RAYSTATION 12A

Beam Commissioning Data Specification

RayStation

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Declaration of conformity

CE 2862

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1 INTRODUCTION

About this document

This document is valid for RayStation 12A and describes the required input for beam modeling and machine commissioning of C-Arm LINAC treatment machines, TomoTherapy LINAC treatment machines and ion PBS treatment machines.

C-Arm LINAC treatment machines

The required parameters for photon and electron beam modeling and machine commissioning that need to be entered in RayPhysics for C-Arm LINAC treatment machines are described in *chapter 2 C-Arm LINAC treatment machines*.

The Machine and Photon Data Specification is an Excel document that contains tables of machine properties and photon measurements needed as a prerequisite for photon beam modeling and is included as an attachment to this PDF (*RSL-D-RS-12A-MPDS, RayStation 12A Machine and Photon Data Specification*).

The Electron Data Specification is an Excel document that contains tables of electron measurements needed as a prerequisite for electron beam modeling and is included as an attachment to this PDF (*RSL-D-RS-12A-EDS, RayStation 12A Electron Data Specification*).

When the required parameters in the Machine and Photon Data Specification, and the Electron Data Specification (if applicable), have been completed for one specific LINAC, they constitute all required parameters for a first commissioning of the treatment machine.

After having created a photon beam model that gives a good match to rectangular profiles and depth dose curves, the next step is to import dose curves for arbitrary test fields or to use the Beam 3D modeling module to create test plans and DICOM export dose for comparison to measurements in an external system. MLC parameters (offset, gain, curvature, leaf-tip and tongue-and-groove) must be validated and fine-tuned to ensure dose accuracy for the full range of clinical plans.

TomoTherapy LINAC treatment machines

The required procedures for commissioning TomoTherapy LINAC treatment machines are described in *chapter 3 TomoTherapy LINAC treatment machines*.

CyberKnife LINAC treatment machines

The required parameters for CyberKnife LINAC beam modeling and machine commissioning that need to be entered in RayPhysics are described in *chapter 4 CyberKnife LINAC treatment machines*.

The CyberKnife Machine and Data Specification is an Excel document that contains tables of machine properties and measurements needed as a prerequisite for beam modeling and is included as an attachment to this PDF (*RSL-D-RS-12A-CKMDS, RayStation 12A CyberKnife Machine and Data Specification*).

To be able to use a CyberKnife machine model to create treatment plans in RayStation, a RAMP file for the specific LINAC also needs to be imported.

PBS treatment machines

The beam data requirements for beam modeling a generic PBS treatment machine in RayPhysics are described in *chapter 5 PBS treatment machines*. This chapter only covers the requirements for the beam modelling of the treatment machine. Additional machine parameters need to be entered in RayPhysics in order to commission the treatment machine described in the *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual*.

About beam modeling and treatment machine commissioning

Treatment machine commissioning is the procedure where a machine is created in RayPhysics to later be used in treatment planning in RayStation. The process includes defining machine hardware properties, such as geometrical specifications, importing measured beam data (dose profiles, etc.), manually or automatically editing beam model parameters and finally approving the machine for treatment planning in the machine commissioning step. The machine properties together with the beam model parameters make up the complete data set for the treatment machine.

One important part of the treatment machine commissioning procedure is the beam modeling step, where the user adapts the model to the characteristics of a specific individual treatment machine by changing beam model parameters using manual or automatic tools until computed dose curves match the imported data.

In this document

The following information is included in this manual:

- **Chapter 1 Introduction** - An introduction to the purpose and contents of this manual.
- **Chapter 2 C-Arm treatment machines** - Describes the required parameters for photon and electron beam modeling and machine commissioning that need to be entered in RayPhysics for C-Arm LINAC treatment machines.
  - **Section 2.1 Coordinate systems and curve formats** - Describes the dose curve coordinate system in RayPhysics and the accepted curve formats.
  - **Section 2.2 Machine setup** - Lists data required for machine setup and machine editing.
  - **Section 2.3 Photon measurements** - Describes basic requirements for the photon scan data needed for beam modeling. The effective parameters in the beam model are listed in *section 2.3.4 Effective parameters for modeling computations on page 25*.
  - **Section 2.4 Electron measurements** - Describes procedures for acquiring electron beam data needed to create a beam model for the Monte Carlo electron dose calculation in RayStation.
- **Chapter 3 TomoTherapy LINAC treatment machines** - Describes the procedures required for commissioning TomoTherapy LINAC treatment machines.

- **Chapter 4 PBS treatment machines** - Describes the beam data needed to create a beam model for PBS ion treatment machines.

Contact information

For any questions regarding the contents of this document, please contact RaySearch Support, support@raysearchlabs.com.

2 C-ARM LINAC TREATMENT MACHINES

This chapter describes the machine parameters and measured data which is required and need to be entered in RayPhysics before starting photon and electron beam modeling when commissioning C-Arm LINAC treatment machines.

In this chapter

This chapter contains the following sections:

2.1 COORDINATE SYSTEM AND CURVE FORMATS

This chapter describes the dose curve coordinate system in RayPhysics and the accepted curve formats. Refer to *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual* for detailed information on definitions and the coordinate systems.

In this section

This section contains the following sub-sections:

2.1.1 Dose curve coordinate system in RayPhysics

The Beam Commissioning module has a dose curve coordinate system corresponding to the IEC gantry coordinate system, translated so that the origin is on the central axis at the surface of the water phantom. The x-axis is aligned with the cross-line axis. The y-axis is aligned with the inline axis, with the positive direction towards the gantry. The negative z-direction, from source towards isocenter, is aligned with the depth direction. The gantry and collimator angles are always assumed to be zero degrees for the dose curves in the Beam Commissioning module. The model is fully reflection symmetric in the xz- and the yz-plane, whereas measurements can sometimes be mildly asymmetric.

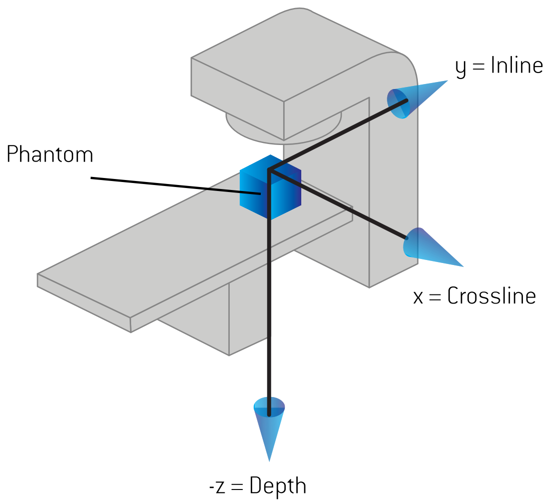


Figure 1. The dose curve coordinate system.

2.1.2 Accepted curve formats

- RFA (.asc)
- Comma-separated values (.csv)
- Mephysto (.mcc)
- Sun Nuclear (.snctxt)
- Brainlab Monte Carlo (.xmcdat), photons only

For information about format for ions, see *section 5.2 Accepted curve format on page 65*.

The dose curve formats are described in more detail in *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual*.

2.2 MACHINE SETUP

This section summarizes the required machine properties for commissioning of the treatment machine.

The *RSL-D-RS-12A-MPDS, RayStation 12A Machine and Photon Data Specification* is included as an attachment to this manual and can be used as an aid in the machine setup. All other coordinate systems not specified in the Photon Data Specification are according to IEC 61217.

In this section

This section contains the following sub-sections:

2.2.1 Machine setup parameters

The following machine setup parameters should be entered in RayPhysics. The *RSL-D-RS-12A-MPDS, RayStation 12A Machine and Photon Data Specification* can be used as an aid when entering these parameters.

- General parameters
- Geometric parameters
- Jaw parameters
- MLC parameters. For more information, see MLC parameters below.
- Dose rate parameters
- Arc properties (when applicable)
- Block parameters (when applicable)
- Wedge and cone parameters (when applicable)
- DICOM parameters

All parameters which define a physical position or opening, for example MLC minimum tip position and cone diameter, are given on the isocenter plane.

2.2.2 MLC parameters

MLC Leaf Center Positions and Widths should be specified in the Photon Data Specification. MLC leaf center positions are given as y-coordinates in the IEC 61217 beam limiting device coordinate system (x-coordinates for machines with MLC type Y).

Limits on leaf tip positions are given for the X2 leaf bank according to IEC 61217 naming convention (Y2 leaf bank for machines with MLC type Y). Positive values are open positions, zero is aligned with the isocenter and negative values overtravel the central position. The minimum position should be a numerically lower value than the maximum position. The limits for the opposite leaf bank are assumed to be reflection symmetric.

Minimum leaf/jaw overlap: The minimum overlap between the tip of the overtravelling leaf and the opposing jaw when hiding closed leaf pairs behind the jaw.

Use minimum dynamic tip gap for static fields: If checked, the Minimum dynamic tip gap will be applied to all leaf pairs that move between segments within a beam. For some machines this reduces interrupts during delivery of a static beam. Closed leaf pairs that do not move will be placed using the Minimum static tip gap.

Fill in the applicable MLC parameters in the *RSL-D-RS-12A-MPDS, RayStation 12A Machine and Photon Data Specification*.

2.3 PHOTON MEASUREMENTS

This chapter summarizes the required measurements for photon beam modeling.

The *RSL-D-RS-12A-MPDS, RayStation 12A Machine and Photon Data Specification* is included as an attachment to this manual and can be used as an aid when collecting the measurements needed for photon beam modeling. All coordinate systems not specified in the Photon Data Specification are according to IEC 61217.

In this section

This section contains the following sub-sections:

2.3.1 Measurement data - rectangular fields

All measurements must be made with the same SSD. Measurements must also be made with gantry and collimator at angles 0 degrees in IEC 61217 coordinate systems (un-rotated).

The following setup conditions will be used by RayPhysics for computation during the modeling and have to be specified:

- Depth dose curves on the central axis
- Profiles (X, Y and diagonal)
- Output factors
- Absolute dose calibration point for reference field size

Depth dose curves and x- and y-profiles

Depth dose curves for a particular field may be included in the data set without corresponding profile also being included. Profiles on the other hand require the corresponding depth dose curve to be included. One reference field in the range of 9 – 11 cm is required, all other field sizes optional – but important to cover the range of clinically relevant field sizes that will be used for treatment planning.

Recommendations of depths for profile measurements:

- D_{max}
- 5 cm
- 10 cm
- 20 cm

It is not a requirement to measure both inline and crossline profiles, but it is strongly recommended.

All depth dose curves and profiles to be included should be listed in the Photon Data Specification together with their respective output factors, detector model, detector dimensions, and for depth dose curves what depth offset has been applied before saving the curves to file (if any).

Diagonal profiles

It is also strongly recommended to import at least one diagonal profile for the largest supported field size to correctly model the field corners. Diagonal profiles at several depths can be imported. If only one diagonal profile is imported, it is recommended to use a depth well below the build-up region. The diagonal profiles may have an arbitrary angle. It is not possible to import diagonal profiles in *.xmcdat format.

Only diagonal profiles that cross the central axis are supported.

Place the phantom so that a scan can be made all the way past the corner along a diagonal. Use the diagonal profiles to tune the beam profile correction to recreate the corners which are generally cut off due to the primary collimator.

Output factors

Depth dose curves and profiles shall be complemented with:

- Output factors, normalized at the reference field, for every field size present among the depth dose curves.
- Depth at which output factors were measured. (10 cm suggested for energies up to 15 MV, deeper for higher energies e.g., 15 cm for 18 MV)
- Wedge factors for wedged fields, including EDW and Siemens virtual wedge. Note that for every wedged field that is measured, a corresponding output factor for a same size open field is also required. For details, refer to *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual*.
- Cone factors for each supported cone size.

Field setup for measurements

Section *Rectangular field interpretation* in *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual* describes the rectangular field interpretation used during dose curve computation in the Beam Commissioning module in RayPhysics. When performing measurements, it is necessary to define the setup of the fields on the LINAC's treatment console, exactly the same as they will be interpreted in Beam Commissioning. This applies to all measurements: depth dose curves, profile curves, output factors and absolute calibration.

Guard leaves in field setup

Special attention must be paid to applying a correct number of guard leaves for machines where the y-jaw is positioned downstream of the MLC. If the machine utilizes guard leaves, a number of leaf pairs under the y-jaw must be opened, such that the distance between the jaw position and the edge of the first closed leaf pair is at least equal to the user-specified **Guard leaves distance** in the machine model (see section *Guard leaves* in *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual*). These leaf pairs are placed at the same x-positions as the outermost exposed leaf pair on the same side of the field. If no guard leaves are used in the machine model in RayPhysics, no additional leaf pair should be opened when performing the measurements.

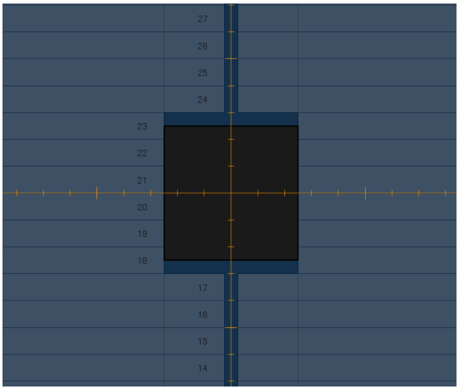
To visualize the field setup used in Beam Commissioning for the user-defined **Guard leaves distance**, a rectangular field can be created in RayStation planning or in the Beam 3D modeling module in RayPhysics.

Note: *There was a change in guard leaves behavior in RayStation 10B compared to previous versions. For most machines and field sizes, the field setup in Beam Commissioning is not affected by this change.*

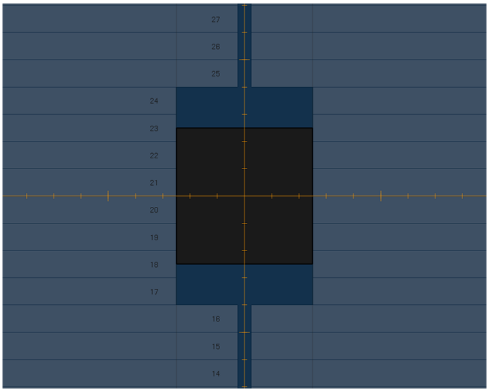
In versions prior to RayStation 10B, there was no user-defined Guard leaves distance in the machine model, but one guard leaf pair was applied for the rectangular field setup in the Beam Commissioning module. There was an exception to this for machines and field sizes where the half of the field size in the direction perpendicular to leaf movement was not equal to an integer number of leaf widths. In that case, no extra leaf pair was opened in addition to the outermost leaf pair which was partly covered by the jaw.

In RayStation 10B and later versions, the user-defined Guard leaves distance was introduced. For a machine that uses guard leaves with the guard leaves distance set to one leaf width, for fields where the half field size in the direction perpendicular to the movement of the leaves is not equal to an integer number of leaf widths, one guard leaf pair will be opened in addition to the outermost leaf pair partly covered by the jaw. This is in accordance with the definition of the user-defined Guard leaves distance.

When upgrading from earlier versions to RayStation 10B or later, these particular field sizes should be re-measured using the current Guard leaves distance definition, and curves measured with a setup corresponding to the old guard leaves behavior should be replaced by the new ones in the Beam Commissioning module. An example of the changed behavior is shown in Figure 2.



A) RayStation versions before 10B.



B) RayStation 10B and later versions.

Figure 2. Guard leaves behavior for field sizes where the half field size in the direction perpendicular to the movement of the leaves is not equal to an integer number of leaf widths. A) shows RayStation versions before 10B, where no extra leaf pair is opened when the outermost open MLC leaf pair is partly covered by the jaw. B) shows RayStation 10B and later versions, where the user-defined **Guard leaves distance** is set to one leaf width, and one leaf pair is opened in addition to the partly covered leaf pair.

Measurement conditions

Depth dose curves and profiles shall be complemented with:

- Detector type.
- Dimensions (height and width for active volume) of detectors used for measuring curves. Note that relevant height and width shall correspond to the detector orientation that was used during measurements.
- The depth offset that has been applied to the depth dose curves before export (if any). The offset is the distance from the detector reference point to the effective point of measurement used for the coordinates in the dose curve files. A shift towards the surface corresponds to a negative offset (typical for ionization chambers).
- Information on how the measured fields were collimated, either by MLC only, Jaws only or Jaws and MLC. All measurements per beam quality must be collimated the same way. If some fields are measured for different conditions than others, a separate machine must be created to properly model these.

  If the MLC only option is used for a machine with both X and Y jaws and the jaws positioned above the MLC (for example Varian machines), it is recommended to not position the jaws fully retracted and to not use the same jaw field size for all field sizes. Instead, position the jaws only at a slightly larger field size than the MLC, for example retracted 0.5–1 cm.

  For fixed jaw machines, closed leaf-pairs should be parked at a distance of the minimum leaf/jaw overlap behind the x-jaw border both for the MLC only option and for the Jaws and MLC option.

  If measurement data is on the *.xmcdat format, this information is not needed since MLC and jaw field sizes are read from the file. The nominal field size is set to the minimum opening of MLC and jaws. It is not possible to select another field collimation.

  The phantom size entered should correspond to the side of a cubic water phantom.

2.3.2 Measurements for arbitrary fields

Any photon beam with gantry and couch angle zero degrees which does not have blocks, wedge or cone can be copied to a list of fields in the patient database which will be available in the Beam commissioning module for dose curve calculation. The same curve types as for rectangular fields are supported (depth, x-profiles, y-profiles, diagonal profiles). It's possible to import profile curves without corresponding depth dose curve. Supported dose curve formats for arbitrary field curves are *.asc, *.csv, *.mcc and *.snctxt. All dose curves belonging to a specific arbitrary field must be measured with the same SSD, but the SSD is not required to match the SSD of the rectangular fields and dose curves belonging to different arbitrary fields can have different SSD. For each dose curve belonging to an arbitrary field, a scale factor is needed which scales the dose values in the dose curve file to absolute dose in cGy.

The same measurement conditions as for rectangular fields are applied to dose curves for arbitrary fields as well, except for collimation settings (MLC only, Jaws only or Jaws and MLC collimated).

Comparing measured and computed dose curves for arbitrary test fields will help the modeling of for example MLC parameters, which are difficult to see the effect of with only rectangular fields.

Refer to *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual* for more information about administration of the arbitrary fields list.

2.3.3 Detector selection

PDDs for fields ≥ 4 × 4 cm^2 should be measured with a medium air-filled ionization chamber to avoid effects from variation in energy response (*AAPM TG-106 Report, Das et al 2008*). For smaller fields, high-resolution detectors such as small volume ion chambers, diodes or diamond detectors should be used.

For profiles, high-resolution detectors should be used to minimize blurring in penumbra regions. Use the same detector for output factor measurement as for the PDD. Absolute dose calibration should be made with a calibrated ionization chamber.

Since the measured PDDs are used to normalize the measured profiles in RayPhysics, these should either be measured with the same detector, or the detector widths must both be chosen such that they give the same dose to the central axis.

For details on detector selection, we recommend the *AAPM TG-106 Report (Das et al 2008)* and the *IAEA TRS 483* for small field dosimetry, as well as specifications from the detector manufacturer.

Enter in the Measurement and dosimetric calibration data in the Photon Data Specification. In addition, enter the required Photon Scan Summary information in the Photon Data Specification.

2.3.4 Effective parameters for modeling computations

The parameters in this section are effective parameters entered in the **Fluence** tab during beam modeling and may all be adjusted during modeling. Enter reasonable starting values, close to the real physical values, or start with a RayStation template machine and ensure that the values are reasonable for your LINAC.

The MLC transmission used in the beam model is the average transmission. No interleaf leakage is taken into account for leaf edges that are not exposed. The jaw transmission for the jaw perpendicular to the MLC movement direction is always 0 and cannot be edited.

Enter the effective parameters for modeling computations in the *RSL-D-RS-12A-MPDS, RayStation 12A Machine and Photon Data Specification*.

2.3.5 Photon scan summary and measurement conditions

Enter the depth dose curves and profiles to be used for the photon beam modeling together with the respective output factors, and measurement conditions in the *RSL-D-RS-12A-MPDS, RayStation 12A Machine and Photon Data Specification*.

One example of these tables should be filled in for every beam quality and every wedge angle.

Table 2.1: Example: PDDs and Profiles open fields for beam quality of 6 MV.

Field size [cm x cm]	Type (PDD/ Profiles)	Detector height [cm]	Detector width [cm]	Applied depth offset [cm]	Detector model	Output factor
10 × 10	PDD	0.55	0.56	0	CC13	1.000

2.4 ELECTRON MEASUREMENTS

This section describes the procedures for acquiring beam data needed for the beam modeling of the electron dose calculation in RayStation. The specifications are valid for standard C-arm linear accelerators equipped with applicators with cutouts (Varian Clinac series, Elekta Versa HD/Synergy/Precise and Siemens Primus etc.)

The beam modeling procedure requires measurements of electron beams delivered with an applicator and electron beams delivered without an applicator. The former will in the following document be referred to as 'applicator measurements' and the latter as 'open measurements'.

The *RSL-D-RS-12A-EDS, RayStation 12A Electron Data Specification* is included as an attachment to this manual and can be used as an aid when collecting the measurements needed for electron beam modeling. The Electron Data Specification is a worksheet for a given energy and a given linear accelerator head (Elekta Agility, Elekta MLCi/MLCi2, Elekta Beam Modulator, Varian and Siemens). The worksheet needs to be completed for each energy.

In this section

This section contains the following sub-sections:

2.4.1 Open water depth dose

Per nominal beam energy one open water depth dose curve is measured without the applicator mounted. The collimators (jaw(s) and MLC) should be maximally retracted. The measurement must be performed at SSD = 100 cm.

As most linear accelerators have interlocks prohibiting electron beam delivery without an applicator mounted, open field measurements typically must be done in service or physics mode following special procedures.

Fill in the applicable grey fleids in the Water profiles tab in *RSL-D-RS-12A-EDS, RayStation 12A Electron Data Specification*.

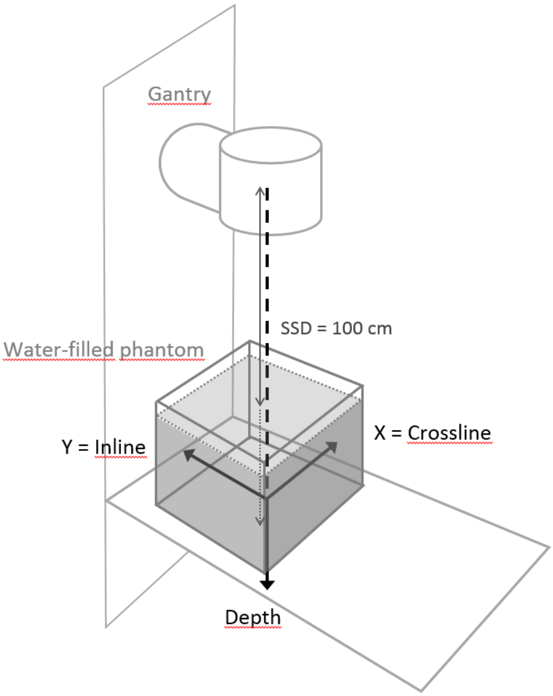


Figure 3. Open water depth dose measurement at SSD = 100 cm.

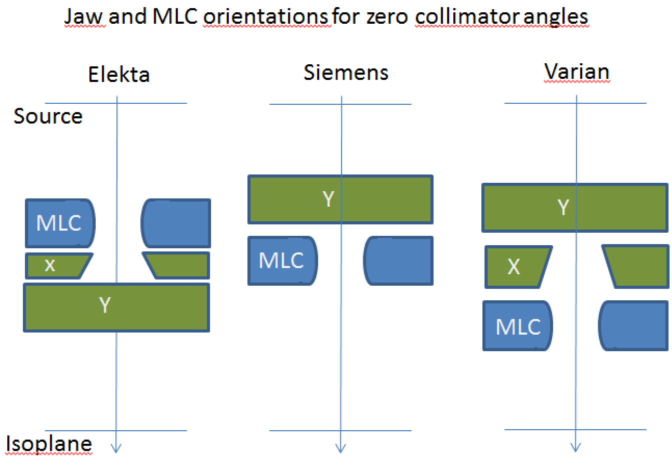


Figure 4. Jaw and MLC orientations for zero collimator angles. The figure shows schematically the locations and orientations of the jaws and the MLC for LINACs described in this document.

2.4.2 Applicator water dose

For all measurements in water SSD = 100 cm must be used. All angles (collimator, couch and gantry) should be zero degrees in IEC 61217 coordinate systems. The pre-programmed and fixed settings of the jaws and MLC should be reported for all energy and applicator combinations in the Water profiles tab in *RSL-D-RS-12A-EDS, RayStation 12A Electron Data Specification*.

All scan measurements must be converted to dose, i.e., ionization measurements must be converted with whatever dosimetry protocol is customary.

Measurements are to be performed without a cutout mounted in the applicator. Applicators from some vendors (Elekta and Varian) are provided with a 'factory cutout' that defines the nominal field size. If this is the case, the applicator should be used with the factory cutout in place.

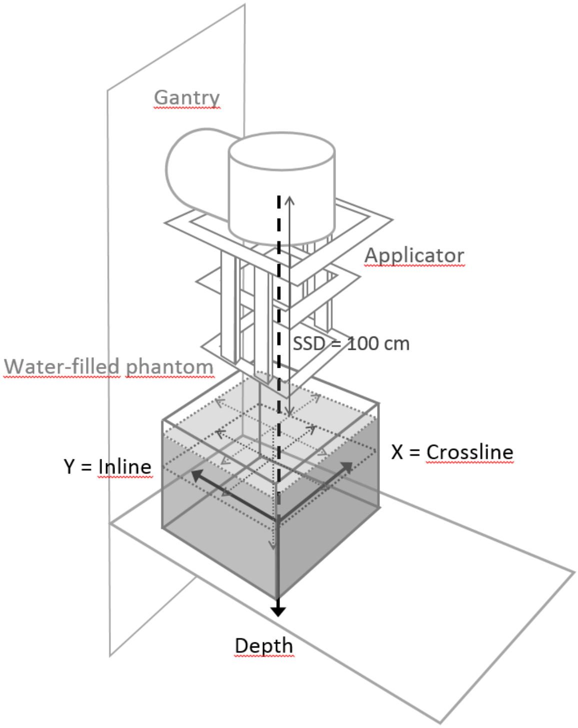


Figure 5. Applicator water dose measurements at SSD = 100 cm and different SDD.

Applicator water depth dose

For each energy and applicator, a depth dose curve measurement is required. The depth dose curves must extend beyond the depth of the Bremsstrahlung scan (*Applicator x- and y-water profiles on page 31*). The depth dose measurements should have a resolution not exceeding 0.1 cm for lower energies (= 6 MeV) but may be increased to 0.2 cm at higher energies.

Applicator x- and y-water profiles

For each energy and applicator, x- and y-water profiles are measured at a shallow depth (high dose region) and at a large depth (beyond the electron practical range, in the photon Bremsstrahlung region) as specified in the tables below. Outside the field the scans should extend at least 4 cm on each side of the field edge. The lateral resolution may vary along the profile scans but in high gradient regions such as the field edges the scan step should not exceed 0.2 cm. In low gradient regions the scan step may be increased to 0.4 cm.

Table 2.2: Suggested depths for shallow x- and y-water profiles

Electron energy [MeV]	Profile depth [cm]
4 MeV ≤ E ≤ 6 MeV	1.0
6 MeV < E ≤ 15 MeV	2.0
15 MeV < E ≤ 25 MeV	3.0

Table 2.3: Suggested depths for Bremsstrahlung region x- and y-water profiles

Electron energy [MeV]	Profile depth [cm]
4 MeV ≤ E ≤ 6 MeV	5.0
6 MeV < E ≤ 15 MeV	10.0
15 MeV < E ≤ 25 MeV	15.0

Applicator water dosimetry calibration data

For each combination of energy and applicator the absolute dose per fixed number of monitor units should be reported. Note that it is required that the dosimetry calibration data is specified for SSD = 100 cm. Fill in the fields highlighted in grey in the Water profiles tab in *RSL-D-RS-12A-EDS, RayStation 12A Electron Data Specification*. The recommended depths for the absolute dosimetry data should be according to the relevant nationally recommended dosimetry protocol.

2.4.3 File name specification

We strongly recommend using a file name naming convention for electron scan files following the description below.

The file names are constructed from a beam type acronym and a scan type acronym together with particle type (E), energy (ee) and collimation type (c) according to:

Eee_cxxyy_zzz.pp_ddd

Parameter	Description
E	The letter E is used for electrons.
ee	The nominal energy ee (integer) is replaced by the nominal energy, e.g., 6 or 06 for a 6 MeV electron beam.
c	The letter c represents the collimating type and can be: • A - an applicator mounted • U - uncollimated, i.e., no applicator.
xxyy	Field size at isocenter distance along the x-axis and y-axis in the Beam Data coordinate system. For applicators, the nominal field side in the X- and Y-direction should be used where X is cross plane.
zzz	SSD in cm.

Parameter	Description
pp	Type of profile: • D - Depth dose • PX - Profile scan in the x direction • PY - Profile scan in the y direction
ddd	Depth in mm for the scan (omitted for a depth dose scan).

Field sizes are given in cm (using integers) at the isocenter, whereas are given in mm. If an applicator is used, the nominal field size is stated.

The combination of keywords is best described by examples as follows:

Example	Description
E12_A0606_100.D	Central axis depth dose for a 6 cm × 6 cm applicator in a 12 MeV electron SSD = 100 cm beam.

Example	Description
E15_A2020_100.PX_020	Profile scanned along the x-axis at 20 mm depth for a 20 cm × 20 cm applicator in a 15 MeV electron beam.

2.4.4 Additional specifications

The following data is also required:

- Detector type(s) used. For the water scans we do not specify any particular detector to be used. The user may use different detectors as long as the data is converted to dose and the detector size is adequate with respect to local gradients (i.e., do not use a large IC to capture dose in high gradient regions). Use the *RSL-D-RS-12A-EDS, RayStation 12A Electron Data Specification* to fill in the Detector fields highlighted in grey.
- The applicator type/model in the Water profiles tab in *RSL-D-RS-12A-EDS, RayStation 12A Electron Data Specification*.
- Cutout thickness in the Water profiles tab in *RSL-D-RS-12A-EDS, RayStation 12A Electron Data Specification*.

Note that the value for cutout photon transmission cannot be obtained from the beam commissioning measurements alone. The cutout is made of an intermediate-Z alloy with low melting point such as cerrobend. How much of the photon energy fluence that passes through the cutout must be gathered from material specifications or supplementary measurements such as from semi-blocked fields.

2.4.5 Sample data set

The following list shows a complete set of scan files for a 12 MeV beam for a Varian accelerator with 6 × 6, 10 × 6, 15 × 15 and 25 × 25 applicators.

```
E12_A0606_100.D.asc
E12_A0606_100.PX_020.asc
E12_A0606_100.PX_100.asc
E12_A0606_100.PY_020.asc
E12_A0606_100.PY_100.asc

E12_A1006_100.D.asc
E12_A1006_100.PX_020.asc
E12_A1006_100.PX_100.asc
E12_A1006_100.PY_020.asc
E12_A1006_100.PY_100.asc

E12_A1515_100.D.asc
E12_A1515_100.PX_020.asc
E12_A1515_100.PX_100.asc
E12_A1515_100.PY_020.asc
E12_A1515_100.PY_100.asc

E12_A2525_100.D.asc
E12_A2525_100.PX_020.asc
E12_A2525_100.PX_100.asc
E12_A2525_100.PY_020.asc
E12_A2525_100.PY_100.asc

E12_U4040_100.D.asc
```

3 TOMOTHERAPY LINAC TREATMENT MACHINES

This chapter describes the required procedures for commissioning of TomoTherapy LINAC treatment machines.

In this chapter

This chapter contains the following sections:

3.1 PREPARATIONS

Background

The absolute output of a TomoTherapy treatment machine beam model in RayStation needs to be checked and if necessary adjusted as part of the beam modeling process. The dose computation for TomoDirect and TomoHelical plans uses the same beam model, and the calibration procedure covers both techniques. The output can only be verified by comparing measurements of TomoHelical plans optimized in RayStation to computed dose. The comparison must be done for all different field widths supported by the machine.

Create a commissioned temporary treatment machine

First, the corresponding machine must be imported from iDMS to get the correct machine IDs and then the machine must be commissioned in RayPhysics so that it can be used in RayStation to create test plans. Note that this commissioned machine only is temporary and needed in order to create the test plans in RayStation. It is recommended to give the temporary machine a name that reflects that it is not for clinical use. After creating and evaluating the test plans, the temporary machine needs to be replaced with an adjusted machine as described in *section 3.4 Update the beam model and commission the new machine on page 46*.

For more information about iDMS import and machine commissioning, refer to the *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual*.

3.2 CREATING THE TEST PLANS

After the temporary machine has been created, the test plans can be created. Another prerequisite is to have CT data of the cheese phantom imported into RayStation.

In this section

This section contains the following sub-sections:

3.2.1 Create ROIs and POIs

Prior to creating the test plans, a number of Regions of Interest (ROIs) and one or more Points of Interest (POIs) need to be created in the Patient Modeling module:

1. Create an External ROI for the phantom (dark green in Figure 6).
2. Set a material override on the External ROI. If CT densities are used, only materials found in the human body are considered when mapping to a material from HU values. The plastic material in the cheese phantom is not very similar to human tissue, and it is therefore recommended to use a material override instead of CT density. Refer to *RSL-D-RS-12A-USM, RayStation 12A User Manual* for more information about setting a material override, and *RSL-D-RS-12A-REF, RayStation 12A Reference Manual* for information about density handling in the collapsed cone dose engine. See *Selecting material override for the cheese phantom on page 40* for guidelines on selecting the correct material override.
3. Create Support ROIs to account for the attenuation of the beam through the treatment couch (orange and pink in Figure 6).
4. Create a cylinder ROI (radius 3 cm and length 8 cm), make it a target and give it the name "PTV1". Repeat this for another target ROI and call it "PTV2". One target ROI (cyan in Figure 6) is located in the center of the phantom, the other is centered 8 cm off axis in the left-right direction (dark blue in Figure 6).
5. Create an organ ROI of the same shape and size and call it "OAR". The OAR ROI is centered 8 cm below the center of the first target (yellow in Figure 6).
6. Create a ring ROI called "PTV1 ring" around "PTV1" and another ring ROI called "PTV2 ring" around "PTV2". A ring ROI is created by using the ROI algebra tools as described in *RSL-D-RS-12A-USM, RayStation 12A User Manual*. Let the outer radius of the ring ROIs be 3.8 cm and the inner radius 3.3 cm.
7. Create a POI of type **Localization point** which is needed to export the plan to iDMS. The **Localization point** POI corresponds to the red laser, refer to the *RSL-D-RS-12A-USM, RayStation 12A User Manual* for more information.
8. It is also recommended to create either a POI or a small ROI in the points within each target ROI where dose will be measured. If the detector to be used for the measurement cannot be considered point like, it is recommended to define an ROI around the volume that will be occupied by the active chamber volume.

Selecting material override for the cheese phantom

The cheese phantom comes in two versions:

- Med-Cal Virtual Water Tomo-Phantom
- Sun Nuclear High Equivalency Solid Water Tomo-Phantom HE

Older treatment machines came with the Med-Cal Tomo-Phantom, but recently the change has been made to use the Sun Nuclear Tomo-Phantom HE instead, and newer machines come with this one.

These two versions have different material properties, and it is important to set a material override matching the correct phantom.

The Med-Cal Tomo-Phantom is reddish-brown in color, and has three fiducials distinguishable in CT images. The Sun Nuclear Tomo-Phantom HE is blue in color, and has four fiducials. The fiducials are embedded into the phantom surface in the central transverse slice in one half of phantom.

The reddish-brown Med-Cal Tomo-Phantom is made of Virtual Water material with elemental composition specified by McEwen et al. [1]. This matches the Virtual Water material found among the RayStation pre-defined materials, which is a suitable material override for this version of the cheese phantom.

The blue Sun Nuclear Tomo-Phantom HE is made of High Equivalency Solid Water with material properties specified in Araki [2]. This material is not included among the RayStation pre-defined materials. One option is to create a new common material with the material composition described in Araki. The other option is to use Water as material override. The High Equivalency Solid Water very closely approximates the attenuation of water, with electron density relative to water specified by the manufacturer as 1.000 ± 0.005. The collapsed cone dose engine uses an effective density, which is a slightly adjusted version of the electron density (see *RSL-D-RS-12A-REF, RayStation 12A Reference Manual* for more information). For the standard Tomo energy spectrum, the effective density relative water for the High Equivalency Solid Water material is 1.0019, which gives minimal differences in dose compared to using Water as material override.

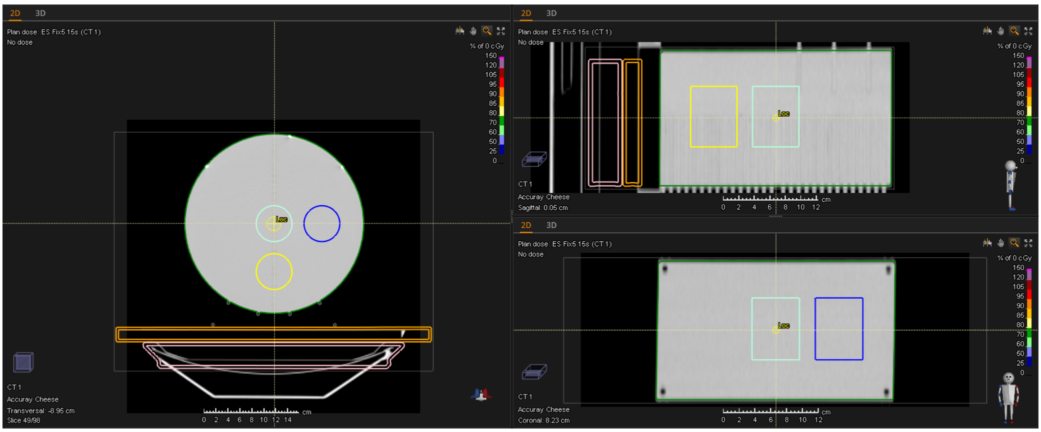


Figure 6. The figure displays the cheese phantom with ROIs in the Patient Modeling module.

1 McEwen MR, Niven D. Characterization of the phantom material virtual water in high-energy photon and electron beams. Med Phys. 2006 Apr;33(4):876-87.
2 Araki F. Dosimetric properties of a Solid Water High Equivalency (SW557) phantom for megavoltage photon beams. Phys Med. 2017 Jul;39:132-136.

3.2.2 Create the test plans

Once the ROIs and POIs have been created, the test plans can be created in the Plan Setup module:

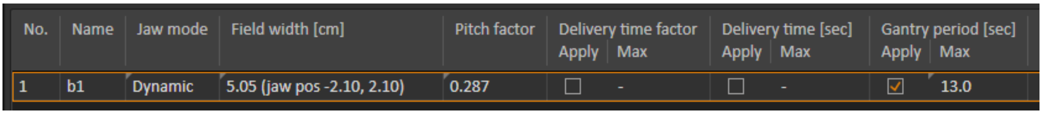
1. Create a TomoHelical plan with 50 fractions for each of the following configurations:

    - **Jaw mode** Fixed, **Field width** 1 cm
    - **Jaw mode** Fixed, **Field width** 2.5 cm
    - **Jaw mode** Fixed, **Field width** 5 cm
    - **Jaw mode** Dynamic, **Field width** 2.5 cm
    - **Jaw mode** Dynamic, **Field width** 5 cm

    For more information on how to create plans in RayStation, refer to the *RSL-D-RS-12A-USM, RayStation 12A User Manual*.

2. Set the dose grid to 0.3 cm or smaller in each direction.
3. Create a beam and let the isocenter be positioned at the center of the External ROI.
4. In the **Beam Optimization Settings**:

    - Select **Jaw mode**.
    - Enter the **Field with**.
    - Set the **Pitch factor** to 0.287.
    - Set the maximum **Gantry period** to around 13 sec.



No.	Name	Jaw mode	Field width [cm]	Pitch factor	Delivery time factor Apply	Delivery time factor Max	Delivery time [sec] Apply	Delivery time [sec] Max	Gantry period [sec] Apply	Gantry period [sec] Max
1	b1	Dynamic	5.05 (jaw pos -2.10, 2.10)	0.287	☐	-	☐	-	☑	13.0

Figure 7. The Beam Optimization Settings.

3.2.3 Optimize the plans

1. Set up an optimization problem in the Plan Optimization module according to Figure 8.

Function	Constraint	Dose	ROI	Description	Robust	Weight
Physical Composite Objective						
Uniform Dose		Plan	PTV1	Uniform Dose 10000 cGy		20
Uniform Dose		Plan	PTV2	Uniform Dose 10000 cGy		20
Max Dose		Plan	PTV2 ring	Max Dose 8000 cGy		0.1
Max Dose		Plan	PTV1 ring	Max Dose 8000 cGy		0.1
Max DVH		Plan	OAR	Max DVH 3000 cGy to 15% volume		10
Dose Fall-Off		Plan	External	Dose Fall-Off [H]10000 cGy [L]5000 cGy, Low dose distance 2.00 cm		0.5

Figure 8. The optimization problem.

2. Enter the same optimization settings as shown in Figure 9.

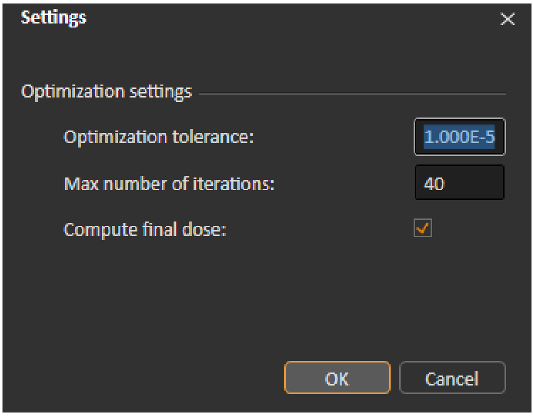


Figure 9. The optimization settings.

3. Optimize each plan by first clicking the **Start** button, and after the first optimization clicking the **Continue** button.

4. Study the dose distribution in the Plan Evaluation module. The goal is to have uniform dose in the two target ROIs.

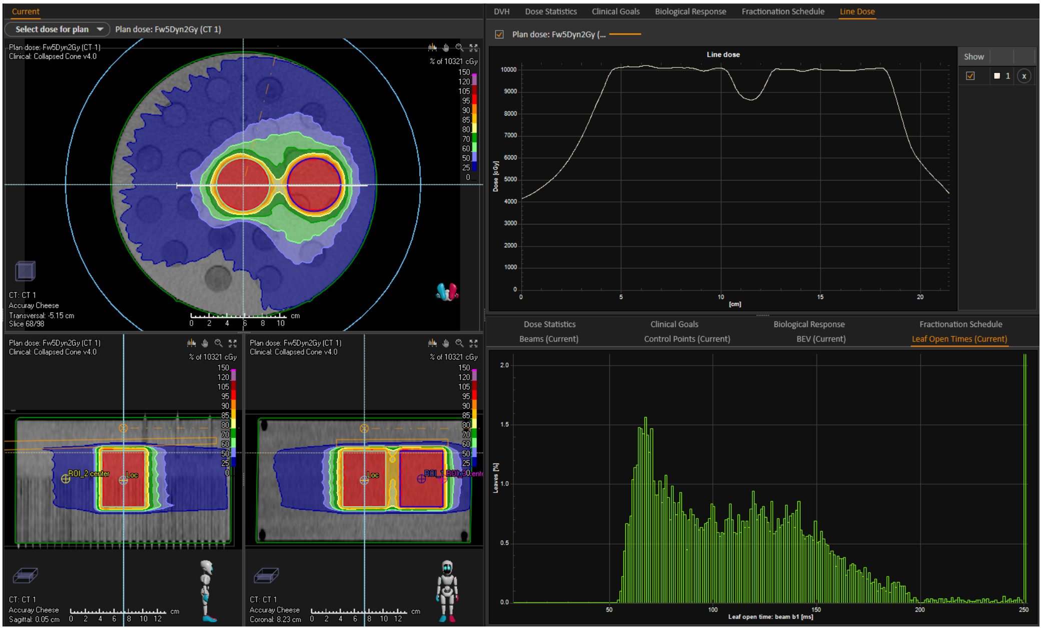


Figure 10. The dose distribution with uniform dose in the two targets in the Plan Evaluation module.

3.3 DELIVER THE TEST PLANS AND COMPARE THE DOSES

1. DICOM export the plan to iDMS (refer to the *RSL-D-RS-12A-USM, RayStation 12A User Manual* for more information).

2. Deliver the test plans on the TomoTherapy treatment machine with the cheese phantom in-beam and measure the dose with ion chambers in at least two points, one in each of the targets.

3. Compare the measured dose to the dose computed in RayStation.

   The dose can be read out by hovering with the mouse in the 2D views, or read from the POI/ROI statistics if a POI/an ROI is created at the point of measurement. The RayStation doses need to be divided by the number of fractions to match the measured dose and it might also be necessary to convert between cGy and Gy. The dose in a POI or the average dose in an ROI can also be extracted using scripting, see *Appendix A Example scripts* for an example of such a script.

4. Compare the measured and computed dose for each field width, averaging over all measured points. For field widths 2.5 cm and 5 cm, also average over the plans with fixed and dynamic jaws.

3.4 UPDATE THE BEAM MODEL AND COMMISSION THE NEW MACHINE

The output of the beam model needs to be updated based on the differences between the measured and computed dose. To update the output of the beam model and to commission the new machine:

1. Create a new version of the machine in RayPhysics and at the same time deprecate the temporary machine version, see *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual* for more information.

2. To change the overall output of the beam model, affecting all field widths, change the **Dose normalization** in the **Energy spectrum** tab, Figure 11.

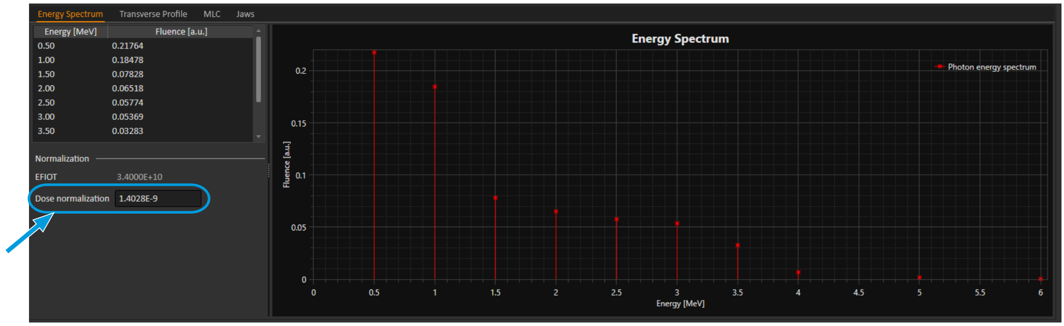


Figure 11. The **Energy spectrum** tab.

Changing the **Dose normalization** changes the output of the computation for all field widths, use this to get the correct output for the largest field width.

3. To change the output of one specific field width, change the **Output factor** of that field width in the **Jaws** tab:

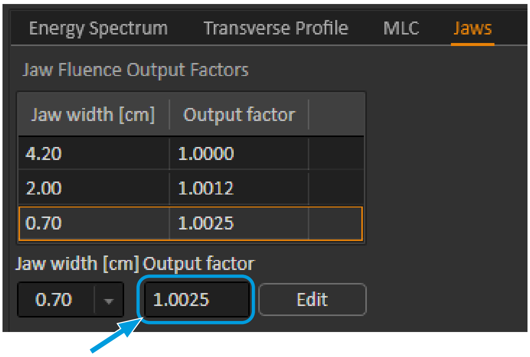


Figure 12. The **Jaws** tab.

4. Commission the new machine.

5. In RayStation, use the same test plans and change to the new machine version. Calculate the dose for all test plans with the new machine and compare the measured and computed doses again.
6. If the match between measured and computed dose still not is satisfactory, adjust the **Dose normalization** and/or jaw **Output factors** again.

4 CYBERKNIFE LINAC TREATMENT MACHINES

This chapter describes the machine parameters and measured data which is required and need to be entered in RayPhysics before starting beam modeling when commissioning CyberKnife LINAC treatment machines.

In this chapter

This chapter contains the following sections:

4.1 DOSE CURVE COORDINATE SYSTEM AND FORMATS

CyberKnife LINAC machines use the same dose curve coordinate system and dose curve formats as C-arm LINAC machines, as described in *section 2.1 Coordinate system and curve formats on page 12* with one exception; the Brainlab Monte Carlo (.xmcdat) format is not supported for CyberKnife LINAC machines.

4.2 MACHINE SETUP

This section summarizes the required machine properties for commissioning of the CyberKnife treatment machine. The *RSL-D-RS-12A-CKMDS, RayStation 12A CyberKnife Machine and Data Specification* is included as an attachment to this manual and can be used as an aid in the machine setup. All coordinate systems in the Data Specification are according to IEC 61217.

In this section

This section contains the following sub-sections:

4.2.1 Machine setup parameters

The following machine setup parameters should be entered in RayPhysics. The *RSL-D-RS-12A-CKMDS, RayStation 12A CyberKnife Machine and Data Specification* can be used as an aid when entering these parameters.

- General parameters
- MLC parameters. For more information, see *section 4.2.2 MLC parameters on page 53*.
- Cone parameters for fixed cones and iris cones. For more information, see *section 4.2.3 Cone parameters on page 54*.

All parameters which define a physical position or opening, for example MLC minimum tip position and cone diameter, are given on the isocenter plane.

4.2.2 MLC parameters

If the CyberKnife to be modeled uses MLC, the MLC parameters need to be entered.

MLC leaf center positions and widths should be specified in the Data Specification. MLC leaf center positions are given as y-coordinates in the IEC 61217 beam limiting device coordinate system.

Limits on leaf tip positions are given for the X2 leaf bank according to IEC 61217 naming convention. Positive values are open positions, zero is aligned with the isocenter and negative values over-travel the central position. The **Minimum tip position** should be a numerically lower value than the maximum position. The limits for the opposite leaf bank are assumed to be reflection symmetric. For CyberKnife LINACs, the same **Minimum tip position**/**Maximum tip position** must be entered for all leaf pairs. The standard value is -6.85 cm for the **Minimum tip position** and 6.85 cm for the **Maximum tip position**.

Minimum leaf/jaw overlap: The minimum overlap between the tip of the over-traveling leaf and the opposing jaw when hiding closed leaf pairs behind the jaw.

The machine has carriage shall not be checked.

Use **Minimum dynamic tip gap** for static fields: If checked, the **Minimum dynamic tip gap** will be applied to all leaf pairs that move between segments within a beam. For some machines this reduces interrupts during delivery of a static beam. Closed leaf pairs that do not move will be placed using the **Minimum static tip gap**. For CyberKnife LINACs, both **Minimum static tip gap** and **Minimum dynamic tip gap** can normally be set to zero.

A CyberKnife equipped with MLC is modeled as a LINAC with fixed jaws in RayPhysics. The fixed x-jaws model the patient plane shield in the x-direction, behind which closed MLC leaves are parked. To get closed MLC leaves to park at the correct position, the **X2 jaw position**, the **Minimum static tip gap** and the **Minimum leaf/jaw overlap** should sum to 6.85 cm.

The fixed y-jaws model the side protection plates of the MLC, which are at the same position as the outer edge of the first/last MLC leaf and effectively act as one additional closed MLC leaf pair.

Fill in the applicable MLC parameters in the *RSL-D-RS-12A-CKMDS, RayStation 12A CyberKnife Machine and Data Specification*.

4.2.3 Cone parameters

Both fixed and iris CyberKnife cones come in the following nominal field sizes: 0.5, 0.75, 1.0, 1.25, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 5.0 and 6.0 cm. The smallest iris cone aperture (0.5 cm) can however sometimes be mechanically unstable and is not supported by RayStation 12A.

The fixed 6 cm cone is the reference field and is required, all other cones are optional.

As all iris cones share the same hardware, the physical top and bottom positions have to be the same for all iris cone sizes.

Fill in the applicable Cone parameters in the *RSL-D-RS-12A-CKMDS, RayStation 12A CyberKnife Machine and Data Specification*.

4.2.4 Measurements

This chapter summarizes the required measurements for CyberKnife beam modeling.

The *RSL-D-RS-12A-CKMDS, RayStation 12A CyberKnife Machine and Data Specification* is included as an attachment to this manual and can be used as an aid when collecting the measurements needed for beam modeling. All coordinate systems used in the Data Specification are according to IEC 61217.

Information about setting up a CyberKnife LINAC for beam data measurements can also be found in the *Accuray Physics Essentials Guide*. Note that the set of required beam commissioning measurements listed in this *Physics Essentials Guide* is not identical to the measurements required by RayPhysics. The most important difference is that RayPhysics requires percentage depth dose curves (PDD) instead of tissue phantom ratios (TPR).

4.2.5 Measurement data

All measurements must be made with the same SSD and the depth offset should preferably be zero.

Measurements must also be made with a fixed 80.0 cm SAD setup and no rotations (yaw, pitch and roll all set to 0 degrees).

The following measurements used by RayPhysics for beam modeling must be entered:

- Percentage depth dose curves on the central axis
- Profiles (X, Y and diagonal)
- Output factors
- Absolute dose calibration point for 6 cm fixed cone

Percentage depth dose curves and x- and y-profiles

Percentage depth dose curves for a particular field may be included in the data set without including the corresponding profiles. Profiles on the other hand require the corresponding depth dose curve to be included. For fixed and iris cones, dose curves must be entered for all supported cone sizes. For MLC, the field sizes are optional – but it is important to cover the range of clinically relevant field sizes that will be used for treatment planning. A recommended set of field sizes for MLC is: 0.76 cm x 0.77 cm, 1.54 cm x 1.54 cm, 2.3 cm × 2.31 cm, 3.08 cm × 3.08 cm, 3.84 cm × 3.85 cm, 4.62 cm × 4.62 cm, 5.38 cm x 5.39 cm, 6.92 cm × 6.93 cm, 8.46 cm × 8.47 cm, 10.0 cm × 10.01 cm and 11.5 cm × 10.01 cm.

The SSD used when measuring the curves should be close to 80 cm. The Accuray calibration point for all CyberKnife treatment machines is 1 cGy/MU at 1.5 cm depth with SSD 78.5 cm for the 6 cm fixed cone. The SSD for the absolute dose calibration in RayPhysics (see section *Absolute dose calibration point* below) must be the same as used for the dose curves. To be able to enter the Accuray machine calibration point as absolute dose calibration point in RayPhysics, SSD 78.5 cm must be selected when measuring the dose curves.

Minimum recommendations of depths for profile measurements:

- 1.5 cm
- 5 cm
- 10 cm
- 30 cm

For iris cones the aperture is not a true circle, but a dodecahedron (i.e., a 12-sided aperture). The iris aperture is approximated with a circle in the dose computation, and the entered iris profiles should be an average over radial profiles spread across different scan angles. Profiles should be measured at four different scan angles for each depth: 0 degrees (x-profile), 15 degrees, 90 degrees (y-profile) and 105 degrees. The definition of the scan angle is shown in Figure 13. The four profiles should be averaged, and the values for the profile averaged symmetrically across the origin to give one average radial profile for the beam. The profile can be imported as either a x-profile or as a y-profile into RayPhysics.

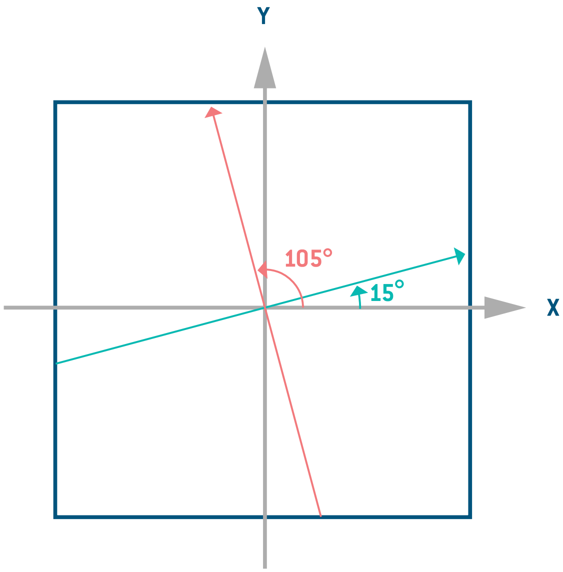


Figure 13. Scan angle definition.

For fixed cones, it is recommended to measure one x- and one y-profile for each depth.

For MLC, it is strongly recommended to measure both x- and y-profiles.

All depth dose curves and profiles to be included should be listed in the Data Specification together with their respective output factors, detector model, detector dimensions and applied depth offset [cm] before curve export.

Diagonal profiles for MLC

For MLC modeling, it is also strongly recommended to import at least one diagonal profile for the largest supported field size (11.5 cm × 10.01 cm) to correctly model the field away from the x- and y-axes. Diagonal profiles at several depths can be imported. If only one diagonal profile is imported, it is recommended to use a depth significantly below the build-up region. The diagonal profiles may have an arbitrary angle, but it is recommended to use 45 degrees or 135 degrees. Only diagonal profiles that cross the central axis are supported.

Place the phantom so that a scan can be made all the way past the corner along a diagonal. Use the diagonal profiles to tune the beam profile correction for the entire field opening.

Output factors

Depth dose curves and profiles shall be complemented with:

- Output factors for each supported fixed and iris cone size and for each MLC field size present among the depth dose curves. The output factors shall be normalized relative to the 6 cm fixed cone reference field. The output factors must be measured at the same SSD as the dose curves.
- The depth at which output factors were measured.

Absolute dose calibration point

To set the absolute normalization of the beam model, a dose to MU calibration is needed for the 6 cm fixed cone reference field. The absolute dose calibration point includes SSD, a depth and the dose per MU in this point. The Accuray calibration point for all CyberKnife treatment machines is 1 cGy/MU at 1.5 cm depth with SSD 78.5 cm for the 6 cm fixed cone. If another SSD or depth is used for the absolute dose calibration point, it should still correspond to the Accuray machine calibration. Note that the SSD for the absolute dose calibration must be the same as used for the dose curves.

Measurement conditions

Depth dose curves and profiles shall be complemented with:

- Detector model.
- Dimensions (height and width for the active volume) of detectors used for measuring curves. Note that relevant height and width shall correspond to the detector orientation that was used during the measurements.
- The depth offset that has been applied to the depth dose curves (if any). The offset is the distance from the detector reference point to the effective point of measurement used for the coordinates in the dose curve files. A shift towards the surface corresponds to a negative offset (typical for ionization chambers).
- The size of the water phantom in which the dose curves were measured. Only a cubic phantom size can be entered, use a suitable average side length if the phantom is non-square. The phantom size is relevant for the computed dose curves if points of the measured dose curves are close to the outer extension of the phantom.

4.2.6 Measurement setup

When measuring depth dose curves, especially for the smallest MLC and cone field sizes, it is very important that the detector is well centered in the beam. It is important that the water tank mechanics is verified beforehand, so that the measuring device is stable and capable of keeping the detector in the center of the beam.

For information about detector selection, refer to *section 2.3.3 Detector selection on page 24*.

4.2.7 Photon scan summary and measurement conditions

Enter the depth dose curves and profiles to be used for the photon beam modeling of fixed cones, iris cones and MLC, when applicable, together with the respective output factors and measurement conditions in the *RSL-D-RS-12A-CKMDS, RayStation 12A CyberKnife Machine and Data Specification*.

One example of how these tables should be filled in is given below.

Table 4.1: Example: PDDs and Profiles fixed cone fields.

Diameter [cm]	Type (PDD/ Profiles)	Detector height [cm]	Detector width [cm]	Applied depth offset [cm]	Detector model	Output factor
6	PDD	0.15	0.2	0.0	CC13	1.0

4.2.8 Node set

After beam modeling and machine commissioning have been completed, a RAMP file for the specific CyberKnife machine needs to be imported to the machine in RayPhysics. The RAMP file is exported from iDMS and contains information about the different node sets available for treatment planning. This information is needed to be able to use the machine when creating treatment plans in RayStation.

5 PBS TREATMENT MACHINES

This chapter describes the required beam data for beam modeling of a generic PBS treatment machine in RayPhysics. Additional machine parameters needed for commissioning of the treatment machine are described in the *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual*.

In this chapter

This chapter contains the following sections:

5.1 SYSTEM REQUIREMENTS

The PBS treatment machine has to fulfill the following requirements:

- All beam data is invariant with respect to the magnitude of beam deflection in X and Y
- All beam data is invariant with respect to the gantry angle

5.2 ACCEPTED CURVE FORMAT

For ion treatment machine measurements, .csv is the only accepted format.

The dose curve formats are described in more detail in *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual*.

5.3 BEAM DATA FOR A GENERIC PBS MACHINE

The beam data needs to fulfill the requirements described in this section.

In this section

This section contains the following sub-sections:

5.3.1 Pristine Bragg peaks

- Pristine (nominally mono-energetic) Bragg peak depth dose curves in water shall be obtained for the entire range of available beam energies with an approximate energy spacing corresponding to 1-2 cm spacing in depth range. The energy spacing should not be more than 10 MeV.
- Pristine Bragg peaks measurements for nominal energies covering the minimum and maximum energy limits shall be included in the data set.
- The Pristine Bragg peak measurements shall start at the water phantom surface and include the zero dose level after the Bragg Peak.
- Measurements of single spot doses using an integrating detector, and depth doses of a scanned field in a regular pattern are supported.
- The size of the single spot detector, or magnitude of the scanned field is accurately taken into account in the modeling, and therefore Bragg peaks measurements that have been post processed to account for the finite size of the detector shall not be used since they will yield an erroneous beam model.
- In the auto modelling in RayPhysics the following Bragg Peak conditions are supported:
    - Single spot: Detector diameter of 8.16 cm, 12.0 cm or 14.7 cm
    - Scanned field size in regular pattern: 10 x 10 cm^2

  Contact RaySearch Service if you need any other detector or scanned field size than those mentioned above
- The file format and the data that should be recorded for each measurement are described in the Ion treatment machines Appendix in the *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual*.

5.3.2 Absolute dosimetry

- Absolute point doses measured in the center of a mono-energetic scanned field in a regular pattern in water shall be obtained for the same (or similar) energies as those used for obtaining the pristine Bragg peaks. The energy spacing should not be more than 10 MeV.
- The absolute dose measurements for nominal energies exactly matching the minimum and maximum energy limits defined in the model shall be included in the data set.
- The measurements are recommended to be performed at a depth approximately midway between 1 cm and one half of the position of the Bragg peak maximum.

  Absolute dose measurements at a fixed depth are also acceptable, but not recommended since small deviations between measured and modeled IDDs have been observed for some models at shallow depth and high energy.

  The absolute dose measurements shall be converted to dose per nominal meterset for the field (Gy/MU or Gy/NP) before import in *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual*.

  For Sumitomo HI (SHI) Line Scanning machines it is stipulated that the plans used to obtain the absolute doses have been created in RayStation using the Add energy layer function in the Plan optimimzation module, see *section 5.3.6 Scanned fields on page 72*. If absolute doses are recorded using plans generated in e.g., some service mode, large errors in the absolute meterset calibration may occur due to the SHI line segment weight rounding algorithm. For SHI Line Scanning machines it is also required to import the nominal meterset separately. Note that it is the nominal/prescribed meterset from the plan that should be used, not the delivered/measured meterset.
- The file format and the data that should be recorded for each measurement are described in the Ion treatment machines Appendix in the *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual*.

Note: *In RayStation, beam models can be created based on physical dose or on RBE, 1.1 scaled dose. If a beam model shall be based on RBE dose, the 1.1 factor shall be included in the Dose per Meterset values that are imported to RayPhysics.*

5.3.3 Spot profiles

- In air single spot fluence profiles along the (IEC) Gantry X and Y axes shall be measured.
- The spot profiles shall be obtained in air for several beam energies over the entire range of available beam energies. The number of energies shall be in the same range as those for the pristine Bragg peaks and Absolute dose measurements. The energy spacing should not be more than 10 MeV.
- Spot profiles for nominal energies covering the minimum and maximum energy limits shall be included in the data set. The profiles shall be centered around (0,0) and the X and Y profile shall be normalized in the same way.
- The measurements shall be performed at a minimum of three planes along the gantry IEC z-axis, but it is recommended to perform the measurements for at least five planes.
- The position of the planes shall cover the range of therapeutic interest.
- If the machine is modeled to include a range shifter, the most upstream position of the profiles should match the upstream surface point of the range shifter, with the snout position set to the most distal point that will be used clinically. If this position cannot be reached, measure as far upstream as possible.
- Optionally, the whole set of spot shape beam data can be obtained for several snout positions over the range of possible snout positions. If provided, the angular scattering in the beam model will be dependent on snout position. This could be necessary for example for system with the vacuum window placed in the movable snout. However, for most systems, it should be sufficient to obtain the measurements at one snout position only. Notify RaySearch Service if this option is considered.
- The file format and the data that should be recorded for each measurement are described in the Ion treatment machines Appendix in the *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual*.

5.3.4 Virtual Source Axis Distance

The Virtual Source Axis Distance in X and Y (Focal length in RayPhysics) are provided directly by the clinic. Please contact RaySearch Service if you need recommendations on how to extract the Virtual Source Axis Distances.

5.3.5 Range shifter

The effect of the range shifter is modeled in the RayStation dose engine, and no beam modeling data is therefore required.

5.3.6 Scanned fields

When scanned fields are used for measurements they should preferably be created in RayStation using the **Add energy layer** function. The scanned fields shall be set up in a regular pattern, not a hexagonal grid. The field edges are defined as the center positions of the outermost spots/lines.

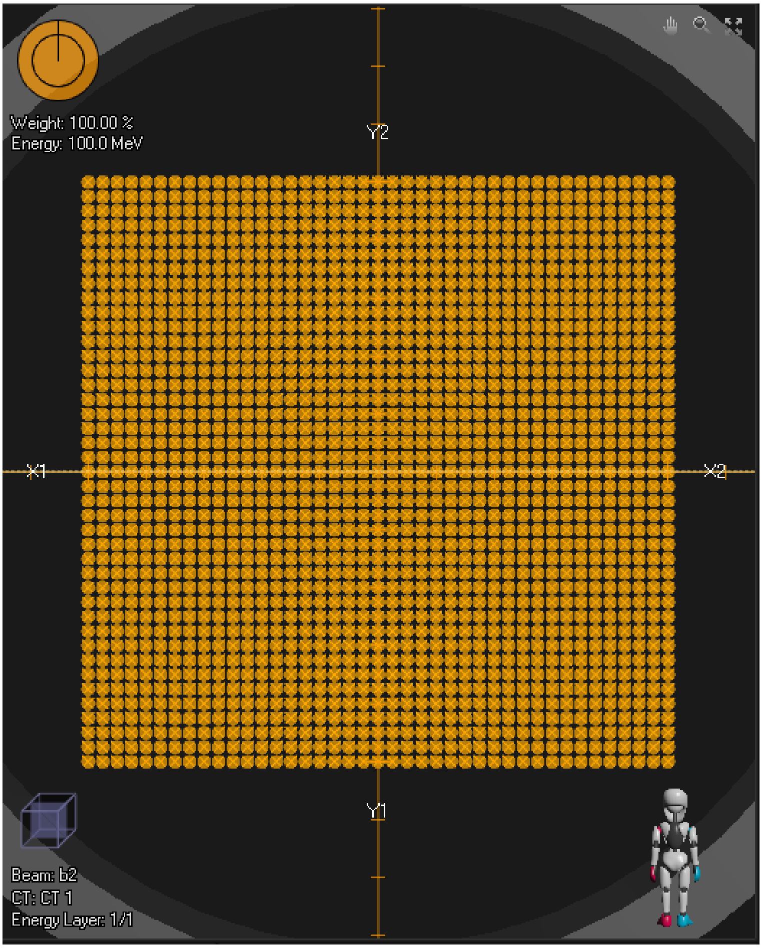


Figure 14. Single energy spot map for **discrete spot PBS delivery** created in RayStation using the Add energy layer function using a regular spot pattern with a scanned field size of 10x10 cm^2 and a spot spacing of 0.25 cm.

Figure 15. Single energy spot map for **Line Scanning** created in RayStation using the Add energy layer function using a regular spot pattern with a scanned field size of 10x10 cm^2 and a spot spacing of 0.25 cm.

5.4 BEAM DATA FOR A MEVION S250I (HYPERSCAN) SYSTEM

The Mevion Hyperscan system has only a single nominal beam energy corresponding to the highest deliverable energy by the machine. The energy of the protons, referred to as the "beam energy" below, is chosen using the Mevion energy selector. The energy selector is comprised by several plastic range shifting plates in the nozzle, which means that the beam energy of a given energy layer is uniquely defined by the combination of used energy selector plates (the energy selector setting). A table provided by Mevion specifying the beam energy corresponding to each supported energy selector setting must be imported in the **General** tab. This energy does not affect the beam model. However, if there is a large difference between the beam energy and the actual energy of the protons as they exit the nozzle, it may cause the initial spot placement to miss the distal edge of the target during optimization. In the beam data specifications below, the energy selector setting (binary combination of used plates) shall be used.

Note: *For Mevion Hyperscan machines, the beam model is based only on measured data for the highest deliverable energy. The validation data should, however, be chosen to cover the deliverable range of energies. In addition, to validate the properties of energy selector plates, these validation energies should also be chosen in such a way that each plate is included at least once in combination with as few other plates as possible.*

5.4.1 Pristine Bragg peaks

- Modeling data: A pristine Bragg peak depth dose curve in water must be obtained for the highest deliverable energy of the machine, that is, with all energy selector plates fully retracted.
- Validation data: Pristine Bragg peak depth dose curves in water must be obtained for a number of energy selector settings covering the interval of deliverable energies and chosen so that each plate is included at least once in combination with as few other plates as possible.
- Pristine Bragg peak measurements shall start as close as possible to the water phantom surface and include the zero-dose level after the Bragg peak.
- Measurement of single spot dose using an integrating detector shall be obtained. The size of the single spot detector is accurately considered in the modeling. Bragg peaks that have been post processed to account for the finite size of the detector will not be accepted. (For single spot measurements, the beam model quality is not expected to improve by using an integrating detector that is larger than the often-used size of 8.16 cm.)
- The following Bragg peak conditions are supported:

  Single spot: detector diameter of 8.16 or 12 cm. Contact RaySearch Service for other detector sizes than those mentioned above.
- The following data shall be recorded (see measurement file format template for details):
  - Energy selector plate setting
  - Nozzle exit window configuration. Should not be present in the beam line for modeling data and should be present for validation data.
  - Isocenter to phantom surface distance
  - Snout position
  - Size of detector (single spot measurements).

5.4.2 Absolute MU calibration

- Recommended field size is 10x10 cm^2 with a regular spot spacing of 2.5 mm, providing a field with 1681 spots.
- Modeling data: Absolute dose measured in the center of the field for a scanned (~10x10 cm^2) mono-energetic beam in water for the highest deliverable energy of the machine, that is, with all energy selector plates fully retracted.
- Validation data: Absolute dose measured in the center of the field for a scanned (~10x10 cm^2) mono-energetic beam in water for a number of energy selector settings covering the interval of deliverable energies and chosen so that each plate is included at least once in combination with as few other plates as possible.
- Measurements are recommended to be performed at a depth approximately one fourth of the depth of the Bragg peak maximum
- Note that RayStation 12A supports RBE for protons. The clinic may however decide not to use this functionality and can include the RBE prediction in the absolute dose measurements, e.g., by multiplying the measured doses by a factor 1.1. This is the responsibility of the clinic when preparing the beam model data. This needs to be clearly communicated in the beam data.
- The following data shall be recorded (see measurement file format template for details):
    - Energy selector plate setting
    - Nozzle exit window configuration. The nozzle exit window should be present in the beam line.
    - Isocenter to phantom surface distance
    - Snout position
    - Depth of measurement
    - Scanning area (as defined by the positions at the isocentric plane of the centers of the outermost spots)
    - Spot spacing of the regular spot grid
    - Delivered MU (monitor units)
    - If the measurement includes an RBE prediction (i.e., if the provided value is Gy or Gy (RBE)).

5.4.3 Beam spot shape

- Modeling data: Spot beam data must be obtained in air for the highest deliverable energy of the machine, that is, with all energy selector plates fully retracted.
- Validation data: Spot beam data must be obtained in air for a number of energy selector settings covering the interval of deliverable energies and chosen so that each plate is included at least once in combination with as few other plates as possible.
- In air fluence profiles along the (IEC) Gantry, X and Y axes shall be determined for a single spot.
- The measurements shall be performed at a minimum of three planes along the beam line axis, but it is recommended to perform the measurements for at least five planes.
- The position of the planes should start from as far upstream as possible (preferably inside the nozzle) and cover the range of therapeutic interest.
- The following data shall be recorded (see measurement file format template for details):
  - Energy selector plate setting
  - Nozzle exit window configuration. Should not be present in the beam line for modeling data and should be present for validation data.
  - Position of measurement plane on the central beam axis (IEC Gantry Z axis)
  - Positive Z values are upstream of negative values in the IEC Gantry coordinate system
  - Snout position

5.4.4 Virtual Source Axis Distance

The Virtual Source Axis Distance in X and Y (Focal length in *RSL-D-RS-12ARPHY, RayStation 12A RayPhysics Manual*) are provided directly by the clinic. Contact RaySearch Service if you need recommendations on how to extract the Virtual Source Axis Distances.

A EXAMPLE SCRIPTS

This chapter includes example scripts for POI dose determination and for ROI average dose determination.

Example scripts

This chapter contains several references to example scripts. These scripts are included in the installation of RayStation.

In this chapter

This chapter contains the following sections:

A.1 EXAMPLE SCRIPT FOR POI DOSE DETERMINATION

This section includes an example script for POI dose determination. This script prints the dose per fraction in Gy for all POIs of the selected beam set.

Example script

Refer to the script called "*Example_BCDS1_POI_dose_determination.py*".

A.2 EXAMPLE SCRIPT FOR ROI AVERAGE DOSE DETERMINATION

This section includes an example script for printing the average dose per fraction in Gy for all ROIs of the selected plan. Note that the script assumes that there is only one beam set.

Example script

Refer to the script called "*Example_BCDS2_ROI_average_dose_determination.py*".

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