The Abdus Salam International Centre for Theoretical Physics

School on Medical Physics for Radiation Therapy:
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Treatment Time / MU calculation in RT

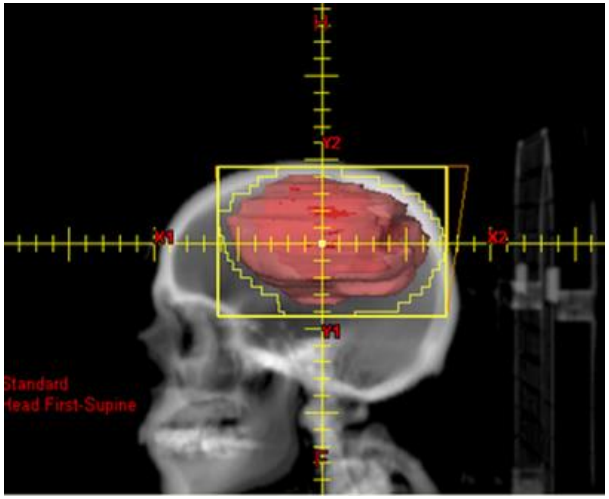
Maria Rosa Malisan

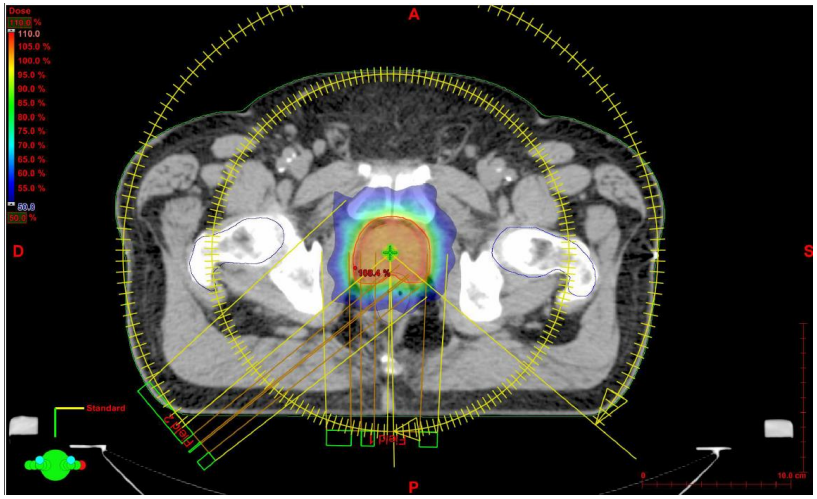
Clinical Dose Calculations

- Computing absorbed doses in a patient using data measured in a phantom has been the standard of practice in radiotherapy (RT).
- This is because **direct measurement** of absorbed doses in a patient is impractical and often impossible.
- Therefore, the treatment planning has to be based on calculation models.
- Even if direct measurements were possible, it would still be much more practical and convenient to perform planning based on calculation models.
- The dose predicted by a calculation method should correspond to the real absorbed dose in the patient as accurately as possible.

RT Planning

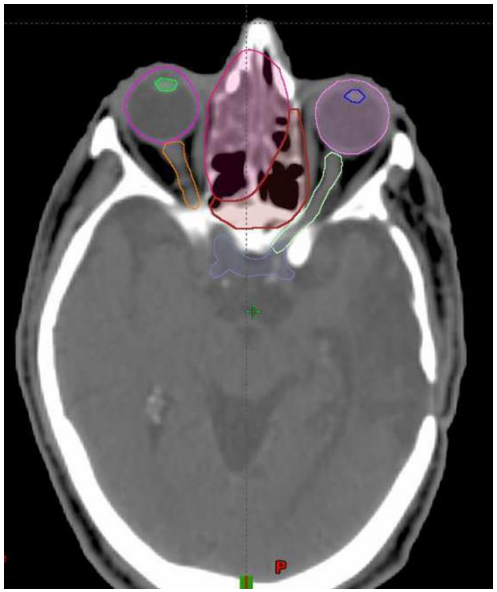
- In RT treatment planning, the purpose is to devise a treatment, which produces as uniform dose distribution as possible to the target volume and minimizes the dose outside this volume.

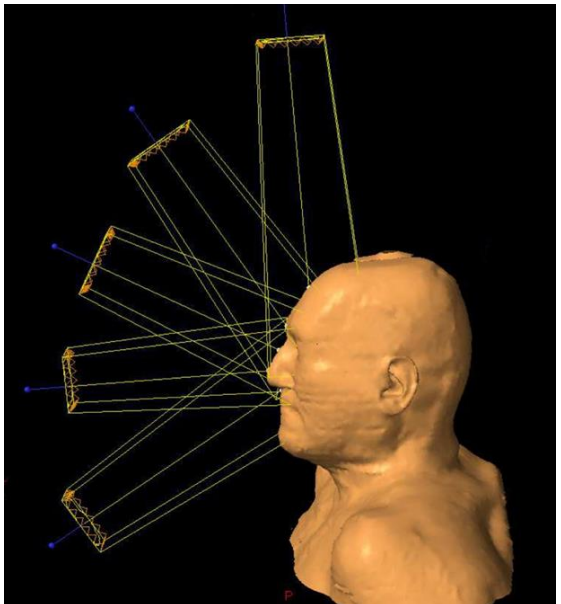


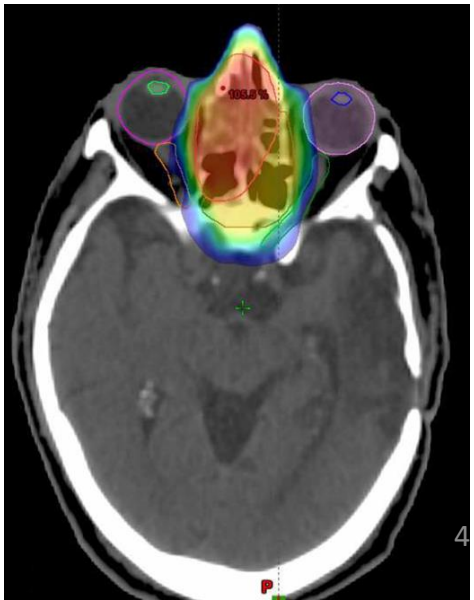


RT Planning

- In RT planning, the beam qualities, field sizes, positions, orientations and relative weights between the fields are typically modified.
- It is also possible to add certain accessories (e.g. wedge filters or blocks) to the fields to account for oblique patient surface or to shield critical structures from radiation exposure.

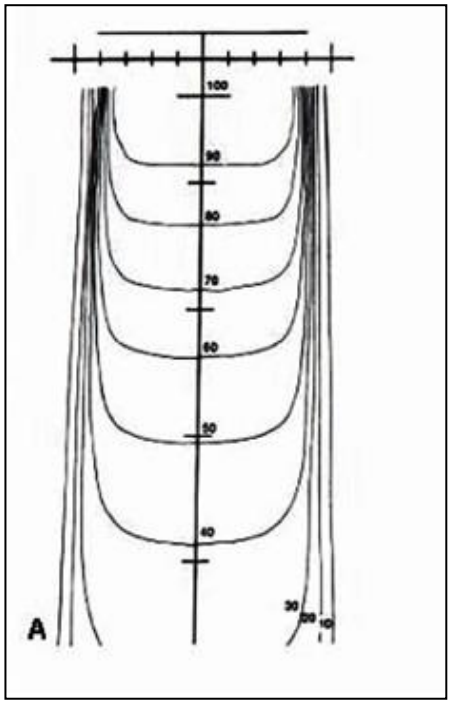


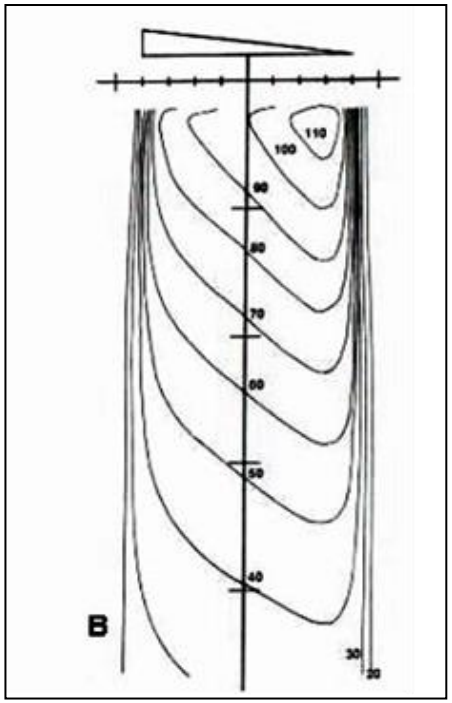




Historical Background

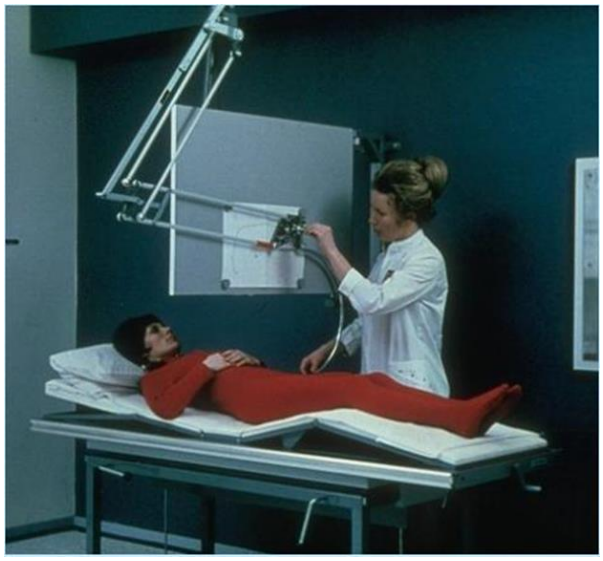
- Practising of treatment planning started in 1940's when the developments in radiation dosimetry enabled each clinic to measure the **isodose charts** for any type of treatment field, thus enabling manual 2D planning.
- To avoid laborious isodose measurements, empirical methods for the calculation of dose distribution were developed later.
- e.g. the percent depth dose (PDD) was introduced to calculate doses for treatments delivered using fixed treatment distance machines.

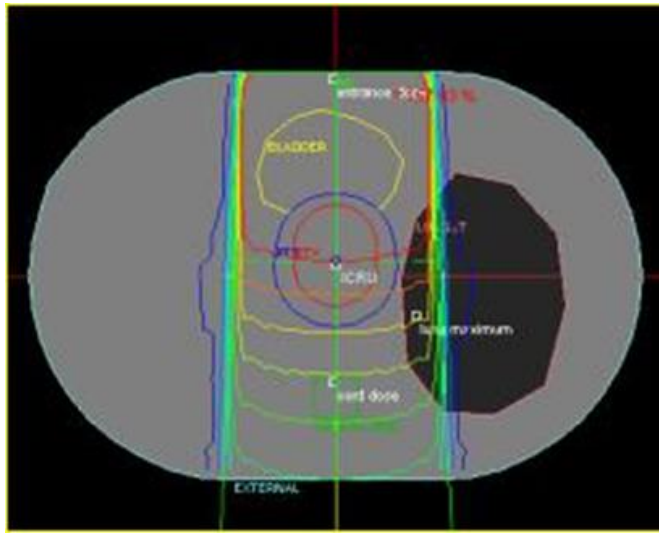




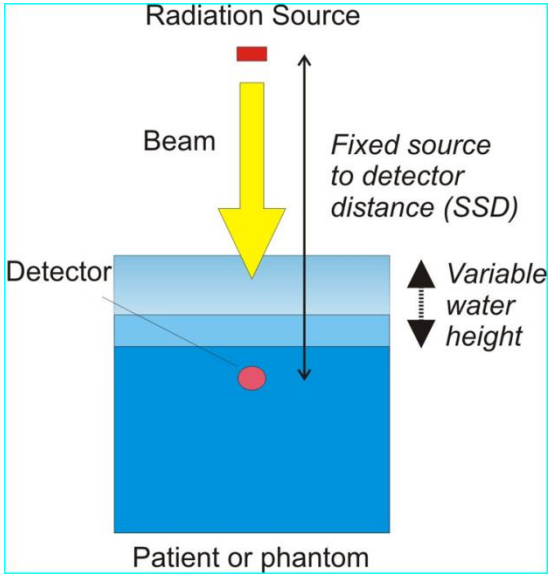
Historical Background

- Computer-based treatment planning systems (TPSs), first introduced in the ‘70’s of last century, allowed the planner to see the effect of the beam modifications immediately on the predicted dose distribution.
- This resulted in better quality plans, since it became easier to experiment with a larger set of treatment parameters.





Factor vs Model-based algorithms



- First TPS's made use of factor based models, where the dose per MU is typically expressed as the dose to a **reference point under reference conditions**, corrected with a set of factors.
- Each factor accounts for one or several different effects:
  - ***beam size, beam shape, depth, distance, wedges, etc.***
- These factors are typically measured or calculated through simple modelling and stored in tables.
- The method is intuitive and robust, but lacks general applicability.
- It is in principle impossible to account for all different treatment design possibilities which are a part of modern radiotherapy.

Modern Treatment Planning Systems

- Therefore the **model-based calculation methods** were introduced within TPS's, where the commissioning measurements are used to determine a set of more fundamental physical parameters which characterize the radiation from the treatment unit.
- Model based algorithms can be made fully general without the need for a large set of characterization measurements.
- Recently, 3D TPS's have become common in RT departments offering improved accuracy and enhanced visualization in the RT treatment planning process.
- With recent improvement in computing technology, the newer TPS now correctly model the radiation transport properties three dimensionally and estimate the dose deposition precisely.

Modern Treatment Planning Systems

A modern TPS intended for routine treatment planning should address the following challenges:

1. The calculation model should be applicable to generalized beam setups, including irregularly shaped beams and varying SSDs.
2. The effects of oblique patient skin and heterogeneous tissue on primary and scattered radiation components should be accurately modelled.
3. The radiation beam produced by the linac should be characterized using only a limited set of technical information.
4. The beam model should be adaptable to an individual treatment machine.
5. The computation time should be short enough to facilitate interactive plan

L. Korhonen, 2009

MU calculation

- In external beam RT, monitor units (MU) or beam-on time for a given treatment plan allows the RT technologists to deliver the actual dose to a patient.
- MU are calculated by the TPS by means of sophisticated algorithms from the calculated dose distribution and dose prescription.
- It is essential for the user of a TPS to **understand the principles** of the MU calculation algorithm!
- However, in "simple" cases MU can be computed by means of several dosimetric functions introduced to relate absorbed doses measured in a phantom to absorbed doses in a patient:

Manual calculation

Why *Manual* MU Calculation ?

- Traditionally manual calculation is carried out by means of factor-based models.
- It can sound utterly *out of fashion* in the era of physics-based models or Monte Carlo TPS !
- However, it can result useful as a powerful QA tool **during TPS commissioning.**
- In fact, modern model-based TPS's dose calculations, make use of characterization measurements to determine more basic parameters: errors in characterization measurements can result in unexpected and systematic calculation errors.
- Moreover, software errors can go undetected during commissioning and manifest subsequently in clinical planning

Why *Manual* MU Calculation ?

- ICRP Report 86 has categorised accidents reported in ext RT: 28% in treatment planning and dose calculation.
- The ***human factor*** is the cause for a large majority of the incidents and accidents. In routine clinical practice, more likely sources of systematic dose error for individual patients result from misuse of the system:
  - inadequate understanding of normalization protocols,
  - misinterpretation of the system output
  - data transfer errors

46 accidents/incidents reported for external radiotherapy as categorized by ICRP 86

TYPE	#
Equipment problem	3
Maintenance	3
Calibration of beams	14
Treatment planning and dose calc	13
Simulation	4
Treatment setup and delivery	9

T. Nyholm, 2008

List of reported bugs from the TPS vendors collected from the FDA MAUDE database for the time period 2004-2008.

Year	Report Number	Problem
2007	8043933-2007-00003	The MLC is not taken correctly into consideration under certain circumstances.
2006	MW1039971	Calculation error for physical wedges
2006	1937649-2006-00004	Physical wedge included in dose calculations but not in RTPlan exported to OIS system
2006	1937649-2006-00003	Position of X-jaw was ignored for Siemens accelerators, i.e. the field size was too large in the calculations
2006	9617016-2006-00001	MU calculations up to 5 times wrong.
2005	1937649-2005-00003	Dose calculations not removed or updated when changing treatment unit within the TPS
2005	1937649-2005-00001	Underestimation of the dose in the penumbra under specific circumstances for Siemens accelerators. Leads to cold spots in IMRT plans.
2004	1937649-2004-00004	Calculation error for Varian EDW when the central axis is blocked

- The companies are not obligated to report all problems, and different companies have different policies regarding the reporting.
- The presented list of identified bugs are therefore far from complete and is perhaps not even representative.

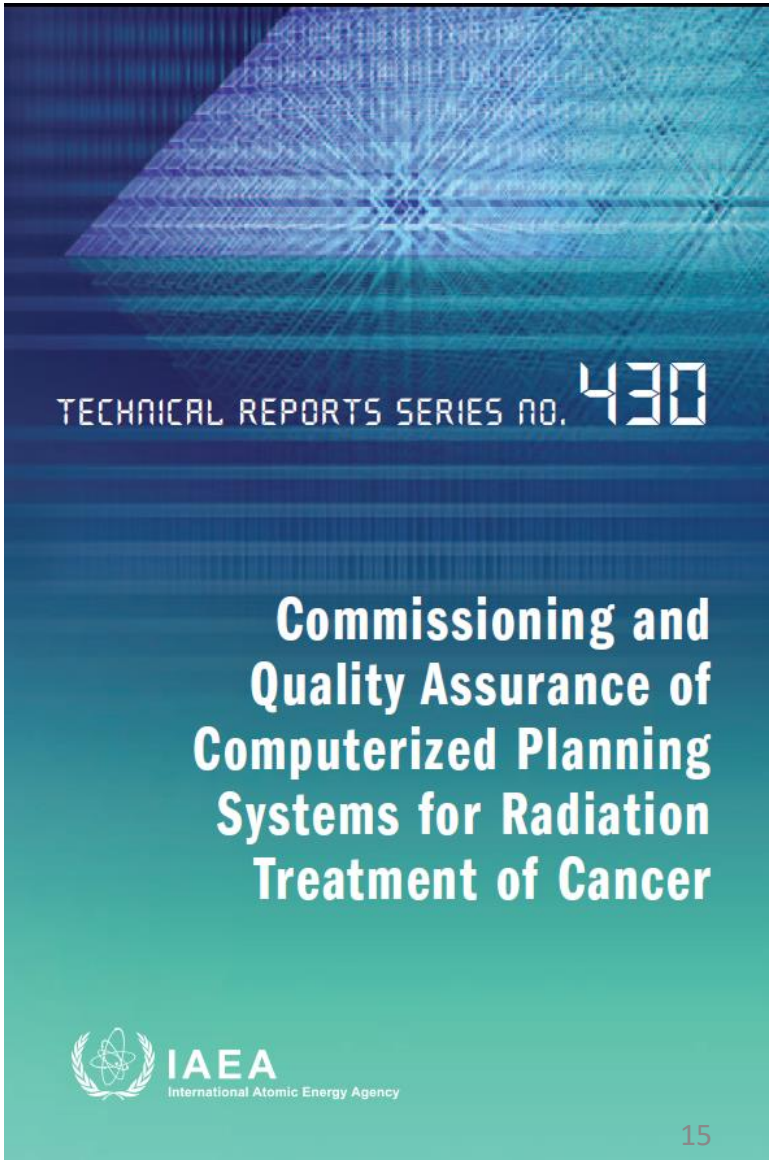
T. Nyholm, 2008

Why *Manual* MU Calculation ?

- The ICRP Report 86 concluded that many of these accidents could have been prevented through ***independent verification*** of the TPS and with systematic use of in-vivo dosimetry.
- Independent verification can also enhance confidence in the accuracy of the algorithm and integrity of the beam data used.
- It may also be a formidable didactic tool to learn the influence on the dose of the several treatment parameters, although this is not generally the main intention!

MU Calculation for TPS Commissioning

- IAEA TRS 430 Report lists some of the relevant issues that should be investigated
- It briefly describes the types of test that can help to verify the correct behaviour of the entire planning and MU/time calculation process.
- Detailed checks of the entire planning and MU/time calculation process should be performed.



IAEA TRS 430: MU calculation tests

- A number of important aspects of the treatment planning process affect the way one should calculate the MU's or time **(e.g. normalization)**

- For these 9 test situations, the MU/time calculation performed using the TPS should be compared to the manual MU/time calculation.

TABLE 48. ISSUES FOR THE MU/TIME CALCULATION PROCESS

	Issue	Test
Open fields	Basic MU/time calculation Inverse square law	MU test 1
Tangential fields	Missing scatter Contour correction	MU test 2
Wedged fields	Wedge factor Wedge hardness correction Wedge OAR	MU test 3
Blocked fields	Equivalent square method Integration over shape Other method Separate head and phantom scatter	MU test 4
MLC shaped fields	Equivalent square method or integration over shape Does the calculation include jaw effects and a head scatter factor? Small MLC shapes and multisegment IMRT fields	MU test 5
Beam normalization point blocked	When MLCs or blocks shield the beam normalization point, how does beam weighting and MU/time calculation handle this situation?	MU test 4a MU test 5a
Inhomogeneity corrections	How are MU/time calculations performed when inhomogeneity corrections are used in the TPS plan? How are the differences in absolute dose to plan and beam normalization points handled?	MU test 6
Off-axis calculations	What approximations are involved in off-axis calculations?	MU test 7
Dose prescription	How is dose prescription carried from the TPS plan to MU/time calculations? Are there limitations on allowed prescriptions?	MU test 8
Dose distribution units	How do different units used for the display of TPS dose distribution affect the MU/time calculation?	MU test 9
Documentation for the treatment chart	Check that the entire output from the MU/time calculation agrees with the TPS output and machine use	MU issue 1
Clinical check procedure	Verify that the clinical check procedure used for MU/time calculation checks is adequate for the complexity of the plans allowed	MU issue 2

IAEA TRS 430: Overall Clinical Tests

- Measurement or manual dose evaluation of the **final dose delivery** should be performed,
- to ensure that the correct absolute dose would be delivered to the patient following the completion of the total treatment planning process.

TABLE 60. EXAMPLE CLINICAL TESTS EVALUATING THE TOTAL TREATMENT PLANNING PROCESS

	Description	Test
Open fields	Four field box and open fields	Clinical test 1
Blocking	Same four field box and heavily corner blocked fields	Clinical test 2
Wedges	Wedge pair	Clinical test 3
CT planning	AP–PA plan treating inhomogeneity (anthropomorphic or plastic phantom)	Clinical test 4
Conformally shaped fields	Six field axial conformal prostate plan	Clinical test 5
Non-axial or non-coplanar fields	Conformal non-coplanar brain plan	Clinical test 6
Electrons	Combined photon–electron plan	Clinical test 7
Brachytherapy applicator	Gynaecological: tandem and ovoids	Clinical test 8
Multiplanar implant	Two plane breast implant	Clinical test 9
Volume implant	Prostate implant	Clinical test 10
HDR	HDR test case	Clinical test 11

- While it is not necessary to implement these particular examples, it is important that some typical situations be developed and tested right through to the evaluation of absolute dose. This is especially true for a new TPS.

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 1, NUMBER 3, SUMMER 2000

On the need for monitor unit calculations as part of a beam commissioning methodology for a radiation treatment planning system

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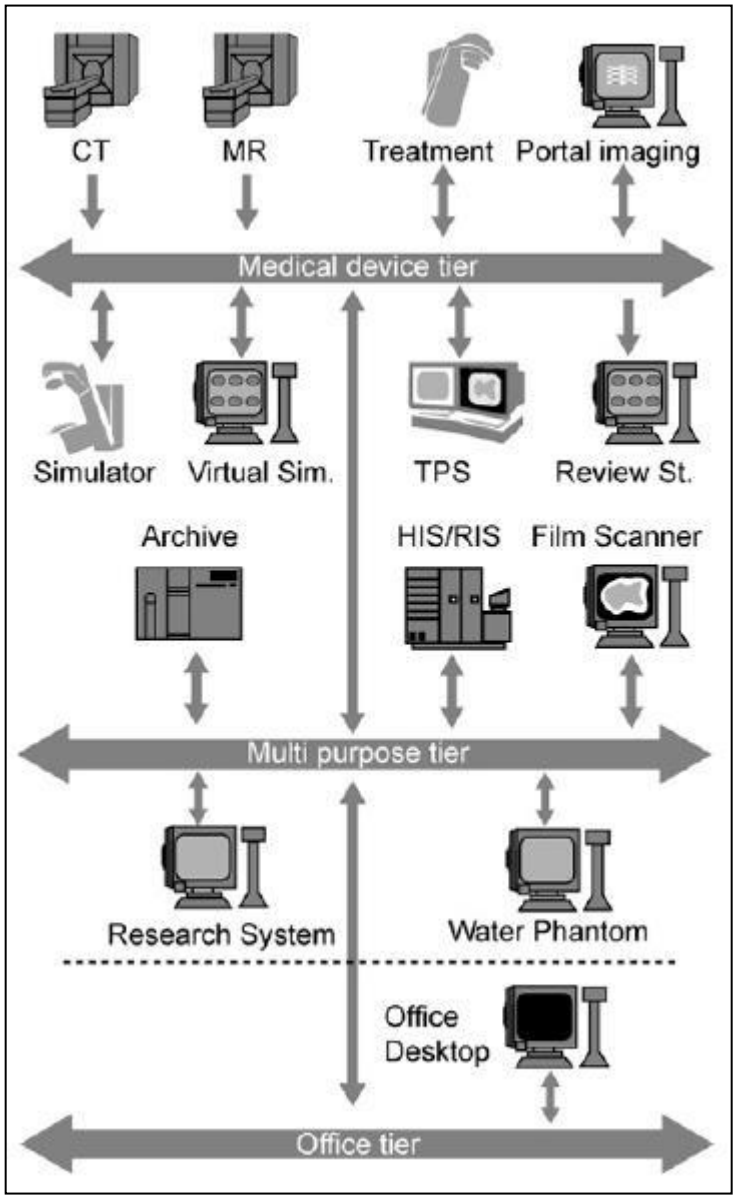
Laura O'Neill,[d] Linda A. Miller,[e] and Isaac I. Rosen[f]
Department of Radiation Physics, The University of Texas M. D. Anderson Cancer Center, Houston, Texas 77030-4095

- MU's calculated using the TPS were compared with MU's calculated from point dose calculations from TMR tables. **Discrepancies in MU calculations** were both significant (up to 5%) and systematic.
  Analysis of the dose computation software found:
- 1) a coordinate system transformation error,
- 2) mishandling of dose-spread arrays,
- 3) differences between dose calculations in the commissioning software and the planning software,
- 4) shortcomings in modeling of head scatter.
- Corrections were made in the beam calculation software or in the data sets to overcome these discrepancies. Consequently, ***we recommend validation of MU calculations as part of commissioning process***.

RT Planning QA

- TPS optimized dose distributions with beam data are transferred through a **computer network to the linac** for automatic delivery of radiation.
- In this process there are many steps where both systematic and random errors can be introduced, but very few intrinsic possibilities for manual inspection/verification of the delivered dose.
- Hence, there is a great need for well designed and ***efficient quality systems*** and procedures to compensate for diminished human control.



Siochi et al, JACMP 2009

RT Planning QA

- Even if the TPS's are commissioned and kept under QA programs to maintain their accuracy, errors may be introduced.
- Especially, the ***human factor*** is an uncontrolled parameter that may introduce errors.
- Thus, unintentional changes or incorrect handling of data may occur **during clinical use** of the equipment.
- Having an independent dose calculation system implemented in the **daily quality assurance process** may assure a high quality of treatments and avoidance of severe errors.

Safety Legislation

- In several European countries there are legal aspects based on EURATOM directive 97/43 for independent QA procedures and their implementation into national radiation protection and patient safety legislation.
- In particular, Article 8 states: "Member States shall ensure that… appropriate quality assurance programmes including *quality control measures and* ***patient dose assessments*** are implemented by the holder of the radiological installation….".
- This is also emphasized in Article 9 with respect to Special Practices: *"…special attention shall be given to the quality assurance programmes, including quality control measures and* ***patient dose*** *or administered activity assessment, as mentioned in Article 8*."
- In a broad sense this directive directs the holder to assure that the delivered dose to the patient corresponds to the prescribed dose.

Independent Dose calculation

- Dose calculation with a TPS represents one of the most **critical links** in the RT treatment process, since it is the only realistic technique to estimate dose delivery *in situ*.

- Even though the calculation algorithms are tested during the commissioning of TPS and results are achieved with 1-2% accuracy in water phantom geometry, a good QA programme further requires that

all MU's calculated for clinical use should be verified using a second independent calculation method

- so that any errors due to software faults and improper use of the systems could be identified.

Independent MU calculation

- Dose errors arising in computing the MU could potentially affect the whole course of treatment and therefore are of particular concern.
- So, **independent checking** of MU calculations, ***for each RT treatment plan***, is essential for QA.
- It is considered more than desirable if the beam data set and calculation algorithm are independent of those of the TPS.
- AAPM also recommends an independent calculation of the dose at one point in the plan, preferably at the isocenter or at a point near the center of the PTV.
- If the independent calculation differs from the treatment plan by more than a pre-set tolerance level, **the disparity should be resolved** before commencing or continuing treatment.

Independent dose calculation

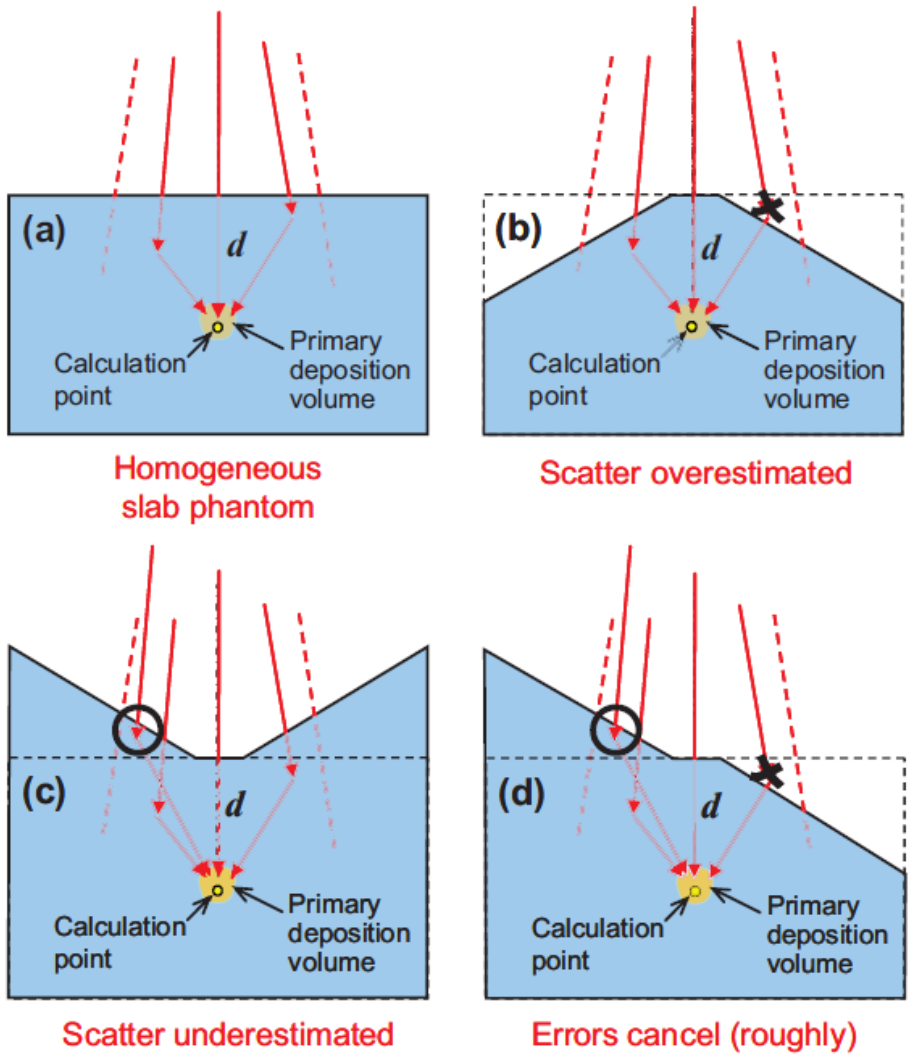
- Dose calculations can be performed through various methods utilizing fairly different approaches.
- A tool for independent dose calculations, or any other kind of dose calculation device, is **a compromise** between the benefits and drawbacks associated with different calculation methods in relation to the demands on **accuracy, speed, ease of use**.
- Independent dose calculations have been used for a long time as a routine QA tool in conventional RT using empirical algorithms in a manual calculation procedure, or utilizing software based on fairly simple dose calculation algorithms
- (Dutreix *et al.*, 1997; Knöös *et al.*, 2001; van Gasteren *et al.*, 1998).

MU Verification: ESTRO and AAPM docs

- During the last decade recommendations for MU verification have been published by **ESTRO (Booklets 3 and 6)** and by the Netherlands Commission on Radiation Dosimetry, NCS .
- AAPM Task Group 71 was formed in 2001 to create a consistent nomenclature and formalism (national protocol) for MU Calculations. In 2014 the Report 258 has been published: Monitor unit calculations for external photon and electron beams: Report of the AAPM Therapy Physics Committee TG No. 71, Medical Physics, Vol 41, Issue 3
- In these reports it is common practice to verify the dose at a point by translating the treatment beam geometry onto a flat homogeneous semi-infinite water phantom or **"slab geometry"**.
- Users should be aware of the limitations of this compromise that favors simplicity and calculation speed over accuracy!

Limits of the manual MU verification

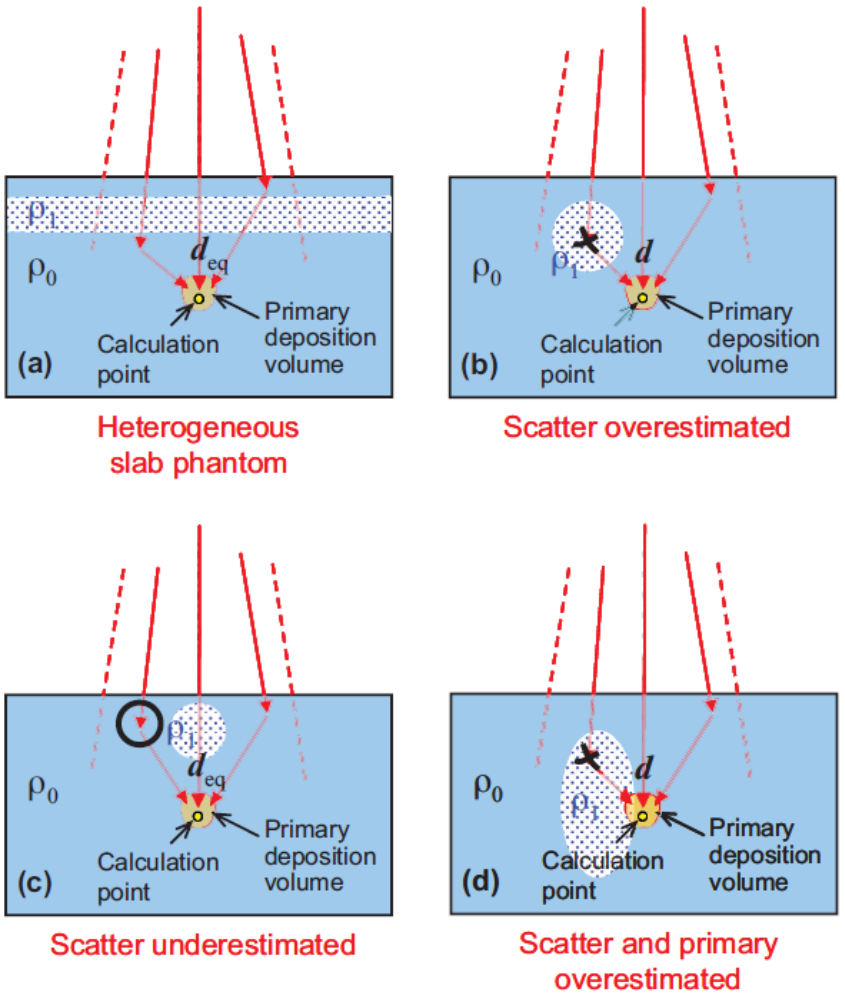
- Conventionally, MU calculation verification methods assume ‘‘water phantom geometry’’ in which the beam is presumed to be incident on a slab of material affording full scatter conditions.
- It is evident that this assumption yields over- or underestimated scatter contributions, depending on the exact geometry.



ESTRO Booklet 10

Limits of the manual MU verification

- Various methods to handle and correct for density variations (heterogeneities) in the literature
- Most often these heterogeneity corrections rely on one-dimensional depth scaling along ray lines from the direct source, employing equivalent/ effective/ radiological depths that replace the geometrical depths in the dose calculations.
- In general, the full 3D nature of the process can not be properly modelled.
- The result is that all deviations from the ideal slab phantom geometry will cause different errors in the calculated doses.



ESTRO Booklet 10

Heterogeneity Corrections

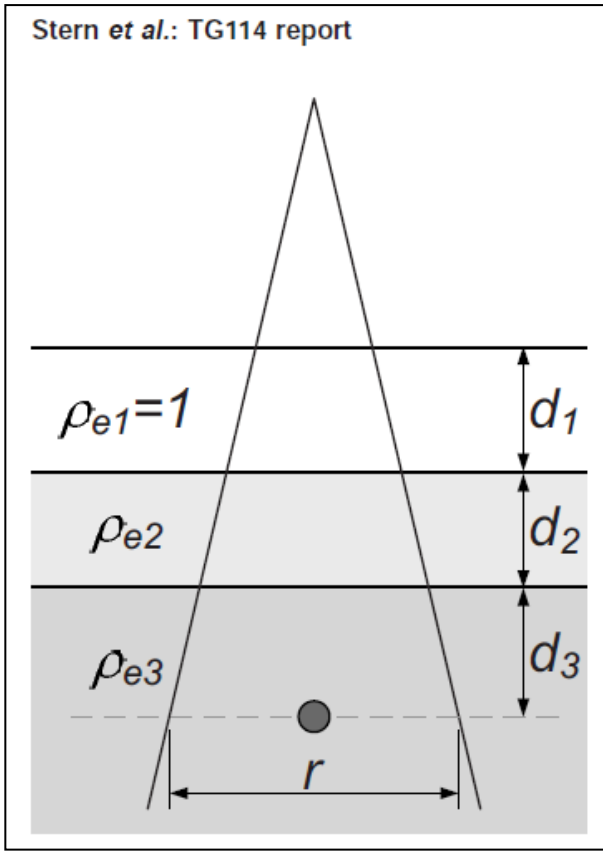
- Using the ratio of TAR method proposed by O'Connor and more conventional parameters, the **inhomogeneity correction factor** may be calculated:

$$CF = \left(\frac{TPR(d_{eff}, r_d)}{TPR(d, r_d)} \right)$$

- According the Batho's method, later extended by Sontag and Cunningham, the correction factor can be expressed as:

$$CF = \left(\frac{TPR(d_3, r_d)^{\rho_{e3}-\rho_{e2}}}{TPR(d_2 + d_3, r_d)^{1-\rho_{e2}}} \right)$$

- However, these simple ratio methods described above do not take into account the effect of the **lateral dimension of the heterogeneity** !



Photon dose calculation to a point in a heterogeneous phantom. The first layer of material is assumed to be water equivalent.

Manual MU Verification experiences

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 1, NUMBER 4, FALL 2000

Independent corroboration of monitor unit calculations performed by a 3D computerized planning system

Konrad W. Leszczynski* and Peter B. Dunscombe
Department of Medical Physics, Northeastern Ontario Regional Cancer Centre, 41 Ramsey Lake Road, Sudbury, P3E 5J1, Canada, Department of Radiology, University of Ottawa, Ottawa K1N 6N5, Canada, and Department of Physics, Laurentian University, Sudbury P3E 2C6, Canada

- An independent MU calculation is created in an **MS-Excel spreadsheet**. The method is shown sufficiently sensitive to identify significant errors and is consistent on the magnitude of uncertainties in clinical dosimetry.
- It is reported that using straightforward but detailed computer based verification calculations, **it is possible to achieve a precision of 1%** when compared with a 3D Helax TPS MU calculation.

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 3, NUMBER 4, FALL 2002

Comparison of monitor unit calculations performed with a 3D computerized planning system and independent "hand" calculations: Results of three years clinical experience

Jackson Chan,* David Russell,† Victor G. Peters,‡ and Thomas J. Farrell§
Department of Medical Physics, Hamilton Regional Cancer Centre, 699 Concession St., Hamilton, Ontario, Canada L8V 5C2

- the MU's calculated by Pinnacle planning system were compared with **hand calculations from lookup tables** for nearly 13,500 treatment fields without considering the tissue inhomogeneity.
- The 3D TPS MU calculation was systematically higher than the ''hand'' calculation: for simple geometries the mean difference was 1% and was as high as 3% for more complicated geometries.
- Careful attention to factors such as **patient contour** could reduce the mean difference.
- ''Hand'' calculations were shown to be an accurate and useful tool for verification of TPS MU calculations.

ELSEVIER

Radiotherapy and Oncology 58 (2001) 201–208

RADIOTHERAPY & ONCOLOGY
JOURNAL OF THE EUROPEAN SOCIETY FOR THERAPEUTIC RADIOLOGY AND ONCOLOGY

www.elsevier.com/locate/radonline

Independent checking of the delivered dose for high-energy X-rays using a hand-held PC

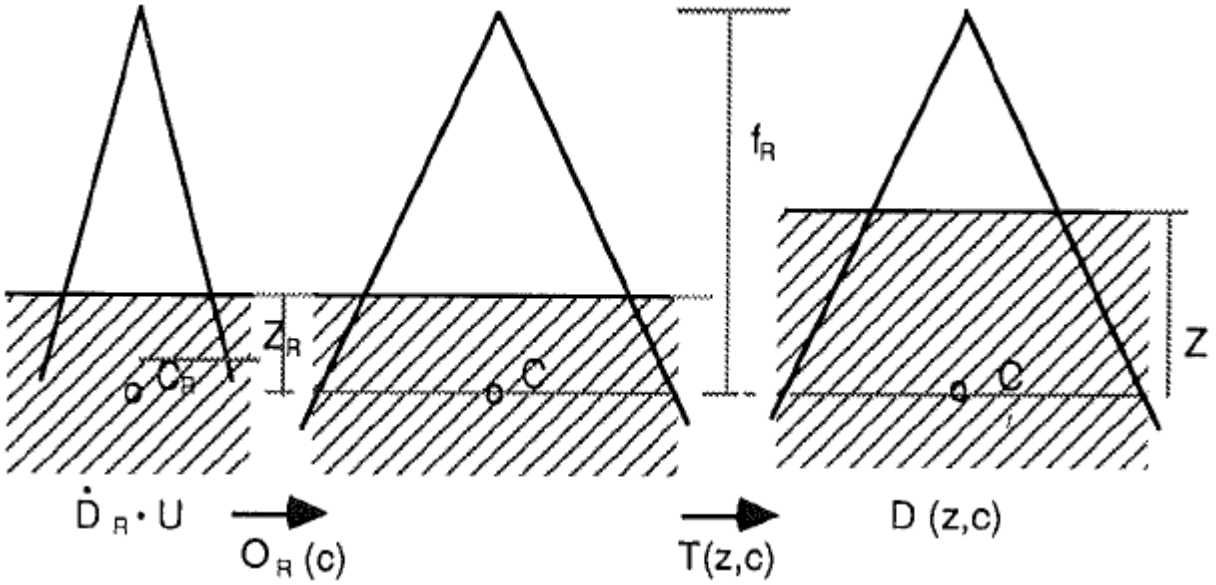
Tommy Knöös*, Stefan A. Johnsson, Crister P. Ceberg, Andrej Tomaszewicz, Per Nilsson

Radiation Physics, Lund University Hospital, SE-221 85 Lund, Sweden

- This system has been implemented into the **daily clinical quality control** program.
- A hand-held PC allows direct calculation of the dose to the prescription point when the **first treatment** is delivered to the patient.
- The model is validated with measurements and is shown to be within ±1.0% (1 SD).
- Comparison against a state-of-the-art TPS shows an average difference of 0.3% with a standard deviation of ± 2.1%.
- An **action level** covering 95% of the cases has been chosen, i.e. **± 4.0%.**
- Deviations larger than this are with a high probability due to erroneous handling of the patient set-up data.

Factor-based dose calculation

- Traditionally the most common way of calculating the dose is through a series of multiplicative correction factors that describe one-by-one the change in dose associated with a change of an individual treatment parameter, such as field size and depth**, starting from the dose under reference conditions**.
- This approach is commonly referred to as *factor-based* calculation and has been the subject of detailed descriptions.



Factor-based dose calculation

- The individual factors are normally structured in **tables** derived from measurements or described through parametrizations.
- Some factors can be calculated through simple modelling, for example the inverse square law accounting for varying treatment distances.
- From an implementation point of view a factor-based method may be an attractive approach due to its **computational simplicity**, once all the required data are available.

Table 7.3 Tissue-Phantom Ratios

6MV X-rays
QI = 0.675

d_{ref} = 10 cm

Side of square field (cm)	*4*	*5*	*6*	*8*	*10*	*12*	*15*	*20*	*25*	*30*	*35*	*40*
depth												
1.0	1.304	1.284	1.270	1.243	1.221	1.207	1.186	1.173	1.156	1.140	1.132	1.125
1.5	1.371	1.346	1.330	1.297	1.272	1.254	1.229	1.209	1.188	1.167	1.158	1.152
2.0	1.369	1.348	1.331	1.297	1.270	1.253	1.229	1.207	1.189	1.170	1.161	1.155
2.5	1.350	1.331	1.315	1.284	1.262	1.245	1.220	1.197	1.179	1.161	1.153	1.148
3.0	1.332	1.316	1.300	1.270	1.248	1.232	1.210	1.190	1.172	1.152	1.145	1.140
3.5	1.311	1.293	1.279	1.253	1.232	1.217	1.194	1.178	1.163	1.146	1.139	1.135
4.0	1.282	1.268	1.256	1.234	1.217	1.204	1.184	1.165	1.151	1.137	1.130	1.124
5.0	1.234	1.226	1.217	1.198	1.182	1.170	1.155	1.142	1.129	1.115	1.109	1.109
6.0	1.188	1.181	1.172	1.155	1.145	1.136	1.125	1.116	1.107	1.097	1.092	1.092
7.0	1.138	1.134	1.129	1.116	1.107	1.101	1.092	1.087	1.080	1.071	1.068	1.068
8.0	1.094	1.091	1.087	1.076	1.071	1.067	1.063	1.061	1.056	1.050	1.046	1.046
9.0	1.043	1.045	1.044	1.039	1.034	1.031	1.028	1.029	1.028	1.024	1.023	1.026
10.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
11.0	0.956	0.959	0.960	0.960	0.962	0.964	0.967	0.973	0.975	0.974	0.975	0.979
12.0	0.915	0.919	0.921	0.922	0.925	0.929	0.932	0.941	0.947	0.948	0.949	0.953
13.0	0.876	0.880	0.883	0.887	0.893	0.898	0.902	0.913	0.921	0.923	0.926	0.931
14.0	0.837	0.842	0.846	0.852	0.858	0.864	0.870	0.884	0.894	0.897	0.900	0.907
15.0	0.803	0.808	0.812	0.816	0.823	0.831	0.839	0.853	0.864	0.869	0.874	0.882
16.0	0.768	0.773	0.778	0.789	0.796	0.803	0.811	0.827	0.842	0.847	0.852	0.860
17.0	0.733	0.739	0.744	0.753	0.760	0.768	0.779	0.797	0.811	0.820	0.828	0.835
18.0	0.703	0.707	0.711	0.725	0.733	0.741	0.752	0.770	0.787	0.796	0.805	0.814
19.0	0.673	0.679	0.684	0.694	0.704	0.715	0.724	0.744	0.765	0.772	0.780	0.787
20.0	0.643	0.648	0.653	0.666	0.675	0.684	0.697	0.718	0.737	0.748	0.758	0.767
21.0	0.618	0.624	0.629	0.638	0.647	0.659	0.672	0.693	0.711	0.722	0.732	0.741
22.0	0.586	0.591	0.596	0.611	0.622	0.633	0.647	0.668	0.686	0.697	0.708	0.718
23.0	0.565	0.571	0.576	0.588	0.598	0.608	0.621	0.643	0.665	0.675	0.685	0.696
24.0	0.544	0.548	0.552	0.562	0.571	0.583	0.597	0.619	0.643	0.654	0.665	0.675
25.0	0.519	0.524	0.528	0.539	0.549	0.561	0.575	0.597	0.619	0.632	0.644	0.655
26.0	0.500	0.504	0.508	0.519	0.528	0.539	0.553	0.575	0.598	0.612	0.625	0.635
27.0	0.479	0.482	0.485	0.495	0.504	0.515	0.530	0.554	0.575	0.589	0.602	0.612
28.0	0.458	0.461	0.464	0.475	0.485	0.497	0.511	0.533	0.555	0.568	0.580	0.591
29.0	0.438	0.442	0.446	0.457	0.466	0.476	0.490	0.513	0.535	0.549	0.560	0.571
30.0	0.420	0.424	0.428	0.439	0.448	0.458	0.472	0.494	0.515	0.530	0.542	0.553

ESTRO Booklet 6

Limits of the Factor-based dose calculation

- The obvious **problem** associated with this approach is the required amount of commissioned beam data as this type of method can not calculate doses **when the beam setup is not covered by the commissioned set of data**.

- For treatment techniques that can make use of many degrees of freedom, such as the shape of an irregular field, it becomes practically impossible to tabulate or parameterize all factors needed to cover all possible cases.

- Hence, the factor-based approach is **best suited for point dose calculations along the central beam axis in beams of simple shapes and simple modifiers** (wedges, blocks, MLC…).

Independent MU calculation: suggested steps by NCS (2005)


Quality assurance of 3-D treatment planning systems for external photon and electron beams

Practical guidelines for initial verification and periodic quality control of radiation therapy treatment planning systems

NEDERLANDSE COMMISSIE VOOR STRALINGSDOSIMETRIE

Report ## of the Netherlands Commission on Radiation Dosimetry

a. Develop a MU calculation program, either for manual calculation or using a computer program, based on the formalisms given in ESTRO Booklets 3 and 6 or NCS Report 12. See also Venselaar *et al.*

b. Include in the program the dependence on depth (using the percentage depth-dose, PDD, or tissue-phantom ratio, TPR), SSD, field size, and preferably taking the collimator exchange effect into account.

c. Take into account the dose variation with field size in case of the presence in the beam of a wedge or a blocking tray by using field size dependent correction factors.

d. **For more complex situations** involving tissue inhomogeneities, off-axis situations and MLC-shaped fields, **more sophisticated algorithms are required**. Several groups are currently in the process of developing these algorithms.

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Verification of monitor unit calculations for non-IMRT clinical radiotherapy: Report of AAPM Task Group 114

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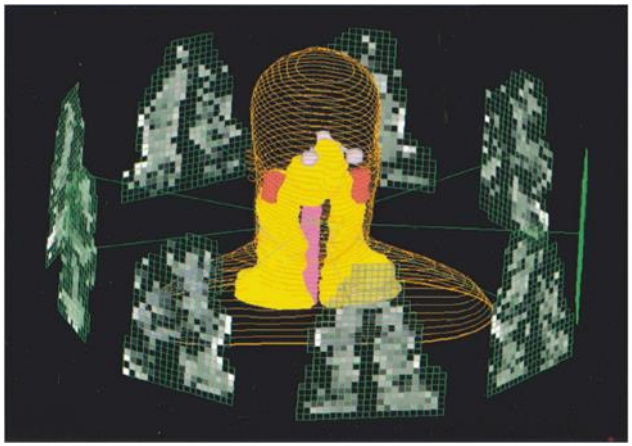
MU Verification Software

- The manual calculations are expected to be **less accurate** than those performed by the TPS because factors such as patient surface convexity, tissue heterogeneity or beam obliquity are not considered.
- Moreover, with the introduction of Intensity Modulation Radiation Therapy (IMRT), an independent manual calculation of MU becomes difficult due to the complex relationship between the MU and the beam shape as well as the technique used to generate the intensity modulation.
- Currently, a variety of **new MU verification software packages** have been introduced in the market and are claimed to be capable of accurately calculating the monitor units even for IMRT.



Medical Physics
The International Journal of Medical Physics Research and Practice

SU-E-T-06: Comparison of Different Commercial MU Verification Software in Terms of Accuracy and Performance

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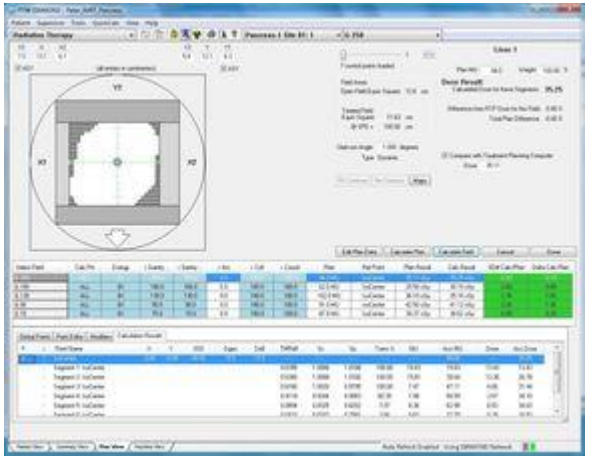
+ VIEW AFFILIATIONS

Med. Phys. **40**, 204 (2013); http://dx.doi.org/10.1118/1.4814440

IMSURE QA

RADCALC

MUCHECK



DIAMOND

Conclusion: ***the variation of the MU calculations between the examined software was found to be very similar indicating that their ability to be used as QA tools of the TPS calculations is equivalent.***

AAPM TG114:
Computer-based MU verification programs

- Most computer-based MU verification programs use an automated **table look-up method** similar to that outlined for manual calculation, e.g. in *ImSure* software:

$$MU = \frac{RxDose / IsoDoseLine}{TMRxOCRxWFxTFxSc(FS)xSP(FS')xCFxUFxInvSqCorr}$$

- Some more complex MU calculation programs use pencil beam or convolution/superposition algorithms based on the empirical data.

- **These computer programs require commissioning** at multiple points **and periodic QA** to verify the continued data integrity and calculation algorithm functionality.

AAPM TG114: Guidance for Action Levels

- Recommendations on establishing **action levels for agreement between primary calculations and verification**, and guidance in addressing discrepancies outside the action levels are provided.
- These recommendations shall not be interpreted as requirements.
- It is important that the **physicist knows the accuracy and limitations** of both the primary and the verification systems in order to set reasonable and achievable action levels and to better **interpret the causes of differences between the two results.**
- The level of agreement achievable depends on the details of the patient geometry, the primary and the verification calculation programs, and the clinical situation, in addition to whether corrections for tissue heterogeneities are used.
- It is therefore reasonable to have **different action levels for different situations.** Each institution must determine the proper action levels for that particular clinic.
- Results from planning system commissioning are useful in establishing these levels.

AAPM TG114: Guidance for Action Levels

- The action level guidelines given the Report are based primarily on the collective experience and expectations of the TG members, due to the limited literature on the expected level of agreement between primary and verification calculations for modern image-based 3D planning systems.

- **A base action level of 2% was postulated for simple field geometries**, consistent with the TG-53 criterion of 2% dose accuracy between calculations and measurements.

- From this starting point, additional range was added to account for the increased uncertainties of complex treatment geometries.

- The action level guidelines are divided into two tables, depending on whether or not tissue heterogeneities are taken into account in the primary calculation.

AAPM TG114: Guidance for Action Levels

TABLE II. Guidelines for action levels for disagreement between verification and primary calculations for homogeneous conditions.

	Similar calculation algorithms			Different calculation algorithms		
Primary calculation geometry	Same patient geometry (%)	Approx. patient geometry (%)	Uniform cube phantom approx. (%)	Same patient geometry (%)	Approx. patient geometry (%)	Uniform cube phantom approx. (%)
Minimal field shaping	2	2.5	3	2.5	3	3
Substantial field shaping and/or contour change	2.5	3	4	3	3.5	4
Wedged fields, off-axis	2	2.5	3	3.5	4	5

TABLE III. Guidelines for action levels for disagreement between verification and primary calculations with heterogeneity corrections.

	Similar calculation algorithms		Different calculation algorithms	
Primary calculation geometry	Same patient geometry (%)	Approx. patient geometry (%)	Same patient geometry (%)	Approx. patient geometry (%)
Large field	2	3	2.5	3.5
Wedged fields, off-axis	2	3	3.5	4.5
Small field and/or low-density heterogeneity	3	3.5	4	5

AAPM TG114: Guidance for Action Levels

- When a discrepancy is noted, the first action should be to verify that a **calculation error** has not been made.
- If this basic review fails to identify the cause of a discrepancy, the next step should be to confirm that an **appropriate comparison point** has been chosen.
- Differences in accounting for **patient geometry** between the primary and the verification calculations can also lead to large discrepancies between results (e.g. breast treatment).
- Density corrections are required for verification of calculations which include **heterogeneity effects**. The verification calculation must at least take into account the radiological thickness of tissues overlying the point of calculation.
- At a minimum, if a discrepancy is attributed to **differences in the calculation algorithms**, an assessment to confirm that the discrepancy is the correct order of **magnitude and direction** should be made.

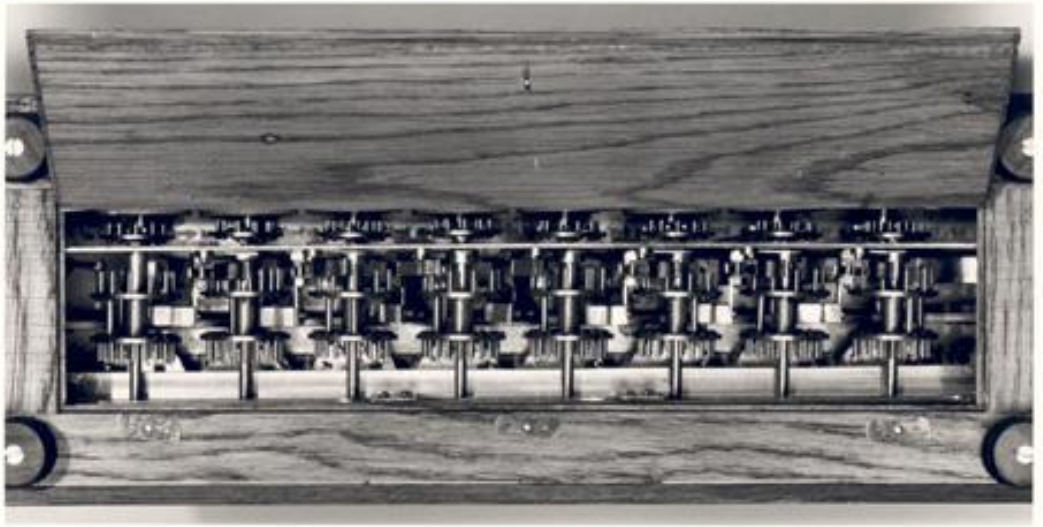
Conclusions-1

- «Manual» MU/time calculation can still have a role in modern RT characterised by sophisticated computation algorithms and 3D complex patient models.
- A measurement-based algorithm can have a good ***didactic value*** since it enables to decompose a calculation and consider the impact of each factor on an individual basis.
- It can be of value during **commissioning** of clinical model-based TPS's , as required by the IAEA TRS 430.

Conclusions-2

- It results an essential tool in the "**independent second check**" for MU's or time calculated to deliver the prescribed dose to a patient, where a key aspect is the independent nature of the calculation methodology and of the beam data and treatment parameters.

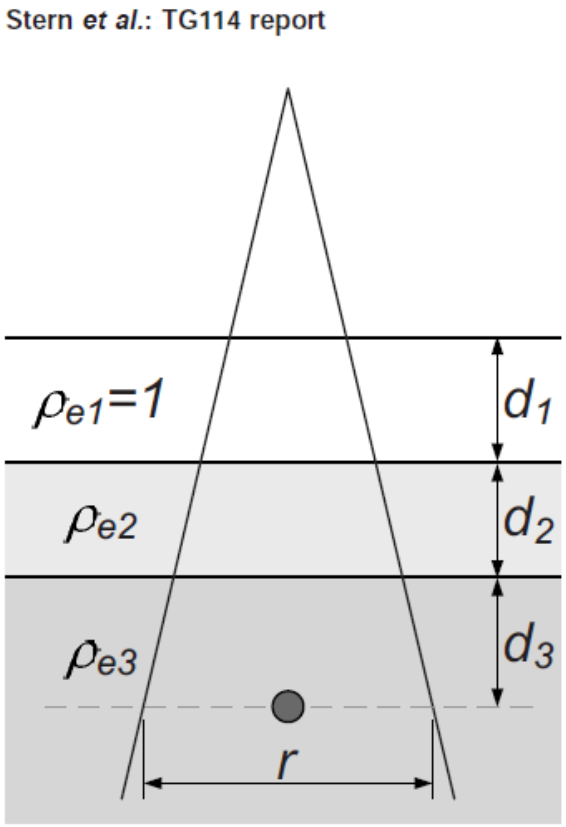
- However, its effectiveness in clinical practice relies on a **proper commissioning** in order to assess its accuracy and limitations, so to set **reasonable action levels** and to better interpret the causes of differences between the two calculations.



Manual Calculation Tools

Heterogeneity Corrections

- The heterogeneity correction is usually small in most clinical sites, such as breast or prostate, but can be substantial for chest treatments when a large volume of lung is being irradiated or when the tumor is surrounded by lung tissue.
- Typically, heterogeneity corrections will improve the dose accuracy compared to a homogeneous dose calculation.
- For a heterogeneous dose calculation, the most important parameter is the radiological depth along the ray-line to the point of calculation.
- While the radiological depth is typically the largest component for this correction, in low-density regions, such as the lung, electronic disequilibrium effects due to the lateral extent of the field and rebuild-up can also be significant



$$CF = \left(\frac{\text{dose in heterogeneous medium}}{\text{dose at same point in homogeneous medium}} \right)$$