CT Dose Profiler

Probe for evaluation of CT systems

CT Dose Profiler User's Manual - English - Version 6.2A

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CT Dose Profiler

The CT Dose Profiler probe makes it possible to evaluate the performance of modern CT scanners.

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Intended Use of the CT Dose Profiler probe

Together with the Ocean Software from RTI Electronics AB it is to be used for quality control, service and maintanance of CT systems.

With the CT system in stand-by condition without patients present, the probe is intended to be used:

- to provide the operator with information on radiation beam parameters that might influence further steps in an examination but not an ongoing exposure.
- for assessing the performance of the CT scanner.
- for evaluation of of examination techniques and procedures.
- for service and maintanance measurements.
- for quality control measurements.
- for educational purposes, authority supervision, etc.

The product is intended to be used by hospital physicists, X-ray engineers, manufacturer's service teems, and other professionals with similar tasks and competencies. The operator need s basic knowledge about the software Ocean before starting to use the CT Dose Profiler probe. This can be achieved by studying the relevant documentation.

The product is NOT intended to be used:
- for direct control of any diagnostic X-ray system performance during irradiation of a patient.
- so that patients or other unquilified persons can change settings of operating parameters during and immediately before and after measurements.

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Chapter 1

Introduction

1 Introduction

Regular quality assurance measurements on CT scanners are necessary in order to monitor the dose levels patients are exposed to during medical examinations. In many countries, governments require regular quality compliance testing information from clinics and hospitals that perform CT examinations.

Today, computed tomography (CT) comprises approximately 70% of the total dose given to patients during X-ray examinations. With the rapid advancements in CT technology, there is increasing demand to develop new testing strategies and measuring equipment to maintain the highest possible standard of patient care. It was found that using the standard 10 cm CT ionization chamber may result in inaccurate measurements due to its tendency to underestimate the dose profile. Our answer to this problem is the CT Dose Profiler (CTDP) probe.

The CT Dose Profiler (CTDP) probe is a highly advanced point dose probe designed to fit into the standard phantoms to evaluate computed tomography systems. There is no limit to the slice width that users can measure with the CTDP. When using this probe for CTDI measurements, the traditional five axial scans with an ion chamber are replaced with one helical (spiral) scan with the CTDP probe in the center hole of the phantom (head or body). The CT Dose Profiler replaces the conventional TLD and OSL methods or film for dose profile measurements.

The CT Dose Profiler probe is designed to be used with the Piranha X-ray multimeter and a PC running the Ocean 2014 software. You can measure several different parameters with Ocean 2014 and the CTDP probe. There are two standard templates, one for CTDI and one for geometric efficiency, that come with Ocean 2014 which can be used with all license levels.

As mentioned above, the CTDI measurement can be done with one helical scan. After the helical scan, Ocean 2014 gives several parameters at the same time such as CT dose profile, $CTDI_{100}$, $CTDI_{w}$, $CTDI_{vol}$, DLP and FWHM.

The scientific methods used in the CT Dose Profiler have been evaluated in a variety of studies; see the reference list (especially 1, 4, 10, 11, 12, 14, 15 and 16).

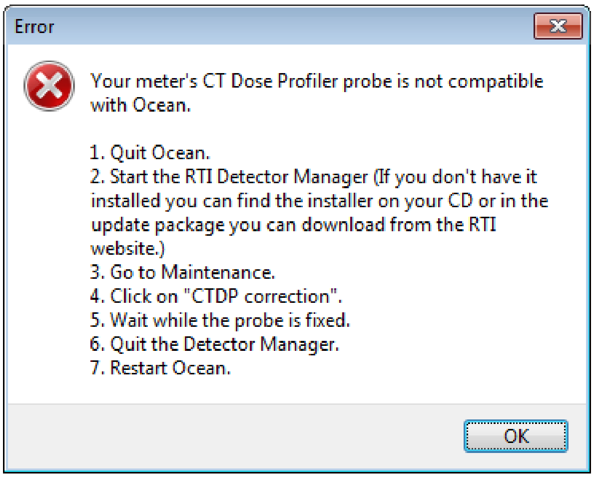
Note:
This manual will show you how to use the CT Dose Profiler probe with a Piranha and the Ocean 2014 software. It will also give examples of practical measuring methods. It is assumed that you have installed Ocean 2014 and are familiar it. If you haven't installed Ocean 2014 yet, do that first. You will find instructions in the Ocean 2014 User's Manual.

⚠ The CT Dose Profiler shall be handled with care even if it is much more durable than a traditional CT ion chamber. If it is dropped or subjected to strong shocks, the detector chip may be damaged.

1.1 Users of the "old" software

Beginning October, 2012 Ocean software replaces the CT Dose Profile Analyzer software. All new CT Dose Profiler probes from this date are delivered with the Ocean 2014 software. If you already have a probe and are using the CT Dose Profile Analyzer software please note the following:

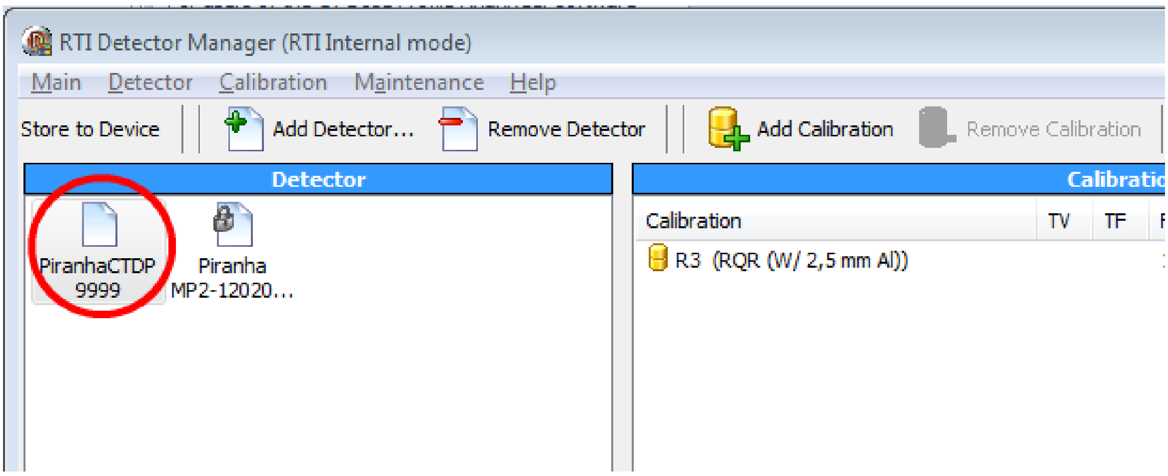
- The first version of the CT dose profiler probe, called CT-SD16, will not work with Ocean 2014. If you have this probe you have to continue to use the software you have or update to the new probe called "CT Dose Profiler".
- When you start Ocean 2014 for the first time with the CT Dose Profiler probe and you use Piranha, Ocean 2014 may show a message that your probe needs to be reprogrammed:



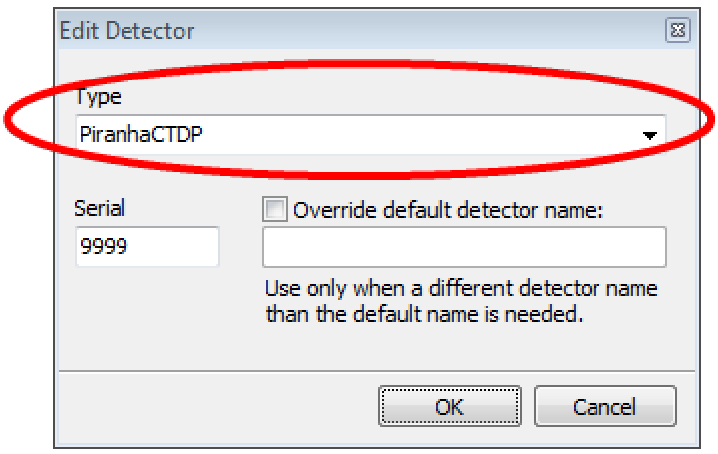
Once you have done this, the probe will not work with the CT Dose Profiler Analyzer software (the "old" software). To use it with this program again, you have to use the Detector Manager again and "reverse" the fix:

1. Start the Detector Manager with the Piranha and the CD Dose Profiler probe connected.

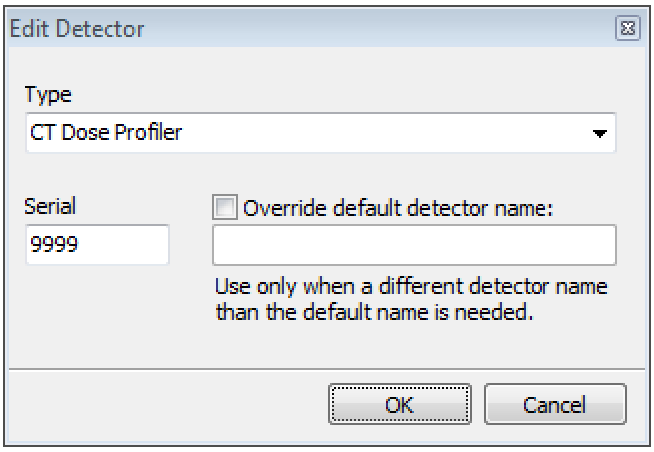
2. The Detector Manager will show the probe and its type is "PiranhaCTDP":



3. Double-click on the probe and the following pop-up window is shown:

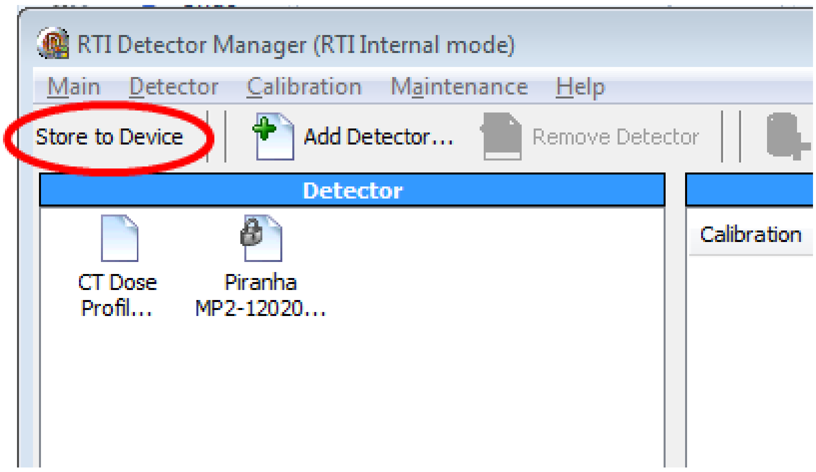


4. Change the type to "CT Dose Profiler".



5. Click on OK to close the window.

6. Now click on "Store to device":



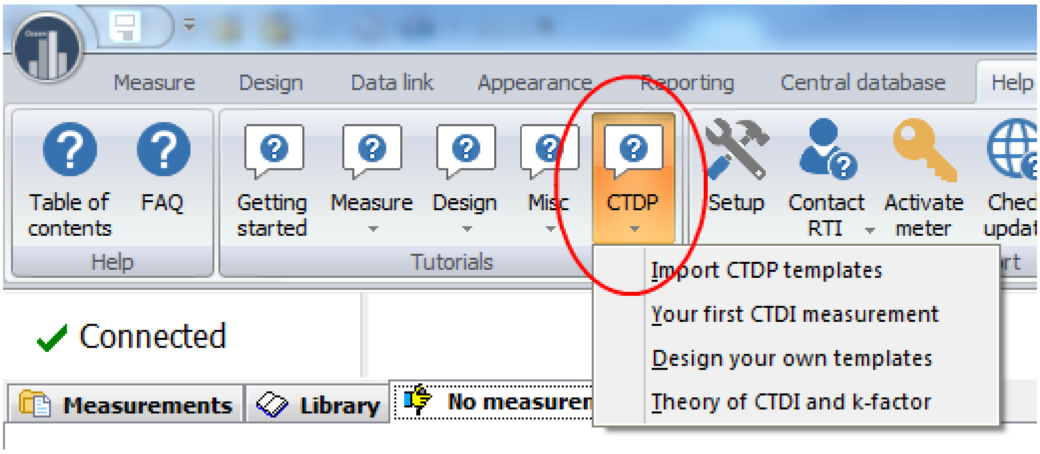
7. Wait until programming of the probe is completed.

8. Close the Detector Manager. You can now use the probe with the CT Dose Profiler Analyzer ("old" software) again.

Next time you use Ocean 2014 again and Ocean 2014 "complains" again and asks you to correct the probe, you can follow the above procedure.

1.2 Help in Ocean 2014

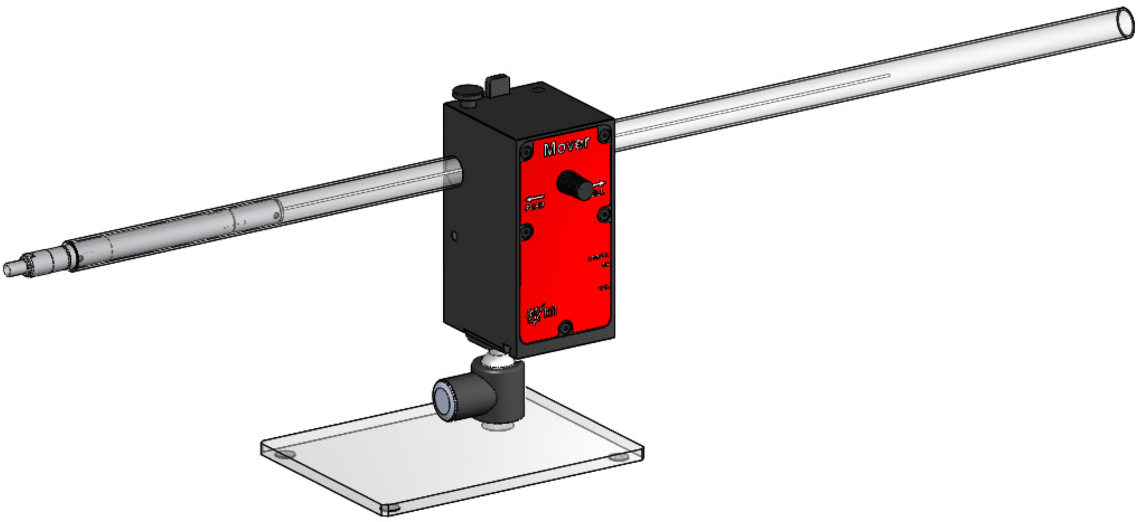
The manual for the CT Dose Profiler is available as a help tutorial in Ocean 2014. Go to the Help page on the ribbon bar:



Click on the CTDP tutorial button and select what you want to read about.

1.3 The RTI Mover

The RTI Mover is an accessory that can be used with the CT Dose Profiler Probe and is supported in Ocean 2014. The RTI Mover makes it possible to measure CT dose profiles with an axial scan.



The RTI Mover is described in a separate manual, RTI Mover User's Manual.

Chapter 2

Start measuring

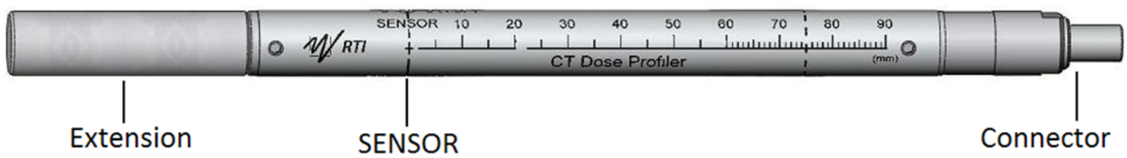
2 Start measuring

The Ocean 2014 software is used to evaluate and calculate all parameters based on the measured dose profile. Ocean 2014 is available in three different license levels; Display, Connect and Professional. Depending on the level you are running you have different possibilities.

Connect
You can use Quick Check or the templates that come with Ocean 2014. These templates are locked and you cannot modify the structure. However, you can change set values and parameters that are used to make the measurement and evaluate the result. You can only use real-time display mode.

Professional
You can use Quick Check or the templates that come with Ocean 2014 but you can also create your own templates. This gives you more possibilities to adapt the templates to your own needs, add pass and fail criteria and more. You can do both real-time display measurements and include the CT Dose Profiler measurements in a QA session.

The CT Dose Profiler probe is a point dose detector that has a solid-state sensor placed 3 cm from the end of the probe. The probe can be extended with an extension piece made of PMMA to fill different phantoms. The extension is 45 mm. When this is attached, the detector will be centered in the middle of a 150 mm wide PMMA phantom when the end of the extension reaches the end of the phantom.



The sensor is very thin (250 µm) in comparison to the beam width and is therefore always completely irradiated when it is in the beam.

The sensor collects the dose profile. As radiation hits the sensor, in either direction, the detector registers the dose value at that point and sends the information to the software. The electrometer can collect 2000 such dose values per second. When the dose profile is collected all of the data points are put into a graph. The recommended and most convenient method to measure the dose profile is to use "Timed mode". This mode makes it possible to define exactly how long you want to measure and by that being able to ensure that you don't miss any radiation. You simply check on the CT scanner how long the scan will take and then use a certain margin of your choice in specifying "measuring time".

To be able to collect the dose at the different positions, thereby creating the dose profile, the probe must be moved through the CT beam. This is achieved by placing it free in air or in a phantom and then using the couch movement to scan the probe (perform a helical scan). Therefore it is not possible to use axial scans for measuring the CTDI with the CT Dose Profiler probe. You could, of course, make many axial scans in small steps with the detector and plot a dose profile, but that takes a lot of time. With a helical scan you will receive the dose profile in a few seconds. It has been proven that the CTDI can be measured with helical scans as long as corrections are made for the pitch (see reference 10). This correction is done automatically in Ocean 2014.

2.1 Make your first CTDI measurement

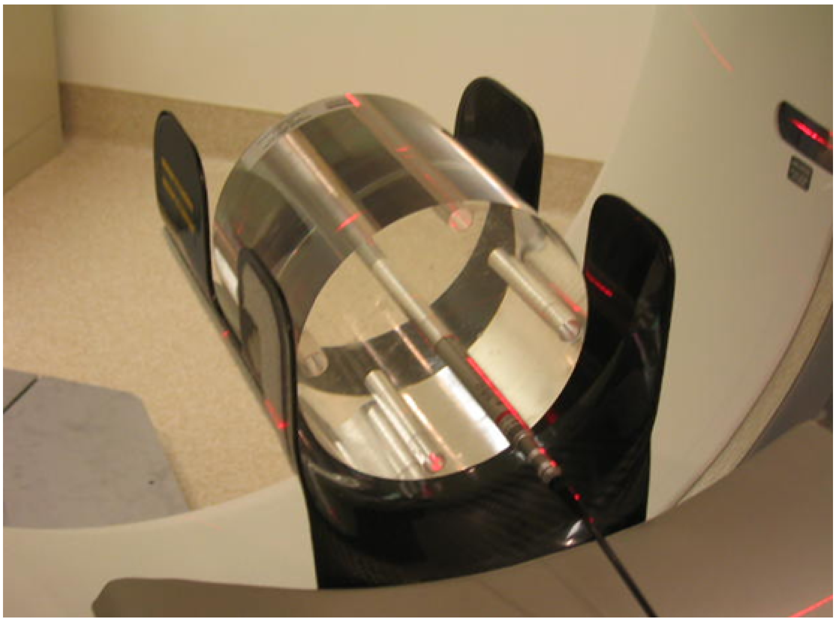
We will use the measuring template that comes with Ocean 2014 in this first example. As mentioned before, it is assumed that you are familiar with Ocean 2014. If you need general information about Ocean 2014, please consult its User's Manual. You can do the measurement in Quick Check or in Ocean 2014's main mode. If you use Quick Check, just follow the instructions on the screen but read in the text here how to setup the phantom, probe and how to set the scanner.

Assume that you want to measure CTDI(100) using a head phantom:

First setup the meter, phantom and probe.

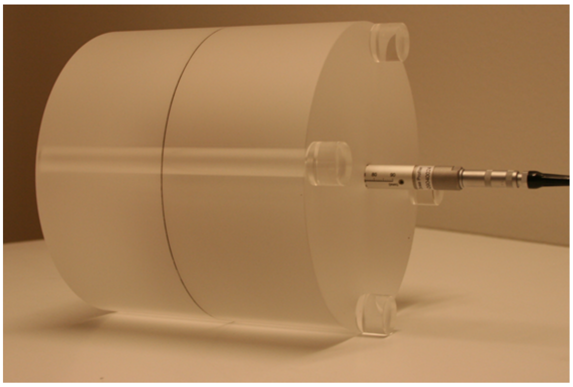
1. Connect the CTDP probe to the Piranha via the extension cable. If you are using USB cable between the meter and PC, connect it now.

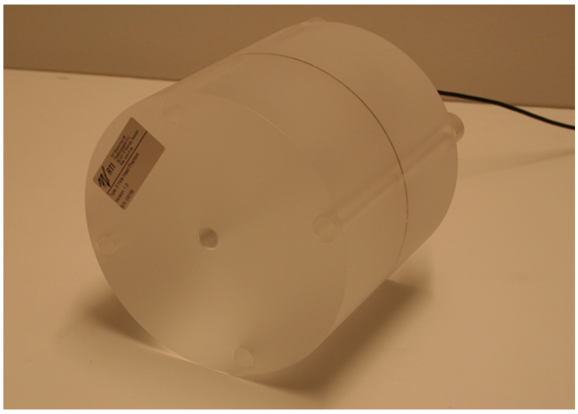
2. Place the CT head phantom on the head support and the CTDP probe in the center hole with the connector pointing towards the couch as shown in the picture.



Note: Only one exposure with the probe in the center hole is required. The section "Theory of CTDI and k-factor" describes the theory behind this method.

3. Make sure that the sensor is in the center of the phantom. This can be accomplished easily by using the graded scale on the CTDP probe. Assuming you are using a standard phantom with a length of 150 mm, the stitched mark at 75 mm on the CTDP probe should be place in the phantom opening and the end of the extension should then be at the end of the phantom as shown in the pictures below:





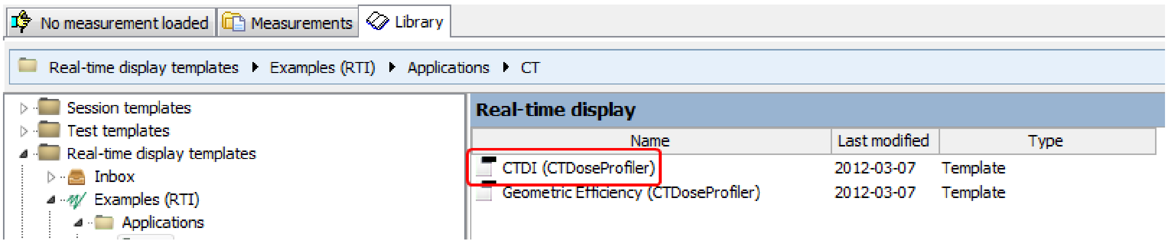
4. Make sure that the two horizontal CT lasers are visible on the probe, approximately in the middle of it. Also verify that the vertical laser is approximately in the middle of the phantom. Center the CT at this position (put this position to zero).

5. Put a piece of tape along the probe, attaching it to the phantom. This is to ensure that the probe is not dislodged within the phantom when the couch starts to move.

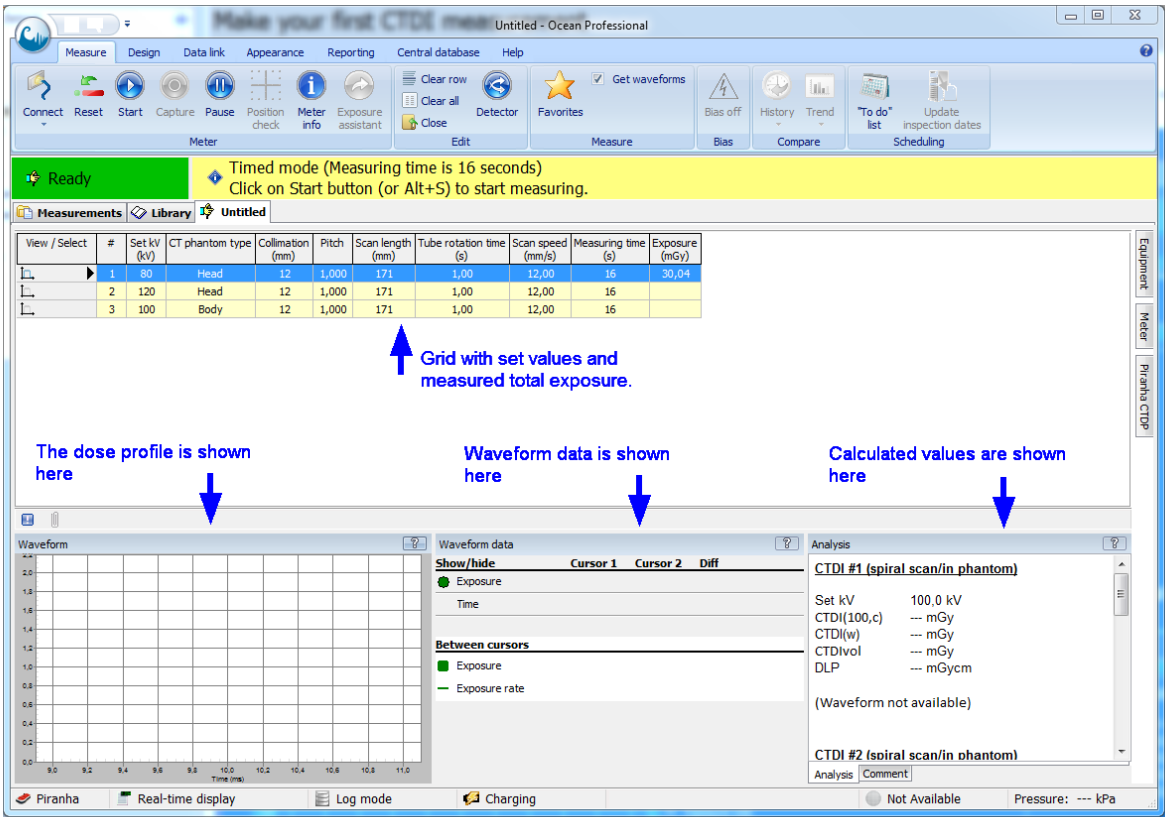
6. Start Ocean 2014.

7. Go to the Library tab and open the **Examples(RTI) -> Application -> CT** folder. (If you can't find the examples, please read the section **Import CT Dose Profiler templates**.)

8. Select the template **CTDI (CTDoseProfiler)** by double-clicking on the name.



9. A hint is shown that briefly describes how to perform the measurement. Click OK to close it (you can reopen it by clicking on the hint icon). The template is loaded and a new measurement is initiated. Ocean 2014 will automatically connect to the meter at this point.

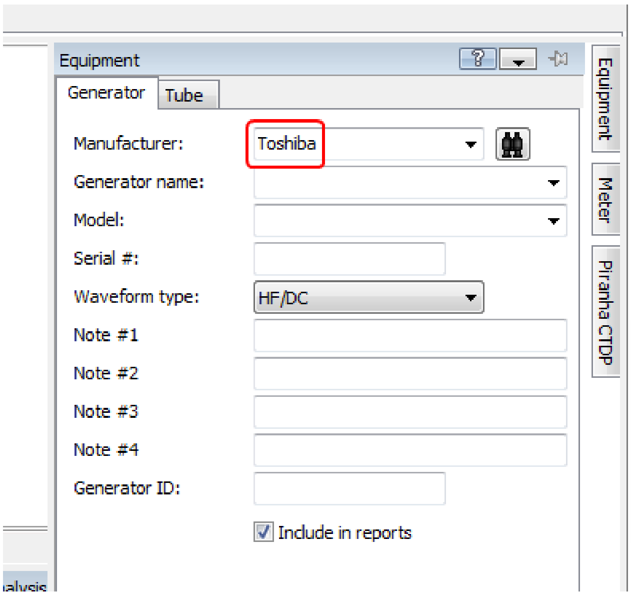


Note: Waveform grid, cursor data and analysis are empty right now, since no measurement has been performed yet.

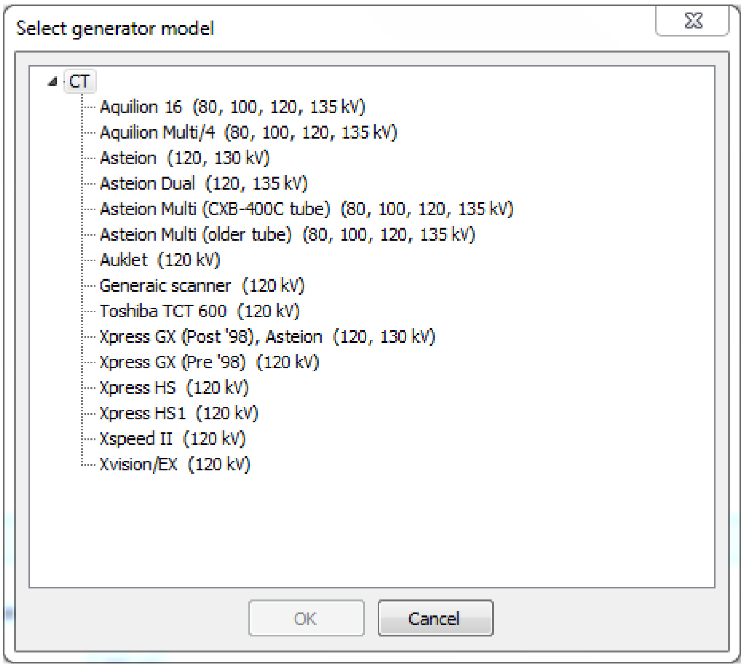
The template performs four different CTDI measurements (note only one exposure is needed for each one), two with head phantom and two with body phantom. You can change Set kV and phantom type if you want.

10. The first thing you should do is to select CT scanner in Ocean 2014. Go to the Equipment tab.

11. Specify the CT scanner manufacturer.



12. Now select the CT scanner model. Click on the binoculars to see the CT scanner list for the specified manufacturer. If you don't find your CT scanner in the list, select the "Generic scanner". You can also read more in the section "Unlisted CT scanners".



13. Select CT scanner model and click OK. Note also that for each model the possible kV settings are also listed. If you can't find the CT scanner you are looking for, read the section **Unlisted CT scanners**. For the purpose of following this example select one that is similar to the one you have.

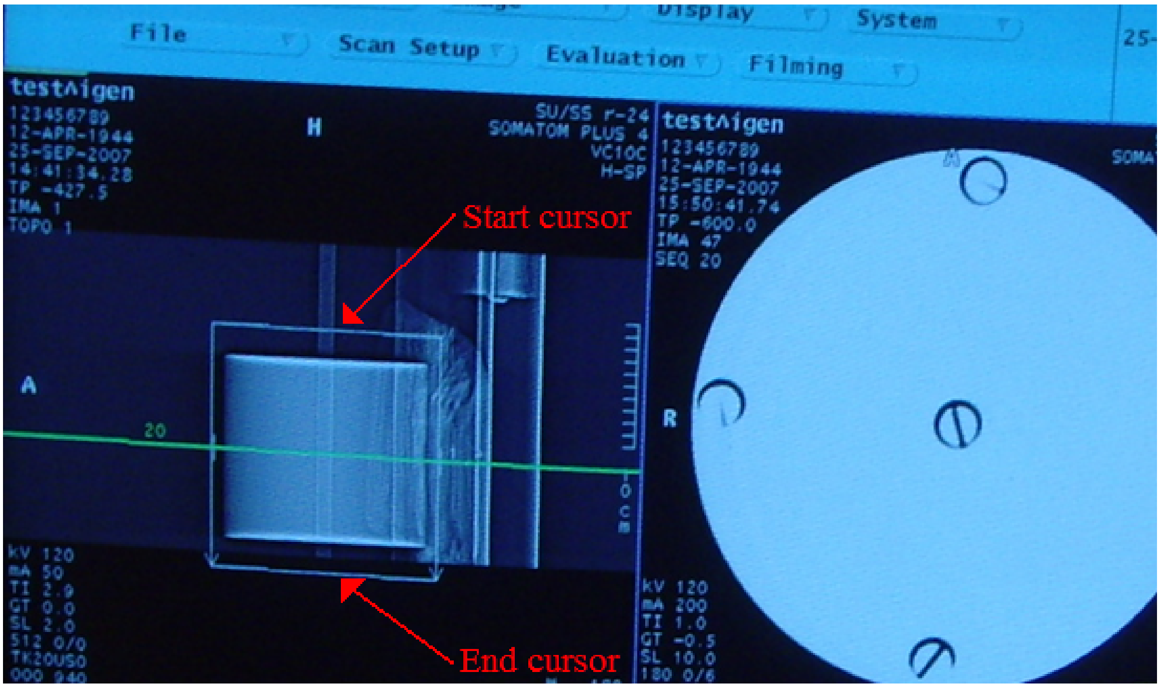
When you select the CT scanner model the required data will be pulled into your measurement from a database including energy correction factors and the k-factor. You can read more about the k-factor in the section "Theory of CTDI and k-factor". A more complete list of k-factors is available in the "Appendix" section of this manual.

14. If you know the total filtration, go to the Tube tab and enter it. If you don't know, use the default value (7 mm).

Now it is time to prepare the CT settings. You will be required to perform the following: perform a topogram (a scout image), know how to set the cursors to define the scan area for the spiral/helical scan and be able to perform the scan. It is very important that these CT-parameters are read and set correctly; otherwise the measurement will be incorrect.

15. First, perform a topogram (scout image) over the whole CT Dose Profiler when it is positioned inside the phantom. Ocean 2014 is not used at this stage and the meter will not record any data. You do not have to be concerned with any settings or measured data since the reason for this scan is to find out where to set the cursors of the CT machine for the helical scan.

16. The CT console will show the scanned image similar to the one below.



Locate the sensor in the scanned image. Set the start cursor approximately 3 cm before the phantom and the end cursor approximately 3 cm after the phantom. While these are not exact numbers the measurement should start a little bit before the phantom and stop a little bit after it. Note down the scan time that the CT unit needs to perform this scan as you will need this value later on to select a suitable measuring time.

17. You must enter the following parameters before you can perform your first measurement.

- kV
- Pitch (-)
- Tube rotation time (s)
- Collimation (mm)
- Phantom type (head or body)

To be able to acquire DLP you also need to specify:

- Scan length (mm)

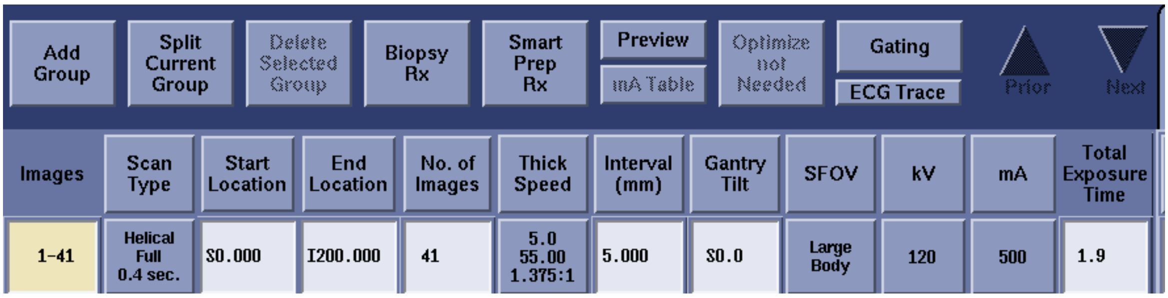
The scan speed is automatically calculated.

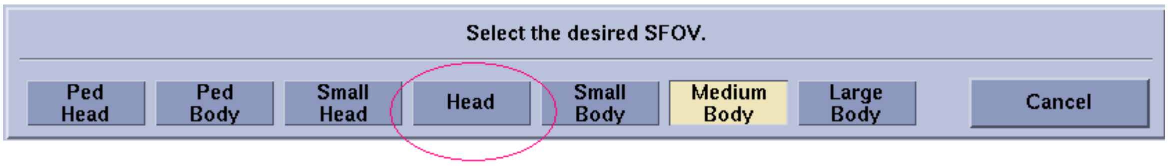
You now have to find the corresponding parameters on the CT console. Parameters may have different names on units from different manufacturers.

18. First select spiral/helical scan on the CT scanner.

19. Choose the correct Scan Field of View (SFOV) on the CT console. The SFOV should be chosen according to the type of phantom that is used. Select the phantom type in Ocean 2014.

Here is an example of how a console may appear on a GE CT scanner when SFOV is selected.

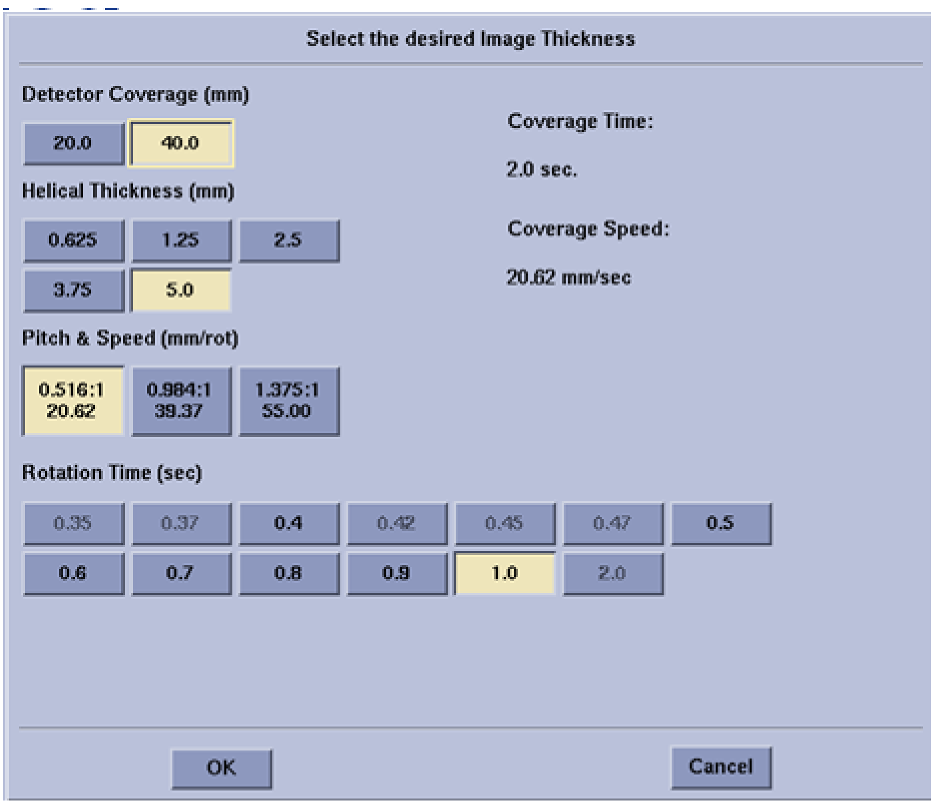




Select SFOV according to what kind of phantom you use:

SFOV type	CTDI phantom
Ped Head	16 cm Phantom
Ped Body	
Small Head	
Head	
Small Body	32 cm Phantom
Medium Body	
Large Body	

Set values on the console:



20. Select the kV at which you want to do the measurement and enter it into Ocean 2014. Select one of the supported kVs that was shown when you selected the scanner model (see point #12).

21. Select the pitch and enter it into Ocean 2014.

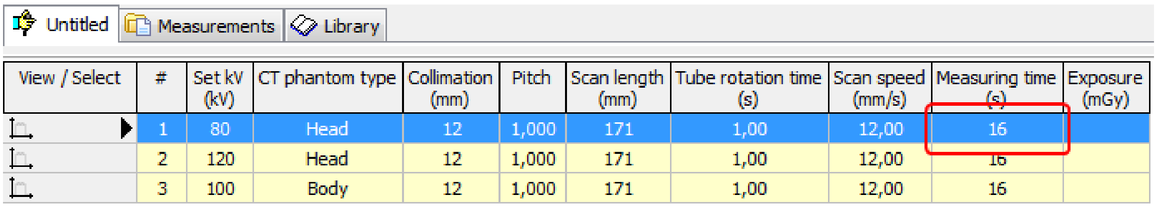
22. Select the tube rotation time and enter it into Ocean 2014.

23. Select Collimation and enter it into Ocean 2014. Ocean 2014 defines Collimation as the total width of the beam, the number of slices multiplied by the width of each slice.

24. Make sure to select "A(center)" for the "CT phantom position" in Ocean 2014.

25. If you want DLP, enter the scan length into Ocean 2014.

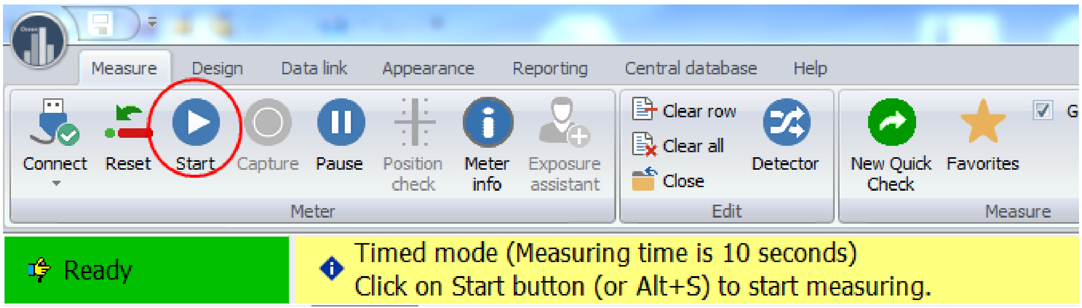
26. Make sure that the "Measuring time" is set to the same or a slightly larger value than the scan time you noted in point #16 (if you specify a longer measuring time than you actually need, you lose resolution in the dose profile).



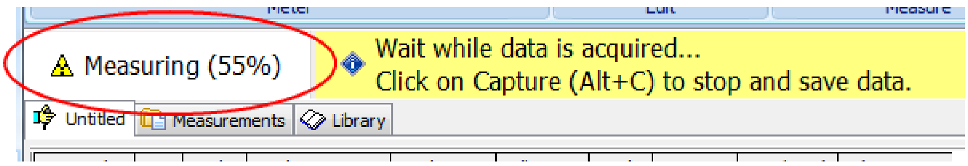
View / Select	#	Set kV (kV)	CT phantom type	Collimation (mm)	Pitch	Scan length (mm)	Tube rotation time (s)	Scan speed (mm/s)	Measuring time (s)	Exposure (mGy)
	1	80	Head	12	1,000	171	1,00	12,00	16	
	2	120	Head	12	1,000	171	1,00	12,00	16	
	3	100	Body	12	1,000	171	1,00	12,00	16	

You are now ready to perform the measurement. **Timed mode** will be used and you must start the measurement manually before you start the CT scan.

27. Click the Start button in Ocean 2014 and begin the CT scan from the console.



28. You will see how the measurement is progressing on Ocean 2014's status bar.



The dose profile will now be measured. Be sure that the entire scan is covered by the measuring time you have chosen. If not, you should increase the measuring time in Ocean 2014 and redo the measurement.

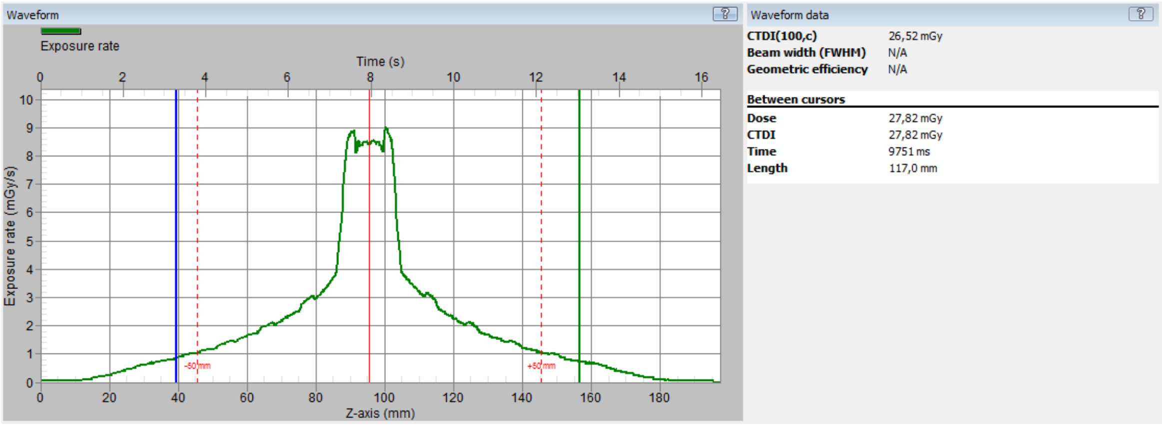
29. As soon the measurement is completed Ocean 2014 will display the dose profile and calculated data. The dose profile is shown in the waveform window and the total measured dose is shown in the Exposure column in the grid.

Toshiba huvudfantom | Measurements | Library

View / Select	#	Set kV (kV)	CT phantom type	Collimation (mm)	Pitch	Scan length (mm)	Tube rotation time (s)	Scan speed (mm/s)	Measuring time (s)	Exposure (mGy)
	1	80	Head	12	1,000	171	1,00	12,00	16	30,04
	2	120	Head	12	1,000	171	1,00	12,00	16	
	3	100	Body	12	1,000	171	1,00	12,00	16	

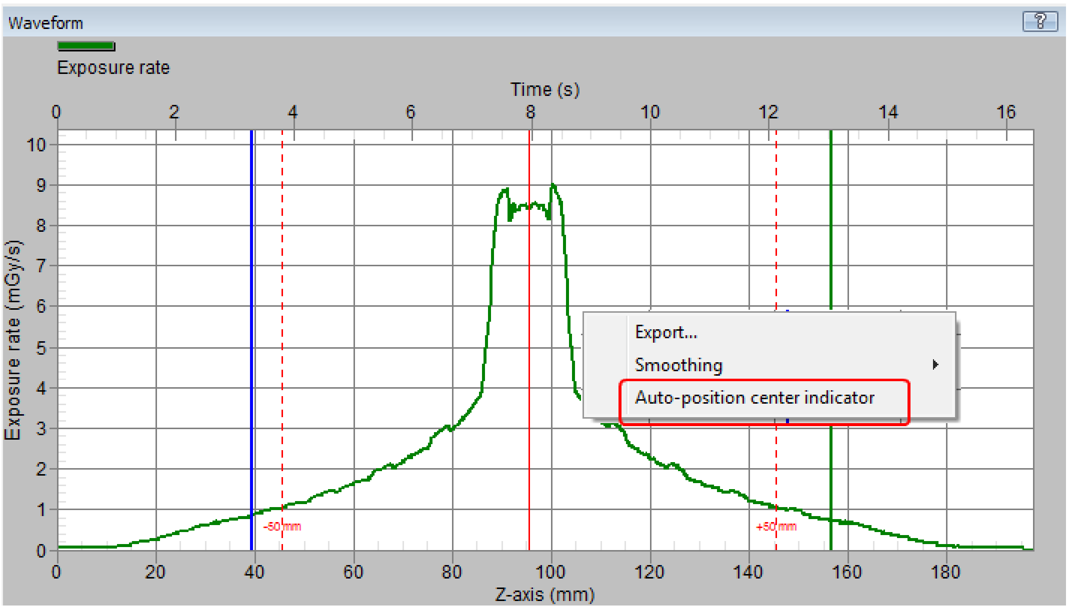
Make the necessary adjustments and redo the measurement if you don't get a value in the Exposure column.

The waveform graph shows the dose profile:

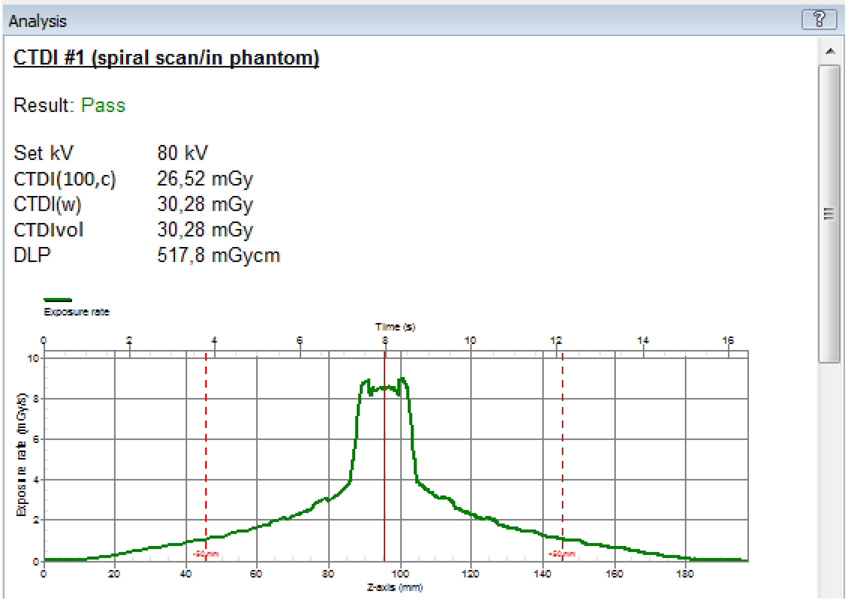


There are two cursors that can be moved. Corresponding cursor values are shown in the waveform data window.

The center indicator can be moved manually. This can be useful in situations when Ocean 2014 isn't able to find the correct center position. When the center indicator is moved all values related to its position and the +/-50 mm indications are recalculated. To move the center indicator just move mouse pointer over it and use drag-and-drop. Right-click on the graph and select **Auto-position center indicator** if you want to restore the automatically calculated position.



30. The calculated values are shown in the Analysis window.

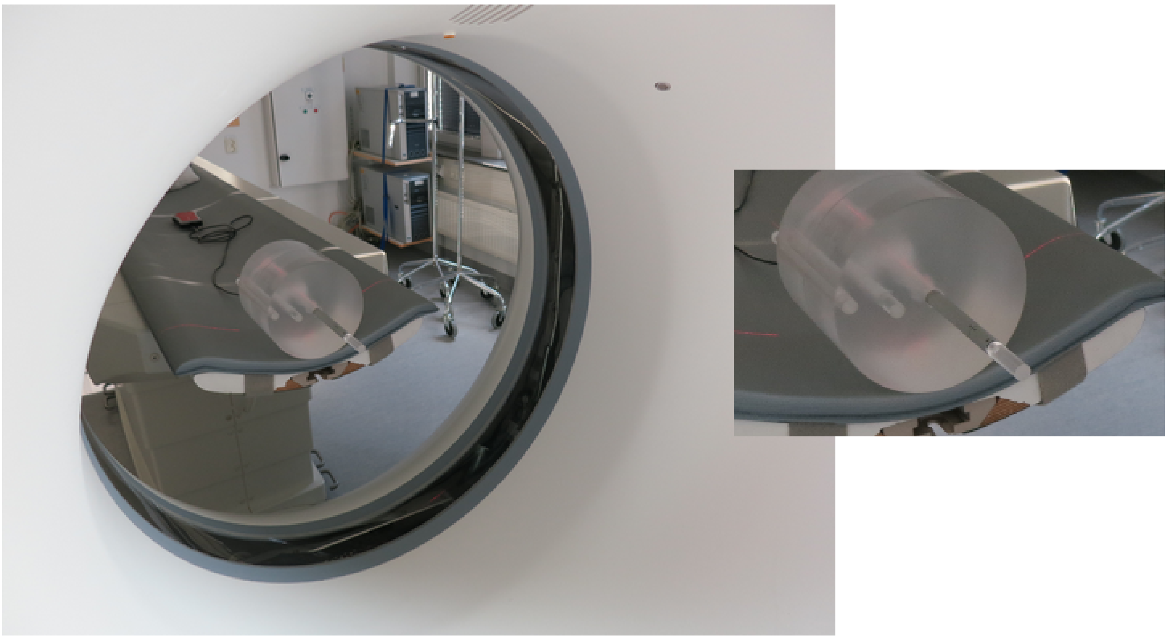


31. The first CTDI measurement is now done. You can now measure the remaining CTDI values using the above method.

2.2 Measurement free-in-air

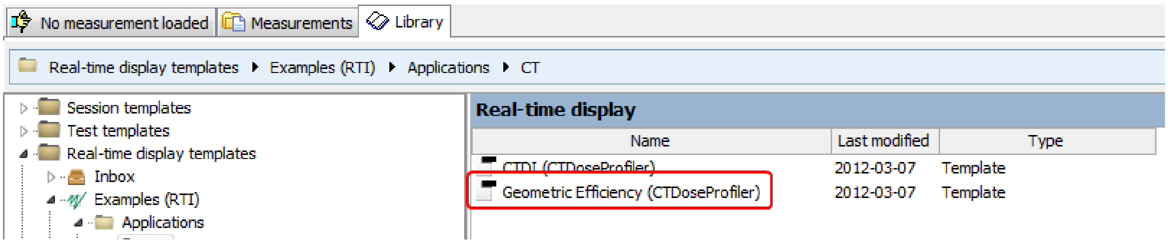
The second standard template that comes with Ocean 2014 is for measurements free-in-air. This template calculates CTDI free-in-air and Geometric Efficiency. You perform this measurement the same way as described in the previous section but in this case is no phantom used.

Hint
When you do the free-in-air measurement, you may use the phantom as a holder for the probe as shown in the picture below:



1. Go to the Library tab and open the **Examples(RTI) -> Application -> CT** folder. (If you can't find the examples, please read the section **Load CT Dose Profiler templates**.)

2. Select the template **Geometric Efficiency (CTDoseProfiler)** by double-clicking on the name.



3. Load the template.

Measurements | **Library** | **Untitled**

View / Select	#	Set kV (kV)	Collimation (mm)	Pitch	Tube rotation time (s)	Scan speed (mm/s)	Measuring time (s)	Exposure (mGy)
▶	1	120	24	1,000	1,00	24,00	5	
	2	120	12	1,000	1,00	12,00	15	
	3	120	12	1,000	1,00	12,00	5	

4. You must enter the parameters below before you can perform your first measurement.

- kV
- Pitch (-)
- Tube rotation time (s)
- Collimation (mm)

5. Now perform the measurement the same way as the CTDI measurement described in the previous section.

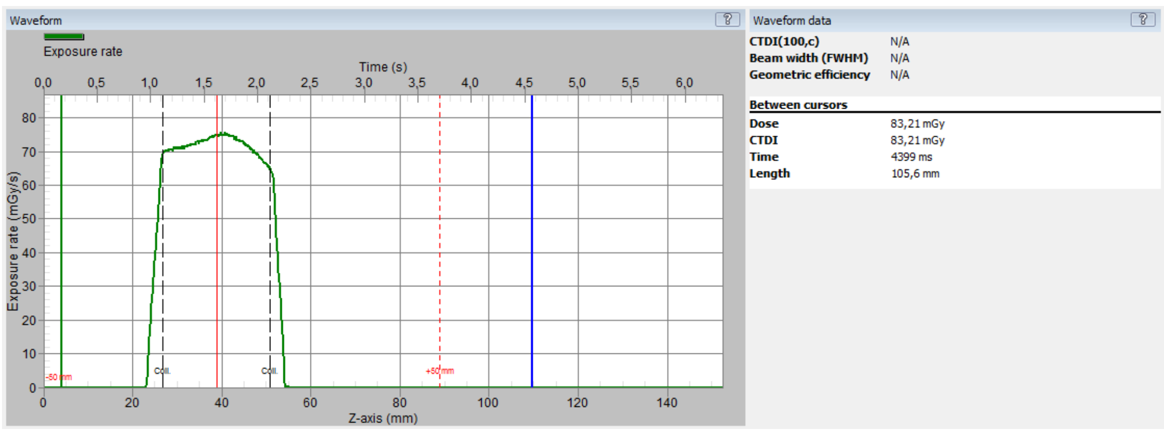
6. As soon the measurement is completed Ocean 2014 will display the dose profile and calculated data. The dose profile is shown in the waveform window and the total measured dose is shown in the Exposure column in the grid.

Measurements | **Library** | **Toshiba 16 Free in Air**

View / Select	#	Set kV (kV)	Collimation (mm)	Pitch	Tube rotation time (s)	Scan speed (mm/s)	Measuring time (s)	Exposure (mGy)
▶	1	120	24	1,000	1,00	24,00	5	87,89
	2	120	12	1,000	1,00	12,00	15	
	3	120	12	1,000	1,00	12,00	5	

Make the necessary adjustments and redo the measurement if you don't get a value in the Exposure column.

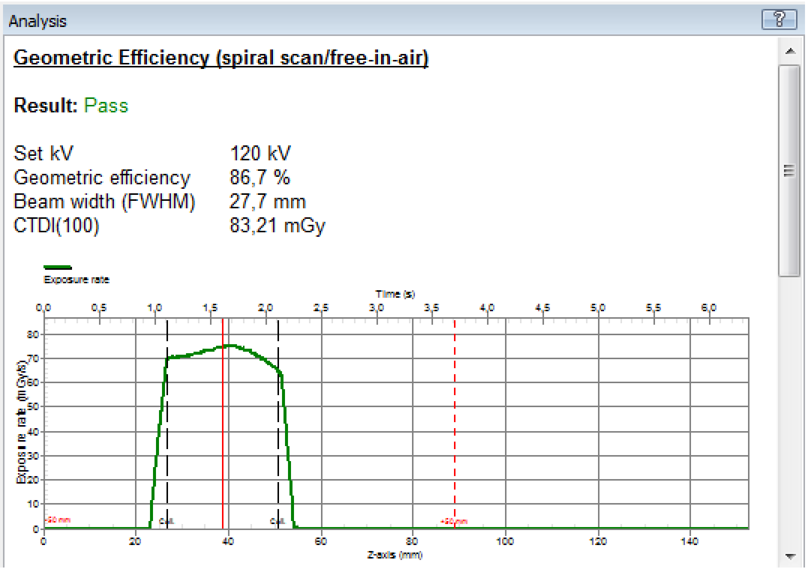
The waveform graph shows the dose profile:



There are two cursors that can be moved. Corresponding cursor values are shown in the waveform data window.

If the center point and FWHM can't be found automatically the analysis will show a calculation error. In this case, in the waveform graph (not the analysis graph), use the mouse pointer and grab the center pointer. You can now move it. Position it manually in the center of the dose profile. Two new indicators, for FWHM, become visible. Move these and position in a position where the dose rate is half of the maximum dose rate.Now are all parameters in the analysis calculated based on the manual positions you have done. If you want to go back to automatic calculation; right-click on the waveform graph and check "Auto-position center indicator".

7. The calculated values are shown in the Analysis window.

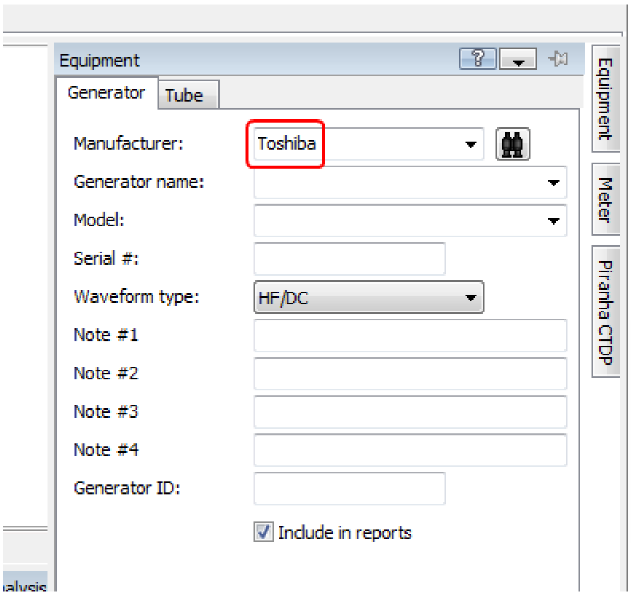


8. The first measurement Geometric Efficiency is now done. Other parameters measured with this template are the CTDI(100) free-in-air and the Beam width (FWHM = Full Width Half Maximum).

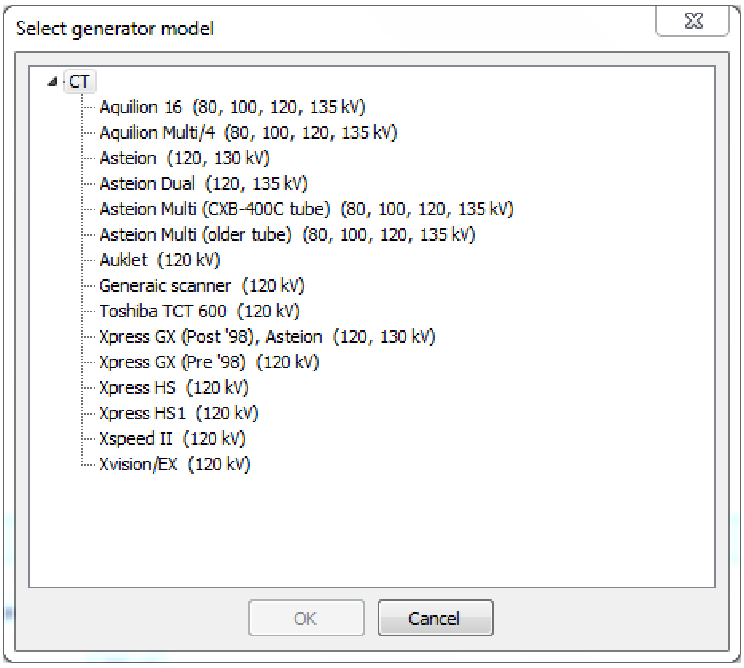
2.3 Unlisted CT scanners

The scanners we currently have k-factors for (required for the method to measure CTDI with only one scan) are listed in Appendix k-factors. Note that you can always specify the k-factor after the measurement if you don't know it when you perform the measurement. Add a user-defined k-factor later and specify it. all calculations will be updated according to the new k-factor you specify.

As described in section Make your first CTDI measurement you select the CT scanner by clicking on the binoculars on the Equipment tab after specifying the manufacturer name.



When you click on the binoculars the available scanners for selected manufacturer are shown:



If you don't find the scanner model you are looking for do the following:

- Select one that is similar to one in the list
- Use the Generic scanner
- Use your own k-factor. You must then instead select the CTDI template in the folder **User-def k-factors** or if you are using Ocean 2014 Professional, modify the template and add a column for the k-factor.

Select one that is similar

1. Select one that you think is similar.

2. Edit the model field.

3. Proceed according to the description in section Make your first CTDI measurement.

Select "Generic scanner"

1. Select the "Generic scanner".

2. Edit the model field.

3. Proceed according to the description in section Make your first CTDI measurement.

Use your own k-factor

The k-factor is used by Ocean 2014 to calculate the weighted CTDI ($CTDI_w$) from only one measurement in the center hole of the phantom. The k-factor is calculated as:

$$k = \frac{CTDI_w}{CTDI_{100(center)}}$$

If you know this factor for a certain CT scanner, you can use it by building your own template and include the k-factor column:

Toshiba huvudfantom | Measurements | Library

View / Select	#	Set kV (kV)	CT phantom type	Collimation (mm)	Pitch	Scan length (mm)	Tube rotation time (s)	Scan speed (mm/s)	Measuring time (s)	Exposure (mGy)	K-factor
	1	80	Head	12	1,000	171	1,00	12,00	16	30,04	1,090
	2	120	Head	12	1,000	171	1,00	12,00	16		
	3	100	Body	12	1,000	171	1,00	12,00	16		

As soon as you enter a value in the k-factor column, this value is used for the calculation. It will overrule any value available in Ocean 2014's database.

Chapter 3

Create your own templates

3 Create your own templates

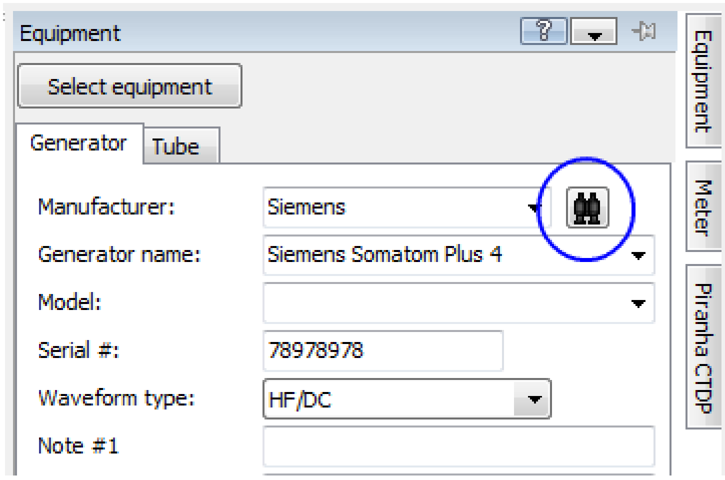
The templates we have used so far have been the standard templates delivered with Ocean 2014. These templates are locked and cannot be modified (you can only change existing set values but not the structure). You can build your own templates, real-time display or test templates, if you have Ocean 2014 Professional.

Ocean 2014's helptext and User's Manual give a general description of how to create a template. The next two topics give specific information about required columns, calculations and other information required to measure CTDI and Geometric Efficiency using the CT Dose Profiler and Ocean 2014.

3.1 CTDI template (in phantom)

The theory behind the method of only one helical scan with the probe in the center hole of the phantom used in Ocean 2014 to measure the CTDI is described in the section CTDI and k-factor. This section describes what columns and analyses you must include in a template to evaluate $CTDI_{100}$, $CTDI_w$, $CTDI_{vol}$ and DLP.

The CTDI analysis is used to evaluate the CT dose index on computed tomography systems using the RTI CT Dose Profiler detector. Ocean 2014 uses one helical scan exposure with the CTDP in the center hole of a 5-hole phantom and calculates the $CTDI_w$, $CTDI_{vol}$ and DLP. Since a known relationship exists between the the center hole and the peripheral holes, only one helical scan measurement is done in the center hole of the phantom to calculate the CTDI. This relationship is unique for each CT scanner and is defined in Ocean 2014 as the k-factor. A list of k-factors Ocean 2014 uses is available in the Appendix. Use the binoculars to select a scanner from the list. Ocean 2014 will choose the correct k-factor based the CT scanner name you selected.



If you want to modify the standard analysis (Ocean 2014 Professional is required), see topic **Modify analysis** and **Advanced analysis** in the Ocean 2014 Reference Manual (or Help text).

A typical CTDI (in phantom helical scan)

This example shows three measurements, each with its own analysis. Two is a measurement in a head phantom and the other is in a body phantom. In this case is only one measurement performed.

View / Select	#	Set kV (kV)	CT phantom type	Collimation (mm)	Pitch	Scan length (mm)	Tube rotation time (s)	Scan speed (mm/s)	Measuring time (s)	Exposure (mGy)
	1	80	Head	12	1,000	171	1,00	12,00	16	30,04
	2	120	Head	12	1,000	171	1,00	12,00	16	
	3	100	Body	12	1,000	171	1,00	12,00	16	

Note:
- You should use TIMED MODE for this measurement. The measuring time is defined by the column

"Measuring time".

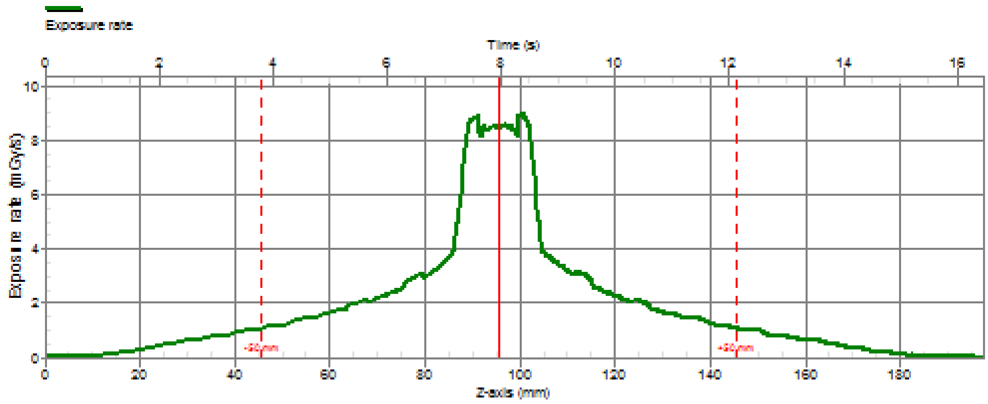
- Use Low sensitivity for Head phantom and free-in-air and High sensitivity for Body phantom.

The calculation (analysis) for the first measurement looks like this:

CTDI #1 (spiral scan/in phantom)

Result: Pass

Set kV	80 kV
CTDI(100,c)	26,52 mGy
CTDI(w)	30,28 mGy
CTDIvol	30,28 mGy
DLP	517,8 mGycm



Default pass/fail criteria

When you add the CTDI (in phantom helical scan) analysis the following pass/fail criteria is shown:

	Min	Max	
☑ Use CTDI(100,w) limit			mGy

You must choose your own default limits for the pass/fail criteria. If you leave a limit blank no pass/fail analysis is performed for that item.

When you modify a CTDI (in phantom helical scan) analysis (Ocean 2014 Professional is required), all pass/fail criteria are available:

	Min	Max	
☐ Use CTDI(100,w) limit			mGy
☐ Use CTDI(100,w,n) limit			mGy/mAs
☐ Use CTDI(100,vol) limit			mGy
☐ Use DLP limit			mGycm

You must modify the layout to see the results of the additional parameters.

Result layout and macros

As described in the topic **Advanced analysis** in the Ocean 2014 Reference Manual (or Help text), it is possible to modify the the layout of the analysis result (Ocean 2014 Professional is required). The layout is defined as text combined with "macros". When the analysis result is shown, the macros are replaced with the appropriate calculated values, set values and measured values. The default layout for the CTDI (in phantom helical scan) analysis looks like this:

```
$Title

Result: $TestResult

Set kV          $SetkV kV
CTDI(100,c)     $CTDIc $Unitw
CTDI(w)         $CTDIw $Unitw
CTDIvol         $CTDIvol $Unitvol
DLP             $DLP $UnitDLP

$DoseProfileGraph
```

This text can be modified and more macros can be added to show more calculated results, for example, the relative difference. The following macros are available for the CTDI (in phantom helical scan) analysis:

$Title (Specified title)

$Result (Analysis result)

$TestResult (Pass or fail text, the overall result for the test)

$SetkV (Set kVp)

$SetmAs (Set mAs)

$SetPitch (Set pitch)

$SetScanTime (Set value for the scan time)

$SetTubeRotTime (Set tube rotation time)

$SetCollimationNT (Set value for the collimation)

$SetPhantomType (Set value for phantom type)

$ScanSpeed (Calculated scan speed = Set Pitch * Collimation(NT) / Set Tube Rot Time)

$DoseProfileGraph (The CT dose profile graph)

$CTDIc (Measured CTDI(100,c) (center position) from waveform)

$CTDIwn (Measured value CTDI normalized)

$Unitwn (Unit for CTDI normalized)

$MinCTDIwn (Minimum value)

$MaxCTDIwn (Maximum value)

$CTDIw (Measured value CTDI weighted)

$Unitw (Unit for CTDI weighted)

$MinCTDIw (Minimum value)

$MaxCTDIw (Maximum value)

$CTDIvol (Measured value CTDI volume)

$Unitvol (Unit for CTDI volume)

$MinCTDIvol (Minimum value)

$MaxCTDIvol (Maximum value)

$DLP (Measured value for Dose Length Product)

$UnitDLP (Unit for Dose Length Product)

$MinDLP (Minimum value)

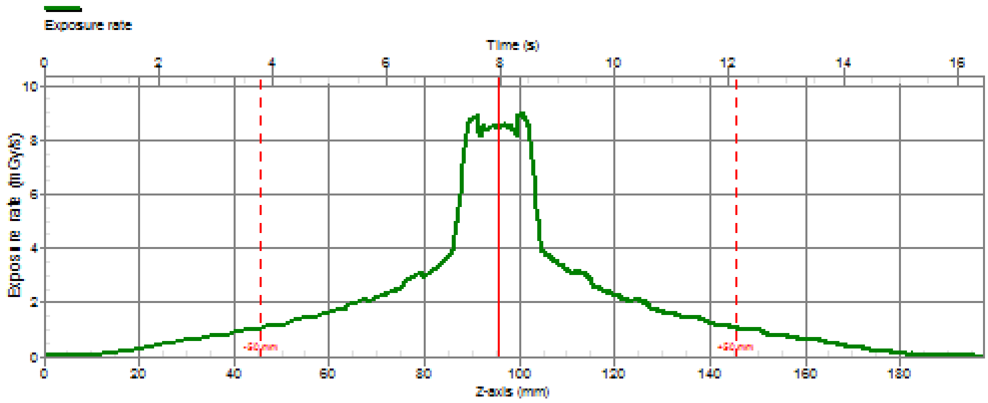
$MaxDLP (Maximum value)

$kFactor (Used k-factor (if blank, automatically selected by the analysis))

Calculations

The CTDI(100,c) is calculated in the following way:

All calculations are done from the dose profile waveform.



The waveform is an array of samples where the Z-axis (see graph above) represents the position of the sensor and the y-axis represents the exposure rate. The waveform includes a maximum of 1024 samples.

Ocean 2014 finds key locations in the waveform in the following way:

1. Find the maximum dose rate that occurred during the scan.
2. Search backward from this point to find where the dose profile goes below 50% of the maximum value and call this position X1 (not shown on graph).
3. Search forward from the point found in step 1 to find where the dose profile goes below 50% of the maximum value and call this position X2 (not shown on graph).
4. Calculate the position halfway between X1 and X2. Call this point X3 (shown as a solid red line in graph above).
5. Calculate "X3-50 mm" and "X3+50 mm" and call these positions X4 and X5, respectively. They are marked with red dotted lines in the graph above and labeled with the text "-50 mm" and "+50 mm", respectively.

If the points X1 and X2 can't be found automatically the analysis will show a calculation error. In this case, in the waveform graph (not the analysis graph), use the mouse pointer and grab the center pointer. You can now move it. Position it manually in the center of the dose profile. Two new indicators, for FWHM, become visible. Move these and position in a position where the dose rate is half of the maximum dose rate.Now are all parameters in the analysis calculated based on the manual positions you have done. If you want to go back to automatic calculation; right-click on the waveform graph and check "Auto-position center indicator".

The central CTDI, CTDI(100,c) is calculated as:

$CTDIc = "Integrated dose between X4 and X5" * Pitch

Pitch must be specified in the grid.

The weighted CTDI, CTDI(100,w), is calculated as:

$CTDIw = $CTDIc * $kFactor

The k-factor is from the table in the Appendix. The k-factor is found based on kVp, phantom type and CT scanner name. If you want to specify your own k-factor add the "k-factor" column to the template.

The volume CTDI, CTDI(100,vol) for a helical scan is calculated as:

$CTDIvol = $CTDIw / Pitch

The dose-length product, DLP, is calculated as:

$DLP = $CTDIvol * Scan length

Recommended columns (or general settings)

The following columns are recommended for the CTDI(in phantom helical scan) analysis.

Parameter	Description
Exposure(Measured)	The measured dose from the CT Dose Profiler detector.
Set kV	The set value for kV
CT Phantom type (Set value)	The phantom type, specifies head or body for this analysis
CT phantom position (Set value)	This specifies where the CT chamber is positioned in the phantom. (*not required, center hole is assumed if not specified*)
Collimation (Set value)	This column specifies the collimation.
Pitch (Set value)	This column specifies the pitch.
Scan length (Set value)	This specifies the length of the scan.
Scan speed (Set value)	This specifies the scan speed.
Measuring time	This is the measuring time for TIMED MODE. This is a meter setting (a value used by the meter).
Tube rotation time (Set value)	This is the tube rotation time.

3.2 CTDI (free-in-air) and Geomtetric Efficiency template

The CTDI (free-in-air helical scan) analysis is used to evaluate the geometric efficiency, CTDI free-in-air and beam width (FWHM) on computed tomography systems using the RTI CT Dose Profiler detector. It uses one helical scan exposure and calculates the geometric efficiency.

The Geometric efficiency is, simply speaking, the quotient between the dose inside the collimation width NT and the total dose profile along the z-axis expressed in percentage. The exact definition can be seen in reference 13. The Geometric efficiency gives an indication of how good the collimation on the CT system is and how much of the radiation goes outside the detectors. An example of measured Geometric efficiency is shown in the picture below. The two dotted black lines represent the length of NT. Ideally, all the active detectors should receive the same amount of radiation and no radiation should be outside the detectors. That would give a Geometric efficiency of 100%, but that is probably not possible due to the penumbra, etc. A Geometric efficiency over 70% is good for a multi-slice CT (MSCT).

If you want to modify the standard analysis (Ocean 2014 Professional is required), see topic **Modify analysis** and **Advanced analysis** in Ocean 2014 Reference Manual (or Help text) for more information.

A typical CTDI and Geometric Efficiency (free-in-air helical scan) test

This example shows three measurements, each with its own analysis. Only the first measurement is performed in this case.

View / Select	#	Set kV (kV)	Collimation (mm)	Pitch	Tube rotation time (s)	Scan speed (mm/s)	Measuring time (s)	Exposure (mGy)
	1	120	24	1,000	1,00	24,00	5	87,89
	2	120	12	1,000	1,00	12,00	15	
	3	120	12	1,000	1,00	12,00	5	

Note:
- You should use TIMED MODE for this measurement. The measuring time is defined by the column

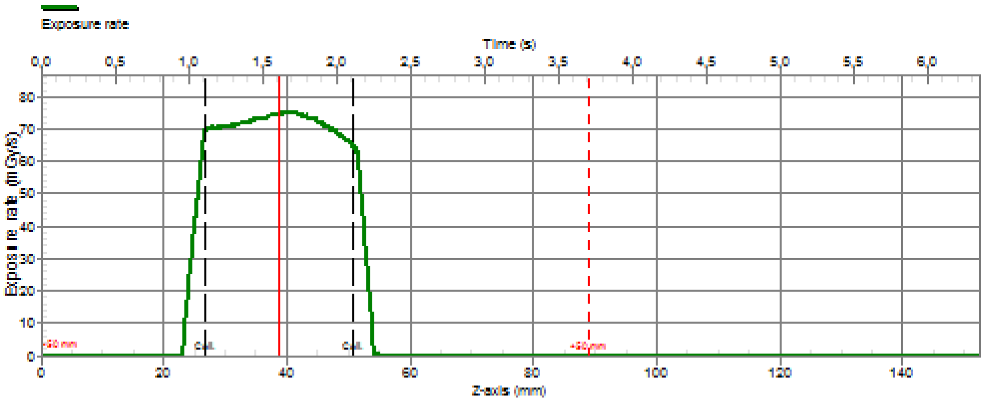
"Measuring time".
- Use Low sensitivity for Head phantom and free-in-air and High sensitivity for Body phantom.

The calculation (analysis) for the first measurement looks like this:

Geometric Efficiency (spiral scan/free-in-air)

Result: Pass

Set kV	120 kV
Geometric efficiency	86,7 %
Beam width (FWHM)	27,7 mm
CTDI(100)	83,21 mGy



Default pass/fail criteria

When you add the CTDI(helical scan/free-in-air) analysis the following pass/fail criteria is shown:

	Min	Max	
Geometric efficiency:			%
Beam width (FWHM):			mm

No default limits are specified, you must fill out limit. If you leave a limit blank not test for that criteria is done.

Result layout and macros

As described in the topic **Advanced analysis** in the Ocean 2014 Reference Manual (or in the Help text), it is possible to modify the the layout of the analysis result. The layout is defined as text combined with "macros". When the analysis result is shown, the macros are replaced with the appropriate calculated values, set values and measured values. The default layout of text CTDI (free-in-air helical scan) analysis looks like this:

$Title	
Result: $TestResult	
Set kV	$SetkV kV
Geometric efficiency	$GeometricEfficiency %
Beam width (FWHM)	$BeamWidthFWHM mm
CTDI(100)	$CTDI100 $UnitCTDI100
$DoseProfileGraph	

This text can be modified and more macros can be used to show more calculated results, for example the relative difference. The following macros are available for the CTDI(free-in-air helical scan) analysis:

$Title (Specified title)

$Result (Analysis result)

$TestResult (Pass or fail text, the overall result for the test)

$SetkV (Set kVp)

$SetmAs (Set mAs)

$SetPitch (Set pitch)

$SetScanTime (Set value for the scan time)

$SetTubeRotTime (Set tube rotation time)

$SetCollimationNT (Set value for the collimation)

$SetPhantomType (Set value for phantom type)

$ScanSpeed (Calculated scan speed = Set Pitch * Collimation(NT) / Set Tube Rot Time)

$DoseProfileGraph (The CT dose profile graph)

$CTDI100 (Measured CTDI100)

$UnitCTDI100 (Unit for CTDI)

$BeamWidthFWHM (Beam width from waveform)

$MinBeamWidthFWHM (Minimum value)

$MaxBeamWidthFWHM (Maximum value)

$GeometricEfficiency (Geometric efficiency (from waveform))

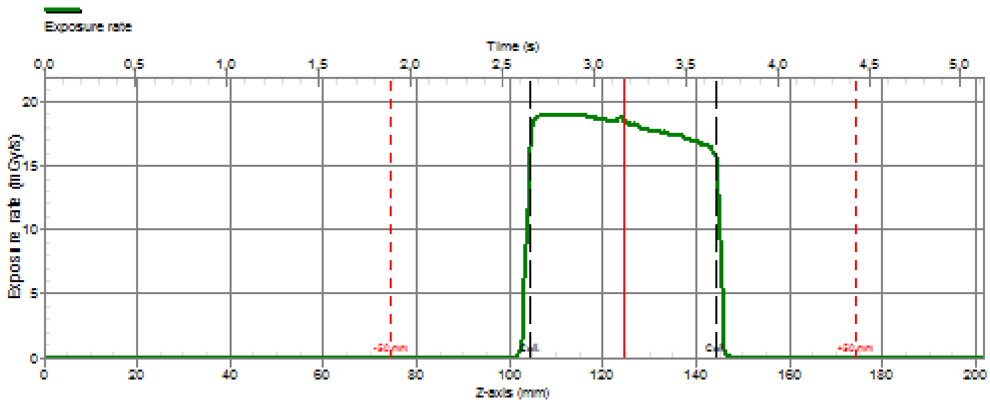
$MinGeometricEfficiency (Minimum value)

$MaxGeometricEfficiency (Maximum value)

Calculations

The CTDI(100,c) is calculated in the following way:

All calculations are done from the dose profile waveform.



The waveform is an array of samples where the Z-axis (see graph above) represents the position of the sensor and the y-axis represents the exposure rate. The waveform includes a maximum of 1024 samples.

Ocean 2014 finds key locations in the waveform in the following way:

1. Find the maximum dose rate that occurred during the scan.
2. Search backward from this point to find where the dose profile goes below 50% of the maximum value and call this position X1 (not shown on graph).
3. Search forward from the point found in step 1 to find where the dose profile goes below 50% of the maximum value and call this position X2 (not shown on graph).
4. Calculate the position halfway between X1 and X2. Call this point X3 (shown as a solid red line in graph above).
5. Calculate "X3-50 mm" and "X3+50 mm" and call these positions X4 and X5, respectively. They are marked with red dotted lines in the graph above and labeled with the text "-50 mm" and "+50 mm", respectively.

If the points X1 and X2 can't be found automatically the analysis will show a calculation error. In this case, in the waveform graph (not the analysis graph), use the mouse pointer and grab the center pointer. You can now move it. Position it manually in the center of the dose profile. Two new indicators, for FWHM, become visible. Move these and position in a position where the dose rate is half of the maximum dose rate.Now are all parameters in the analysis calculated based on the manual positions you have done. If you want to go back to automatic calculation; right-click on the waveform graph and check "Auto-position center indicator".

The central CTDI, CTDI(100,c) is calculated as:

$CTDI100 = "Integrated dose between X4 and X5" * Pitch

Pitch must be specified in the grid.

FWHM is calculated as the distance between X1 and X2:

$BeamWidthFWHM = X2 - X1

Calculate Geometric efficiency in the z-direction (according to IEC 60601-2-44) as:

$GeometricEfficiency = 100* (Dose between X6 and X7) / (Total dose)

Note!
The dose profile waveform is adjusted with the following function (X = FWHM) for 3 mm < X < 40 mm:

CorrF = 1.25466313 - 0.43935032 * X +0.34546921 * X^2 - 0.14128364 * X^3 + 0.03057638 * X^4 - 0.00330919 * X^5 + 0.00014071 * X^6

For X < 3 mm, no valid correction available

For X > 40 mm, CorrF = 1.00

This means that the total dose indicated "between cursors" will differ from the dose value shown in the grid (in the Exposure column) when the FWHM is less than 40 mm.

Recommended columns (or general settings)

The following columns are recommended for the CTDI (free-in-air helical scan) analysis.

Parameter	Description
Exposure(Measured)	The measured dose from the CT Dose Profiler detector.
Set kV	The set value for kV
CT Phantom type (Set value)	The phantom type, specifies head or body for this analysis (*not required*)
Collimation (Set value)	This column specifies the collimation.
Pitch (Set value)	This column specifies the pitch.
Scan length (Set value)	This specifies the length of the scan. (*not required*)
Scan speed (Set value)	This specifies the scan speed.
Measuring time	This is the measuring time for TIMED MODE. THis is a meter setting (a value used by the meter).
Tube rotation time (Set value)	This is the tube rotation time.

Chapter 4

Theory

4 Theory

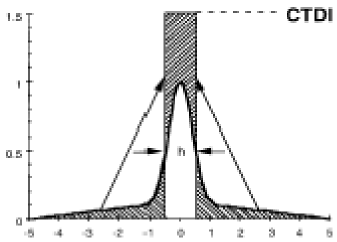
4.1 CTDI and k-factor

A quick and convenient way to determine $CTDI_{vol}$ is to use a method we call the Central Point Method. This method is based on the observation that the ratio between $CTDI_w$ and $CTDI_{100,central}$ is a constant for specific CT scanners in combination with the type of phantom used in the measurement (see reference 10). If the k-factor is known, you can perform a $CTDI_{100(central)}$ measurement and the software will then calculate $CTDI_w$ and $CTDI_{vol}$ automatically. The Appendix k-factors lists all scanners currently supported in Ocean 2014.

There are a number of different quantities related to CTDI. The most common are summarized in the table below:

Quantity	Symbol	Remarks
CT Dose Index	CTDI	General dose description for CT
Multiple Scan Average Dose	MSAD	As CTDI but corrected for pitch
CTDI (100)	$CTDI_{100}$	Current definition of CTDI
Weighted CTDI	$CTDI_w$	Main descriptor of local dose
Volume CTDI	$CTDI_{vol}$	As $CTDI_w$ but corrected for pitch, same as $CTDI_{eff}$
Dose length product	DLP	Takes the irradiated volume into account

The CTDI quantity can be interpreted as the radiation energy deposited in a slice with a thickness corresponding to the nominal beam collimation thickness. The dose inside the slice is the CTDI and the dose outside the slice is excluded (see figure below).



In single slice CT the expression for CTDI is defined as:

$$CTDI = \frac{1}{T}\int_{-\infty}^{\infty} D(z)dz$$

where T is the nominal beam collimation thickness in mm and D(z) is the dose profile. On the y-axis the quantity is relative dose. $CTDI_{100}$ is acquired by reducing the integral to go between -50 and 50.

For MSCT, CTDI is defined as:

$$CTDI = \frac{1}{N \cdot T}\int_{-\infty}^{\infty} D(z)dz$$

where N is the number of detectors and T is the width of a detector.

$CTDI_w$ (weighted) represents an average value of the $CTDI_{100}$ inside a phantom (this requires five measurements, one in each hole):

$$CTDI_w = \frac{1}{3} \cdot CTDI_{100(center)} + \frac{2}{3} \cdot CTDI_{100(perpheral)}$$

In the case of single slice CT, the slice thickness is determined by the width of the detector. In multislice CT (MSCT), the slice thickness is determined by the number of detectors and the widths of the detectors.

In spiral CT there is an additional factor called the CT pitch factor. It is defined as the table movement per gantry rotation:

$$Pitch = \frac{\Delta d}{N \cdot T}$$

where Δd is the distance in mm that the couch moves between consecutive serial scans or per 360º rotation in helical scanning. N is the number of detectors and T is the detector thickness in mm (IEC 2003).

$CTDI_{vol}$ is the same as $CTDI_W$ but with respect to the pitch factor in helical (spiral) scanning:

$$CTDI_{vol} = CTDI_w / Pitch$$

The displayed $CTDI_{vol}$ given by a manufacturer may be a representative figure for that model and not the value measured on the particular CT scanner (see reference 13).

The dose-length product, DLP, includes the irradiated volume and represents the overall exposure for an examination and is calculated as following:

$$DLP = CTDI_{vol} \cdot L$$

where L is the scan length of a certain examination.

The scan length is defined as:

$$L = R \cdot p \cdot N \cdot T$$

where R is the number of tube rotations, p is the pitch factor, N is the number of detectors and T is the detector thickness.

The effective dose to a region is defined as:

$$E = E_{DLP} \cdot DLP$$

where DLP (mGycm) is defined in equation 6 and E_{DLP} is the region specific, DLP normalized effective dose (mSv/mGycm).

A quicker way to perform quality assurance has been introduced by using the CT Dose Profiler probe and the Ocean 2014 software. To be able to use it, the k-factor must be known for the CT-unit and the type of phantom that is used for the measurement. A number of k-factors for common CT-units are used by the software and listed in the Appendix k-factors. The factor is calculated by dividing $CTDI_W$ with $CTDI_{100(central)}$ from measurements obtained with pencil ion chambers:

$$k = \frac{CTDI_w}{CTDI_{100(center)}}$$

For head phantoms the k-factor is around 1 and for body phantom the k-factor is around 1.7 at 120 kV.

4.2 Why use a k-factor?

To measure the $CTDI_{100}$ with the CT Dose Profiler in the center hole of a head or body phantom with one helical scan exposure and then multiply it with the k-factor to get $CTDI_w$ and $CTDI_{vol}$ is, of course, faster than doing the five exposures with the pencil ion chamber. With the CT Dose Profiler you can also see a visible image of the dose profile that will tell you if something is wrong with the system. Another reason why the k-factor should be used is that it is hard to compare axial measurements over a pencil ion chamber with helical measurements over the CT Dose Profiler in the peripheral holes.

The nominal beam width is defined in the center of the CT where it is constant during the rotations. If you move a detector outside the center axis the beam width and dose rate will oscillate during the rotation. The pencil ion chamber is only partly irradiated so it is not affected the same way by the inverse square law and divergence in the beam width as a fully irradiated detector. Measurements with the pencil ion chamber do not tell you if you measure on a thin dose profile with high dose rate or a broad dose profile with a low dose rate if they have the same dose area. It can only measure a value that can foretell the dose but it cannot give a visible image of the dose profile.

The point dose detector can measure the same $CTDI_{100}$ in the center of the CT with helical scans as the pencil ion chamber can measure with axial scans. On the central axis the dose is non-oscillatory and the beam width is constant. When measurements are performed in the peripheral holes the conditions are not the same any more. The dose rate and the beam width in a peripheral hole oscillate during a rotation. The dose rate oscillates due to varying x-ray attenuation and beam divergence with changing distances affected by the inverse square law. The beam width varies due to the divergence from the x-ray source which becomes wider with increasing distance.

A single axial scan irradiates the same amount of dose to a detector with good rotation symmetry for every full 360 degree rotation, it does not matter where the rotation starts and stops as long as it makes one whole rotation and it is very easy to get good reproducibility. It is not the same for helical scans over a point dose detector because then you measure the point dose and not the dose length of, for example, 100 mm. The beam divergence from the x-ray source will have a big influence over the helical dose distribution among the peripheral holes in the phantom. That makes it hard to measure reproducible values if a suitable pitch is not used; a so called target pitch. The target pitch can be calculated with the following equation:

$$Target\ pitch = \frac{FWHM}{NT} \times \frac{(S-R)}{S}$$

where S is the distance between the x-ray source and CT center and R is the distance between the CT center and the detector. Observe that you have to know the FWHM in the center of the CT. Few CTs have the possibility to scan with any pitch value which makes it hard to perform this measurement. A pencil ion chamber is not affected by the divergence in beam width and distance the same way as a point detector. The $CTDI_{100}$, p from a measurement with the pencil ion chamber and the point dose detector are a little hard to compare but the point doses simulate the dose to a point in a phantom better.

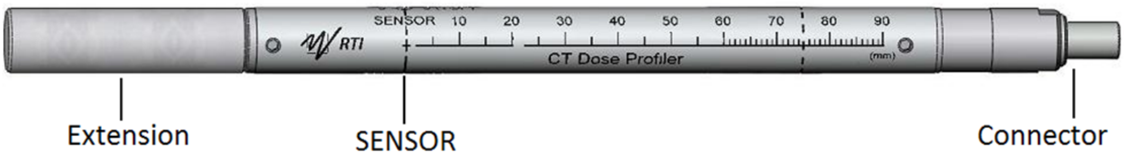
This is the reason why it is recommended to use the one exposure method with the k-factor.

Chapter 5

The CT Dose Profiler Probe

5 The CT Dose Profiler Probe

The CT Dose Profiler has one solid-state sensor placed 3 cm from the end of the probe. The probe can be extended with an extension piece made of PMMA to fill different phantoms. The standard extension is 45 mm. When this extension is on, the detector will be centered in the middle of a 150 mm wide PMMA phantom when the end of the extension reaches the end of the phantom.



The sensor in the CT Dose Profiler probe is very thin (250 µm) in comparison to the beam width and is therefore always completely irradiated when it is in the beam.

The sensor is used to collect the dose profile and it can also be used as a trigger. As radiation hits SENSOR, in either direction, the detector registers the dose value at that point and sends the information to the software. The electrometer can collect 2000 such dose values per second. The recommended and most convenient method to measure the dose profile is to use the update mode called Timed. This mode makes it possible to measure exactly the length of time you like. You simply check on the CT-system how the scan will take and then use a margin in your choice of Measuring time.

To be able to collect the dose at the different positions, thereby creating the dose profile, the probe must be moved through the CT. This is achieved by placing it free in air or in a phantom and then using the couch movement to scan the probe. In short, do a helical (spiral) scan. Therefore it is not possible to use axial scans for measuring CTDI with the CT Dose Profiler probe and Ocean 2014, since then the dose profile is not measured. When the table is not moving, the CT Dose Profiler acts as an ordinary dose detector and simply gives the point dose reading at that position. You can, of course, make many axial scans in small steps with the detector and plot a dose profile, but that takes a lot of time. With a helical scan you will receive the dose profile in a few seconds. It has been proven that the dose profile can be measured with helical scans as long as corrections are made for the pitch (see reference 10).

5.1 Specifications

Supported meters:	Barracuda with EMM-1Ch, EMM-2Ch, EMM-Bias, EMM-BiasB and EMM-BiasW (with Ocean) Piranha with external input (with Ocean 2014)
Typical cal. factor:	0.28 mGy/nC
Material:	Al and PMMA
Connector:	Triaxial LEMO
Length (Detector + extension):	165 mm + 45 mm
Diameter:	12.5 mm
Sensor width:	250 um
Max sensitivity variation:	Less than ±5 %
Weight (Probe + extension):	40 g + 10 g

5.2 Energy correction

When using the Piranha with Ocean 2014 and the CT Dose Profiler probe in the radiographic range, all dose and rate values measured are automatically compensated for the energy dependence of the sensor.

The kV range is 55-150 kV and the total filtration ranges from 1 to 55 mm Al for measurements free-in-air and from 3 to 22 mm Al for measurements in head and body CT phantoms. The reference point for all correction factors is at 120 kV with 2.5 mm Al filtration free-in-air (calibration R3 (RQR)).

Energy correction factors free-in-air (beam quality RQR)

Al (mm)	1	2	2,5	3	5	7	10	13	15	19	22	25	29	34	38	44	55
55 kV	1,30	1,15	1,07	1,02	0,91	0,86	0,82	0,81	0,79	0,77	0,77	0,78	0,78	0,77			
60 kV	1,25	1,11	1,04	0,99	0,89	0,85	0,82	0,81	0,80	0,79	0,79	0,79	0,79	0,79	0,79	0,80	0,82
70 kV	1,18	1,06	1,00	0,96	0,88	0,85	0,84	0,83	0,83	0,83	0,84	0,84	0,84	0,85	0,86	0,87	0,89
80 kV	1,13	1,03	0,98	0,95	0,88	0,87	0,87	0,87	0,87	0,88	0,90	0,91	0,91	0,93	0,94	0,96	0,98
90 kV	1,11	1,02	0,97	0,95	0,90	0,89	0,90	0,91	0,92	0,93	0,96	0,97	0,98	1,01	1,03	1,05	1,09
100 kV	1,09	1,01	0,98	0,95	0,92	0,92	0,94	0,96	0,97	0,99	1,02	1,04	1,05	1,09	1,11	1,14	1,21
110 kV	1,07	1,01	0,99	0,96	0,94	0,95	0,97	1,00	1,02	1,05	1,08	1,10	1,12	1,17	1,19	1,24	1,33
120 kV	1,05	1,02	1,00	0,98	0,96	0,98	1,01	1,04	1,06	1,10	1,14	1,17	1,19	1,24	1,27	1,33	1,45
130 kV	1,04	1,02	1,01	0,99	0,99	1,01	1,05	1,09	1,11	1,15	1,20	1,23	1,26	1,31	1,35	1,43	1,56
140 kV	1,04	1,03	1,02	1,00	1,01	1,04	1,09	1,13	1,16	1,21	1,26	1,30	1,33	1,39	1,45	1,52	1,67
150 kV	1,07	1,04	1,02	1,01	1,04	1,07	1,14	1,19	1,21	1,27	1,33	1,38	1,42	1,47	1,56	1,62	1,76

Energy correction factors for Head Phantom (beam quality RQR)

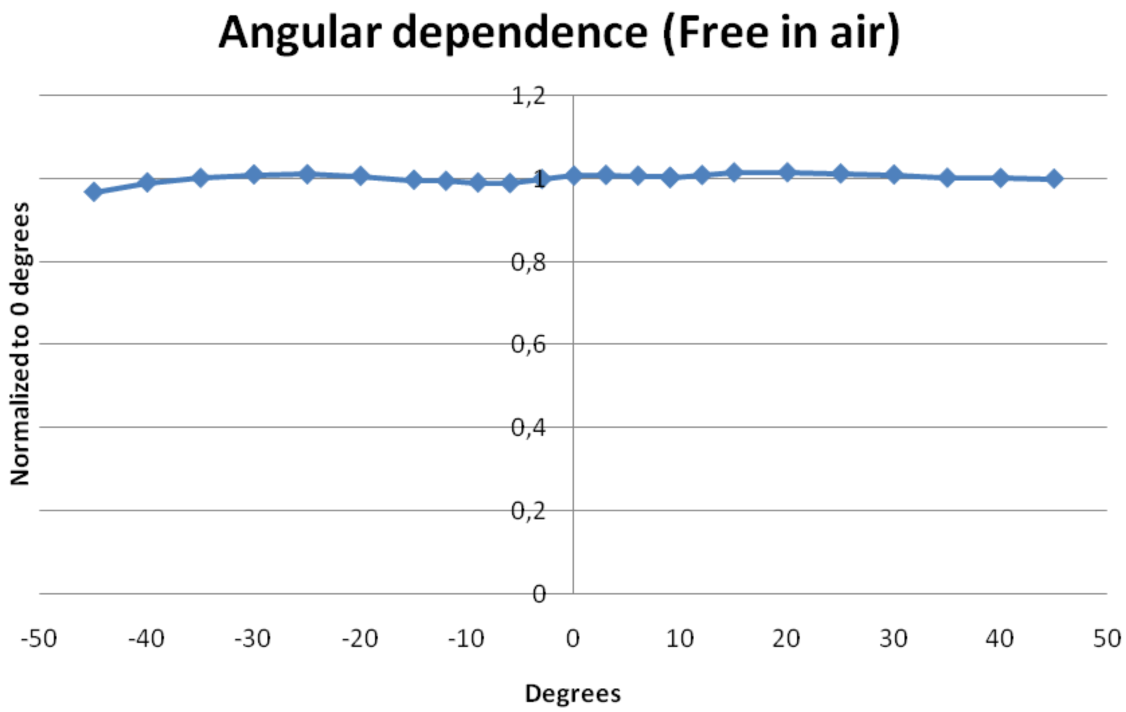
Al (mm)	3	5	7	10	13	19	22
55 kV	0,86	0,88	0,88	0,89	0,91	0,92	0,94
60 kV	0,87	0,88	0,89	0,90	0,92	0,93	0,95
70 kV	0,88	0,89	0,90	0,91	0,93	0,95	0,97
80 kV	0,90	0,91	0,92	0,93	0,95	0,98	1,00
90 kV	0,91	0,93	0,94	0,95	0,97	1,01	1,03
100 kV	0,93	0,94	0,96	0,97	1,00	1,04	1,06
110 kV	0,95	0,97	0,98	1,00	1,03	1,07	1,10
120 kV	0,97	0,99	1,00	1,03	1,06	1,11	1,13
130 kV	1,00	1,01	1,03	1,06	1,09	1,15	1,17
140 kV	1,02	1,04	1,06	1,09	1,12	1,19	1,22
150 kV	1,05	1,07	1,08	1,13	1,16	1,24	1,26

Energy correction factors for Body Phantom (beam quality RQR)

Al (mm)	3	5	7	10	13	19	22
55 kV	0,83	0,84	0,85	0,86	0,88	0,89	0,90
60 kV	0,84	0,85	0,86	0,87	0,89	0,90	0,91
70 kV	0,85	0,86	0,87	0,88	0,90	0,92	0,94
80 kV	0,87	0,88	0,89	0,90	0,92	0,95	0,96
90 kV	0,88	0,89	0,91	0,92	0,94	0,97	0,99
100 kV	0,90	0,91	0,93	0,94	0,96	1,00	1,02
110 kV	0,92	0,93	0,95	0,96	0,99	1,04	1,06
120 kV	0,94	0,95	0,97	0,99	1,02	1,07	1,09
130 kV	0,96	0,98	0,99	1,02	1,05	1,11	1,13
140 kV	0,98	1,01	1,02	1,05	1,08	1,15	1,17
150 kV	1,01	1,03	1,05	1,09	1,12	1,20	1,22

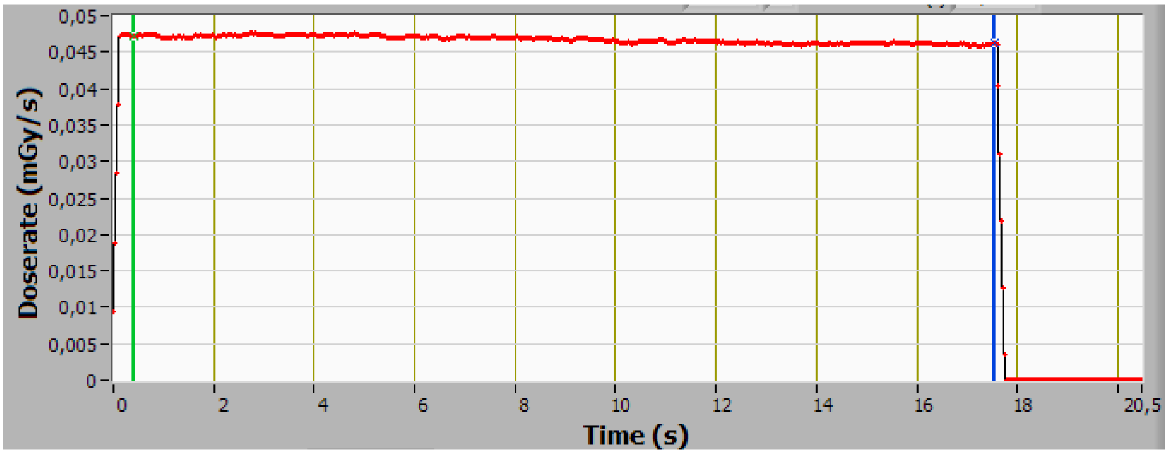
5.3 Angular dependence

This is a graph of the typical angular dependence of the CT Dose Profiler probe measured at 120 kV.



5.4 Rotation symmetry

The rotation symmetry can be measured by rotating the CT Dose Profiler along its longest axis under an irradiating x-ray tube. A typical rotation symmetry for one whole rotation is shown in picture below.

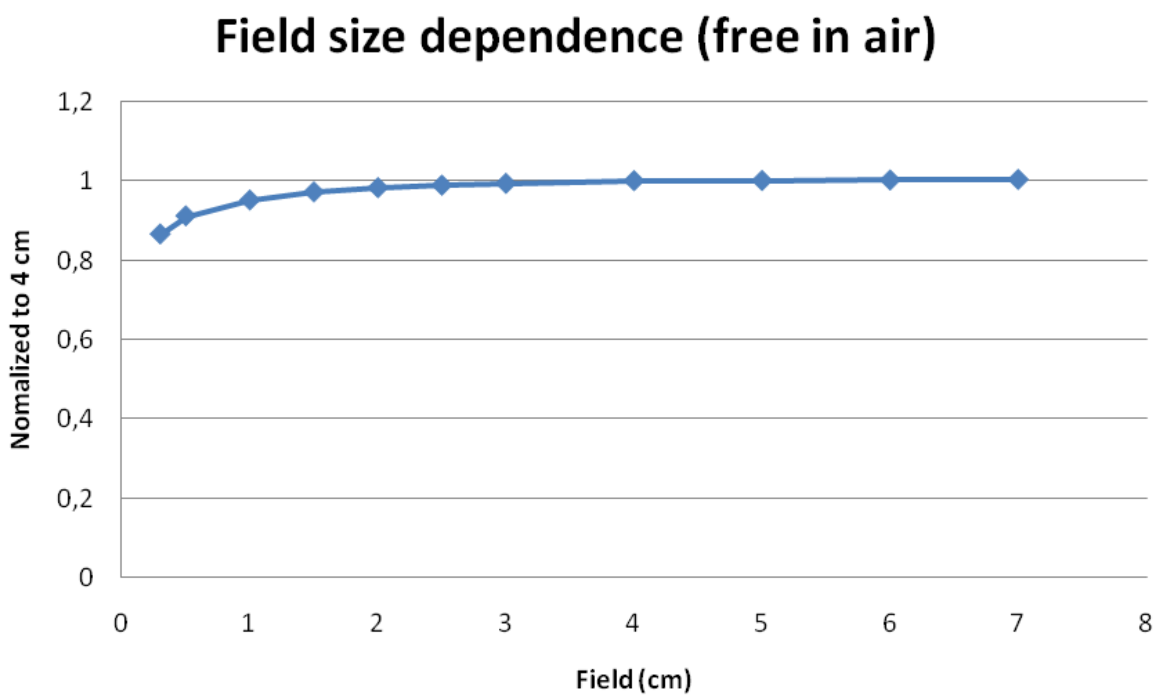


(the output from the tube was going down slightly during the long exposure)

Typical deviation for the CT Dose Profiler probe is about ± 1 %.

5.5 Field size dependence

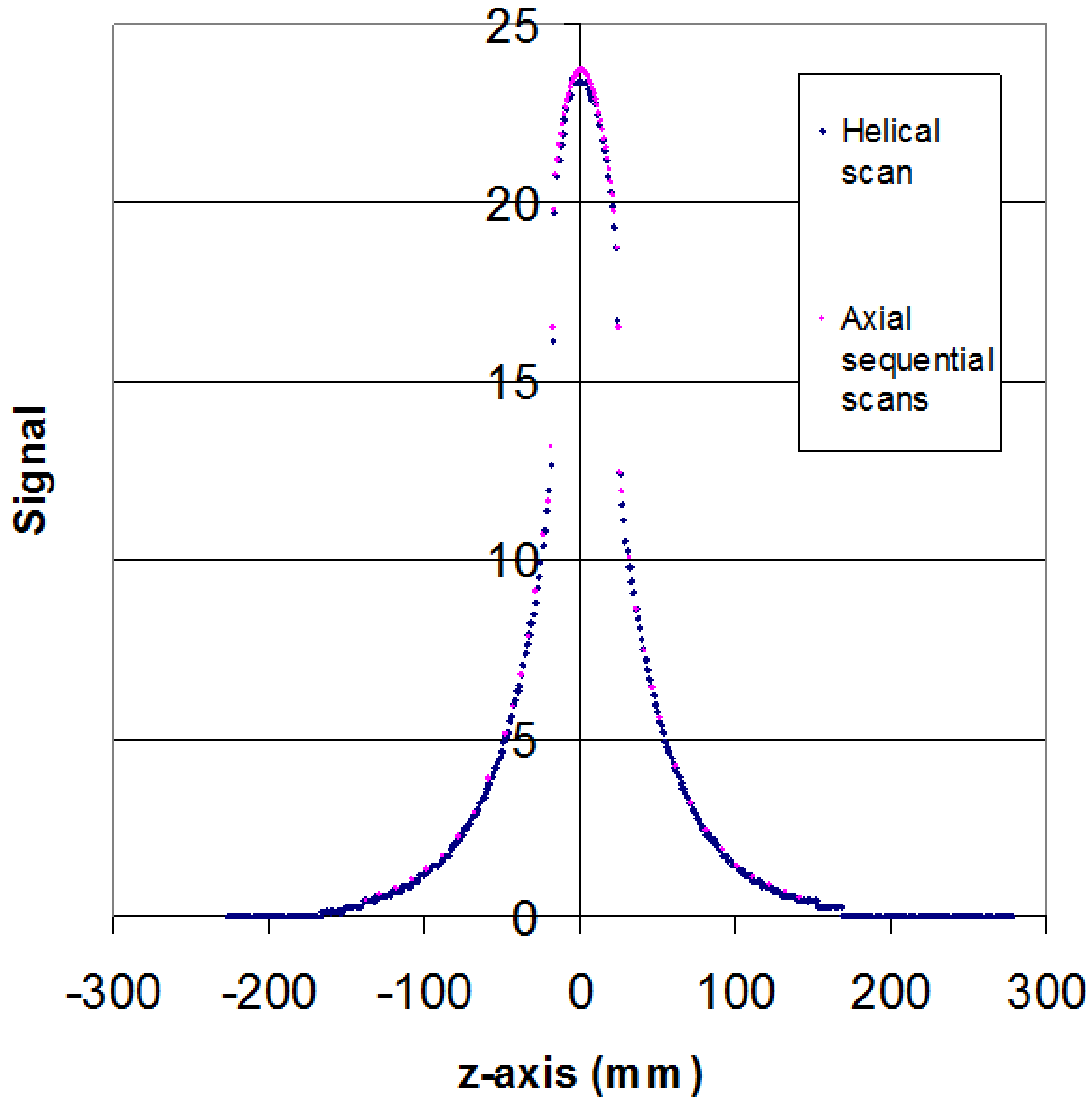
The CT Dose Profiler probe is calibrated with a 5 cm wide field. When measurements are performed free in air with small fields (< 4 cm and down to 3 mm) the calibration factor is no longer accurate and must be corrected, see picture below. This is automatically done in Ocean 2014 when you measure free-in-air and the FWHM lower then 4 cm.



No correction is needed in a phantom due to the large amount of scattering material.

5.6 Axial sequential scans vs. helical scans

The two methods to receive a dose profile, axial sequential scans and helical scans, have been compared and two dose profiles from the two methods are shown in the picture below. The measurement with the axial sequential scans took a long time to perform and the helical scan took a couple of seconds. The measurements were made in a phantom (without the couch in the beam).



Chapter 6

Appendix

6 Appendix

6.1 k-factors

The table below shows the k-factors Ocean uses. There bis one factor for head and body, respectively. The k-factors are based on data from impactctscan.org.

Manufacturer	Name	kVp	Head	Body
Elscint	Exel 2400 Elect	120	1,069	1,527
Elscint	Exel 2400 Elect	140		1,430
Elscint	CT Twin	120	1,047	1,466
Elscint	Helicat	120	1,047	1,466
Elscint	Generic scanner	120	1,050	1,500
GE	8800/9000 Series	120	0,962	1,680
GE	9800 Series	120	1,038	1,585
GE	9800 Series	140	1,020	1,503
GE	HiLight	80	1,047	1,600
GE	HiLight	100	1,008	1,636
GE	HiLight	120	1,030	1,605
GE	HiLight	140	1,015	1,571
GE	HiSpeed CT/i no SmartBeam	80	1,047	1,600
GE	HiSpeed CT/i no SmartBeam	100	1,008	1,636
GE	HiSpeed CT/i no SmartBeam	120	1,030	1,605
GE	HiSpeed CT/i no SmartBeam	140	1,015	1,571
GE	HiSpeed CT/i with SmartBeam	80	1,047	2,093
GE	HiSpeed CT/i with SmartBeam	100	1,008	1,827
GE	HiSpeed CT/i with SmartBeam	120	1,030	1,607
GE	HiSpeed CT/i with SmartBeam	140	1,015	1,568
GE	CT Max	120	0,961	1,505
GE	Pace	80	1,162	2,164
GE	Pace	120	1,053	1,734
GE	Pace	135	1,041	1,627
GE	Pace	140	1,061	1,636
GE	Sytec	80	1,162	2,164
GE	Sytec	120	1,053	1,734
GE	Sytec	135	1,041	1,627
GE	Sytec	140	1,061	1,636
GE	Prospeed	120	1,052	1,713
GE	Prospeed	140	1,040	1,610
GE	FX/i	80	1,145	2,213
GE	FX/i	120	1,058	1,692
GE	FX/i	140	1,037	1,605
GE	LX/i	80	1,145	2,213
GE	LX/i	120	1,058	1,692
GE	LX/i	140	1,037	1,605
GE	QX/i	80	1,032	1,927
GE	QX/i	100	0,999	1,730
GE	QX/i	120	0,987	1,633
GE	QX/i	140	0,977	1,570
GE	LightSpeed	80	1,032	1,927
GE	LightSpeed	100	0,999	1,730
GE	LightSpeed	120	0,987	1,633
GE	LightSpeed	140	0,977	1,570
GE	LightSpeed Plus	80	1,032	1,927
GE	LightSpeed Plus	100	0,999	1,730
GE	LightSpeed Plus	120	0,987	1,633
GE	LightSpeed Plus	140	0,977	1,570
GE	HiSpeed ZX/i	80	1,027	1,810
GE	HiSpeed ZX/i	120	0,993	1,500
GE	HiSpeed ZX/i	140	0,968	1,480

GE	HiSpeed NX/i	80	1,027	1,810
GE	HiSpeed NX/i	120	0,993	1,500
GE	HiSpeed NX/i	140	0,968	1,480
GE	LightSpeed Ultra	80	1,042	2,009
GE	LightSpeed Ultra	100	1,009	1,787
GE	LightSpeed Ultra	120	0,994	1,656
GE	LightSpeed Ultra	140	0,985	1,614
GE	LightSpeed 16	80	1,046	1,819
GE	LightSpeed 16	100	1,010	1,627
GE	LightSpeed 16	120	0,993	1,611
GE	LightSpeed 16	140	0,984	1,483
GE	LightSpeed Pro 16	80	1,057	1,996
GE	LightSpeed Pro 16	100	1,013	1,771
GE	LightSpeed Pro 16	120	0,994	1,652
GE	LightSpeed Pro 16	140	0,983	1,577
GE	LightSpeed RT	80	1,093	2,140
GE	LightSpeed RT	100	1,052	1,897
GE	LightSpeed RT	120	1,028	1,770
GE	LightSpeed RT	140	1,015	1,694
GE	LightSpeed VCT	80	1,136	2,046
GE	LightSpeed VCT	100	1,088	1,778
GE	LightSpeed VCT	120	1,066	1,648
GE	LightSpeed VCT	140	1,048	1,566
GE	LightSpeed VCT (small hd, large bd)	80	1,061	2,041
GE	LightSpeed VCT (small hd, large bd)	100	1,022	1,802
GE	LightSpeed VCT (small hd, large bd)	120	1,004	1,684
GE	LightSpeed VCT (small hd, large bd)	140	0,993	1,614
GE	Optima CT660	80		2,010
GE	Optima CT660	100		1,810
GE	Optima CT660	120	0,949	1,700
GE	Optima CT660	140		1,650
GE	Discovery CT750	80	0,965	2,100
GE	Discovery CT750	100	1,111	1,850
GE	Discovery CT750	120	1,090	1,730
GE	Discovery CT750	140	1,084	1,670
GE	Discovery CT750 (small, bd)	120		1,560
GE	Generic scanner	120	1,050	1,700
Philips	Philips 310 (GE2, no Cu)	120	1,089	
Philips	Philips 350 (GE2, no Cu)	120	1,089	
Philips	Philips 310 (GE2, w. Cu)	120	1,025	
Philips	Philips 350 (GE2, w. Cu)	120	1,025	
Philips	Philips 310 (GE3, no Cu)	120		1,956
Philips	Philips 350 (GE3, no Cu)	120		1,956
Philips	Philips 310 (GE3, w. Cu)	120		
Philips	Philips 350 (GE3, w. Cu)	120		
Philips	Philips AV	80	1,120	2,034
Philips	Philips AV	100	1,061	1,795
Philips	Philips AV	120	1,061	1,718
Philips	Philips AV	130	1,066	1,739
Philips	Philips AV	140	1,048	1,666
Philips	Philips LX	80	1,120	2,034
Philips	Philips LX	100	1,061	1,795
Philips	Philips LX	120	1,061	1,718
Philips	Philips LX	130	1,066	1,739
Philips	Philips LX	140	1,048	1,666
Philips	Philips SR7000	80	1,120	2,034
Philips	Philips SR7000	100	1,061	1,795
Philips	Philips SR7000	120	1,061	1,718
Philips	Philips SR7000	130	1,066	1,739
Philips	Philips SR7000	140	1,048	1,666
Philips	Philips CX	120	1,059	1,572
Philips	Philips CX/S	120	1,059	1,572

Philips	Philips SR4000	120	1,053	1,724
Philips	Philips SR 5000	120	1,065	1,768
Philips	Philips SR 5000	130	1,052	1,886
Philips	Philips M/EG	120	1,199	2,640
Philips	Philips M/EG	130	1,196	2,631
Philips	Philips TX	100		
Philips	Philips TX	120	1,038	
Philips	Philips TX	130		
Philips	Philips CT Secura	120	1,060	1,688
Philips	Philips CT Secura	140	1,052	1,638
Philips	Philips Mx8000	90	1,096	1,888
Philips	Philips Mx8000	120	1,061	1,683
Philips	Philips Mx8000	140		1,653
Philips	Philips AcQSim	120	1,130	2,057
Philips	Philips AcQSim	130	1,114	1,983
Philips	Mx8000 IDT/Brilliance 16 (& Power)	90	1,072	1,765
Philips	Mx8000 IDT/Brilliance 16 (& Power)	120	1,059	1,623
Philips	Mx8000 IDT/Brilliance 16 (& Power)	140	1,062	1,554
Philips	Philips Aura	120	1,114	1,667
Philips	Philips Big Bore	90	1,113	1,996
Philips	Philips Big Bore	120	1,083	1,778
Philips	Philips Big Bore	140	1,063	1,718
Philips	Generic scanner	120	1,060	1,700
Picker	Picker 1200SX	80		3,008
Picker	Picker 1200SX	120	0,950	2,087
Picker	Picker 1200SX	130	1,018	2,053
Picker	Picker 1200SX	140	0,895	1,938
Picker	Picker PQ Series	120	0,966	1,960
Picker	Picker PQ Series	130	0,950	2,053
Picker	Picker PQ Series	140	0,950	1,937
Picker	Picker UltraZ	80	1,076	3,328
Picker	Picker UltraZ	100	1,047	2,185
Picker	Picker UltraZ	120	0,977	1,955
Picker	Picker UltraZ	130	0,965	1,926
Picker	Picker UltraZ	140	0,960	1,868
Picker	Generic scanner	120	1,000	1,900
Philips	Philips/Marconi Mx8000	90	1,096	1,888
Marconi	Marconi Mx8000	90	1,096	1,888
Marconi	Marconi Mx8000	120	1,061	1,683
Marconi	Marconi Mx8000	140		1,653
Marconi	Marconi AcQSim	120	1,130	2,057
Marconi	Marconi AcQSim	130	1,114	1,983
Marconi	Generic scanner	120	1,100	1,750
Shimadzu	Shimadzu SCT	80	1,134	2,470
Shimadzu	Shimadzu SCT	120	1,079	1,992
Shimadzu	Shimadzu SCT	130	1,070	1,984
Shimadzu	Generic scanner	120	1,070	1,900
Siemens	Siemens CR	125	1,121	2,164
Siemens	Siemens CR512	125	1,121	2,164
Siemens	Siemens DRH	125	1,121	2,164
Siemens	Siemens Somatom 2	125	1,117	2,190
Siemens	Siemens DR1/2/3	125	1,117	2,190
Siemens	Siemens DRG	125		
Siemens	Siemens DRG1	125		
Siemens	Somatom Plus 4 Series	80	1,100	2,047
Siemens	Somatom Plus 4 Series	120	1,075	1,782
Siemens	Somatom Plus 4 Series	140	1,062	1,738
Siemens	Somatom AR-C	110	1,076	1,817
Siemens	Somatom AR-C	130	1,067	1,736
Siemens	Somatom AR.SP	110	1,076	1,817
Siemens	Somatom AR.SP	130	1,067	1,736
Siemens	Somatom AR-T	110	1,076	1,817

Siemens	Somatom AR-T	130	1,067	1,736
Siemens	Siemens AR.HP	130	1,036	1,565
Siemens	Siemens Plus	120	1,102	1,789
Siemens	Siemens Plus	137	1,068	1,749
Siemens	Siemens DXP	120	1,102	1,789
Siemens	Siemens DXP	137	1,068	1,749
Siemens	Siemens Plus-S	120	1,102	1,789
Siemens	Siemens Plus-S	137	1,068	1,749
Siemens	Siemens Hi Q	133	1,079	2,027
Siemens	Siemens Balance	110	1,085	1,806
Siemens	Siemens Balance	130	1,074	1,729
Siemens	Siemens Emotion	110	1,085	1,806
Siemens	Siemens Emotion	130	1,074	1,729
Siemens	Siemens Volume Zoom	80	1,201	2,135
Siemens	Siemens Volume Zoom	120	1,124	1,750
Siemens	Siemens Volume Zoom	140	1,107	1,696
Siemens	Access	80	1,201	2,135
Siemens	Access	120	1,124	1,750
Siemens	Access	140	1,107	1,696
Siemens	Emotion Duo	80	1,108	1,951
Siemens	Emotion Duo	110	1,055	1,666
Siemens	Emotion Duo	130	1,039	1,606
Siemens	Sensation 4	80	1,156	1,939
Siemens	Sensation 4	120	1,086	1,656
Siemens	Sensation 4	140		1,602
Siemens	Sensation 16	80	1,142	1,893
Siemens	Sensation 16	100	1,103	1,743
Siemens	Sensation 16	120	1,079	1,639
Siemens	Sensation 16	140		1,584
Siemens	Sensation 16 Straton	80	1,258	1,893
Siemens	Sensation 16 Straton	100	1,209	1,663
Siemens	Sensation 16 Straton	120	1,088	1,629
Siemens	Sensation 16 Straton	140		1,571
Siemens	Emotion 6	80	0,821	1,751
Siemens	Emotion 6	110	0,854	1,584
Siemens	Emotion 6	130	1,024	1,526
Siemens	Sensation 10	80	1,155	1,893
Siemens	Sensation 10	100	1,111	1,743
Siemens	Sensation 10	120	1,086	1,639
Siemens	Sensation 10	140		1,584
Siemens	Sensation Open	80	1,071	1,812
Siemens	Sensation Open	100	1,046	1,674
Siemens	Sensation Open	120	1,037	1,601
Siemens	Sensation Open	140		1,558
Siemens	Sensation 64	80	1,042	1,684
Siemens	Sensation 64	100	1,027	1,581
Siemens	Sensation 64	120	1,022	1,532
Siemens	Sensation 64	140		1,538
Siemens	Definition AS	80	1,054	1,851
Siemens	Definition AS	100	1,036	1,680
Siemens	Definition AS	120	1,031	1,587
Siemens	Definition AS	140	1,027	1,525
Siemens	Generic scanner	120	1,070	1,600
Toshiba	Toshiba TCT 600	120	0,987	1,527
Toshiba	Xspeed II	120	0,995	1,598
Toshiba	Xpress GX (Pre '98)	120	1,035	
Toshiba	Xvision/EX	120	0,952	1,354
Toshiba	Xpress HS1	120	1,039	1,369
Toshiba	Xpress HS	120	1,000	1,359
Toshiba	Xpress GX (Post '98), Asteion	120	1,035	1,501
Toshiba	Xpress GX (Post '98), Asteion	130	1,017	1,472
Toshiba	Asteion	120	1,035	1,501

Toshiba	Asteion	130	1,017	1,472
Toshiba	Aquilion Multi/4	80	1,117	2,072
Toshiba	Aquilion Multi/4	100	1,079	1,846
Toshiba	Aquilion Multi/4	120	1,057	1,728
Toshiba	Aquilion Multi/4	135	1,034	1,672
Toshiba	Auklet	120	1,019	1,470
Toshiba	Asteion Multi (older tube)	80	1,141	2,131
Toshiba	Asteion Multi (older tube)	100	1,099	2,039
Toshiba	Asteion Multi (older tube)	120	1,076	1,731
Toshiba	Asteion Multi (older tube)	135	1,062	1,841
Toshiba	Asteion Multi (CXB-400C tube)	80	1,141	2,131
Toshiba	Asteion Multi (CXB-400C tube)	100	1,099	2,039
Toshiba	Asteion Multi (CXB-400C tube)	120	1,076	1,731
Toshiba	Asteion Multi (CXB-400C tube)	135	1,062	1,841
Toshiba	Asteion Dual	120	1,117	1,857
Toshiba	Asteion Dual	135	1,070	1,685
Toshiba	Aquilion 16	80	1,147	2,206
Toshiba	Aquilion 16	100	1,070	1,959
Toshiba	Aquilion 16	120	1,056	1,779
Toshiba	Aquilion 16	135	1,051	1,728
Toshiba	Generaic scanner	120	1,050	1,700

Chapter 7

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Please find more information about the basis of the dose profile detector in these thesis works:

"Development and evaluation of a new detector and software for measuring CT dose profile, CTDI and CT tube current variation"

"Evaluation of two thin CT dose profile detectors and a new way to perform QA in a CTDI head phantom"

You can download these papers and other application notes as a PDF file from our website at www.rti.se

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