The water tank less annual and two-hour monthly QA, ways to improve your life with detector arrays without sacrificing quality

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Linac QA with detector arrays – Is the water tank dead
Peter Balter, Ph.D.

Learning Objectives:

- To understand the validation of the array calibration to ensure that it does not introduce systematic errors.
- To understand beam profile measurement with detector arrays compared with in water scanning data, to establish energy monitoring procedures for both photon and electrons.

Disclosures

- Raysearch Laboratories – Sponsored Research Agreement
- Varian Associates – Sponsored Research Agreement

These projects are not related to the work in this presentation.

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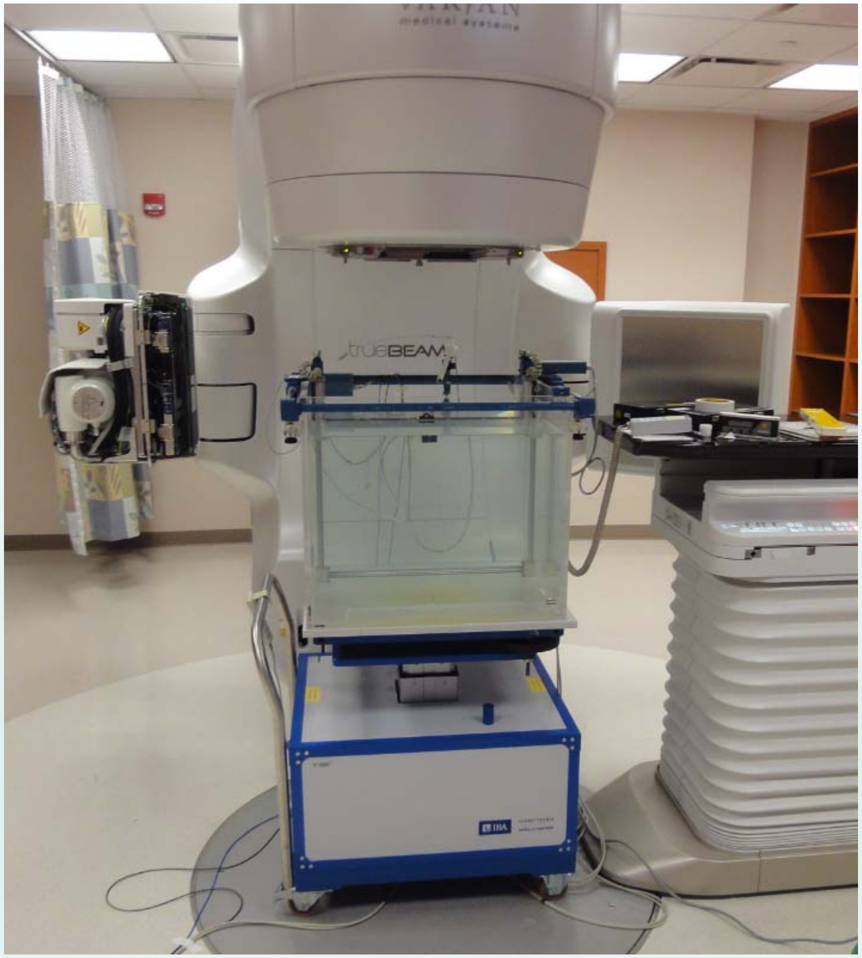
Water Scanners

Why we like them

- Used for modeling treatment planning systems and generating reference data
- Single stable detector used for all points in a field(requires a reference detector)
- Many choices of detectors and they can be quickly exchanged
- High spatial resolution (< 1mm positioning precision, about 1 mm accuracy)
- Physics of beams in water is well understood

Why we don’t

- Water tanks are expensive to buy and maintain
- Water tanks are hard to use unless you do it often
- Water tanks may have operator dependence
- Water tanks are difficult to move/store
- Water tanks are slow



Array Detectors

Why we like them

- They capture the entire profile in real time
  - Beam steering and diagnostics
  - Verification of dynamic treatments (EDW)
- They are less expensive than water tanks
- They are easy to setup
- Can be mounted to the gantry for checking profiles vs gantry angle

Why we don't

- Detector spacing is sparse (5mm) and/or field size is limited
- Non-water materials
- Cannot effectively measure PDD/TMRs
- Largest ones smaller than maximum field size for most machines
- Changing detectors requires purchasing a new array

Medical Physics Practice Guideline #8.a for Linac QA (TG-265)

3D Water Scanners (3DS) are generally used for

D1: Output - Annual

D2: Beam Profile – Annual

D3: Electron Beam Energy – Annual

D4: Photon Beam Energy – Annual

D1: Can be done in a small ($30x30x30\ cm^3$ water tank)

D2-D4: Can be done with a properly normalized detector array at the same or higher precision than could be done with a 3DS

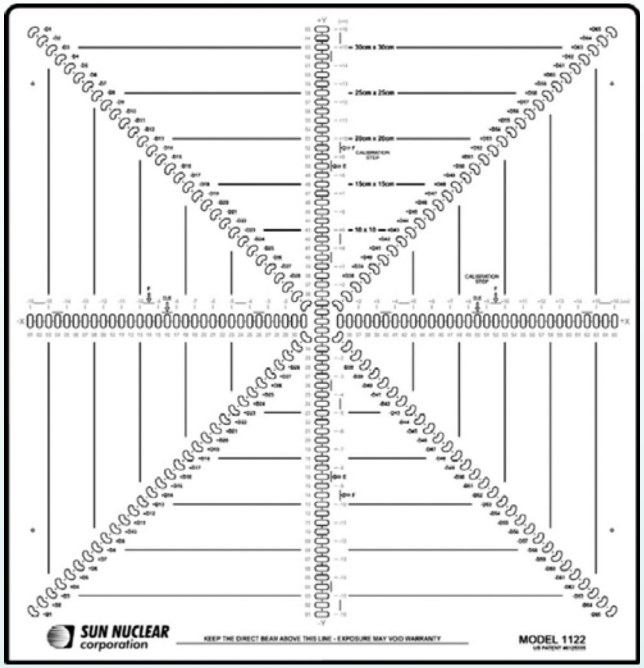
Table 2 Dosimetry Tests.

Item	Test	Frequency	Tolerance
D1	Photon and electron output constancy	Daily[a]	3% of baseline
		Monthly	2% of baseline
		Annual	1% of TG51
D2	Photon and electron beam profile constancy	Daily[a]	2%
		Monthly	2%
		Annual	2% of TPS OAFs[b]
D3	Electron beam energy	Monthly	2 mm
		Annual	2 mm
D4	Photon beam energy	Monthly	1% of PDD/TPR (relative change in value)
		Annual	1% of PDD/TPR at reference depth
D5	Dynamic delivery control	Monthly	3% of open field dose
D6	Photon MU linearity (output constancy)	Annual	2% >10 MU for open field; 2% for segmented field
D7	Electron MU linearity (output constancy)	Annual	2% for clinical range
D8	Photon output vs dose rate	Annual	2%
D9	Photon and electron output vs gantry angle	Annual	2% of IEC gantry 0° output
D10	Photon and electron OAF vs gantry angle	Annual	2% of OAFs at IEC gantry 0°
D11	Arc mode (expected MU, degree)	Annual	2% of MU and 2°
D12	Special procedure mode (TBI/TSET)	Annual	Output: same as regular beam; energy: same as regular beam; profile: same as regular beam

[a]Daily checks should be conducted for the energies used that day.
[b]Tolerance is the same as what was acceptable for TPS model evaluation at the time of commissioning.

Array Calibration (normalization)

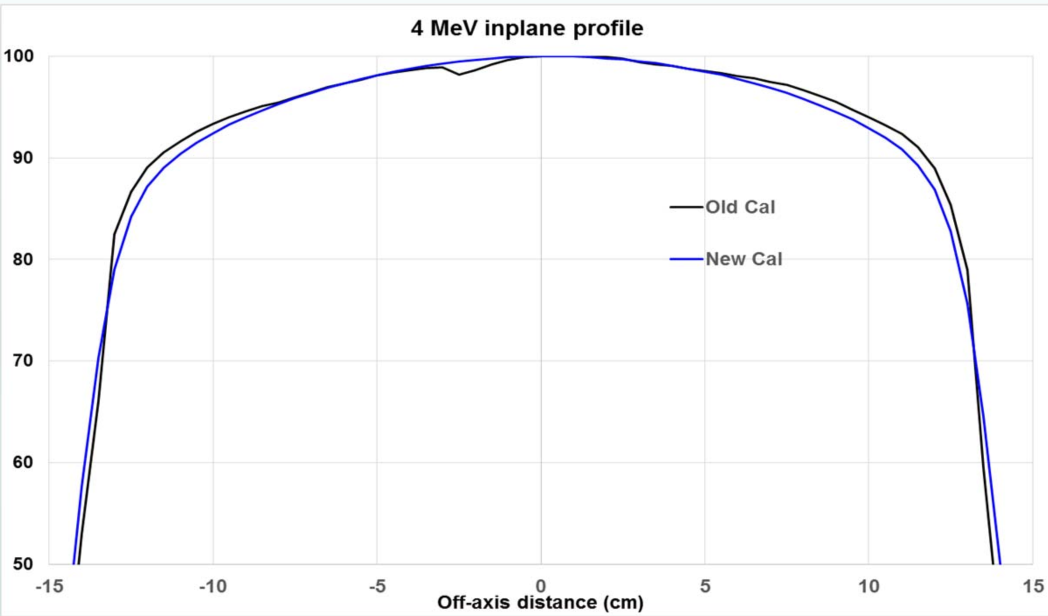
- Array detectors have hundreds of detectors
- There will be some variation in response of these detectors
- Each manufacturer provides a normalization procedure to correct the response of each detector to match that of a reference detector (generally the CAX detector)
- Correction factors may be:
  - Energy dependent
  - Modality dependent
  - Dose rate dependent
  - Changing with time (short term and long term stability)

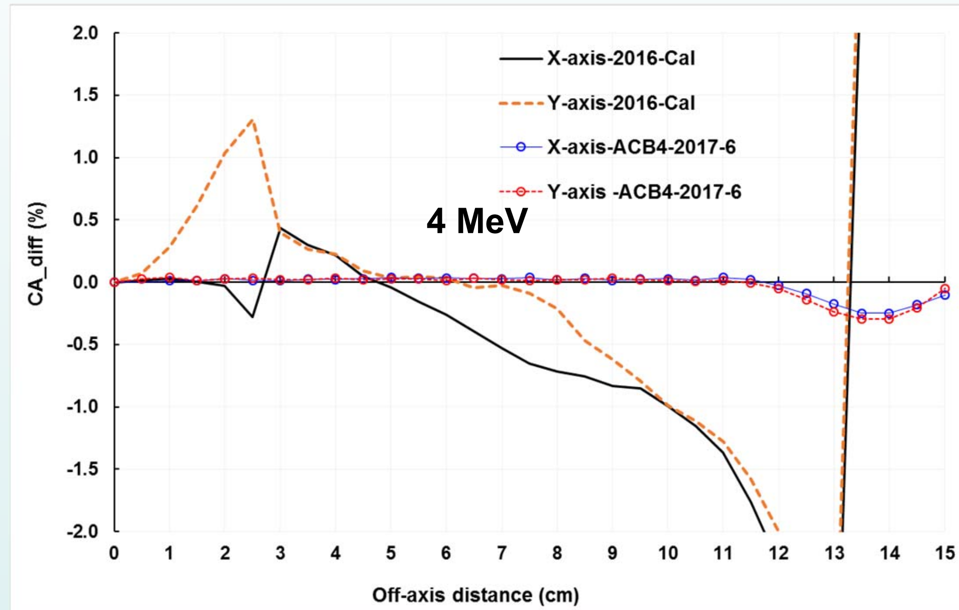


Medical Physics, Volume: 37, Issue: 11, Pages: 6101-6111,
First published: 01 November 2010, DOI: (10.1118/1.3505452)

Array Normalization accuracy

2 different array normalizations were applied to the same measurement resulting in different profiles





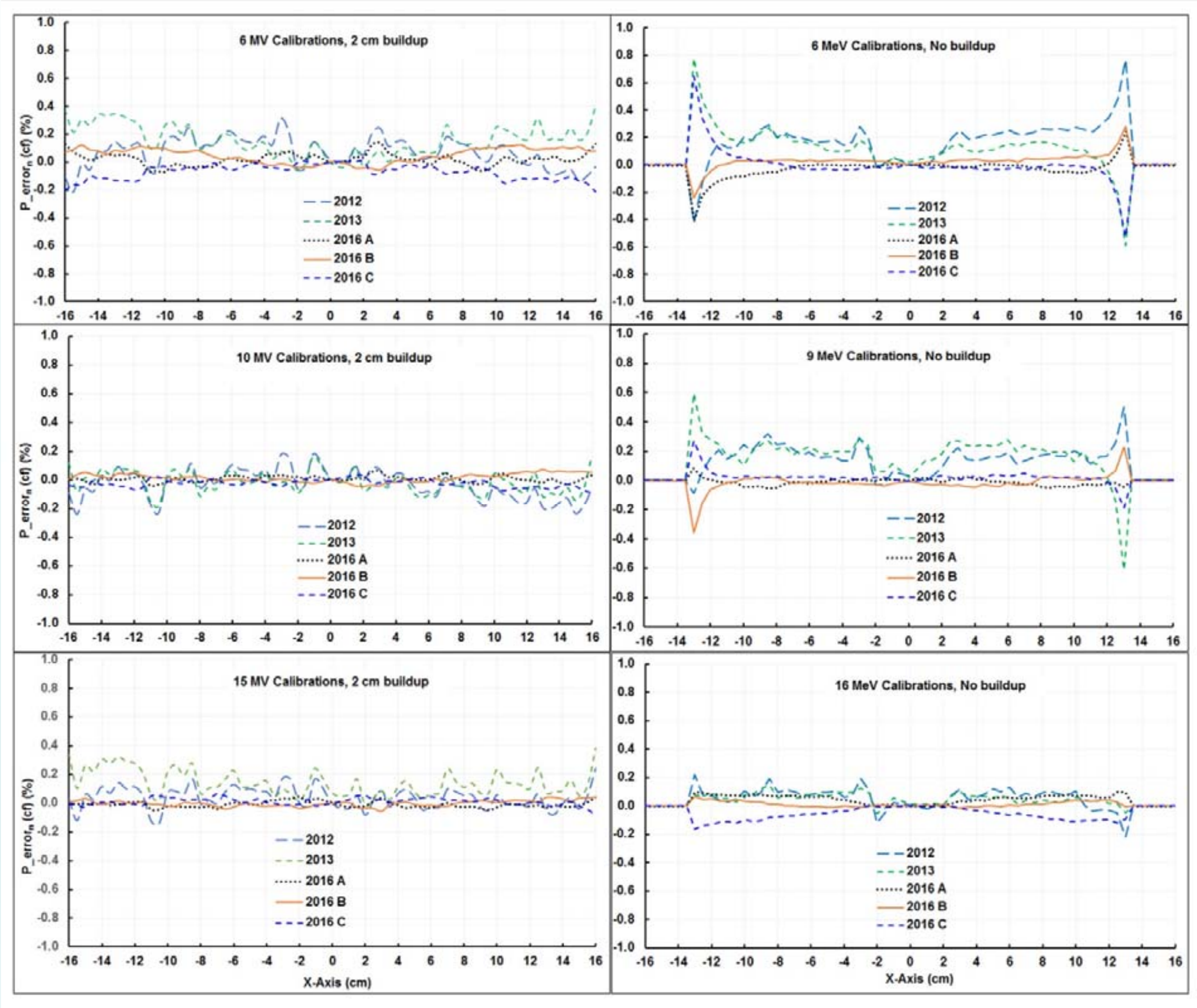
Accuracy and stability of normalization correction

Residual errors after normalization corrections should be less than 0.5%

Normalization corrections have shown to be stable for long periods of time.

Normalization corrections and their stability are energy dependent

Photon normalization corrections should be acquired with enough material on top of the array to remove contaminate electrons (generally 2 cm plus the intrinsic B/U in the array itself)



Note on Symmetry Metrics and Beam Steering

There are a large number of commonly used symmetry metrics

Examples from SNC Profiler

- CAX Point Difference Symmetry
- Point Ratio Symmetry
- Positive Point Difference Symmetry
- Area Average Symmetry
- Area Symmetry

> **Note:** *Different types of symmetry can be selected in the Analysis Panel and the On Graph Symmetry. Verify the selected settings are correct for your needs.*

From SNC IC Profiler Reference Guide

These metrics

- Show different ratios (comparisons to mirror points, to CAX, to average over areas)
- Have different default included areas in analysis (generally between 100% to 80% of field size)
- Symmetry metrics defaulted by the system may not be the ones specified by the institution (linac vendor)
- Signs may be reversed or not included at all based on the metric and the vendors implementation.

Comparison of Profiles measured with an ICA to Water

- Array detectors have been shown to give profiles equivalent to those measured in water
  - Across a range of field sizes
  - At a variety of depths
- Issues:
  - Sparseness of detectors
  - Out of filed energy dependency
- Suggested use case
  - Validation that the profile has not changed since a reference profile was acquired
  - Comparison with models in a treatment planning system
    - Annual comparisons with TPS
    - Initial acceptance of Linac/TPS combination
- Not suggested
  - Acquiring data for creation of a de novo beam model

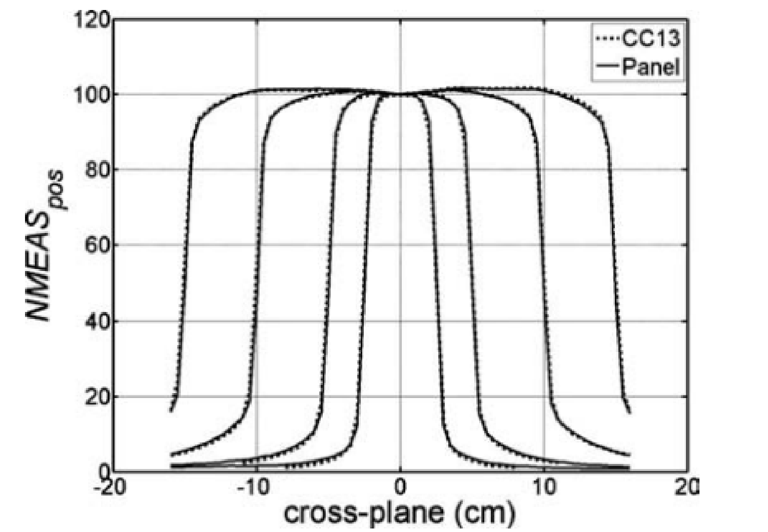


FIG. 11. Normalized cross-plane measurements with a CC13™ and the panel. The beam energy was 6 MV and the buildup was 10 g/cm^2.

Simon *et al.*: Characterization of a multi-axis ion chamber array

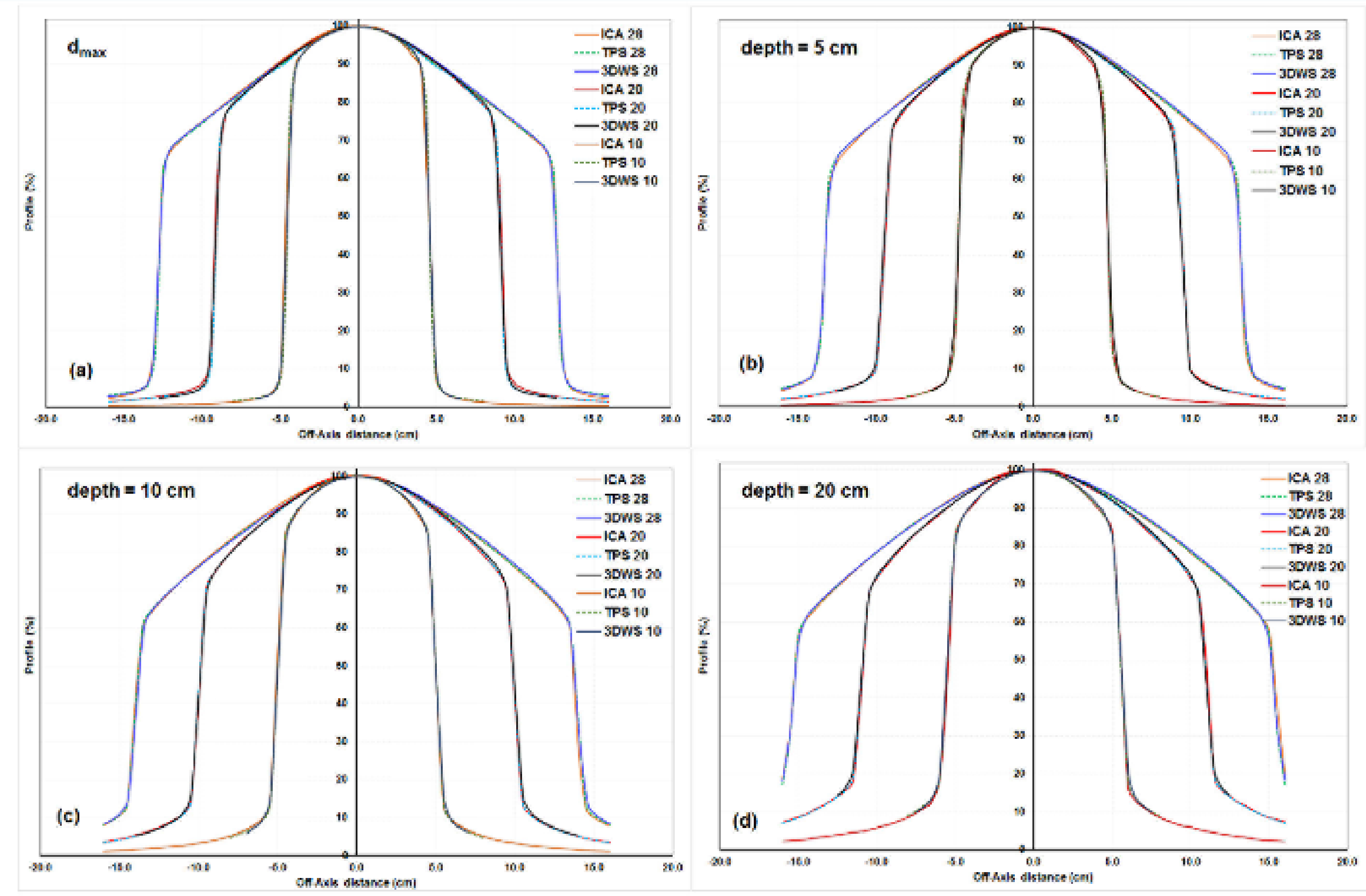
Profile Comparisons

Profiles were compared between an array, a water tank and a TPS Model

MPPG 5a (TPS guidelines) were used to compare dose:

- **In High Dose Region**
- **In Low Dose Tails**
- **In the Penumbra**

Good agreement was found in all regions showing the array was adequate for accepting a treatment planning model



Energy Metrics

Photon:

- Traditional metric: is attenuation in water for a reference field size with full scatter
- Alternative metrics:
  - Off axis ratio
  - attenuation in high density materials
  - Combination of the above

Electron:

- Traditional metric: Depth in water for the 50% dose in a field large enough for full scatter
- Alternative metrics:
  - Attenuation in medium density materials

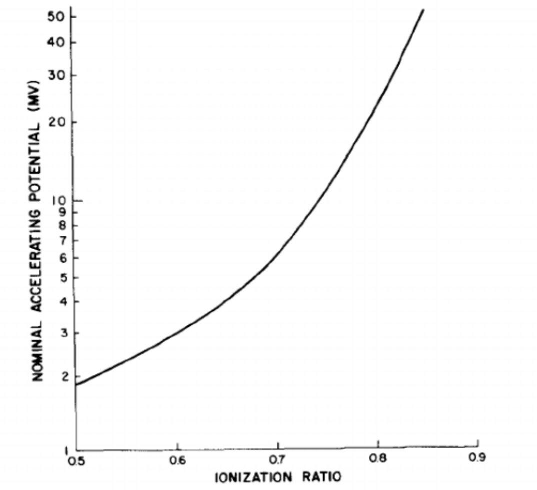
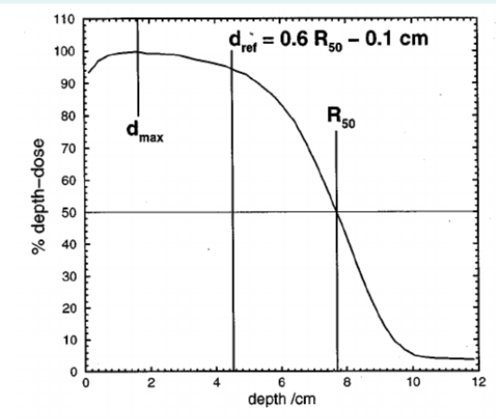


FIG. 3. Nominal accelerating potential (MV) as a function of the ionization ratio.

AAPM Protocol: Task Group 21: A Protocol for absorbed dose from high-energy beams



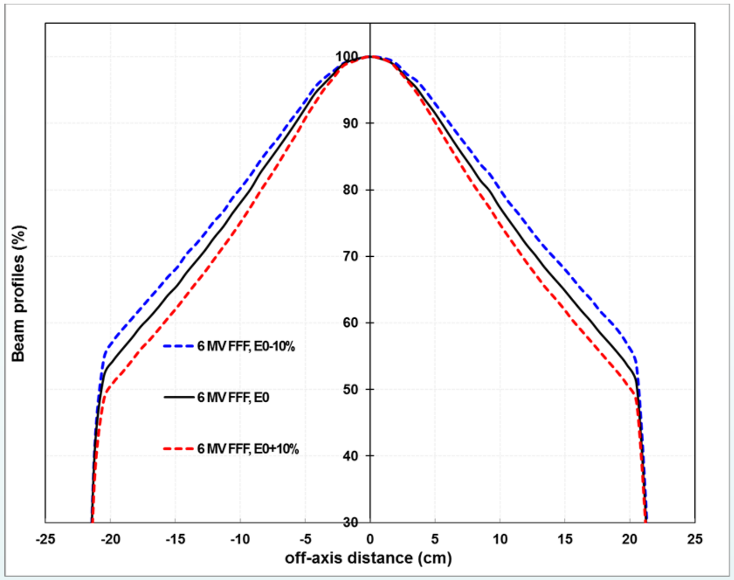
Almond *et al.*: AAPM's TG-51 protocol

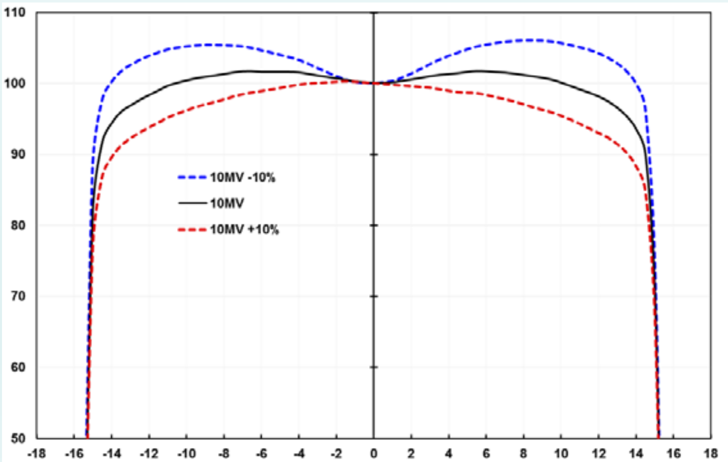
Precision of Photon Beam Energy

- Photon beam energy is traditionally characterized by penetration in water
- The ability the determine this is limited by the ability to set detector depth (approximately 1 mm/0.15%)

- Changes in off axis ratio can be used as a metric for changes in energy
  - OAR changes due to changes in angular distribution of the bremsstrahlung distribution with energy
  - Due to changes in penetration of the flattening filter with energy
- The ability to measure OAR with an array detector is limited by the reproducibility of the detector (approximately 0.08%)

- The ability of OAR based metrics to detect changes in energy is 5X better than PDD based metrics.

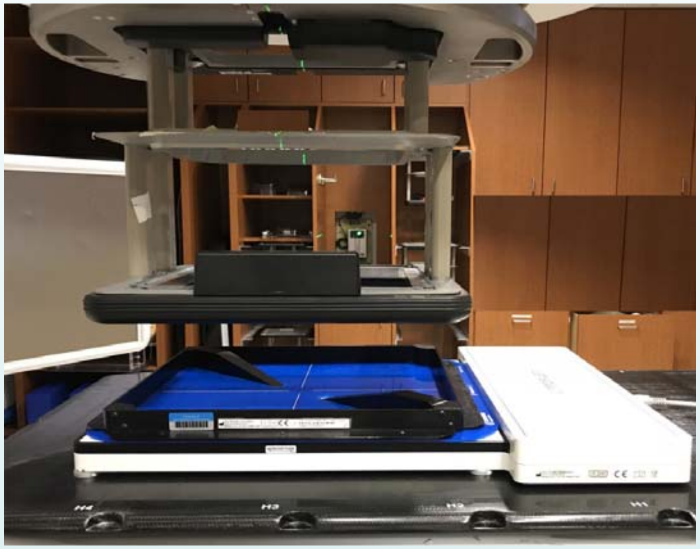




Gao et al., Monitoring photon beam energy, JACMP (2016) 17(6) 242-253

Monitoring Electron Beam Energy

- Wedge shaped filters can be placed on top of the array to provide different measurement depths
- The ratio of the signal at any detector location to a reference detector with be the relative ionization ratio * the off-axis ratio.
- This will be consistent for a give class of linear accelerator and energy
- If the results of corrected for off axis ratio the calibration becomes energy independent



Measuring beam energy with an array detector has been shown to agree with measurements in water within 1 mm.

Gao, et al., Monitoring linear accelerators electron beam energy constancy with a 2D ionization chamber array and double-wedge phantom, JACMP (2020) 21(1): 18-25.

What was discussed in this section and the 2 hour monthly

Monthly QA on a linac beam involves

- Output checks (not discussed)
- Energy Checks
- Profile Checks
- Radiation Field Size Checks(not discussed)

All of these checks can be done with an array detector with only needing the enter the room once to remove the photon build up and install the cone and wedge plate.

All these checks for a 7 Energy (2 photons + 5 Electrons) machine can be done in less than 20 minutes.

This leaves 1 hour and 40 minutes to do the rest of the QA.

Summary of this section

- Detector arrays can be used to
  - Steer photon and electron beams
  - Verify that beam profiles have not changed since a reference date and/or match a TPS model
  - Verify that the energy of a photon or electron beam has not changed
- A detector array combined with a small ($30x30x30\ cm^3$) water tank can be used to complete all needed beam checks or annual QA on a linear accelerator