



# Quality control of treatment planning systems for teletherapy

## RECOMMENDATIONS No 7

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# Introduction

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With the introduction of CT based computerised treatment planning in radio-oncology the treatment planning system (TPS) has become a key element in the radiotherapy process. Regarding patient safety and success of therapy, its accurate and stable functioning is an issue of highest importance. For these reasons quality assurance (QA) procedures have to be implemented for the commissioning phase and for the clinical routine running of a TPS.

Being a hardware and software system, each TPS may incorporate errors [\[14\]](#) from any of these different kinds:

- Software implementation errors may result in a system behaviour which differs from system specifications.
- Inaccuracies in algorithms and models could produce dose results not accurate enough to be used in clinical routine.
- Errors could result from inaccurate or wrong model parameters being applied by the operator [1](#).
- Errors could result from technical deficiencies of computer peripherals (printers, plotters, etc.).
- Intentional or unintentional changes in data or software files could produce erroneous results.
- Errors of different kinds could be introduced in the system during the software upgrade process.

This recommendation is the counterpart of the issue of the SSRMP "Physical and Dosimetric Checks in Teletherapy" [\[27\]](#). Its purposes are defined in the same way:

- to provide help to the medical physicist for the implementation of quality assurance procedures for TPS for external therapy with photons and electrons.
- to be used during evaluation and commissioning of a TPS, in case of implementation of new beam data or new software releases and also during routine clinical use.
- to create an unity of doctrine in QA of TPS in Switzerland
- to establish a base document for the public health authority.

It is the medical physicist's responsibility to implement the QA procedures described in this document

Chapter 1 describes QA Procedures (QAP) for commissioning a TPS for both photons and electrons beams, chapter 2 and 3 deal with QA aspects after implementation of new software releases and new beam data respectively and chapter 4 lists QA recommendations for routine use of a TPS. After a bibliography of related literature, the appendix contains a summary of tolerances and frequencies of tests.

Future publications of QA guidelines by other national or international authorities, may necessitate a revision of this document.

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# Chapter 1

## Commissioning

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Commissioning of a TPS by a qualified medical physicist is necessary before the system is used for clinical purposes. Commissioning has to validate the proper functioning of the system according to the vendor's specifications and to clinical requirements. The results can be used to establish standards of acceptance for the demonstration of the correct working of the TPS in regular QA-checks. Calculations for commissioning test cases shall be compared against measurements done at the same time as those used to characterise the treatment unit model<sup>2</sup>.

### 1.1. Prerequisites of Commissioning

Prior to the commissioning process, the following points and suggestions should be considered.

#### 1.1.1. Vendor<sup>3</sup> Tasks

##### a) Generalities

- The IEC document [\[13\]](#) specifies the following vendor tasks :
  - The vendors shall fulfil the conditions described in the IEC document concerning the safety of radiotherapy TPS.
  - Coherence of the units
    - All distances and linear dimension units shall be in centimetres.
    - All values of radiation (printed or displayed) shall include their units.
    - Units of radiation should conform to the SI convention.
  - Password protection, or the use of a key, shall be employed to ensure that only authorised persons perform treatment planning.
  - All data entered by the operator or acquired from a device or network shall be compared against fixed limits and not accepted if outside of these limits. Other consistency checks on data should also be appropriate to the expected nature of the data.
- The vendor should provide high quality training for the operators. For sophisticated 3D systems, this training should include not only teaching the operators what the effect of a particular operation inside the software will be, but also concentrate on the strategies for planning that are useful, and on various issues that only the experienced operator may come in contact with [\[34\]](#).
- A total protection against unauthorised access by the network is difficult to implement. The vendors shall take steps to ensure this point. They should inform the system administrator (SA, [see 1.1.2.](#)) about the method to be used as a precaution.
- The vendor should make the data of the beam library accessible. He/She should allow the SA to enter, inspect and modify all relevant data.
- The vendor shall provide a set of patient's files and beam data for demonstration purposes. The beam data can be taken from the report [\[1\]](#) of the "Task Group #23 of Radiation Therapy

Committee".

- The vendor should provide sufficient software tools to enable the operator (and SA) to check the accuracy of the data introduced in the beam library (e.g. plots/printed tables for profiles, PDD, TMR).
- The vendor should provide a checksum utility to perform tests on the beam data library and executable files.
- In case of new releases, the vendor should provide the possibility to reuse the files of previously calculated cases. The archiving and reading back of patient files shall be possible. The re-calculation of such cases shall be and correct.

## **b) General requirements for planning [13]**

- Planning shall not be possible using an incomplete treatment unit<sup>4</sup> or patient anatomy model unless the operator overrides a cautionary message which states that the model is incomplete.
- It shall not be possible to specify beam limiting devices or beam modifiers other than those allowed at the selected treatment unit model.
- It shall not be possible to specify customised blocking devices and customised beam modifiers as being in any position relative to the beam source other than those allowed at the selected treatment unit model.
- It shall not be possible to specify a beam size or position which is not within the range of the beam limiting device or applicator at the selected treatment unit model, or larger than the maximum size for a particular beam modifier (such as a wedge).

## **c) Documentation**

- Extensive documentation on how the TPS software works should be available, including a description of the overall design, the theory of operation, the limitations, and detailed information on what happens as each step of the planning process is performed [34]. The vendor should supply descriptions of the calculation and geometry algorithms used in their systems (see next section for details). The understanding of the algorithms allows the operator to appreciate the limitations imposed by the physical models and to design simple checks to ensure the proper functioning of the system in clinical routine (e.g. hand calculation of monitor units).
- The vendors shall provide information on the hardware and software QA program which is used to design, develop, test, document, and release the software. A detailed description is not necessary, but the vendor should supply it on request [34].
- The vendor should release detailed descriptions of the datafile formats and contents which has been used for data import and export, along with examples of correct implementation of this data transfer mechanism [34]. Whenever possible, generally accepted protocols (ACR/NEMA [2], DICOM3 [7]) should be used.

## **d) Algorithms**

- All algorithms used for dose calculation shall be clarified in the technical description. This shall include a description of the factors taken into account by the algorithm, the mathematical equations which form the basis of the calculation, and the limits of all variables used in the equations. References to the literature shall be provided for published algorithms [13].
- Where a choice of algorithms is provided for a particular calculation, the instructions for use shall clearly identify the relative advantages and disadvantages of the different algorithms [13].
- For each algorithm used, the accompanying documentation shall state the accuracy of the algorithm relative to measured data for at least one set of pre-defined conditions [11],[13].

### **1.1.2. User<sup>5</sup> and System Administrator Tasks**

- The operator is responsible for learning how to use the TPS correctly. The user (institution) should also identify for each TPS unit one physicist to receive extra training, so that he/she can fulfil

his/her responsibility as the overall supervisor of how the planning system is used at that institute [34]. This person will be called system administrator (SA) for the rest of this document.

- The commissioning shall be performed or supervised by the SA.
- The SA shall have a full understanding of the operation of the hardware and software.
- The uncertainty associated with the measured data, data entry and output shall be noted. Known inaccuracies in the planning algorithm, through publications and/or vendor documentation, should be understood by the SA.
- A log-book shall be used for the commissioning of the software and used also, after commissioning period, during routine use. The aim of this log-book is to document all the events and changes concerning the TPS. The log-book is maintained by the SA.
- The SA shall have total control of the data of the beam library; it is recommended that he/she should be able to enter, inspect, and modify, by himself, all relevant data [11].
- It is not possible to cover all possible applications but checks should cover a representative set of those applications used in the institute.
- The SA should establish standard procedures for the use of the TPS. These procedures shall be carefully tested. The operators shall follow the standard procedures.

### **1.1.3. Preliminary Checks for Commissioning**

TPS hardware tests are required in order to ensure that both the computer and its peripherals are operating according to specifications. Most computers have an automatic system diagnostics that include tests for the processor, memory and disk operation. In addition the following items are to be tested:

- Plotter, printer, digitizer : connection and self-tests
- Display : the distortion of the video display shall be checked using a grid displayed on screen
- Presence of a checksum utility to be performed on the executable files and beam data files. This checksum utility could be very helpful to track any abnormal change in important files.

## **1.2. Checks for Commissioning**

### **1.2.1. Non-Dosimetric and Non-Geometric Checks**

Allowed ranges and directions of linear and rotational scales for technical treatment machine parameters should correspond to the actual situation for individual treatment units. If not, this shall be taken into account and a specific procedure shall be defined concerning the transfer of set-up information from treatment plans to the corresponding therapy unit.

The data transfer from TPS to the simulator and/or the accelerator shall be tested.

All the parameters describing beams shall be checked for completeness, availability and consistency on screen or paper (e.g. isodose chart).

All patient identification details shall be checked for completeness, availability, consistency and uniqueness. All reproductions on hard copies or printed pages shall be complete with regard to date, time, plan identification number and version number of the calculation.

An independent check shall be undertaken to ensure that the basic input data has been entered correctly. This can be done by printing out tables of entered beam characterisation parameters, e.g. values of TAR, TPR, depth doses, output factors etc., if the algorithm is based on tabulated data. The aim is to ensure correctness of data input.

### **1.2.2. Geometry**

The accuracy and completeness of the 3D-models of the patient and the beams have to be checked (the

required tolerance regarding to distances is 0.1 cm). Every TPS has its own functions and these have to be tested according to their use. The following list shall be completed according to the TPS particularities:

## **a) Geometry**

- The transfer of patient data from CT to TPS shall be geometrically correct.
- The transfer of images (CT, MRI, PET, ...) shall preserve the pixel values and magnification and linearity of the image.
- The (manual or automatic) definition of volumes of interest (geometrically simple objects) shall correspond to the real dimension and position and shall not be distorted in cardinal and oblique sections.
- The outline of a shaped beam cut by a cardinal or oblique section shall be correct. It could be tested by comparison with a light field on the treatment machine.
- Bolus, although often considered on a beam-by-beam basis, is sometimes treated more as a part of the patient anatomy, at least in how it interacts with dose calculation algorithms. The following tests shall be applied [\[34\]](#):
  - Verification that the bolus is correctly added into the calculation algorithm,
  - Verification that the hardcopy output and other display of geometric information (e.g., the SSD displayed when bolus is used on the surface of the patient) agree with the stated method,
  - Verification of the effect on monitor unit calculations,
  - Verification that density of the bolus is correct.

## **b) 3D options**

- Once a number of outlines are defined, the multiple outlines defined on slices (CT slices) shall then often meshed into a 3D surface description if they are to be used for a 3D model of the patient (this can also apply to a 3D volumetric representation). The algorithm used to create this 3D surface can be quite complex [\[34\]](#). Therefore, the QA program for this feature shall consist of :
  - A straightforward testing of a set of extreme cases which could be mishandled (square outline next to a three sided outline, use of sharply pointed outlines, outlines with one or two points only, unclosed outlines, outlines missing on adjacent slices, etc.),
  - A more rigorous testing of a subset of manually entered cases (sphere, cylinder, cube or pyramid) where the exact formation of the surface mesh is easy to estimate and can be compared to the one calculated by the TPS,
  - A testing of interpolated outlines.
- If it is possible to extract or "cut" an outline from that 3D description. This feature requires additional testing [\[34\]](#):
  - The general limitations to the implementation (e.g. the algorithm can only cut axial outlines),
  - The results with complicated structure issuing in multiple independent outlines in a particular slice or cut,
  - The shape of simple objects (sphere, cylinder, cube, ...) cut in different ways (cardinal or not)

Note : Not all of these options are available in all TPS.

## **c) Beam's-eye-view**

- The relative size, position and shape of known objects in beam's-eye- and observer's-eye-view shall be correct.



- The beam's-eye-view shaping and size of the beam (blocks, multileaf collimator) shall correspond to the reality.
- The Digitally Reconstructed Radiograph (DRR) shall be compared to the original films from the simulation procedure (with phantoms where measurements of distances can be performed).

## **d) Dose-Volume Histogram**

- The total volume on DVHs (if they exist) shall be checked and compared with other methods of computation of the size of volumes of interest (VOIs).
- Consistency checks with the isodoses charts shall be applied.

## **1.2.3. Devices (peripherals)**

### **a) Printing/Plotting Devices**

On each treatment plan printed or plotted, two scales in both directions (horizontal and vertical) with centimetre marks at least over 10 centimetres are required. However all the marks shall be verified with a ruler, they must be at the right place (i.e. no distortion and no displacement).

- Tolerance: 0.1cm

### **b) Digitizer**

The vertical and horizontal scales are to be tested along 10 cm showing an agreement better than 0.1cm.

- Tolerance: 0.1cm

### **c) Film scanner**

An object on a film with particular dimensions is scanned. The size displayed by the TPS is then compared to the real one.

- Tolerance: 0.1cm

### **d) Computed Tomography (CT)**

General QAP of CT are not the subject of these recommendations, additional information on CT QAP can be found in the literature [\[19\],\[20\],\[25\],\[32\]](#). Issues covered here are the transfer of CT data to the TPS and the use of CT data by dose calculation algorithms.

- To check CT image transfer a QAP has to be set up consisting of several CT examinations of an object of known shape and dimension. The QAP has to check the correctness of the transfer of the complete 3D information (position and magnification) from CT to TPS for all relevant patient set-ups (head-first, feet-first, prone, supine, left, right) and CT parameters (scan and reconstruction diameters, tube angle for topograms - scout views -, etc.).

Geometrical distortions shall be less than 0.1 cm

- Hounsfield numbers of the CT images normally are used by the TPS to extract radiation absorption properties of the tissues at therapeutic beam qualities. QAPs therefore have to be set up to ensure the correct transfer and use of the Hounsfield numbers. The details of these QAPs depend on TPS algorithms. Normally CT examinations have to be made of a phantom containing tissue like material of known chemical compositions and densities. TPS extracted parameters (physical or electron densities, absorption coefficients, scattering or stopping powers, ...) can then

be checked directly. Knowing the dose calculation algorithms of the TPS, the impact of inaccuracies in extracted parameters on dose calculation results can be estimated.

To give an idea of the expected accuracy :

- Electronic density relative to water ( $\leq 1.5$ ): Tolerance is 0.05
- Electronic density relative to water ( $> 1.5$ ): Tolerance is 0.1

## **e) Block cutting device**

Information to produce blocks (and compensators) have to be transferred from the TPS to the block cutting device. The proper functioning of data transfer shall be checked by examining blocks of clinically relevant shapes.

## **f) Archiving and reading back of patient data**

If the TPS includes an archiving system, the correctness of treatment plan parameters and patient data read back from the archive has to be checked (correct treatment plans irrespective of TPS development and addition of therapy units etc.). The scale of outlines, the shape of the beam, the date (for a Cobalt-60 unit) are to be checked.

## **1.2.4. Dosimetric Measurements for TPS Validation**

### **a) General Considerations**

The dosimetric measurements for TPS validation have two goals; test the accuracy of point dose calculation and interpolation (or analytic computation) procedures. It is good practice to use for the acquisition of control data sets a better spatial resolution than those imposed by the TPS for the acquisition of the basic reference data. The same consideration should be made for the choice of the measuring depths.

Tolerance limits for the calculation of relative dose distribution in region of low dose gradient, are quoted as percentage of the central axis dose in a single field case or as percentage of the dose at the prescription point in a clinical case. In areas of high dose gradient (penumbra, build-up) the tolerance should also be specified in terms of displacement (shift of isodose in cm) of corresponding dose values. The level of acceptance stated in this report is based on the experience of different authors and reflects the precision actually achievable [8],[15],[11],[18],[22]. For each recommended measurement a particular tolerance is given. Deviations in some regions or under some circumstances in excess of the tolerance limits have to be judged in the light of their clinical relevance.

The part concerning the calculation of Monitor Units (MU) is reported in the section concerning the repeated checks. You should also refer to the [section 4.2.2](#) for the commissioning.

### **b) Photon dosimetry (Photon beam Tests)**

The following tests shall be made for each photon beam quality and each therapy unit available.

#### **(i) Beam characterisation data**

The aim of this test is to check the basic beam data which is used by the planning system to set up a beam model. Algorithms in commercially available planning systems are based either on tabulated beam data (A) or on analytical treatment unit models (B). Checking beam characterisation data for case (A) means

direct checking of the tabulated data by suitable means (graphs, tables, software tools). Errors are not expected and not accepted in these checks. In case (B), beam characterisation data is used to fit some more fundamental model parameters. Some deviations therefore may be expected when beam characterisation situations are recalculated and the calculated values are not necessarily identical to the characterisation data. The following table lists dose differences and isodose shift distances between calculated and measured results, which are considered to be acceptable.

Testing set		
The data used for beam characterisation (TMR, PDD, TAR, TPR, profiles, output factor and relative output factor) shall be checked by comparison with recalculation. The cases (A) and (B) have different tolerances. In the region of high dose gradient, the distance between isodose lines is more appropriate than % difference.		
Description	Difference in % of the maximum	Shift of isodoses [cm]
TMR, TAR, TPR or PDD on beam axis, profiles	A : no diff. B : 1	- B : 0.1
Description	% of the measured factor	
Dose per Monitor Unit <sup>6</sup> (for the reference field e.g. 10x10 cm <sup>2</sup> )	A : no diff. B : 0.5	
Relative output factor <sup>7</sup>	A : no diff. B : 1	

(ii) Open and wedged beams for fields not used for beam characterisation (field sizes of clinical relevance, either interpolated or outside characterisation range)

All these tests are to be performed for the proposed minimal set of fields (assuming that these fields were not used for beam characterisation).

Testing set		
Description	Difference in % of the maximum	Geometric differences [cm]
These tests shall be performed by means of calculation of point doses and/or dose distributions compared with measurements. Minimal set of field sizes: - 5x5, 10x10, 25x25, 40x40 (max. square field) - 5x10 5x25 5x40, 10x5, 25x5, 40x5		
● PDD on beam axis (except in the build-up region)	2	
● PDD in the build-up region		0.2
● The dose profiles (or isodoses) in main (X and Y) and diagonal directions and at 5, 10, 20 cm depth: ● high dose, low dose gradient region ● low dose, low dose gradient (i.e. <7% of the normalisation dose)	2	
● The dose profiles (or isodoses) in main (X and Y) and diagonal directions and at 5, 10, 20 cm depth: ● high dose gradient (>30%/cm) region ● the beam size defined by the 50%		0.2

isodose at the depth of reference for the field size <ul style="list-style-type: none"> <li>the penumbra defined by the 20%-80% dose level distance (5x5,10x10,25x25,40x40)</li> </ul> <ul style="list-style-type: none"> <li><u>note</u>: here 100% correspond to the dose at maximum at the depth of measurement</li> </ul>		
Depth dose at a point along the beam central axis for different SSDs clinically used (e.g. 80 and 120 cm) at different depths (e.g. 5, 10 and 20 cm) and square fields).	2	
<b>Description</b>	<b>Difference (% of the measured value)</b>	
Relative output factor	2	

(iii) Irregular, multileaf collimated, asymmetric and dynamically wedged fields

Although all these features may be present in one single field in clinical practice, separated tests should be performed for each of them.

Description of the testing set		
<b>Description</b> These tests shall be performed by means of calculation of point doses and/or dose distributions compared with measurements.	<b>Diff. in % of the maximum</b>	<b>Geometric differences [cm]</b>
<ul style="list-style-type: none"> <li>PDD in an open part of the field (not in a penumbra region)</li> </ul>	2	
<ul style="list-style-type: none"> <li>PDD in the build-up region</li> </ul>		0.2
<ul style="list-style-type: none"> <li>Dose profiles (in any direction) and at 5, 10, 20 cm depth:             <ul style="list-style-type: none"> <li>high dose, low dose gradient</li> <li>low dose, low dose gradient (i.e. &lt;7% of the normalisation dose)</li> </ul> </li> </ul>	3	
<ul style="list-style-type: none"> <li>Dose profiles (in any direction) and at 5, 10, 20 cm depth:             <ul style="list-style-type: none"> <li>high dose gradient (&gt;30%/cm)</li> </ul> </li> </ul>		0.3
<ul style="list-style-type: none"> <li>Dose behind large blocks (or multileaf collimator) (it measures the accuracy of calculated transmission)  <b>Note:</b> Doses under small blocks are difficult to calculate and to measure, the precision should be estimated for situations corresponding to clinical applications</li> </ul>	2	
<b>Description</b>	<b>Difference (% of the measured value)</b>	
Relative output factor	2	

(iv) Co - decay

The output of the reference field for different irradiation times shall be tested.

Testing set	
<b>Description</b> This test shall be performed by means of TPS calculations compared with hand calculations.	<b>max. difference [%]</b>
Output of reference field and for reference conditions (dose per unit of time)	0.5

(v) Inhomogeneity correction, surface irregularities and oblique incidence fields

The dose per monitor unit on the central ray in region of electronic equilibrium shall be tested. Some cases of inhomogeneities are proposed and described in the figure below. Of course, other situations of clinical relevance can also be verified. As the measurements can be difficult [\[28\]](#), it is a good practice to compared with situations found in the literature [\[24\]](#).

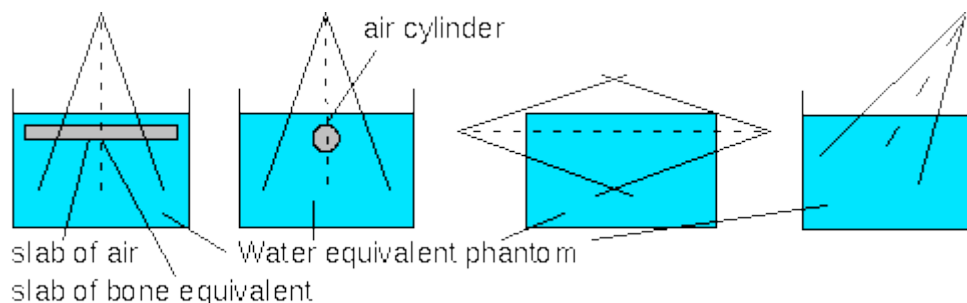


figure 1. Description of a proposed testing set

Description of the testing set	
<b>Description</b> These tests shall be performed by means of calculations compared to measurements.	<b>% of the measured factor</b>
Dose per monitor unit	3

(vi) Standard treatment plans (3D distributions, rotational irradiation, multiple beams)

Several anthropomorphic phantom tests can be used for a final complete test of the entire calculation algorithm. These test cases should be similar to treatment techniques used in the clinic, and of interest to the physicians and physicists involved. Some examples:

Description of the testing set	
<b>Description</b> These tests shall be performed by means of calculations compared to measurements.	<b>% of the normalisation dose</b>
At the point of reference (ICRU point as defined in ICRU Report 50 <a href="#">[12]</a> ) and anywhere in low dose gradient region	4



- mantle field,
- breast field: tangential field breast with lung,
- four-fields treatment (e.g. prostate),
- non-coplanar fields (e.g. head & neck)

### c) Electron dosimetry (Electron beam Tests)

For electrons, the dose gradient is steep along the central axis beyond the maximum and at beam edges. In order to avoid uncertainty in the position of the measurement high resolution detectors (diode detector, film, small ionisation chambers) and detectors which have a well defined effective points of measurement should be used (plan parallel ionisation chamber). In the conversion from depth ionisation (ionisation current) to depth dose the SSRMP protocol should be used.

The contents of the test shall include planar dose distributions in a number of planes: (a) a transverse plane containing the central axis of the beam, (b) a transverse plane a few centimetres off axis, (c) planes normal to the beam axis (beam's-eye-view planes) at several depths [33]. Normal plane isodoses verify the fluence distribution over the entire surface which in combination with the depth doses enables beam data verification over the whole volume.

As stated by many authors, the difference between measured and calculated dose could be relatively large (10%) [8],[9],[16] in the case of electron beams. The following tolerances should be regarded as ideal.

The following tests shall be made for each electron beam quality and each therapy unit available.

#### (i) Beam characterisation data

The aim of this test is to check the basic beam data which is used by the TPS to set up a beam model. Algorithms in commercially available planning systems are based either on tabulated beam data (A) or on analytical treatment unit models (B). Checking beam characterisation data for case (A) means direct checking of the tabulated data by suitable means (graphs, tables, software tools). Errors are not expected and not accepted in these checks. In case (B), beam characterisation data is used to fit some more fundamental model parameters. Some deviations therefore have to be expected when beam characterisation situations are recalculated and the calculated values are not necessarily identical to the input data.

Testing set		
Description	Difference in % of the maximum	Shift of isodoses [cm]
The data used for beam characterisation (PDD, profiles, output factors and relative output factors) shall be checked by comparison with recalculation. The cases (A) and (B) have different tolerances.		
PDD on beam axis or profiles	A : no diff. B : 1	- B : 0.1
Description	% of the measured factor	
Dose per Monitor Unit (for the reference field)	A : no diff. B : 0.5	
Relative output factor	A : no diff. B : 1	

(ii) Open fields not used for beam characterisation (field sizes of clinical relevance, either interpolated or outside the characterisation range)

All these tests shall be performed for a minimal set of field sizes. The field sizes to be included in this set are electron energy and accelerator specific. They could depend also on the calculation algorithm and shall be chosen in order to get an idea where possible weaknesses in the dose calculation would occur. For accelerators using electrons applicators, tests for all of them shall be performed.

Testing set		
<b>Description</b> These tests shall be based on a comparison of the computer calculated dose distributions with measured electron beam dose distribution. As a minimal test, dose profiles at two different depths should be measured to verify both underlying angular and fluence distribution of the electrons. It is recommended to consider profiles at the depth of the clinically relevant isodose outlines (say, 100%, 90%, 80%, 50%).	<b>Diff. in % of the maximum</b>	<b>shift of isodose [cm]</b>
PDD on beam axis within the therapeutic range (up to 80% dose level)	1	
PDD on beam axis beyond the therapeutic range	2	0.2
Practical range $R_p$		0.2
The dose profiles (or isodoses) in main directions (X and Y and diagonal) <ul style="list-style-type: none"> <li>● region of low dose gradient</li> </ul>	2	
The dose profiles (or isodoses) in main directions (X and Y and diagonal) <ul style="list-style-type: none"> <li>● region of high dose gradient</li> </ul>		0.2
<b>Description</b>	<b>% of the measured value</b>	
Relative output factor	2	
Dose per Monitor Unit (MU) at extended and reduced SSD encountered in the clinical situations.	2	

(iii) Irregular field shapes, asymmetric and oblique incidence

Situations that would be encountered in the clinical treatment planning should be evaluated: oblique incidence as in the irradiation of the neck or chest wall, irregular geometry as the irradiation of tumours in and behind the nose, fields with low melting point alloy blocking, dose distribution behind bolus.

Description of the testing set		
<b>Description</b> These tests should be based on a comparison of the computer calculated distribution with the	<b>Diff. in % of the maximum</b>	<b>Shift of isodoses [cm]</b>

experimentally obtained electron beam distribution.		
PDD on beam axis	2	0.2
The dose profiles (or isodoses) in main directions (X and Y) and at minimum two depths (see. Section c (ii)):  <ul style="list-style-type: none"> <li>● low dose gradient in high dose region</li> <li>● low dose gradient in low dose region(i.e. &lt;7% of the normalisation dose)</li> </ul>	3	
The dose profiles (or isodoses) in main directions (X and Y) and at minimum two depths (see. Section c (ii)):  <ul style="list-style-type: none"> <li>● high dose gradient (&gt;30%/cm)</li> </ul>		0.3
<b>Description</b>	<b>% of the measured factor</b>	
Relative output factor	3	

(iv) Inhomogeneity correction and irregularities of the surface

The dose per monitor unit below slab inhomogeneity of lung and bone density in point of electronic equilibrium shall be tested.

Description of the testing set	
<b>Description</b> These tests shall be performed by means of calculation compared to measurements.	<b>% of the measured factor</b>
Dose per monitor unit	5

(v) Standard treatment plans

Several anthropomorphic phantom tests can be used for a final complete test of the entire calculation algorithm. These test cases should be similar to treatment techniques used in the clinic, and of interest to the physicians and physicists involved (the nose, mandible, etc.). Particular attention shall be paid to the superposition and matching of field, (also with mixed photon and electron beams according to the TPS capabilities).

Description of the testing set	
<b>Description</b> These tests shall be performed by means of calculations compared to measurements.	<b>% of the normalisation dose</b>
At the point of reference (ICRU point as defined in ICRU Report 50 <a href="#">[12]</a> ) and anywhere in low dose gradient region  <ul style="list-style-type: none"> <li>● standard treatment cases</li> </ul>	5





# Chapter 2

## ***Tests after implementation of a new software release***

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### **2.1. Introduction**

After any software upgrade (installation of new releases or other modification) it is recommended to check the reliability, correctness and constancy of relevant parameters and of calculation algorithm. To be more efficient, a detailed study of the changes expected in the new version, and good documentation of all the expected changes shall be furnished by the vendor [\[34\]](#). New software releases and upgrades could be classified into two subsets: those not directly influencing the calculation algorithm and those where substantial variation on physical models implemented are introduced (e.g. change in irregular fields treatment, head scatter corrections...)

In this latter case, given the complexity of TPS program structures, the whole calculation algorithm has to be considered changed and as a consequence all involved treatment units shall be checked as already described for commissioning.

In the case of software releases related only to ancillary or to presentation utilities (like graphic tools added or modified), only a subset of the commissioning procedure check are mandatory before the use of the TPS in clinical routine. The following paragraphs are devoted to this case suggesting an explicit verification list.

### **2.2. Acceptance tests for a new software release not affecting physical algorithms**

#### **2.2.1. Non dosimetric checks**

All clinically used tools and programs, whether or not involved in the software upgrade, shall be checked: coarse checks, geometry and 3-D functionality, peripherals (see paragraphs [1.2.1](#) to [1.2.3](#)) need a control as for the commissioning (see paragraph [1.2](#)). It is also important to check for the completeness of the functions, as this may interfere with clinical routine.

#### **2.2.2. Dosimetric checks**

##### **a) photon beams**

- point dose at 3 depths ( $d_{\max}$ , 5 cm, 10 cm) for 5x5 cm<sup>2</sup>, 10x10 cm<sup>2</sup> and maximum open square fields, a rectangular 5x30 cm<sup>2</sup> field and an irregular field.
- profiles: for open beams (10x10 cm<sup>2</sup> and the maximum square field) at 10 cm depth; for wedged beams only the maximum field allowed at 10 cm depth.

## **b) electron beams**

- point dose for reference field, at 2 depths:  $d_{\max}$  and a point in the fall off region
- profiles in the same conditions

## **c) standard cases**

The dose distribution in at least the central beam section and one off-axis section shall be calculated. As recommended in section [1.1.3](#) (Preliminary check for commissioning), the vendor shall provide a standard and common set of patients and beam data with their output (dose distribution). This set shall be used to test the local implementation of the new software release allowing for inter-comparisons with other TPS. The results obtained from these test patients may be compared with the data obtained from the previous release by means of a systematic dose verification in predefined points and on isodoses distributions.

As an alternative method 3 real patients locally treated could be used to check the new version following the same procedure.

Isodoses, monitor units calculations and DVH results (when available) from the new release, compared with those obtained from the previous one shall match without any quantitative difference unless mentioned as corrections by the vendor.

### **2.2.3. Verification of all potentialities of the TPS**

The standard procedure defined in [1.1.2](#) shall be tested. This systematic method is intended to reduce necessary time to check all functions, menus and submenus and to avoid doubled checks.

If any task in any TPS related program does not work as expected, it shall be noted in the TPS log-book and precisely reported to the manufacturer customer support teams. The operators shall be informed and temporary alternative procedures set up.

# Chapter 3

## ***Tests after addition of a new therapy unit and/or implementation of new beam data***

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The implementation of a new therapy unit or new beam data concerns all steps of a TPS Quality Assurance Program; this implies that in order to exclude any systematic error in treatment planning, all the functions relied to this new treatment unit have to be carefully checked and evaluated before clinical use. From this statement, it follows that a complete set of tests of the software and dose calculation is required as for commissioning. Recommendations described in paragraph [1.2.1](#) and [1.2.4](#) apply here.

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# Chapter 4

## ***Repeated TPS checks***

### **4.1. Introduction**

The aim is to ensure the constancy of calculation, dose distribution and all outputs from the TPS. Errors can occur from 4 different parts of the whole process of treatment planning : (1) programs, (2) beam data, (3) peripheral devices or (4) operators. Regarding to QA, all these parts shall be periodically tested. The periodic tests shall be made by different operators of the TPS. The idea is that operators can have their own habits in the schedule of executions and consequently use different algorithms in the program and perhaps obtain divergent results. The results could be operator dependent, hence the reason to impose standard procedure for the use of TPS.

Repeated checks as formulated here are an important part of the QAP, but a continued vigilance on the part of the operator is also required. The idea is to recognise the more subtle problems or differences which may occur. Investigation may uncover important issues which shall be resolved [\[34\]](#).

"In vivo" dosimetry is an overall test of the TPS, this subject is left to the judgement of the physicist as it lies outside the scope of these guidelines.

### **4.2. Tests and frequencies**

In this section, the tests are to be performed as described for the commissioning ([section 1.2](#)). The frequency of the checks are abbreviated as follow:

<b>Frequenc y</b>	<b>Abbreviatio n</b>
monthly	m
quarterly	3m
yearly	y

#### **4.2.1. Peripherals**

You should report to the paragraph mentioned to see more details.

<b>Description of the testing set</b>		
<b>Description</b>	<b>Frequency</b>	<b>Tolerance</b>
Printing/Plotting device ( <a href="#">see section 1.2.3.a</a> )	m	0.1 [cm]
Digitizer ( <a href="#">see section 1.2.3.b</a> )	m	0.1 [cm]
Film scanner ( <a href="#">see section 1.2.3.c</a> )	m	0.1 [cm]

Computer Tomography ( <a href="#">see section 1.2.3.d</a> )	m	0.1 [cm]
<ul style="list-style-type: none"> <li>Geometry of particular object</li> </ul>		
Computer Tomography ( <a href="#">see section 1.2.3.d</a> )	y and at each revision of the CT	if $\rho_{e-} \leq 1.5$ then 0.05 if $\rho_{e-} > 1.5$ then 0.1
<ul style="list-style-type: none"> <li>Electronic density (<math>\rho_{e-}</math>) in function of CT#, (<math>\rho_{e-}</math>) compared to known densities relative to water (if accessible)</li> </ul>		
Block cutting device ( <a href="#">see section 1.2.3.e</a> )	y	no diff
Archiving and reading back of patient data ( <a href="#">see section 1.2.3.f</a> )	y	no diff

## 4.2.2. Monitor Units (MU)

A test concerning the calculation of MU shall be performed monthly on clinical cases. See also the reference [6] for more details. The verification of the monitor unit calculation for each patient is not treated in this document, as it is not a part of the TPS QA.

Description of the testing set	
<b>Description</b> These tests shall be performed by means of calculation of the TPS compared to previous calculation.	<b>Tolerance</b>
MU Photons beams	no diff.
MU Electrons beams	no diff.

## 4.2.3. Standard treatment plan

The tolerance given in paragraphs [1.2.4.b.vi](#) and [1.2.4.c.v](#) are relative to the measured dose at the point of normalisation in an anthropomorphic phantom. Here the tolerance (1%) concerns the reliability of the checks done during commissioning. At each point verified the divergence in dose should not exceed 1% of the dose at the point of normalisation.

Description of the testing set		
<b>Description</b> Standard patients/phantom (compare with previous tests, see section <a href="#">1.2.4.b.vi</a> and <a href="#">1.2.4.c.v</a> )	<b>Frequency</b>	<b>Tolerance</b>
<ul style="list-style-type: none"> <li>with the possibility of performing checksums on beam data and executable files</li> </ul>	y	1%
<ul style="list-style-type: none"> <li>without checksums</li> </ul>	3m	1%

#### 4.2.4. "Checksum"

The program cannot be modified by the operators therefore it should be verified that it has not been corrupted by any virus or wrong operations. The beam data can be modified (e.g. new measurement more precise). Such modification of the beam data shall be checked by the appropriate procedure as described below. When the beam data are supposed to be definitive, the integrity of the executable files or beam data shall be certified. If a virus corrupts programs or somebody makes a wrong operation on the system, a checksum utility program pointing on the executables, beam data and other important files can identify the problem [4]. It is the task of the vendor to implement it. This recommended test cannot be avoided if periodic tests are performed with standard clinical cases. Checks fulfilled on standard clinical cases only reveal problems without any explanation. On the other hand checksum tests can identify the problem and they can be executed automatically at each start of the TPS (boot procedure). A good practice is to ensure that the checksum is carried out after a registered modification of a parameter.

Description of the testing set		
Description	Frequency	Tolerance
Executable and beam data files: This concerns the scripts, binary executables and beam data files. The checksum program shall compare the current executables files with a situation of reference done at the commissioning of the TPS and periodically updated. It shall also highlight deleted and new executable files.	m	no diff

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# Appendix

The two following tables represent a summary of all the tests that should be performed for the commissioning, respectively repeated QA procedures.

## Commissioning checks (see [chapter 1](#))

Section	Description	Tolerance	Extension
<a href="#">1.2.1</a>	Non-Dosimetric and Non-Geometric Checks		
	<ul style="list-style-type: none"> <li>Definition of technical treatment machine parameters</li> </ul>	<ul style="list-style-type: none"> <li>no diff.</li> </ul>	<a href="#">(1)</a>
	<ul style="list-style-type: none"> <li>Data transfer between TPS and simulator/treatment machine</li> </ul>	<ul style="list-style-type: none"> <li>no diff.</li> </ul>	
	<ul style="list-style-type: none"> <li>Beam description</li> </ul>	<ul style="list-style-type: none"> <li>no diff.</li> </ul>	
	<ul style="list-style-type: none"> <li>Patient identification for each plan/version</li> </ul>	<ul style="list-style-type: none"> <li>no diff.</li> </ul>	
	<ul style="list-style-type: none"> <li>Introduction of data</li> </ul>	<ul style="list-style-type: none"> <li>no diff.</li> </ul>	<a href="#">(2)</a>
<a href="#">1.2.2a</a>	Geometry and 3D functionality - Geometry		
	<ul style="list-style-type: none"> <li>Transfer of patient data and images</li> </ul>	<ul style="list-style-type: none"> <li>no diff.</li> </ul>	
	<ul style="list-style-type: none"> <li>Definition of VOIs</li> </ul>	<ul style="list-style-type: none"> <li>0.1 cm</li> </ul>	
	<ul style="list-style-type: none"> <li>Outline of the shaped beam in a section</li> </ul>	<ul style="list-style-type: none"> <li>0.1 cm</li> </ul>	
	<ul style="list-style-type: none"> <li>Bolus (modification of patient's outline, associated with beams or not, density inside)</li> </ul>	<ul style="list-style-type: none"> <li>0.1 cm +verif.</li> </ul>	
<a href="#">1.2.2.b</a>	Geometry and 3D functionality - 3D options		
	<ul style="list-style-type: none"> <li>Mesh of 3D surfaces</li> </ul>		
	<ul style="list-style-type: none"> <li>extreme cases</li> </ul>	<ul style="list-style-type: none"> <li>verif.</li> </ul>	
	<ul style="list-style-type: none"> <li>geometrically simple objects</li> </ul>	<ul style="list-style-type: none"> <li>0.1 cm</li> </ul>	
	<ul style="list-style-type: none"> <li>interpolated outlines</li> </ul>	<ul style="list-style-type: none"> <li>verif.</li> </ul>	
	<ul style="list-style-type: none"> <li>Extracted outline</li> </ul>		
	<ul style="list-style-type: none"> <li>general limitations</li> </ul>	<ul style="list-style-type: none"> <li>verif.</li> </ul>	
	<ul style="list-style-type: none"> <li>multiplies outlines/section</li> </ul>	<ul style="list-style-type: none"> <li>verif.</li> </ul>	
	<ul style="list-style-type: none"> <li>shape of geometrically simple objects in section</li> </ul>	<ul style="list-style-type: none"> <li>0.1 cm</li> </ul>	
<a href="#">1.2.2.c</a>	Geometry and 3D functionality -Beam's-eye-view		

	● Shape and position of geometrically simple objects	● 0.1 cm	
	● Shape and position of the beam	● 0.1 cm	
	● DRR	● 0.1 cm	
<a href="#">1.2.2.d</a>	Geometry and 3D functionality -Dose Volume Histogram		
	● Total volume	● verif.	
	● Consistency checks with the isodoses charts	● verif.	
<a href="#">1.2.3 a</a>	Devices - Printing/Plotting device	0.1 cm	
<a href="#">1.2.3 b</a>	Devices - Digitizer	0.1 cm	
<a href="#">1.2.3 c</a>	Devices - Film Scanner	0.1 cm	
<a href="#">1.2.3 d</a>	Devices - CT		
	● CT shape of particular object	● 0.1 cm	
	● Electronic density ( $\rho_{e-}$ ) in function of CT#, ( $\rho_{e-}$ ) compared to known densities relative to water	● 0.05/0.1	<a href="#">(4)</a>
<a href="#">1.2.3 e</a>	Devices - Block cutting device	no diff.	
<a href="#">1.2.3 f</a>	Devices - Archiving and reading back of patient data	no diff	
<a href="#">1.2.4 b</a>	Photon dosimetry		
<a href="#">1.2.4 b (i)</a>	Beam characterisation data		<a href="#">(3)</a>
	● TMR,TAR,TPR,PDD on beam axis and profiles	● A : no diff. ● B : 1% or 0.1 cm	
	● Dose per Monitor Unit for the reference field	● A : no diff. ● B : 0.5%	
	● Relative output factor	● A : no diff. ● B : 1%	
<a href="#">1.2.4 b (ii)</a>	Open and wedged beams		<a href="#">(5)</a>
	● PDD on beam axis excepted build-up region	● 2%	
	● PDD in the build-up region	● 0.2 cm	
	● The dose profiles (5,10,20 cm depth)		
	● high dose, low dose gradient	● 2%	
	● low dose, low dose gradient	● 2%	
	● high dose gradient (>30%/cm)	● 0.2 cm	
	● the beam size defined by the 50%	● 0.2 cm	

	isodose		
	<ul style="list-style-type: none"> <li>the penumbra defined by the 20%-80% distance</li> </ul>	<ul style="list-style-type: none"> <li>0.2 cm</li> </ul>	
	<ul style="list-style-type: none"> <li>SSD correction</li> </ul>	<ul style="list-style-type: none"> <li>2%</li> </ul>	
	<ul style="list-style-type: none"> <li>Relative output factor</li> </ul>	<ul style="list-style-type: none"> <li>2%</li> </ul>	
<a href="#">1.2.4 b (iii)</a>	Irregular, MLC, multileaf collimated, asymmetric and dynamically wedged fields		
	<ul style="list-style-type: none"> <li>PDD in an open part of the field</li> </ul>	<ul style="list-style-type: none"> <li>2%</li> </ul>	
	<ul style="list-style-type: none"> <li>PDD in the build-up region</li> </ul>	<ul style="list-style-type: none"> <li>0.2 cm</li> </ul>	
	<ul style="list-style-type: none"> <li>The dose profiles (5,10,20 cm depth)</li> </ul>		
	<ul style="list-style-type: none"> <li>high dose, low dose gradient</li> </ul>	<ul style="list-style-type: none"> <li>3%</li> </ul>	
	<ul style="list-style-type: none"> <li>low dose, low dose gradient</li> </ul>	<ul style="list-style-type: none"> <li>3%</li> </ul>	
	<ul style="list-style-type: none"> <li>high dose gradient (&gt;30%/cm)</li> </ul>	<ul style="list-style-type: none"> <li>0.3cm</li> </ul>	
	<ul style="list-style-type: none"> <li>Dose behind large blocks</li> </ul>	<ul style="list-style-type: none"> <li>2%</li> </ul>	
	<ul style="list-style-type: none"> <li>Relative output factor</li> </ul>	<ul style="list-style-type: none"> <li>2%</li> </ul>	
<a href="#">1.2.4 b (iv)</a>	Co-decay, output of the reference field and conditions using different irradiation times	0.5%	
<a href="#">1.2.4 b (v)</a>	Inhomogeneity correction, surface irregularities and oblique incidence fields	3%	
<a href="#">1.2.4 b (vi)</a>	Standard treatment plans	4%	
<a href="#">1.2.4 c</a>	Electron dosimetry		
<a href="#">1.2.4 c (i)</a>	Beam characterisation data		<a href="#">(3)</a>
	<ul style="list-style-type: none"> <li>PDD on beam axis or profiles</li> </ul>	<ul style="list-style-type: none"> <li>A : no diff.</li> <li>B : 1% or 0.1cm</li> </ul>	
	<ul style="list-style-type: none"> <li>Dose per Monitor Unit for the reference field</li> </ul>	<ul style="list-style-type: none"> <li>A : no diff.</li> <li>B : 0.5%</li> </ul>	
	<ul style="list-style-type: none"> <li>Relative output factor</li> </ul>	<ul style="list-style-type: none"> <li>A : no diff.</li> <li>B : 1%</li> </ul>	
<a href="#">1.2.4 c (ii)</a>	Open fields not used for beam characterisation		
	<ul style="list-style-type: none"> <li>PDD on beam axis</li> </ul>		
	<ul style="list-style-type: none"> <li>within the therapeutic range</li> </ul>	<ul style="list-style-type: none"> <li>1%</li> </ul>	
	<ul style="list-style-type: none"> <li>beyond the therapeutic range</li> </ul>	<ul style="list-style-type: none"> <li>2% or 0.2 cm</li> </ul>	
	<ul style="list-style-type: none"> <li>another suitable parameter Rp</li> </ul>	<ul style="list-style-type: none"> <li>0.2cm</li> </ul>	
	<ul style="list-style-type: none"> <li>Profiles (depth of 100,90,80,50%)</li> </ul>		
	<ul style="list-style-type: none"> <li>low dose gradient</li> </ul>	<ul style="list-style-type: none"> <li>2%</li> </ul>	
	<ul style="list-style-type: none"> <li>high dose gradient</li> </ul>	<ul style="list-style-type: none"> <li>0.2cm</li> </ul>	
	<ul style="list-style-type: none"> <li>Beam size</li> </ul>	<ul style="list-style-type: none"> <li>0.2cm</li> </ul>	

	● Relative output factor	● 2%	
	● Dose per Monitor Unit at extended and reduced SSD	● 2%	
<a href="#">1.2.4.c (iii)</a>	Irregular shaped field, asymmetric, oblique incidence field		
	● PDD on beam axis		
	● low dose gradient	● 2%	
	● high dose gradient	● 0.2cm	
	● Profiles (depth of 100,90,80,50%)		
	● low dose gradient in high dose region	● 3%	
	● low dose gradient in low dose region	● 3%	
	● high dose gradient (>30%/cm)	● 0.3cm	
	● Beam size defined by the 50% isodose	● 0.3cm	
	● Relative output factor	● 3%	
<a href="#">1.2.4.c (iv)</a>	Inhomogeneity correction	5%	
<a href="#">1.2.4.c (v)</a>	Standard treatment plans	5%	

- (1) In case of disagreement, a specific procedure should be implemented
- (2) The check apply for any entered data
- (3) The check shall attest that the calculations based on the entered data are correct (see also [section 1.2.1](#))
- (4) The case of electronic densities is given as an example (see related sections)
- (5) Minimal set of field sizes : 5x5,10x10,25x25,40x40 (max. square field), 5x10, 5x25,5x40, 10x5, 25x5, 40x5

#### Repeated checks (see [chapter 4](#))

Section	Description	Frequenc y	Toleranc e	Extension
<a href="#">4.2.1</a>	Printing/Plotting device	m	0.1cm	
<a href="#">4.2.1</a>	Digitizer	m	0.1cm	
<a href="#">4.2.1</a>	Film scanner	m	0.1cm	
<a href="#">4.2.1</a>	Computer Tomography Geometry Electronic densities	m y	0.1cm 0.05/0.1	<a href="#">(1)</a>
<a href="#">4.2.1</a>	Block cutting device	y	no diff	<a href="#">(2)</a>
<a href="#">4.2.1</a>	Archiving and reading back of patient data see also section 1.2.3.f	y	no diff	
<a href="#">4.2.2</a>	Monitor Units (MU) Photon and electron beams	m	no diff.	
<a href="#">4.2.3</a>	Standard treatment plan	y	1%	

	With checksum Without checksum	3m	1%	
<a href="#">4.2.4</a>	Checksum	m	no diff	<a href="#">(3)</a>

- (1) This check shall also be executed at each revision of the CT.
- (2) This check consist in a verification of the data transfer.
- (3) This check should be included in the boot procedure of the TPS.

## Footnotes:

1. The operator designates the person which performs the routine planning on the TPS
  2. Treatment unit model: All physical and radiation parameters, for a particular piece of medical electrical equipment, that are needed to plan a course of radiotherapy, including dose calculation [\[13\]](#)
  3. Manufacturer could also be mentioned here, but vendor is preferred considering that he is the responsible for the correct functioning of the TPS.
  4. As example, a treatment unit model without the wedge data, or without data concerning some energies available on the actual treatment unit.
  5. The term *user* shall be understood in the meaning of institution (e.g. the hospital)
  6. Dose per Monitor Unit is a more general term than output factor ([see next note](#)).
  7. The British Journal of Radiology [\[3\]](#) defines the output factor as the absorbed dose rate at the point on the beam axis at the depth  $d_m$  for a given field size, normalised to unity for a specified standard field size. Relative output factor can be considered as a synonym for output factor.
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