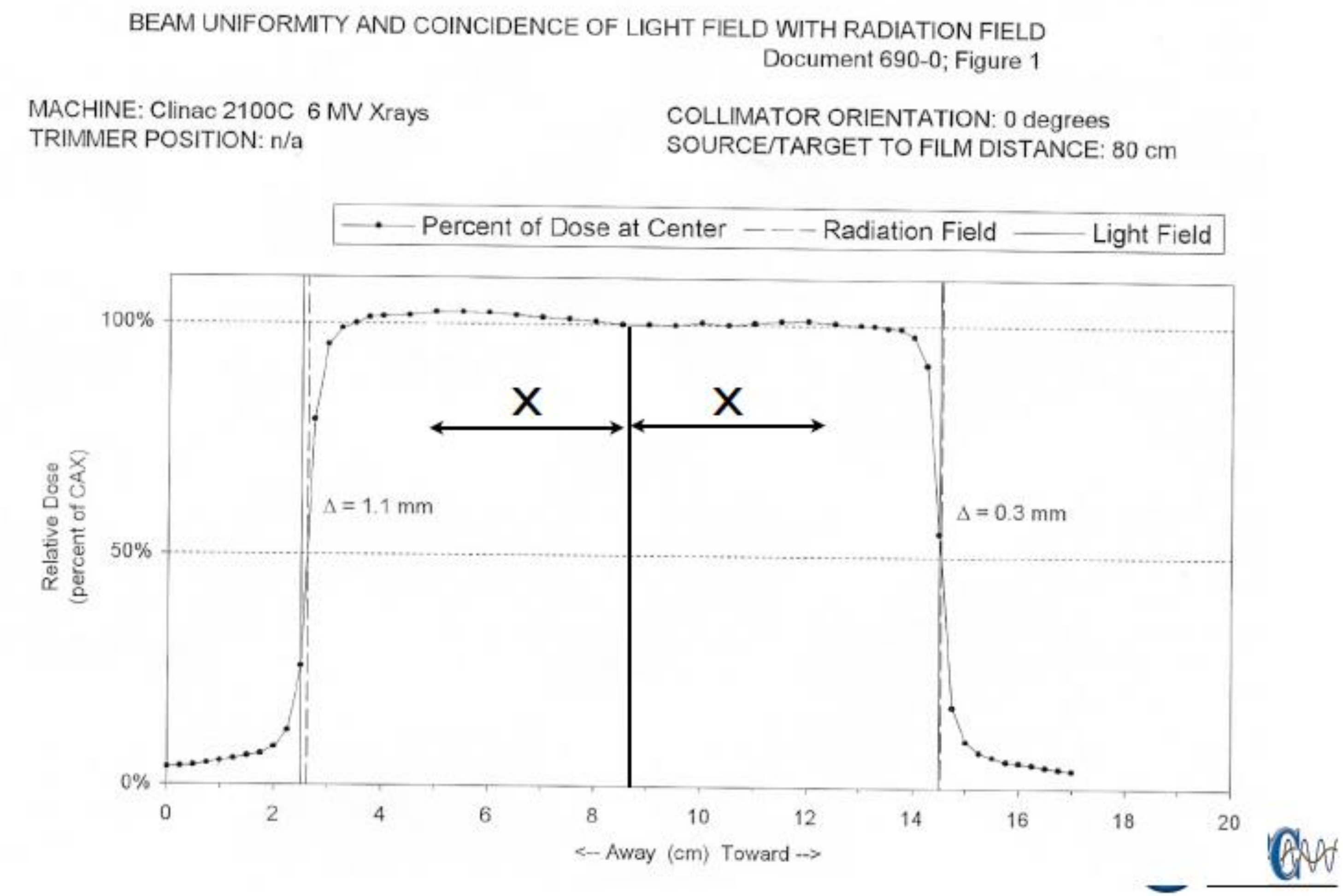
Energy	90%	80%	50%	30%
4	0.89	1.00	1.26	≤2.00
6	1.71	1.90	2.30	≤2.60
9	2.68	2.95	3.50	≤3.90
12	3.77	4.15	4.89	≤5.40
16	4.87	5.45	6.49	≤7.30
20	5.52	6.55	8.13	≤9.30

- Depths in cm, tolerance ±1mm

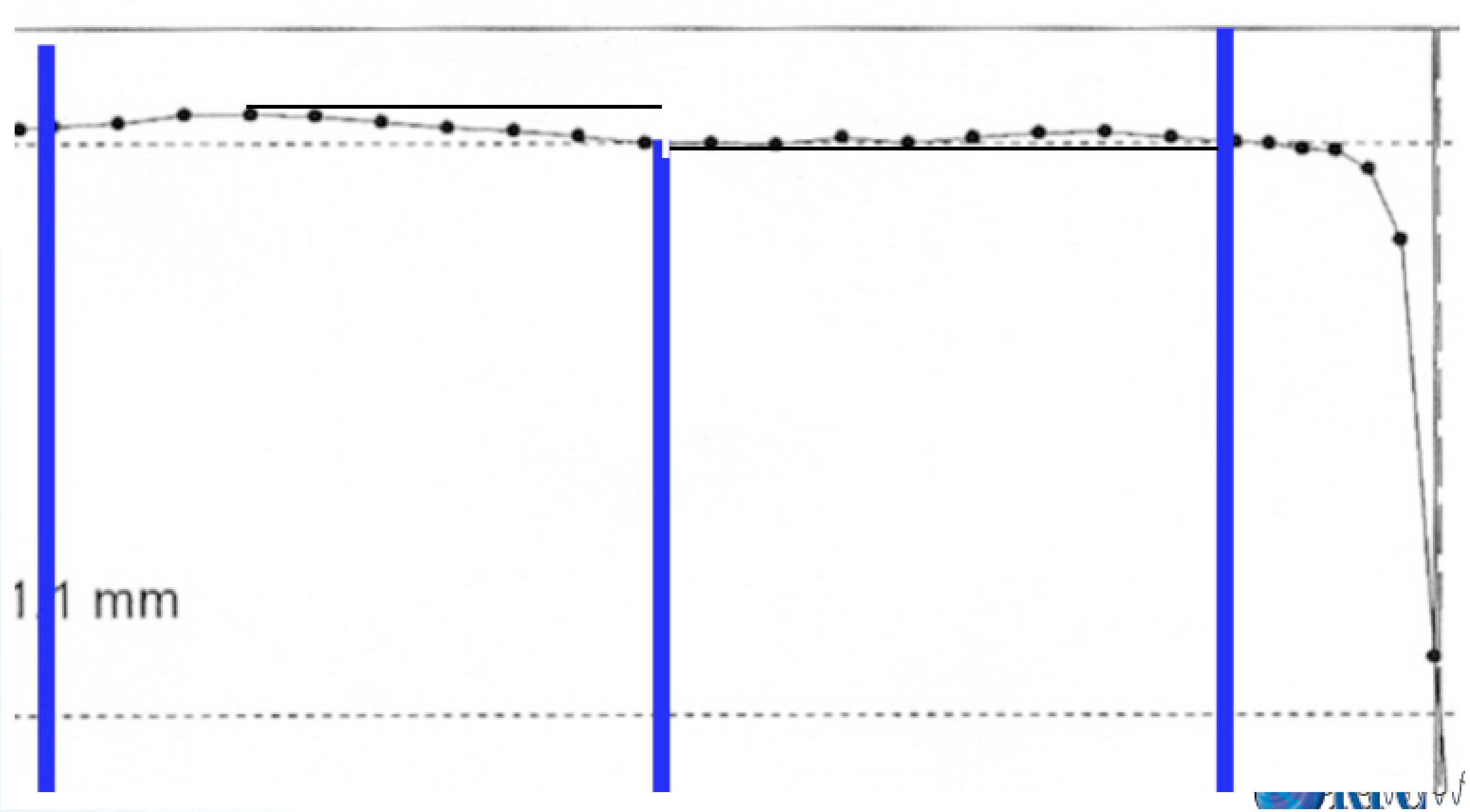
Field flatness and symmetry

- Flatness: variation over central 80 % of the field: use 10x10 or larger, flatness ≤±3% of mean of max and min
- Symmetry: dose rate at points equidistant from the CAX must not differ by >2%

Field Symmetry



Field Flatness



Electron field flatness

- Test performed in same manner, but specification less stringent (5 % over central 80 % of field for 10 x 10 and 25 x 25 cm field)

Interlocks

- Symmetry interlock must be tested
- Technician creates an asymmetric beam → beam on → trip (hopefully)

Dosimetry

- Is linac calibrated? TRS398
- Reproducibility of delivered dose
- Long-term reproducibility
- Reproducibility with gantry angle
- Linearity of dose monitor
- Reproducibility with dose rate
- Accuracy of dose rate (Gy/min)

Independent check on dosimetry

- Can also happen later, but very important that it is done
- Get another medical physicist to do TRS398 with their equipment on your unit
- Do a dosimetry audit (IAEA or similar)
- Results should be within 2%

Dynamic Therapy

Wedges

- Both hard and dynamic wedges
- Slope of isodose should agree with intended slope
- Dose delivery per unit jaw movement should agree with intended

Special considerations

- ?unusual machines / characteristics / techniques

Special Considerations

- Portal Imager
- kV Imager
- R&V system

Acceptance Testing Completed

- Machine meets your specifications
- Safe to use
- Payment can be made
- Now we start commissioning!

Acceptance Documents

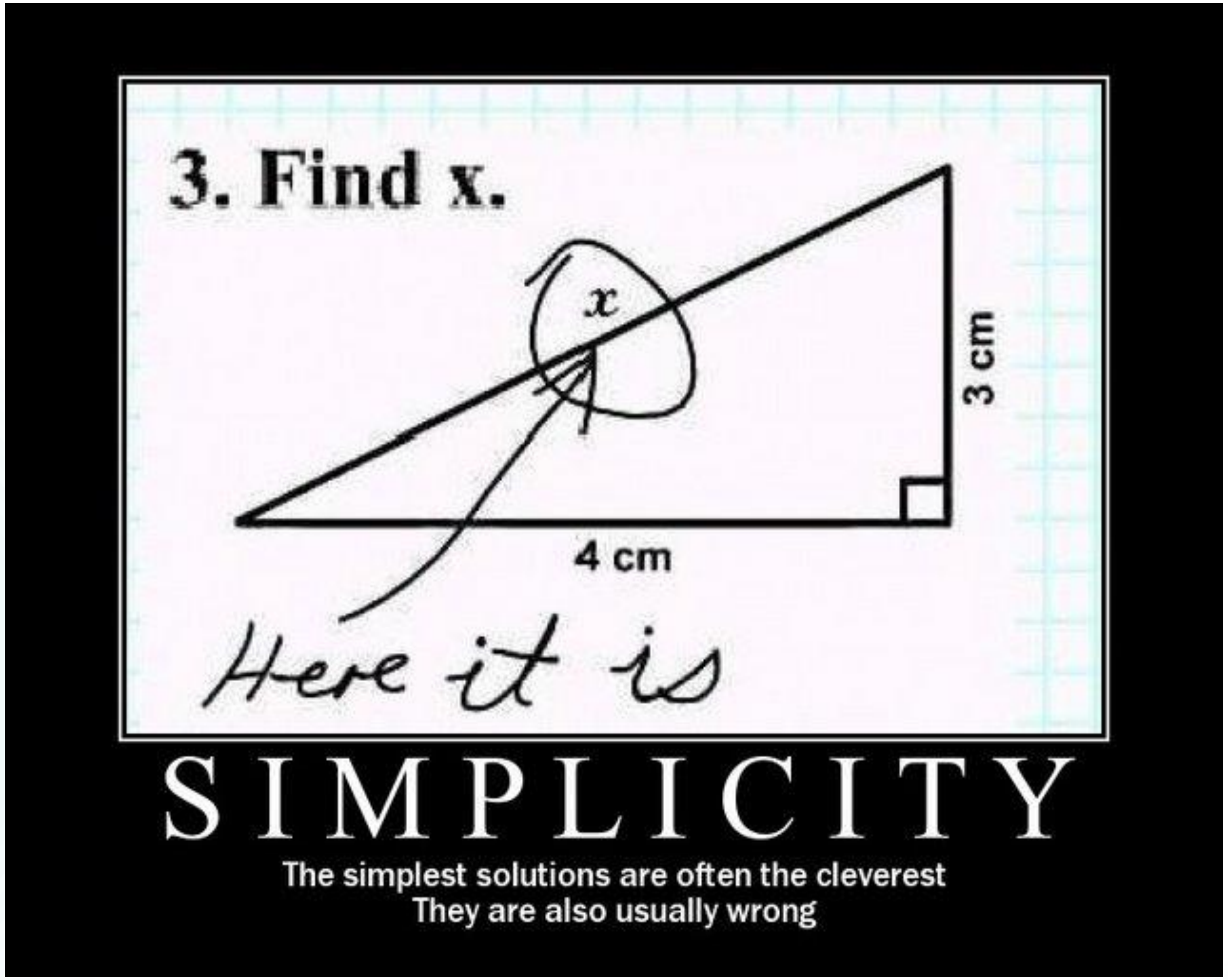
- Lots of pages to sign, installation engineer takes originals, good idea to make copies

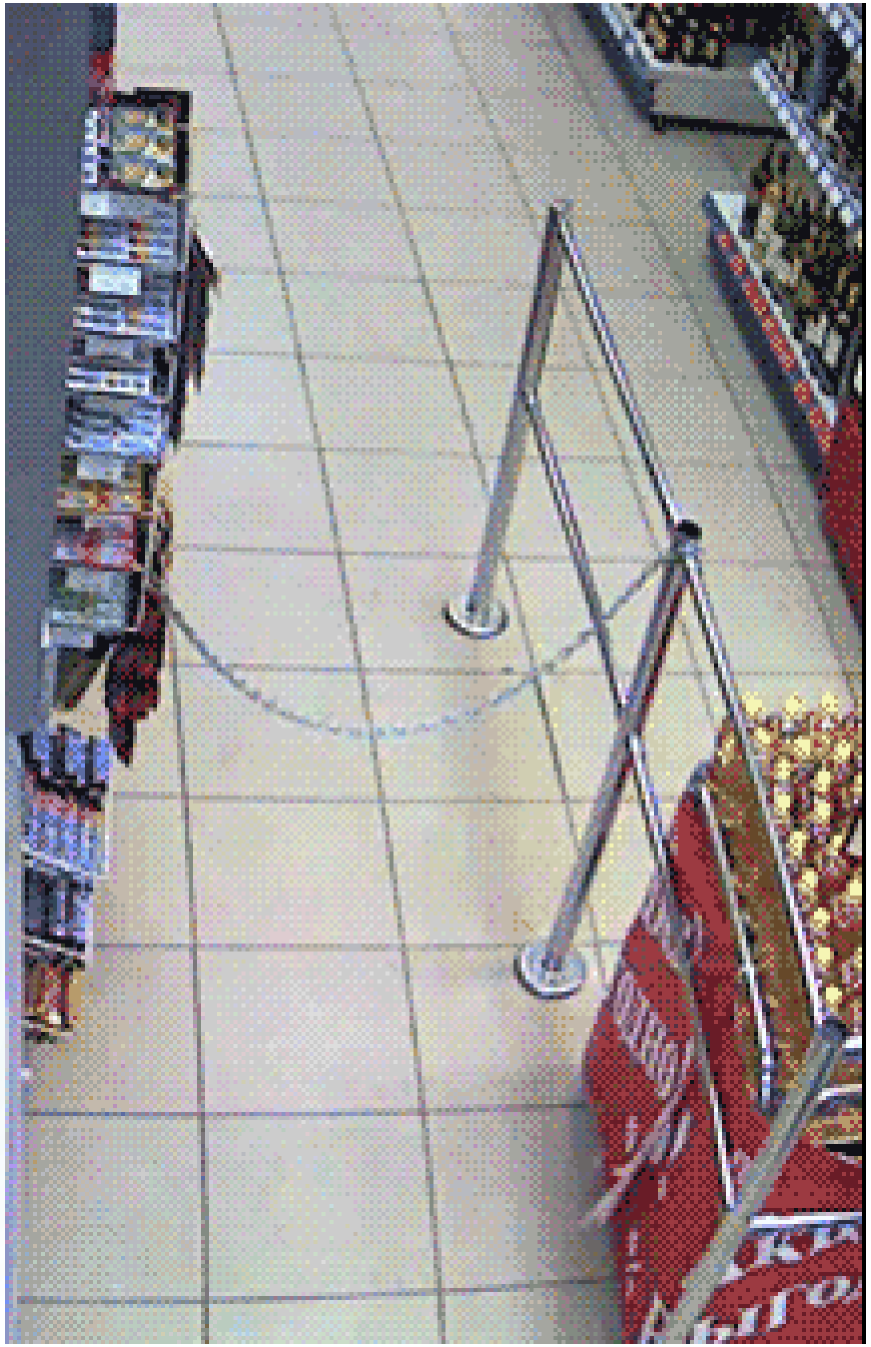
Commissioning

Why do we commission a linac?

- Goal:
  - Generate data for TPS
  - Generate data for MU check program
  - Establish baseline values for future comparison
    - Establish daily / monthly QA standards
    - Have reference data to look for machine changes

Beware of shortcuts!



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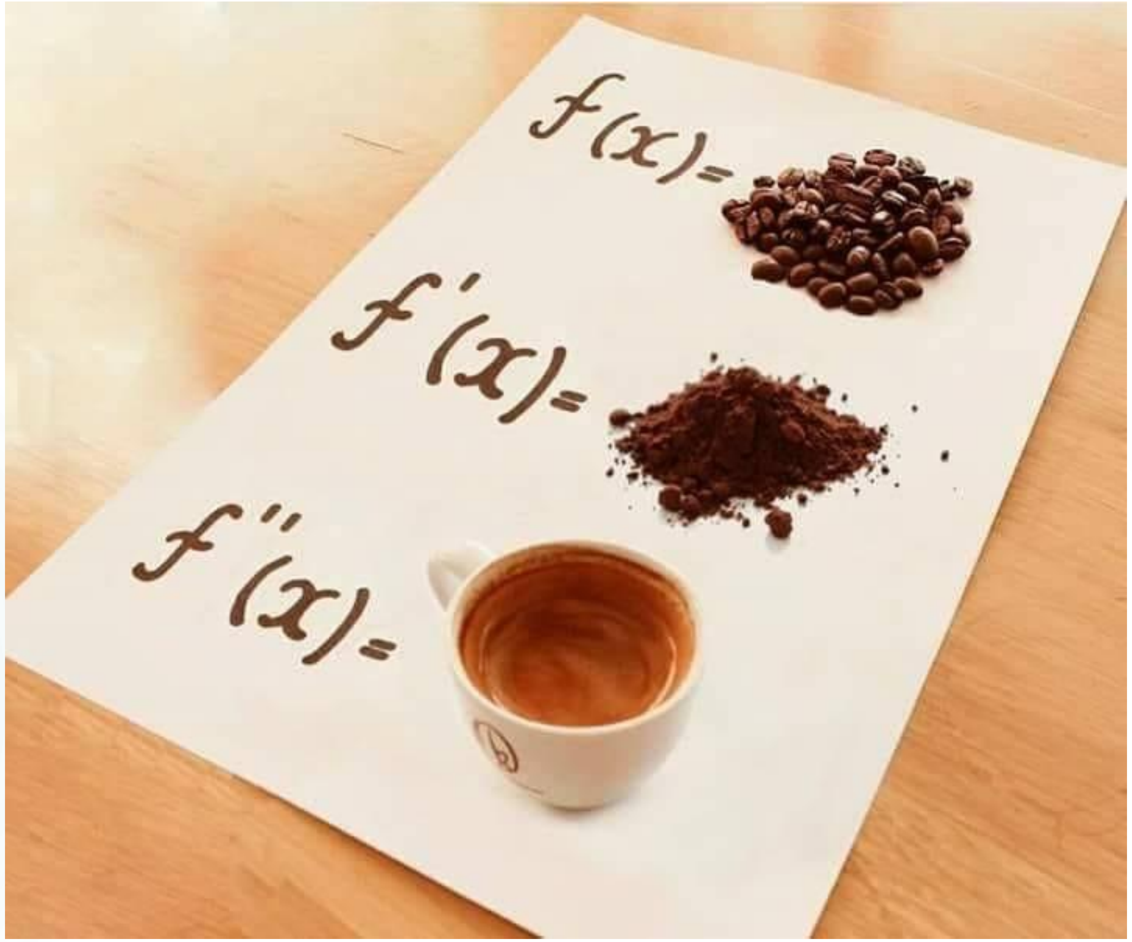
Commissioning

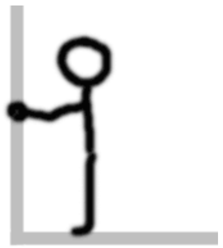
- Long and tedious process!
- Coffee will be your friend

Coffee for the Physicists



Commissioning

- Mistakes will happen, recognize them and fix them, do not cover them up!




FORGIVE YOUR MISTAKES
Nobody's perfect.
lukeprog.com

Commissioning

- Do commissioning in pairs if possible
- Cross-checking is good!

‘cause he still doesn’t know what he’s doing wrong…

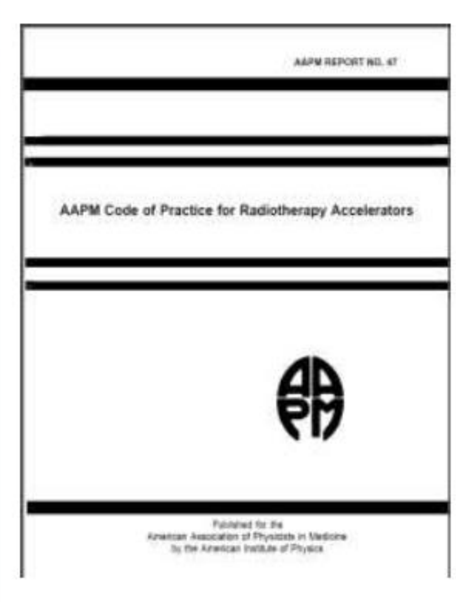
Purpose

- Determine and record beam characteristics
- Acquire data for TPS, manual calculation

- How much data? What data?
  - Must have a minimum data set necessary for treatment planning and manual calcs
  - Depends on TPS

References

- - TG 45 & 53 & 106: General data requirements for commissioning & 3D planning systems
  - IAEA Textbooks




Accelerator beam data commissioning equipment and procedures: Report of the TG-106 of the Therapy Physics Committee of the AAPM

Indra J. Das*
Chee-Wai Cheng
Ronald J. Watts
Anders Ahnesjö
John Gibbons
X. Allen Li
Jessica Lowenstein
Raj K. Mitra
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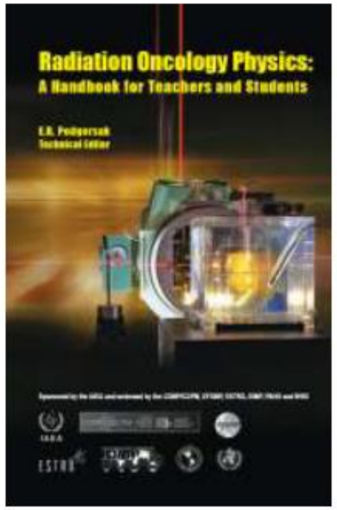
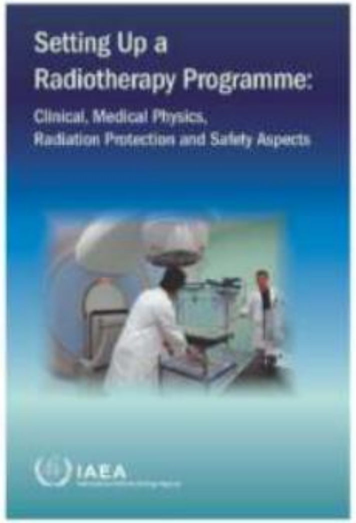
Timothy C. Zhu





Beam data requirements

- Photons
- Electrons
- Other data (eg tray distances)

- Luckily, this is not guesswork, because any TPS should have a manual of what data is needed

- Choose correct tools for beam data acquisition
- Develop a plan, make a spreadsheet

- Beam data – highly dependent on TPS
- Each vendor has minimum requirements
- Many have optional requirements
- Many have courses on modelling

Minimum data

- What coordinate system convention?
  - Jaws X and Y, gantry angle, bed angle …
- TRS398 calibration
- CAX depth doses (PDD or TMR/TPR)
- Dose profiles at different depths
- Isodose distributions (open/wedges)
- Output factors (head, phantom, total scatter factors) – at what depth?
- Wedge and tray factors
- Distances

Data continued

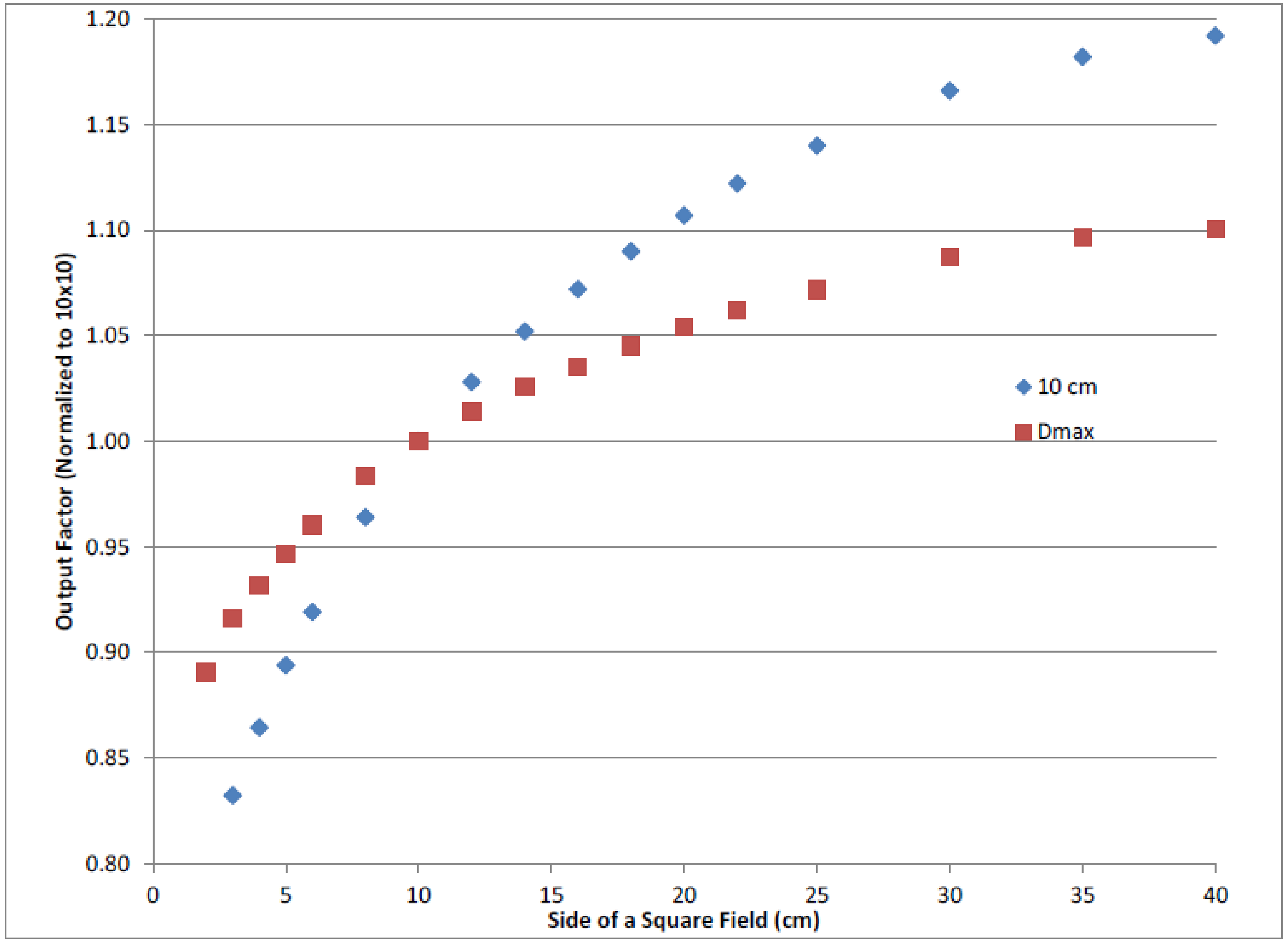
- Off-axis ratios
- Entrance dose / build-up region
- What reference depth?
- TPS data verification

- Special considerations: SRS, TBI, IORT, TSE…

Hand calcs / MU check data

- Hand calc data should not be derived from the TPS → loss of independence
- At what depth do you define output factor for hand calcs? (usually dmax)
- Single wedge factor or not?

Output factor at wrong depth?



Equipment

- Scanning tank (50x50x50 cm)
  - Scan in 3 directions
  - At least 40 cm scan range
  - Accurate chamber positioning (0.1 mm)
  - Min setup time
  - Remote control very useful
  - Data transfer in the right format to computer
  - Lift table

More Equipment

- Electrometer & ion chambers
- Small water phantom for calibration
- Possibly plastic phantom for output measurements
- Different thicknesses plastic / solid water
- Right cables, thermometer, barometer, reference chamber system, check source

Detectors need to be:

- Sensitive enough
- Stable
- No leakage
- No energy dependence
- Good spatial resolution
- Linear response

- Use the appropriate detector!!!
  - Example: electrons, small fields, EDWs

Diodes – careful!

- “Before using a diode detector, one should compare it with ion chamber measurements to confirm its operation and actuary in data “ TG-106

Tank setup

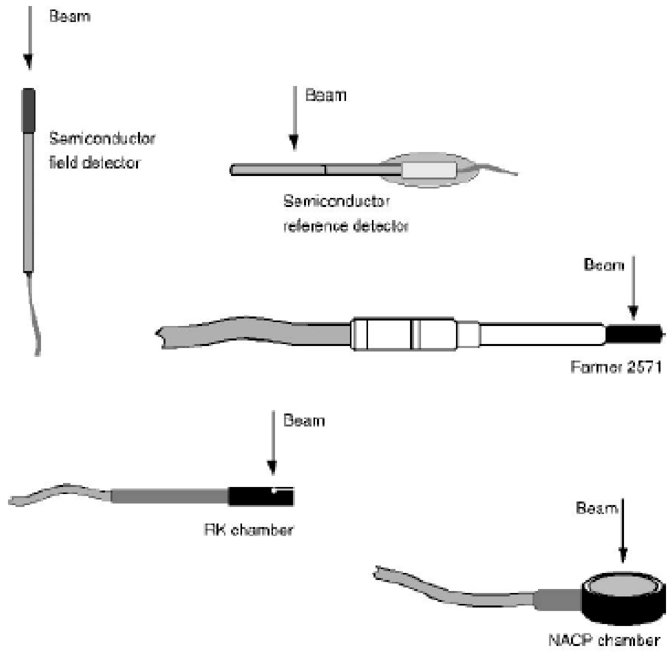
- Verify movements work & electrometer functions
- Heavy!
- Check for water leaks!
- Preferably distilled or de-ionized water
- Position tank so crosshairs are in the center
- Level empty tank
- Fill
- Adjust to correct SSD
- Check level
- Set movement limits

Caution

- Do not store the water in the tank for long periods of time
- Do not leave ion chamber in water
- Beware of voltage

Detectors

- Field and reference chambers
- Choose correct chamber and correct chamber voltage!



Find center of the chamber

- Correct for effective point of measurement of ion chamber!

Signal per Gy from various detectors

- Farmer chamber (0.6 cc): 20 nC/Gy
- Marcus chamber (0.02 cc): 0.67 nC/Gy
- PinPoint chamber (0.015 cc): 0.4 nC/Gy
- MicroDiamond(PTW) : 1nC/Gy
- PhotonDiode(PTW): 9 nC/Gy (fs <40x40)
- PhotonDiode SRS: 175 nC/Gy (fs <10x10)

When measuring:

- Set up the measurements so that they make sense – logical order
- Automate, program sequences to save time
- Save in the correct folder
- Use a reasonable time per measurement to obtain a representative dose measurement
- Use the same equipment and procedures for similar measurements
- Use a reference chamber

Good idea

- Do a base measurement, e.g. dose at 10 cm depth in a 10x10 field to monitor consistency of the output and measuring system

- Be aware of sudden temperature and/or pressure changes

Measured data summary

- Depth dose curves
- Dose profiles, also extending to outside the field to check for scatter and jaw transmission
- Various output factors
- Tray, MLC, block transmission
- Wedge data (depth dose, profiles, OF)
- All for various field sizes and energies

Measured data summary

- Depth dose curves
  - From bottom up

Measured data summary

- Beam profiles
  - Spacing
    - 1 mm in penumbra
    - 2 mm for rest
    - At least 5 cm beyond field if it is used to model jaw transmission
- In-plane and cross-plane
- Ensure correct chamber orientation!

Measured data summary

- Output factors
- Total scatter factor = collimator scatter factor x phantom scatter factor
- Which one(s) does your TPS need?
- Collimator exchange effect? Can be up to 3.5 % or so, ignored in hand calcs

Measured data summary

- Tray factors
  - For a variety of field sizes, but usually just one tray factor
  - Relative measurement – can use plastic phantom

Measured data summary

- Wedges:
  - Fixed or EDW?
  - Max field size? Which jaw?
    - EDW: min 22 MU, Y only
- Do I need a linear array? Depends on TPS
- Ion chamber direction important!
- Wedge Factor
  - Varies <1.5% for fixed wedge
  - If TPS only allows 1 wedge factor – DO NOT USE EDW

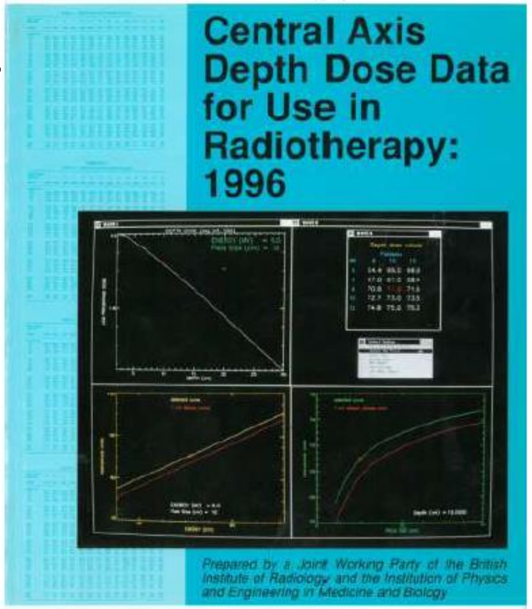
Some TPS require more data

- Half field scans might require the tank to be shifted
- Data at different SSDs for TPS modelling
- Diagonal scans
- In-air measurements?
- Asymmetric jaws, large field IMRT, MLC, EDW

- Measure depth doses continuously or step-by-step? What stepsize?

VERIFICATION

- Data should be checked against an independent sou



- BJR-25
- Golden Beam data
- Spot checks by an independent physicist

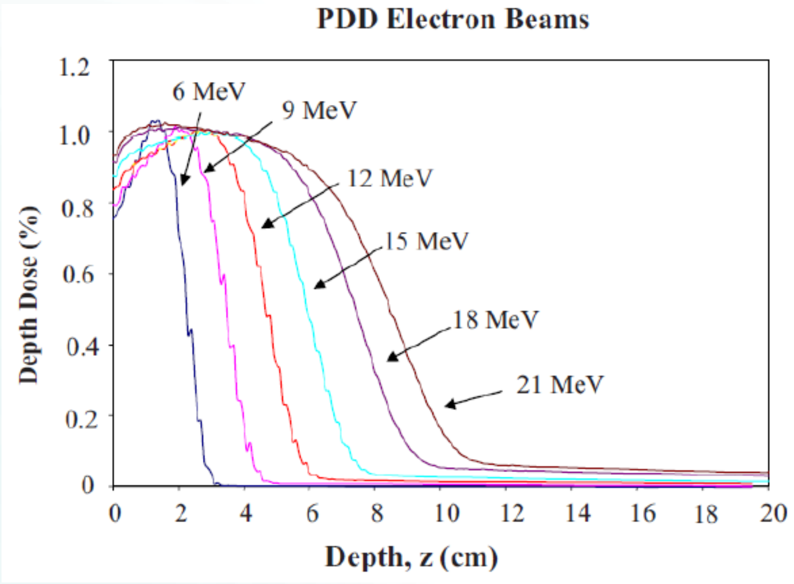
Measured data - electrons

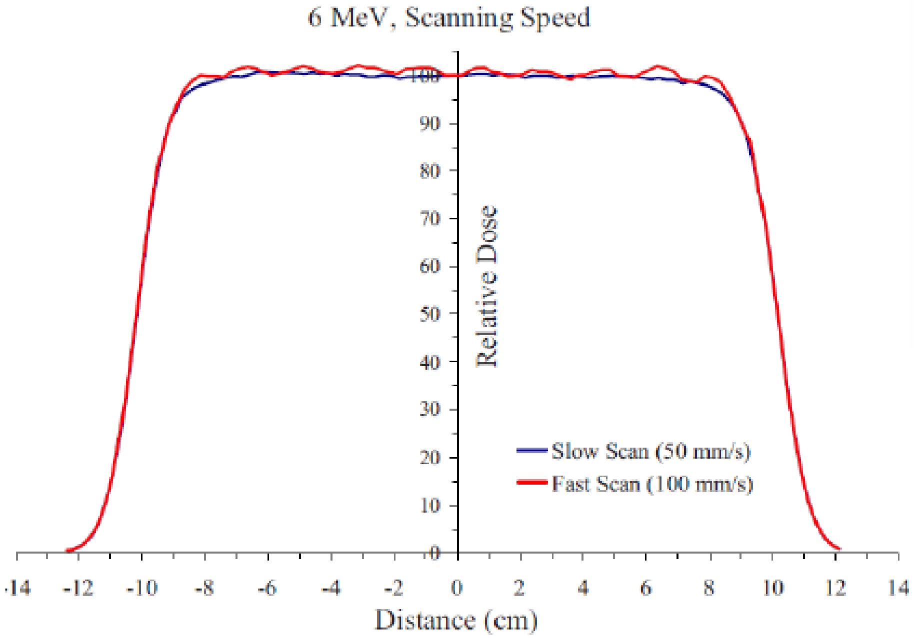
- CAX depth doses
- Applicator factors
- Dose profiles – all applicators, various insert sizes for each
- Virtual source distance
- Output factors
- Various SSDs
- Often electron calculations are done manually

Cone Size	Field Size	SSD
6 cm	2 cm	100 cm
		105 cm
		110 cm
		115 cm
		120 cm
	3 cm	100 cm
		105 cm
		110 cm
		115 cm
		120 cm

Electrons – points to remember

- High speed scanning can cause ripples, then the scanning probe sees varying depths





Electrons – points to remember

- You are measuring ionization curves!
- Have to convert PDI to PDD using replacement correction factors and restricted stopping power ratios (both a function of depth)
- Check if your system does this or if you have to!

Electrons – small fields?

- Rule of thumb: field diameters should be > E/2

eMC in Eclipse

- For each electron energy
  - Profile in air for no cone
  - PDD in water for no cone
  - Absolute dose in water for no cone
  - PDD in water for each cone
  - Absolute dose in water for each cone

Measurements

- TRS398
- Establish factors for relative dosimetry in smaller or plastic phantom

- Remember: NOW is the time to do all the measurements, NOW you have time on the machine! Later it is late nights or weekends only…

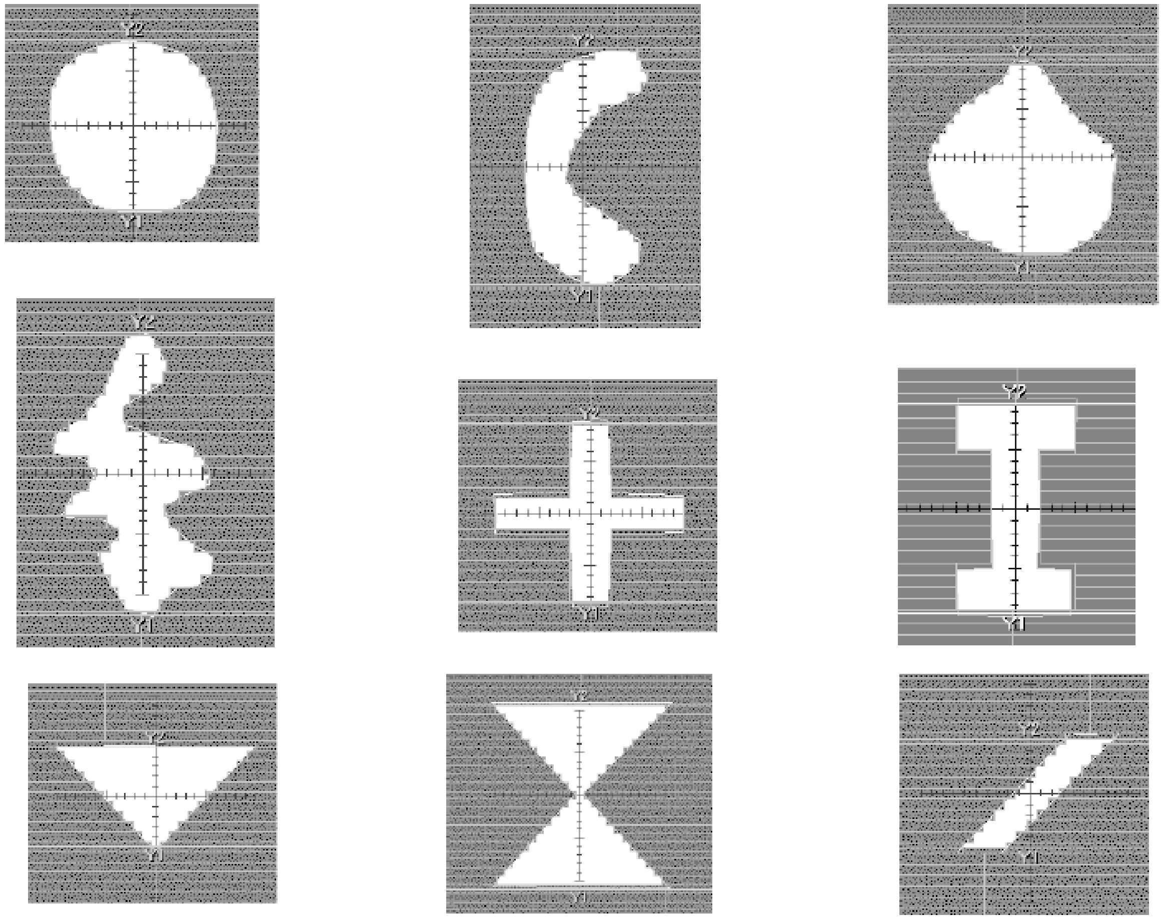
MLC

- Replace conventional blocking
- 3DCRT and more advanced

- Be aware:
  - Does MLC replace jaws?
  - Permanent or add-on?
- MLCs generally travel less than full field of view

IMRT

- Various tests and checks to be done, test patterns to check leaf position accuracy



TPS commissioning

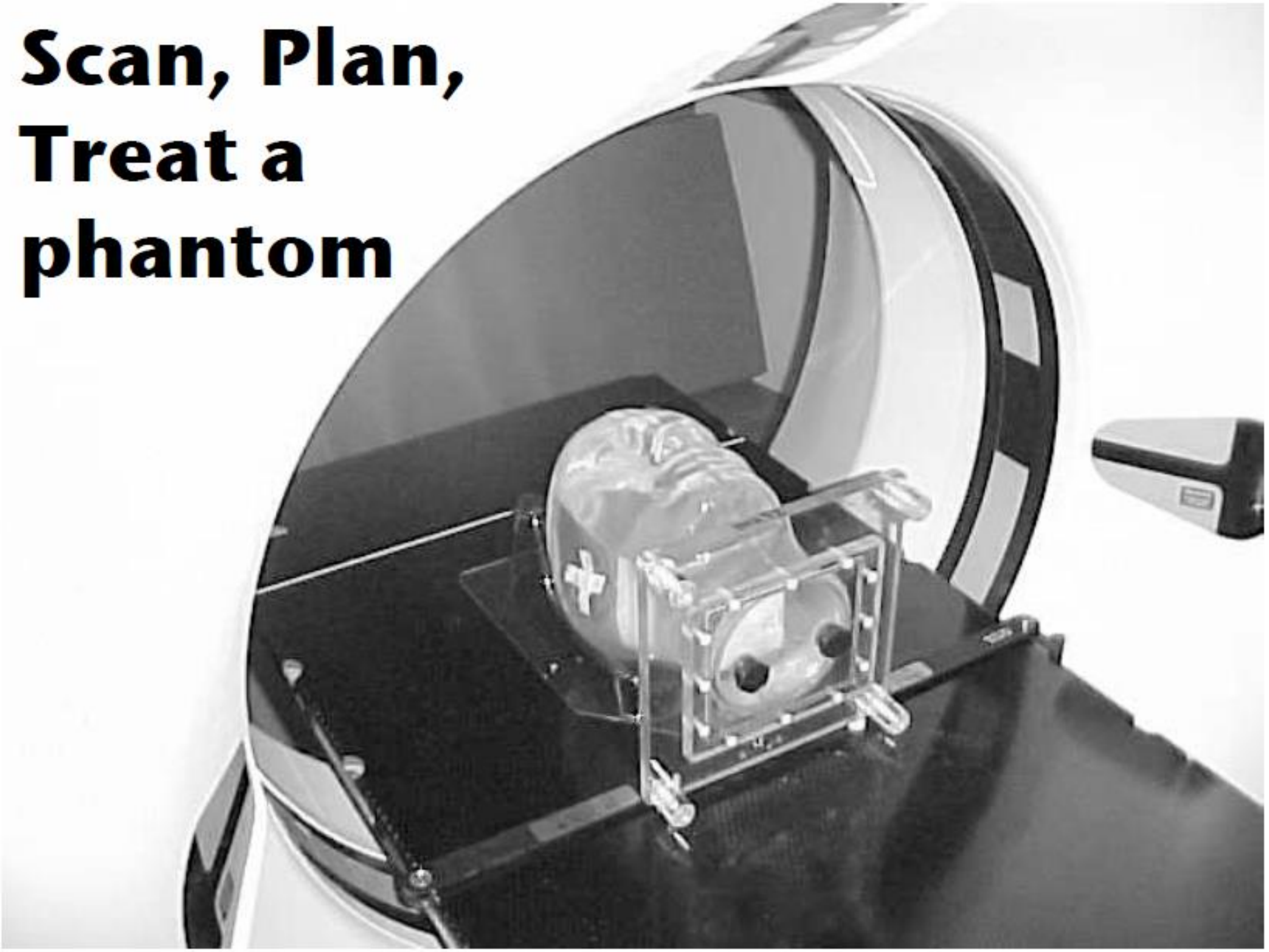
- Verify model based solution with measurements
- Documentation!!!

- Point dose calculation vs measurement

Special procedures

- TBI
- TSE
- SRS
- IMRT
- VMAT
- ...

Final check



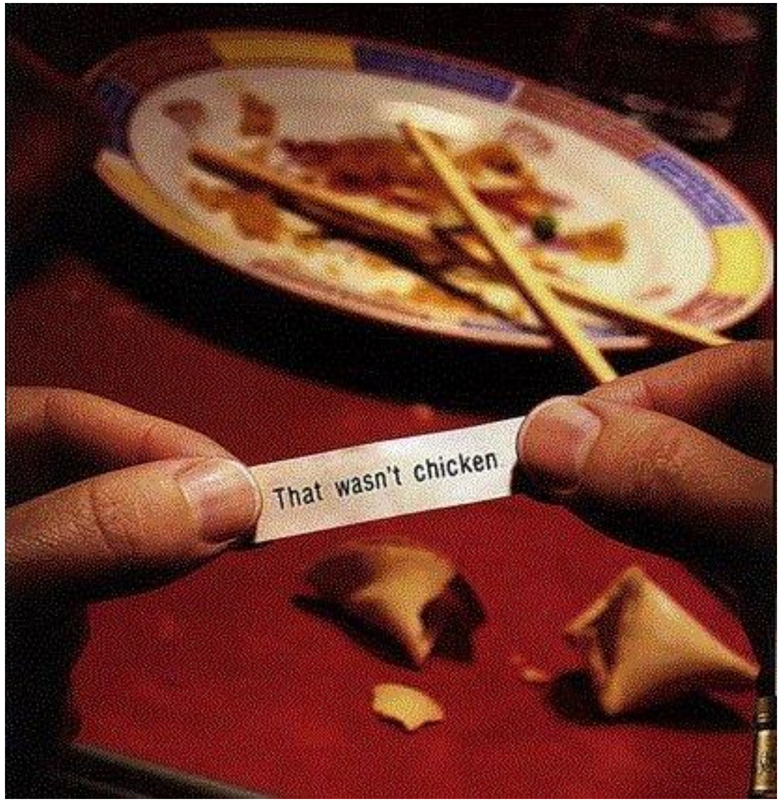
How long does this take?

- Depends on a lot of things:
  - Availability and experience of personnel
  - Proper instrumentation
  - Type of accelerator

Finally, How long will this process take?

- a single energy photon machine can be commissioned in about 2-4 weeks
- a multimodality accelerator with two photon energies and several electron energies can take about 6-8 weeks of intensive effort (requiring 16-h shifts)

- Commissioning is a long and laborious process, but very necessary. In the end, we don’t want any surprises…



Quality Assurance

- On accelerator
- On MLC
- On TPS
- On EPID
- …

Linac

- Interlocks
- Beam status indicators
- Laser-crosswire coincidence
- ODI
- Optical back pointer
- Field size indicator
- Output constancy
- Emergency off

Linac

- Gantry angle readout
- Collimator angle readout
- Couch position readout (vertical, lat & long)
- Couch isocenter
- Couch angle
- Crosswire centering
- Light/Radiation co-incidence

Linac

- TRS398
- Beam energy
- Flatness & Symmetry
- Radiation isocenter (Winston-Lutz)

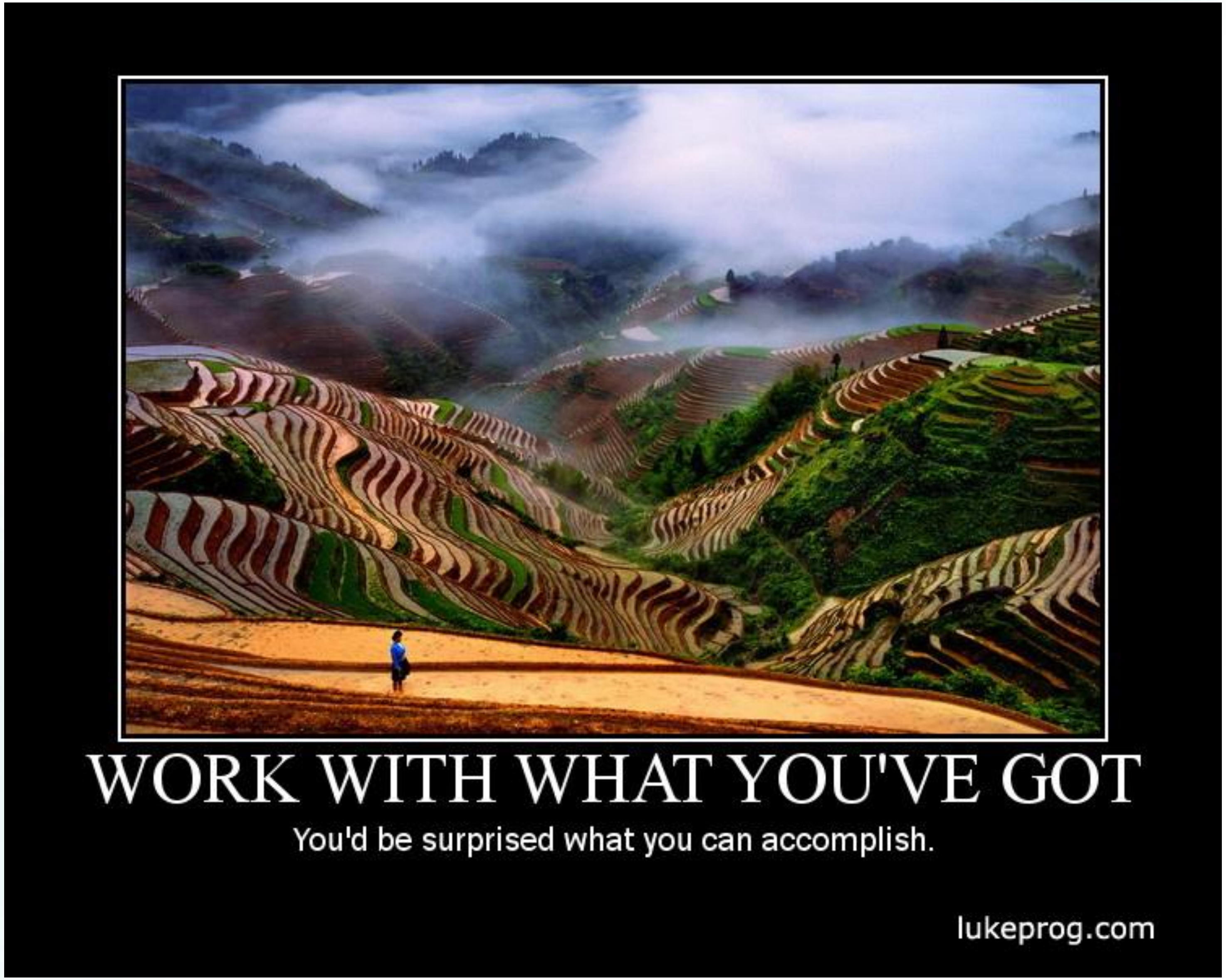
- Documentation & Records!!!

MLC

- Leaf position for std template
- Leaf alignment
- Leaf leakage / transmission
- Stability with gantry rotation
- Alignment with jaws
- …

EPID

- Mechanical and electrical integrity
- Collision interlocks
- Image quality
- Positioning of the EPID – reproducibility
- Spatial resolution
- Noise
- Distance estimates cf. to true distances
- …


WORK WITH WHAT YOU'VE GOT
You'd be surprised what you can accomplish.
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