EasyTom 150/160 micro Computed Tomography System - Quick Guide

General Figure of uCT System

Safety:

Red Emergency Stop Button

- **Switches off x-rays, but not the power of the high voltage generator**
- Turns off power of motorized axis
- Opens the electrical door lock
- System Recovery post Emergency Stop Use
    - Release emergency stop button
        - Twist the red button on the hand controller or use the key
    - Re-arm emergency stop
        - Open lower left panel and push the orange "rearmement" button
    - Computer password "rx"

Red Emergency Stop Buttons

Ionizing Radiation

- Ionizing Radiation is invisible and painless, but can cause serious bodily injury or death.
- Red light signifies x-ray emission is on
- Do Not Defeat System Interlocks. For protection the x-ray tube is installed in a lead cabinet. Interlocks require cabinet closure for x-ray generation. Do not attempt to put hands inside of tool or cable ports when x-rays are emitted.

Biohazards

- The laboratory is not a BSL2, and cannot support open samples that must be inside a BSL2 or higher.

Lead

- Tool uses lead shielding. Avoid contact with lead shielding. Wash hands when finished with tool, especially prior to eating, drinking, or touching hands to face, etc.

Beryllium

- The output window of the 150 KV sealed x-ray tube (i.e. the red x-ray source) is made of a thin passivated beryllium foil. Do not touch it or damage it.
- If output window is broken then shut down system and do not breathe dust.

Motorized Axis

- Keep a safe distance from axis movements.
- **Do Not Ram samples into the x-ray tubes (there is no warning)**
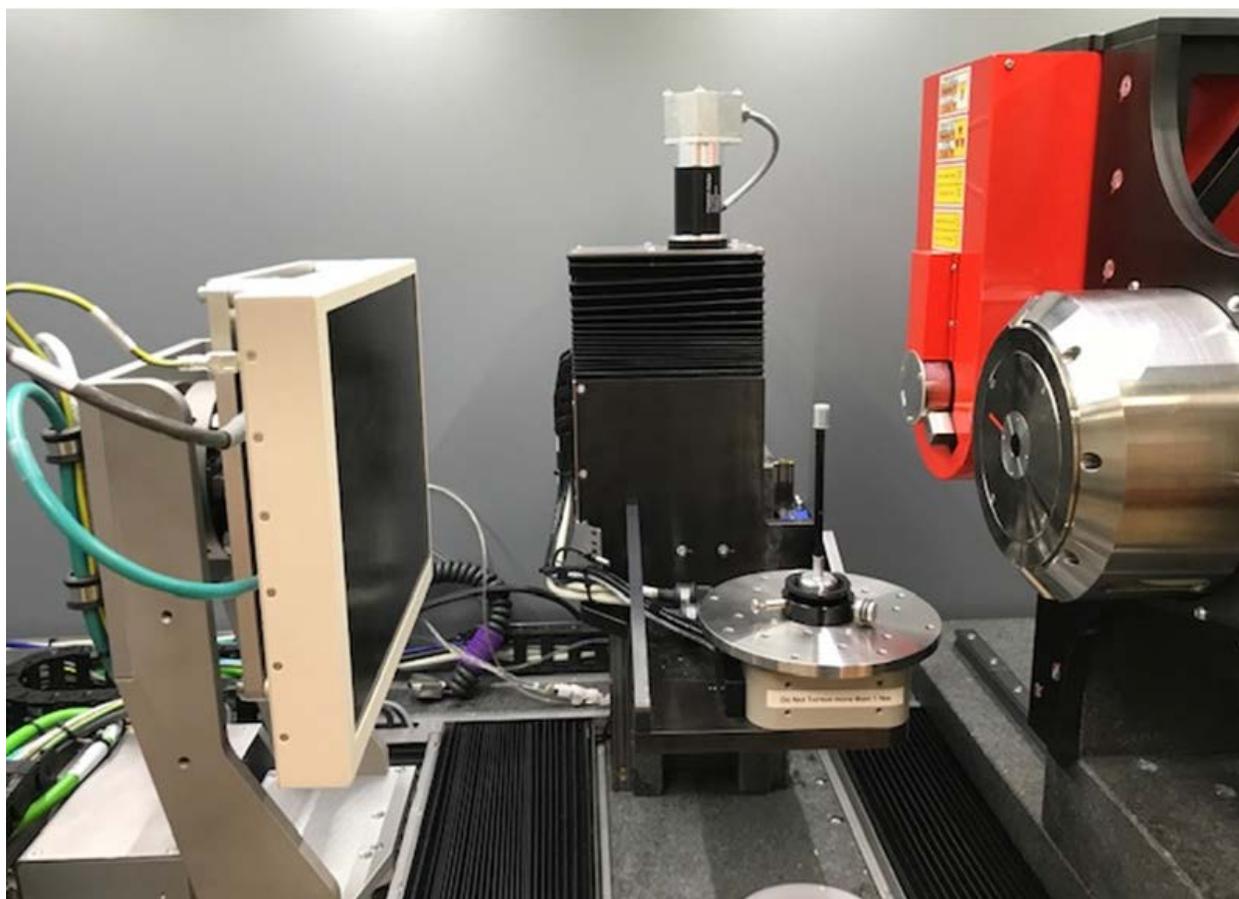
Shown from left to right: Flat Panel Imager X-ray Detector, Rotating Sample Stage (silver plate with sample mounted on stick), Red Sealed Tube X-ray Source (back right), Silver Open Tube X-ray Source (front right).

X-ray Computed Tomography:

- Consists of placing a sample between an x-ray source and a detector, irradiating the sample at different angles, and using mathematical algorithms to create cross-sectional images.
    - o This cone beam system collects 2-D x-ray image projections and uses reconstruction algorithms to produce a 3-D image.

System Geometry:

- Cone beam geometry
    - o X-radiation diverges from the source and passes thru the sample before striking an area imager (detector). Since it is not a parallel beam, there could be blurring and reconstruction error.
        - ▪ A larger cone angle should produce more reconstruction error.
            - • The imager pixels impinged upon by the center of the cone are exposed to a parallel beam, whereas regions further from the center are exposed to a divergent beam. If one thinks of the sample as having slices, the pixels rows that are further from the center of the imager will receive photons that pass through multiple slices, complicating reconstruction.

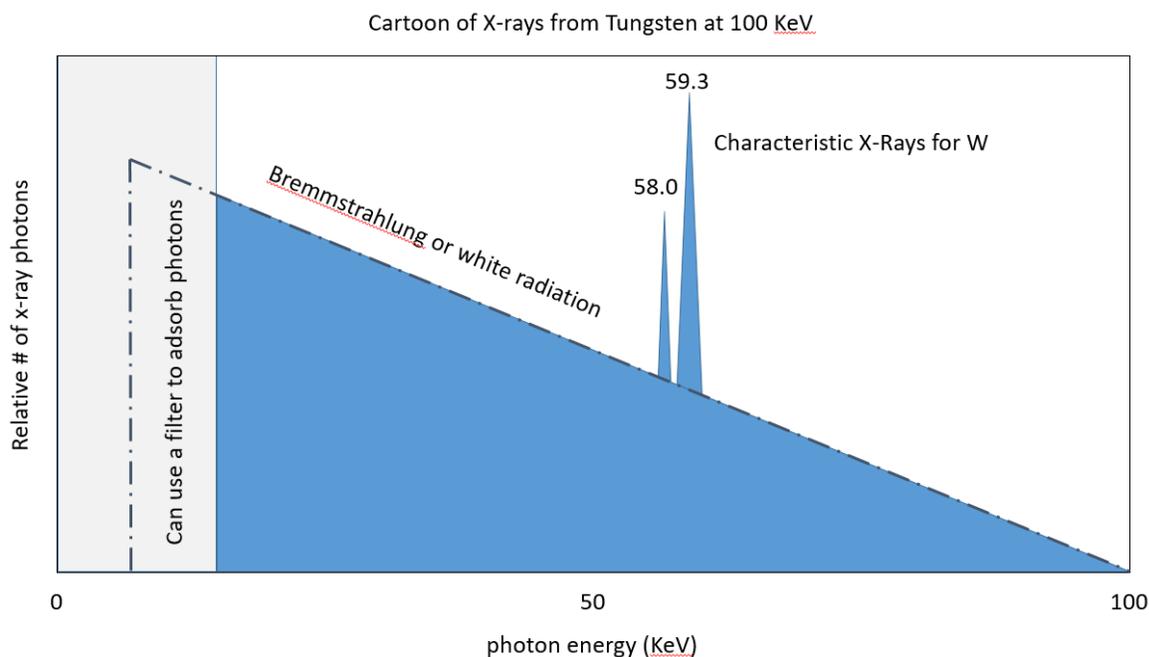## **Sample Size and Weight:**

- Maximum sample diameter – 350 mm
- Maximum sample weight for rotation stage – 20 kg

X-ray Tubes & Beam Filters:

X-ray tubes

Produce up to 160 keV x-ray photon energies

- Produce a broad spectrum, including Bremsstrahlung radiation and characteristic peaks.

Cartoon of X-rays from Tungsten at 100 KeV

Cartoon of X-rays from Tungsten

160KV open tube

The 160KV tube is silver, and is also referred as the open tube as it uses vacuum pumping. This tube has LaB6 crystal and W filament options.

- LaB6 crystal for 20 to 100KV
- LaB6 focus modes
    - 0.4um resolution capability max target current of 16 (at max voltage)
    - 0.75um resolution capability at max target current of 31 (at max voltage)
    - 1.5um resolution capability at max target current of 51 (at max voltage)
- W filament for 20 to 160KV.
- W focus modes
    - 0.8um resolution capability max target current of 16 (at max voltage)
    - 1.5um resolution capability at max target current of 41 (at max voltage)
    - 4um resolution capability at max target current of 61 (at max voltage)
- 160KV tube is used for high resolution scan of small samples.
- **Contact staff in advance for LaB6 and W changeovers**. Changeover is not a quick process (requires manual maintenance, vacuum recovery, etc.).

150KV sealed tube

The 150KV tube is red, and is factory sealed.

- 5um resolution, 40 to 150KV, maximum current of 500uA
- 3 focal spot (emission point) modes
    - Small – 5um, max power 4W
    - Middle – 20um, max power 30W
    - Large – 50um, max power 75W
- Faster acquisition times, at the expense of resolution

In this picture the red sealed source has an optional beam filter installed, whereas the silver open source does not have an optional beam filter installed.

Beam Filters

- Physical filters (e.g. Cu, Al, stainless steel) can be mounted at end of x-ray tube
    - Used to block lower energy photons. The lower energy photons are preferentially absorbed reducing the energy spectrum width.
        - Filter material (Z) matters (e.g. a thin Cu filter will blocks higher energy x-ray photons than a significantly thicker Al filter).

- o Mostly used to reduce beam hardening. Reducing beam hardening can enhance the image quality by reducing the brighter voxels at the outer edges of the volume of a homogeneous material.
  - ▪ Beam hardening occurs when lower energy photons attenuate in the sample material, reducing the amount of soft x-rays that are passing thru the sample, whereas the higher energy x-rays (i.e. hard x-rays) pass through the sample, therefore the percentage of hard x-rays increases as the x-rays pass thru the sample (hence the term "beam hardening").
- o Can be used to reduce oversaturation of imager
  - ▪ Example: When a mostly x-ray transparent sample requires high energy x-rays to penetrate x-ray dense features of the sample, the use of a filter to reduce the low energy x-rays may prevent oversaturation of the imager.

## Imagers or Detectors or Cameras:

Flat Panel

- Pixel size 127um, but screen is large and can obtain high resolution thru use of geometric magnification
- Very low geometric distortion
- Good signal to noise, as thick scintillator produces maximum efficiency
- Real-time imaging (fast reading time)

CCD

- **Do Not Use above 100keV, as this will damage CCD sensor**
- Pixel size: 9um, can get high resolution without geometrical magnification
  - o CCD has a small screen, limiting the pixel size benefit to tiny samples
- X-ray conversion and sensitivity limited to low energy, has thin scintillator
- Before doing CT calibrations or acquisition wait for the Peltier stage to cool to 12C.

Changing Imager

- Disconnect cable(s), use handled pin to loosen mount, remove and install desired imager, use handled pin to tighten mount, reconnect cable(s)
  - o Note: If you disconnect the cables after opening the xact64 program, you may need to exit and restart the xact64 program to re-establish communication.
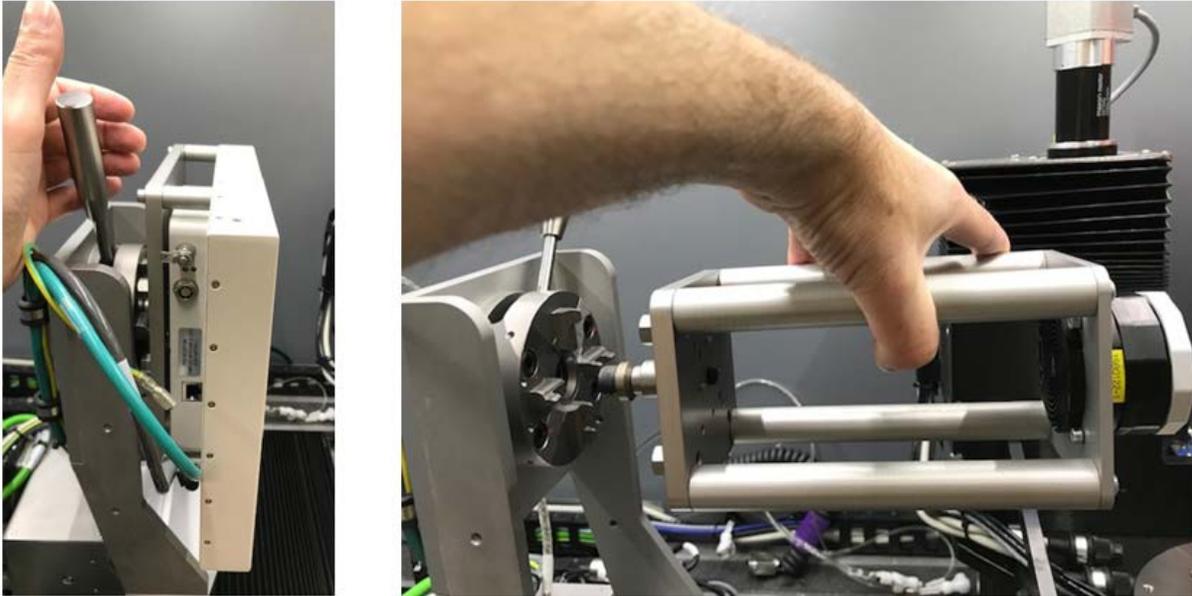
Left figure shows Flat Panel with tightened clamp (pin it pointed towards the installer). Right figure shows CCD with loosened clamp (pin is pointed away from installer).

The tiny red dot on the flat panel connector faces to the left (i.e. the 9 o'clock position)

Resolution

- Achievable pixel and voxel size depends on system geometry and hardware, sample size, and the distance between imager, object and source.
  - o To improve resolution or reduce the voxel size
    - Decrease sample size
    - Increase imager screen size (allows larger projection)
    - Decrease imager pixel size
    - Decrease x-ray focal spot size
    - Move the sample closer to the source and adjust the imager zoom such that the sample x-ray projection fills the imager screen.
      - When using the Flat Panel, orientate it for best utilization of the screen (this is not applicable to the CCD as its orientation cannot be changed)
      - Use helical or stacked acquisitions for best utilization of the screen
  - o For a simplified general case the physical voxel size = (detector pixel size) / (magnification)
    - Where magnification = (x-ray source to detector distance) / (x-ray source to sample rotation axis distance)

X-ray absorption and imaging

- The linear attenuation coefficient of the material, μ, depends on electron density
  - o Retrieve μ at every point and use it to construction a map
    - Difficult to determine μ if the whole sample is not imaged
- Grey level is a function of thickness, atomic number, energy of incident photons, see Beer-Lambert law.

Sample scan and data acquisition procedure

Determine size of sample, required x-ray energy and resolution as these influence choice of x-ray tube, filament, and detector.

Install needed Imager

Open program – "xact64"

Warm up the x-ray tube that will be used (required if tube was not used within the last 8 hours)

- **XRay160/Tools/Start Warmup**
  - o Go to Plot tab. Confirm voltage goes to 110KV for the 100KV LaB6 filament or 170KV for the 160KV,
  - o Run 15 minutes or more to stabilize target current and focus position
- **XRay150/Start Warmup**
  - o This tube emits x-rays during warmup
  - o Run 15 minutes or more to ensure a stable photon flux and focal spot position

Mount Sample

- Sample adhesives
  - o Carbon tape, double sided tape, epoxy, utility wax, UV resin, modeling clay, silly putty
- Sample container (if used)
  - o Must prevent sample movement (avoid blurring), and be x-ray transparent
  - o Container should be uniform thickness
  - o Sample volume to be analyzed should be fully within or fully outside of the container
  - o EPS or XPS foam, florist foam, plastics, carbon fiber, cotton ball wads (for packing), thin cardboard
- Open door and load sample
- ***Center the sample to stage rotation axis***. Confirm the sample does not wobble when rotated
  - o If analyzing a portion of a sample, then the volume of interest should be centered
- Close door

Position Sample

- ***CAUTION* - DO NOT RUN YOUR SAMPLE INTO THE X-RAY TUBE**
  - o Center and Zoom sample using hand controller.
    - ▪ Use of Overlays/Grid is helpful
  - o For best resolution the sample should be as close to the x-ray source as possible and perfectly centered to stage rotation
    - ▪ Recommend voxel size = 1/8 size of smallest inspected feature
  - o Rotate sample 360 degrees to ensure it stays within imager view and does not hit x-ray source

Turn on Imager

- Imager or CCD/Start

Histogram of Imager

- Click on Histogram to see Counts vs Grey Scale
    - o Confirm x-rays penetrate the sample at all angles of rotation
    - o Confirm detector is not oversaturated, check with sample at all angles of rotation
    - o Confirm contrast
        - ▪ If better contrast is required set up the acquisitions parameters to utilize a broad range of the grey scale (this can be an exposure or run time trade-off)
    - o Use to ease your sample viewing
        - ▪ Adjust the histogram cursors to filter the portion of grey scale that "you see" (the full histogram will still be collected during data acquisition, moving the cursors only filters what is viewed by you on the monitor).
        - ▪ Invert the histogram cursors to invert the gray scale that "you see". You can view higher to lower adsorption as progressing from white to black or alternatively as progressing from black to white.

Turn on XRay and set KV:

- XRay160 or XRay150/XRay On
    - o for XRay160 watch Plot of Voltage & Current to confirm on
- Set Focal Spot Mode (small, middle, large)
- Set KV
    - o Ensure sample transparency in dense areas at full rotation
- Confirm (see laminated charts) Target Current is as expected for the Tube Voltage, Filament Type, and Focal Spot Mode that is being used.
    - o If needed adjust value of Tube Current Setting or perform a Beam Calibration
- Run x-rays continuously for 30 minutes to enhance beam and system stability prior to starting sample data collection.

Sample Contrast:

- Use the full spectrum of detector grey scale (refer to above section: **Histogram of Imager**)
- Use lower x-rays energy to improve contrast
    - o For example if trying to analyze air bubbles in foam the use of 20KV (or lower) x-ray photons will result in better contrast than 100KV x-rays. For reference our system minimum is 20KV.

- Collect enough photons per imager pixel
  - o Inverse Square Law: Doubling the distance from radiation source => ¼ intensity (since the radiation get spread over 4x the area)
- Use frame averaging to obtain projections with less noise and better contrast resolution
- Use a contrasting agent
  - o Example of contrasting agent that was reportedly used to find cracks in carbon fiber: 250 grams zinc iodide (x-ray absorbing contrasting agent) + 80 ml distilled water + 80 ml IPA + 1 ml Kodak Photo-Flo. Soak sample for 1 or 2 days allowing zinc iodide to get into sample cracks and crevices.

Set Exposure:

- **Set the image brightness to obtain the best grey scale definition.**
  - o Adjust Focal Spot Mode (if needed)
  - o Set Tube Current
  - o Set Frame Rate – number of images or frames per second
    - ▪ Higher frame rate = Faster pictures = Darker imagers
    - ▪ A higher frame rate with frame averaging and a slightly lower signal can achieve a better signal to noise ratio than a lower frame rate and a slightly higher signal level.
      - • 5 FPS with 5 frame averages requires one second of exposure time, as does 1 FPS with 1 frame average, but the former achieves better signal to noise.

Set Quality:

- Set the Num of aavr Frames
  - o Increasing the number of frames used to build a single averaged image reduces the random noise, but takes additional time

Black Calibration:

Can be run manually or immediately prior to data acquisition by selecting the appropriate check box.

- Black Calibration – eliminates offset to obtain a value close to 0 when no x-rays are received.
  - o **Never run black calibration with x-rays on,** and wait for ghost images to disappear (typically 2 to 5 minutes) before starting calibration

Gain Calibration:

Can be run manually or immediately prior to data acquisition by selecting the appropriate check box.

- Gain Calibration (also referred to as flat field correction) acquires a sequence of white images and uses them as a reference for a flat field
  o **Never run gain calibration with a sample in field of view**
    ▪ Ensure samples is out of the way, turn on x-ray and let the beam stabilize
      • 30 minutes stabilization recommended prior to long data acquisitions
  o **Never run gain calibration with a saturated imager**
  o **Always run gain calibration at the settings that will be used for data collection (tube voltage, tube current, exposure and frames per second, focal mode, and x-ray source to detector spacing)**
    ▪ Imager sensitivity depends on dose

Choose Project Directory where data will be saved: Tomography/CT_Data/your_directory

- Image prefix – usually start at 0
- Type – select
- Option –Select
- Images per turn or Auto
- Typically want to select Black Calibration, Beam Alignment (for open tube), Gain Cal, Anti Ring Shift (optional), Switch off X-ray.

Move & Lock Axes in tomography position

- Click "Move and Lock Axes in Tomography Position"
- Virtual Centering (select, it is usually desired to have the x-ray source and detector track the virtual center of the sample during data aquistion).
  o Use x/z arrows to center sample
  o Axis/Rotation/Zero, then set to 90 and center sample again

Start Tomography Sequence

- Start
- Move sample outside the field of view for gain calibration (Vertical/Zero/-#), then hit "Done" and wait for gain cal to complete and system to start collecting data.

Reconstruction (for details read Xact_EN.pdf at This PC > CT_Data > Documentation)

- Open the Xact Software on the reconstruction computer and progress thru the tabs from left to right.
- Note: press CONTROL + MOUSE WHEEL allows you to zoom in/out of images

Load (pages 74-76)

- Go to the Load Tab/Reconstruction Project then select the load folder icon and drive to the desired unireconstruction.xml file

Volume (pages 77-78)

- Record your resolution or voxel size as this is required input for reconstructions done with other software (e.g. Dragonfly, Avizo).
- You can fit the volume to your sample, which can decrease computer processing time

Spot (pages 79-80)

- Corrects for movement of x-ray spot on imager, or slight sample movement.
  - o Compares projection images to the reference projections and tries to minimize the difference by shifting in horizontal and vertical dimensions and scaling one image against the other.
  - o You can Show Differences With Reference Images
    - ▪ A uniform grey difference image means there are no differences between the projection and the reference image.

Geometry (pages 81-85)

- Corrects for system misalignment at acquisition (e.g. x-ray tube focal spot drift or other hardware drift)
  - o Use if reconstruction slices are blurred or if artifacts exit

Filter (pages 86-87)

- Correct rings and arcs artifacts that are due to defective pixels that have variable sensitivity and gain. (Black calibration, gain calibration, and anti-ring shift help, but does not eliminate all pixel artifacts.)
  - o "Ring Filter" reduces smooth circular artifacts visible in horizontal slices
    - ▪ The filter can induce new artifacts
  - o "Bad pixel correction" reduces strong arcs or rings created by defective pixels

Beam (pages 88-91)

- Correct for beam hardening artifacts.

- o Attenuation in material is higher for soft photons than for hard photons, so the proportion of hard photons increases as the beam passes thru the material, resulting in the image of a homogeneous material appearing to have a brighter outside layer.

Advanced (pages 92-97)

- Metal Artefacts Correction – Heavy elements inside a sample can mask other materials.
- Phase Contrast Correction – For use with small angle scattering phenomenon in low adsorption materials.

Projections

- Identify the projections you want to use for the reconstruction.

Reconstruct

- Select Noise filtering (Low Noise (lots of smoothing) or High Detail)
- Identify if you want to save X, Y, or Z slice reconstruction
    - o Typically just select Y slices. Although you can save each of X, Y, Z there is no additional information obtained by saving all three.
- Select Format to save data in and decide if you want any video or STL (stereolithography) file of the surface geometry.
- Click "Volume Reconstruction"

MicroCT Remote Data Access

- Windows Explorer ->This PC -> Computer -> Map network drive
- Drive: choose any free letter. Folder: \\10.165.32.216\CT_Data. Connect using different credentials.
- User name: CT_USER & Password: 150160xraydata
- If using a MAC, then: Finder -> Go -> Connect to server Smb://10.165.32.216