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Commissioning of Radiotherapy Treatment Planning Systems: Testing for Typical External Beam Treatment Techniques

Report of the Coordinated Research Project (CRP) on Development of Procedures for Quality Assurance of Dosimetry Calculations in Radiotherapy

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COMMISSIONING OF RADIOTHERAPY TREATMENT PLANNING SYSTEMS:
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FOREWORD

Quality Assurance (QA) in the radiation therapy treatment planning process is essential to ensure accurate dose delivery to the patient and to minimize the possibility of accidental exposure. Computerized radiotherapy treatment planning systems (RTPSs) are now widely available in both industrialised and developing countries so, it is of special importance to support hospitals in the IAEA Member States in developing procedures for acceptance testing, commissioning and ongoing QA of their RTPSs. Responding to these needs, a group of experts developed a comprehensive report, the IAEA Technical Reports Series No 430 "Commissioning and quality assurance of computerized planning systems for radiation treatment of cancer", that provides the general framework and describes a large number of tests and procedures to be considered by the RTPS users.

To provide practical guidance for implementation of IAEA Technical Reports Series No. 430 in radiotherapy hospitals and particularly in those with limited resources, a coordinated research project (CRP E2.40.13) "Development of procedures for dosimetry calculation in radiotherapy" was established. The main goal of the project was to create a set of practical acceptance and commissioning tests for dosimetry calculations in radiotherapy, defined in a dedicated protocol. Two specific guidance publications that were developed in the framework of the Coordinated Research Project E2.40.13 are based on guidelines described in the IAEA Technical Report Series No. 430 and provide a step-by-step description for users at hospitals or cancer centres how to implement acceptance and commissioning procedures for their RTPSs. The first publication, "Specification and acceptance testing of radiotherapy treatment planning systems" IAEA-TECDOC-1540 uses the International Electrotechnical Commission (IEC) standard IEC 62083 as its basis and addresses the procedures for specification and acceptance testing of RTPSs to be used by both manufacturers and users at the hospitals.

Commissioning is one of the most important parts of the entire QA programme for both the RTPS and the planning process. Commissioning involves testing of system functions, documentation of the different capabilities and verification of the ability of the dose calculation algorithms to reproduce measured dose calculations. The current report is limited to treatment simulation tests for external high-energy photon beams that are performed prior to clinical use of RTPS. The report deals with the verification of the dose calculations through commissioning tests that cover typical treatment techniques only. This report also summarizes the results of a pilot study of the clinical commissioning recommendations that was performed by the participants of the Coordinated Research Project at their home institutions. The summary of the pilot study is available to medical physicists as an example of the implementation of the clinical commissioning procedures for RTPSs at their hospitals. Issues related to intensity modulated radiation therapy (IMRT) or other specialized techniques such as stereotactic radiosurgery are not addressed in this clinical commissioning report. While recognizing the specific scope of this report, this publication is useful to the purchasers of RTPSs in any country although they may have to perform tests beyond those described in this report to meet the needs of specialized techniques that have not been addressed here.

The IAEA wishes to express its gratitude to all authors and reviewers of this publication as listed at the end of the publication. The final editorial contribution of J. Van Dyk (Canada), G. Ibbott (United States of America), R. Schmidt (Germany), and J. Welleweerd (Netherlands) is gratefully acknowledged. The IAEA staff member responsible for the preparation of this publication was S. Vatnitsky from the Division of Human Health.

EDITORIAL NOTE

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CONTENTS

1. INTRODUCTION

1.1 Background

The IAEA Technical Reports Series No. 430 [1] provides a general framework and describes a large number of tests and procedures that should be considered by the users of RTPSs. However, the workload for the implementation of the recommendations from TRS-430 is enormous and requires far more personnel and instrumentation resources than is available in most facilities, particularly within smaller hospitals. These hospitals are not always able to perform complete characterization, algorithm validation and software testing of dose calculation algorithms used in RTPS. Dose computation verification is an important part of acceptance testing and commissioning procedures and it was recognized that there is an urgent need for a "practical" document describing a limited number of test cases, to be performed by a user in a hospital, which can be carried out in a reasonable amount of time. Such cases should help to avoid severe errors in the treatment planning process in a specific institution. Reduction of extensive published quality assurance (QA) recommendations to a QA program feasible in all hospitals can be achieved without loss of comprehensiveness by appropriate and optimal division of effort during acceptance testing between the RTPS vendor and hospital staff.

To provide practical guidance for implementation of IAEA TRS-430 in radiotherapy hospitals and particularly in those with limited resources, a coordinated research project (CRP E2.40.13) "Development of procedures for dosimetry calculation in radiotherapy" was established. The main goal of the project was to create a set of practical acceptance and commissioning tests for dosimetry calculations in radiotherapy, defined in a dedicated protocol. Two documents that were developed in the framework of the Coordinated Research Project E2.40.13 are based on guidelines described in IAEA TRS-430 and provide a step-by-step description for users at hospitals or cancer centres to implement acceptance and commissioning procedures for RTPSs.

The first document "Specification and acceptance testing of RTPS" [2] uses the IEC 62083 standard [3] as its basis and serves as a protocol to be used by both manufacturers and users for the specification and acceptance testing of RTPSs. Recommendations are provided in this report for specific tests to be performed at the manufacturing facility – type tests, and acceptance tests to be performed at the user's site – site tests. The vendor performs factory type tests using preloaded generic machine data and a preinstalled simple water phantom as a tool for testing dosimetry calculations. Following the recommendations of this IAEA report [2] the user will acquire the initial knowledge of the algorithms used in the system and verify their accuracy. This will be done together with the vendor during the demonstration of the RTPS performance for specific dosimetry calculation site tests. Using pre-installed beam data the vendor will show the user that similar results can be obtained on-site compared to the factory type tests results. After signing the acceptance document the user can move to the next step — commissioning — to implement a RTPS into clinical practice.

1.2 Scope and purpose of the current report

Commissioning is one of the most important parts of the entire QA programme for both the RTPS and the planning process. Commissioning involves testing of system functions, documentation of the different capabilities and verification of the ability of the dose calculation algorithms to reproduce measured dose calculations. The current document is limited to treatment simulation tests for external high-energy photon beams that are performed prior to clinical use of RTPS. The document deals with the verification of the dose calculations through commissioning tests that cover typical treatment techniques only. The

purpose of this testing is to confirm that the logistic chain starting from CT scanning, anatomic modelling, treatment planning and monitor unit/time (MU/time) calculation is operable for typical treatment techniques and leads to the desired results with sufficient accuracy. Following TRS-430, the tests of RTPS for typical treatment techniques described in the current document are defined as clinical commissioning tests.

During clinical commissioning tests the RTPS performance will be verified for typical conventional and conformal radiotherapy techniques, including the comparison of dose calculation results and measured values for an inhomogeneous anthropomorphic phantom, and the MU/time calculation checks. The procedures for clinical commissioning tests described in the document are based on the use of the CIRS phantom Model 002LFC that was selected following specific study described in Appendix C. The phantom is equipped with a set of certified electron density reference plugs that enable the verification of the CT number/electron density conversion procedure. The tests are structured so that at first, the dose distributions for single beams are considered, then standard multiple field techniques are used, and finally complex multi-field arrangements are applied. These checks are primarily aimed at confirming that the planned absolute doses delivered to the phantom agree with those as determined by measurement.

Issues related to intensity modulated radiation therapy or other specialized techniques are not addressed in the IAEA commissioning document. While recognizing the specific scope of the document, users of RTPSs will find the report useful. However, they may have to perform tests beyond those described in this report to meet the needs for the full range of clinical techniques.

The clinical commissioning procedures were tested through a pilot study by the participants of the IAEA CRP to ensure its recommendations are practical and can be performed in reasonable time. The pilot study includes a comparison of test results that are grouped into tabular form for different RTPS algorithms showing the observed range of deviations.

The results of RTPS commissioning can be used as the reference data for the ongoing periodic QA programme that covers checks of the integrity of hardware, software and data transfer. General procedures for Quality Control (QC) checks of RTPS are outlined in TRS 430 together with a reference to a test designed to perform that check, and a suggested frequency for the test. The current report also provides specific recommendations on the implementation of the results of clinical commissioning tests based on the use of the CIRS phantom Model 002LFC into the practice of periodic QA for RTPS used in external radiotherapy treatment planning. If another phantom was used for clinical commissioning tests, the recommended procedure can be adjusted to the features of this phantom. The QC of brachytherapy options and the re-commissioning after upgrades are outside of the scope of the current report.

1.3 Target audience

This report is aimed at all those individuals who participate in any aspect of RTPS commissioning and QA. In general, such individuals are medical physicists with specialized radiation oncology physics training and practical clinical experience. This report is especially relevant to those individuals who have a major responsibility for the RTPSs in their departments.

1.4 How to use this report

This report is intended as a guide for testing RTPS calculations for typical treatment techniques and provides step-by-step instructions for these tasks. The clinical commissioning

tests based on the use of the specified phantom should be completed according to the recommendations described in Section 2 and Appendix A. If the institution is using treatment techniques that are beyond the scope of this report, the set of clinical dose calculation-commissioning tests should be extended (see TRS-430 for details).

This protocol was tested through a pilot study by the participants of the IAEA Coordinated research project E2.40.13 and the test results are given in Appendix B for Co-60 and high-energy photon beams, including a table with estimated time needed to perform each test. The dose comparison results are given for different algorithms used in RTPSs to show the observed ranges of deviations.

The characteristics of phantoms that can be used during clinical commissioning are discussed in Appendix C.

The results of RTPS commissioning can be used as the reference data for the ongoing periodic QA programme and Appendix D provides specific recommendations on the implementation of the results of clinical commissioning tests into the practice of periodic QA for RTPS used in external radiotherapy treatment planning.

If the results of clinical commissioning tests are outside of the acceptance testing tolerances, the user should seek possible explanations for observed deviations. As a first step it is advised to perform beam specific calculation checks as it is indicated in Appendix E. In case of persisting deviations the user may consult the results of acceptance testing and contact the manufacturer for advice.

2. CLINICAL COMMISSIONING TESTS

2.1. Introduction

Complete characterisation, algorithm validation and software testing of a dose calculation algorithm used in RTPS are typically beyond the capabilities of most radiotherapy hospitals. Therefore, this report proposes, in combination with the IAEA Report [2], a limited set of tests, which will help an individual institution to prepare each photon dose calculation algorithm used in an RTPS for routine clinical use. The user must define the treatment capabilities which will be used, provide appropriate input data, perform beam fitting, acquire a measured data set for RTPS testing and analyse results, then finally to take responsibility for the verification of the dose calculation algorithm(s) which will be tested and then used clinically.

Using the IAEA Report [2] the user will acquire the initial knowledge of the algorithms used in the system and check their accuracy. The acceptance testing will be performed together with the vendor using pre-installed beam data in order to show the user that the same results can be obtained on-site compared to the factory type tests results.

After completion of acceptance testing a set of data measured following the manufacturer specifications has to be entered into the system for beam fitting. This beam fitting procedure must be validated by comparing the difference in measured and computed doses with tolerance values given in Table 8 of IAEA Report [2]. Test conditions must include the clinical range for open, irregular and wedged fields measured in a homogeneous water phantom. It is mandatory that beam fitting and validation be done for every algorithm that will be used clinically in the accepted RTPS.

The general description of the clinical commissioning procedures are given below, but the details and observed outcomes are presented in Appendixes A and B. The clinical commissioning test cases are designed according to the typical treatment planning process. A specific phantom should be used that can be applied for anatomical and dosimetric tests. The anatomical tests are related to the creation of an anatomical model for the patient's treatment planning. The dosimetric tests are designed to cover a wide range of treatment techniques applied in clinical practice. The details of the clinical commissioning tests are given in Appendix A. The dose comparison results are given in Appendix B for different algorithms used in RTPSs to show the observed ranges of deviations between measured and calculated doses.

2.2. Phantom for clinical commissioning tests

The features of phantoms suitable for clinical commissioning and QA of RTPS are suggested in TRS-430 [1]. Several categories should be considered:

- CT phantom
  - Check of CT number to relative electron density (RED) conversion
  - Beam geometry assessments
  - Digitally reconstructed radiograph (DRR) generation
  - Multiplanar reconstruction
- Slab geometry phantom
  - Water/tissue equivalent material
  - Possibility for film dosimetry
  - Check of corrections for inhomogeneous geometries
- Anthropomorphic phantom
  - Dosimetric measurements of typical or special treatment techniques

The clinical commissioning tests described in this report are based on the use of CIRS Thorax phantom Model 002LFC (see Figure 1). This phantom was chosen for clinical commissioning tests, as it is commercially available and complies with the most of the requirements listed above (see Appendix C for details). The use of other suitable phantoms for clinical commissioning testing is possible, but it will require adaptation of test geometries and the selection of the appropriate measurement points. The comparison of measured and calculated data in these phantoms may also influence the range of observed deviations. The application of several phantoms that can be used during clinical commissioning is discussed in Appendix C.

The CIRS Thorax phantom is elliptical in shape and represents an average human torso in proportion, density and two-dimensional structure. The phantom has a body made of plastic water, lung and bone sections with holes to hold interchangeable rod inserts. Tissue equivalent interchangeable rod inserts accommodate ionization chambers allowing point dose measurements in multiple planes within the phantom. The placement of holes allows verification in the most critical areas of the chest. One half of the phantom is divided into 12 sections, each 1 cm thick, to support either radiographic or radiochromic films. Handling, assembly and proper orientation of the phantom is provided with the use of an alignment base and holding device. The phantom is completed with a set of four certified electron density reference plugs (muscle, bone, lung and adipose equivalent tissue, see Table 1).

A cross mark is located on the top of the phantom, together with two additional lateral markers to ease the phantom set-up. For each test the phantom is aligned with the help of these markers. The clinical commissioning measurements are performed with ionization

chambers having a calibration traceable to a standards laboratory, placed into the corresponding holes in the phantom.

Table 1 Certified density reference materials as included in the manual for the CIRS phantom

	Density (g/cm^3)	***Electron density per cm^3 x 10^{23}***	***Electron density relative to water***
Lung	0.21	0.69	0.207
Bone	1.60	5.03	1.506
Muscle	1.06	3.48	1.042
Adipose	0.96	3.17	0.949
Plastic water (body)	1.04	3.35	1.003

Figure 1 Thorax Phantom (CIRS Model 002LFC).

2.3. Description of clinical commissioning test cases

Clinical commissioning test cases covering a wide range of typical clinical situations are structured in such a way that dose distributions are first checked for single beams, then standard multiple field techniques are used, and finally complex multi field arrangements are applied. These tests are primarily aimed at confirming that the planned dose will be in agreement with that determined by measurement. The dose calculations for each test are performed for each available algorithm based on the grid size normally used in clinical practice. A small volume ionization chamber is recommended for the measurements. The chamber is placed in the corresponding plug, and this plug is fully inserted into the selected hole of the phantom. All doses refer to absorbed dose to water regardless of the measurement region of the phantom (lung, bone). During the measurements all empty holes should be filled with supplied plugs of densities corresponding to the regions. The measurements will be performed for each single beam and for all beams for multi-field techniques. The comparison of measured and calculated dose values are to be reported in the corresponding tables of Appendix A. As a part of the clinical commissioning process the user should perform independent MU/time calculations for each single beam and compare the results with RTPS calculated MUs/time values.

2.3.1. Anatomical and input test cases

The anatomical and input test cases are designed so that they cover the process of creating a patient's model for treatment planning including the process of converting CT numbers to relative electron densities. Furthermore the graphic input/output hardware is also checked.

Case 1: Verification of digitized contour – non-dosimetric test

The purpose of this test is to verify the digitizing capabilities of the RTPS by comparing the digitized master copy of the CIRS 002LFC Front view transverse cross-section contour (provided by the manufacturer) with the printed copy produced by RTPS or with the corresponding contour of the CIRS phantom created from CT images. This test covers input tests 1 and 2 and anatomical test cases 1 to 4 from TRS-430.

Case 2: Verification/determination of CT numbers to relative electron density conversion in the RTPS

The purpose of this test is to determine and, if needed, to adjust the CT number to RED conversion curve used by the RTPS. The CIRS 002LFC phantom should be scanned in the available CT scanner using the local scanning protocol and following the set-up given in Figure A.2. This test covers the CT conversion test described in TRS-430 - section 9.2.9.

2.3.2. Dosimetric test cases

The purpose of each dosimetric test case is described below. As these cases are the subset of the cases summarized in TRS 430, the correspondence to the tests in TRS-430 is also given. Generally one dosimetric test case covers the check of several parameters. A detailed instruction for performing the testing and evaluating the results is given in Appendix A. A second CT scan of the phantom that will be used for dosimetric test calculations should be done with all plugs inserted into the corresponding holes (Figure A.3).

Case 1: Testing for reference condition based on CT data

The purpose of this test is to verify the calculation for the reference field, based on relative electron densities converted from CT data. A 10 cm x 10 cm field with a gantry angle of 0° and collimator angle of 0° is used. This test corresponds to photon test 1 and MU test 1 in TRS 430.

Case 2: Oblique incidence, lack of scattering and tangential fields

The purpose of this test is to verify calculations in case of lack of scattering for the tangential field. A 15 cm x 10 cm field with a wedge and a gantry angle of 90° and collimator angle depending on the wedge orientation is used. This test corresponds to photon tests 7, 10 and MU test 2 in TRS 430.

Case 3: Significant blocking of the field corners

The purpose of this test is to verify the calculation for the blocked field: a 14 cm x 14 cm field with a collimator angle of 45° is blocked to a 10 cm x 10 cm field with standard blocks or

with the multileaf collimator (MLC). This test corresponds to photon tests 1, 3 and MU test 4 in TRS 430.

Case 4: Four field box

This technique is used in many hospitals and the purpose of this test is to verify the calculation of the dose delivered with separate beams and the total dose from four fields. This test corresponds to overall clinical test 1 in TRS-430.

Case 5: Automatic expansion and customized blocking

The purpose of this test is to verify the auto-aperture function of the RTPS and customized blocking as well as the calculations with lung inhomogeneity. A cylinder of 8 cm diameter and 8 cm length centered in point #2 should be expanded with a margin of 1 cm in all directions using the expansion tools available. An MLC or block to conform to expanded volume should be applied. This test combines test conditions related to beam test 8, photon test 13, MU test 6, and clinical test 4 as described in TRS-430.

Case 6: Oblique incidence with irregular field and blocking the centre of the field

The purpose of this test is to verify the calculations for irregular fields with the blocking of the centre of the field. A 20 cm x 10 cm field with gantry angle of 45° is used. An L-shaped field should be created by blocking off a 6 cm x 12 cm portion of the field using a custom block or MLC. This test corresponds to MU test 4 as described in TRS-430.

Case 7: Three fields, two wedge-paired, asymmetric collimation

The purpose of this test is to verify the calculations with wedge-paired fields and asymmetric collimation (if asymmetric collimators are not available, half-beam block may be used). This test corresponds to MU test 3 and overall clinical test 3 a described in TRS-430.

Case 8: Non coplanar beams and test of couch rotation and collimator rotation.

The purpose of this test is to verify the calculations with the couch and collimator rotations. Three fields with different gantry angles and collimator rotations are used.

This test corresponds to beam tests 6, 12 and overall clinical test 6 in TRS-430.

APPENDIX A
CLINICAL TEST CASES RECOMMENDED DURING COMMISSIONING

The clinical commissioning test cases are modeled to follow the procedures of the treatment planning process. The anatomical tests are related to the creation of an anatomical model of the patient for the following patient's treatment planning. The dosimetric tests are designed to cover a range of typical treatment techniques applied in the clinical practice. The CIRS 002LFC phantom is used to demonstrate the procedure. It was mentioned that the user can apply any phantom that is compliant to the requirements of IAEA Technical Reports Series No. 430 [1]: however, the tests conditions and selection of measurement points should be adjusted to the geometry of the selected phantom, see Appendix C. The set-up of each test is described below. A set of instructions for performing each test is also included. If necessary, additional hints for performing the set-up and the measurements are given. The calculations are performed for each available algorithm. The grid size used in clinical practice shall be employed.

For the evaluation of the measured (D_{meas}) and RTPS calculated (D_{cal}) values the criteria that were specified in TRS-430 are employed. However, due to the limited number of available positions for dose measurements in the CIRS phantom, dose differences are normalized to the dose measured at the reference point for each test case.

The following equation should to be used:

$$\text{Error } [\%] = 100*(D_{cal}-D_{meas})/D_{meas,ref} \quad \text{(A.1)}$$

where $D_{meas,\ ref}$ is the dose value measured at the reference point. This reference point is specified for each test case. For multiple beam combination the difference between measured and calculated dose values for selected beam should be related to the dose measured at the reference point for the corresponded beam. For example, the difference between measured and calculated dose values for anterior beam should be related to the dose measured at the reference point for the anterior beam. The agreement criteria for each case are given in corresponding tables of this Appendix.

A.1 Anatomical and input test cases

Case 1: Verification of digitized contour – non-dosimetric test

The purpose of this test is to verify the contouring capabilities of the RTPS. Two comparisons should be done:

- Digitize the master copy of the CIRS 002LFC Front view transverse cross-section contour using the available digitizer and compare the digitized contour with the master copy.
- Create contours of the CIRS 002LFC phantom from CT images using appropriate image contrast "level and window" and compare the master copy of the CIRS 002LFC Front view transverse cross-section contour with the contour produced from the CT image.
- Do this contouring manually and automatically, if possible.

Compare distances A (AP diameter), B (LL diameter), C (RL diameter of hole #10), D (height of lung cross-section through the centres of holes #6 & #7), and E (width of lung cross-section at the level of the centre of hole #5), as indicated in figure A.1. The results of the comparison should be written into Table A.1. The deviation should be about 1-2 mm depending on the windowing used in the image for contouring.

Table A.1. Comparison of contour dimensions.

Type of the contour	**Measured distances**				
	A	**B**	**C**	**D**	**E**
Master copy					
Digitized					
CT image					

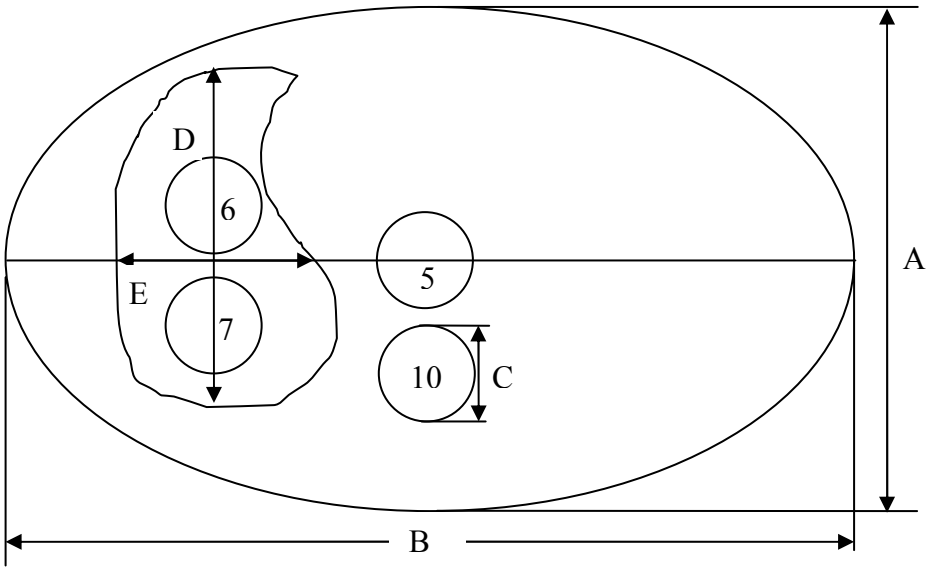


Figure A.1. Specification of distances used for comparison.

Case 2: Verification/determination of CT numbers to relative electron density conversion used by RTPS

The purpose of this test is to determine and, if needed to adjust the CT numbers to RED conversion curve stored in the RTPS. The CIRS 002LFC phantom should be scanned in the available CT scanner (Fig. A.2) with the following parameters: *HEAD FIRST SUPINE* (considering as *HEAD* the phantom film section), use the kV, Field of View, CT image reconstruction kernel, slice thickness and spacing as usually applied in the department for a typical thoracic scanning protocol. The labeling of holes and recommended arrangement of the certified electron density reference plugs for the CT scan is given in Figure A.3.

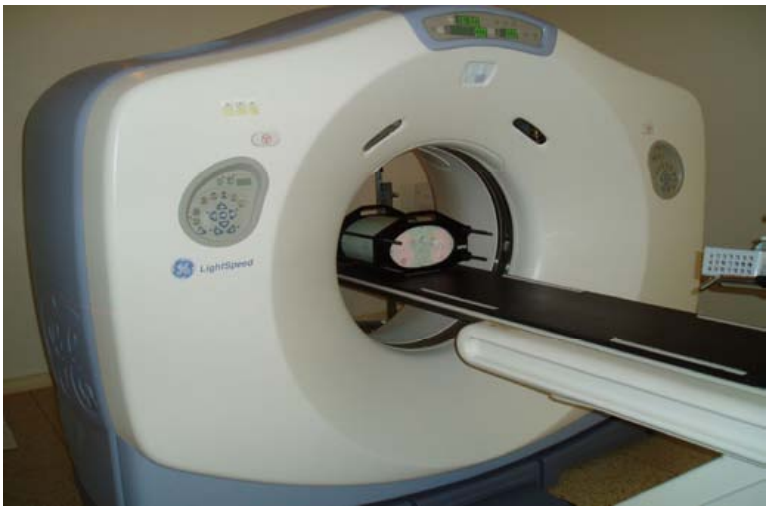


Figure A.2. Set-up of CIRS 002LFC phantom during CT scanning.

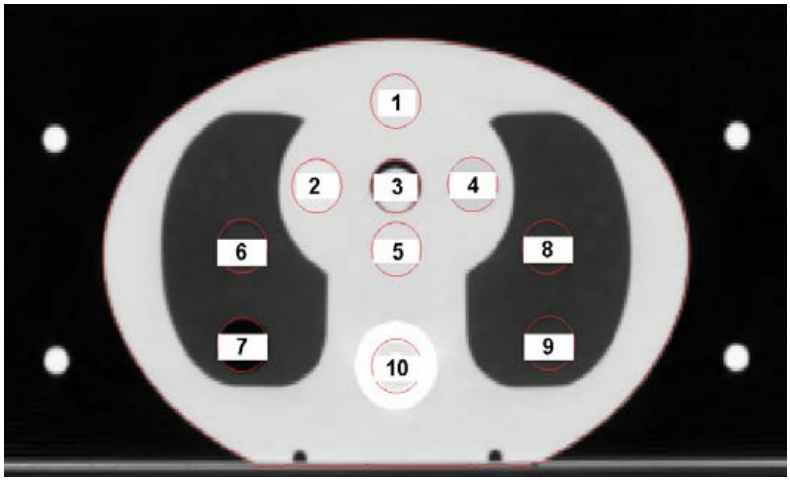


Figure A.3. Labelling of holes and the recommended arrangement of the certified electron density reference plugs for the CT scan: Plug 1-water equivalent, plug 2- muscle substitute, plug 3 - syringe filled with water, plug 4 - adipose substitute, plug 5 - water equivalent, plug 6 - lung substitute, plug 7 - should be empty to represent air, plugs 8 & 9 - lung substitutes, plug 10- bone substitute.

For each selected inhomogeneity, water and air, the CT numbers should be averaged over a fixed area (the diameter of averaged region of interest should be close to 0.5 radius of the insert). The region of interest for which the CT numbers are averaged should not be close to the edge of the selected area. The averaged values should be compared to the CT numbers used in the CT numbers to RED conversion curve stored in the RTPS. Agreement within 0.02 is acceptable for REDs, i.e. CT numbers for a given object should not vary by more than +/- 20 CT numbers. If a significant change to CT numbers is observed and cannot be eliminated by recalibration of the CT scanner, new CT numbers to RED data need to be entered into the RTPS. If CT data are input using film, geometric checks for scaling and distortion are necessary. Distortion may arise from either the CT filming process or the digitization process. Produce a film of the test phantom, making sure that the image contrast (level and window) are as before. Input the film in the usual way (e.g., CCD camera or digital scanner). If film digitization is used for inhomogeneity corrections, bulk densities are usually assigned manually (listed in Table 1). If the RTPS automatically maps the digital matrix to densities, check that the densities are correct. As an example, Figure A.4 represents the CT numbers to RED conversion results based on the CT scans with the CIRS 002LFC phantom performed at different hospitals. It can be seen that the use of different CT scanners shows differences

especially in the region with densities above that for water. The magnitude of the error in calculated dose due to this difference may be approximately 2% for a 6 MV photon beam passing through a thickness of 5 cm of the material with the RED of 1.5 (800 CT numbers).

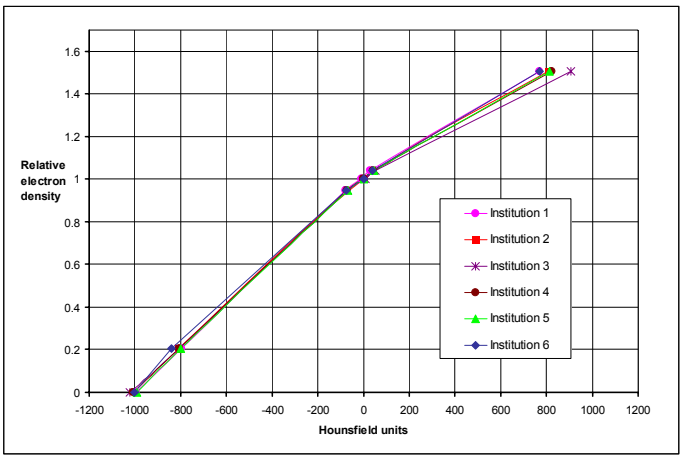


Figure A.4. CT calibration curves measured with CIRS phantom at different hospitals.

A.2. Dosimetric test cases

Case 1: Testing for reference conditions based on CT data

The purpose of this test is to verify the calculation for the reference field. A 10 cm x 10 cm field with a gantry angle of 0° and collimator angle of 0° is used to confirm the basic beam data. The measurement points are defined in the middle of holes 1, 3, 5, 9 and 10: see Figure A.3 and Table A.2.

Table A.2 Geometry for case 1

Case	Number of beams	Set-up	Reference point	Measurement point	Field Size [cm] L x W	Gantry angle	Collimator angle	Beam modifiers
1	1	SSD=SAD 100 cm (linac) 80 cm (Co-60)	3	1 3 5 9 10	10x10	0	0	none

Instructions for Case 1:

(1) Perform the treatment plan with the RTPS according to Table A.2 and document it.
(2) Calculate with RTPS MU/time needed to deliver 2 Gy to the reference point #3.
(3) Report the computed dose at points 1, 5, 9 and 10.
(4) Perform manual MU/time calculation and compare result with RTPS MU/time calculated values.
(5) Set up the phantom on the couch of the treatment machine with Head first supine towards gantry.
(6) Align the phantom with lasers intersection at the centre of hole #5.
(7) Set gantry angle to 0º.
(8) Set SSD=100 cm (80 cm for C0-60 or nominal SSD).
(9) Set collimator rotation to 0º.
(10) Set field size: Length (Y) = 10 cm Width (X) = 10 cm

(11) Insert ionisation chamber into the tissue plug and place it into hole #3.
(12) Irradiate the phantom with the RTPS calculated MU/time.
(13) Register the value of the measured doses. Repeat irradiation at least three times and determine average value.
(14) Change the position of the ionisation chamber to the next hole #5.
(15) Repeat steps 12 and 13 after changing the position of the chamber.
(16) Change the position of the ionisation chamber to the next hole #1.
(17) Repeat steps 12 and 13 after changing the position of the chamber.
(18) Insert ionisation chamber into the bone-equivalent plug and place it into hole #10.
(19) Repeat steps 12 and 13 after changing the position of the chamber.
(20) Insert ionisation chamber into the lung-equivalent plug and place it into hole #9.
(21) Repeat steps 12 and 13 after changing the position of the chamber.
(22) Fill in Table A.3 with calculated and measured data and compare results.

If several algorithms are available for dose calculations provide comparison of calculated and measured values for each algorithm used. An example of the calculated dose distribution is given in Figure A.5.

Table A.3. Comparison of measured and calculated data for case 1

Case	Location of measuring point	Calculated dose [Gy]	Measured dose [Gy]	Deviation [%]	Agreement criterion [%]
1	1				2
	3				2
	5				2
	9				4
	10				3

Figure A.5. A sample dose distribution in central plane for case 1.

Case 2: Oblique incidence, lack of scattering and tangential fields

The purpose of this test is to verify calculations in case of lack of scattering for the tangential field. A 15 cm x 10 cm field with a gantry angle of 90° and collimator angle depending on the wedge orientation is used. The isocentre and measurement point is defined in the middle of hole #1: see Figure A.3 and Table A.4.

Table A.4. Geometry for case 2

Case	Number of beams	Set-up	Reference point	Measurement point	Field Size [cm] L x W	Gantry angle	Collimator angle	Beam modifiers
2	1	SAD	1	1	15x10 RL	90	0 or based on wedge orientation	45 degree wedge or the largest wedge angle available

Instructions for Case 2:

(1) Perform the treatment plan with the RTPS according to Table A.4 and document it.
(2) Calculate with RTPS MU/time needed to deliver 2 Gy to the reference point #1.
(3) Perform manual MU/time calculation and compare the result with RTPS MU/time calculated values.
(4) Set up the phantom on the couch of the treatment machine with Head first supine towards gantry.
(5) Align the phantom with lasers intersecting at the centre of hole #5.
(6) Set gantry angle to 0º, lower the couch to SSD =97 cm. for a 100 cm SAD machine
(7) Set collimator rotation to 0º (collimator angle may be changed due to the conditions of wedge orientation).
(8) Set field size: Length (Y) = 15 cm; Width (X) = 10 cm (wedged direction)
(9) Move gantry to 90º.
(10) Insert the wedge, if needed rotate collimator.
(11) Insert ionisation chamber into the tissue plug and place it into hole #1.
(12) Irradiate the phantom with the RTPS calculated MU/time.
(13) Register the value of the measured dose. Repeat irradiation at least three times and determine average value.
(14) Fill in Table A.5 with calculated and measured data and compare results.

If several algorithms are available for dose calculations provide comparison of calculated and measured values for each algorithm used. An example of a calculated dose distribution is given in Figure A.6.

Table A.5. Comparison of measured and calculated data for case 2

Case	Location of measuring point	Calculated dose [Gy]	Measured dose [Gy]	Deviation [%]	Agreement criterion [%]
2	1				3

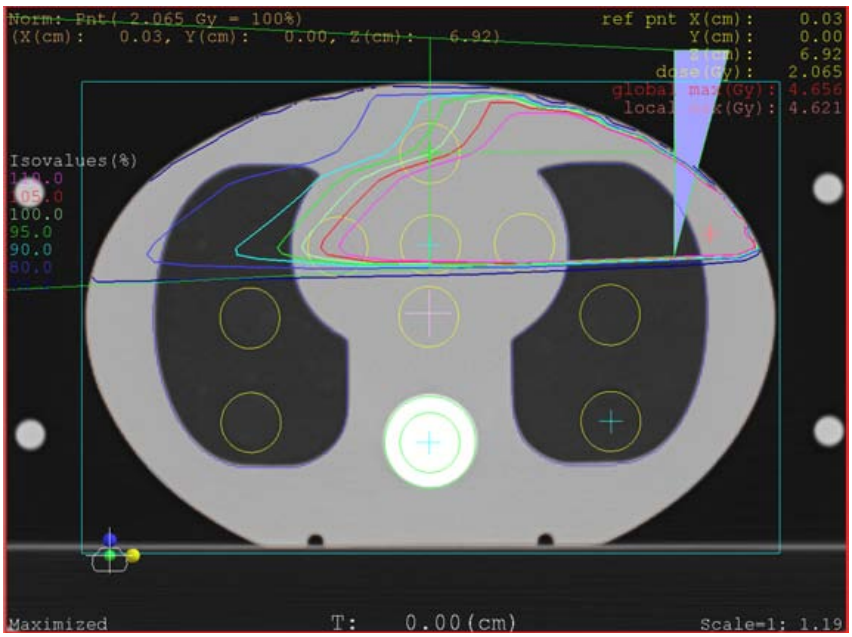


Figure A.6. A sample dose distribution in central plane for case 2.

Case 3: Significant blocking of the field corners

The purpose of this test is to verify the calculation for the blocked field. Use a 14 cm x 14 cm field with a collimator angle of 45° blocked to a 10 cm x 10 cm field with standard blocks or with the MLC. The measurement point is defined in the middle of hole #3: see Figure A.3 and Table A.6.

Table A.6. Geometry for case 3

Case	Number of beams	Set-up	Reference point	Measurement point	Field Size [cm] L x W	Gantry angle	Collimator angle	Beam modifiers
3	1	SSD=SAD	3	3	14x14 shaped to 10x10	0	45	Blocks or MLC

Instructions for Case 3:

(1) Perform the treatment plan with the RTPS according to Table A.6 and document it.
(2) Calculate with RTPS MU/time needed to deliver 2 Gy to the reference point #3.
(3) Perform manual MU/time calculation compare result with RTPS MU/time calculated values.
(4) Set up the phantom on the couch of the treatment machine with Head first supine towards gantry.
(5) Align the phantom with lasers intersection at the centre of hole #5.
(6) Set gantry angle to 0º.
(7) Set SSD=100 cm (80 cm for C0-60 or nominal SAD).
(8) Set collimator rotation to 45º.
(9) Set field size: Length (Y) = 14 cm Width (X) = 14 cm
(10) Block the field corners to 10 cm x 10 cm. (figure A.9)
(11) Insert ionisation chamber into the tissue plug and place it into hole #3.

(12) Irradiate the phantom with the RTPS calculated MU/time.
(13) Register the value of the measured dose. Repeat irradiation at least three times and determine average value.
(14) Fill in Table A.7 with calculated and measured data and compare results.

If several algorithms are available for dose calculations provide comparison of calculated and measured values for each algorithm used. An example of the calculated dose distribution and Beams Eye View (BEV) are given in Figures A.7 and A.8.

Table A.7. Comparison of measured and calculated data for test 3

Case	Location of measuring point	Calculated dose [Gy]	Measured dose [Gy]	Deviation [%]	Agreement criteria [%]
3	3				3

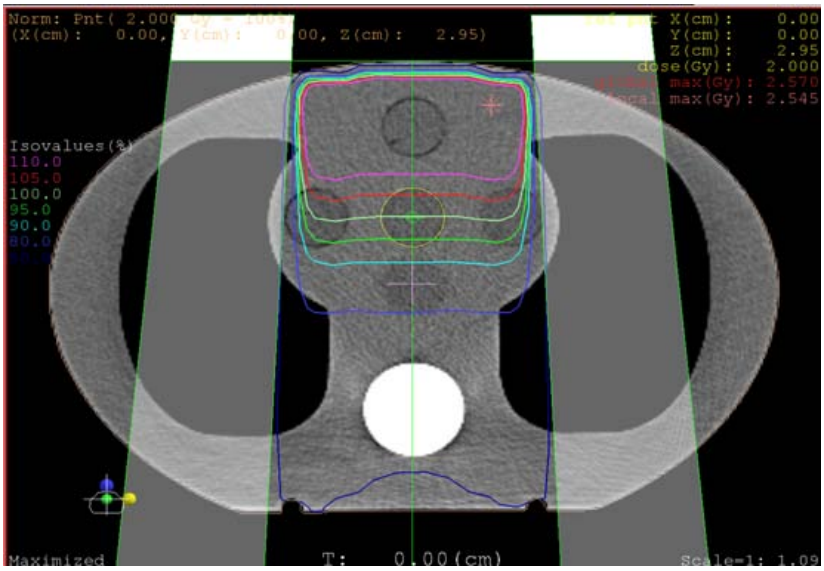


Figure A.7. A sample dose distribution in central plane for case 3.

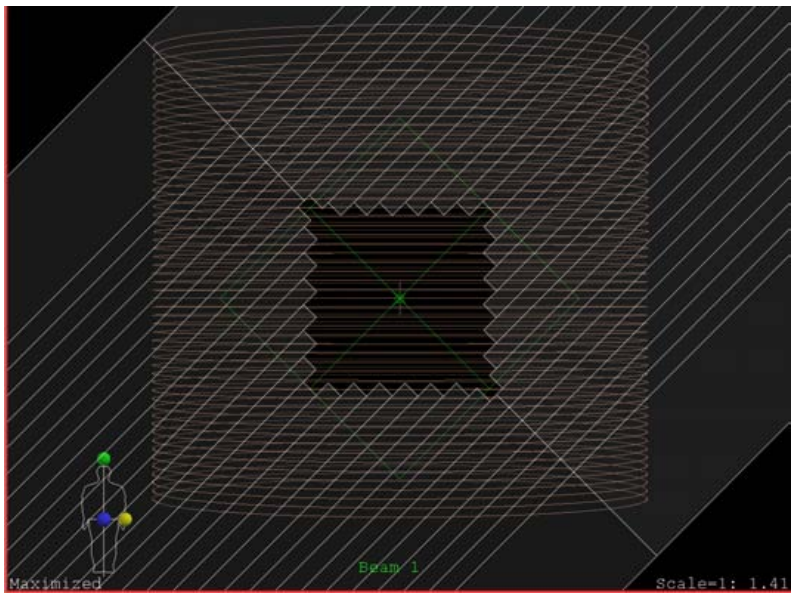


Figure A.8. A sample BEV for case 3.

Case 4: Four field box

This technique is used in many radiotherapy hospitals and the purpose of this test is to verify the calculation of the dose delivered with an individual beam and the total dose from four fields. The four fields are weighted equally and the parameters and measurement points are defined in the middle of holes 5, 6 and 10: see Table A.8 and Figure A.3. In each measurement point the difference between measured and calculated dose for the selected beam should be related to the dose measured at the reference point for the corresponded beam (for example: the difference between measured and calculated dose for anterior beam should be related to the dose measured at the reference point for the anterior beam).

Table A.8. Geometry for test case 4

Case	Number of beams	Set-up	Reference point	Measurement point	Field Size [cm] L x W	Gantry angle	Collimator Angle	Beam modifiers
4	4	SAD	5	5	15x10 Ant	0	0	none
				6	15x10 Post	180	0	
				10	15x8 RL	270	0	
					15x8 LL	90	0	

Instructions for Case 4:

(1) Perform the treatment plan with the RTPS according to Table A.8 and document it.
(2) Calculate with RTPS MU/time needed to deliver 2 Gy to the reference point #5.
(3) Report the computed dose at points #6 and #10.
(4) Perform manual MU/time calculation for each field and compare the results with RTPS MU/time calculated values.
(5) Set up the phantom on the couch of the treatment machine with Head first supine towards gantry.
(6) Align the phantom with lasers intersecting at the centre of hole #5.
(7) Set gantry angle to 0º.
(8) Set collimator rotation to 0º.
(9) Set field size: Length (Y) = 15 cm Width (X) = 10 cm
(10) Insert ionisation chamber into the tissue plug and place it into hole #5.
(11) Irradiate the phantom with the RTPS calculated MU/time for anterior field only.
(12) Register the value of the measured dose. Repeat irradiation at least three times and determine average value.
(13) Rotate gantry to 180º.
(14) Irradiate the phantom with the RTPS calculated MU/time for the posterior field.
(15) Register the value of the measured dose. Repeat irradiation at least three times and determine average value.
(16) Rotate gantry to 90º.
(17) Set field size: Length (Y) = 15 cm Width (X) = 8 cm
(18) Irradiate the phantom with the RTPS calculated MU/time for this field only.
(19) Register the value of the measured dose. Repeat irradiation at least three times and determine average value.
(20) Rotate gantry to 270º.
(21) Irradiate the phantom with the RTPS calculated MU/time for this field only.
(22) Register the value of the measured dose. Repeat irradiation at least three times and determine average value.
(23) Repeat steps 7 to 22 (except step 10) with the ionization chamber placed in hole #6.
(24) Repeat steps 7 to 22 (except step 10) with the ionization chamber placed in hole #10.
(25) Fill in Table A.9 with calculated and measured data and compare results.

If several algorithms are available for dose calculations provide comparison of calculated and measured values for each algorithm used. An example of the calculated dose distribution is given in Figure A.9.

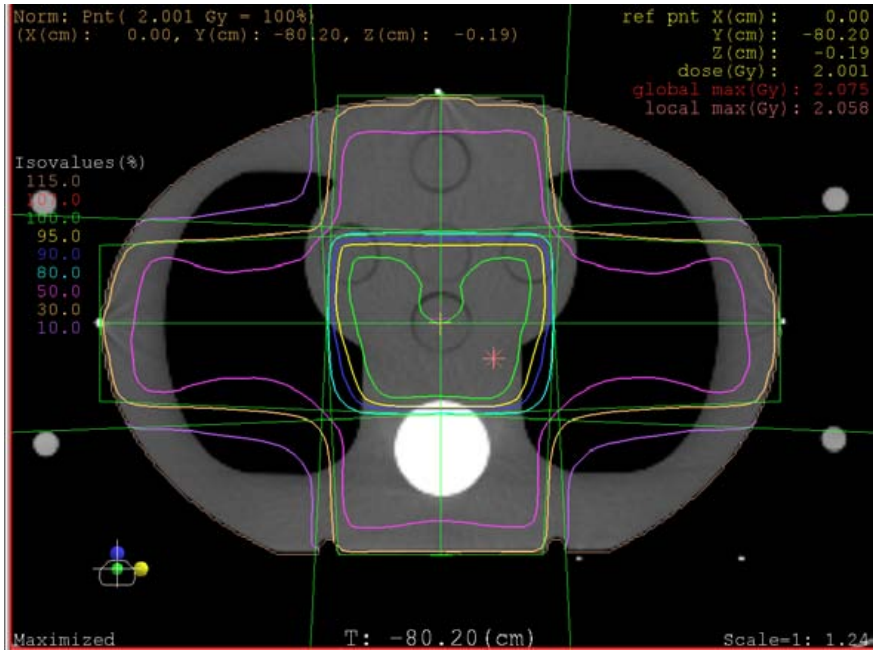


Figure A.9. A sample distribution in the central plane for case 4.

Table A.9. Comparison of measured and calculated data for case 4

Case	Location of measuring point		Calculated dose [Gy]	Measured dose [Gy]	Deviation [%]	Agreement Criterion [%]
4		**F1: 0°**				2
		F2: 90°				3
		F3: 270°				3
	5	**F4: 180°**				3
		Σ				
		F1: 0°				4
		F2: 90°				3
	6	**F3: 270°**				3
		F4: 180°				4
		Σ				
		F1: 0°				3
		F2: 90°				4
	10	**F3: 270°**				4
		F4: 180°				3
		Σ				

Case 5: Automatic expansion and customized blocking

The purpose of this test is to verify auto-aperture function of RTPS and customized blocking as well as the calculations with lung inhomogeneity. A cylinder of 8 cm diameter and 8 cm long centered in point #2 should be expanded with a margin of 1 cm in all directions using the expansion tools available. An MLC or block to conform to expanded volume should be applied. The measurement point is defined in the middle of the hole 7: see Figure A.3 and Table A.10.

Table A.10. Geometry for case 5

Case	Number of beams	Set-up	Reference point	Measurement point	Field Size [cm] L x W	Gantry angle	Collimator angle	Beam modifiers
5	1	SAD	2	2 7	defined by block or MLC	0	45	Custom block or MLC

Instructions for Case 5:

(1) Perform the treatment plan with the RTPS according to Table A.10 and document it.
(2) Calculate with RTPS MU/time needed to deliver 2 Gy to the reference point #2.
(3) Report the computed dose at point #7.
(4) Perform manual MU/time calculation and compare the result with RTPS MU/time calculated value.
(5) Set up the phantom on the couch of the treatment machine with Head first supine towards gantry.
(6) Align the phantom with lasers intersecting at the centre of hole #5.
(7) Set gantry angle to 0º.
(8) Move the table 4 cm laterally and 3 cm down (isocentre at hole #2).
(9) Set collimator rotation to 0º.
(10) Insert custom block or conform MLC (whether applicable) and set the field size.
(11) Insert ionisation chamber into the tissue plug and place it into hole #2.
(12) Irradiate the phantom with the RTPS calculated MU/time.
(13) Register the value of the measured dose. Repeat irradiation at least three times and determine average value.
(14) Insert ionisation chamber into the lung equivalent plug and place it into hole #7.
(15) Follow steps 10-11.
(16) Fill in Table A.11 with calculated and measured data and compare results.

If several algorithms are available for dose calculations provide comparison of calculated and measured values for each algorithm used. An example of the calculated dose distribution and BEV is given in Figures A.10 and A.11.

Table A.11. Comparison of measured and calculated data for case 5

Case	Location of measuring point	Calculated dose [Gy]	Measured dose [Gy]	Deviation [%]	Agreement criterion [%]
5	2				2
	7				4

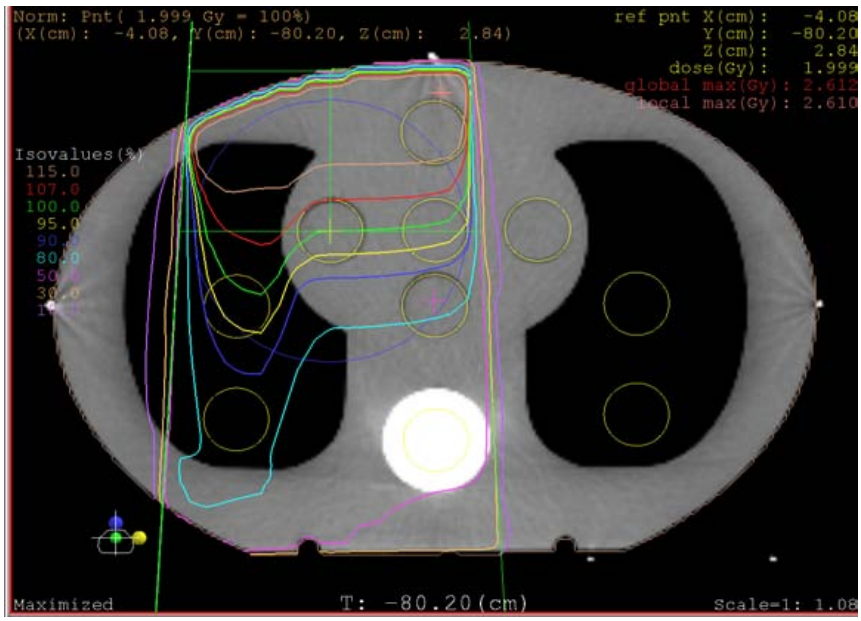


Figure A.10. A Sample dose distribution in central plane for case 5.

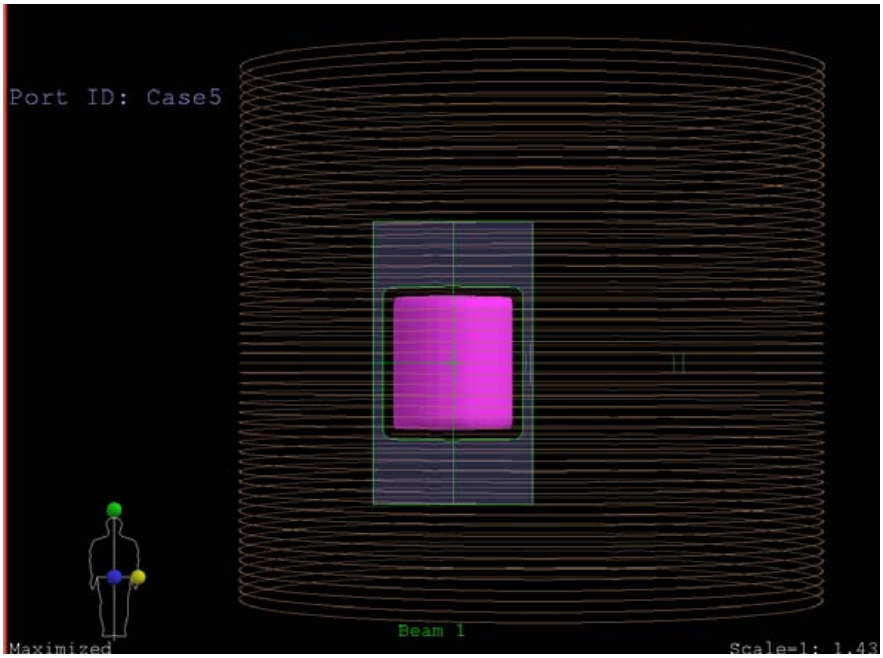


Figure A.11. A sample BEV for case 5.

Case 6: Oblique incidence with irregular field and blocking the centre of the field

The purpose of this test is to verify the calculations for irregular fields with the blocking of the center of the field. The isocentre should be set in the centre of the hole #5. A 20 cm x 10 cm field with gantry angle of 45° and collimator angle of 90° is used. An L-shaped field should be created by blocking off a 6 cm x 12 cm field using custom block or MLC. The parameters and measurement points are defined in the middle of holes 3 (reference point), 7, and 10: see Table A.12 and Figure A.3.

Table A.12 Geometry for case 6

Case	Number of beams	Set-up	Reference point	Measurement point	Field Size [cm] L x W	Gantry angle	Collimator Angle	Beam modifiers
6	1	SAD	3	3	L-shaped	45	90	Custom block or MLC
				7	10x20			
				10				

Instructions for Case 6:

(1) Perform the treatment plan with the RTPS according to Table A.12 and document it.
(2) Calculate with RTPS MU/time needed to deliver 2 Gy to the reference point #3.
(3) Report the computed dose at points #7 and #10.
(4) Perform manual MU/time calculation and compare the result with RTPS MU/time calculated value.
(5) Set up the phantom on the couch of the treatment machine with Head first supine towards gantry.
(6) Align the phantom with lasers intersecting at the centre of hole #5.
(7) Set gantry angle to 45º.
(8) Set collimator rotation to 90º.
(9) Set field size: Length (Y) = 10 cm Width (X) = 20 cm
(10) Insert ionisation chamber into the tissue plug and place it into hole #3.
(11) Insert custom block or shape the field with the MLC.
(12) Irradiate the phantom with the RTPS calculated MU/time.
(13) Register the value of the measured dose. Repeat irradiation at least three times and determine average value.
(14) Insert ionisation chamber into the lung equivalent plug and place it into hole #7.
(15) Repeat steps 12 and 13 after changing the position of the chamber.
(16) Insert ionisation chamber into the bone equivalent plug and place it into hole #10.
(17) Repeat steps 12 and 13 after changing the position of the chamber.
(18) Fill in Table A.13 with calculated and measured data and compare results.

If several algorithms are available for dose calculations provide comparison of calculated and measured values for each algorithm used. An example of the calculated dose distribution and BEV is given in Figures A.12 and A.13.

Table A.13 Comparison of measured and calculated data for case 6

Case	Location of measuring point	Calculated dose [Gy]	Measured dose [Gy]	Deviation [%]	Agreement criterion [%]
6	3				3
	7				4
	10				5

Figure A.12. A sample distribution in the central plane for case 6.

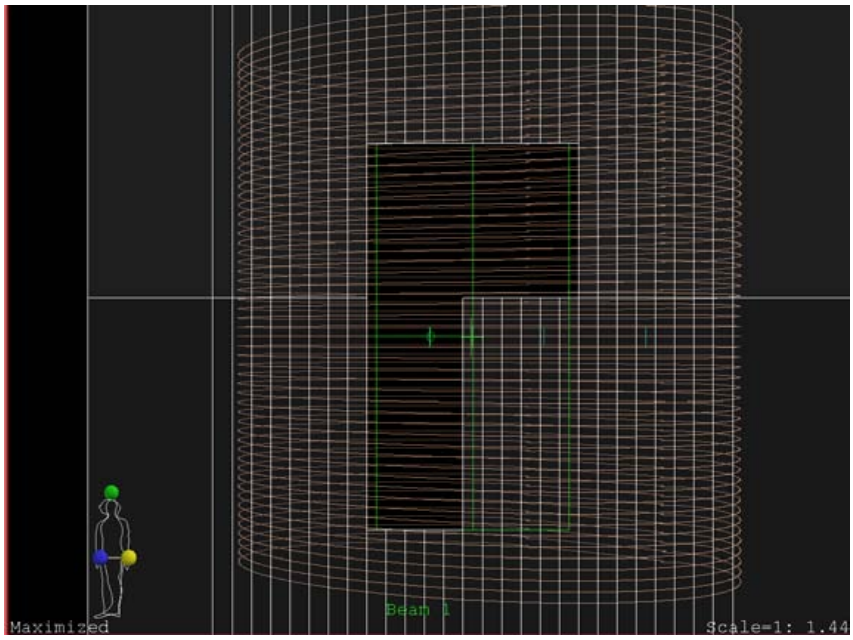


Figure A.13. A sample BEV for case 6.

Case 7: Three fields, two wedge-paired, asymmetric collimation

The purpose of this test is to verify the calculations with wedge-paired fields and asymmetric collimation (if asymmetric collimators are not available – use half-beam block). The isocentre should be set in the centre of the hole #3. All fields are equally weighted. Collimator angle should be set depending on the wedge insertions. The parameters and measurement point are defined in the middle of the hole #5: see Table A.14 and Figure A.3.

Table A.14 Geometry for test case 7

Case	Number of beams	Set up	Reference point	Measurement point	Field Size [cm] L x W	Gantry angle	Collimator angle	Beam modifiers
7	3	SAD	5	5	10x12	0	0	None
					10x6 assym	90	According to wedge orientation	Physical wedge 30° Soft wedge 30°
					10x6 assym	270		

Instructions for Case 7:

(1) Perform the treatment plan with the RTPS according to Table A.14 and document it.
(2) Calculate with RTPS MU/time needed to deliver 2 Gy to the reference point #5.
(3) Perform manual MU/time calculation for each field and compare the results with RTPS MU/time calculated values.
(4) Set up the phantom on the couch of the treatment machine with Head first supine towards gantry.
(5) Align the phantom with lasers intersecting at the centre of hole #5.
(6) Set gantry angle to 0º.
(7) Set collimator rotation to 0º.
(8) Lower table 3 cm down (isocentre at hole #3).
(9) Set field size: Length (Y) = 10 cm Width (X) = 12 cm
(10) Insert ionisation chamber into the tissue plug and place it into hole #5.
(11) Irradiate the phantom with the RTPS calculated MU/time for anterior field.
(12) Register the value of the measured dose. Repeat irradiation at least three times and determine average value.
(13) Rotate gantry to 90º.
(14) Set collimator rotation angle to provide proper wedge orientation.
(15) Set field size: Length (Y) = 10 cm Width (X1) = 0, Width (X2) = 6cm (those who do not have asymmetric jaws use on this field half beam block and set the field size to 10cm x 12 cm)
(16) Insert 30º physical wedge (see figure A.14).
(17) Irradiate the phantom with the RTPS calculated MU/time for LL field.
(18) Register the value of the measured dose. Repeat irradiation at least three times and determine average value.
(19) Rotate gantry to 270º.
(20) Set collimator rotation angle to provide proper soft wedge orientation. (See figure A.14). In case you have no soft wedge, repeat insertion of 30° physical wedge.
(21) Irradiate the phantom with the RTPS calculated MU/time for RL field.
(22) Register the value of the measured dose. Repeat irradiation at least three times and determine average value.
(23) Fill in Table A.15 with calculated and measured data and compare results.

If several algorithms are available for dose calculations provide calculated values for each algorithm used. An example of the calculated dose distribution is given in Figure A.14.

Table A.15 Comparison of measured and calculated data for case 7

Case	Location of measuring point		Calculated dose [Gy]	Measured dose [Gy]	Deviation [%]	Agreement criterion [%]
7	5	**F1: 0º**				2
		F1: 90º				4
		F1: 270º				4
		Σ				

Figure A.14. A sample dose distribution in the central plane for case 7.

Case 8: Non coplanar beams with couch and collimator rotation

The purpose of this test is to verify the calculations with couch and collimator rotation. Three fields with different gantry angles and collimator rotations are equally weighted. The isocentre should be set in the centre of the hole #5. The parameters and measurement point are defined in the middle of the hole #5: see Table A.16 and Figure A.3.

Table A.16. Geometry for test case #8

Case	Number of beams	Set-up	Reference point	Measurement point	Field Size [cm] L x W	Gantry angle	Collimator angle	Beam modifiers
8	3	SAD	5	5	4x16 LL	90	330	None
					4x16 RL	270	30	
					4x4 (table 270)	30	0	

Instructions for Case 8:

(1) Perform the treatment plan with the RTPS according to Table A.16 and document it.
(2) Calculate with RTPS MU/time needed to deliver 2 Gy to the reference point #5.
(3) Perform manual MU calculation for each field and compare the results with RTPS MU/time calculated values.
(4) Set up the phantom on the couch of the treatment machine with Head first supine towards gantry.
(5) Align the phantom with lasers intersecting at the centre of hole #5.
(6) Set gantry angle to 90º.
(7) Set collimator rotation to 330º.
(8) Set field size: Length (Y) = 4 cm Width (X) = 16 cm
(9) Insert ionisation chamber into the tissue plug and place it into the hole #5.
(10) Irradiate the phantom with the RTPS calculated MU/time for LL field.
(11) Register the value of the measured dose. Repeat irradiation at least three times and determine average value.
(12) Set gantry angle to 270º.
(13) Set collimator rotation to 30º.
(14) Irradiate the phantom with the RTPS calculated MU/time for RL field.
(15) Register the value of the measured dose. Repeat irradiation at least three times and determine average value.
(16) Set gantry angle to 30º.
(17) Set collimator rotation to 0º.
(18) Rotate table isocentrically to 270º.
(19) Set field size: Length (Y) = 4 cm Width (X) = 4 cm
(20) Irradiate the phantom with the RTPS calculated MU/time for non coplanar field.
(21) Register the value of the measured dose. Repeat irradiation at least three times and determine average value.
(22) Fill in Table A.17 with calculated and measured data and compare results.

If several algorithms are available for dose calculations provide calculated values for each algorithm used. An example of the calculated dose distribution is given in Figure A.15.

Table A.17. Comparison of measured and calculated data for test 8

Case	Location of measuring point		Calculated dose [Gy]	Measured dose [Gy]	Deviation [%]	Agreement criterion [%]
8	**5**	**F1: 90º**				3
		F1: 270º				3
		F1: 30º				3
		Σ				

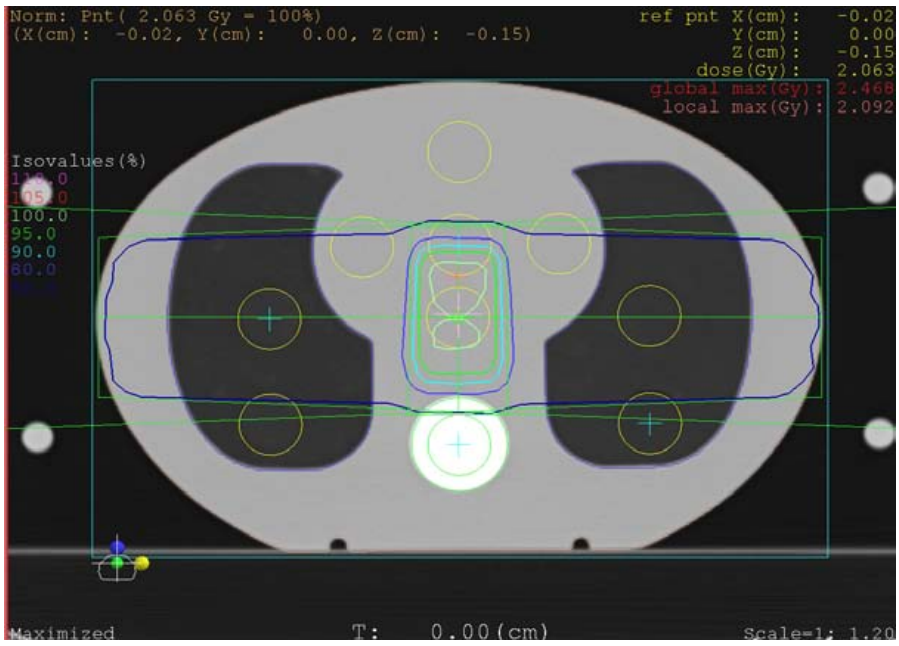


Figure A.15. A sample dose distribution in the central plane for case 8.

A.2.Summary of clinical commissioning testing

The tests, location of measuring points and agreement criteria for each point are summarized in Table A.18. The user may utilize this table to document the results of the clinical commissioning for future reference.

Table A.18. Form to document summary of clinical commissioning results (reference points for each test case are marked with asterisk).

Description	Case No.	Meas. Point/Field		Agreement criteria (%)	User's difference
Testing for reference field based on CT data; test corresponds to photon test 1and MU test 1 in TRS 430	1	1		2	
		3*)		2	
		5		2	
		9		4	
		10		3	
Oblique incidence, lack of scattering and tangential fields; test corresponds to photon tests 7, 10 and MU test 2 in TRS 430.	2	1*)		3	
Significant blocking of the field corners; test corresponds to photon tests 1, 3 and MU test 4 in TRS 430.	3	3*)		3	
Four field box; test corresponds to clinical test 1 in TRS 430.	4	5*)	**F1: 0°**	2	
			F2: 90°	3	
			F3: 270°	3	
			F4: 180°	3	
			Σ		
		6	**F1: 0°**	4	
			F2: 90°	3	
			F3: 270°	4	
			F4: 180°	3	

Description	Case No.	Meas. Point/Field		Agreement criteria (%)	User's difference
			∑		
		10	**F1: 0°**	3	
			F2: 90°	4	
			F3: 270°	3	
			F4: 180°	4	
			∑		
Automatic expansion and customized blocking; test combines test conditions related to beam test 8, photon test 13, MU test 6, and clinical test 4 as described in TRS 430.	5	2*)		3	
		7		4	
Oblique incidence with irregular field and blocking the centre of the field; test corresponds to MU test 4 as described n TRS 430.	6	3*)		3	
		7		5	
		10		5	
Three fields, two wedge-paired, asymmetric collimation; test corresponds to MU test 3 and clinical test 3 a described in TRS 430.	7	5*)	**F1: 0°**	2	
			F2: 90°	4	
			F3: 270°	4	
			∑		
Non coplanar beams with couch and collimator rotation; test corresponds to beam tests 6, 12 and clinical test 6 in TRS 430.	8	5*)	**F1: 0°**	3	
			F2: 90°	3	
			F3: 270°	3	
			∑		

APPENDIX B
RESULTS OF PILOT STUDY

Introduction

The clinical commissioning procedures described in the current report were tested by the participants of the Coordinated Research Project E2.40.13 to verify practicability of the tests, selection of measurements points in the phantom and the needed amount of time to perform the measurements for each test. All participants used the same phantom and employed ionization chamber dosimetry. A total number of 14 algorithms from 9 different RTPSs brands installed in 18 hospitals were tested. The calculated and measured doses are compared for all algorithms using exactly the same treatment plans and data points. The algorithms are listed in Table B.1 according to the manufacturer's description. The third column of Table B.1 lists the energies used. The results of pilot study are given in Table B.2 and show the range of deviations for each test, for each measurement point and for each algorithm. The columns "min" and "max" contain the minimum and maximum dose deviations observed for all energies tested for the specific algorithm (refer Table B.1). Following the RTPS manuals the hospital users may identify the algorithms and inhomogeneity correction methods for their RTPS and compare the results of their commissioning tests to the data for the selected algorithm presented in the report. The user may also consult AAPM Report 85 [4] for more detailed information on algorithms used in RTPSs.

Algorithms A3, A4 and A5, labeled as pencil beam convolution with inhomogeneity corrections based on equivalent TAR method implemented differently in RTPSs used. The same is related to algorithms A7, A9, labeled as pencil beam convolution (kernel scaling with depth). Figure B.1 shows the percentage of measurements with results outside the criteria of agreement as a function of algorithm used and photon beam energy.

Table B.1. Dose computation algorithms

Algorithm identifier	Algorithm description	Beam energies
A1	Effective pathlength	6, 15 MV
A2	Clarkson (effective pathlength)	Co-60, 6,10,15 MV
A3*	Pencil beam convolution: Equivalent TAR method	6, 15 MV
A4*	Pencil beam convolution: Equivalent TAR method	6, 10, 20 MV
A5*	Pencil beam convolution: Equivalent TAR method	6 MV
A6	Pencil beam convolution: Modified Batho power law method	4, 6, 10, 18, 20 MV
A7*	Pencil beam convolution (kernel scaling with depth)	6, 10, 15 MV

* Implementation in different RTPSs

Algorithm identifier	Algorithm description	Beam energies
A8	Pencil beam convolution: TAR and 3D SAR integration	6 MV
A9*	Pencil beam convolution (kernel scaling with depth)	6 MV
A10	FFT (convolution kernels not scaled but beam hardening taken into account)	Co-60, 6, 10, 15 MV
A11	Anisotropic Analytical Algorithm	4, 6, 18 MV
A12	Multi-grid superposition	Co-60, 6, 10, 15 MV
A13	Collapsed cone point kernel with 3D scaling	6, 15 MV
A14	Collapsed cone convolution / superposition	6 MV

Table B.2 Range of deviations (percentage as calculated from equation A.1) between measured and calculated doses in different locations of CIRS phantom for different algorithms.

		Agreement criteria (%)	A1		A2		A3		A4		A5		A6		A7		A8		A9		A10		A11		A12		A13		A14	
Case Nr.	Meas. point		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1	1	2							-1.0	-1.0					0.8	1.4	-1.5	-1.5	-0.6	-0.6	0.0	1.0			0.3	0.9			-0.4	2.2
	3	2	-0.7	-0.3			-1.4	-1.0	0.0	0.0	-1.0	1.8	-1.2	1.8	-2.2	0.1			-0.4	-0.4	-1.4	1.8	-0.5	0.7	-1.6	0.8			-0.8	1.8
	5	2							-0.5	-0.5					-0.3	-0.1	-0.5	-0.5			0.6	0.9			0.4	0.9			-1.4	1.5
	9	4	-7.6	-4.0	-7.0	-0.5	-4.3	-2.4	0.1	0.1	-8.4	-4.6	-8.6	-1.8	-4.5	-2.5	-3.1	-3.1			-6.8	0.7	-1.1	1.8	-3.4	1.3				
	10	3	-3.1	-1.8	-3.7	0.7	-2.2	0.8	1.6	1.6	-2.6	3.7	-2.2	0.6	-2.0	0.9	0.9	0.9	-0.3	-0.3	-2.7	0.8	-3.1	-0.9	-3.1	0.2			-7.0	-0.4
2	1	3	2.5	2.7	0.2	4.4	-4.3	-1.0	1.7	1.7	-3.2	-0.3	-3.2	2.9	-3.9	2.5	0.5	0.5	1.6	1.6	-2.1	6.1	-1.5	0.8	-3.5	2.9	0.6	1.4	-1.8	1.1
3	3	3	1.1	1.8	-1.4	0.7	-0.2	2.2	1.5	1.5	-1.3	-0.7	-1.3	0.9	-2.9	0.3			0.8	0.8	-1.2	1.1	-1.3	-0.2	-0.9	0.8	0.1	0.1	0.0	3.6
4	5	2			-2.0	-0.4	-1.6	-0.8	0.2	0.2			-1.0	1.3	-2.0	2.4	-0.4	-0.4	0.1	0.1	-1.6	0.4	-0.2	1.3	-1.6	0.5	1.3	1.8	-1.8	-0.4
		3			-1.6	4.6	0.8	1.6	-0.9	-0.9			0.4	1.3	-3.8	1.5	-0.5	-0.5	1.2	1.2	-3.1	10.6	-2.0	0.5	-3.1	2.0	-2.5	1.8	-2.5	1.2
		3			-3.1	6.6	-3.0	-2.9	-0.4	-0.4			1.1	3.0	-1.6	3.2	-0.1	-0.1	-1.5	-1.5	-4.2	3.5	2.6	3.0	-2.7	4.4	2.4	3.5	-3.1	1.3
		3			-1.2	1.6	0.4	1.6	-1.8	-1.8			1.4	3.9	-2.3	2.5	-0.7	-0.7	0.7	0.7	-2.7	9.4	2.2	3.9	-2.7	0.4	1.2	1.8	-4.5	0.4
		3	-1.5	-1.3	-2.0	2.2	-0.8	-0.1	-2.9	-2.9	-0.5	0.6	-0.5	2.3	-3.4	-2.4	-1.7	-1.7			-2.5	6.1	0.9	1.5	-2.9	1.0				
	6	4			-2.0	0.8	0.8	3.6	0.1	0.1			-2.3	-1.3	-2.0	-2.0			0.7	0.7	-1.8	2.0	0.2	0.7	-1.2	1.2	-0.4	0.0	-6.7	-0.2
		3			-0.4	7.4	-8.2	-5.4	-2.3	-2.3			3.2	3.3	8.6	8.7	0.1	0.1	2.7	2.7	-0.4	9.9	0.1	2.4	-0.8	2.3	-4.6	-2.1	-7.5	17.3
		4			-6.0	0.0	-0.4	0.8	0.3	0.3			-4.8	-1.6	-3.4	-2.3	-0.2	-0.2	0.2	0.2	-6.4	0.3	-4.2	0.4	-3.6	0.4	0.0	0.3	-0.1	12.2
		3			-1.2	8.4	-9.7	-2.7	-1.6	-1.6			2.8	6.6	2.6	3.6	1.4	1.4	-4.1	-4.1	-1.2	20.6	-1.0	2.6	-1.6	1.7	-0.8	-0.1	-7.3	-0.2
		4	0.6	0.7	-1.3	3.8	-3.5	-2.1	-3.0	-3.0	0.3	1.9	-0.3	0.9	1.5	2.5	1.3	1.3			-0.3	8.5	-0.5	0.8	-0.8	1.0				
	10	3			-3.9	-0.2	-2.0	-0.4	-0.7	-0.7			-3.8	-1.2	-1.8	-0.3	-0.6	-0.6	0.1	0.1	-3.9	-0.4	-3.5	0.0	-3.9	0.4	-4.6	-4.4	-0.9	0.2
		4			-3.1	8.4	-3.5	5.4					-12.0	-9.5	0.7	2.7	0.1	0.1	-1.1	-1.1	-1.2	10.6	-0.4	-0.4	-1.2	6.5	-3.6	-1.3	-0.5	1.4
		3			-8.9	5.9	-4.5	-2.5	-0.2	-0.2			-4.0	-0.3	-2.6	0.1	-1.3	-1.3	-1.8	-1.8	-8.9	1.1	-4.1	-4.1	-8.9	2.7	-3.5	-2.9	-2.7	3.2
		4			-5.4	1.2	10.1	14.4	0.7	0.7			-12.6	-9.6	1.3	1.5	0.7	0.7	-0.5	-0.5	-5.4	3.0			-2.7	0.0	-3.8	-3.4	-0.6	1.8
		4	-1.7	0.7	-4.9	1.5	0.1	4.5	-1.2	-1.2	-5.9	-1.2	-8.0	1.5	1.6	1.8	-1.1	-1.1			-4.9	3.7	-3.0	-0.4	-4.9	1.9				
5	2	3	-0.2	1.8	-0.1	1.7	-0.2	-0.1			-1.4	0.4	-0.6	2.6	-0.6	1.6			0.8	0.8	-4.7	2.4	-0.1	1.0	-5.5	0.6			-0.9	0.3
	7	4	8.4	11.2	-4.5	10.8	0.9	1.1			6.1	12.4	4.3	11.8	1.3	12.1			10.3	10.3	1.0	24.3	-0.5	1.9	-4.0	6.4			-3.6	-3.6
6	3	3	-2.0	-2.0	-1.7	1.9	-3.2	0.1	1.9	1.9	-0.8	3.7	-0.8	3.7	-2.1	6.0	0.5	0.5	1.5	1.5	-0.3	2.3	-1.3	0.0	-1.7	2.9			-0.7	4.8
	7	5			5.0	12.1			-1.8	-1.8			-4.3	-4.3			5.5	5.5			7.8	13.4	-5.4	-5.4	0.7	3.3				
	10	5			-1.2	0.7	1.9	4.5			-1.8	1.5	-1.9	1.7	2.6	3.8					0.4	2.6	-0.8	0.3	-2.5	1.9				
7	5	2			-1.4	1.0	-0.3	0.3	1.2	1.2	-0.1	0.4	-0.1	0.4	-3.1	1.8	-0.2	-0.2	0.7	0.7	-4.0	2.1	0.2	1.3	-4.4	0.1			-1.7	0.2
		4			-2.1	2.0	-3.4	-1.1	-1.9	-1.9	-1.8	-0.1	-1.8	-0.1	-4.6	0.3	-0.9	-0.9	-0.1	-0.1	-2.0	5.3	-1.4	2.4	-3.8	2.1			-1.9	0.7
		4			-4.9	-0.6	-3.1	-0.6	-2.1	-2.1	-1.9	-1.4	-1.7	-0.2	-0.8	3.3	-1.0	-1.0	0.1	0.1	-2.7	5.1	-1.4	1.0	-3.8	5.4			-2.9	-0.1
		3	-2.8	-2.2	-1.6	0.0	-2.2	-0.7	-2.5	-2.5	-1.1	-0.7	-1.1	1.0	-2.6	-0.8	-2.0	-2.0			-1.7	2.4	-0.6	1.3	-4.4	-1.4				
8	5	3			-7.0	-1.2	-6.6	-1.3	-1.7	-1.7			-0.6	-0.6	-5.0	7.6	-0.5	-0.5			-1.6	4.6	-1.2	-0.4	-1.3	0.5			-6.2	-1.7
		3			-0.8	1.4	-2.8	2.0	-1.7	-1.7			2.2	2.2	-4.2	-0.8	-0.7	-0.7	-1.1	-1.1	0.8	7.4	0.1	2.2	-2.3	3.1			-0.3	1.0
		3			-2.1	-0.6	-2.8	1.7	-1.0	-1.0			2.4	2.4	-6.3	0.9	1.1	1.1	0.2	0.2	0.0	2.0	0.1	2.4	-2.9	2.0			-1.6	0.0
		3	-0.7	-0.5	-2.4	-0.4	-3.9	0.9	-4.3	-4.3	-1.3	-1.3	-1.3	2.2			-0.1	-0.1			-0.5	3.6	0.2	2.3	-2.2	-0.3				

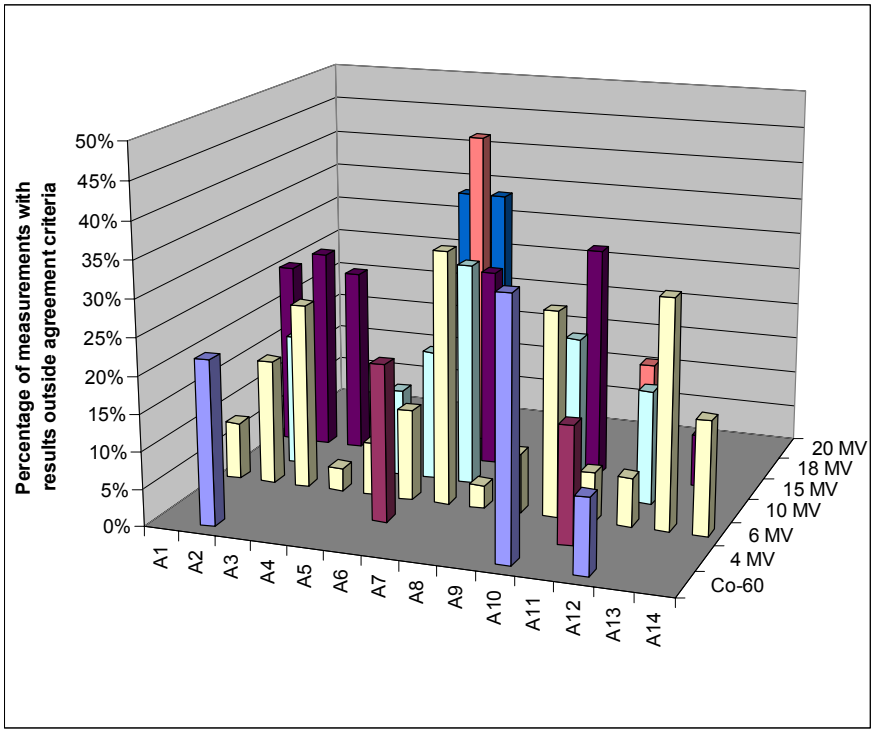


Figure B.1. The percentage of measurements with results outside agreement criteria as a function of algorithm and photon beam energy.

The practicality of these clinical commissioning procedures has been studied through trial use in several facilities and the measurements were performed on different treatment machines. Table B.3 provides time estimates for treatment units with and without record and verify (R&V) system with automatic set-up option. The hospital user can consult the data for treatment machines to estimate the time needed to perform the measurements at his/her facility.

Table B.3. Time estimate needed to perform measurements of clinical commissioning tests.

Test case No.	**Minimum time estimate (minutes)**	
	with automatic set-up	without automatic set-up
1	20	25
2	15	20
3	10	15
4 (all fields)	40	80
5	15	20
6	15	20
7 (all fields)	15	30
8 (all fields)	20	30
TOTAL:	**150**	**240**

The time required to perform the whole chain of activities: phantom assembly and set-up, CT scanning, planning, measurements and analysis would be approximately 16 hours (2 working

days) for dual energy machine. The estimated “machine” time required: CT scanner about 30 min; RTPS about 5 hours; treatment machine about 5 hours.

APPENDIX C
COMPARISON OF DIFFERENT PHANTOMS FOR CLINICAL COMMISSIONING OF RTPS FOLLOWING AN IAEA PROTOCOL

Introduction

The IAEA recommendations include clinical commissioning test cases that cover typical treatment techniques used in majority of radiotherapy hospitals. The test cases were designed to cover the widest possible range of the test case scenarios described in TRS-430. A phantom that simulates the thorax including lung and bone inhomogeneities is best suited to support the clinical commissioning tests. The shape of the thorax phantom will allow simulating an oblique surface and have the possibility to include dosimeters inside volumes with lung or bone equivalent materials. A solid phantom will have limitations in the number of possible measurement points for ionization chambers. Therefore the number and the location of the measuring points in the phantom are important. The RTPS clinical commissioning testing should be as easy and accurate to perform as possible. Therefore the set up and handling of the phantom should not be fault-prone or time-consuming. Several phantoms were evaluated in terms of their suitability to support the tests described in the current report.

Phantoms

Five different multi-purpose phantoms commercially available at the time of the project have been selected for comparison study: Model 002LFC (Computerized Imaging Reference Systems), EasyBody (Euromechanics Medical GmbH), Quasar (Modus Medical Devices Inc.), phantom 91235 (Standard Imaging Inc.), TomoTherapy cheese phantom (Gammex RMI). Brief description of each phantom is given below.

The phantom Model 002LFC from Computerized Imaging Reference Systems Inc., (CIRS), Norfolk, Virginia, USA was described in details in section 2.3.1 and shown in Figure 1.

The EasyBody phantom was developed by Euromechanics Medical GmbH, Schwarzenbruck, Germany in cooperation with the University Medical Center Hamburg-Eppendorf, Germany. It consists of the basic cubic phantom EasyCube and two expanders to form an abdominal shaped phantom. The material is solid water (RW3) and the dimensions are 36 cm × 18 cm ×18 cm. The phantom consists of several solid water plates that can be replaced by the plates made of bone or lung-equivalent material to create an anthropomorphical arrangement (see Figure C.1). Ionization chamber holders, made of RW3, can be placed at nearly any position in the phantom due to the plate structure. Films can be placed between every pair of plates and also special plates with cutouts are available for better fixation of the film. A grid with 1 cm steps is marked on the phantom to be used for alignment purposes. A set of four certified electron density plugs (lung, adipose, muscle and bone) can be inserted in the phantom for CT calibration. An additional hollow plug can be filled with water and used as a reference.

The Quasar phantom is a product from Modus Medical Devices Inc., London, Ontario, Canada. It is made of solid acrylic and has a size of 30 cm × 12 cm × 20 cm (see Figure C.2). It is elliptically shaped and has three openings (diameter 8 cm) for cylindrical acrylic or low density wood inserts (lung-equivalent). A film cassette can also be included in these openings or even an adaptor to simulate respiratory motion. Six smaller openings (diameter 2 cm) for a bone equivalent rod or acrylic ionization chamber holder can be used. Several alignment markers are located on the phantom.

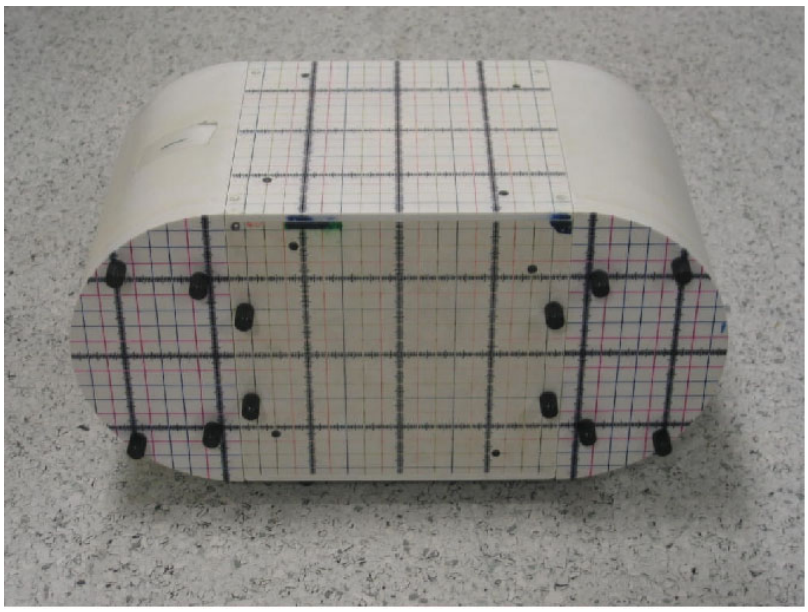


Figure C.1. The phantom Euromechanics GmbH, EasyBody.

An additional adaptor with five certified electron densities (lung inhale, polyethylene, water equivalent, inner bone and dense bone) in a fixed arrangement is available for CT calibration purposes.

Figure C.2. The phantom Quasar, Modus medical devices Inc.

The 91235 phantom from Standard Imaging Inc., Middelton, Wisconsin, USA consists of six plates each of 3 cm thickness and dimensions of 30 cm × 45 cm which can be stacked and fixed with pins to reach a height of 18 cm (see Figure C.3). The set up mimics a human torso. The main material is virtual water. Two plates have an inclusion of lung-equivalent material; the other four plates are solid apart from the holes (1 cm diameter) in all six plates where ionization chamber holders made of virtual water can be inserted. A solid rod made of bone equivalent material also fits in these cavities. Markers on the phantom allow an easy alignment. Films can be included between any pair of plates. No CT calibration is possible with this phantom because no certified density materials are available.

Figure C.4. The Standard imaging phantom 91235.

The TomoTherapy cheese phantom is a solid water phantom that was manufactured by Gammex RMI, Middleton, Wisconsin, USA for verification purposes of the TomoTherapy machines (see figure C.4). It is cylindrical in shape, its dimensions are 30 cm (∅) × 18 cm and has 20 holes of 2.8 cm diameter in which 12 different plugs of certified electron densities can be included for CT calibration. All other holes can be filled with solid water plugs. Also ionization chamber holder made of solid water can be included in these openings. For dose verification purposes the phantom can not be expanded or filled with inhomogeneities to mimic a human torso. The phantom consists of two semi-cylindrical halves, in between which a film can be included. Metallic markers are placed on the surface for alignment purposes.

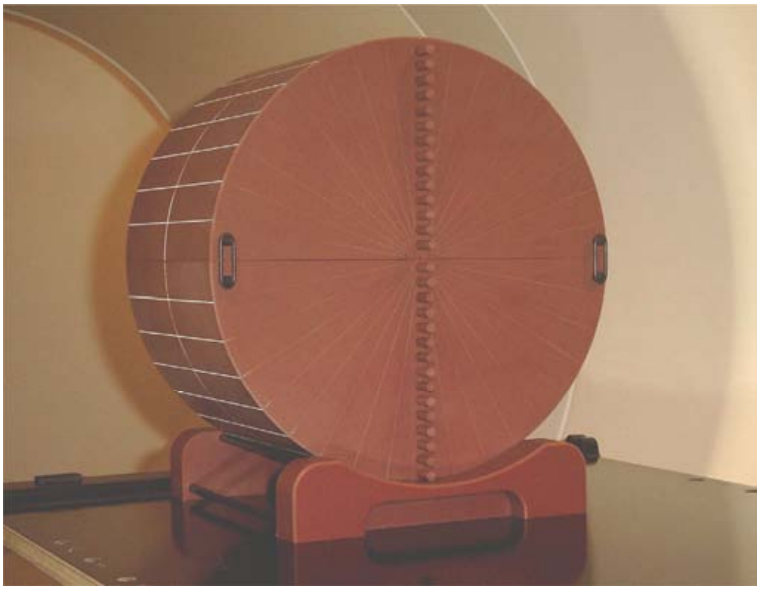


Figure C.4. The phantom Gammex RMI, TomoTherapy cheese phantom.

Parameters evaluated

The suitability of each phantom for clinical commissioning was investigated. This includes checking whether a CT calibration is possible, the possible anthropomorphic set-ups of the phantoms, the investigation of the materials and the possibilities for dose verifications. The possibility of an anthropomorphic set-up is necessary to check DRRs and inner contours. The existence of alignment markers and error-proneness of the alignment and set up process were also examined. All phantoms with certified electron densities were set up for CT scanning. As an example Figure C.5 shows one CT slice for each phantom. Based on the results of CT scanning a CT number/RED conversion table was determined for each phantom.

Three clinical commissioning test cases described in the current document (cases 1, 2 and 6 - Appendix A) were performed for all five phantoms. An anthropomorphic setup for each phantom was created where it was possible. Figures C.5 shows the corresponding CT images of the phantoms that were scanned for treatment planning.

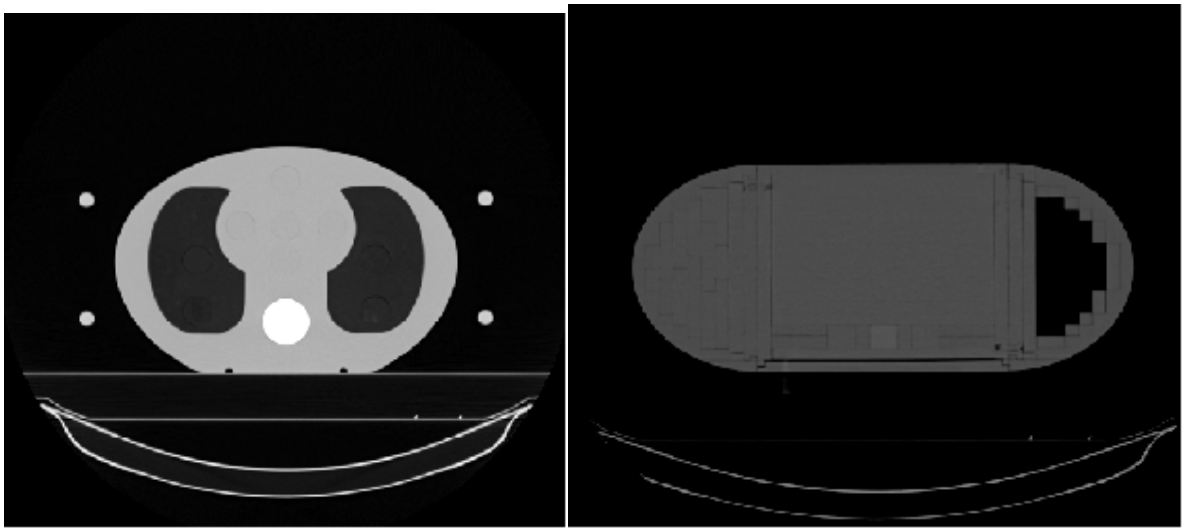


Figure C.5. CT mages of CIRS Inc model 002LFC (left) and Euromechanics GmbH EasyBody (right) phantoms used for clinical commissioning tests.

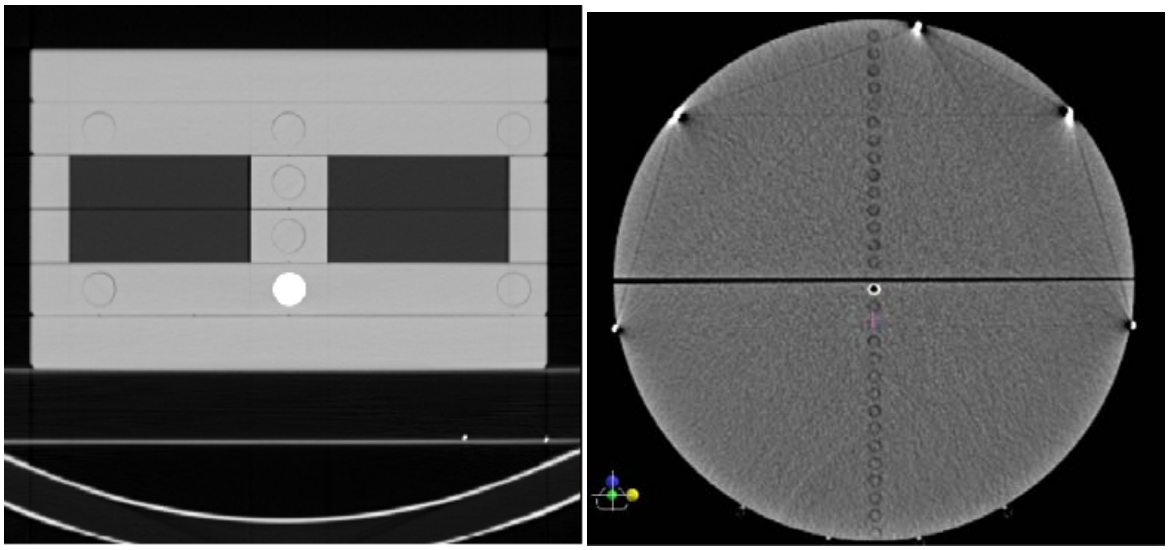


Figure C.6. CT mages of Standard Imaging 91235(left) and Gammex RMI TomoTherapy Cheese (right) phantoms used for clinical commissioning tests.

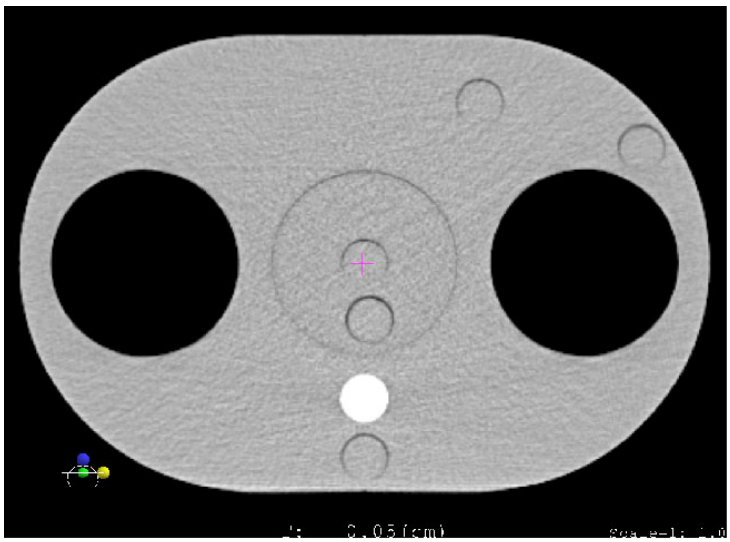


Figure C.7. CT mage of Modus Medical Quasar phantom used for clinical commissioning tests.

Table C.1. Characteristics of the studied phantoms

Manufacturer	CIRS Inc	EUROMECHANICS MEDICAL GmbH	MODUS MEDICAL DEVICES Inc	STANDARD IMAGING Inc	GAMMEX RMI
Phantom/feature	002LFC	Easybody	Quasar	91235	Tomotherapy Cheese
Dimensions (W x L x H) cm	30x30x20	36x18x18	30x12x20	30x45x18	∅30x18
Shape	Thorax	Abdominal	Thorax	Thorax	Cylinder
Body material	Solid water	RW3	Acrylic	Virtual water	Solid water
Ion chamber locations	10 (inside tissue, lung, bode)	Several - depending on plates structure (inside tissue, lung, bone)	6 (inside tissue, lung, bone)	16 (inside tissue)	20 (inside tissue)
Film placement (plane)	Transversal	Transversal, coronal, saggital	Transversal, coronal, saggital	Coronal	Coronal, saggital
Number of certified ED plugs	5	4	5	none	12
Oblique incidence modelling	Yes	Yes	Yes	Only for tilted beams	Yes
Inhomogeneities	Tissue, lung, bone	Tissue, lung (optional), bone	Tissue, lung (optional), bone	Tissue, lung (optional), bone	None
Alignment markers	Metallic markers	Grid on surface	Markers on surface	Grid on surface	Metallic markers

Results

Anatomical tests and CT calibration

The TomoTherapy cheese phantom provides only verification of calculation for a homogeneous volume. Therefore its testing was limited to CT calibration with use of flexible arrangement of the 12 different calibrated materials. The possibilities for inserting ionization chambers is sufficient as well as the possibility for film measurements were also evaluated.
The Standard Imaging phantom does not provide certified materials for CT calibration. An inhomogeneous set-up is possible for dose verification measurements, but the plate structure inhibits the use of a curved beam entry surface. The possibilities for placement of ionization chamber and films for dose verification measurements are sufficient; however, measurements in bone and lung are not possible.

The Modus Medical Quasar phantom allows measurements with an anthropomorphic set-up. Ionization chamber measurements are possible in acrylic and lung volumes. Chamber holders made of lung-equivalent material are not provided. Film measurements using the film cassette are possible only in coronal and sagittal direction. As the phantom has no plate structure, the area for film measurements is limited. A CT calibration is possible, but the adaptor with a fixed arrangement of materials can not be mounted inside the phantom. The adaptors‘ dimensions are very small and it does not simulate a human body. This arrangement influences the accuracy of the CT calibration.

The Euromechanics EasyBody can be used with an anthropomorphic arrangement. Measurements with ionization chambers and films are possible, as this phantom is the most flexible due to the plate structure. Measurements in bone and lung volumes are possible, but ionization chamber holders are made only from RW3. A CT calibration is possible, but the user has to select an appropriate arrangement.

The CIRS Model 002LFC provides one set-up for all tests. The number of measurement points for ionization chambers is sufficient and the film measurements provide enough information. The shape of the phantom is simulating human torso and a CT calibration is possible. The phantom is the only one which provides ionization chamber holders made from lung and bone-equivalent materials in order to perform measurements inside these materials.

CT calibration tests for all phantoms shows similar results (see Figure C.8). A slight influence of the phantom size for dense materials can be seen. Due to the beam hardening and the energy spectrum present at the location of the material, larger phantoms will lead to a smaller CT value for a material. Therefore a realistic phantom shape similar to the human body is necessary.

Clinical commissioning test cases

The clinical test cases 1, 2 and 6, described in details in Appendix A, were used to investigate five phantoms with respect to their applicability for the clinical commissioning tests. The first test case can be performed with all five phantoms. Measurement points at the central axis (CAX) are possible for all phantoms; measurements in lung volume are possible for the CIRS 002LFC, the EasyBody and the Quasar phantoms. Only CIRS 002LFC and EasyBody phantoms allow measurements in the spine area (bone inhomogeneity). The second test case could not be performed for the Standard Imaging phantom as it has a flat surface and the

tangential wedged field can not be placed in an adequate manner. For the other phantoms the set-up with gantry angle of 90° could be realised and the use of a measurement point at the central axis is possible. For the third test case different gantry angles were used for the different phantoms. As the TomoTherapy cheese phantom does not include lung inhomogeneity the phantom was not used for this test case. The Standard Imaging phantom does not allow measurement in lung volume, nevertheless all other measurement points could be used. Figure C.8 shows the four CT calibration curves obtained

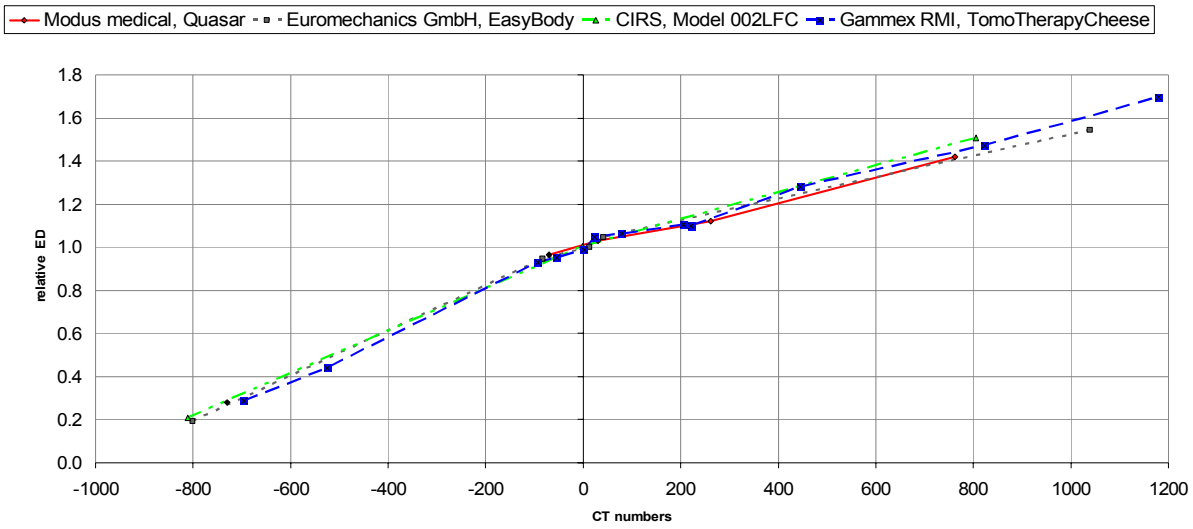


Figure C.8. CT calibration curves. A slight influence of the phantom size can be seen for dense materials. Larger phantoms lead to smaller CT values for the same material.

Summary

The phantoms differ with respect to their flexibility to be used for CT calibration and dose verification.

TomoTherapy cheese phantom provides the largest possibilities for CT calibration, but due to the lack of an anthropomorphic set-up, no testing of the inhomogeneity corrections for the clinical test cases is possible

EasyBody provides the largest number of possible measurement points, but this flexibility requires modifications of the whole set-up for CT calibration and then changing selection of measurement points. This makes the set-up fault-prone and time consuming.

Standard Imaging phantom does not include certified electron densities and lacks sufficient realistic shape for the investigated clinical commissioning tests.

Quasar phantoms` shape does not simulate well human body for CT calibration.

CIRS thorax phantom can support properly both the CT calibration and the test cases.

Recommendations

Only phantoms with an anthropomorphic geometry and removable plugs with certified electron densities are able to support full scale clinical commissioning of a RTPS. Anthropomorphic phantoms with sliced structure are suitable for film dosimetry measurements in homogenous and inhomogenous regions.

Each phantom that was investigated in this study has advantages and disadvantages for the specific tests. Clinical commissioning of RTPS that might be used in different hospitals requires a phantom with minimal restricted flexibility and easy handling. On the other hand the phantom must have the capability to perform all dosimetric and anatomical test cases. The thorax phantom is the most suitable as it provides large volume inhomogeneities, curved

surface and its large overall size allows accommodating large fields. Taking this into consideration, the CIRS phantom Model 002LFC is preferable to support clinical commissioning tests of RTPS.

APPENDIX D
THE USE OF CLINICAL COMMISSIONING TEST RESULTS IN PERIODIC QUALITY ASSURANCE OF RTPS

Introduction

The results of RTPS commissioning can be used as the reference data for the ongoing periodic QA programme that covers checks of the integrity of hardware, software and data transfer. General procedures for QC checks of RTPS are outlined in IAEA Technical Reports Series No. 430 [1] together with a reference to a test designed to perform that check, and a suggested frequency for the test. This section of the current report describes the implementation of the results of clinical commissioning tests into the practice of periodic QA for RTPS used in external radiotherapy treatment planning as recommended in TRS-430. It is based on the use of the CIRS phantom Model 002LFC. If another phantom was used for clinical commissioning tests, the recommended procedure can be adjusted to the features of that phantom. All these tests are constancy checks. The proposed periodic checks include some tests (5, 7, 9 and 11) marked as patient specific tests in TRS-430. However these constancy checks cannot replace those checks that are required to be performed for each individual patient.

The implementation results of clinical commissioning tests into periodic QC

Table D.1 is based on Table LVIII from TRS-430 where the generic checks are substituted with the specific recommendations. Checks that are marked in italic are directly reproduced from TRS 430.

Table D.1 Example of QC checks and corresponding frequencies

Subject	Test	W	M	Q	A
Hardware					
CPU	*QC Test 1*		*		
Digitizer	QC Test 2	*[1)]	*[2)]		
Plotter	QC Test 3			*	
Backup recovery	QC Test 4			*	
Anatomical information					
CT (or other) scan transfer	QC Test 5[3)]			*	
CT geometry and density check	QC Test 6			*	
Patient anatomy	QC Test 7[3)]			*	
External beam software (photons)					
Revalidation (including MU/time)	QC Test 8				*
MU/time	QC Test 9[3)]			*	
Plan details	QC Test 10[3)]			*	
Electronic plan transfer	QC Test 11[3)]			*	

W = Weekly, M =Monthly, Q = Quarterly, A = Annual. Test in italic is reproduced from IAEA Technical Report Series No. 430 [1] [1)] Sonic digitizer [2)] Electromagnetic digitizer [3)] Patient specific test according to TRS-430.

QC Test 1: CPU

Purpose:

To check that the CPU, memory, file systems, operating system are functioning optimally.

Procedure:

Restart or reboot the computer as recommended by the vendor, or as appropriate. (Unix-based systems in particular can benefit from such a reboot.) Observe screen messages during reboot to detect possible system malfunctions.

QC Test 2: Digitizer

Purpose:

To check that the digitizer sensitivity has not drifted

Procedure:

Use the procedure from clinical commissioning Case 01. Digitize the master copy of the CIRS 002LFC Front view contour using the available digitizer and compare the digitized contour with the master copy. Do this contouring manually and automatically, if possible.

Table D.2. Comparison of the parameters of the contours.

Type of the contour	**Parameters of the contours**				
	A	**B**	**C**	**D**	**E**
Master copy					
Digitized					

Compare distances A (AP diameter), B (RL diameter), C (diameter of hole #10), D (height of lung cross-section through the centres of holes #6 & #7), and E (width of lung cross-section at the level of the center of hole #5), as indicated in Figure A.1. The results of the comparison should be written into Table D.2. The deviation should be less than 1-2 mm depending on the windowing used in the image for contouring.

QC Test 3: Plotter

Purpose:

To check that plotter scaling has not drifted.

Procedure:

Plot the CIRS 002LFC Front view contour (Case 01) from QC Test 2. Compare distances A, B, C (diameter of the hole #10), D and E (cross-sections of the lung through the centres of the holes 5 and 6-7) as indicated in Figure A.1. The results of the comparison should be included into the table (Table D.3).The deviation should be within 1 mm.

Table D.3 Comparison of the parameters of the contours.

Type of the contour	Parameters of the contours				
	A	**B**	**C**	**D**	**E**
Master copy					
Plotted					

QC Test 4: Back-up recovery

Purpose:

To confirm that data that has been backed up can be recovered correctly.

Procedure:

Use the protocol normally used for backing-up patient data to back-up at least one of the clinical test cases, e.g. test case no 8. Delete the test case from the RTPS and restore the data that has been recently backed up. Check the integrity of the restored test case plan data against the known plan parameters of the test case(s).

Depending on the RTPS's back-up utility, a separate procedure may be necessary for patient data, beam data, and executables.

QC Test 5: CT transfer

Purpose:

To check that CT transfer protocols have not changed.

Procedure:

Transfer CT studies of CIRS 002LFC phantom (clinical commissioning Case 02) and verify that appropriate markers on the left, right, superior, and inferior are in agreement with the labelling on the screen (e.g., L-R, S-I).

QC Test 6: CT density/geometry

Purpose:

To check that the relationship between CT number and density, and image geometry has not changed.

Procedure:

Use as a reference the data and results of clinical commissioning Case 02. Transfer the images of the phantom CIRS 002LFC to the TPS, use TPS tools to measure densities and distances. The averaged values should be compared to the CT numbers used in CT number to RED conversion curve stored in the RTPS. Agreement within 2 mm is reasonable for distances. Agreement within 0.02 is reasonable for relative electron densities, i.e. CT numbers for a given object should not vary by more than +/- 20. If a significant change to CT number is observed and cannot be eliminated by recalibration of the CT scanner, new CT number to RED data need to be entered into the RTPS. If CT data are input using film, geometric checks

for scaling and distortion are necessary. Distortion may arise from either the CT filming process or the digitization process. Produce a film of the test phantom, making sure that the image contrast (level and window) are as before. Input the film in the usual way (e.g., CCD camera or digital scanner). If the film digitization is used for inhomogeneity corrections, bulk densities are usually assigned manually. If the RTPS automatically maps the digital matrix to densities, check that the densities are correct.

QC Test 7: Patient anatomy

Purpose:

To check that patient anatomy representation has not changed

Procedure:

Use as the reference the results of clinical commissioning for case 02 for the phantom CIRS 002LFC. Overlaying hard copy is the easiest way, providing that QC Test 3 has been done first. Agreement within 2 mm is reasonable.

QC Test 8: External beam revalidation

Purpose:

Check constancy of external beam dose calculations to safeguard against inadvertent alteration or corruption of files.

Procedure:

(1) A checksum of all the data files will show if any files have changed. If this cannot be done, an alternative is to review the directory that contains the data. Check the creation dates of files to ensure none have been inadvertently altered. If the input data have been parameterized or processed, it is the most recent data which must be checked. The raw data are of secondary importance, although they also should be maintained. The data can usually be scrutinized directly - display and print RTPS configuration and calculation model parameters and check against commissioning data.

(2) Because of the complexity of modern RTPSs, it is not practical to check every pathway in every program for corruptions, nor is it likely that such a failure will occur. However, it is good to have a standard set of plans that exercises a range of the software. It is recommended that the institution develops its own set from the set of clinical commissioning tests (select from clinical test cases 1-8), consistent with the techniques that are in use, based on the following broad principles. Use the selected set to check constancy of external beam calculations.

    Look for reproducibility, not accuracy: the result of each test should be exactly the same as the original from the commissioning results. When software has been upgraded, with new or improved algorithms, output from the new version becomes the benchmark.

    Be aware of different options – if more than one algorithm is invoked or explicitly chosen under different conditions, test all that are used.

Be sure to repeat the test plans from scratch, including the image transfer if possible, so that the entire process is checked, not just the dose calculation.

QC Test 9: Monitor units/time

Purpose:

To check that there has been no change to the RTPS's MU or time calculation.

Procedure:

For the clinical commissioning test cases selected to perform QC Test 8, use the RTPS to calculate MU or time and check for exact agreement with clinical commissioning data.

QC Test 10: Plan details

Purpose:

To check that the plan information shown on the hard copy has not changed.

Procedure:

For the clinical commissioning test cases selected to perform QC Test 8, check that the isocentre co-ordinates, details of field size, SSD, wedges, blocking, etc. are printed out exactly as before.

QC Test 11: Electronic plan transfer

Purpose:

To check that there has been no change to transfer protocols and data.

Procedure:

A standard set of test cases that exercise the most commonly-used parts of the transfer process should be maintained. Again, this could be the output from plans used in QC Test 8. This set of test transfers should be run whenever a change in data files, code, system software, or other parts of the RTPS and/or machine control systems is modified or updated.

APPENDIX E
BEAM SPECIFIC CALCULATION CHECKS

Introduction

Beam specific calculation checks may assist the user in case the differences between measured and calculated doses are outside the agreement criteria. These checks relate to single beam irradiations of water phantom under the conditions close to those used for the clinical commissioning tests. The checks were designed in such manner that the user should be able to use previously measured data and compare the results for selected points with the calculated dose values. The format of the beam specific calculation checks is similar to the acceptance dose calculation tests from IAEA report [2] and includes the check of output factors, field width and penumbra for a range of field sizes for open and wedged fields used in clinical commissioning and also a check of the doses in different parts of the water phantom for open and wedged beams.

Overview of beam specific calculation checks

The beam specific checks comprise:

- Check of output factors at the reference point (central axis at depths of d_{max} or 5 cm or 10 cm, wherever the output factors are defined) for a range of field sizes for open and wedged fields;

- Dose calculation checks for three open fields: small field size (as close as possible to 4 cm x 4 cm), 10 cm x 10 cm and a large field size (as close as possible to 25 cm x 25 cm);

  - Measurement depths to be repeated for each field size: shallow depth as close as possible to d_{max}, as well as up to five more depths of which 5 cm , 10 cm, and 20 cm depth values are recommended;

  - Dose to points on the central axis, one off-axis point within the beam edge and one off-axis point outside the beam edge;

  - Calculation of the radiological field width (50% - 50% distance) at the same range of depths;

  - Calculation of the lateral beam profile parameters (50% - 90% distance) at the same range of depths;

- Dose calculation checks for wedges that were used in clinical commissioning test cases - small field size (as close as possible to 4 cm x 4 cm), 10 cm x 10 cm and a large field size (as close as possible to 15 cm x 15 cm);

  - Measurement depths to be repeated for each field size: shallow depth as close as possible to dmax, as well as up to five more depths of which 5 cm, 10 cm, and 20 cm depth values are recommended;

  - Dose to points on the central axis, one off-axis point within the beam edge and one off-axis point outside the beam edge.

The difference between these calculated data and the corresponding measured data can be calculated and analysed in the same way as proposed in the IAEA report [2].

Detailed description of recommended beam specific calculation checks

Test preparation

The following checks require calculation of the dose at a range of locations within a water phantom. The calculated dose has to be compared to the dose obtained from the measurements at the local machine. Dose calculation checks for Co-60 radiation should be expressed in dose relative to the dose for a 10 cm x 10 cm field size, 80 cm SSD and 1 cm depth (d_{ref}). Dose calculation checks for high-energy x-ray beams should be expressed in dose (cGy) for an irradiation with 100 MU with the machines calibrated to deliver 1 Gy per 100 MU for a 10 cm x 10 cm field size, 100 cm SSD and depth of maximum dose (d_{max}). Unless otherwise indicated, the nominal SSD for all test cases is 100 cm for high-energy photon beams from linear accelerators and 80 cm for Co-60 beam.
For each check case, the operator should position the radiation beam as defined by the check case, and identify calculation points at the requested depths and off-axis distances preferably at positions where measured data points are already available. A sufficiently large beam weight should be used to ensure adequate precision of the calculated results. In other words, it is not recommended to use small beam weights if this results in the rounding or truncating of calculated doses to values having a precision of less than 1%.
In some treatment planning systems, the beam weight corresponds to the dose delivered by the beam at d_{max}, while in other systems the beam weight identifies the corresponding dose at d_{max} for the reference field size (i.e., 10 cm x 10 cm). The user should be familiar with the beam weight definition, and ensure that the calculated results are consistent with the conditions under which the corresponding measured data were obtained.
As initial step, the user is advised to define in the RTPS a cubic water phantom, 40 cm on each side. Most RTPSs allow the entry of calculation points by their co-ordinates. However, if not, it may be helpful for each test to identify points that will indicate the central axis of the radiation beam, suggested off-axis distances of 1 cm, 3 cm, 5 cm, 9 cm, and 19 cm, and suggested calculation depths of d_{max}, 5 cm, 10 cm and 20 cm[*]. In each test case the needed off-axis distances and depths are defined by the user and are based on available measured data[#] as an input into the RTPS for beam fitting.
The graphical representation of the geometries for beam specific calculation checks is given at the end of this section and similar to that described in the IAEA Report [2].

Evaluation of measurements

For the evaluation of measured and RTPS calculated values, two approaches used in IAEA report [2] may be employed:

relative error: related to measured dose, i.e.

$$Error_1\ [\%]=100*(D_{cal}-D_{meas})/D_{meas} \qquad (D.1)$$

relative normalised error: related to dose on axis at the same depth, i.e.

$$Error_2\ [\%]=100*(D_{cal}-D_{meas})/D_{meas,cax} \qquad (D.2)$$

[*] The user can select the depths according to the available measured data.

[#] If off-axis dose values have not been measured, they can be derived from the central axis depth dose curves and off-axis ratio's at corresponding depths

The recommended equations for comparison of measured and calculated data and sample criteria are given below in Table E.1.

Table E.1. Sample criteria of acceptability for external beam RTPS calculations

	Description	Test numbers	Equation for evaluation	Tolerance [%]
1	Output factors at the reference point	2,3	(D.1)	2 %
2	Homogeneous, simple geometry			
	Central axis data of square and rectangular fields	1	(D.1)	2 %
	Off-axis data	1	(D.2)	3 %
3	Complex geometry (Wedged fields, inhomogeneities, irregular fields, asymmetric collimator setting)			
	Central and off-axis data	4	(D.1)	3 %
4	Outside beam edges			
	In simple geometry	1	(D.2)	3 %
	In complex geometry (see #2)	4	(D.2)	4 %
5	Radiological field width 50%- 50% distance	1, 4		2 mm
6	Beam fringe / penumbra (50% - 90%) distance	1, 4		2 mm

Coordinate system

The following co-ordinate system is defined relative to the water phantom for clarification of beam data and test case geometry:

- The origin is at the treatment unit isocentre (see Figure E.1). For all tests except the isocentric test, the phantom surface is positioned at the isocentre.
- The Z-axis is perpendicular to the upper surface of the water phantom and directed upward from the phantom. With the exception of the oblique entry test case, the Z-axis coincides with the beam central axis and is directed toward the source.
- The X-axis is directed to the right of the Z-axis and the X-Z plane is perpendicular to the treatment unit axis of rotation.
- The Y-axis coincides with the treatment unit gantry axis of rotation and is directed toward the gantry. All calculations are done at points in the X-Z plane (Y = 0).

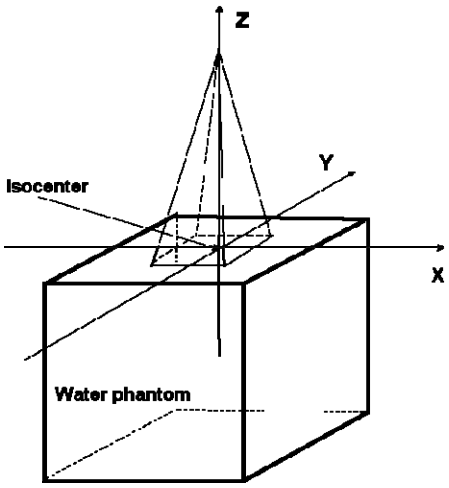


Figure E.1. Co-ordinate system for clarification of beam data and test case geometry.

Instructions for performing beam specific checks

The following detailed instructions are given to guide the user through performing the various beam checks:

(1a) Small Open Field calculation check

Using the cubic water phantom described earlier define a small square field (as close as possible to a 4 cm x 4 cm) and position the beam with the central axis normal to the upward face of the cubic water phantom (see Figure E.1). The central axis of the beam should align with any reference marks made when the water phantom was created, to facilitate the positioning of the calculation points. Set a suitable beam weight, and ensure that there are no beam modifiers in the beam (wedges, trays, etc.). Instruct the computer to calculate the dose distribution and report the doses at a depth as close as possible to dmax. Perform calculations at other depths: 5 cm, 10 cm, and 20 cm depth values are recommended. Compare the calculated data to the measurements.

Doses should also be calculated at all depths selected above at points located at equal distances from the beam central axis but which still fall within the beam. The recommended off-axis distances are ±1 cm for a 4 cm x 4 cm field size. This off-axis distance is intended to place the calculation points approximately midway between the central axis and the field edge. Additional calculation points should be placed symmetrically spaced off axis from the central axis but outside the beam. The selected distances should place the calculation points well outside the field edge, in the tail of the penumbra. The suggested off axis distances are ±5 cm for a 4 cm x 4 cm beam. The doses at these locations will only be a few percent of the doses at the same depths on the central axis. Compare the calculated data to the measurements.

(1b) 10 cm x 10 cm Open Field calculation check

Repeat check 1a using a 10 cm x 10 cm open field. Note that the calculated dose per MU at dmax should be 1.00 cGy/MU (or, for example, 1.00 Gy/min for Co-60) if this field corresponds to the calibration reference conditions. The recommended off-axis distances for this test case are 3 cm and 9 cm.

(1c) Large field size 25 cm x 25 cm Open Field calculation check

Repeat check 1a using a large field size as close as possible to a 25 cm x 25 cm open field. The recommended off-axis distances for this check are 9 cm and 19 cm.

(1d) Radiological Field Width

Calculate the radiological field width for all depths in checks 1a-c. Profiles can be calculated and exported in most treatment planning systems. Analysis of these profiles can provide the required radiological field width.

(1e) Beam Fringe / Penumbra

The distance between the points of the 50% dose and the 90% dose relative to the dose on the central axis (beam fringe/penumbra) can be assessed from all the profiles calculated in check 1d. This distance is influenced by the penumbra modeling during the beam fitting process and the short-range scatter calculation. Depending on the energy this distance will only be relevant to a certain maximum depth.

(2) Output factors at the calibration depth for open fields

In this check the output factors are calculated in points at the calibration depth for a range of field sizes for open beams: square fields with suggested dimensions of 3, 5, 7, 10, 15, 20, 25, 30 and 40 cm. These data should be compared to the previously measured data. The depth of the calculation point should be dmax, 5 cm or 10 cm, depending on the definition of the output factor.

(3) Wedge factors at calibration depth for wedged fields

In this check the calculations that were made for open fields are repeated for wedged fields. The range of field sizes has to be adjusted to the wedge characteristics of the treatment machine. Checks 3 and 4a-c should be done for the wedges used in the clinical commissioning tests.

(4a) Small Wedged Field size calculation check

The calculations for conditions listed for check 1a are repeated for a small field as close as possible to 4 cm x 4 cm for the wedges used in the clinical commissioning tests.

(4b) 10 cm x 10 cm Wedged Field calculation check

Repeat checks 4a using a 10 cm x 10 cm field for the wedges used in the clinical commissioning tests.

(4c) Large field Wedged Field calculation check

Repeat check 4b, using large wedged field with a size as close as possible to the field size for the wedges used in clinical commissioning tests. The recommended off-axis distances for this test case are +5 cm and +13 cm. The selected off-axis distance is intended to place the in-field calculation points approximately midway between the central axis and the field edge. The selected outside-of-field distances should place the calculation points well outside the field edge, in the tail of the penumbra.

(5) Other dosimetric parameters.
To accommodate all the treatment machine options, several additional dosimetric parameters have to be entered into the RTPS and properly documented:

- Tray transmission / absorption factors
- Block dimensions and transmission / absorption factors
- Collimator transmission / absorption factors
- Table / support material transmission / absorption factors.

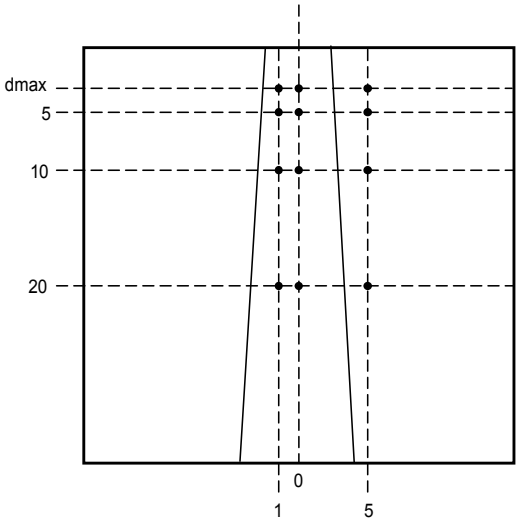
These dosimetric parameters are used in clinical commissioning tests discussed in this report and the user is advised to verify that the entered data are in correspondence with the measured values and the effect of these parameters on the result of the calculation is correct.

Evaluation and documentation

An example of a beam specific calculation check results (Excel spreadsheet) is attached to this report on the accompanying CD-ROM. This spreadsheet includes sample calculated data from RTPS, measured data and comparison results. The second attached Excel file is a blank template spreadsheet and should be used for documenting the beam specific calculation checks results. If needed, the user may modify the parameters of the comparison procedure on this blank template spreadsheet to accommodate local situations.

Graphical representation of beam checks

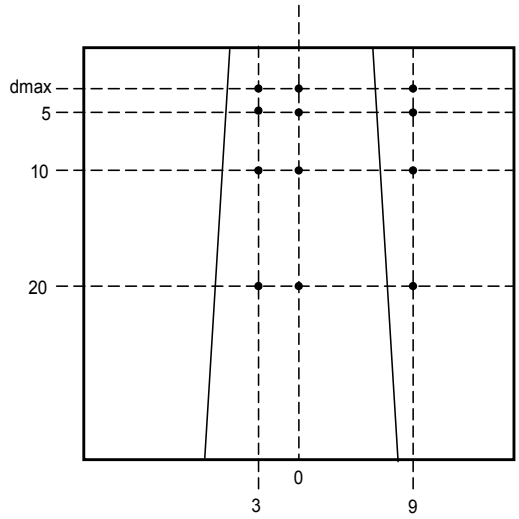
The graphical illustrations listed below may assist the user to understand the location of the points of interest as described for the various beam checks.



Check 1.a

Field size 4cm x 4 cm

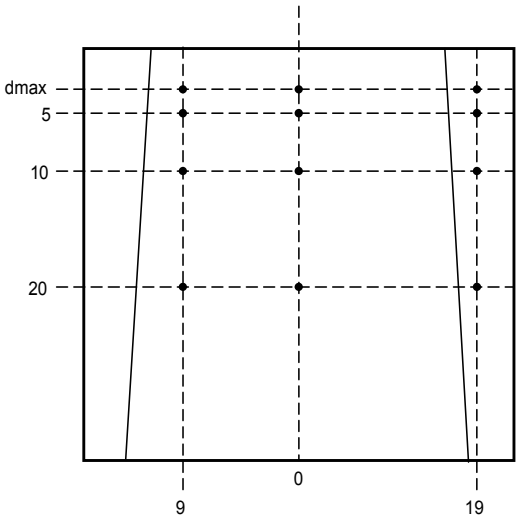
SSD = 100 cm



Check 1.b

Field size 10 cm x 10 cm

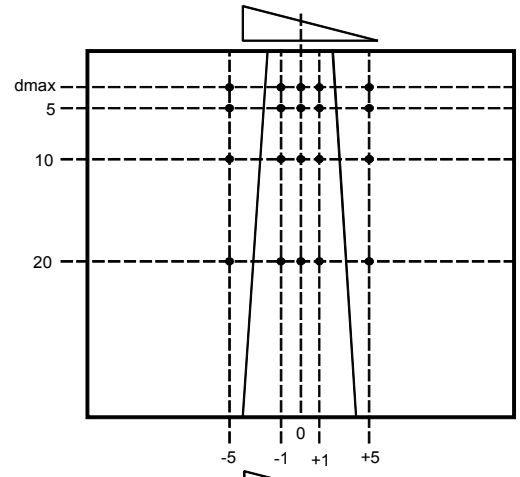
SSD = 100 cm



Check 1.c

Field size 25 cm x 25 cm

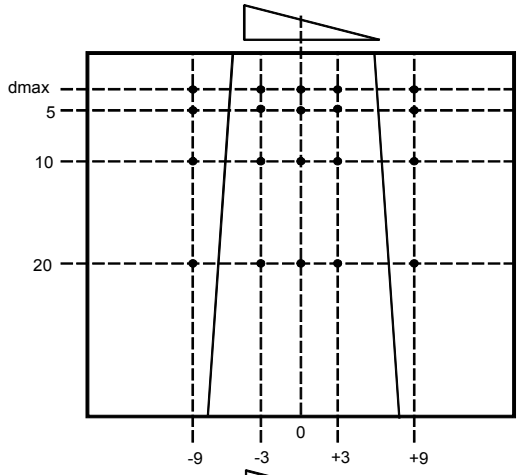
SSD = 100 cm



Check 4.a

Field size 4cm x 4cm

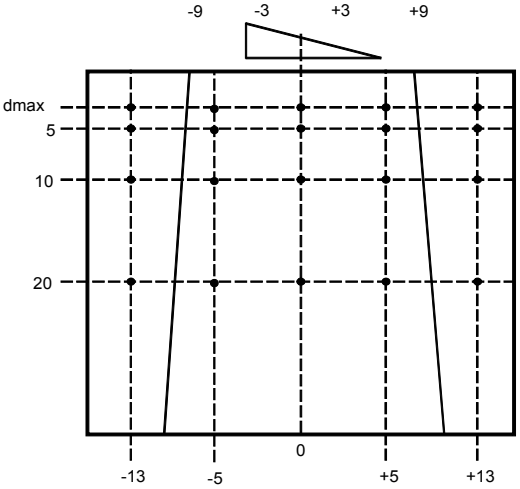
SSD = 100 cm



Check 4.b

Field size 10 cm x 10 cm

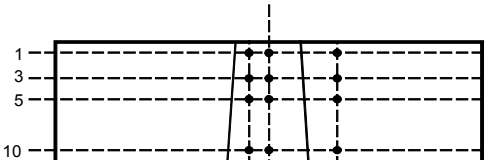
SSD = 100 cm



Check 4.c

Field size 15 cm x 15 cm

SSD = 100 cm



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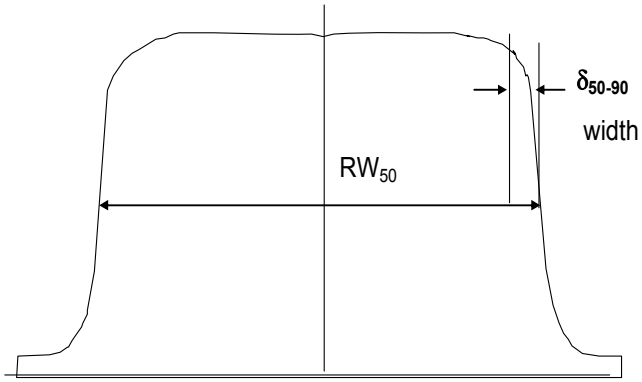
Graphical Representation of checks 1d and 1e



REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Commissioning and Quality Assurance of Computerized Planning Systems for Radiation Treatment of Cancer, IAEA TRS-430, IAEA, Vienna (2004).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Specification and Acceptance Testing of Radiotherapy Treatment Planning Systems, IAEA-TECDOC-1540, IAEA, Vienna (2007).

[3] INTERNATIONAL ELECTROTECHNICAL COMMISSION, Medical Electrical Equipment – Requirements for the Safety of Radiotherapy Treatment Planning Systems, REP. IEC 62083, IEC, GENEVA (2000).

[4] AMERICAN ASSOCIATION OF PHYSICISTS IN MEDICINE, Radiation therapy committee Task Group 65, Tissue Inhomogeneity Corrections for Megavoltage Photon BEAMS, REP. AAPM 85, AAPM (2004).

GLOSSARY

3-D conformal therapy (3-D CRT): Conformation of the high dose region to the target volume in 3-D, while minimizing dose to normal tissues (requires 3-D imaging and 3-D dose calculations).

Absolute dose: Radiation dose with units of Gy or cGy.

Acceptance: User acknowledgement that the system satisfies the purchasing agreement and specifications.

Acceptance testing: Tests performed to confirm that the system performs according to its purchase specifications.

Algorithm: Method used for a calculation – the specific steps involved in the calculation.

Algorithm implementation: The specific software used to perform the algorithm calculation.

Algorithm input data: Data required by an algorithm.

Basic beam data: Beam data for square fields at the standard SSD.

Beam model: The conceptual model used to create the dose distribution for a beam. The beam model is the basis for the algorithm which is coded into the software used for dose calculations.

Beam normalization point: The point at which each individual beam's weight is defined. This point is often defined at d_{max} or at the isocentre for the beam.

Beam weight: Dose (relative or absolute) defined at each individual beam's normalization point under given conditions. (Note, in some RTPSs, "beam weight" is only a relative strength and is not defined as precisely as the current definition).

Beam's eye view (BEV): A 3-D projection of the patient anatomy and beam geometry, from the point of view of the source of the radiation.

Bulk inhomogeneity density corrections: Dose calculations corrected for density values assigned by the user to particular structures, not directly based on CT numbers.

Clinical commissioning tests: Tests of RTPS or dose calculations related to how the system will be used clinically.

Collimation - jaws, MLC, blocks: Devices which collimate the radiation beam on the way out of the head of the accelerator, or Co-60 machine.

Collimator setting: Size of radiation field at defined (standard) distance for the machine, typically the isocentric distance.

Commissioning: All testing, data input and verification checks that are needed to get the system ready for clinical use.

Conformal field shaping (beam's eye view targeting): Conforming the shape of the irradiated field to the shape of the target in BEV.

Contour: Closed curve which describes the intersection of an anatomical structure (typically) with the plane of an image.

Coordinate system: Specification of the origin and directions of the coordinates used to describe objects.

DICOM: Digital Imaging and Communications in Medicine. A standard file format and transfer protocol for images (CT, MR, etc.).

Digitizer: Device used to convert a measured shape (e.g., contour) or image into a digital description that can be used by the computer.

d_{max}: The depth below the surface at which the central axis depth dose has a maximum.

Documentation: Computer file or paper document which describes data or procedures.

Dosimetric data: Measured doses, or distribution of doses.

Electron density, relative electron density (RED): Electron density is the number of electrons per unit volume while the relative electron density is the electron density for a particular medium divided by the electron density for water. This is important for dose calculations and is typically obtained from CT information.

Field size: Different RTPSs (and treatment systems) define "field size" in two ways. Some systems will define the field size as the size of the radiation field at the some distance in the patient, which means that the size of the radiation field at the isocentre changes with the location of the patient. More modern systems typically define the field size to be identical with the collimator setting which define the field size at the isocentre.

Hardcopy: Paper report or graphic output.

Hardware: Computer equipment.

Image: Picture-type information. In this context, usually a CT, MR or other diagnostic scan, or a digital film.

Inhomogeneity corrections: Dose calculation corrections which incorporate the effects of differing density of tissues within the patient. It is a correction applied to a water-like calculation.

Intensity modulated radiotherapy (IMRT): Use of beams which have modulated intensities (intensity of the beam is different in different regions of the beam). Often, IMRT beams are generated using inverse planning procedures.

Input data: Data required by a computer program.

Level: In image display, the numerical value which is the centre of the displayed grey scales.

Multileaf collimator (MLC): Machine collimation system which incorporates a set of computer-controlled leaves which allow the creation of user-defined beam apertures.

Model: Conceptual design for dose calculations, beam description, equipment description.

Model fitting: Defining calculation parameters so that the dose calculation results agree well with measurements.

Monitor units (MU): A numerical value, set on a treatment machine, proportional to beam intensity through the accelerator collimation system. MUs are typically calibrated to define the dose delivered to the patient under reference conditions.

Network: Interconnection of a number of computers.

Normalization: Rescaling a dose distribution to give a specified value at a defined "normalization point".

Non-dosimetric data: Parameters for the RTPS which are not related to the dose distributions (for example, definition of field size or shape or the angle co-ordinate system used for gantry angle).

Overall plan normalization: Renormalization of the dose distribution to give chosen (absolute or relative) dose at plan normalization point. Examples: set dose = 100 %, or 1.8 Gy, or 60 Gy… at the plan normalization point).

Penumbra: The region of the beam where only part of the source is seen: typically the penumbral width is defined as the edge of the beam from 80% of the central value of the beam to 20% of the value.

Periodic quality assurance: QA tests which are performed at regular time intervals.

Peripherals: Computer devices such as printers, digitizers, etc. – distinct from the main computer (CPU, hard disks, memory)

Phantom: Material used for in vitro dose measurements, such as water or solid water or an anthropomorphic phantom (resembling a human).

Pixel: "Picture element", a 2-D element of a digital image.

Plan normalization point (isodose reference point): Point (3-D co-ordinates) at which the overall plan normalization is defined.

Plan transfer: Moving the treatment plan information from the TPS to any other device.

Profile: In dosimetry, the dose measured along a line – typically across a beam.

Quality assurance (QA): Planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality.

Quality control (QC): The regulatory process through which the actual quality performance is measured, compared to existing standards and finally the actions necessary to keep or regain conformance with the standards.

Radiation treatment planning system (RTPS): Device, usually a programmable electronic system, that is used to simulate the application of radiation to a patient for a proposed radiotherapy treatment. In this context, usually the radiation treatment planning system (RTPS) consists of hardware, computer operating system, and RTPS software.

Recommissioning: Rechecking the behaviour of the RTPS after hardware replacement and software updates or upgrades.

Redundancy check: Confirmation that two methods of determining the answer give the same result.

Reference data: Data used as reference for individual system or calculation checks.

Relative dose: Dose distribution displayed in percent, relative to the dose at a particular point under defined conditions.

Slice: A planar image.

Software: Computer instructions or code.

Solid water: Epoxy-like material which has a very similar density and beam absorption characteristics as liquid water. Sometimes loosely used to describe other similar commercial products (plastic water, white water, etc.).

Specifications: Description of the limits within which a piece of equipment is supposed to work or achieve the correct answer.

Structure: A 3-D anatomical object used in a TPS, typically corresponding to an organ or a target for radiation therapy.

System software: Computer operating system software and associated ancillary computer-vendor supplied software (drivers, etc.).

Tertiary blocking: Blocking or shielding placed close to the patient, below the machine collimation system.

Tolerance: Description of variations which are acceptable.

Uncertainty: A parameter that characterizes the dispersion of values that can be obtained for a particular measurement when it is performed repeatedly.

Update: Improved version of software or hardware (typically fixing problems).

Upgrade: More significant improvement in software or hardware (typically including new functionality).

Vendor: Company which sells a product such as RTPS systems, RTPS software or hardware.

Wedge: A metal wedge-shaped absorber in the beam path to produce a dose gradient across the field (physical, hard, mechanical). Can be motorized (auto, automatic or flying wedge). A similar effect can be achieved by movement of one jaw (dynamic or virtual wedge).

Window: In image display, the difference between the limiting numerical values that the grey scale represents.

ABBREVIATIONS

AAPM	American Association of Physicists in Medicine
AP	anterior-posterior
BEV	beam's eye view
CRT	conformal radiation therapy
CT	computerized tomography
DICOM	Digital Imaging and Communications in Medicine
DRR	digitally reconstructed radiograph
ETAR	equivalent tissue-air ratio
IEC	International Electrotechnical Commission
IMRT	intensity modulated radiation therapy
MLC	multileaf collimator
MU	monitor unit
OAR	off-axis ratio
PA	posterior-anterior
PDD	percentage depth dose
QA	quality assurance
QC	quality control
RL	right-lateral
RW	radiological width
SAD	source-axis distance
SAR	scatter-air ratio
SSD	source-surface distance
TAR	tissue-air ratio
RTPS	radiation treatment planning system
2-D	two-dimensional
3-D	three-dimensional

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