# Independent Dose Verification in Radiation Oncology Department

2022 AAPM Guided Tours Section

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# Disclosure and conflict of interest

- Nothing to Disclose

# Learning objectives

1. To understand the rationale for independent dose verification in radiation oncology.
2. To appreciate the current guidelines and recommendations for independent dose verification solutions.
3. To gain familiarity with the various independent dose verification solutions currently available.

# Rationale of the dose verification

- The implementation of new treatment techniques in radiation oncology department increases the complexities and potential for serious errors.


The New York Times

THE RADIATION BOOM

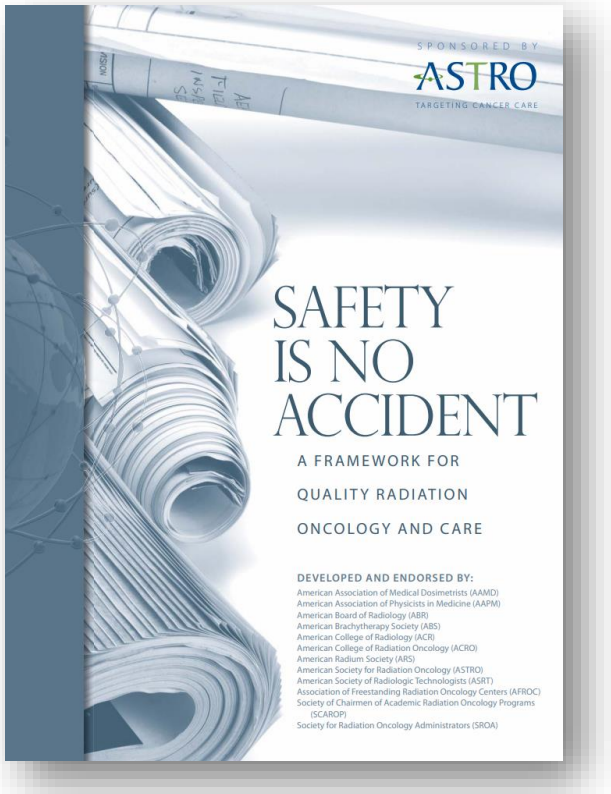
Radiation Offers New Cures, and Ways to Do Harm

Give this article

By Walt Bogdanich

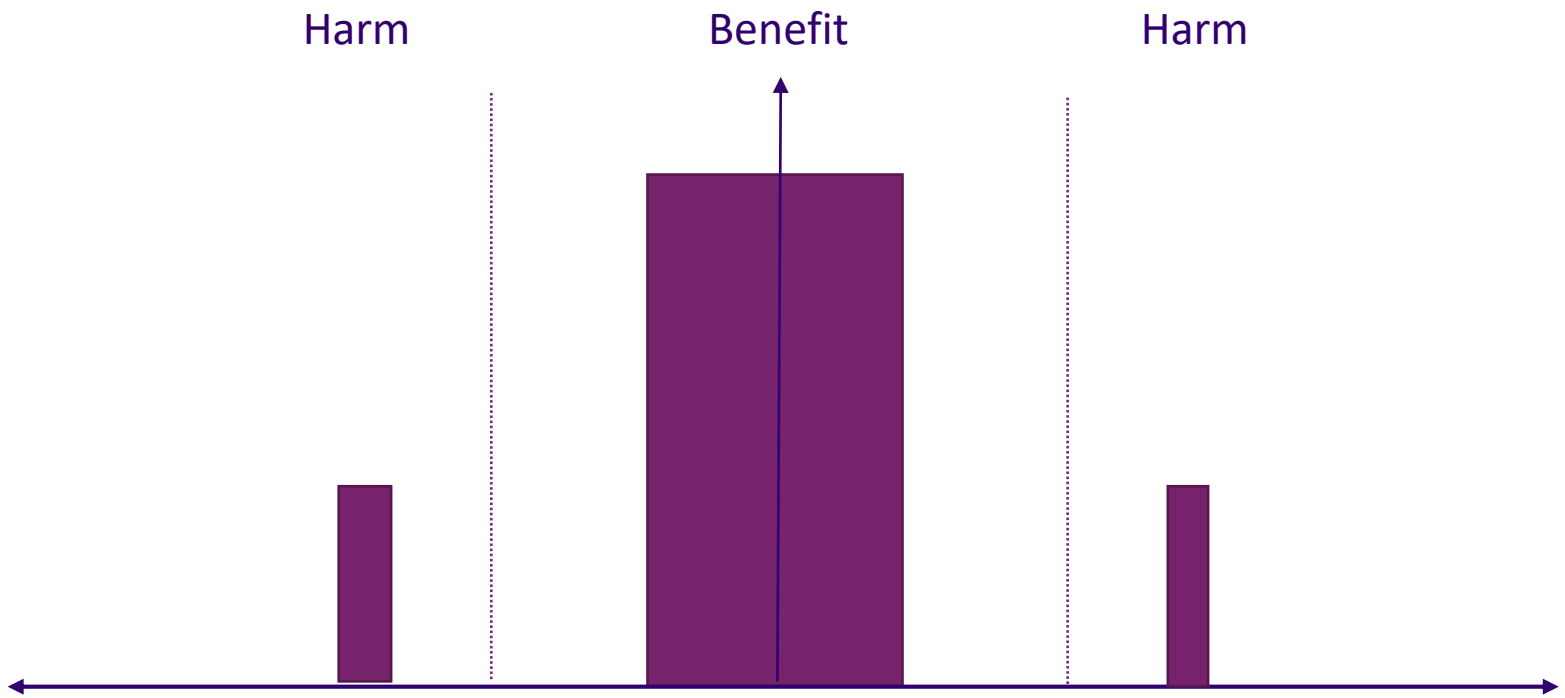
Jan. 23, 2010

[3]



# Goal of pretreatment dose verification

- The goal of pretreatment dose verification procedure is to identify and resolve any errors before patient treatment.




[4]

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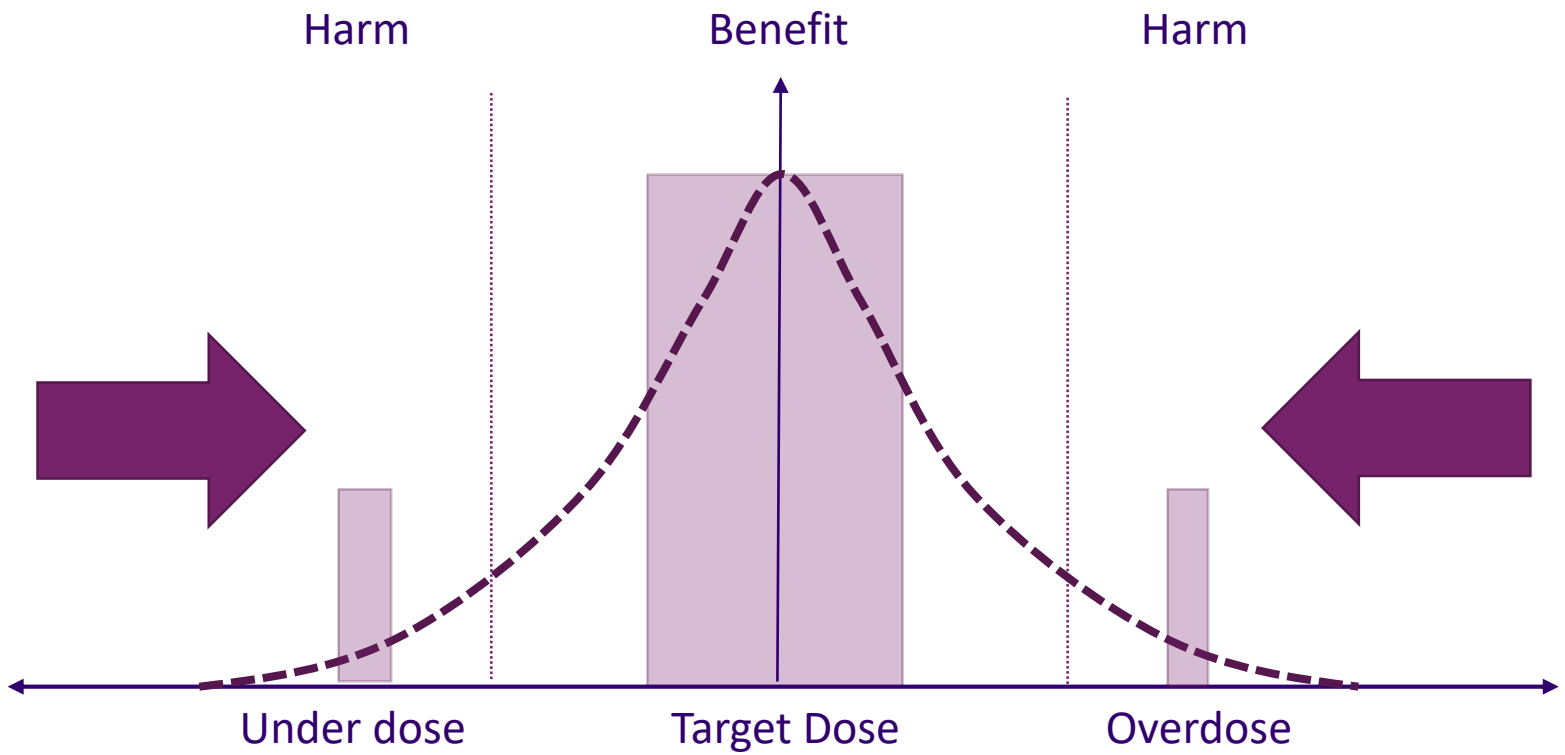
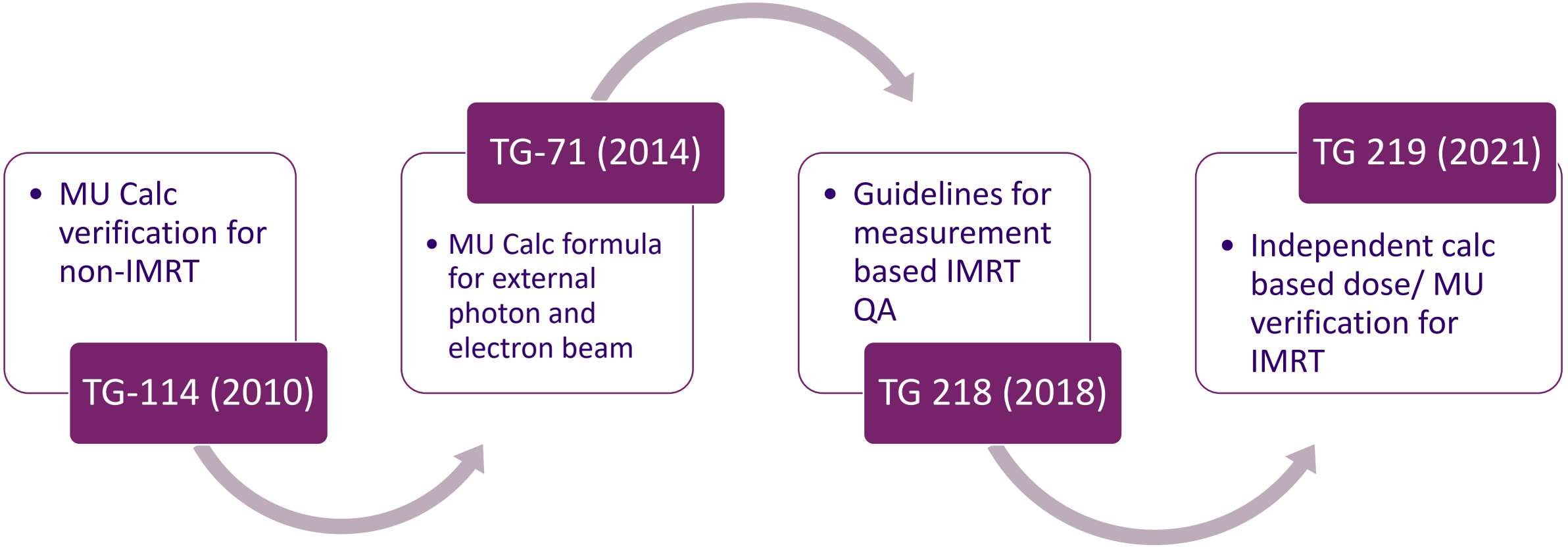



[4]

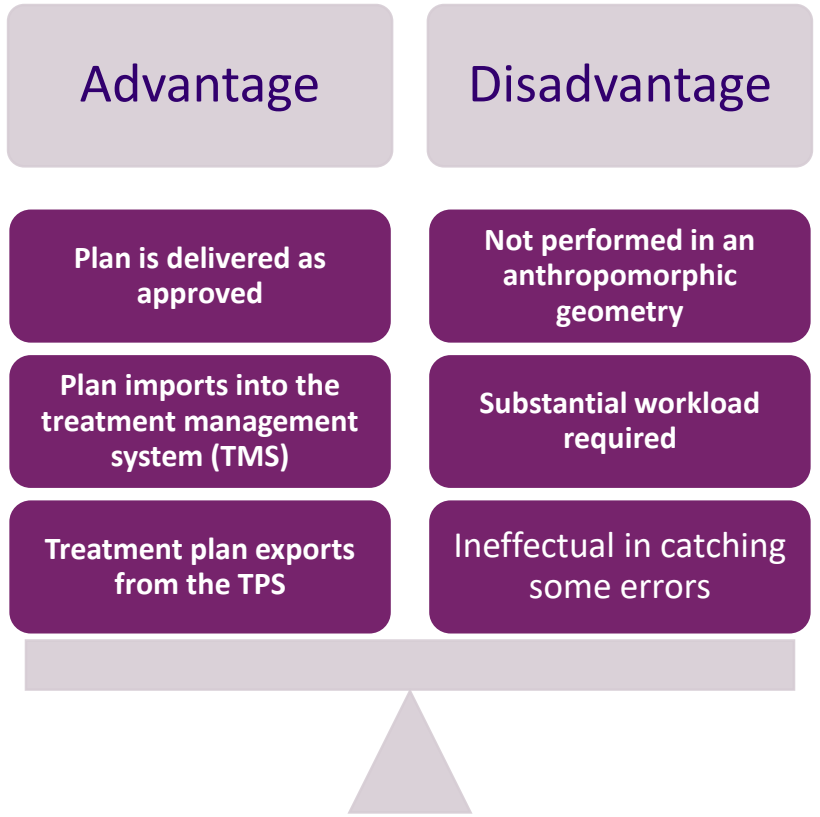
# AAPM TG reports




Clinical practice has changed, with more widespread use of IMRT/VMAT

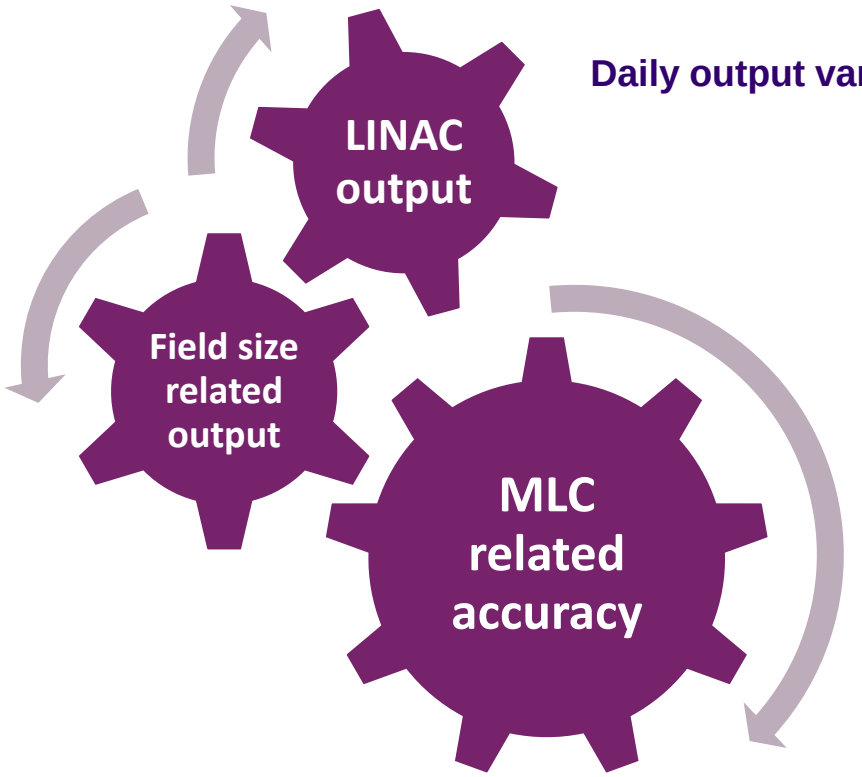
# Experimental based IMRT QA

- Currently, IMRT guidance recommends experimental verification for IMRT patient- specific QA (PSQA)




[6]

# IMRT accuracy




**Daily output variation**

**Small static step- and- shoot field segments and/or narrow sliding-window shapes with low MUs**

- **MLC leaf position accuracy**
- **Leaf- end design**
- **Leaf position**
- **Leaf gap reproducibility**
- **Inter- and intra leaf transmission**
- **Leaf acceleration/deceleration speed**
- **Tongue and groove effect**
- **MLC system sag with gantry rotation**

Errors in the planning and delivery process can result in erroneous dose distributions delivered to the patient

[7]

# Sources of error for IMRT plans

TABLE 1 Sources of error for the secondary MU calculation program as related to IMRT. H = high, M = medium, L = low

| Common sources of error | Probability of error (Algorithm "dimensions") 1D | 2D | 3D | Comment |
|---|---|---|---|---|
| **Data related** | | | | |
| $S_{cp}$ | L | L | L | Errors are more likely for small fields |
| PDD | L | L | L | |
| TMR | M | M | M | Usually calculated from PDD |
| Fit | - | - | M | 1D and 2D algorithms do not usually use a fit to the data |
| User related | | | | |
| Wrong plan | M | M | L | |
| Wrong points | M | M | M | |
| Wrong Rx | L | L | L | High if manually input |
| Wrong images | M | M | M | |
| Plan related | | | | |
| Low dose region | H | M | M | |
| High gradient region | H | H | H | |
| Small field | M | M | M | |
| Small MU | L | L | L | |
| Dynamic beams | H | M | M | |
| Split fields (large angle scattering) | M | M | M | |
| Lateral electron disequilibrium | H | M | M | |

Data related errors

User related errors

Plan related errors
(more specific to IMRT)

[8]

# Role of dose calculation verification

- Independent dose calculations can be an additional complemental QA methods to increase the chance of catching any errors.

- Hybrid approaches, between traditional measurements and pure secondary MU checks are also appearing.
  - Linac log files can be used as input for independent dose verification
  - Measured fluences with an EPID or a transmission detector can be used as input data for independent dose calculation

[9]

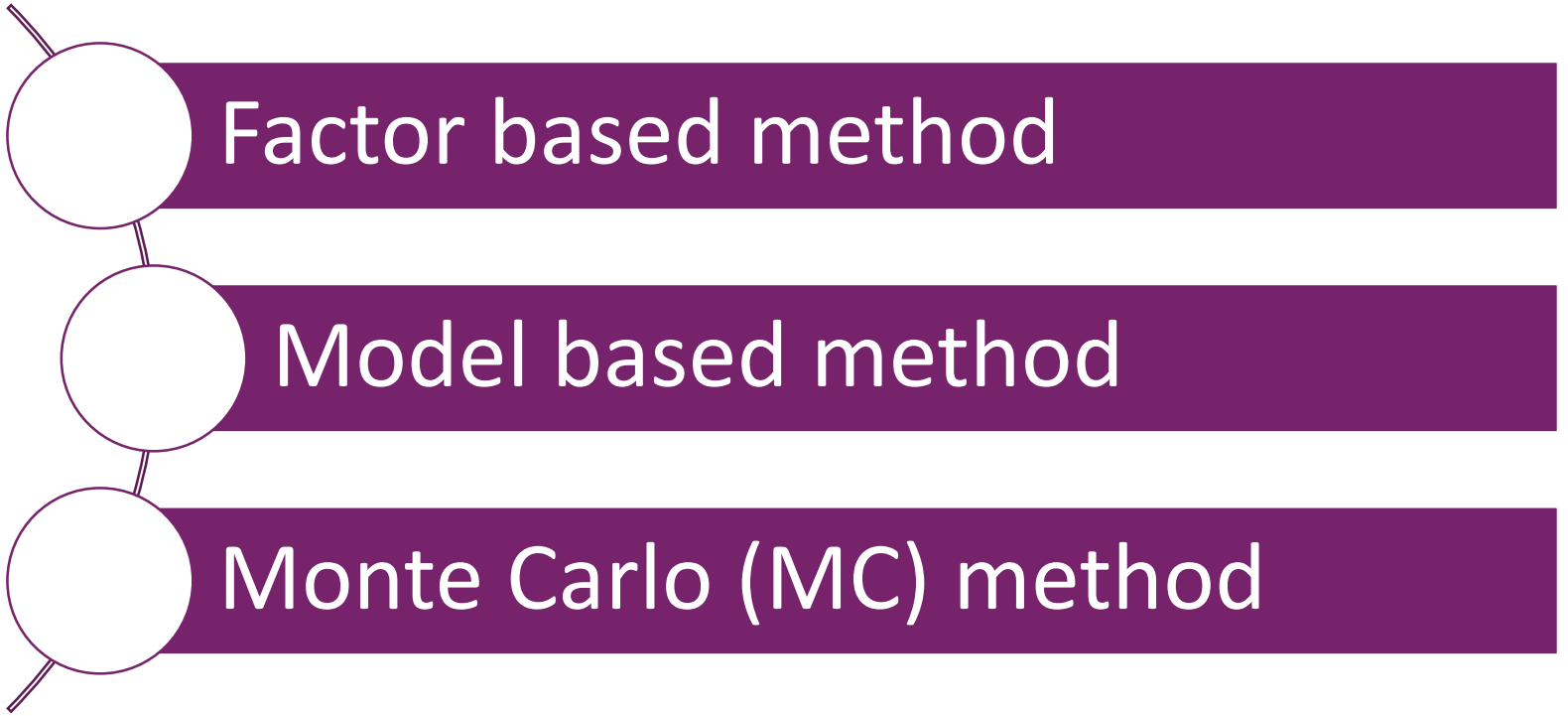
# TG 219 recommendation

- TG 219 recommends that **secondary dose/MU calculation should be performed for every IMRT/VMAT plan**, at least in 1D but preferably in 2D/3D, regardless of the method of measurement-based verification utilized.
  - Far less time consuming
  - Calculation process do not require machine time
  - As personnel feel increasingly confident about the reliability of techniques such as IMRT, it is reasonable to revise efforts in order to reduce the overall workload.

[10]

# Algorithms for MU verification

- The algorithms for dose per MU verification programs can be



# Factor based algorithms

- Tailored for “hand” calculations.
  - The parameters (e.g., TPR, Sc, Sp, etc.) are obtained either from direct measurement in a water phantom or extrapolated from such measurements.
- The dose/MU is determined by using the product of standardized dose ratio measurements.
- Most of the existing commercial systems specifically designed for IMRT verification use factor-based empirical methods

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# Model based algorithms

- Model-based algorithms are usually more versatile and powerful than factor-based empirical models.

- Two-step procedure:

**Step 1**

Modeling the energy fluence exiting the treatment head with a multi-source approach

**Step 2**

Determining the dose deposition in the patient with energy deposition kernels

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# Monte Carlo based algorithms

- Allow for highly accurate calculation of radiation transport through the patient.
  - provided substantially different results, particularly for calculation of dose in highly heterogeneous anatomy (lung), when compared to simple pencil-beam algorithms
- No commercial MC-based secondary MU check systems available at the time TG-219 was written.

[14]

# Alternative model based approach

- The use of a second TPS is an alternative model-based approach for independent dose verification  (not practical => high cost)

- A new generation of calculation-based QA tools are coming into clinical practice that are based on more advanced dose calculation algorithms
  - Superposition/convolution algorithms similar to the ones used for TPS
  - These tools enable efficient and accurate fully 3D independent dose calculations based on the patient's CT dataset, with analysis tools such as DVH verification, etc. similar to a second TPS.

# Accuracy of calculation algorithms

**TABLE 6** Error ranges between secondary MU calculation algorithm types and measurement or Monte Carlo; see Section 3.4 for details

| | Typical error range (local % difference from measurement or MC) | | | | |
|---|---|---|---|---|---|
| | **Center of lung tumor** | **In or downstream of lung** | **In bone** | **At surface** | **High Z (e.g., dental)** |
| Factor-based | 4.9 | 3–10 | 3–10 | >40 | 20–40 |
| AAA[a] | 3.7 | 2–5 | 2–3 | 20 | 10–15 |
| Collapsed cone (C/S) | 3.7 | 2–5 | 1–2 | 20 | 10–15 |
| Deterministic (GBBS) | 1.5 | 1–2 | <1 | - | 5 |
| MC | <1 | - | - | - | 5 |

Numeric values are from Refs 71–87 as detailed in the text of Section 3.4.

[a]AAA stands for Analytical Anisotropic Algorithm, used in Varian Eclipse treatment planning system.

MC > GBBS (ie. Acuros) > C/S and AAA > Factor based

[16]

# Acceptance & commissioning

- The physicist should consult the manufacturer's documentation of the respective software for detailed instructions
- Acceptance and commissioning should be **performed based on the recommendations of AAPM TG 53 and MPPG 5A**
- Table 7 in TG 219 provides key tasks for acceptance and commissioning for the secondary MU calculation

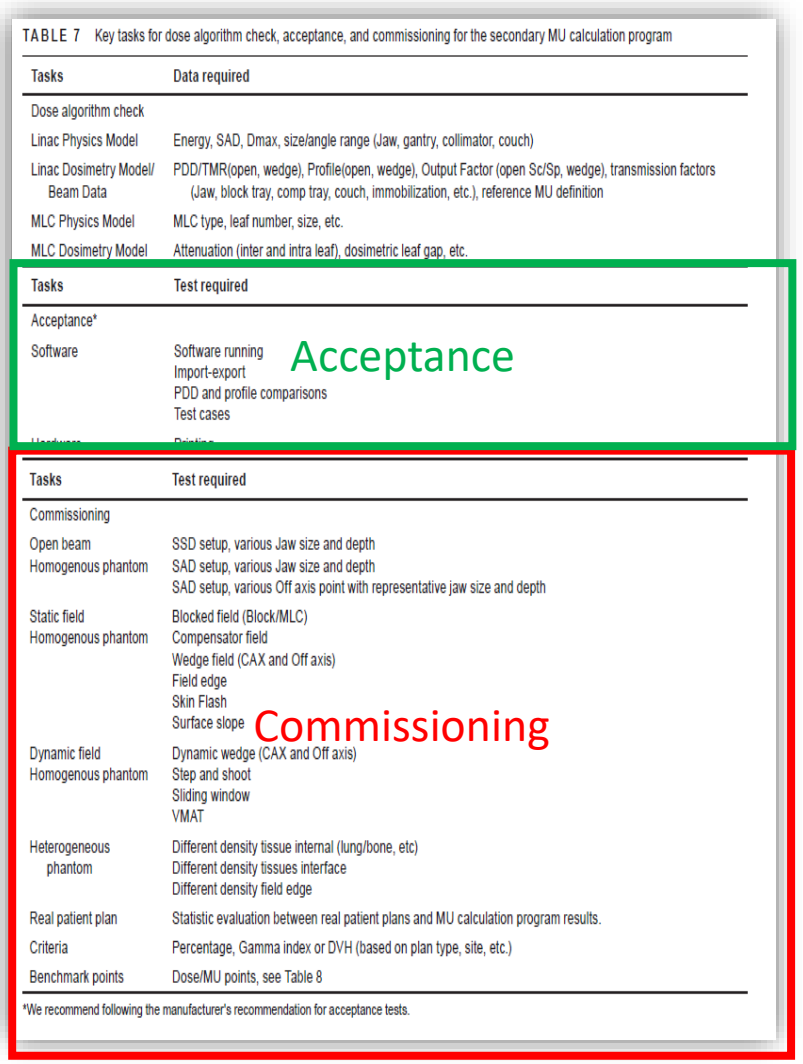

TABLE 7 Key tasks for dose algorithm check, acceptance, and commissioning for the secondary MU calculation program

| Tasks | Data required |
|---|---|
| Dose algorithm check | |
| Linac Physics Model | Energy, SAD, Dmax, size/angle range (Jaw, gantry, collimator, couch) |
| Linac Dosimetry Model/ Beam Data | PDD/TMR(open, wedge), Profile(open, wedge), Output Factor (open Sc/Sp, wedge), transmission factors (Jaw, block tray, comp tray, couch, immobilization, etc.), reference MU definition |
| MLC Physics Model | MLC type, leaf number, size, etc. |
| MLC Dosimetry Model | Attenuation (inter and intra leaf), dosimetric leaf gap, etc. |

| Tasks | Test required |
|---|---|
| Acceptance* | |
| Software | Software running<br>Import-export<br>PDD and profile comparisons<br>Test cases |

Acceptance

| Tasks | Test required |
|---|---|
| Commissioning | |
| Open beam<br>Homogenous phantom | SSD setup, various Jaw size and depth<br>SAD setup, various Jaw size and depth<br>SAD setup, various Off axis point with representative jaw size and depth |
| Static field<br>Homogenous phantom | Blocked field (Block/MLC)<br>Compensator field<br>Wedge field (CAX and Off axis)<br>Field edge<br>Skin Flash<br>Surface slope |
| Dynamic field<br>Homogenous phantom | Dynamic wedge (CAX and Off axis)<br>Step and shoot<br>Sliding window<br>VMAT |
| Heterogeneous phantom | Different density tissue internal (lung/bone, etc)<br>Different density tissues interface<br>Different density field edge |
| Real patient plan | Statistic evaluation between real patient plans and MU calculation program results. |
| Criteria | Percentage, Gamma index or DVH (based on plan type, site, etc.) |
| Benchmark points | Dose/MU points, see Table 8 |

*We recommend following the manufacturer's recommendation for acceptance tests.

Commissioning

[17]

# Commissioning – validation/benchmark

- The software validation and benchmarking
  - Benchmark points suggested in Table 8
  - Follow the recommendations of TG 119
- Ongoing QA for the secondary dose/MU software should be carried out (consistent with MPPG 5A)
  - **Annual QA**
  - **Software upgrade occurs**

**TABLE 8** Benchmark points for independent verification of Dose/MU of photon beams using conditions different from those used for commissioning beam data collection. The table gives an example of 19 comparison points between measurements and secondary dose calculation results for Dose/MU in a 6 MV beam from a Varian TrueBeam. Benchmark measurements should be repeated for all photon energies. The first and second columns give the index and energy specification; the third to sixth columns give the conditions for measurements, for example, SSD, collimator settings, Collimator angle (CA) and Gantry angle (GA), and locations of the measurement point in the water phantom (x, y, z) that matched the coordinates used in a TPS, x and y are parallel to the X and Y jaw, note z is in the depth direction; the seventh to eighth columns give example measured and calculated values for Dose/MU; the ninth column gives the percentage difference between the calculation and the measurement

| Index | Beam | SSD | Jaws (X,Y) | CA/GA | Location (x, y, z) | Meas. [cGy/MU] | 2nd Calc [cGy/MU] | Difference [%] |
|---|---|---|---|---|---|---|---|---|
| 1 | 6 MV | 90 | 10 × 10 | 0/0 | (0,0,10) | 0.801 | 0.801 | 0.0% |
| 2 | 6 MV | 90 | 10 × [−10,20][a] | 0/0 | (0,15,10) | 0.829 | 0.827 | −0.3% |
| 3 | 6 MV | 90 | 10 × [−10,20][a] | 0/0 | (0,16.5,20) | 0.445 | 0.444 | −0.1% |
| 4 | 6 MV | 110 | 36 × 36 | 0/0 | (0,0,5) | 0.810 | 0.804 | −0.7% |
| 5 | 6 MV | 110 | 36 × 36 | 0/0 | (0,12,5) | 0.836 | 0.825 | −1.3% |
| 6 | 6 MV | 110 | 36 × 36 | 0/0 | (12,0,5) | 0.838 | 0.826 | −1.4% |
| 7 | 6 MV | 80 | 5 × 20 | 0/0 | (0,0,5) | 1.280 | 1.281 | 0.1% |
| 8 | 6 MV | 80 | 5 × 20 | 0/0 | (0,5,5) | 1.313 | 1.303 | −0.8% |
| 9 | 6 MV | 80 | 5 × 20 | 0/0 | (0,0,20) | 0.511 | 0.512 | 0.3% |
| 10 | 6 MV | 80 | 20 × 5 | 0/0 | (0,0,5) | 1.266 | 1.262 | −0.3% |
| 11 | 6 MV | 80 | 20 × 5 | 0/0 | (5,0,5) | 1.300 | 1.284 | −1.2% |
| 12 | 6 MV | 80 | 20 × 5 | 0/0 | (0,0,20) | 0.503 | 0.505 | 0.3% |
| 13 | 6 MV | 80 | 4 × 4 | 0/0 | (0,0,5) | 1.185 | 1.183 | −0.2% |
| 14 | 6 MV | 80 | 4 × 4 | 0/0 | (0,0,20) | 0.439 | 0.439 | 0.0% |
| 15 | 6 MV | 80 | 36 × 36 | 0/0 | (0,0,20) | 0.702 | 0.701 | −0.1% |
| 16 | 6 MV | 80 | 36 × 36 | 0/0 | (0,12,20) | 0.670 | 0.662 | −1.3% |
| 17 | 6 MV | 100 | 1 × 1 | 0/0 | (0,0,10) | 0.606 | 0.600 | −1.0% |
| 18 | 6 MV | 100 | 3 × 3 | 0/0 | (0,0,0.5) | 0.993 | 0.988 | −0.5% |
| 19 | 6 MV | 100 | 40 × 40 | 0/0 | (0,0,0.5) | 1.291 | 1.319 | 2.2% |

[a][−10, 20] is for independent collimator jaw setting, Y1 = −10 cm and Y2 = 20 cm so that an offset 10 x 10 $cm^2$ field is formed.

[18]

# Clinical implementation - independence

- Follows the same definition as outlined in TG 114
  A. Independent algorithm
  B. and/or independent beam data
    - Different reference conditions (isocentric versus at fixed SSD)
    - The same setup but acquired for different field sizes
    - Similar data determined by different personnel
    - Golden beam data set

- **It is acceptable to use the same beam data used for the TPS commissioning provided the algorithm for dose calculation is different**

# Clinical implementation – how many points?

- At least in 1D but preferably in 2D/3D
  - Chose point in a high dose and low dose gradient region for 1D

- 2D or 3D calculations to the entire volume and may additionally provide gamma maps for dose evaluation
  - **more broadly meaningful and is thus recommended for general use for IMRT secondary calculations**

# Clinical implementation – action levels?

- TG 219 recommended action levels shown in Table 9.
  - 1D: 5% for composite plan in a high dose/low gradient homogeneous region
  - 2D/3D: 90% for 3%/2mm
- Plan acceptability should be based on the **composite plan**. Single beam agreement may be used to better understand discrepancies.

**TABLE 9** Action levels of the secondary MU calculation compared to TP calculations for various clinical situations for a single point. All percentage differences are defined as local relative difference. Note: the action level is larger than the tolerance level as described in the AAPM TG218 report.[10] For 2D or 3D action levels, use the specification as described by TG218 given the lack of literature specific to second MU calculations.[10] A general guidance is to use 90% for 3%/2 mm as action level.[10] However, the users are allowed to tighten their criteria as they wish

| | Homogeneous | | Heterogeneous | |
|---|---|---|---|---|
| | Single beam | Composite plan | Single beam | Composite plan |
| High Dose/ Low Gradient | 5% | 3% | 7% | 5% |
| Low Dose/ High Gradient[a] | 7% | 5% | 10% | 7% |

[a]Low-dose region is defined as dose <5% of maximum dose, where head scatter and leakage dominate. High gradient region is defined as dose gradient >5%/mm or in regions of electron disequilibrium (e.g., 4x4 cm field in the lung for 15 MV photons).

[21]

# Investigating cases with poor agreement

- Plans failing to meet acceptability criteria should be evaluated to understand the cause of the disagreement and manage it appropriately.

- Multiple levels of investigation :
  1. Poor point placement
  2. Algorithm limitations of small field?
  3. Check if the plan needs to be revised to ensure safe delivery of the plan
  4. Contact the manufacturer for possible software clarification

# Summary of TG 219 recommendation

- Physicists should not rely solely on independent dose/MU calculation tools for IMRT QA
  - ➢Currently can't detect errors in dose calibration, MLC errors etc.
- Secondary dose/MU calculations should be performed for every IMRT/VMAT plan
  - ➢At least 1D but preferably in 2D/3D
- Independence can be comprised of independent algorithms and/or independent beam data
  - ➢Preferred that both the algorithm and beam data are independent

[23]

# Summary of TG 219 recommendation

- Commissioning should be performed based on recommendations of TG 53 and MPPG 5A
  - ➢Software validation and benchmarking should use the benchmark points suggested in table 8 and follow the recommendations of TG 119
- Ongoing QA should be carried out both annually and anytime upgrade occurs
- Should be within the recommended action levels shown in table 9.
  - Action levels suggested by TG 218 should be used for 2D/3D comparison
  - Plans failing to meet acceptability criteria should be evaluated to understand the cause of the disagreement and manage it appropriately

[24]

# Thank You

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