

## Conformance of the Delta<sup>4</sup> Phantom+ for pre-treatment verification of VMAT and IMRT plans to the TG-218 report

This white paper shows that the Delta<sup>4</sup> Phantom+ measures IMRT and VMAT plans according to the recommended methods and is suitable for evaluation of the recommended criteria.

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## Introduction

In March 2018 the AAPM Task Group No. 218 released the rapport *Tolerance limits and methodologies for IMRT measurement-based verification QA*.<sup>[1]</sup> The rapport is an extensive review of different methodologies and tolerance limits in patient specific Intensity Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT), the outcome of which is a collection of recommendation on IMRT Quality Assurance. Of verification of dose distributions and of tolerance and action limits. In this white paper it is examined if the Delta<sup>4</sup> Phantom+ (Scandidos AB, Uppsala) is able to measure IMRT and VMAT plans according to the recommended methods and if it is suitable for evaluation of the recommended criteria.

## Method

### The TG-218 report

#### *Evaluation methods*

The TG218 report reviews a number of methods for comparing dose distributions. Mainly it focuses on the Dose Deviation and Distance to Agreement (DTA) tests, their complementary sensitivity and the  $\gamma$ -test, being a combination of the two.<sup>[2][3]</sup>

The report also discusses normalization and the pros and cons of local and global normalization of  $\gamma$ . When global normalization is used the dose difference between a measured and calculated dose point pair is normalized using the same value for all of the point pairs. For local normalization on the other hand, the dose difference for the point pairs is normalized to a local point. The later will allow you to have the same tolerances in the target structures and in the OAR volumes. However, it will also cause the low-dose regions to have none clinically relevant dose accuracy requirements.

#### *Measurement methods*

In the TG-218 report the three most common phantom substitution measurement methods in a clinical setting are described:

- Perpendicular field-by-field (PFF): the radiation beam is perpendicular to the plane of the measurement device. The device can be placed on the couch or attached to the gantry head. The dose from each of the IMRT beams is delivered and analyzed.
- Perpendicular composite (PC): the radiation beam is always perpendicular to the measurement device detector plane. The device can be placed on the couch or attached to the gantry head. The doses from all IMRT radiation beams are delivered and subsequently summed.
- True Composite (TC): all of the radiation beams are delivered to a stationary measurement device in a phantom placed on the couch using the actual treatment beam geometry for the patient, including MUs, gantry, collimator, couch angles, jaws, and MLC leaf positions. This method most closely simulates the treatment delivery to the patient.

### The Delta<sup>4</sup> Phantom+

#### *System description*

The Delta<sup>4</sup> Phantom+ (ScandiDos AB, Uppsala) for patient specific pre-treatment verification consists of two orthogonal detector boards mounted inside a cylinder of either PMMA or Plastic Water. The system consists of in total 1069 p-doped silicon which are spaced 5 mm apart in the central 6 x 6 cm of the phantom and 10 mm apart outside of that. The total area which can be detected is 20 x 38 cm.

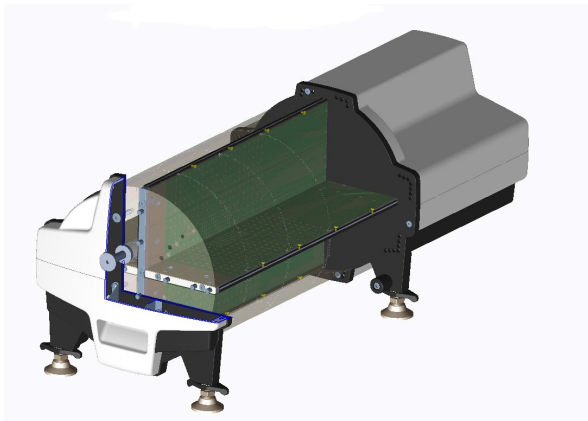


Figure 1 - The Delta<sup>4</sup> Phantom+

During pre-treatment with the Delta<sup>4</sup> Phantom+, a verification plan is created by recalculating the patient plan onto the plastic cylinder in the Treatment Planning System. The phantom is positioned on the treatment couch and the patient plan is then delivered to the phantom while the diodes are measuring the dose, pulse-by-pulse. The measurement process is controlled by the Delta<sup>4</sup> Software. The software gathers raw data from the phantom, sorts it into control points and applies dose calibration factors and correction factors for e.g. depth, energy and angle to obtain absolute dose measurements. The measured dose is compared against the verification plan and the results of the comparison are displayed in the software.

### The Delta<sup>4</sup> Software

The comparison results which are displayed to the user immediately after stopping a measurement is displayed in Figure 2. The criteria for the displayed Dose Deviation, DTA and  $\gamma$  are user definable and can be changed in the Pass/Fail criteria dialog, see Figure 3. The software also features a table view showing the  $\gamma$  pass rate for a number of Dose deviation and DTA criteria, see Figure 4. The normalization point is also user definable and can be changed in the Normalization Levels dialog, see Figure 5.

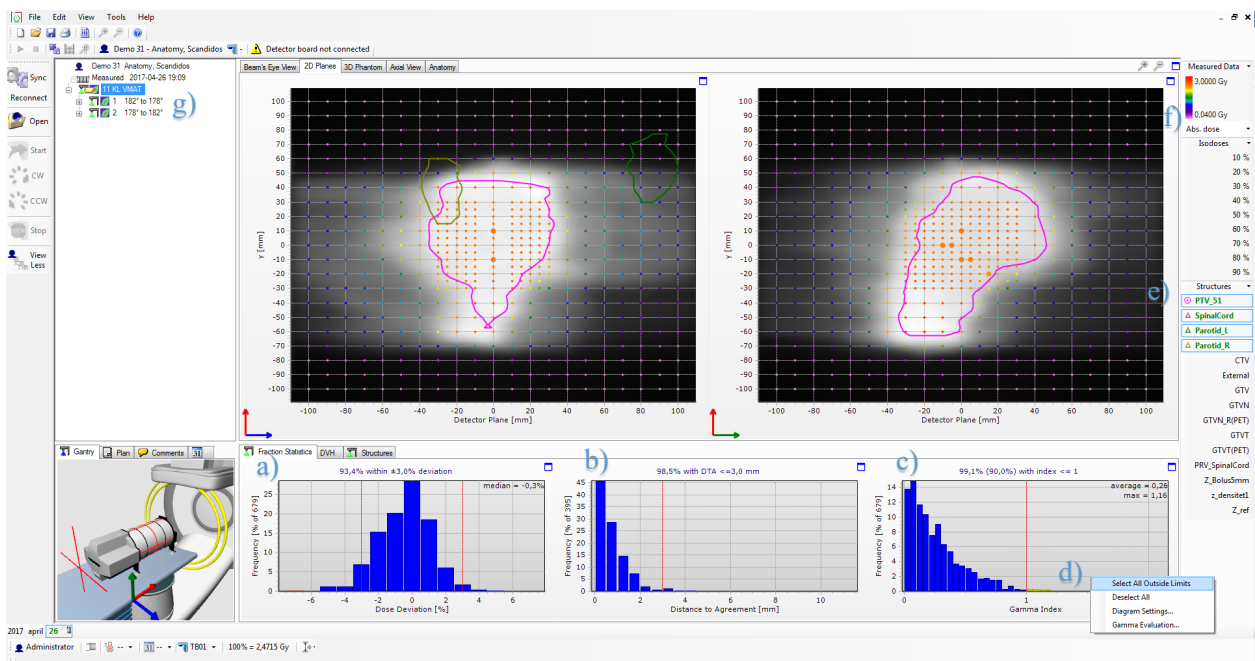


Figure 2 – The main view of the Delta<sup>4</sup> software. This is the view that is displayed to the user immediately after stopping a measurement. a) - c) Dose deviation, DTA and  $\gamma$  pass rate is displayed immediately for the criteria defined by the user, both in numerical and histogram form. For  $\gamma$ , the average and maximum  $\gamma$  is displayed. By hovering over one of the bars in the

histogram, the percentage of detectors contained in that bar will be displayed. d) By clicking on one of the bars in the histograms, or by selecting “Show all outside limits” the detectors contained in the selected bar/the detectors which failed the specified  $\gamma$  criteria will be highlighted. e) By selecting structures in the “Structures”-list, the location of the structures in relation to the dose distribution, and specifically in relation to the failed points can be displayed. f) The coloring of the diodes is default to represent absolute dose, but can also be chosen to represent Relative dose, Absolute dose deviation, relative dose deviation, DTA or  $\gamma$  index. g) The user can select whether to display the information for either the composite plan or for the individual fields.

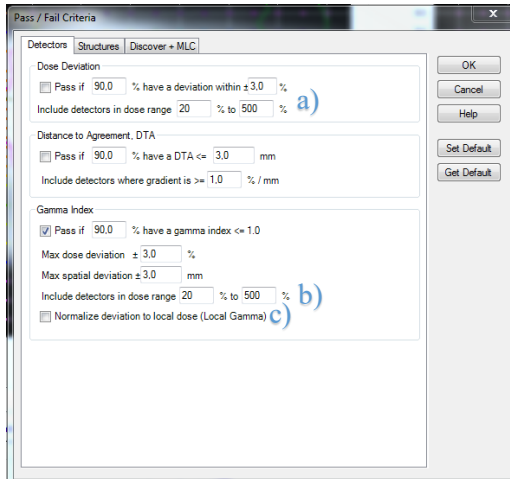


Figure 3 – The criteria for the Dose deviation, DTA and  $\gamma$  index displayed in the software can be set from the Pass/Fail dialog. a) –b) The dose threshold for the dose deviation and  $\gamma$  index can be set. c) Local or global  $\gamma$  can be selected.

Allowed Distance Deviations	Gamma Index Pass Rates									
	0.5 %	1.0 %	1.5 %	2.0 %	2.5 %	3.0 %	3.5 %	4.0 %	4.5 %	5.0 %
5.0 mm	94.6 %	96.0 %	97.6 %	98.4 %	99.4 %	99.7 %	100.0 %	100.0 %	100.0 %	100.0 %
4.5 mm	92.9 %	94.4 %	96.5 %	98.4 %	99.0 %	99.6 %	100.0 %	100.0 %	100.0 %	100.0 %
4.0 mm	91.3 %	93.5 %	95.1 %	97.6 %	98.8 %	99.4 %	100.0 %	100.0 %	100.0 %	100.0 %
3.5 mm	88.4 %	91.6 %	93.8 %	96.5 %	98.7 %	99.3 %	100.0 %	100.0 %	100.0 %	100.0 %
3.0 mm	85.7 %	89.8 %	92.9 %	96.0 %	98.2 %	99.1 %	100.0 %	100.0 %	100.0 %	100.0 %
2.5 mm	82.8 %	87.5 %	91.3 %	95.1 %	97.9 %	99.0 %	99.9 %	100.0 %	100.0 %	100.0 %
2.0 mm	77.9 %	84.5 %	89.2 %	93.5 %	97.5 %	98.5 %	99.7 %	100.0 %	100.0 %	100.0 %
1.5 mm	70.1 %	79.5 %	85.7 %	91.5 %	96.5 %	97.8 %	99.6 %	99.9 %	100.0 %	100.0 %
1.0 mm	59.2 %	71.1 %	80.7 %	88.1 %	94.0 %	97.1 %	99.0 %	99.6 %	100.0 %	100.0 %
0.5 mm	43.2 %	59.9 %	73.0 %	82.2 %	90.9 %	95.3 %	97.6 %	98.4 %	99.0 %	99.6 %

Figure 4 – The gamma evaluation table shows the  $\gamma$  pass rate for a number of Dose Deviation and DTA criteria.

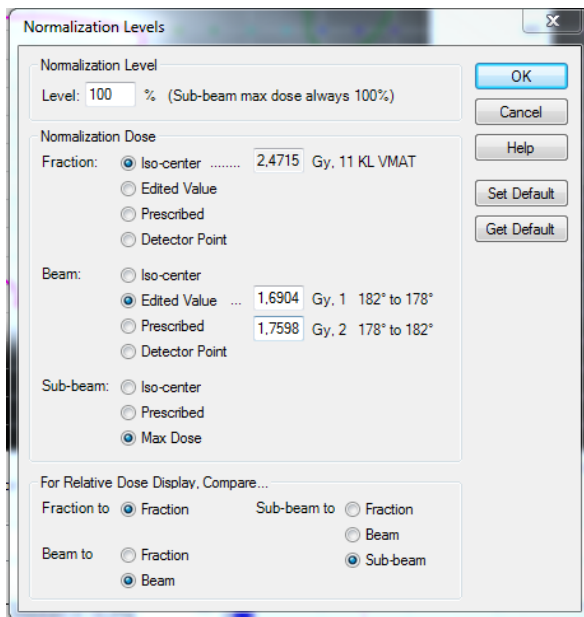


Figure 5 - Normalization levels are user definable and can be set differently for the composite dose than for the individual fields from the Normalization Levels dialog.

The Delta<sup>4</sup> Software also features functionality for displaying continuous dose within the phantom geometry as well as for recalculating the measured dose in the patient geometry.<sup>[4]</sup> This allows the user to see dose volume histograms within target and OAR structures and also to obtain dose deviation, DTA and  $\gamma$  pass rate results inside these structures. Figure 6 shows the software display for dose inside the phantom geometry and Figure 7 for dose within the patient geometry.

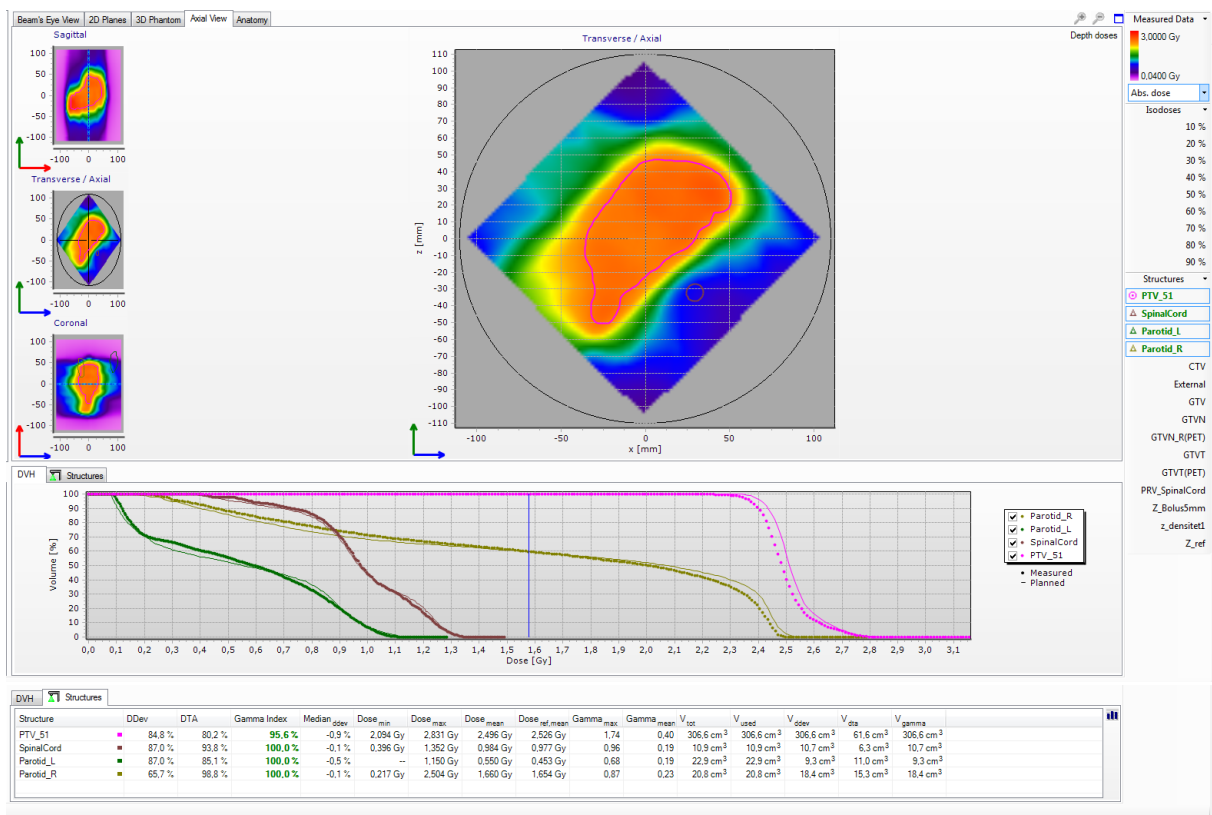


Figure 6 – Structure specific analysis can be obtained in the phantom geometry.

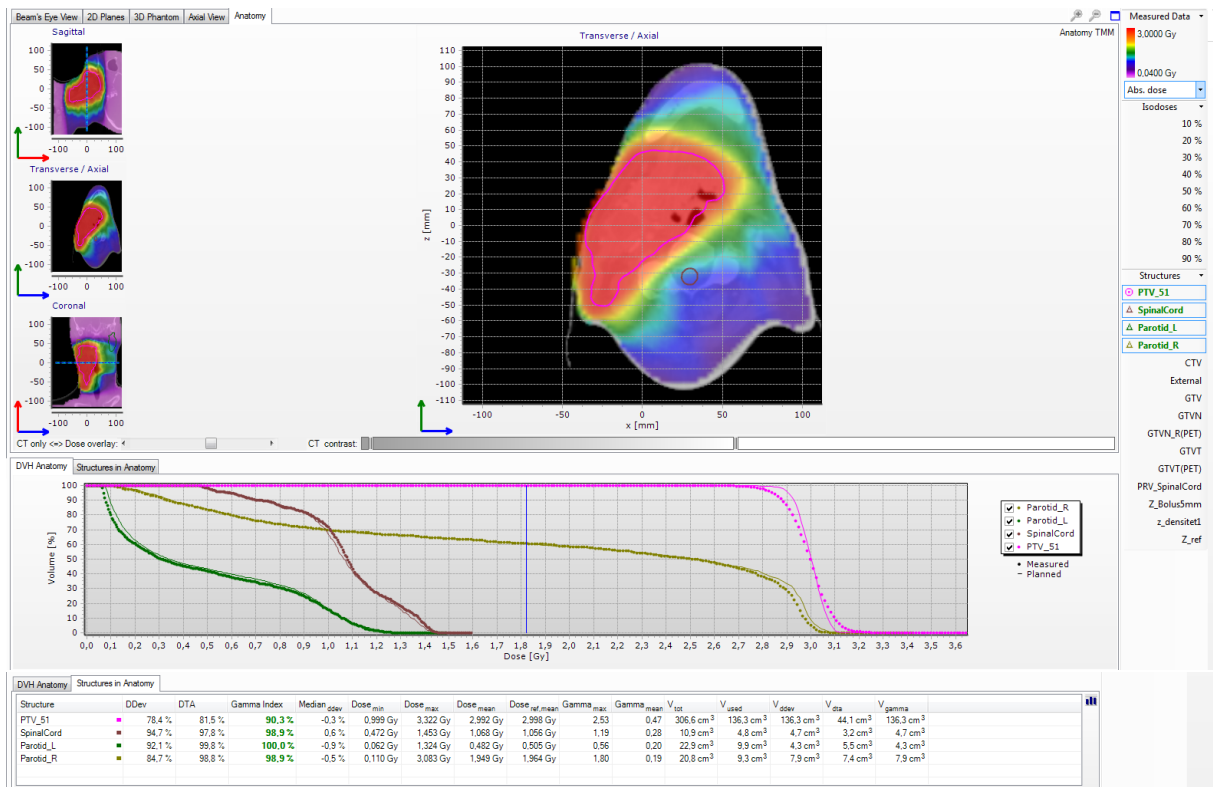


Figure 7 – Structure specific analysis can be obtained in the patient geometry.

## Results

Table 1 shows the recommendations for IMRT QA verification of dose distributions (fixed-gantry IMRT and rotational IMRT) given by given by the AAPM task group 218 and how they are fulfilled by the Delta<sup>4</sup> system.

Recommendation	Fulfillment of requirement by the Delta <sup>4</sup> Phantom+
IMRT QA measurements should be performed using the TC delivery method provided that the QA device has negligible angular dependence or the angular dependence is accurately accounted for in the vendor software.	The Delta <sup>4</sup> Phantom+ measures according to the TC method. The angular dependence of the diodes is accounted for in the Delta <sup>4</sup> Software.
IMRT QA measurements should be performed using the PFF delivery method if the QA device is not suitable for TC measurements, or for TC verification error analysis.	The Delta <sup>4</sup> Phantom+ collects dose pulse by pulse. This allows for the dose from each IMRT beam to be analyzed separately, allowing the analysis to be performed on a beam, and even sub-beam level. This entails that all the advantages of the TC method applies for the Phantom+, but none of the disadvantages since the device is not a 2D array always perpendicular to the field.
IMRT QA measurements should not be performed using the PC delivery method which is prone to masking delivery errors.	The Delta <sup>4</sup> Phantom+ does not measure according to the PC method.
Analysis of IMRT QA measurements and the corresponding treatment plan should be performed in absolute dose mode, not relative dose (the user should not normalize the dose to a point or region, ie., relative dose mode).	The Delta <sup>4</sup> Software defaults to displaying measured dose in absolute dose mode.
A dose calibration measurement compared against a standard dose should be performed before each measurement session to factor the variation of the	The Delta4 System measures the absolute dose and thereby a separate ionization chamber measurement is not required.



detector response and accelerator output into the IMRT QA measurement.	However with the Delta4 software a dose calibration measurement can be performed using the phantom before each measurement session and the result (the daily correction factor) can be applied to all subsequent measurements. The software also allows for a daily correction factor measured by a different device than the phantom to be used.
Global normalization should be used. Global normalization is deemed more clinically relevant than local normalization. The global normalization point should be selected whenever possible in a low gradient region with a value that is $\geq 90\%$ of the maximum dose in the plane of measurement. This will provide a more realistic measure of the comparison between the two dose distributions.	The Delta <sup>4</sup> Software defaults to analysis in Global normalization mode. The normalization point defaults to the isocenter for the composite plan and maximum dose for the individual fields, but the normalization point is user definable.
Local normalization is more stringent than global normalization for routine IMRT QA. It can be used during the IMRT commissioning process and for troubleshooting IMRT QA.	The Delta <sup>4</sup> Software also supports local normalization.
The dose threshold should be set to exclude low-dose areas that have no or little clinical relevance but can significantly bias the analysis. An example is setting the threshold to 10% in a case where the critical structure dose tolerance exceeds 10% of the prescription dose. This allows the $\gamma$ passing rate analysis to ignore the large area or volume of dose points that lie in very low-dose regions which, if included, would tend to increase the passing rate when global normalization is used.	The dose threshold in the Delta <sup>4</sup> Software is user definable.

Table 1 – Recommendations given by the AAPM task group 218 on measurement based pre-treatment QA for IMRT and VMAT treatments and how they are fulfilled by the Delta<sup>4</sup> system.

Table 2 shows the recommendations regarding tolerance limits and action limits for IMRT pre-treatment QA given by the AAPM task group 218 and how the Delta4 system can be used to fulfill them. The recommendations are for  $\gamma$  analysis using global normalization in absolute dose.

<b>Recommendation</b>	<b>Fulfillment of requirement by the Delta<sup>4</sup> Phantom+</b>
Universal tolerance limits: the $\gamma$ passing rate should be $\geq 95\%$ , with 3%/2 mm and a 10% dose threshold.	The Delta <sup>4</sup> Software is able to display the $\gamma$ pass rate for the specified criteria.
Universal action limits: the $\gamma$ passing rate should be $\geq 90\%$ , with 3%/2 mm and a 10% dose threshold. <ul style="list-style-type: none"> <li>If the plan fails this action limit, evaluate the <math>\gamma</math> failure distribution and determine if the failed points lie in regions where the dose differences are clinically irrelevant in which case the plan may be clinically acceptable. If the <math>\gamma</math> failure points are distributed throughout the target or critical structures and are at dose levels that are clinically relevant, the plan should not be used and the medical physicist should follow the steps outlined in section (b) below. It may be necessary to review results with a different detector or different measurement geometry. For example, if the failure is seen with the TC delivery, a PFF analysis can be valuable to further explore the discrepancies between calculations and measurements.</li> </ul>	The Delta <sup>4</sup> Software is able to display the $\gamma$ pass rate for the specified criteria.  The software allows for a visual display of the $\gamma$ pass rate for all the detectors on the detector boards. By overlaying the structures outlined during the treatment planning on the image, it can be displayed where the failing points are in relation to relevant structures.  The system measures dose pulse-by-pulse and all results (Dose deviation, DTA and $\gamma$ ) can be displayed per beam as well as for the composite dose, all with outstanding accuracy.

<p>Equipment- and site-specific limits can be set following the method described in Section 7.</p> <ul style="list-style-type: none"> <li>• If action limits are determined that are significantly lower than the universal action limits recommended above, then action should be taken as outlined in section (b) below to improve the IMRT QA process. From a process perspective, strict adherence to standardized procedures and equipment as well as additional training may also be necessary.</li> </ul>	<p>N/A</p>
<p>Tighter criteria should be used, such as 2%/1 mm or 1%/1 mm to detect subtle regional errors and to discern if the errors are systematic for a specific treatment site or delivery machine.</p>	<p>The Delta<sup>4</sup> Software allows for user definable <math>\gamma</math> criteria. It also features a table display instantly giving the <math>\gamma</math> pass rate for a number of combinations of distance and dose deviation criteria.</p>
<p>For IMRT QA performed with an IC and film, tolerance and action limits for the ion chamber measurement should be within <math>\leq 2\%</math> and <math>\leq 3\%</math>, respectively, and the film <math>\gamma</math> passing rate limits should be assessed as specified above. An IMRT treatment plan should not be used if the chamber measurement error or the <math>\gamma</math> passing rate exceeds the universal action limits.</p>	<p>N/A</p>
<p>For any case with <math>\gamma</math> passing rate less than 100%</p> <ul style="list-style-type: none"> <li>• The <math>\gamma</math> distribution should be carefully reviewed rather than relying only on distilled statistical evaluations.</li> <li>• Review of <math>\gamma</math> results should not be limited to only the percentage of points that fail, but should include other relevant <math>\gamma</math> values (maximum, mean, minimum, median), as well as a histogram analysis.</li> <li>• An analysis of the maximum <math>\gamma</math> value and the percentage of points that exceed a <math>\gamma</math> value of 1.5 should be performed. For a 3%/2 mm, a <math>\gamma</math> value of 1.5 could indicate a dose difference of 4.5% in a low-dose gradient region or a DTA of <math>\sim 3.0</math> mm in a steep dose gradient region. Both of these are examples of failures, but failures that exceed tolerances by 1.5% and 1 mm in the low and steep dose gradient regions, respectively. Such information should be used to deduce clinical relevance whenever possible (e.g., cluster of failing points near or at the boundary of a tumor and critical structure).</li> </ul>	<p>The Delta<sup>4</sup> Software allows for a visual display of the <math>\gamma</math> pass rate for all the detectors on the detector boards. By overlaying the structures outlined during the treatment planning on the image, it can be displayed where the failing points are in relation to relevant structures.</p> <p>The software displays average and mean <math>\gamma</math>. It has histogram views for <math>\gamma</math> index, as well as for Dose deviation and Distance to agreement.</p> <p>From the histogram view, the percentage of detectors obtaining a certain <math>\gamma</math> index (also <math>\gamma</math> index <math>&gt; 1</math>) can be obtained.</p>
<p>The IMRT treatment process should be monitored and thoroughly investigated if the <math>\gamma</math> passing rate is systematically lower than the tolerance limits or higher than the action limits. This includes reviewing dose differences directly without <math>\gamma</math> criteria or using local dose normalization and tighter dose difference and DTA criteria.</p>	<p>The Delta<sup>4</sup> Software allows for review of dose deviation directly, of displaying results using local normalization and of displaying <math>\gamma</math> pass rate for multiple combinations of distance and dose deviation criteria</p>
<p><math>\gamma</math> statistics should be reviewed on a structure by structure basis if the user software allows for it. Vendors should include this feature in their future software development.</p>	<p>The Delta<sup>4</sup> Software allows for structure specific analysis both in the phantom and in the patient geometry. <math>\gamma</math> pass rate can be displayed within the structures outlined during the treatment planning.</p>
<p>Track <math>\gamma</math> passing rates across patients, especially for the same tumor sites, to look for systematic errors in the system.</p>	<p>N/A</p>



Vendors should implement a $\gamma$ tracking feature across patients and for the same tumor sites in their future software development.	N/A
Vendors should implement the simplex method for interpolation-free $\gamma$ calculation and make the $\gamma$ tool more practical and accurate.	N/A
Whenever referring to a $\gamma$ passing rate, always specify the dose difference (global or local) and DTA criteria and the dose threshold. Without these parameters, the passing rate is meaningless.	The criteria for the $\gamma$ pass rate are displayed in the Delta <sup>4</sup> Software, as well as whether the $\gamma$ is local or global
Software tools that can provide a measure of the agreement between measured and calculated DVHs of patient structures are preferred over analysis in phantoms. DVH analysis can be used to evaluate the clinical relevance of the QA results, especially when the $\gamma$ passing rate fails the tolerance limits or is inconsistent.	The Delta4 Software features display of DVH for the structures outlined during the treatment planning, both in the phantom and in the patient geometry.

Table 2 – Recommendations regarding tolerance limits and action limits for IMRT pre-treatment QA given by the AAPM task group 218 and how the Delta<sup>4</sup> system can be used to fulfill them. The recommendations are for  $\gamma$  analysis using global normalization in absolute dose.

## Conclusion

The results of this review shows that the Delta<sup>4</sup> Phantom+ for pre-treatment verification and the associated Delta<sup>4</sup> Software constitutes a system which well fulfills the requirements specified by the AAPM TG218 on measurement devices for patient specific quality assurance of IMRT and VMAT treatments. The system can be used for quality assurance in order to assure that the dose delivered to the patient is within the recommended tolerance limits.

## References

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Additional readings about the Delta<sup>4</sup> Phantom+

[Product page](#)

[Product Video](#)

[References and brochures](#)

**Delta<sup>4</sup>**  
by ScandiDos