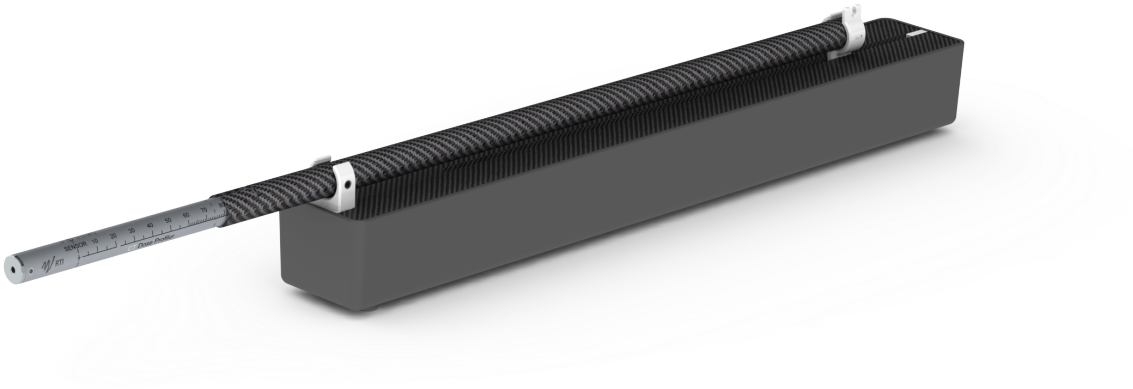
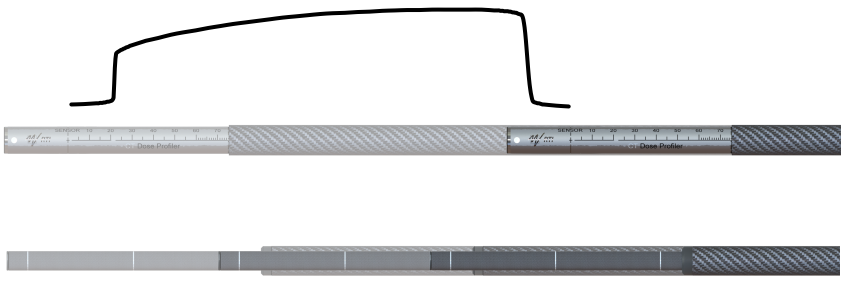
LoniMover



For Measurements Of:

Dose profiles/dose efficiency or $CTDI_{air}$ for broad collimations
according to IEC 60601-2-44 Ed. 3:A1



NOTICE

Lonitech AB reserves all rights to make changes in the Lonimover hardware, LoniCT software and the information in this document without notice.
Lonitech AB assumes no responsibility for any errors or consequential damages that may result from the use or misinterpretation of any information contained in this document.

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INTENDED USE OF THE LONIMOVER

Together with your choice of sensor system it is to be used for quality control of CT systems.

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

- for assessing the performance of the CT scanner.
- for quality control measurements.
- for educational purposes.

The product is intended to be used by hospital physicists, X-ray engineers, manufacturer's service teams, and other professionals with similar tasks and competencies.
The operator needs basic knowledge about the LoniMover system and any measuring system used before starting to use the LoniMover.
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 unqualified persons can change settings of operating parameters during and immediately before and after measurements.
- as the sole measurement system for the approval of an X-ray system for clinical operation.

PREFACE

Chapter 1 Gives an introduction to measurements of CTDI and dose profiles.

Chapter 2 Explains the LoniMover system.

Chapter 3 Explains the necessary preparations of the system.

Chapter 4 Explains how to measure with Sweep mode.

Chapter 5 Explains how to measure with Step mode.

Chapter 6 Explains how to measure with QC $CTDI_w$ mode.

Chapter 7 Explains how to measure with HD Step mode.

Chapter 8 General Information about maintenance, transportation and troubleshooting

Chapter 9 Specifications for the LoniMover system and EC conformity

Chapter 10 References used for this document

It is advisable to read the manual at least once to gain familiarity with the terms used and the capabilities of the LoniMover system.

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Table of Contents

1. INTRODUCTION

⚠ This manual requires the user to have basic knowledge of CT measurements and metrics.

⚠ Before start of any movements, make sure the travel path is clear.

⚠ Before any exposure, ensure that no person is in the proximity of the CT.

⚠ Only use the LoniMover in environments safe for Bluetooth.

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.

Important measurements on CT system include measurements of the Weighted CT dose index ($CTDI_w$) and dose efficiency.

1.1 $CTDI_w$ for wide collimations

Traditionally the $CTDI_w$ is measured with a 100 mm long integrating pencil ionization chamber (Wikipedia, n.d.).

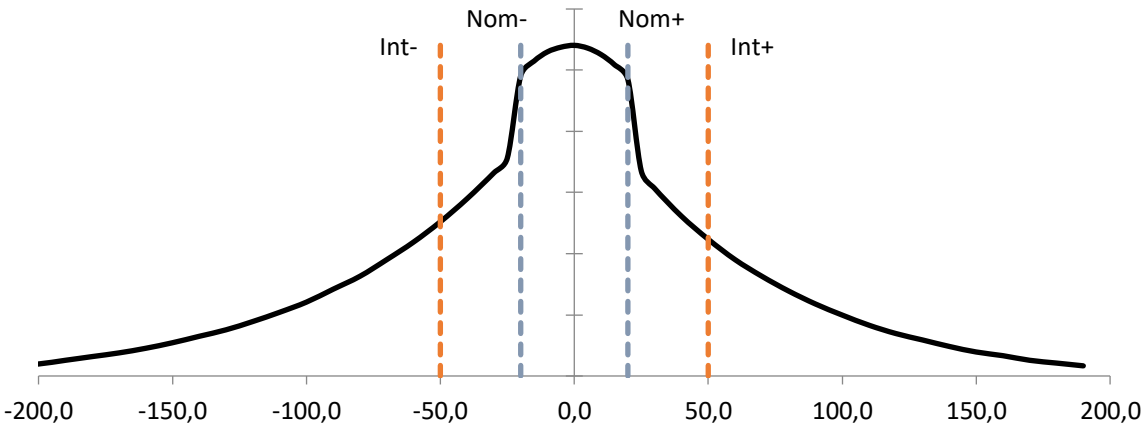


Figure 1. Dose distribution for a 40 mm CT field inside a 300 mm phantom

Figure 1 shows that the integration limits of ±50 mm (100 mm in total) is not enough. It gets even worse with collimations above 40 mm.

In the International Electrotechnical Commission (IEC) publication IEC 60601–2–44 Ed. 3:A1 (IEC 3.1) (International Electrotechnical Commission (IEC), 2012) the Weighted CT Dose Index ($CTDI_w$) has been extended for nominal total collimation widths (NxT) greater than 40 mm and relies on measurements of $CTDI_{free\ air}$.

Each measuring position in traditional $CTDI_w$ calculations is calculated according to Equation 1 below

$$CTDI_{100,NxT>40mm} = CTDI_{100,ref} x \left(\frac{CTDI_{free\ air,NxT}}{CTDI_{free\ air,ref}}\right), \qquad \textbf{Equation 1}$$

or graphically:

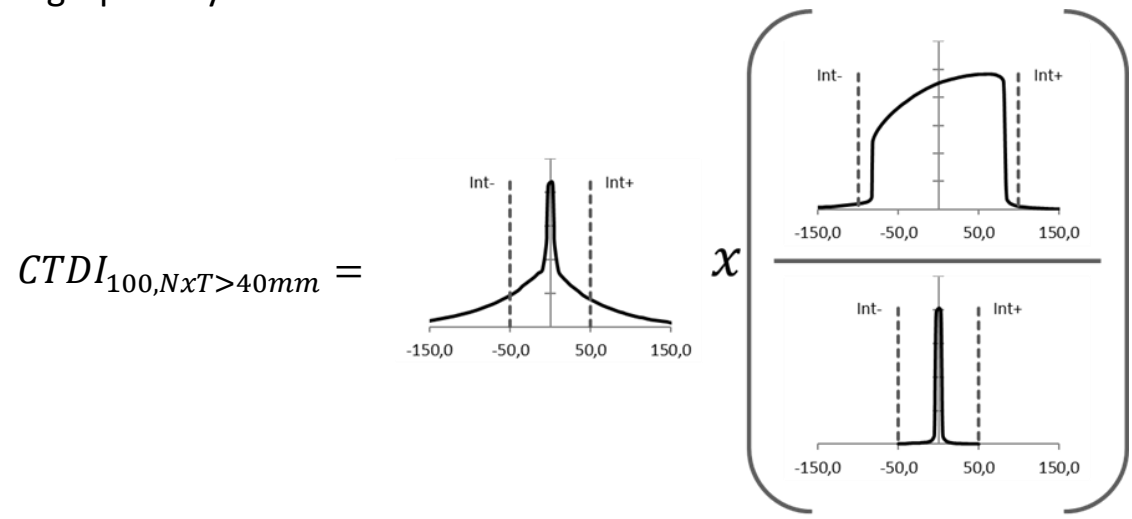


Figure 2. Graphical presentation of Equation 1. Note that the profiles represent CTDI not integrated dose (CTDI = integrated dose/nominal collimation).

The reference collimation is below 40 mm, usually 5-20 mm, and measured both inside a standard CTDI phantom (all positions) and free in air (central axis).

In IAEA Human Health Reports No. 5 ((IAEA), 2011), a method is provided to measure the $CTDI_{free\_air,NxT}$ for nominal total collimation widths exceeding 40 mm.

A 100 mm pencil ionization chamber is suspended in the longitudinal (z) direction. Depending on the nominal total collimation width, the chamber is stepped into different contiguous locations between exposures to envelope the entire radiation field. The positions of the contiguous locations that are recommended by the IAEA to extend the integration length of the CTDIfree air,NxT is presented in Table 1 and graphically in Figure 3 and Figure 4 below.

Collimation, NxT [mm]	Integration Length [mm]	IAEA Positions ((IAEA), 2011) [mm]
≤40	100	0
>40 to <160	200	-50, 50
160	300	-100, 0, 100

Table 1. Recommended positions according to IAEA.

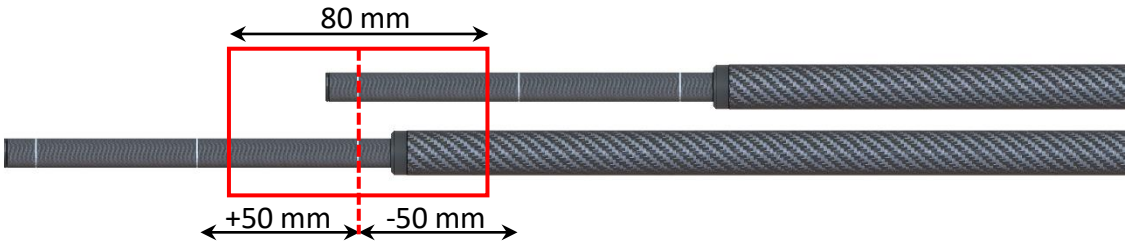


Figure 3. Positions for collimations > 40 mm and < 160 mm (example at 80 mm).

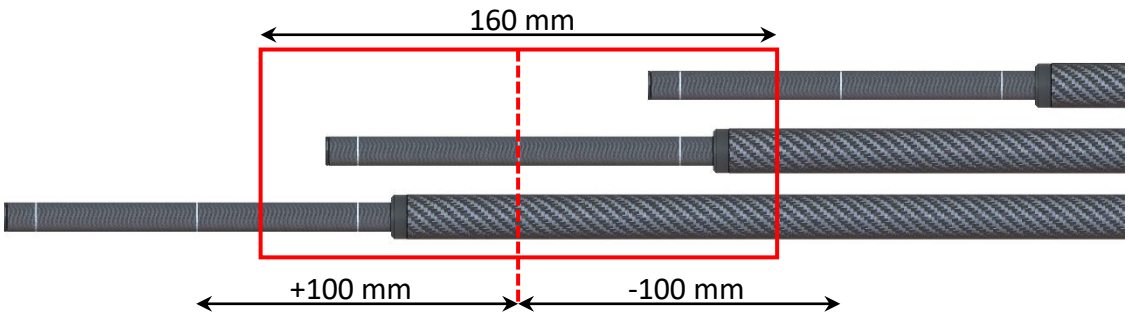


Figure 4. Positions for collimations ≥160 mm (example at 160 mm).

It is also possible to determine $CTDI_{free\ air,NxT}$ from dose profiles (see chapter 1.2).
To learn more about different techniques for determine $CTDI_{free\ air,NxT}$ it is recommended to read reference (Bujila, Kull, Danielsson, & Andersson). Please note that the RTI Mover used, is the precursor to the LoniMover.

1.2 Dose efficiency/profiles with a real time detector

By using a real time detector with a small detector volume and translate the detector through the CT field it is possible to generate dose distribution profiles.

The detector measures real time dose (kerma) continuously and report dose as a function of time.

If the translation speed is known the data can be converted to dose as a function of relative position.

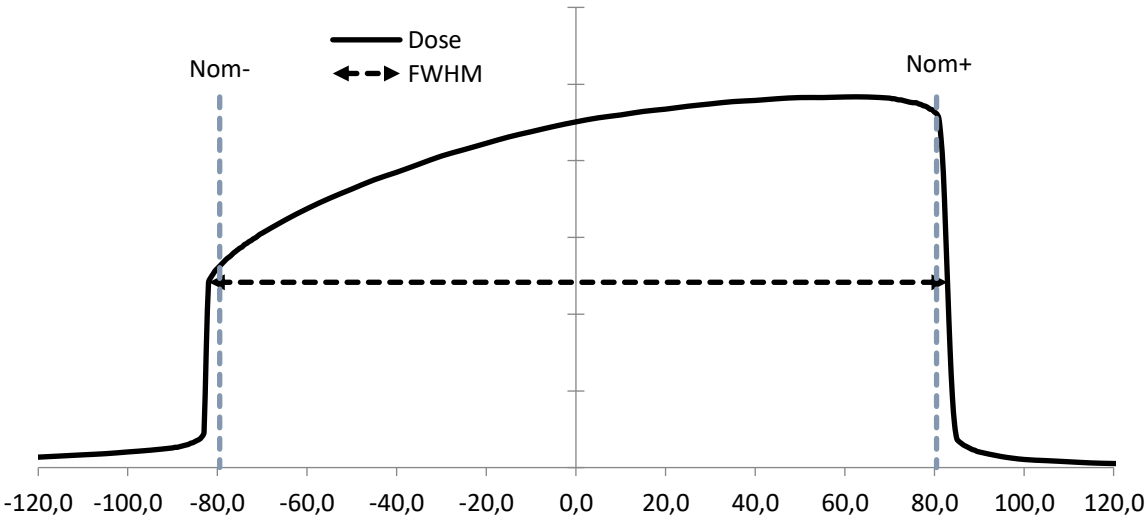


Figure 5. Typical dose profile for a 160 mm nominal collimation on a GE Revolution CT.

From the dose profile many useful metrics could be extracted, including but not limited to:

- Dose efficiency
- Full Width Half Max (FWHM)
- Integrated dose
- $CTDI_{free\ air,NxT}$ for use in IEC 3.1 calculations (see chapter 1.1)

2. THE LONIMOVER SYSTEM

2.1 In the box

The LoniMover system consists of the following:

- Carrying case
- The LoniMover
- Detector holder probe
- Adapter for RTI Pencil chamber
- Power adapter for the LoniMover
- The LoniButton
- USB cable for the LoniMover (long)
- USB cable for the LoniButton (short)

2.2 The LoniMover

The purpose of the hardware system is to move your measuring device either with constant velocity, *Sweep mode*, or to well defined positions, *Step mode*.

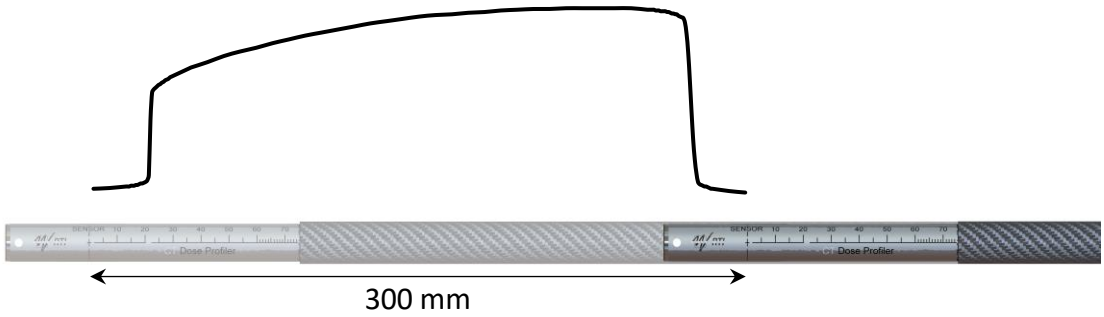


Figure 6. The LoniMover in Sweep mode

Sweep mode works great with small detectors that sample dose or dose rate over time, there by producing dose profiles.

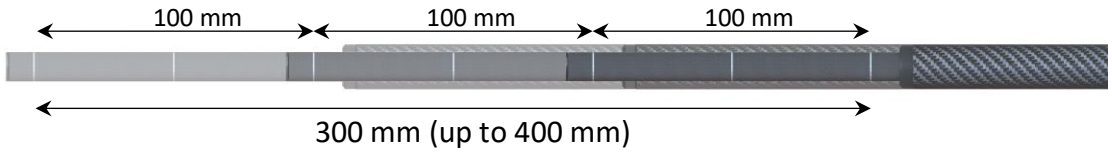


Figure 7. The LoniMover in Step mode

Step mode can be used for joining measurements with a 100 mm long pencil ionization chamber into a virtual 400 mm long chamber.

All mechanical parts are of highest quality and the chamber holder is made of carbon fiber to minimize scatter and are very rigid. There is no drop in the chamber path at the end of travel.

2.3 The LoniButton

The included LoniButton is the link between the software(s), the user and the mover system. To get perfect timing of all the components involved during Sweeps, it even integrates the CT exposure button.

The LoniButton signals with different colors which function the button will trigger. See Table 2 for details.

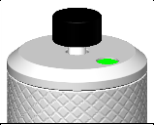
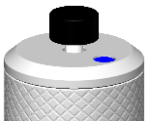
LED color	Function in Sweep mode	Function in Step mode
 Green	Starts sweep	N/A
 Blue	Return to start position	N/A
 Red	Emergency stop if in motion	Emergency stop

Table 2. LoniButton signal system.

The LoniButton is optional and all functions is available through buttons in the LoniCT software.

2.4 The LoniCT Software

2.4.1 Sections

The LoniCT software has three different section (Figure 8):

1. Tabs for selecting mode
2. Mode specific settings and actions
3. Hardware connection buttons, information and emergency stop button

How to use the different modes is described in chapter 4 - 7.

How to use the connection section is described in chapter 3.1.

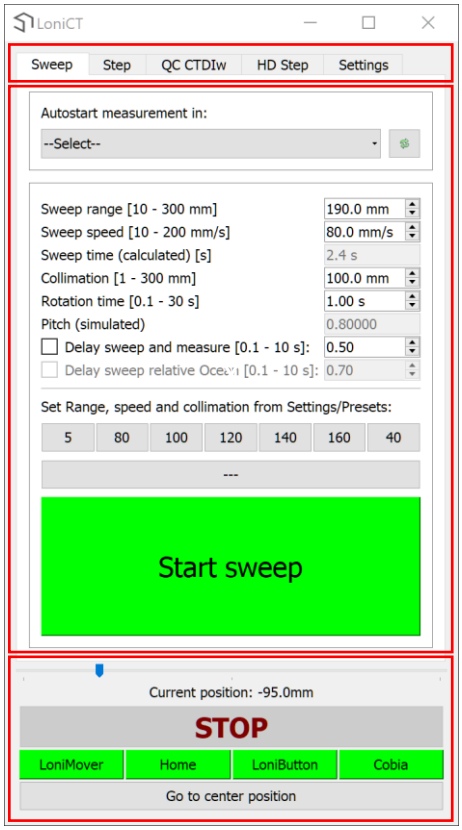


Figure 8. LoniCT overview

2.4.2 General settings

If “Auto return to start position after sweep” checkbox is set, the LoniMover is automatically returned, after a sweep move, to the start position. This movement is automatically triggered, and you should make sure it is safe to use!

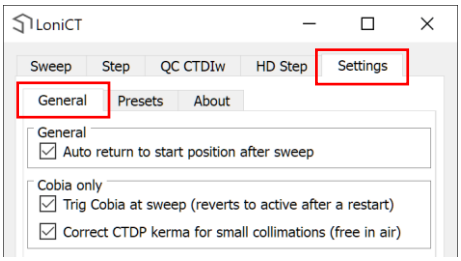


Figure 9. General settings

“Trig Cobia at sweep” is normally active but can be deactivated for testing purposes. When active, Cobia is triggered to start a measurement at sweep start.

The “Correct CTDP kerma for small collimations” checkbox enables a correction for less scatter at smaller collimations (< 40 mm). You can read more about this in the RTI CTDP documentation. It is recommended that you activate this function.

2.4.3 Preset settings

This section defines preset collimations for the *QC CTDIw-mode* and *Sweep-mode*.

In the *QC CTDIw general settings* section you can enter a CT system reference, comments and define the different CT exposure parameters like kVp, bowtie and Focal spot to measure with the *QC CTDIw-mode*.
The exposure parameters should be defined as a single value or a comma separated list of values (no spaces). It is optional to define these parameters.

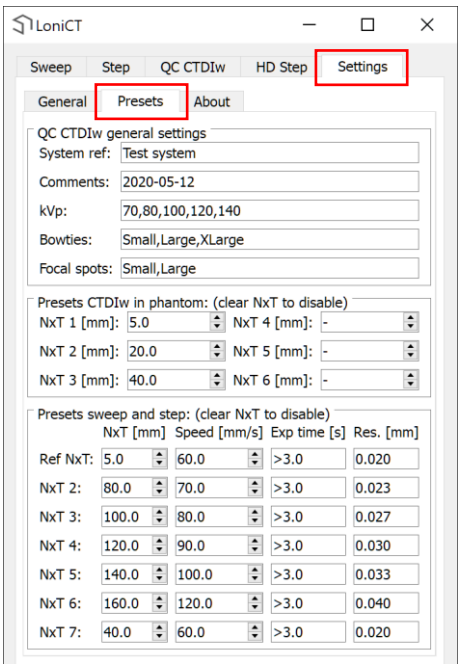


Figure 10. Presets settings

In the *Presets CTDIw in phantom* section you enter the relevant collimations (NxT) you will be measuring in a phantom.
If you plan to use the IEC 3.1 formalism for wide collimations to measure/calculate CTDIw make sure that the reference collimation is included in this section.

In the last section, *Presets sweep and step*, you define the (wide) collimations to measure free in air using the *QC CTDIw-mode*. You can enter any NxT here, not only wide collimations. Make sure to enter the reference NxT for IEC 3.1 formalism in the first row.

The software will automatically calculate the sweep range as:

$$R(NxT) = \begin{cases} 150\ mm & if\ NxT \leq 60\ mm \\ NxT + 90\ mm & if\ 60 < NxT \leq 210\ mm, \\ 300\ mm & if\ NxT > 210\ mm \end{cases}$$ **Equation 2**

Equation 2 is based on the IEC 3.1 statement that no integration range should be shorter than 100 mm and that the integration range should be at least 40 mm longer than NxT, then a margin of 50 mm is added. The maximum range is 300 mm so NxT over 210 mm will use 300 mm sweep range. Please note that NxT over 260 mm will not comply with the "40 mm longer than NxT" integration length.

The *Speed* column is mandatory for Sweeps and you should enter a speed that yields a reasonable exposure time (Exp time column).

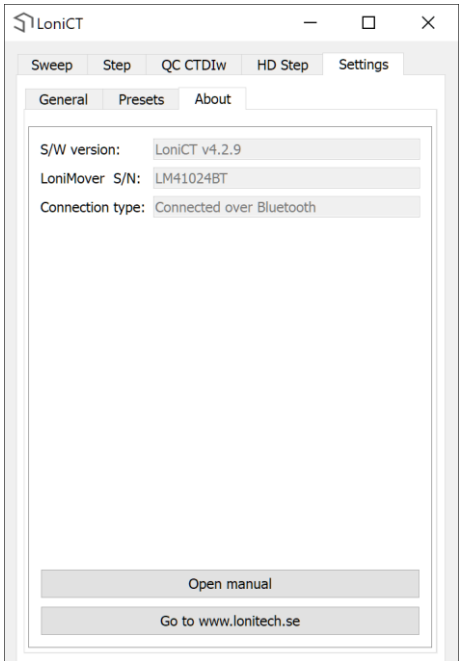
These collimations/speeds are also used as presets for the standard *Sweep-mode*.

The *Exp time* (Exposure time) column is calculated from sweep range and speed with a small margin. Use this value to tune your speed setting so that you get an exposure time that your CT can handle.
Depending on measuring system for standard sweep-mode you also have to take into consideration the sample rate vs. measurement time dependency. Consult the manual for your measuring instrument.
For pulsed X-ray beams use the lowest possible speed.

When using the *QC CTDIw-mode* with the RTI Cobia, the *Res* (Resolution) column displays the resulting resolution of the sweep profile. This value is calculated from exposure time and the Cobia sample time/rate dependency.
Use this value to tune your speed setting for highest resolution. Hover over the Exp time-field to get more information about the sample time/rate dependency of the Cobia.

2.4.4 About

The *About* tab shows software version, LoniMover hardware ID and connection mode.



At this screen, buttons for this manual and link to Lonitech.se is also available.

If there is a new version of the LoniCT software available a button for downloading the new version will be available.

2.4.5 Installation of LoniCT software

To download the latest version of LoniCT visit:

https://lonitech.se/download

Open the downloaded “Install LoniCT 4.x.exe” file as an administrator and you will be presented with the window below.

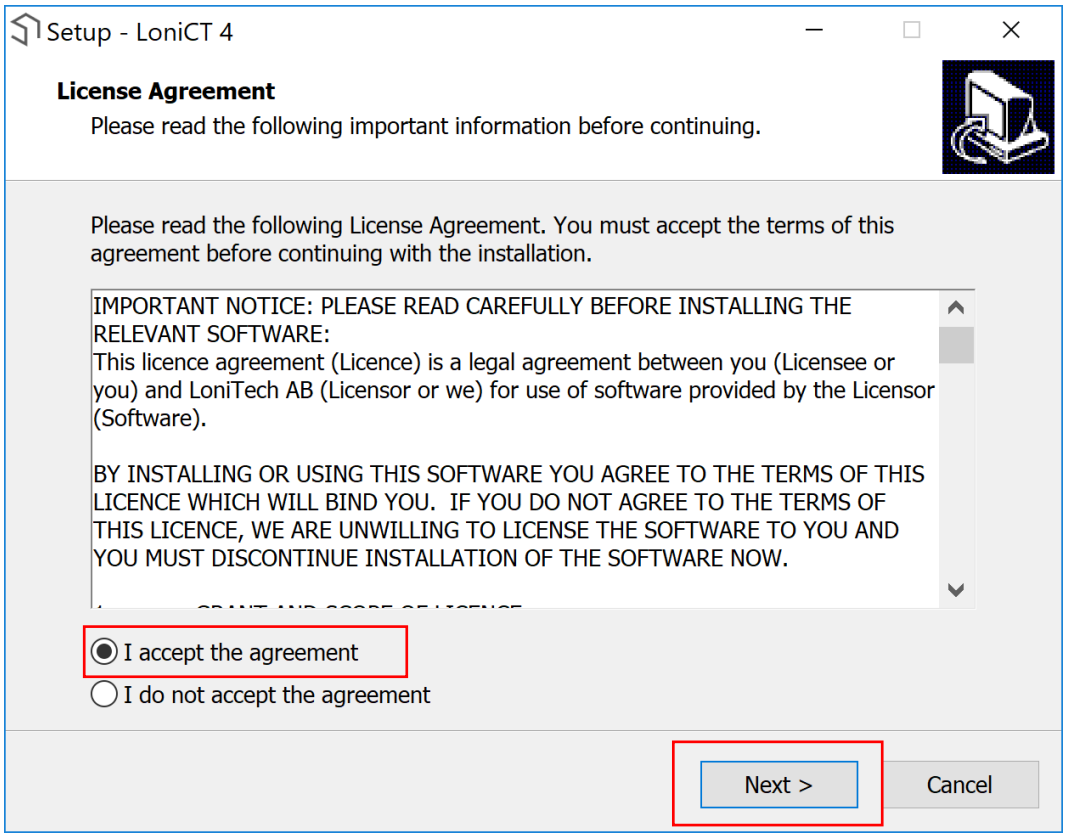


Figure 11. LoniCT installation welcome screen

1. Read through the license agreement and check the “I accept the agreement” if you do agree.

2. Click “Next” and you will be presented with the next screen below.

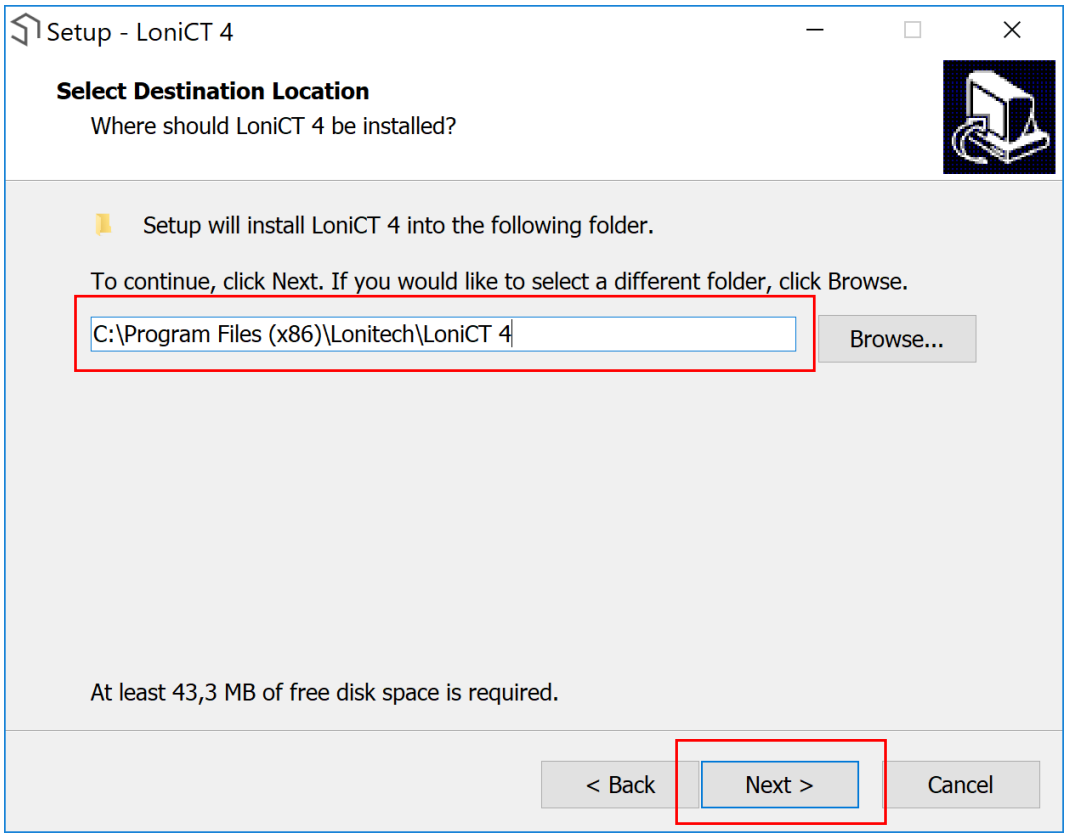


Figure 12. LoniCT installation screen for selecting install location

3. Select where you want to install LoniCT and click “Next”.

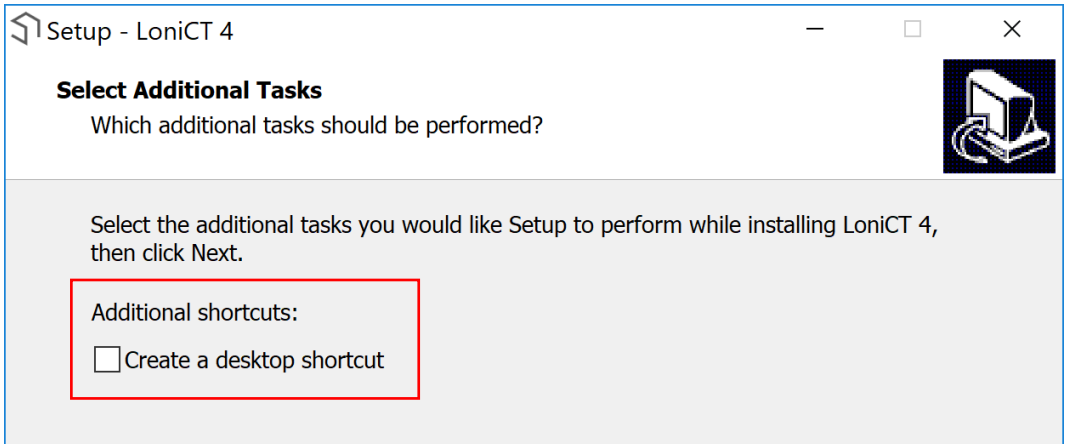


Figure 13. LoniCT installation screen for selecting additional tasks

4. Select if a shortcut to LoniCT should be created on the Desktop and click “Next”.

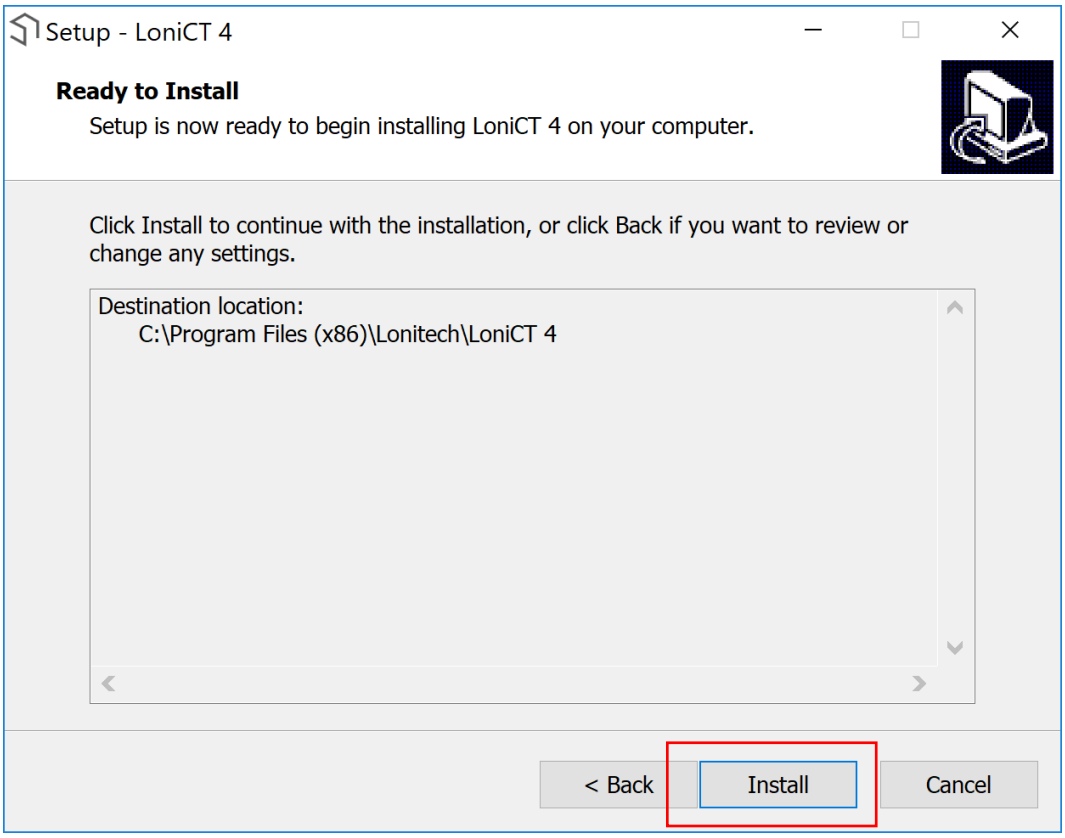


Figure 14. LoniCT "ready to install" screen

5. At the "Ready to Install" screen check that everything is in order and click "Install".

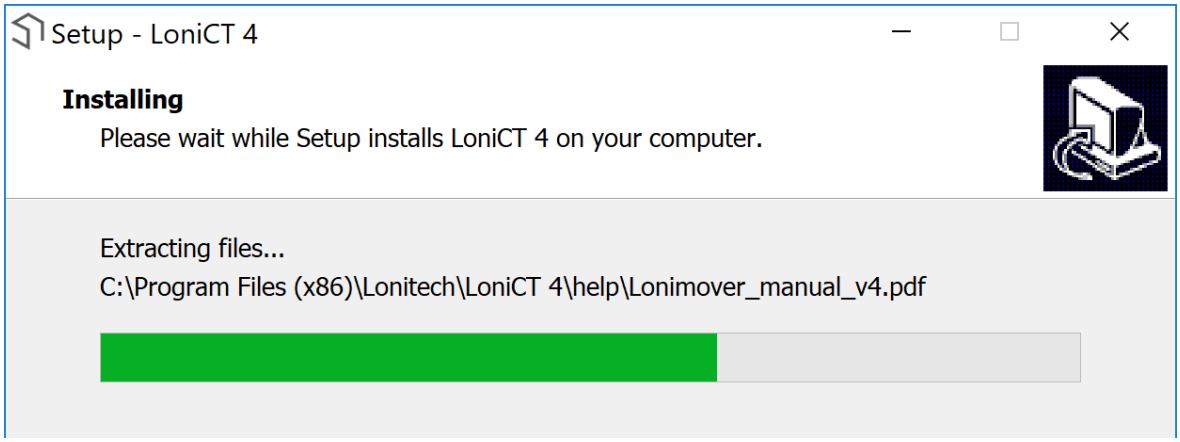


Figure 15. LoniCT installer progress bar

At the end, a driver installation dialogue will appear, click "next" and then "done".

6. Wait for the installation to end.

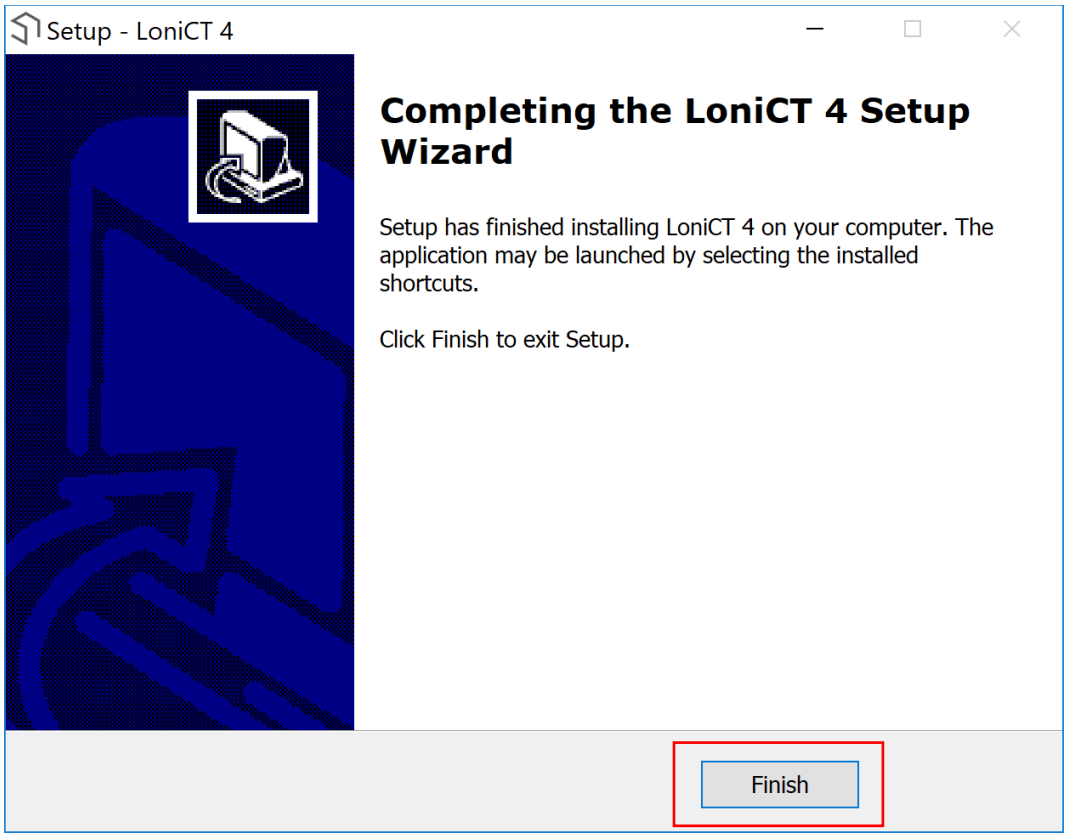
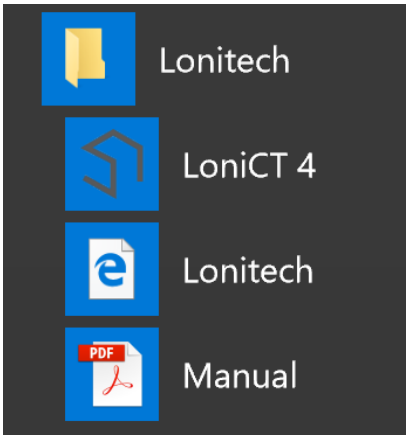


Figure 16. LoniCT installation end window

7. Click “Finish”

The installation of LoniCT, including drivers for the hardware, is now done and you can find shortcuts to LoniCT in the start menu and on the desktop if you chose to install one.

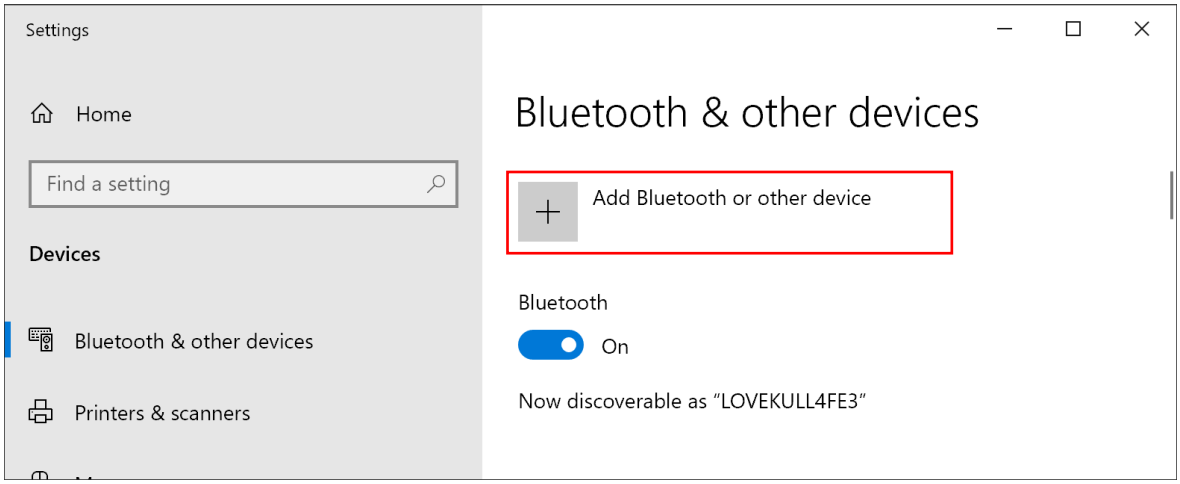
In the start menu you will also find a link to Lonitech.se and this manual.



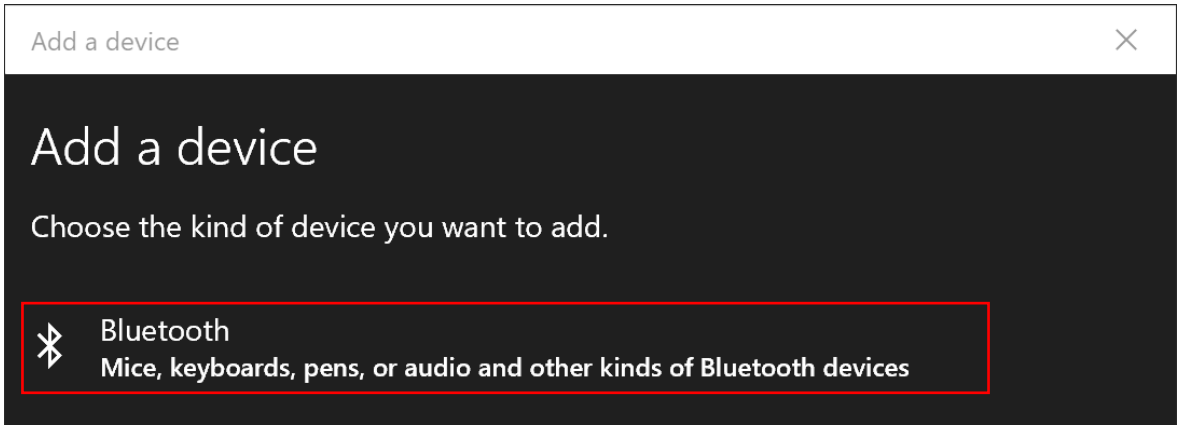
2.4.6 Bluetooth configuration (optional)

If your LoniMover hardware is equipped with Bluetooth (S/N xxxxxx**BT**) you add the LoniMover to your computer by entering the Bluetooth settings in Windows and pair it like any other Bluetooth device.
Make sure the LoniMover is powered and in proximity of the computer.

1. Open the Bluetooth settings panel in Windows and click “Add Bluetooth or other device”

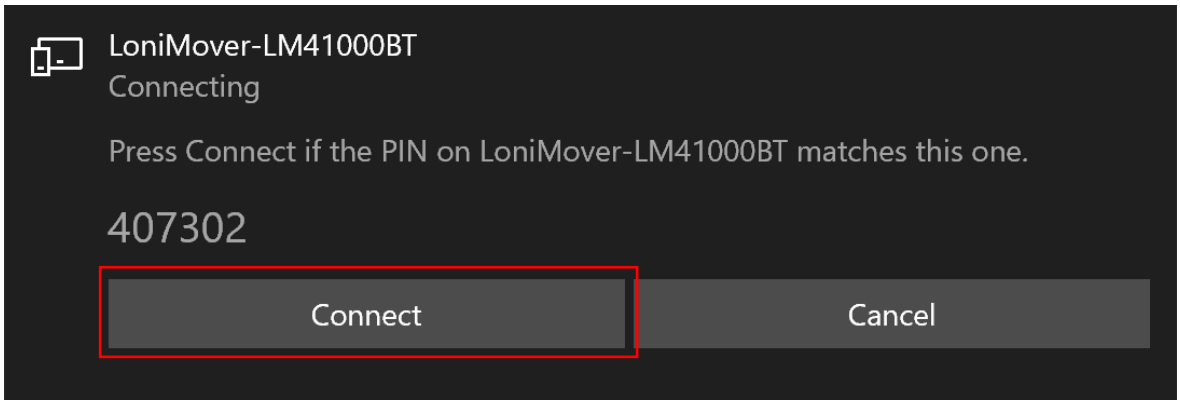


2. Om the “Add a device” screen click “Bluetooth”

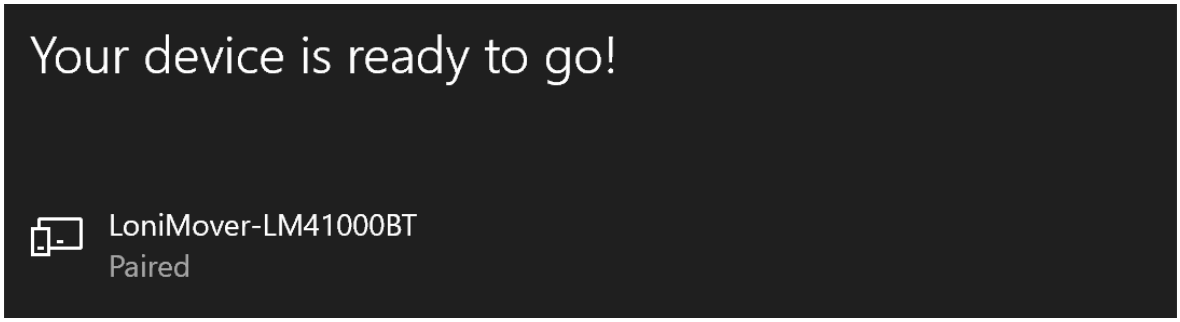


3. On the next screen, wait for the LoniMover to appear.

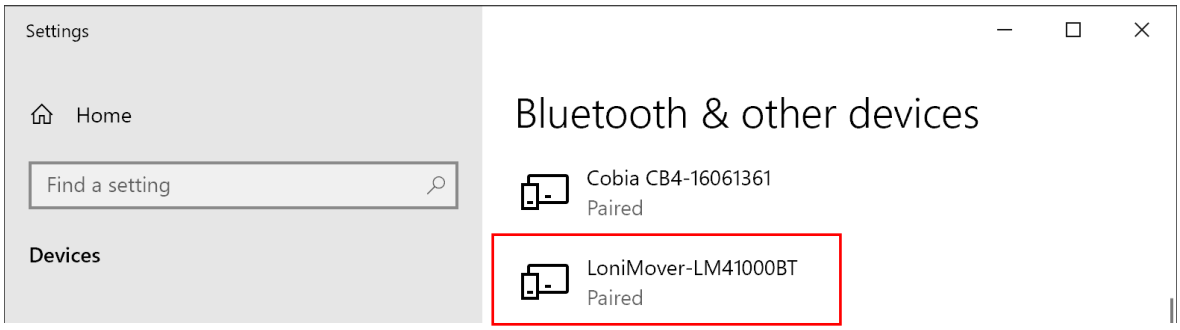
4. Click on the LoniMover device and accept the random generated code by clicking “connect”.



5. Windows will now add the LoniMover Bluetooth COM-port to your computer and you will se this screen, click “Done”.



6. Your LoniMover is now paired with Windows and ready to connect with LoniCT.



2.4.7 Upgrading the LoniCT software

If there is an updated version of the LoniCT software you will get a message about this at startup and in the About section of the Settings-tab there will be a link for download.

If your firewall doesn't accept outgoing https traffic on port 443 LoniCT can't check for updates and you will have to check for an updated version manually by visiting the link below.

https://lonitech.se/download

The upgrade procedure is identical to first time install as described in chapter 2.4.5 with exceptions for the step involving selection of installation directory.

2.4.8 Uninstalling the LoniCT software

Use Windows "Add/Remove software" to uninstall LoniCT.
Please note that the drivers for LoniMover and LoniButton is not removed by this process.

3. PREPARATIONS

3.1 Connection

To connect the hardware to a Windows PC you need one (1) or two (2) available USB sockets depending on connection mode.

3.1.1 Connect the LoniMover

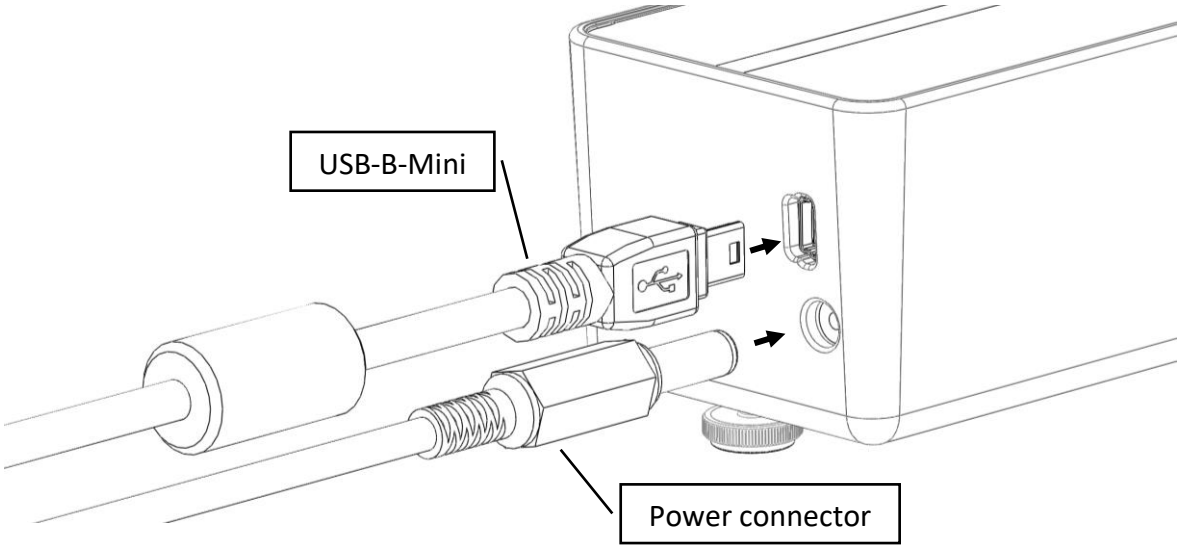


Figure 17. Connection of the LoniMover, USB optional if using Bluetooth

1. Connect power and optionally the long USB cables to the LoniMover according to Figure 17. Make sure the power cable is connected correctly before connecting the power adapter to the mains outlet.
2. Connect the power adapter to the mains outlet.
3. Optionally connect the USB cable to the Windows PC running the LoniCT software.

⚠ Only use supplied power adapter.

3.1.2 Connect the LoniButton

The LoniButton needs a USB-connection to work.

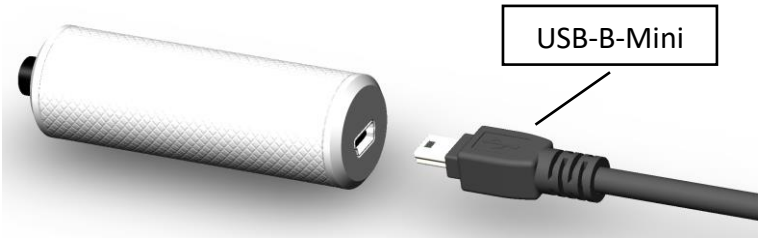


Figure 18. Connection of the LoniButton

LoniButton connection:

1. Connect the short USB cable according to Figure 18
2. Connect the USB cable to the Windows PC running the LoniCT software

3.2 Mount measuring device

The LoniMover system includes a detector holder pipe that is adapted for the RTI CT Dose Profiler probe, RTI DCT10 Pencil Chamber and RTI CT Ion chamber.
Note the cable routing at the back end in Figure 19.

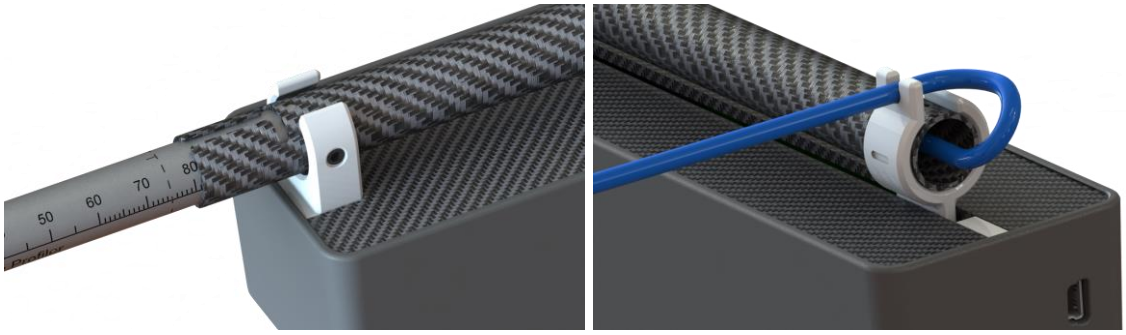


Figure 19. Detector holder pipe end configuration

3.2.1 Mount the RTI CT Dose Profiler (CTDP)

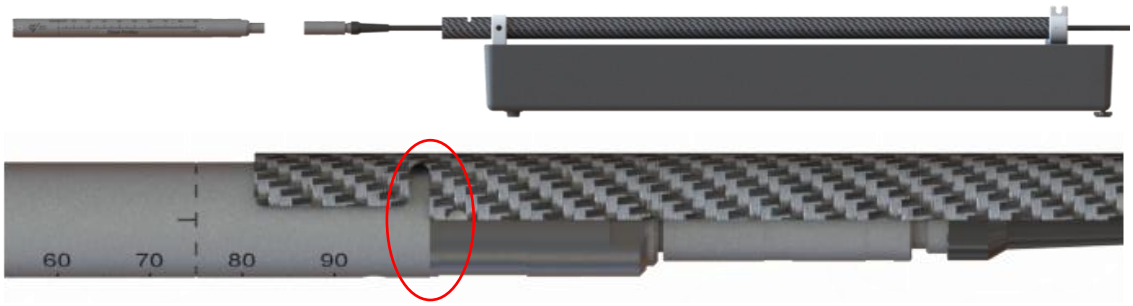


Figure 20. Mounting the RTI CT Dose Profiler

Mounting instructions for the RTI CTDP:

1. Insert CTDP cable with the LEMO connection first through the pipe from the back, note direction of the pipe according to Figure 20.
2. Connect the CTDP to the cable.
3. Insert the CTDP into the pipe, note mounting depth of the CTDP according to Figure 20.
4. If not already mounted on the LoniMover insert the pipe through the front support of the LoniMover.
5. Push the pipe through the moving part of the LoniMover, note the end position of the pipe according to Figure 19.
6. Make sure the cable is still connected to the CTDP and route the cable through the cable holder according to Figure 19.

3.2.2 Mount the RTI DCT10 Pencil chamber or RTI CT Ion chamber

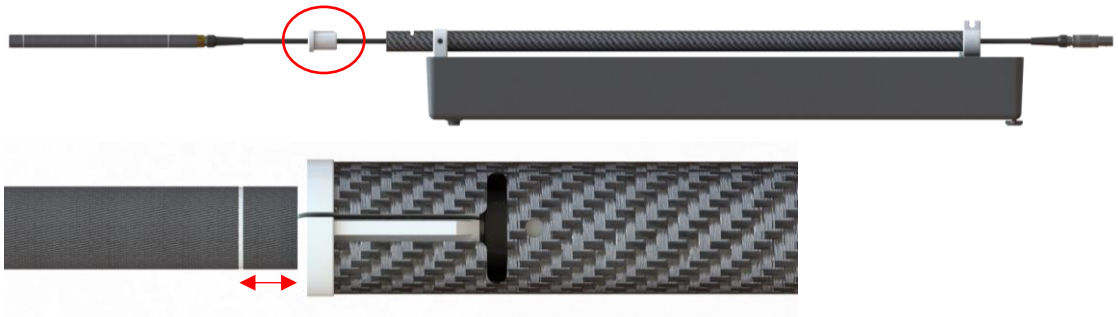


Figure 21. Mounting the RTI DCT10 Pencil Chamber

Figure 22. Mounting the RTI CT Ion chamber.

Mounting instructions for the RTI DCT10 Pencil Chamber or RTI CT Ion chamber:

1. Insert cable with the LEMO connection through the adapter then the pipe, note direction of the pipe according to Figure 21.
2. Insert the chamber into the adapter.
3. Insert the adapter into the pipe according to Figure 21 (DCT10) or Figure 22 (CT Ion chamber)
4. Insert the pipe through the front support of the LoniMover.
5. Push the pipe through the moving part of the LoniMover, note the end position of the pipe according to Figure 19.
6. Route the cable through the cable holder according to Figure 19.

3.3 Connect hardware to software

When LoniCT is loading, it looks for available hardware on USB and/or Bluetooth. This process can take some time. If LoniMover, LoniButton and/or RTI Cobia is available, the software connects to them automatically.

If LoniCT can’t find any device(s) at startup you need to connect the hardware manually by clicking the corresponding buttons at the bottom of the software GUI.
When the hardware is connected, the corresponding button text turns green.

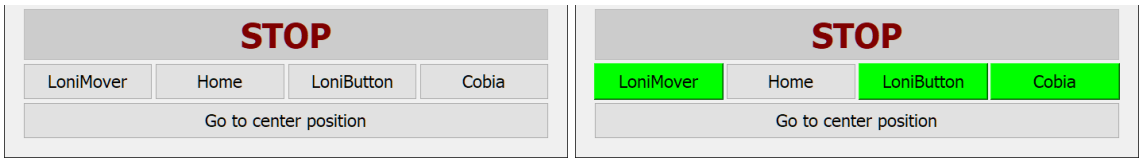


Figure 23. Connection buttons and their status color, left: not connected, right: connected (green)

The LED indicator on the LoniMover will show Bluetooth connection status according to below.

Model	Not connected	Connected
LoniMover SN: LM4000BT – LM4999BT	LED flashes	LED solid
LoniMover SN: LM41000BT –	LED flashes	LED flashes two (2) times

3.4 Homing

Homing of the LoniMover is necessary for the system to know where the absolute position of the probe is. No other moves are possible before the system is homed.

Homing is only possible after the LoniMover is connected to the LoniCT software by the procedure described in chapter 3.3.

The homing sequence:

1. The probe moves backwards until homing switch is hit.
2. The probe moves forward a short distance.
3. Home position is set.

If homing switch is already activated at start of sequence, step 1 is ignored.

Figure 24. Homing sequence of The LoniMover

To execute the homing sequence, push the "*home*" button at the bottom of the software GUI.

Figure 25. Homing sequence of The LoniMover

After a completed homing sequence, the *home* button text turns green.
Homing status is preserved until power are disconnected from the LoniMover, i.e. restarting the LoniCT software will not influence the homing status.

3.5 Alignment

Place the LoniMover on the CT table with the front in line with the tabletop edge. Do not use the table extension. Make sure the cables to the LoniMover has a secure route from the LoniMover to the PC even if the tabletop is moving.

3.5.1 Alignment using the lasers on the CT system

Put the LoniMover in center position by clicking the "*Go to center position*" button at the bottom of the software GUI.

Figure 26. Center position

When in position the button turns green.

Use the CT table and lasers to align the detector and pipe to be in the isocenter of the gantry according to Figure 27.

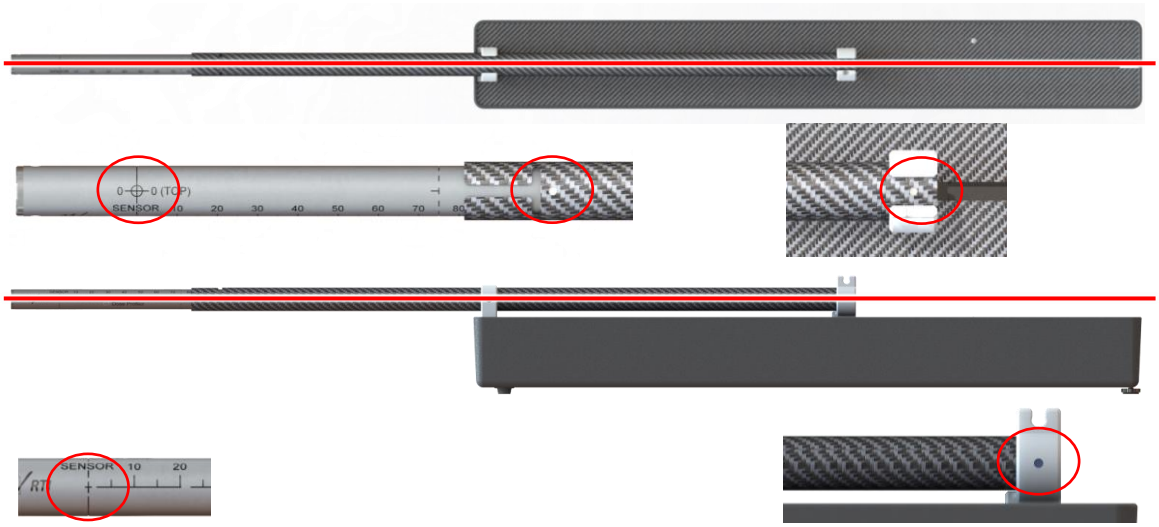


Figure 27. Alignment of the LoniMover using the CT-lasers

If needed, use the adjustment wheel at the back of the LoniMover to adjust angle, see chapter 3.5.2.

After alignment with the lasers it is always a good idea to take two perpendicular CT preview images of the setup and overlay a grid to verify position. Make adjustments if needed.

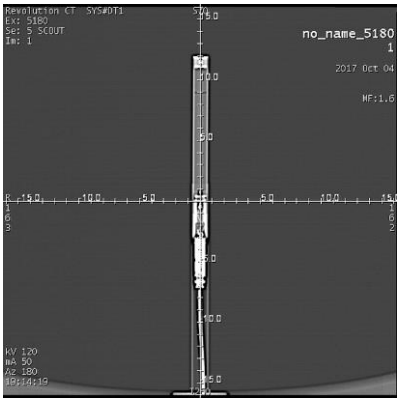


Figure 28. CT PA-preview image with grid overlay

3.5.2 Adjusting tilt angle of the LoniMover

By using the adjustment wheel at the back end of the LoniMover the angle can be adjusted.

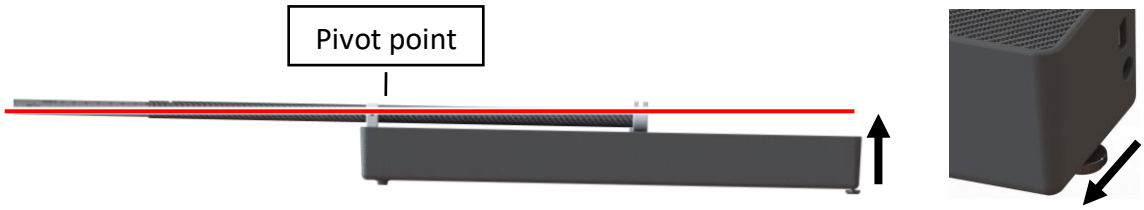


Figure 29. Adjusting the angle of the LoniMover (example)

4. MEASUREMENT WITH A POINT DETECTOR

4.1 Preparing the system for Sweep mode

This chapter use the RTI Ocean, RTI CT Dose Profiler and RTI Piranha/Cobia as an example off possible use of this mode (standard Sweep mode). The same preparations is valid for sweeps during *QC CTDIw* and *HD Step* measurements, see chapter 6 and 7.

Make sure everything is connected, aligned and homed as described in chapter 3.

4.1.1 Alignment in z-direction, Sweep mode

If not active, select the “Sweep” tab in LoniCT and press the “Go to center position” button according to Figure 26.

Using the CT table, align CTDP center of sensor with the z-laser according to Figure 30 below.

Figure 30. CTDP alignment in z-direction

4.1.2 Connect to RTI Ocean®

The LoniCT software integrates with RTI Ocean® by sending “Alt+s” to the Ocean window which will start a measurement.

Before this connection is possible you need to tell LoniCT which Ocean window to use (Ocean needs to be already open).
Click the “Reload” button to populate the dropdown.

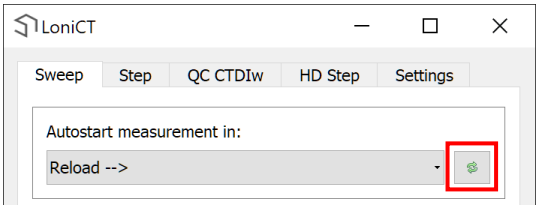


Figure 31. Reload apps

Use the dropdown to select your Ocean window. Make sure you select the right window. Other windows with “Ocean” in their name will also be listed (i.e. explorer windows named something with Ocean).

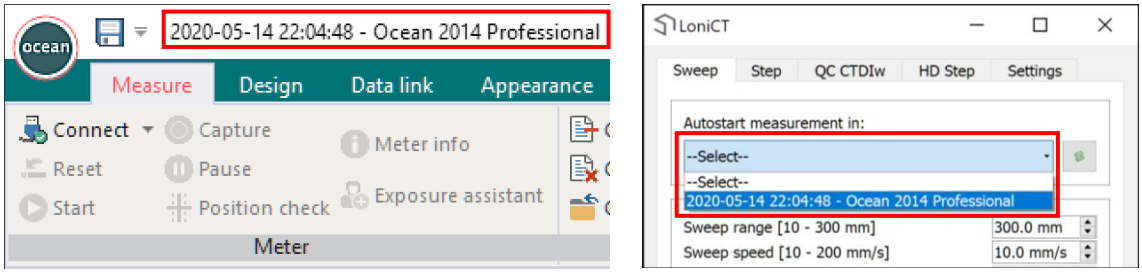


Figure 32. Selection of Ocean window to connect to.

When selected, the RTI Ocean software will flash 3 times to verify that a connection is made.

Please note that if you after connection save the project in Ocean under another name the connection is lost, and you have to reload and connect to the window with the newly saved file name.

4.1.3 Select parameters

Start by choosing a sweep range greater than the nominal collimation.
For CTDI measurements don't use shorter range than 100 mm.

A good starting point for Sweep speed is 100 mm/s. At this speed even the maximum range of 300 mm is covered in 3 seconds which is the longest measurement time for RTI Piranha fastest sample rate. See the manual for RTI Piranha for more information about sample rates.

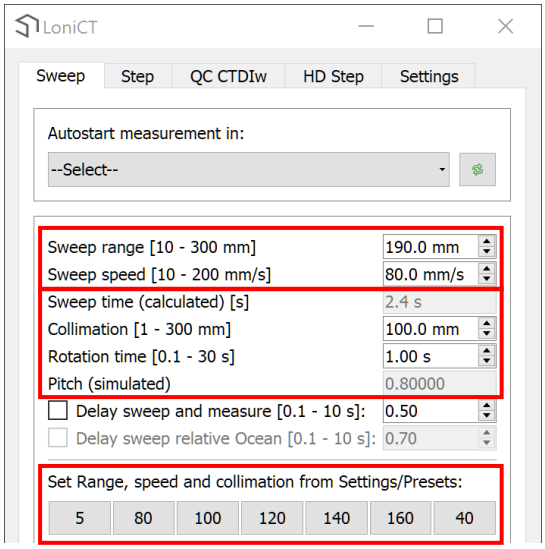


Figure 33. Parameter selection for sweep mode

You can also use the presets defined in Settings, see chapter 2.4.3. When activating a preset, the LoniMover automatically moves to the start position.

By specifying the nominal collimation and a rotation time LoniCT calculates some useful parameters for us in RTI Ocean.
The rotation time does not have to be the true rotation time, but the same value should be used in Ocean.

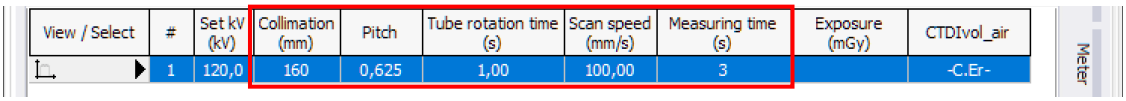


Figure 34. Example parameter setup in RTI Ocean.

The example RTI Ocean template in Figure 34 needs Collimation, Pitch and Tube rotation time to calculate the Scan speed. Transfer these values from LoniCT and make sure the calculated Scan speed is equal to selected Sweep speed in LoniCT.

Check that the Measuring time is equal to or greater than reported Sweep time in LoniCT.

4.1.4 Timing adjustments

Depending on margins on sweep range and delays in exposure there is a need for timing adjustments.

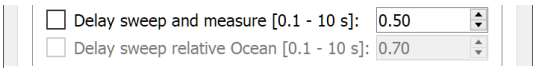


Figure 35. Delay/timing options.

"Delay sweep and measure" is used when there is a delay between activation of the exposure button on the CT system and actual exposure.

"Delay sweep relative Ocean" is only possible if RTI Ocean is connected (section 4.1.2) and this delay is added after Ocean is triggered to start a measurement.

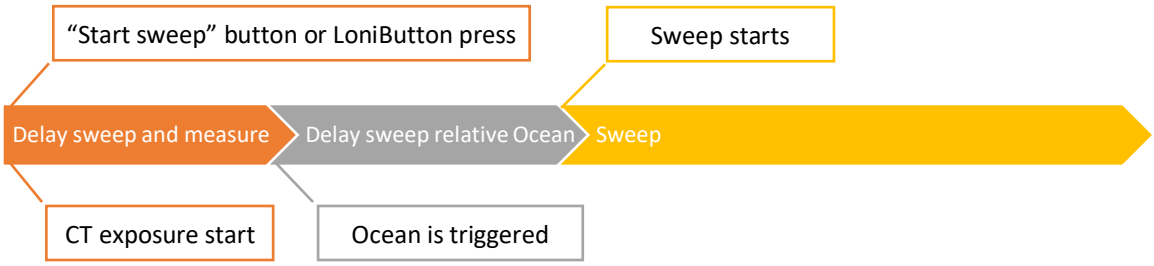


Figure 36. Timing sequence

If the dose profile generated by RTI Ocean during a Sweep is clipped at the left flank (i.e. a vertical left flank) there is a possibility that the CT exposure started after the Sweep and measurement. By adjusting the "Delay start" you give the CT time to actually start the exposure before Sweep.

If the dose profile generated by RTI Ocean during a Sweep is shifted far to the left the "Delay move" parameter will move it to the right at next measurement.
If using a Bluetooth link between RTI Ocean and the RTI Piranha/Cobia the delay is greater than if using a USB link.

4.2 Measurement using Sweep mode

Consult the RTI Ocean manual for setting up a session for CTDP measurements using a spiral scan.

4.2.1 Set up the CT for Sweep mode

The LoniMover system is simulating the table movement during a spiral scan so the CT should be set up to do axial scans without table movement. Select scan parameters according to what you are about to measure.

Make sure the exposure time is long enough to accommodate the whole sweep, with some margin (see Sweep time parameter in LoniCT). Use sine mode on CT to gain longer exposure times with stationary table. If sine mode is not possible use faster Sweep speed (not recommended due to lower resolution) or shorter sweep range.

4.2.2 Prepare LoniMover for Sweep

If the LoniMover is not in start position the “Start sweep” button is grey and LoniButton is blue, click the “Go to start position” button in the LoniCT software or push the LoniButton.

When in start position the “Start sweep” button and the LoniButton is green.

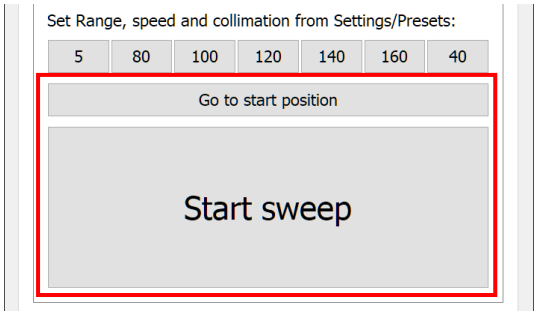


Figure 37. Go to start position active and Start sweep grey.

4.2.3 Sweep measurement using the LoniButton

1. Prepare RTI Ocean for measurement.
2. Prepare the CT.
3. Make sure the LoniMover is in start position (green light).
4. Use the LoniButton to press down the exposure button on the CT console.

At stage 4 the CT starts the scan, LoniCT tells RTI Ocean to start a measurement and then starts the Sweep.

During Sweep the LoniButton signals red (E-stop if pressed) and at the end of Sweep it turns blue, signaling that a push on the button will return the LoniMover to the start position ready for another measurement.

4.2.4 Sweep measurement using your mouse

1. Prepare RTI Ocean for measurement and activate relevant row in template.
2. Prepare the CT.
3. Make sure the LoniMover is in start position (Figure 37).
4. Press the exposure button on the CT and at the same time...
5. …click the “Start sweep” button in the LoniCT software (Figure 37).

At stage 4 the CT starts the scan and at stage 5, LoniCT tells RTI Ocean to start a measurement and LoniCT then starts the Sweep.

During Sweep the STOP button can be used as E-stop.
At the end of Sweep push the “Go to start position” button and the LoniMover will return to the start position ready for another measurement.

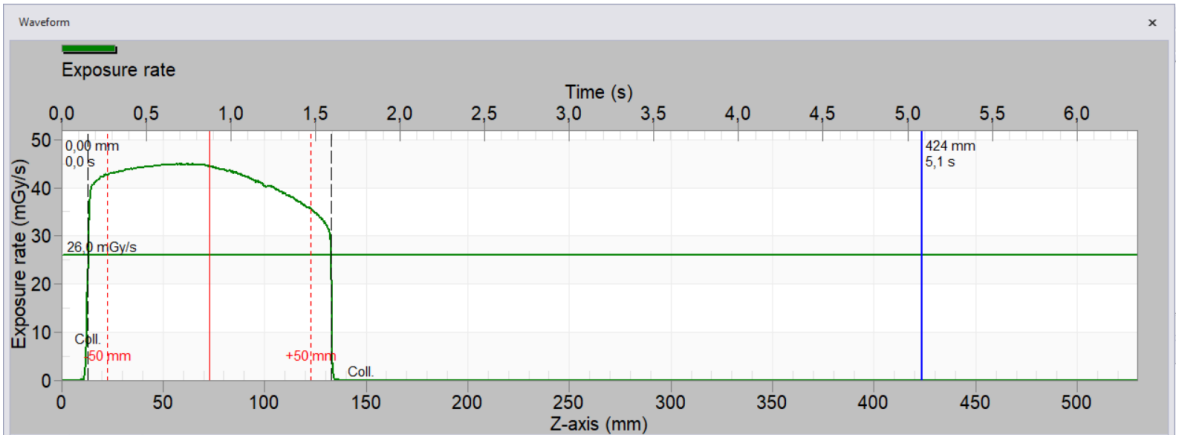


Figure 38. Typical sweep dose profile in Ocean.

5. MEASUREMENT WITH A PENCIL IONIZATION CHAMBER

5.1 Preparing the system for Step mode

This chapter explain how to use the LoniMover system for step-and-shoot with a pencil ionization chamber.

Make sure everything is connected, aligned and homed as described in chapter 3.

5.1.1 Alignment in z-direction, Step mode

If not active, select the “Step” tab in LoniCT and press the “Go to centering position” button according to Figure 26.

When in place button text turns green.

Using the table, align the center of the detector with the z-laser according to Figure 39 below.

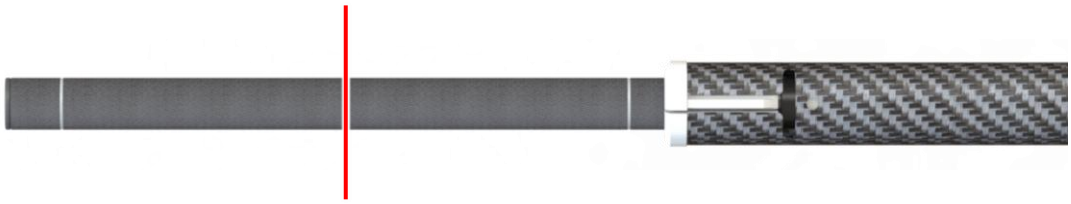


Figure 39. Alignment of the detector in z-direction

5.1.2 Define positions

Positions can be freely selected (within usable range) by entering positions (mm) in the fields “Pos 1” to “Pos 4”. You don’t need to use all the fields.

Instead of entering positions manually you can use the dropdown to select preset positions based on IAEA (International Electrotechnical Commission (IEC), 2012) and GE Revolution CT recommended positions (GE Healthcare, 2015)

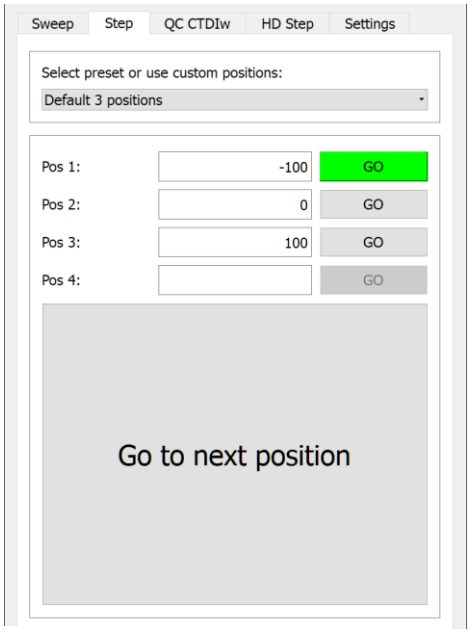


Figure 40. Step mode.

5.2 Measurements using Step mode

5.2.1 Set up the CT for Step mode

The LoniMover system advances the chamber through the CT beam in steps, the CT should be set up to do axial scans without table movement.

5.2.2 Step mode measurement

1. Prepare the CT and measuring system for measurement.
2. Select positions to measure, Figure 40.
3. Push the “Go” button to the right of the position, Figure 40.
4. Wait for the LoniMover to get into position, the “Go” button turns green when ready.
5. Make an exposure and collect the dose data from your measuring system.
6. Repeat steps 3 through 5 for the other positions or click the “Go to next position” button, Figure 40, to advance to the next position in the list.

6. MEASUREMENTS USING THE QC $CTDI_W$ MODE WITH RTI COBIA

This mode is used for Quality Control of $CTDI_w$ for narrow and broad beams on CT systems. It integrates with the RTI Cobia directly and you don't need any other software to do sweep or step measurements. All relevant dose data is automatically calculated.

It can also be used for other measurements involving sweeps or steps, even do sweep profiles with pulsed X-ray beams.

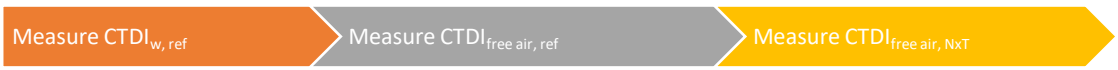
To calculate the $CTDI_w$ for broad beams you need three different dose quantities according to Equation 3 below (see chapter 1.1).

1. $CTDI_{w,\,ref}$ (in phantom) for the reference collimation.
2. $CTDI_{free\ air,\,ref}$ for the reference collimation.
3. $CTDI_{free\ air,\,NxT}$ for the broad collimation (NxT > 40 mm).

$$CTDI_{100,NxT>40mm} = CTDI_{100,ref}\,x\left(\frac{CTDI_{free\ air,NxT}}{CTDI_{free\ air,ref}}\right), \qquad \textbf{Equation 3}$$

(1: $CTDI_{100,ref}$; 2: $CTDI_{free\ air,ref}$; 3: $CTDI_{free\ air,NxT}$)

The LoniCT QC $CTDI_w$ mode makes these measurements and calculations easy by providing you with measuring modes for all three of the required dose quantities and an easy-to-follow workflow.



Please note: All measured dose data is reported in dose rate (mGy/s) and not dose for normalization reasons.

6.1 QC CTDIw tab overview

6.1.1 Detector pane

See Figure 41, section 1.

If the RTI Cobia is connected (Cobia button at the bottom is green) the dropdown will be populated with a list of detector calibrations.

If there is only one calibration for the connected detector it will be automatically selected, if you have more than one calibration for the connected detector you will have to select the one you would like to use.

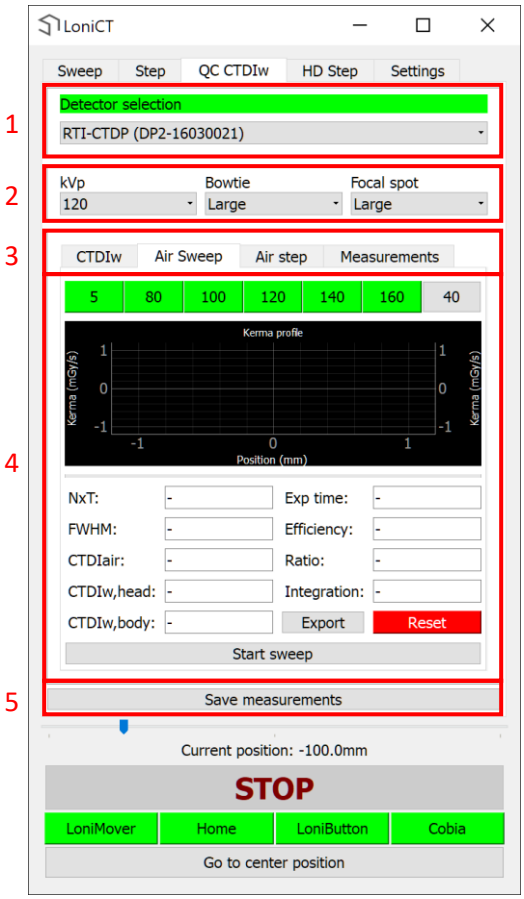


Figure 41. QC CTDIw overview.

The list above the dropdown will signal red if there is no Cobia/detector connected, yellow if the selected detector is not valid for the mode you have selected and green if the selected detector is ready and valid for the selected mode.

6.1.2 Exposure mode pane

See Figure 41, section 2.

In this section you select the desired exposure mode you are about to do measurements on. The preset values in the dropdowns is set in the “Settings/Presets” tab, see chapter 2.4.3 for more information.

Each combination of these parameters (exposure mode) produce unique measurement data and the measurements will be grouped under the active mode.

6.1.3 Measurement mode pane

See Figure 41, section 3.

In this section you select the desired measuring mode, there is also a tab for managing your measurement data (open/save/export).

6.1.4 Mode specific pane

See Figure 41, section 4.

In this section you do measuring-mode specific settings and measurements. See respective chapters below.

The collimation (NxT) buttons is defined in the “Settings/Presets” tab, see chapter 2.4.3 for more information.
Select the collimation you desire, when selected the button turns blue.

If there is measurement data available for the selected exposure mode, the collimation button(s) will turn green and when clicked the measurement data from that measurement will be shown.

Please note that collimation selection on the “Air sweep” tab will trigger a move to start position for that collimation if the LoniMover is connected.

6.1.5 Save pane

See Figure 41, section 5.

This button is always visible when in QC $CTDI_w$ mode, when clicked all the measurements done in QC $CTDI_w$ mode will be saved (to disk).

6.2 Measurements with the QC $CTDI_w$ mode

6.2.1 $CTDI_w$ measurements

This mode is used for measuring $CTDI_w$ for narrow collimations (NxT ≤ 40 mm) in a 16 cm or 32 cm CTDI-phantom. To use the IEC 3.1 formalism to calculate the $CTDI_w$ for broad beams (NxT > 40 mm) you need to measure at least the reference collimation with this mode.

This manual assumes that you have basic knowledge about this process and that the CTDI-phantom is placed in the CT according to CT manufacturer recommendations.

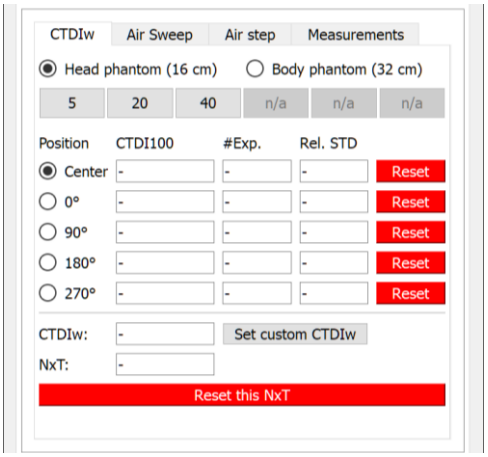


Figure 42. The $CTDI_w$ measurements tab.

1. Make sure the RTI Cobia and the detector is connected and selected.
2. Select exposure mode.
3. Select the "$CTDI_w$" tab.
4. Select phantom size.
5. Select collimation.
6. Prepare the CT for exposure using the same exposure mode, phantom mode and collimation as above.
7. Select desired measuring position in phantom.
8. Place CT Ion chamber in same position in the phantom.
9. Make an exposure.
10. (Make another exposure for better statistics)
11. Repeat steps 6 to 9.

The RTI Cobia measuring system trigger measurement automatically in this mode and the LoniCT software reads dose rate (mGy/s) from the instrument after exposure and populate the "$CTDI_{100}$" field in the measuring pane.

If you like to do more than one measurement per position (recommended for peripheral positions) you can make another exposure with the same settings and the "$CTDI_{100}$" field will show the mean of all measurements.
The "# Exp." and "Rel. STD" fields shows the number of exposures for that position and the relative standard deviation of these measurements for reference.
If you like to review the individual measurements, hover your mouse over the "$CTDI_{100}$" field.

When all five positions are measured the "$CTDI_w$" field will be populated with the calculated $CTDI_w$ for this exposure mode, phantom size and collimation combination.

If you already have an $CTDI_w$-value from previous measurements (with another measuring system) or tabulated values from the CT manufacturer you can enter that value (in mGy/s) in the $CTDI_w$ field directly and click the "Set custom $CTDI_w$" button.

You can reset a measurement position by clicking the "Reset" button next to that row, or all measurements for this exposure mode, phantom size and collimation combination by clicking "Reset this NxT" button.

To view previously measured data, select exposure mode, phantom size and collimation for that measurement and all available fields will be populated with data.

Tip: To minimize the switching of (physical) phantom positions (time-consuming), you can measure all the relevant exposure modes and collimations at one phantom position by selecting different exposure modes between exposures. Make sure you select the corresponding exposure mode at the CT.

6.2.2 Air Sweep measurements

This mode is used for measuring dose profiles (dose distributions), for any collimation, with the RTI Cobia and the RTI CTDP detector.
From the dose profile, $CTDI_{free\text{-}air}$ and many other quantities can be calculated.
This mode also includes a graphics module to display the dose profile.

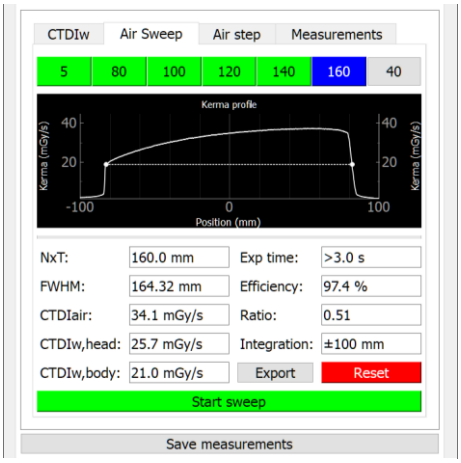


Figure 43. The Air Sweep tab.

From this mode you get data for the following quantities:

- FWHM, full width half max of the beam.
- $CTDI_{free\text{-}air}$ for the beam.
- The geometric efficiency of the beam.
- The ratio $CTDI_{free\text{-}air,NxT}/CTDI_{free\text{-}air,ref}$ (if reference collimation measurements with this mode is available).
- The calculated $CTDI_{w,NxT,head/body}$ for this collimation (if above and $CTDI_{w,ref,head/body}$ is available from the $CTDI_w$ tab).
- Integration limits used for calculation of the $CTDI_{free\text{-}air}$ (for reference).

You also get an interactive graph of the dose profile with the FWHM overlaid.

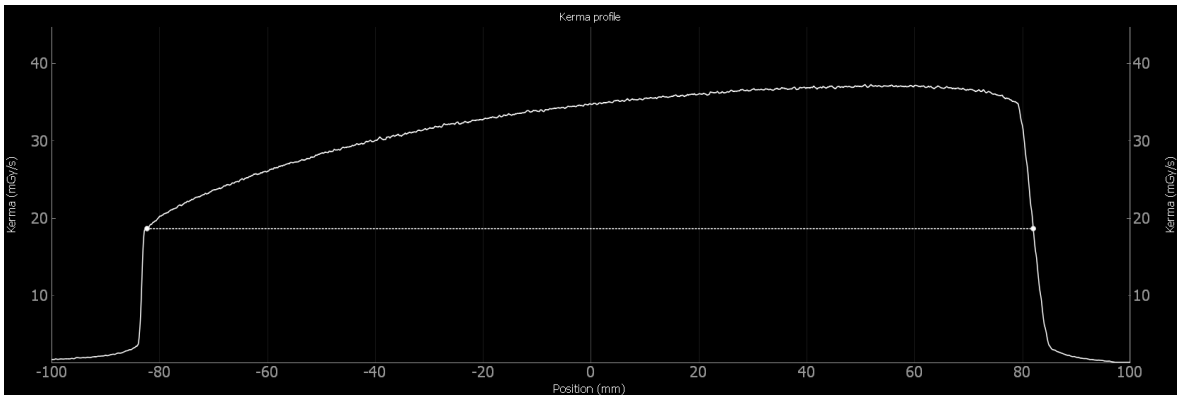


Figure 44. Interactive graph of a dose profile.

Note: For pulsed beams you get FWHM and geometric efficiency but no dose data (at this time) due to the complexity of measuring on pulsed beams. More on pulsed beams in chapter 6.2.2.2 below.

Workflow:

1. Prepare the LoniMover system according to chapter 3 and 4.
2. Make sure the RTI Cobia and the RTI CTDP detector is connected/selected.
3. Select exposure mode.
4. Select the “Air Sweep” tab.
5. Select collimation, please note that if the LoniMover is connected it will move to the start position for that collimation.
6. Prepare the CT for exposure using the same exposure mode and collimation as selected above. Use the “Exp time” field for guidance on required exposure time. Consult chapter 4.2 for more information on how to set up the CT for sweeps.
7. Click the “Start sweep” button and activate exposure at the same time or use the LoniButton (see chapter 4.2.3).
8. Wait for the exposure/measurement to end and for LoniCT to collect the data from the RTI Cobia.

The results will be shown in the measurements pane, example in Figure 43.

Use the “Reset” button to delete measurement data for this NxT.

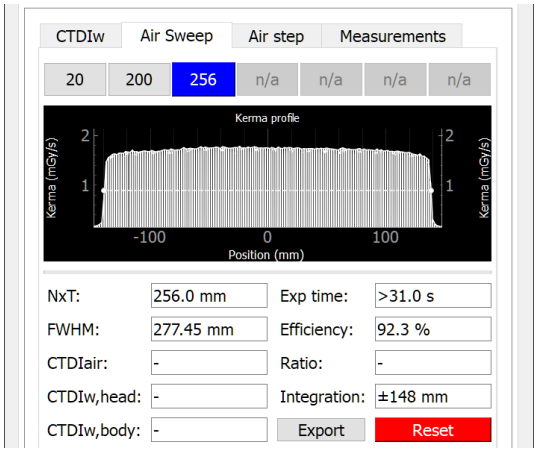
6.2.2.1 Export profile data from sweeps

The “Export” button is used for exporting dose profile data to Excel.

Make sure you have selected a cell in Excel. The exported data matrix will start at the selected cell and be two columns wide and up to a few thousand rows. Click “Export”.

The data is cropped at integration limits and interpolated to 0.05 mm increments for easy comparison between profiles with different resolutions.

6.2.2.2 Air Sweep measurements on pulsed beams



It is possible to do dose profile measurements on pulsed beams with LoniCT and RTI Cobia/CTDP. This is very useful for CBCT systems that use pulsed beams.

The challenge with pulsed beams is that sweep measurements are normally done in the time domain and by knowing the speed we can transfer timestamps to the space domain.
For pulsed beams we get a profile in the time domain that is not the actual dose distribution in space. See the pulsed curves in Figure 45 below where time data has been transferred to space domain.

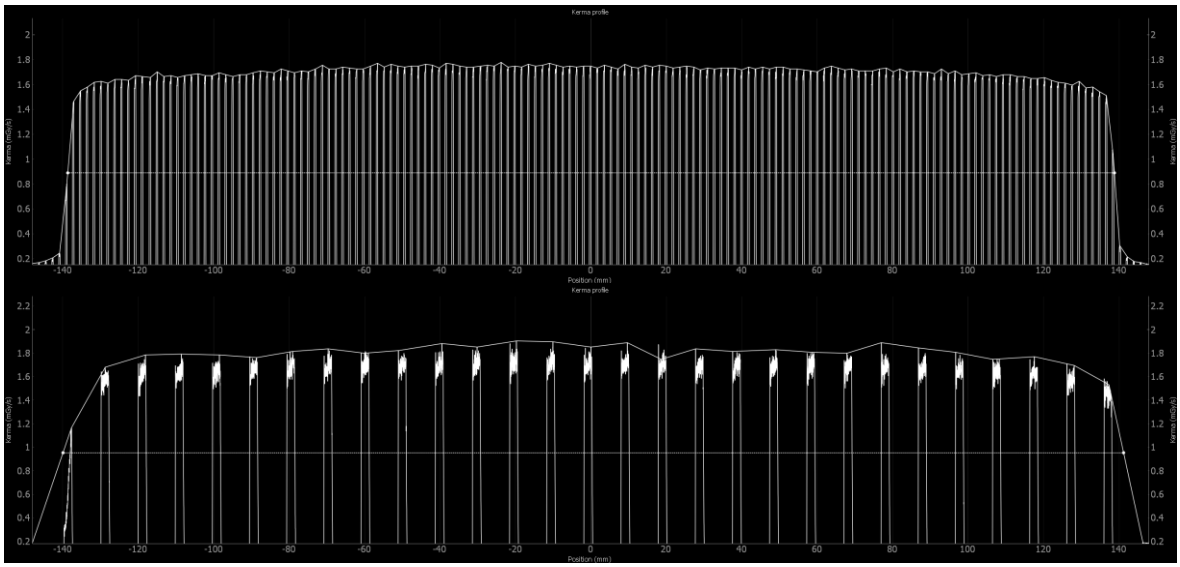
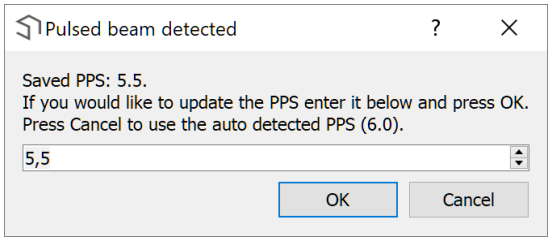


Figure 45. Dose distributions for a pulsed beam at 10 and 54 mm/s sweep speed.

By finding the peaks and create a new curve from these points, a dose profile can be constructed and quantities like FWHM and efficiency can be calculated from the new curve.
CTDI-calculations is calculated from integrated dose under the curve but as seen in Figure 45 the area under the new curve is not correlated to absolute dose and thus this method can't be used for dose calculations. This might be possible in a later release of LoniCT.

LoniCT detects the peaks automatically in a pulsed beam and during that process it tries to determine the pulse frequency (PPS). Depending on many parameters this is more or less easy and to make sure this is done correctly you will be presented with a dialogue when a pulsed beam is detected, showing the detected PPS. In this dialogue you will have the possibility to enter the true PPS of your X-ray system. Consult the manual for your X-ray system for the true PPS.



The precision of the calculated quantities is strongly depending on sweep speed (and sample rate of the Cobia) for pulsed beams. As one can see in Figure 45, the slopes of the curve, where FWHM is calculated, has (to) low resolution in the measurement at 54 mm/s sweep speed. The measurement at 10 mm/s has sufficient resolution for determining FWHM.
For best result, use the slowest possible sweep speed but make sure your X-ray system can make exposures long enough (use the “Exp time” field for guidance).

6.2.3 Air Step measurements

This mode is used for measuring $CTDI_{free-air}$ according to IEC 3.1 and calculate $CTDI_{w,NxT,head/body}$. The workflow is very similar to standard Step measurements but in this mode LoniCT communicates with RTI Cobia for measurement data and positions are automatically chosen from selected NxT.

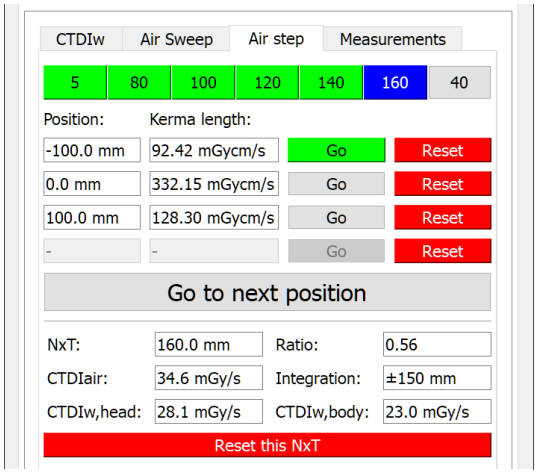


Figure 46. Air Step mode.

From this mode you get data for the following quantities:

- $CTDI_{free-air}$ for the beam according to IEC 3.1.
- The ratio $CTDI_{free-air,NxT}/CTDI_{free-air,ref}$ (if reference collimation measurements with this mode is available).
- The calculated $CTDI_{w,NxT,head/body}$ for this collimation (if above and $CTDI_{w,ref,head/body}$ is available from the $CTDI_w$ tab).
- Integration limits (for reference).

Workflow:

1. Prepare the LoniMover system according to chapter 3 and 5.
2. Make sure the RTI Cobia and DCT10/CT Ion chamber detector is connected and selected.
3. Select exposure mode.
4. Select the “Air Step” tab.
5. Select collimation
6. Prepare the CT for exposure using the same exposure mode and collimation as selected above. Consult chapter 5.2 for more information on how to set up the CT for sweeps.
7. Click the “GO” button next to the position you want to measure and wait for positioning, button becomes green when in position.

8. Make an exposure.
9. Wait for the exposure/measurement to end and for LoniCT to collect the data from the RTI Cobia.
10. Click “GO” on the next position or use the “Go to next position” button.
11. Repeat steps 8 to 10.

The results will be shown in the measurements pane, example in Figure 46.

Use the “Reset” button next to each position to delete measurement data for this position and the “Delete this NxT” button to clear all measurements for this NxT.

6.3 Dependencies

A note on how the different quantities and modes are interconnected.

- The first collimation button to the left in the “Air Sweep” and “Air Step” modes is the reference collimation. For that collimation you will not get ratio- or $CTDI_w$-data, the reference is used for calculating these quantities for other collimations.
- The ratio relies on the $CTDI_{free\ air,ref}$ (above), if that data isn’t available there will be no ratio-data for other collimations.
- The $CTDI_{w,NxT,head/body}$ relies on both the $CTDI_{w,ref,head/body}$ and $CTDI_{free\ air,ref}$, if those data aren’t available there will be no $CTDI_{w,NxT,head/body}$ data.

6.4 Measurements manager

In the “Measurements” tab you will find a list of measured modes in the form of: [*kVp;Bowtie;Focal spot;NxT;mode(;phantom)*].

The “mode” parameters are:

- narrow = $CTDI_w$ in phantom
- wide_sweep = Air Sweep
- wide_step = Air Step

For the narrow mode ($CTDI_w$ in phantom) there is an extra parameter for phantom size.

When clicking on a measurement the exposure mode parameters is populated with the same values as for that measurement and you can then visit the corresponding tab and click relevant NxT to view your data.

At this tab you can also save your progress to file (*.lct) or open saved sessions.

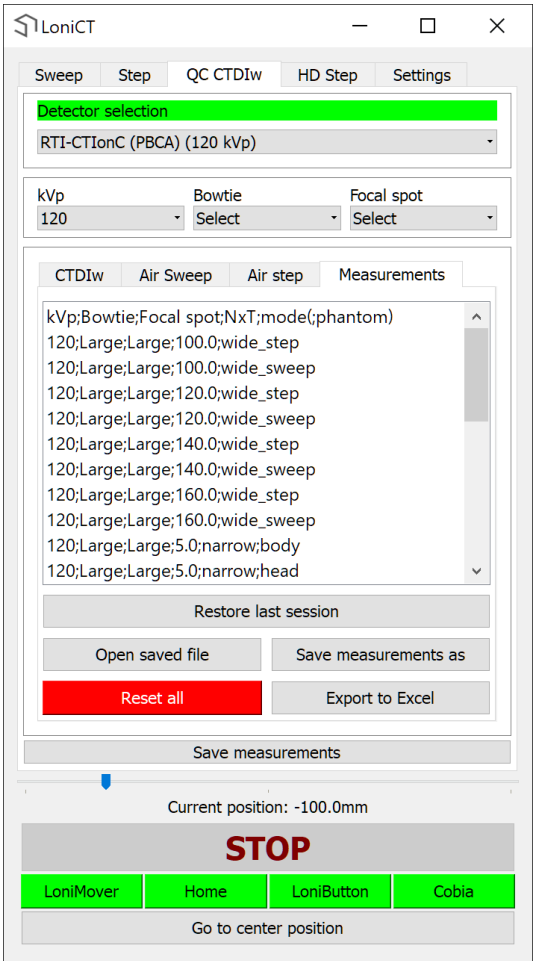


Figure 47. Measurements manager tab.

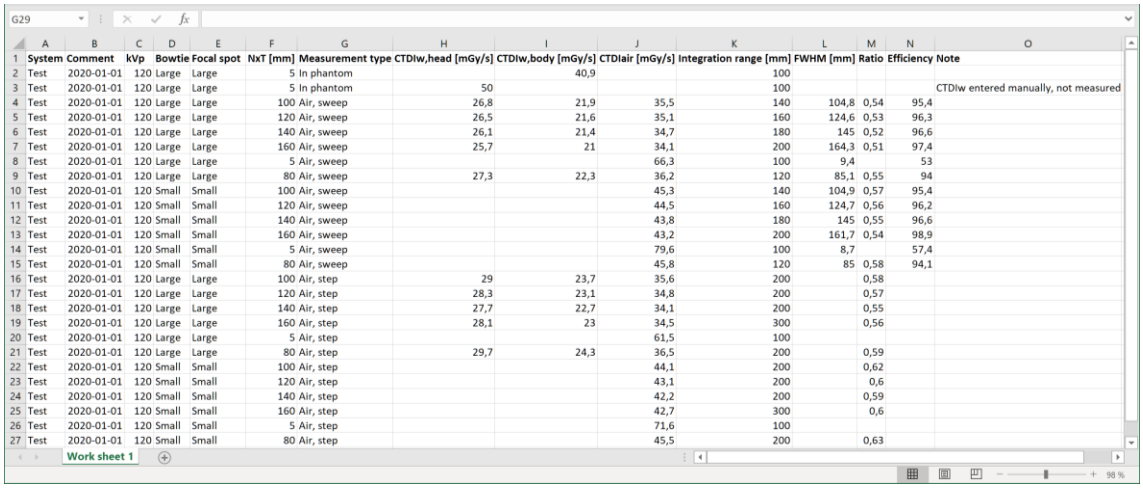
All progress will be saved to a temporary file regardless of manual save or not. This is useful if you forget to save your session before closing the LoniCT software. The “Restore last session” button will load the data from the previous session. Note that any progress in current session will be lost. Use with caution.

The “Reset all” button will erase all measurements in current session. Use with caution.

The “Export” button is used for exporting processed data (results) from current session to Excel®.

Open Excel and select start cell for the data export and click “Export” in LoniCT. You will be asked to verify the selected Workbook, Sheet and cell by clicking “OK”.

Figure 48 below shows the exported data format.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	System	Comment	kVp	Bowtie	Focal spot	NxT [mm]	Measurement type	CTDIw,head [mGy/s]	CTDIw,body [mGy/s]	CTDIair [mGy/s]	Integration range [mm]	FWHM [mm]	Ratio	Efficiency	Note
2	Test	2020-01-01	120	Large	Large	5	In phantom		40,9		100				
3	Test	2020-01-01	120	Large	Large	5	In phantom	50			100				CTDIw entered manually, not measured
4	Test	2020-01-01	120	Large	Large	100	Air, sweep	26,8	21,9	35,5	140	104,8	0,54	95,4	
5	Test	2020-01-01	120	Large	Large	120	Air, sweep	26,5	21,6	35,1	160	124,6	0,53	96,3	
6	Test	2020-01-01	120	Large	Large	140	Air, sweep	26,1	21,4	34,7	180	145	0,52	96,6	
7	Test	2020-01-01	120	Large	Large	160	Air, sweep	25,7	21	34,1	200	164,3	0,51	97,4	
8	Test	2020-01-01	120	Large	Large	5	Air, sweep			66,3	100	9,4		53	
9	Test	2020-01-01	120	Large	Large	80	Air, sweep	27,3	22,3	36,2	120	85,1	0,55	94	
10	Test	2020-01-01	120	Small	Small	100	Air, sweep			45,3	140	104,9	0,57	95,4	
11	Test	2020-01-01	120	Small	Small	120	Air, sweep			44,5	160	124,7	0,56	96,2	
12	Test	2020-01-01	120	Small	Small	140	Air, sweep			43,8	180	145	0,55	96,6	
13	Test	2020-01-01	120	Small	Small	160	Air, sweep			43,2	200	161,7	0,54	98,9	
14	Test	2020-01-01	120	Small	Small	5	Air, sweep			79,6	100	8,7		57,4	
15	Test	2020-01-01	120	Small	Small	80	Air, sweep			45,8	120	85	0,58	94,1	
16	Test	2020-01-01	120	Large	Large	100	Air, step	29	23,7	35,6	200		0,58		
17	Test	2020-01-01	120	Large	Large	120	Air, step	28,3	23,1	34,8	200		0,57		
18	Test	2020-01-01	120	Large	Large	140	Air, step	27,7	22,7	34,1	200		0,55		
19	Test	2020-01-01	120	Large	Large	160	Air, step	28,1	23	34,5	300		0,56		
20	Test	2020-01-01	120	Large	Large	5	Air, step			61,5	100				
21	Test	2020-01-01	120	Large	Large	80	Air, step	29,7	24,3	36,5	200		0,59		
22	Test	2020-01-01	120	Small	Small	100	Air, step			44,1	200		0,62		
23	Test	2020-01-01	120	Small	Small	120	Air, step			43,1	200		0,6		
24	Test	2020-01-01	120	Small	Small	140	Air, step			42,2	200		0,59		
25	Test	2020-01-01	120	Small	Small	160	Air, step			42,7	300		0,6		
26	Test	2020-01-01	120	Small	Small	5	Air, step			71,6	100				
27	Test	2020-01-01	120	Small	Small	80	Air, step			45,5	200		0,63		

Figure 48. Exported data from QC measurements.

Tip: If you store data from all your measurements (different systems and at different times) in the same Excel sheet and use well-chosen text for “System” and “Comment” you can use pivot tables to track systems (or groups of systems) over time.

7. HD STEP

This mode is an advanced step-and-shoot measurements mode with either Cobia and CTDP connected directly to LoniCT or using RTI Ocean together with Cobia/Piranha and CTDP.

The chamber can be positioned at any position within the range of the LoniMover with positions defined in Microsoft Excel® (not provided). The positions can have up to 0.1 mm resolution, positions with more than one decimal precision will be rounded to one decimal.

The positions should be in a continuous column. Make room for the dose data at a column beside the position column.

This mode can be used for high definition dose profiles or any other task that need dose measurements at well-defined positions.

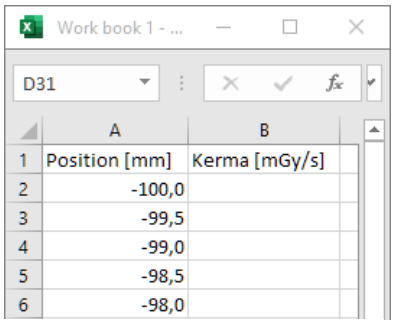


Figure 49. HD Step Excel positions and data.

7.1 HD Step tab overview

This tab, Figure 50, has an information bar at the top that will tell you if a RTI Cobia and CTDP is connected or not (for direct Cobia measurements).

The "*Get position from active cell in Excel and GO*" button will fetch the position data in the active cell and then traverse the LoniMover to that position.

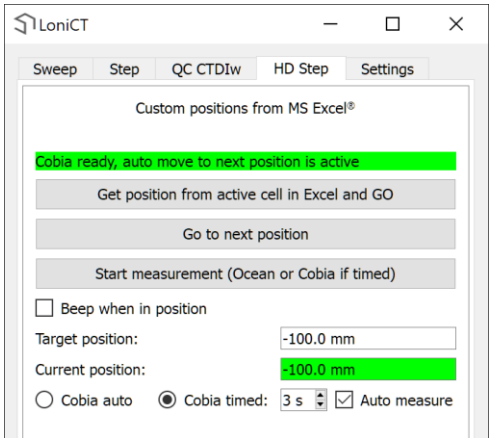


Figure 50. HD Step mode tab overview.

The "*Go to next position*" button will move the LoniMover to the next position in Excel.

The "*Start measurement (Ocean or Cobia if timed)*" button will trigger a measurement in Ocean (if properly connected) or trigger a timed measurement with Cobia. This button has no effect if using Cobia in auto trigger mode. If both Ocean and Cobia is connected to LoniCT, the direct Cobia connection will have priority.

The checkbox "*Beep when in position*" activates a "beep" at the end of a move. This function is useful if using "Timed mode" together with "Auto Measure" where the measure-move-loop requires an exposure at each start of measure, the beep will make the user aware that the LoniMover is in place and a new measurement will start.
This function is also useful for manual measurement start using Ocean or Auto trigger mode with the Cobia, although not critical.
Remember to turn on audio on the computer to hear the beep.

The fields "*Target position*" and "*Current position*" shows the target position fetched from Excel and the current position of the LoniMover. The "Current position" field will turn green when it has reached the target position and if "*Beep when in position*" is activated you also get an audible confirmation.

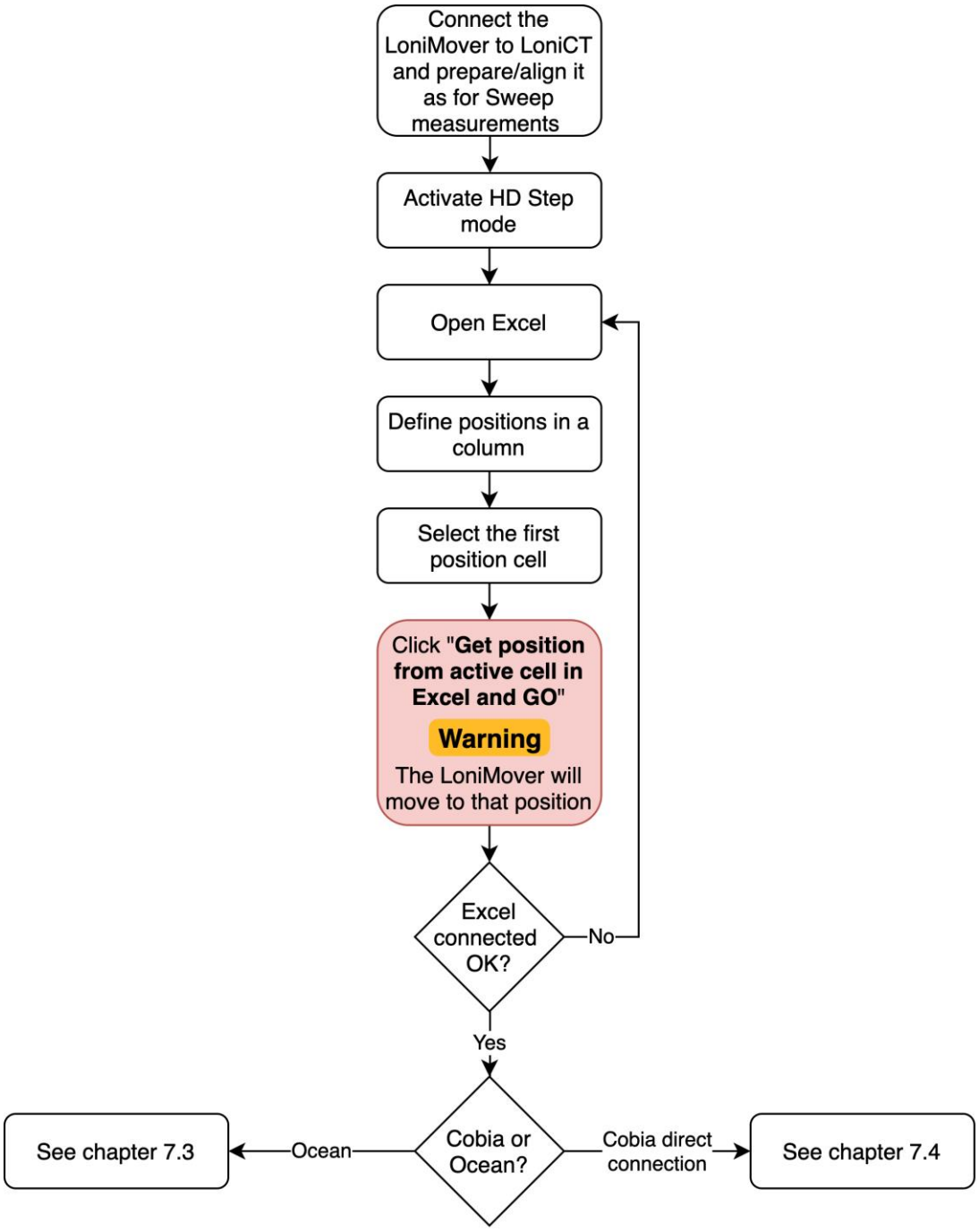
The "*Cobia auto*" mode uses the Cobia auto trigger function and a measurement will start when the Cobia detects an exposure. This mode is the simplest mode to use but when measuring positions outside the primary beam there is no guarantee that the auto trigger will detect the exposure.

The "*Cobia timed*" mode is used together with the "*Start measurement…*" button above, you have to define a measurement time as well.
By checking the "*Auto measure*" box the measure-move-cycle will loop until you uncheck this box.

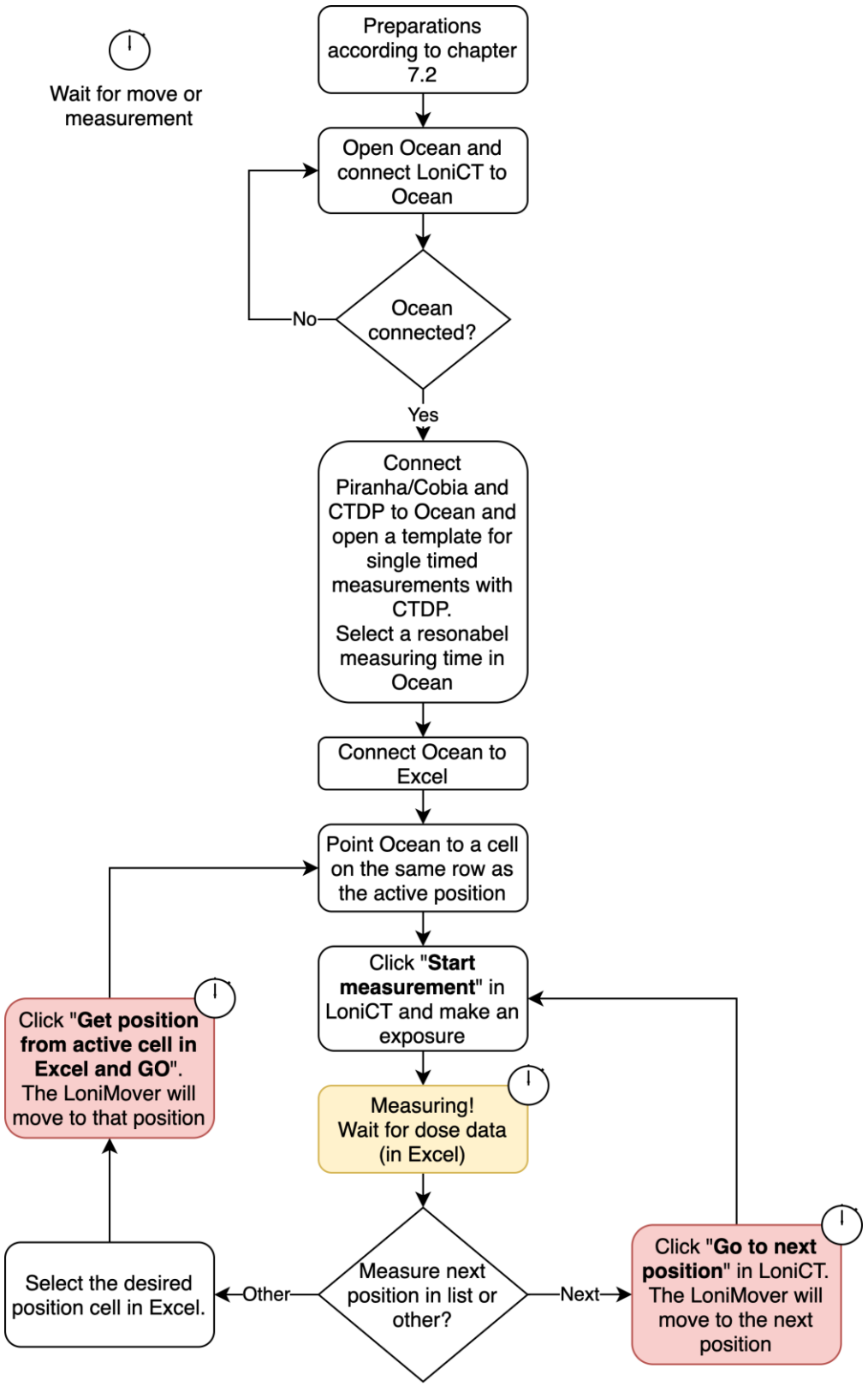
Read more on how to use the different modes in chapter 7.2 to 0.

7.2 HD Step preparations

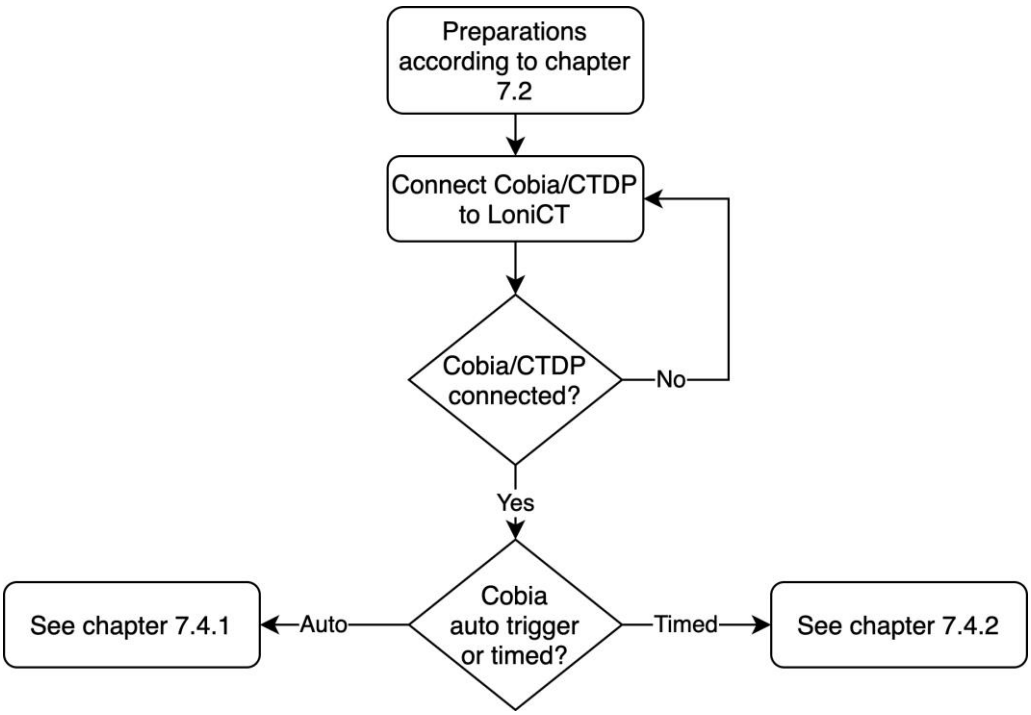
The workflow for HD Step is best described with flowcharts.



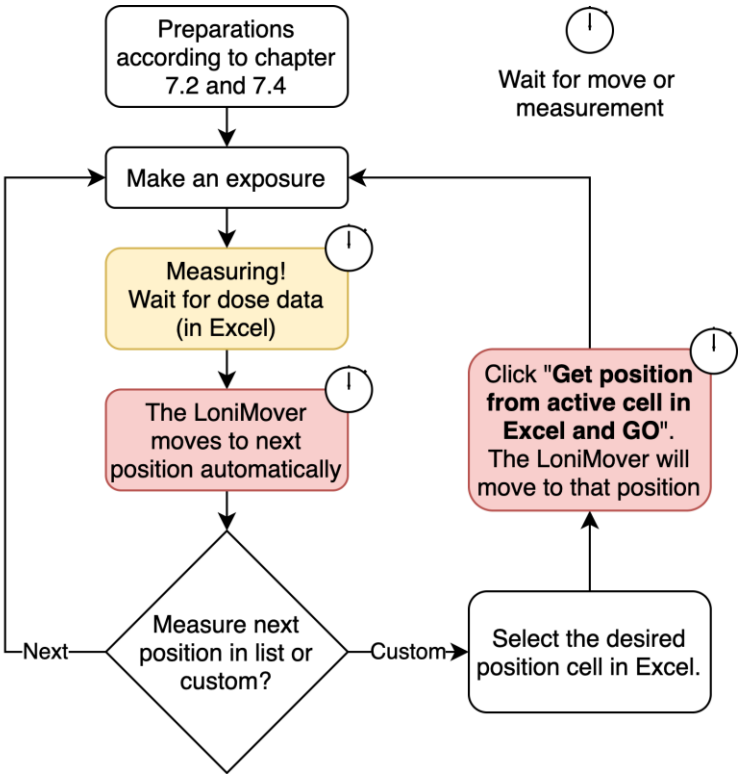
7.3 HD Step using Ocean



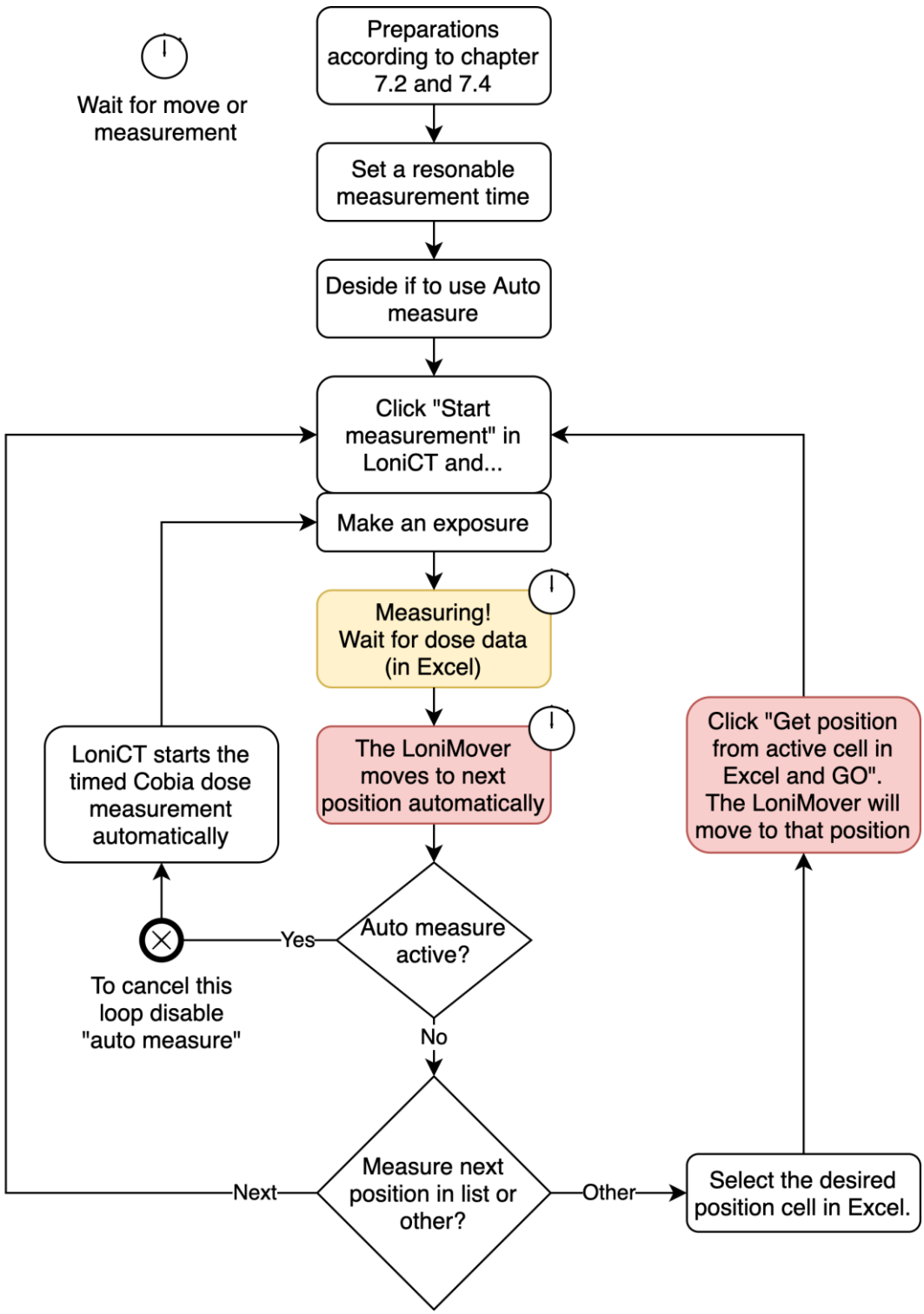
7.4 HD Step using Cobia



7.4.1 HD Step using Cobia in auto trigger mode



7.4.2 HD Step using Cobia timed mode



8. GENERAL INFORMATION

8.1 Maintenance

The LoniMover is a precision instrument and should be treated as such. Make sure that nothing falls into the mechanism and keep the product free of dust.
If necessary, clean with a slightly damp cloth.

The product does not contain any parts that can be serviced. Warranty is voided if product repair is attempted by the end user.

8.2 Storage and transport

The product should be stored in its carrying case when not used and during transport.

8.3 Troubleshooting

Symptom	Cause	Actions to try in priority order
LoniCT software can't find the LoniMover, LoniButton and RTI Cobia (USB or Bluetooth)	IT-policy preventing communication over VCP (Virtual COM-port)	• (Long term solution): Talk to IT-department about allowing VCP communication. • (Short term solution): Disconnect PC from corporate network, i.e., turn off wi-fi and disconnect ethernet cable if connected.
Can't connect over Bluetooth	---	• Cycle PC Bluetooth off and on. • Power cycle the LoniMover. • Restart LoniCT. • Remove LoniMover pairing and re-pair.
The LoniButton does not trigger a move command	The LoniButton is not connected or the button is not pushed hard enough	• Reconnect the LoniButton (USB and connection button in LoniCT). • Push the button harder and make sure the button is pushed straight.
LoniCT does not trigger Ocean	Connection lost between LoniCT and Ocean	• Push the "reload" button and select the correct Ocean window from the dropdown.
LoniCT can't connect to Excel	---	• Excel not open – open Excel. • Active cell is in edit mode, escape edit mode. • Try again. • Reload LoniCT and Excel, remember to save your work in LoniCT.

Table 3. Troubleshooting tips

9. SPECIFICATIONS & CONFORMITY

9.1 Specifications for the LoniMover

Performance	
Range	Up to 300 mm
Speed	7.5 – 200 mm/s
Speed accuracy	Better than 0.2 %
Position accuracy	Better than 0.1 mm
General	
Communication	USB 2.0 and Bluetooth®
Software platform	Windows
Dimensions (L x W x H)	410 x 48 x 70 mm
Weight	850 g
Force	<20 N
Power	12 VDC, 5 W (6 W peak)
Environmental	
Storage temperature	-20°C – 50°C / 0°F – 120°F
Operating temperature	Normal indoor conditions

Table 4. Specifications

Technote about accuracy (link).

9.2 Declaration of Conformity

Herewith, Lonitech ensure that The LoniMover is designed and manufactured in accordance with good technical practice to comply with the basic health and safety requirements in the following Directive:

2006/42/EC Machinery Directive
2014/30/EU Electromagnetic Compatibility Directive

The LoniMover contains a FCC and IC certified transmitter module.

10. REFERENCES

This section contains references and other information suitable for reading if you are interested in CT measurements.

(IAEA), I. A. (2011). *Human Health Reports No. 5: Status of computed tomography dosimetry for wide cone beam scanners.* Vienna: IAEA.

Bujila, R., Kull, L., Danielsson, M., & Andersson, J. (u.d.). Applying three different methods of measuring CTDI(free air) to the extended CTDI formalism for wide beam scanners (IEC 60601–2–44): A comparative study.

GE Healthcare. (2015). *Revolution™ CT Technical Reference Manual Direction 5443887-1EN, Revision 3.* GE Healthcare.

International Electrotechnical Commission (IEC). (2012). *Medical Electrical Equipment - Part 2-44 Edition 3 Amendment 1: Particular requirements for basic safety and essential performance of X-ray equipment for computed tomography, IEC 60601–2–44 Ed. 3:A1.* Geneva: IEC.

Wikipedia. (n.d.). *Computed tomography dose index*. Retrieved from https://en.wikipedia.org/wiki/Computed_tomography_dose_index

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