Leveraging Multi-Dimensional Detector Systems for Quality Assurance Including TG-142

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Disclosures

I have a faculty appointment at the University of Michigan Department of Radiation Oncology and I am employed by the Veterans Health Administration.

I'm part of a consortium investigating how Varian Developer Mode can be used to automate linac QA.

I'm not endorsing any commercial or non-commercial product.

Objective

To describe how detector arrays can be used for machine and planning system quality assurance, including implementation methods, advantages, and potential pitfalls.

1. Introduction

This discussion will address primarily planar (2D) array devices.
Quasi-3D arrays can also be used but planar arrays are often more suitable to linac QA.

Diode or ion chamber arrays can be used.
Diodes are smaller (better resolution), ion chambers may offer other advantages (less energy dependence, for example).

1. Introduction

Examples of 2D array devices

Sun Nuclear Mapcheck 2

IBA MatriXX

PTW 1500

1. Introduction

Potential advantages of arrays over scanning water phantoms include:

1. Faster and easier setup.
2. Less prone to setup errors.
3. Measurements take less time.
4. 2D information in one measurement.
5. Easy comparison to baselines.
6. Can mount the device on the gantry head for response as a function of gantry angle.

2. Validating Arrays

All QA devices require commissioning and validation prior to use.

There is no task group report that specifically describes how to commission array devices.

2. Validating Arrays

FIRST: Know your system for consistent results:

1. Proper set up (level/aligned, temperature, background measurements, electronics warm up, pre-irradiation).
2. Uniformity and dose calibration methods.
3. Configurations for acquisition (modes, digital frame intervals, sampling criteria, thresholds, etc) and data analysis (formulas, averaging, interpolation, etc). <u>Save screen captures!</u>

2. Validating Arrays

Know your system: *continued*

4. Angular response (if applicable).
5. Data save/export formats. Save raw data.
6. Dose rate response, especially if FFF beams.
7. Inherent buildup and backscatter.
8. Spatial sampling and extent limitations. (often avoid direct exposure of electronics).
9. What's inside – recommend you image your device.

2. Validating Arrays

Once you are familiar with your array you can perform a thoughtful commissioning.

Perform your own testing and consult published results.

2. Validating Arrays

Commissioning an Array system for linac QA:

1. Reproducibility.
2. Dose linearity.
3. Output factors as a function of field size.
4. Sensitivity to changes in collimation.
5. Validation against open and wedged fields.
6. Validation of modulated fields.
7. Comparison to water phantom results.

Spezi E, Angelini AL, Romani F, Ferri A. Characterization of a 2D ion chamber array for the verification of radiotherapy treatments. **Phys Med Biol**. 2005;50(14):3361–73.

2. Validating Arrays

Commissioning an Array system for linac QA:

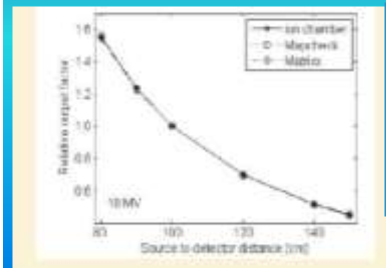
Additional considerations:

8. Instantaneous dose rate dependence.
9. Linac pulse rate dependence.
10. Energy dependence.

Can compare against a standard ion chamber.

Simon, TA. **Using Detector Arrays to Improve the Efficiency of Linear Accelerator Quality Assurance and Radiation Data Collection**. Thesis, University of Florida, 2010.

2. Validating Arrays



From Li: Dose rate dependence can be examined by changing source to detector distance. Here ionization chamber and diode arrays are compared.

Li J, Yan G, Liu C. Comparison of two commercial detector arrays for IMRT quality assurance. **Journal of Applied Clinical Medical Physics**. 2009; 10 (2).

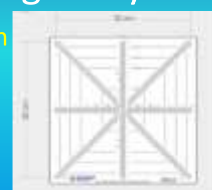
2. Validating Arrays

Many arrays provide real-time display of profiles. Beam steering can be fast and efficient if the method is properly vetted and a large field size with appropriate buildup are used.

Validation against a scanning water phantom is important if you want to use the device for beam steering.

2. Validating Arrays

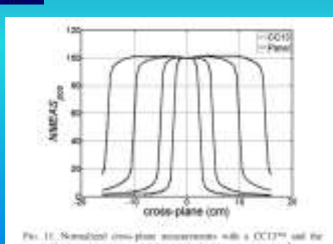
The IC Profiler, an ionization chamber array, has been characterized against a scanning water phantom.



Simon T, Kozelka J, Simon W, Kahler D, Li J, and Liu, C. Characterization of a multi-axis ion chamber array. **Medical Physics**. 2010;37(11):6101-6111.

Gao S, Balter P, Rose M, and Simon W. SU-E-T-645: Qualification of a 2D ionization chamber array for beam steering and profile measurement. **Medical Physics.** 2015;42:3484-3485.

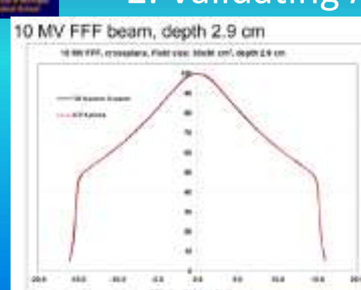
2. Validating Arrays



Comparison between water tank profiles and profiles acquired with the IC Profiler (labeled "Panel" in the figure)

Image from Simon T, Kozelka J, Simon W, Kahler D, Li J, and Liu, C. Characterization of a multi-axis ion chamber array. **Medical Physics**. 2010;37(11):6101-6111.

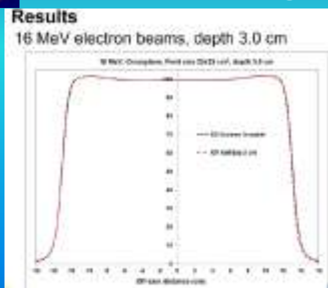
2. Validating Arrays



Comparison between water tank profiles and profiles acquired with the IC Profiler

Figure courtesy of Song Gao, Ph.D., MD Anderson Cancer Center, ref Gao S, Balter P, Rose M, and Simon W. SU-E-T-645: Qualification of a 2D ionization chamber array for beam steering and profile measurement. **Medical Physics.** 2015;42:3484-3485.

2. Validating Arrays



Comparison between water tank profiles and profiles acquired with the IC Profiler

Figure courtesy of Song Gao, Ph.D., MD Anderson Cancer Center, ref Gao S, Balter P, Rose M, and Simon W. SU-E-T-645: Qualification of a 2D ionization chamber array for beam steering and profile measurement. **Medical Physics.** 2015;42:3484-3485.

3. Linac QA with Arrays

Linac QA applications include:

1. TG-142 monthly testing
2. TG-142 annual testing
3. Post repair machine validations
4. Post upgrade validations

Array devices are an excellent tool for routine QA of accelerators via constancy tests.

3. Linac QA with Arrays

TG-142 specifically mentions detector arrays in the report…

The expansion of tests is also justifiable due to the fact that since TG-40 and post-IMRT, the selection of available QA tools makes annual testing less burdensome; these tools range from 3D water scanning tanks to large area detector arrays. The proper tools should be chosen by matching the detectors and software to the needs and sensitivity requirements.

Klein EE, Hanley J, Bayouth J, Yin F-F, Simon W, Dresser S, Serago C, Aguirre F, Ma L, Arjomandy B, Liu C, Sandin C, Holmes T. Task Group 142 report: quality assurance of medical accelerators. Medical Physics. 2009;36(9):4197-4212.

3. Linac QA with Arrays

Potential TG142 Monthly Applications

Monthly Procedure	Tolerance
Photon Beam Profile Constancy	1%
Electron Beam Profile Constancy	1%
Dynamic Wedge Factor Check Each Energy	+/- 2%
Typical Dose Rate Output Constancy	2%
X-ray and Electron Output Constancy ?	*2%*
Light/Radiation Field Coincidence ?	*1mm or 1% (asymmetric jaws)*
Electron Beam Energy Constancy ?	*2%/2mm*

Klein EE, Hanley J, Bayouth J, Yin F-F, Simon W, Dresser S, Serago C, Aguirre F, Ma L, Arjomandy B, Liu C, Sandin C, Holmes T. Task Group 142 report: quality assurance of medical accelerators. Medical Physics. 2009;36(9):4197-4212.

3. Linac QA with Arrays

The tool of choice for checking soft wedges.

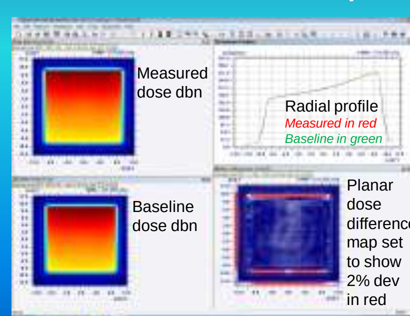
II.E.2.c. Detector arrays. A detector array system can be used for simultaneous data acquisition over the entire open beam and offers the most suitable method for soft wedge (dynamic wedge or virtual wedge) profile measurements. The array system may be an ion chamber array (air or liquid-filled) or a diode array, depending on the manufacturer. Since

Das I J et al: Accelerator beam data commissioning and equipment: report of the TG-106 of the therapy committee of the AAPM. Medical Physics. 2008;35(9): 4186 – 4215.

3. Linac QA with Arrays

Measuring a dynamic wedge with an array.

Fast and efficient!



3. Linac QA with Arrays

There are multiple applications of arrays to TG-142 annual testing.

We will review some of these later in the presentation.

3. Linac QA with

What about redundancy in TG-142?

TG- 142 includes overlap on the frequency of certain tests

Example – profile constancy is tested monthly, while profile flatness/symmetry are tested annually.

Per TG-142:

"This overlap in frequency should have some level of independence such that the monthly check would not simply be a daily check."

Monthly tests performed with one device (e.g. EPID) could be performed annually using a different device (e.g. 2D ion chamber array).

3. Linac QA with Arrays

Potential Other Applications for Linac QA

Procedure	Notes
Dosimetric Leaf Gap	**Can check along one or two dimensions.**
3D Plan Delivery Constancy	**"All in one" plan with all energies and multiple accessories for machine QA and upgrade testing.**
IMRT Plan Delivery Constancy	**A reference plan for machine QA and upgrade testing.**
VMAT Plan Delivery Constancy	**A reference plan for machine QA and upgrade testing.**
Backup Daily QA	**Every facility needs a daily QA backup**
Energy Constancy	**Enables the use of different metrics for energy and not just PDD or TMR.**

3. Linac QA with Arrays

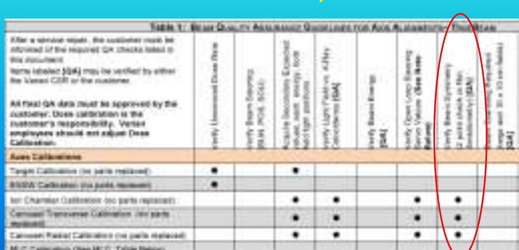
Post Repair Testing

Do you break out the scanning water phantom if one energy is steered?

When a simple repair takes hours, and the machine has been partially disassembled, do you set up the scanning water phantom?

3. Linac QA with Arrays

Representative validation guidelines from Varian Medical Systems



Choose the best statement that completes the following sentence: When measuring dynamic wedges for commissioning purposes…

- 20% 1. a scanning water phantom must be used by the qualified medical physicist
- 20% 2. either ion chamber or diode arrays can be used.
- 20% 3. radiochromic film dosimetry lacks the necessary dynamic range.
- 20% 4. 2D arrays should never be used.
- 20%

10

Choose the best statement that completes the following sentence: When measuring dynamic wedges for commissioning purposes…

20%	1.	a scanning water phantom must be used by the qualified medical physicist
20%	2.	either ion chamber or diode arrays can be used.
20%	3.	radiochromic film dosimetry lacks the necessary dynamic range.
20%	4.	2D arrays should never be used.

Answer is 2

Reference: Das IJ et al.: Accelerator beam data commissioning and equipment: report of the TG-106 of the therapy committee of the AAPM. Medical Physics. 2008;35(9): 4186 – 4215.

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4. Constancy Tests

After we have validated the performance of our array and properly commissioned our linac how do we set up constancy tests using the array?

An example methodology in the context of TG-142 annual testing is provided.

4. Constancy Tests

TG142 Annual Photon Sample Tests

Annual Test	Sample Setup	Cumulative Fields per Photon E
X-ray Flatness Change from Baseline	30 x 30 cm field, 5 cm and 20 cm depths, *if needed reduce SSD to achieve field size*	*2*
X-ray Symmetry Change from Baseline	*Same as above*	*2 + 0 = 2*

4. Constancy Tests

TG142 Annual Photon Sample Tests

Annual Test	Sample Setup	Cumulative Fields per Photon E
Field Size Dependent Photon Output Factors *(measure the output and can acquire profile for reference)*	2 x 2 cm, 7 x 7 cm, 10 x 10 (ref), 20 x 5 cm, 30 x 30 cm fields, 10 cm depth *(field centered on detector, w/ detector appropriate for smallest field size)*	*5 + 2 = 7*
Physical Wedge Factor Constancy	15 x 15 cm field, 10 cm depth	*7 + 4 = 11*

4. Constancy Tests

TG142 Annual Photon Sample Tests

Annual Test	Sample Setup	Cumulative Fields per Photon E
X-ray MU Linearity	15 x 15 cm field, 10 cm depth *Test 2 to 400 monitor units, 8 steps*	*11 + 8 = 19*
X-ray Output Constancy vs Dose Rate	15 x 15 cm field, 10 cm depth *Test min to max dose rate, 3 steps*	*19 + 3 = 22*

4. Constancy Tests

TG142 Annual Photon Sample Tests

Annual Test	Sample Setup	Cumulative Fields per Photon E
X-ray Output Constancy vs Gantry Angle	30 x 30 cm field, approx. Dmax depth *Mount array on gantry and test at cardinal angles*	*22 + 4 = 26*
X-ray Off Axis Factor vs Gantry Angle	Same as above. Analyze 2D dose and/or profiles.	*26*

4. Constancy Tests

TG142 Annual Photon Sample Tests

Annual Test	Sample Setup	Cumulative Fields per Photon E
MLC Transmission	15 x 15 cm field, 10 cm depth. Measure transmission through each bank + open field.	*26 + 3 = 29*
Dynamic Wedge Checks	*20 x 20 EDW60IN and 15 x 10 off axis EDW30OUT,* 10 cm depth	*29 + 2 =31*

4. Constancy Tests

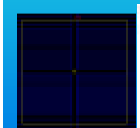
TG142 Annual Photon Sample Test Set
- Accomplishes majority of dosimetry portion.
- 31 measurements per energy, assuming both physical and dynamic wedges.
- Only 4 setup configurations are needed.
- Note that 16 of the measurements are dose to a single chamber, but using the array saves setup time and gives you planar data for further analysis if needed.

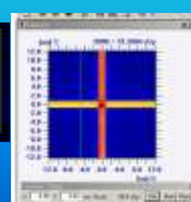
4. Constancy Tests

Setting up precision constancy tests:
1. Use the same water equivalent plastic plates in the same orientation and position each time (label and orient each).
2. Use the same backscatter each time.

4. Constancy Tests

Setting up precision constancy tests:
3. Carefully align and level the array. Imaging or a precision field can be used for alignment.





- The MLC "cross" shape captures the two central rows and two central columns of detectors
- Align to achieve a uniform dose along the two adjacent rows and columns

4. Constancy Tests

Setting up precision constancy tests:

4. Deliver a large uniform photon field to your array and look for detector inconsistencies before you perform any measurements.

4. Constancy Tests

5. Consider custom action/investigation levels and trend track results.

A constancy check with careful baselines may allow action levels < TG-142 tolerances.

This example demonstrates investigation levels of 0.8 % vs the 2% TG-142 tolerance.

5. Examples

Example 1: Photon Energy Check

A method to replace TPR/PDD measurements with a metrics for beam flatness.

Gao S, Balter PA, Rose M, Simon WE. Measurement of changes in linear accelerator photon energy through flatness variation using an ion chamber array. **Medical Physics**. 2013; 40 (4).

Goodall S et al. Clinical implementation of photon beam flatness measurements to verify beam quality. **Journal of Applied Clinical Medical Physics**. 2015;16(6).

5. Examples

Example 1: Photon Energy Check

Use the metric F_{DN}, the diagonal normalized flatness.

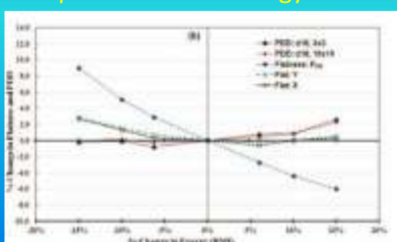
$$F_{DN} = \frac{\left(\sum_{i=1}^{4} R_d^i\right)/4}{R_{CAX}} \times 100, \quad (4)$$

where R_d^i are the readings of the diagonal ion chambers and R_{CAX} is the reading of the CAX ion chamber. In this study, we used the diagonal chambers at 17.7 cm from center.

Gao S, Balter PA, Rose M, Simon WE. Measurement of changes in linear accelerator photon energy through flatness variation using an ion chamber array. **Medical Physics**. 2013; 40 (4).

5. Examples

Example 1: Photon Energy Check



Bend magnet current was changed to simulate an E change. ***The blue line shows the sensitivity of F_{DN} at 18MV.*** *The red and black lines are for PDD.*

Gao S, Balter PA, Rose M, Simon WE. Measurement of changes in linear accelerator photon energy through flatness variation using an ion chamber array. **Medical Physics**. 2013; 40 (4).

Which of the following statements regarding metrics for assessing changes in photon beam energy is correct?

20% 1. Percent depth dose (PDD) at 10 cm is best for detecting increases and decreases in energy.

20% 2. Flatness metrics are more sensitive than PDD for detecting increases and decreases in energy.

20% 3. PDD is more sensitive to increases in beam energy while flatness is more sensitive to decreases.

20% 4. PDD is more sensitive to decreases in energy while flatness is more sensitive to increases.

20%

10

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Answer is 2

Reference: Gao S, Balter PA, Rose M, Simon WE. Measurement of changes in linear accelerator photon energy through flatness variation using an ion chamber array. Med Phys. 2013 Apr;40(4):042101.

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5. Examples

Example 2: Dosimetric Leaf Gap (DLG)

1. LoSasso et al (1998) describes a method for measuring leaf gap offset.
2. Rangel and Dunscombe (2009) showed that a systematic 0.3mm MLC position error can correlate to a 2% EUD deviation for dynamic IMRT delivery.
3. You can easily implement a measurement of DLG in 2D using a planar array.
4. Place the array at a source-to-detector distance that matches MLC leaves to a row of detectors.

5. Examples

Example 2: DLG measured with a 2D array.

Target is 1.05 mm

Values outside 0.9 mm to 1.2 mm are flagged yellow

Leaf Pair	Section 1	Section 2	Section 3	Section 4	Section 5
17	-1.01	-1.01	-1.01	-0.99	-0.99
18	-1.04	-1.02	-1.02	-0.98	-0.97
19	-0.97	[illegible]	[illegible]	.98	-0.99
•••	•••	[illegible]	[illegible]	[illegible]	•••
35	-0.95	[illegible]	[illegible]	.96	-0.98
36	-0.99	-1.00	-0.99	-0.98	-0.97
37	-0.97	-0.96	-0.97	-0.95	-0.94
38	-0.93	-0.93	-0.93	-0.93	-0.92
39	-0.74	-0.73	-0.72	-0.70	-0.69
40	-0.99	-0.97	-0.98	-0.95	-0.94
41	-0.90	-0.89	-0.89	-0.88	-0.86
42	-1.01	-1.01	-1.02	-1.01	-1.00
43	-	[illegible]	[illegible]	1.01	-1.01

Leaf #39 **deliberate** 0.3 mm error

Leaf #41 slightly out of desired range

5. Examples

Example 3: Detecting subtle linac differences.

A great deal of information is acquired when you measure fields with arrays. What do you focus on?

Beyer 's work (JACMP 2013) comparing different Varian accelerators gives us a good starting point.

Consider extremes of field sizes, large distances off axis, shallow (and deep?) depths, and penumbra.

5. Examples

Example 3: Detecting subtle linac differences.

Used a 14 field test plan to compare Varian TrueBeams and a 21EX, machines calibrated identically, 10x10 PDDs within 0.2%.

Small fields, shallow depths off axis, penumbra, and the collimator exchange effect were sensitive beam property indicators...but you had to look close!

Ritter TA , Gallagher I, and Roberson PL. Using a 2D detector array for meaningful and efficient linear accelerator beam property validations. **Journal of Applied Clinical Medical Physics**. 2014; 15(6).

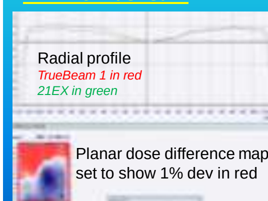
5. Examples

Example 3: Detecting subtle linac differences.

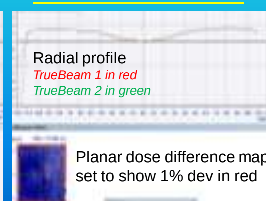
Differences were mild, use action levels < 1%.

34 x 34 cm field at reduced SSD and 1 cm depth

21EX vs TrueBeam



TrueBeam vs TrueBeam



6. TG 244 Applications

MPPG 5 describes essential treatment planning system quality assurance.

A majority of the tests can be efficiently performed with arrays, and the report specifically endorses their use.

Smilowitz JB et al. AAPM Medical Physics Practice Guideline 5.a.: Commissioning and QA of treatment planning dose calculations — megavoltage photon and electron beams. **Journal of Applied Clinical Medical Physics**. 2015;16(5).

6. TG 244 Applications

TABLE 4 Basic photon beam validation tests summary[a]

Test	Description
5.4	Small MLC-shaped field (non SRS)
5.5	Large MLC-shaped field with extensive blocking (e.g., mantle)
5.6	Off-axis MLC shaped field, with maximum allowed leaf over travel
5.7	Asymmetric field at minimal anticipated SSD
5.8	10×10 cm² field at oblique incidence (at least 20°)
5.9	Large (> 15 cm) field for each nonphysical wedge angle[b]

cal wedges. For all tests, measurements in the high-dose region, penumbra, and low-dose tail regions should be compared to calculated values at various depths (including slightly beyond d_{max}, midrange 10–15 cm, and deep 25–30 cm) and off-axis positions. Table 5 summarizes the

Smilowitz JB et al. AAPM Medical Physics Practice Guideline 5.a.: Commissioning and QA of treatment planning dose calculations — megavoltage photon and electron beams. **Journal of Applied Clinical Medical Physics**. 2015;16(5).

6. TG 244 Applications

Commercial array software may be especially amenable to analysis of the planar results.

Table 5. Basic TPS photon beam evaluation methods and tolerances

Region	Evaluation Method	Tolerance[a] (consistent with IROC Houston)
High dose	Relative dose with one parameter change from reference conditions	2%
	Relative dose with multiple parameter changes[b]	5%
Penumbra	Distance to agreement	3 mm
Low-dose tail	Up to 5 cm from field edge	3% of maximum field dose

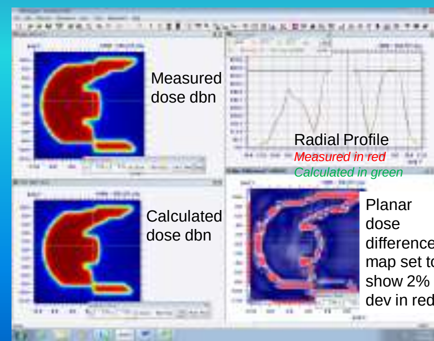
[a] Tolerances are relative to local dose unless otherwise noted
[b] For example, off-axis with physical wedge

Smilowitz JB et al. AAPM Medical Physics Practice Guideline 5.a.: Commissioning and QA of treatment planning dose calculations — megavoltage photon and electron beams. **Journal of Applied Clinical Medical Physics**. 2015;16(5).

6. TG 244 Applications

Examples of TG-244 Testing:

Test 5.5



7. Limitations

What are some of the challenges and limitations with using arrays?

1. Depth dose: Can acquire planes at different depths but depth dose scans are still required.
2. Spatial density / resolution in steep dose gradient regions (such as penumbra). Apply appropriate interpolation for IMRT/VMAT plans (Feygelman, Stathakis talks) or use other methods with higher resolution.

7. Limitations of Arrays

3. Potential non-linearities and energy dependence due to detector response effects, incomplete frame capture, saturation of the electronics, etc.
4. Detector-to-detector differences can hide subtle changes.
5. Field size limitations.
6. Use of water equivalent plastics.

The report of task group 142 on quality assurance of medical accelerators conveys which of the following:

- 20% 1. Arrays are only suitable for daily QA.
- 20% 2. Arrays are only suitable for monthly QA .
- 20% 3. The QMP should scan the beam using a scanning water phantom at intervals not to exceed 14 months.
- 20% 4. The proper measurement tools should be chosen by matching the detectors and software to the needs and sensitivity requirements.
- 20%

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- 20% 4. The proper measurement tools should be chosen by matching the detectors and software to the needs and sensitivity requirements.

Answer is 4

Reference: Klein EE et al.; Task Group 142, American Association of Physicists in Medicine Task Group 142 report: quality assurance of medical accelerators. Med Phys. 2009 Sep;36(9):4197-212.

8. Summary

Perform a complete commissioning of any array you want to use.

Once you have commissioned your linac and array system you can set up constancy tests and acquire baselines.

Understand the limitations of your system and when you need to resort to other tests.

Thank you for your attention!