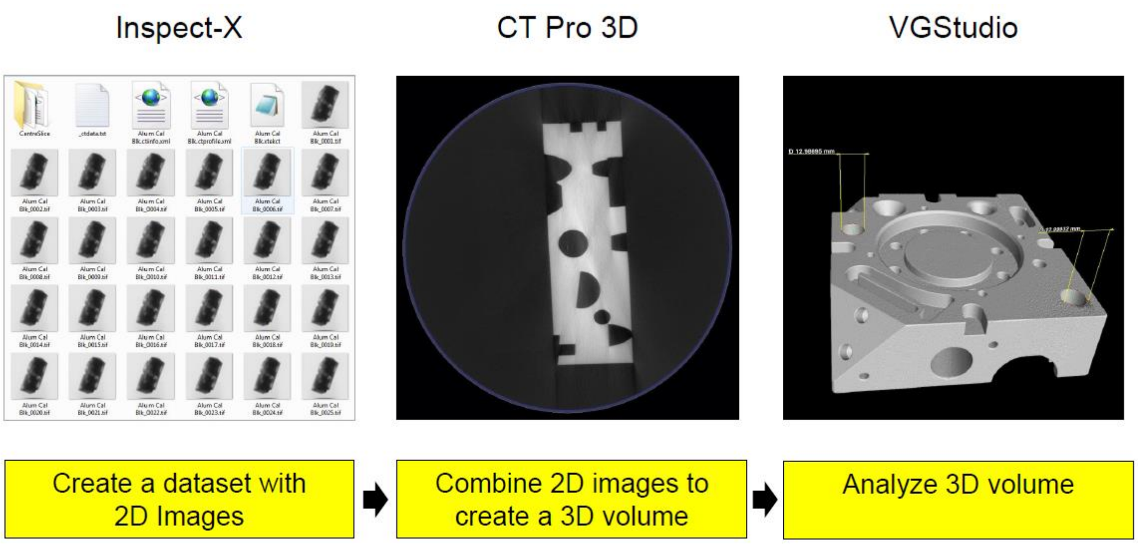
Standard Operating Procedure of X-ray CT

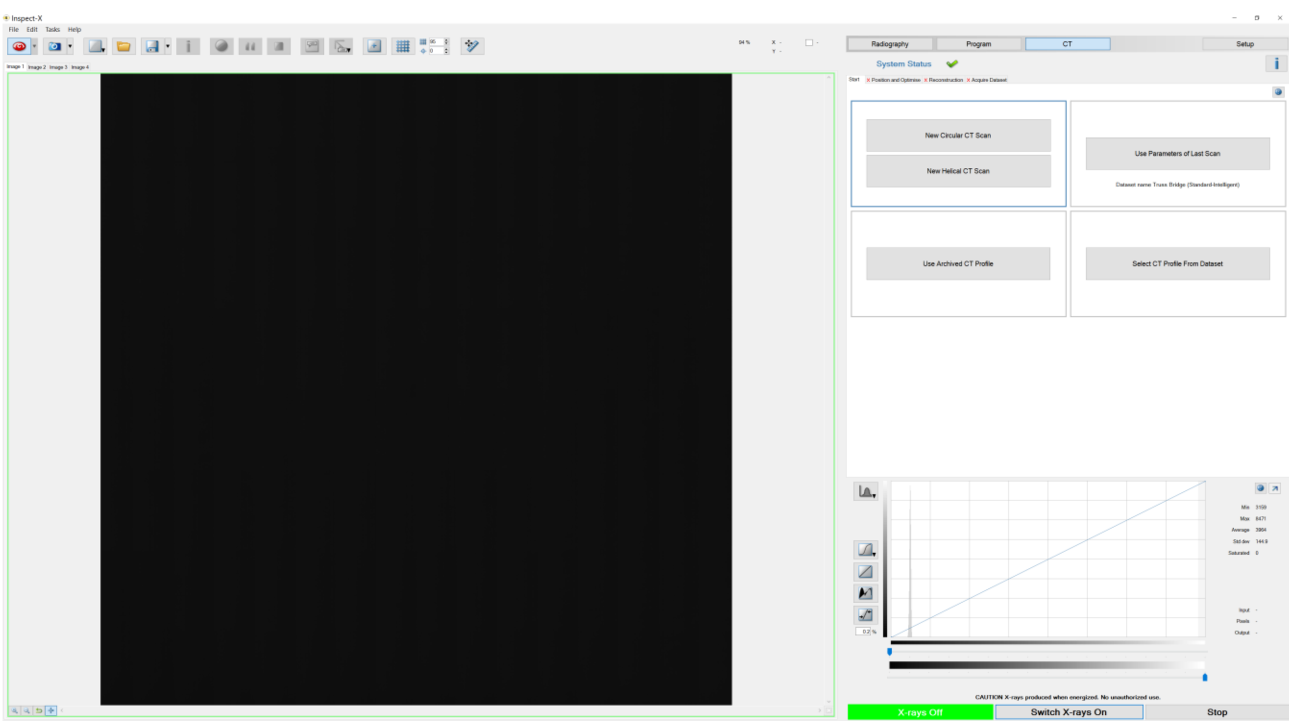
(Nikon XTH225)

There are three main steps for performing X-ray CT on a sample. These steps are as follows:

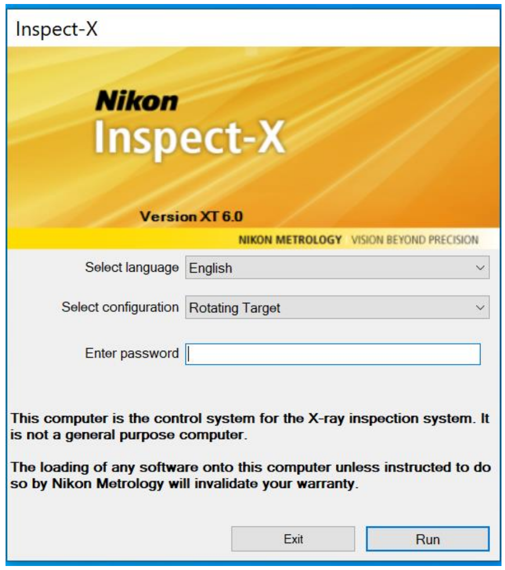


I. Inspect-X – CT Data Acquisition

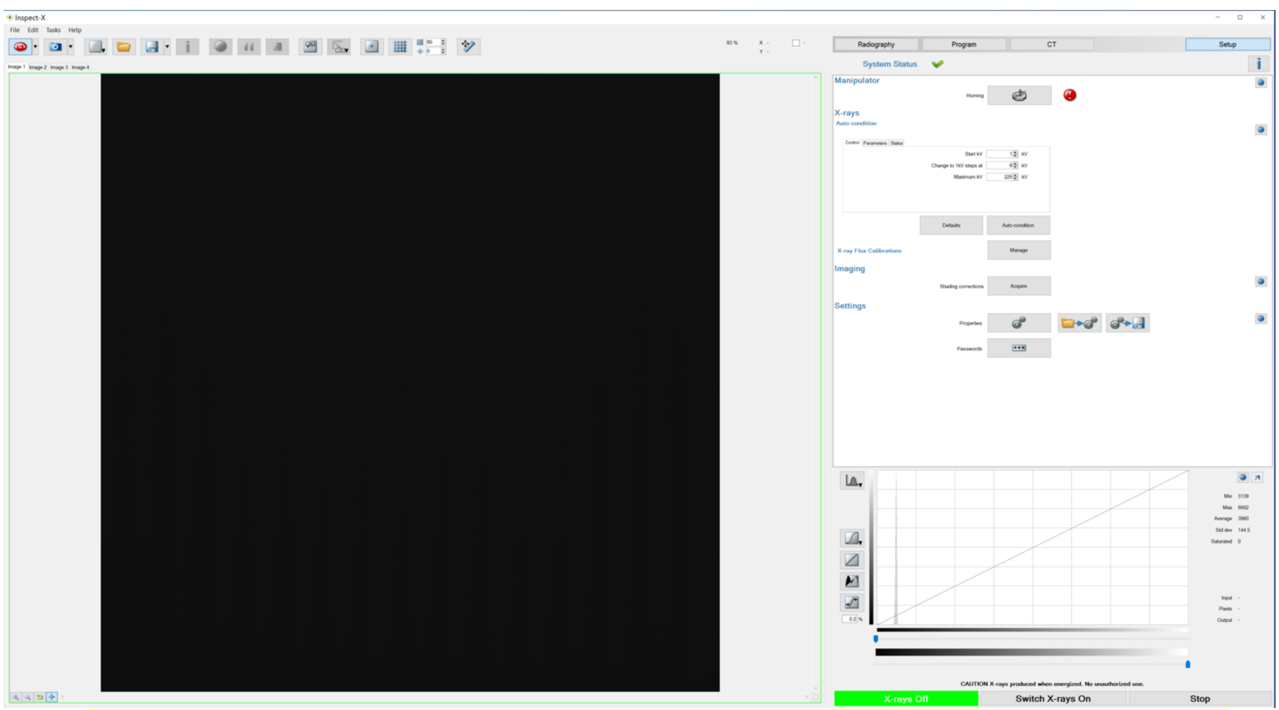
The Inspect-X interface is usually opened on the main computer (Acquisition Computer) as shown below.



In case if the interface was closed by the previous user, double-click on the Inspect-X icon on the screen to start it. The startup window will look as shown below; click “Run” to continue:
Note: No password is required unless you are the equipment manager and would like to perform maintenance or filament change.



After the startup, you will see the following window on the screen.



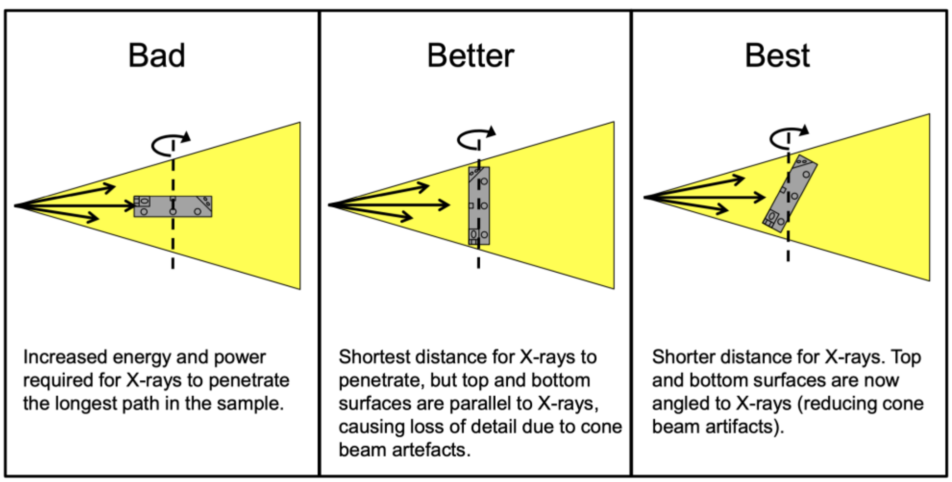
The system must be homed when it is first powered on. As the manipulator will move during this procedure, always make sure that there is nothing on the table or in its way before homing the system. Then click “Homing” tab. After homing is completed, the red exclamation mark by “Homing” icon should change to a green check mark.

For X-ray CT data acquisition follow the steps below:

1. Auto-condition
   Verify that the system has been auto-conditioned before you start the scan. This step is necessary if you are the first user of the day.
   To perform auto-condition, go to Setup and then click on “auto-condition” and wait until the source is stable at the maximum beam energy (225 kV) for at least 5 minutes.

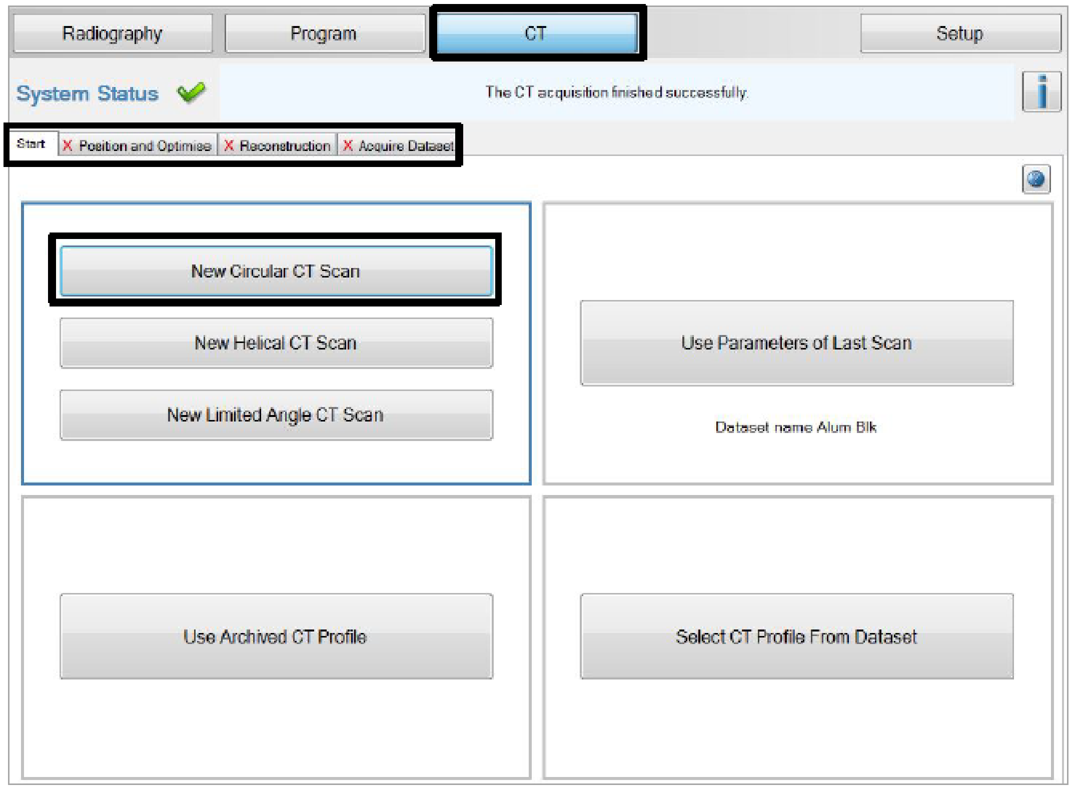
2. Mount the Sample
   Securely mount the sample using hot glue. Tilt the sample, if possible, to minimize cone beam artifacts in circular scan.

Isopropyl alcohol acts as a quick release agent to remove the glue from samples.



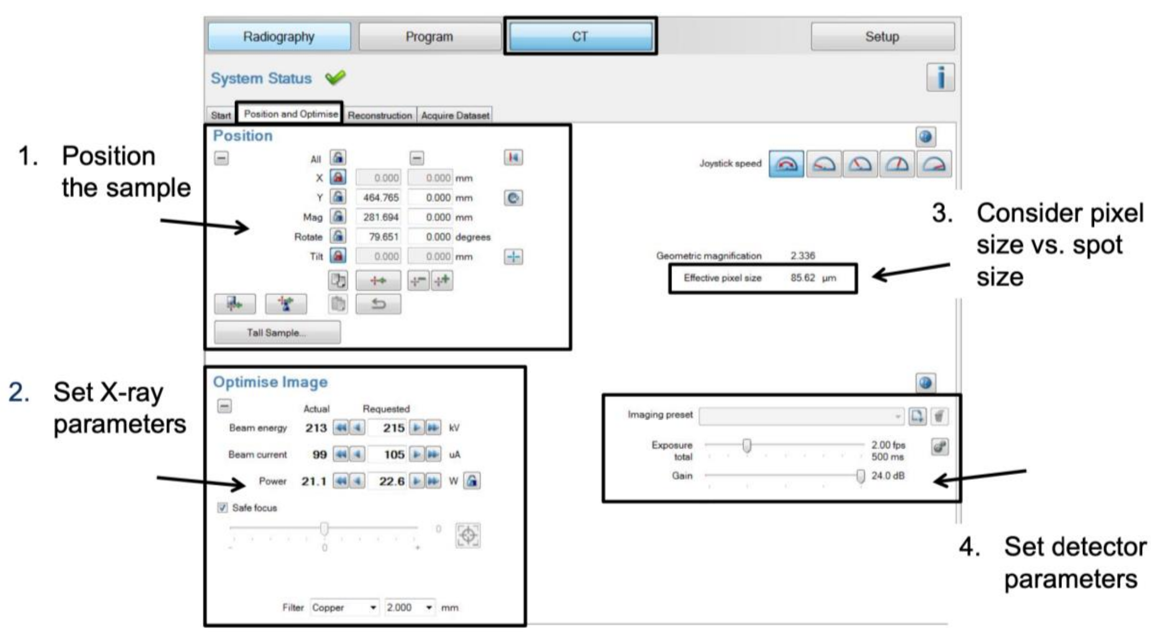
Note that this is a general rule of thumb - the ideal sample mounting position will depend on the sample geometry and material.

3. Choose a Scanning Method
   Go to CT workflow as highlighted in the image below and click “Start” tab to choose a new scan.



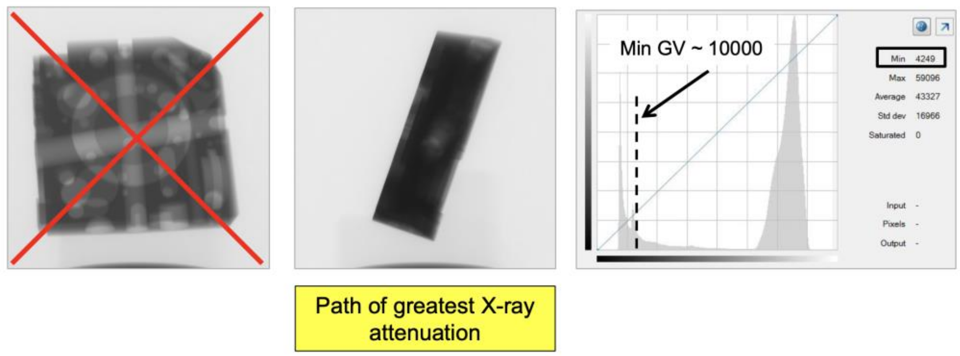
For a small size sample, use "New Circular CT scan". If you have a tall sample or a stack of samples, a "New Helical CT Scan" is recommended. To repeat a scan using previous parameters, you may choose "Use Parameters of Last Scan".

4. Position the Sample and Set the Scanning Parameters
   Use "Position and optimize" tab to position the sample and set the X-ray and detector parameters. Follow the steps bellow:

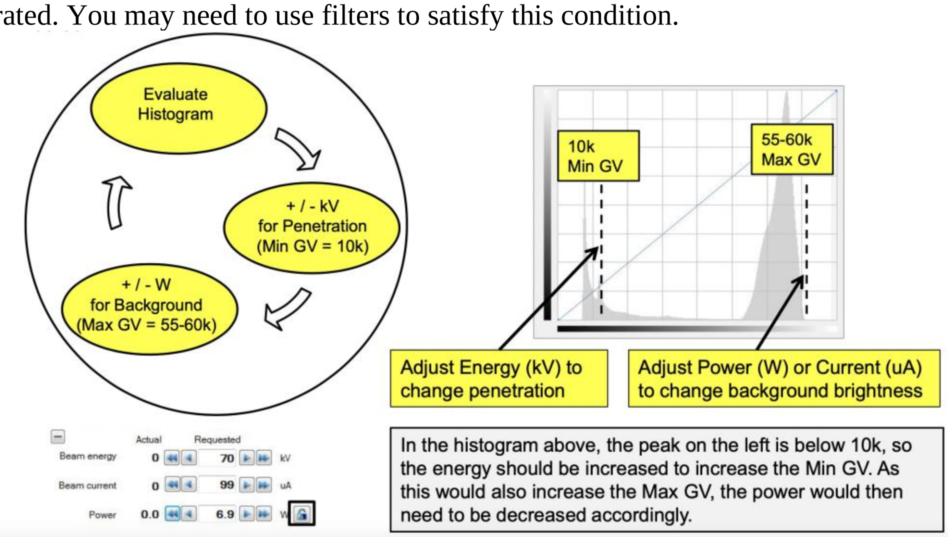


- Use the joysticks on the control panel to zoom in and out as well as to rotate the sample.
- Always leave a thumb between the part and the edges to eliminate artifacts that can occur due to missing voxel data.
- For optimal results, zoom in the sample to the max magnification possible, which results in minimum effective pixel size.
  Make sure the entire part remains within the image window throughout the scan.

- Rotate the sample so that the X-rays pass through the path of greatest attenuation while setting up the parameters.



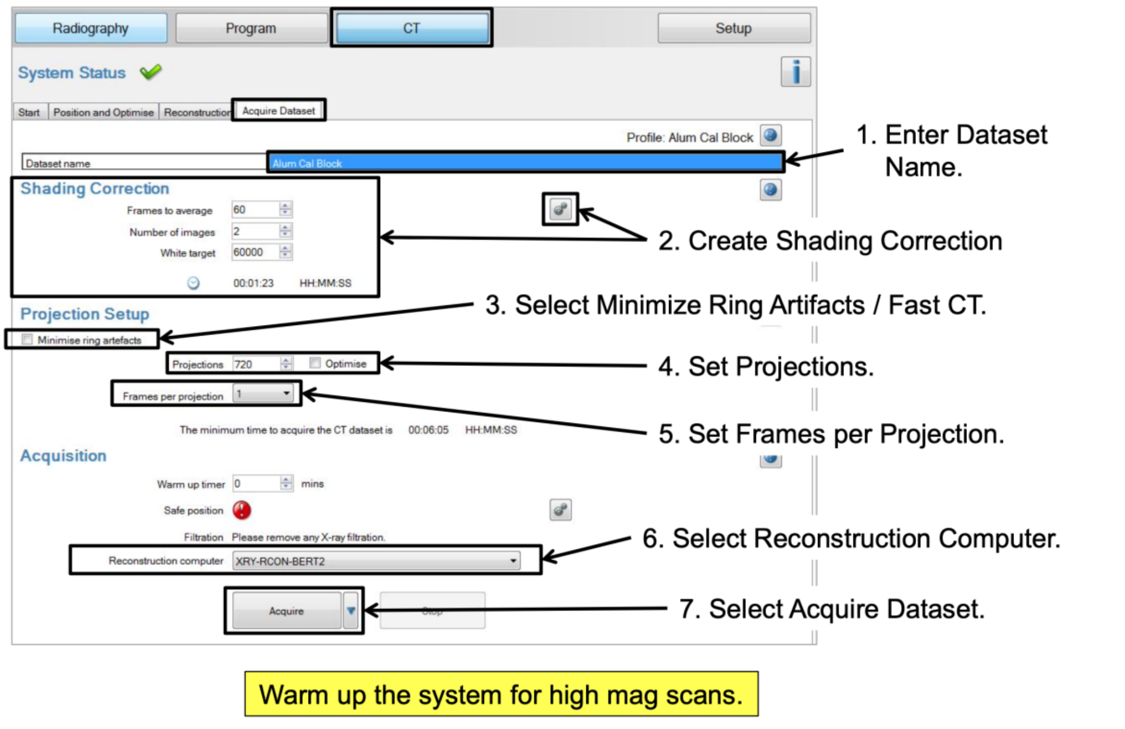
- Optimize X-ray parameters. To increase penetration, especially for dense materials like Inconel and Stainless Steels, a very high beam energy is required. From the image histogram, optimize a range of Gray Values (GV) so that the min GV is around **10k** to ensure penetration and the max GV is **50 – 60k** (Background image/air). Make sure that the background is not saturated. You may need to use filters to satisfy this condition.



Note: The two factors defining the resolution of the image are the X-ray spot size and effective pixel size. As a defocus threshold, make sure that the wattage is always $\leq 4 \times$ (effective pixel size) for a rotating target and 1:1 for a static target.
To keep system power under defocus value, increase exposure and lower power (if possible) (smaller spot size = sharper image).

Increasing the gain and exposure can help adjusting gray value alongside the power. However, high exposure time increases the scanning time while high gain introduces some noise.

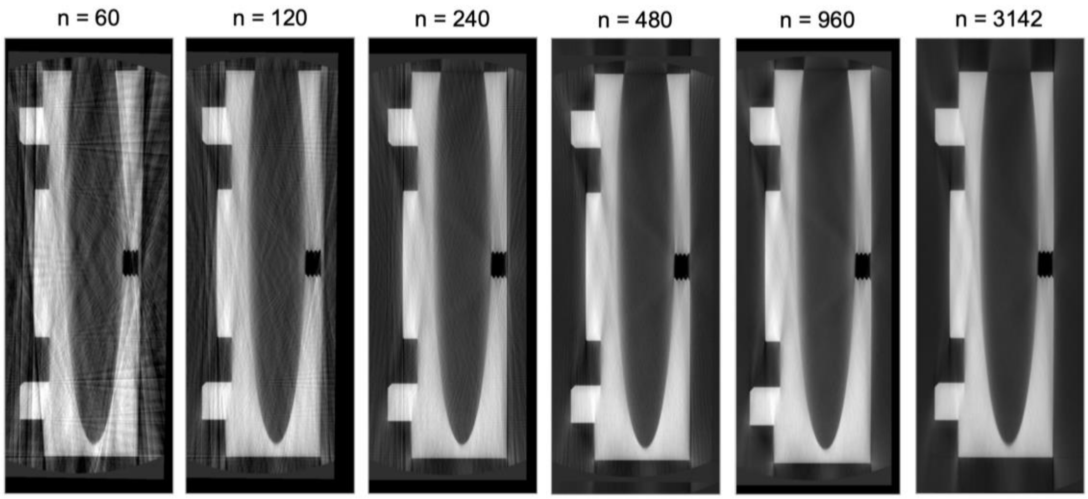
5. Reconstruction (skip this tap unless you would like to do automatic reconstruction, which is not recommended as it does not always give the best results)
6. Acquire Dataset
   In the “Acquire Dataset” tab, do the following steps:
   - Name your sample: it is recommended that you give a meaningful name to your scan because the name will appear on every projection, and it will make it easier for future reference.



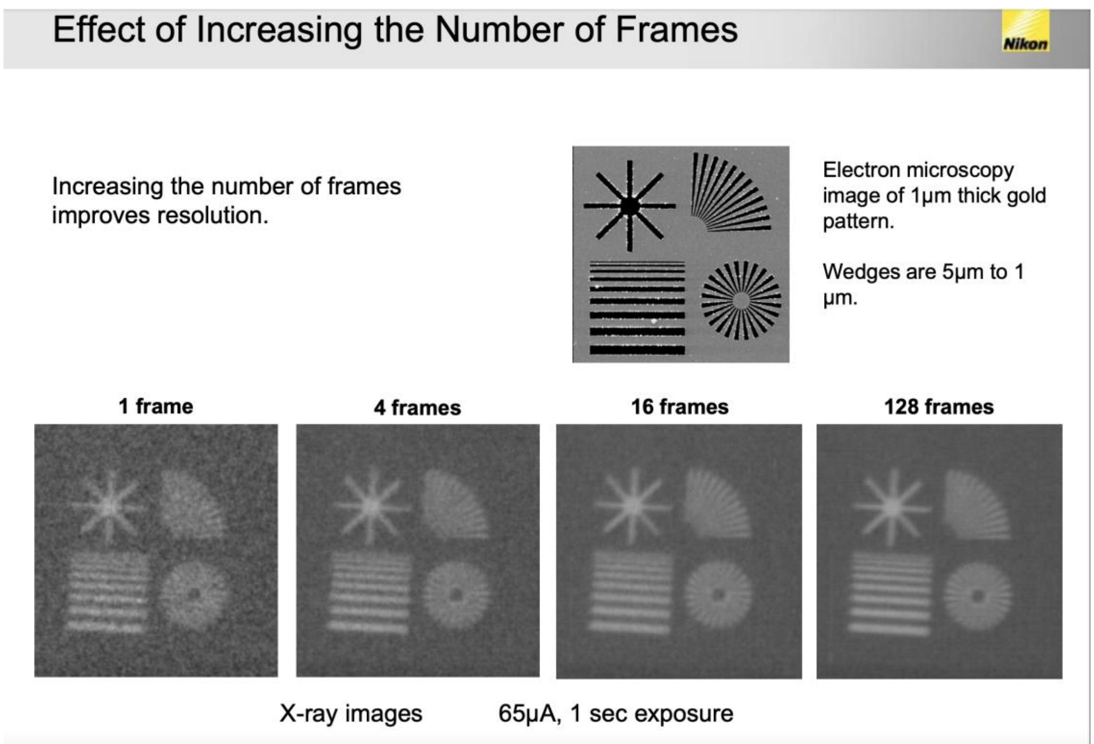
   - Create shading correction: in the shading correction field, increase the number of “Frames to average” until the time is ~ 2:30 seconds. Leave the “Number of images” equals to 2, as the flat panel detector responses linearly to X-ray energy. Leave the “White target” equals to 60k or set it equals to the average grey value from the histogram when the sample is not in view.

   - Minimize ring artifacts: selecting “Minimize ring artifacts” will improve scan quality, but it will increase the scan time.

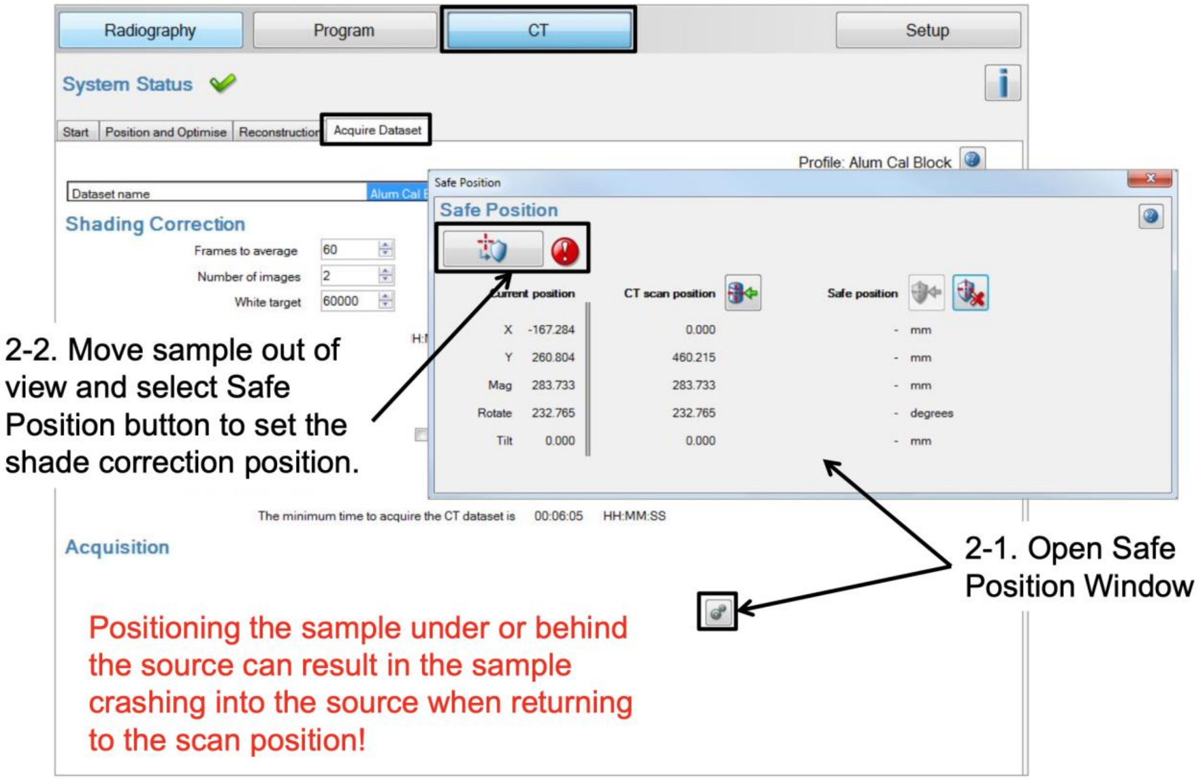
   - Projections: increasing the “Number of projections” will improve quality of the scan; however, there is a limit where there will be no more significant improvement when exceeding the limit. An insufficient number of projections will result in aliasing effect in the data. Use the following image as a reference:



- Frames per projection: increasing the number of frames per projection will improve resolution. However, increasing the number of frames also increases the scan time. A practically suitable number of frames will be 2- 4 frames per projection. See the reference figure below:



- Safe position: set a safe position so that the sample is moved out of the view for shading correction. This can be done as shown below:

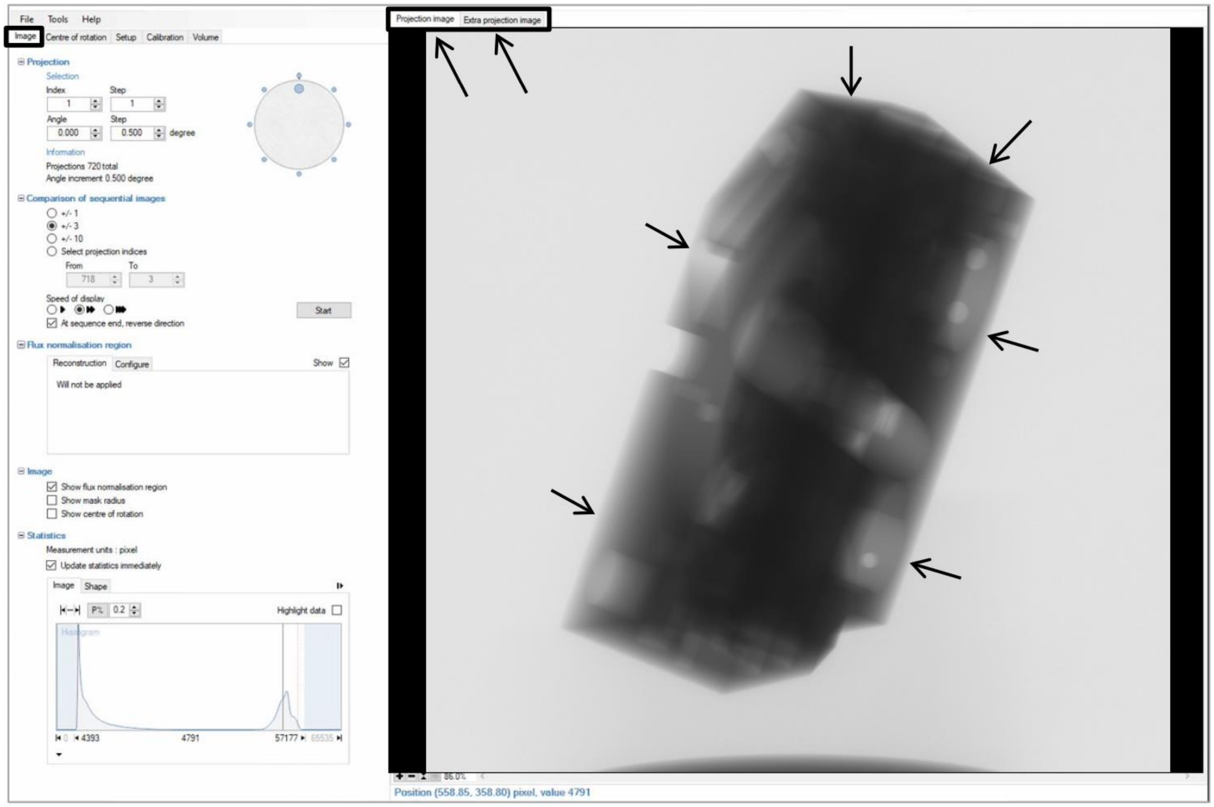


- Then, select the reconstruction computer, where the acquired data will be sent using CT agent and click acquire to start collecting data.

Total Scan Time= (Exposure time) * (Projections) * (Frames)

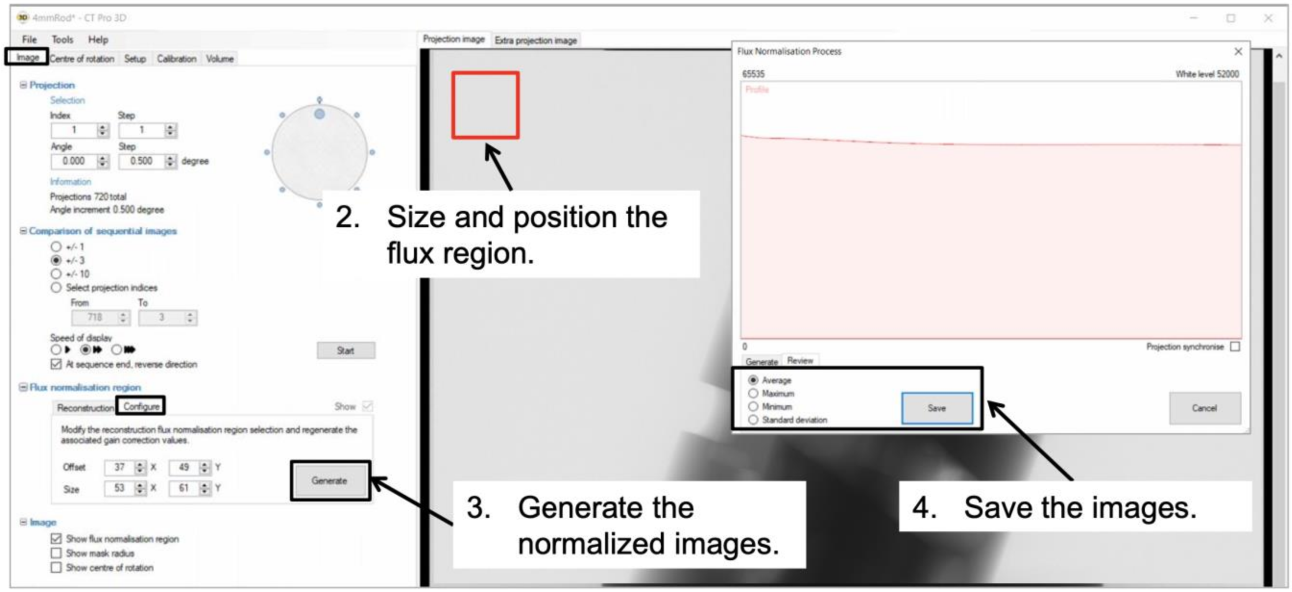
II. CT Pro 3D

The data collected from Inspect-X will be stored in the “Active Project” drive on the reconstruction computer. Go to CT data, locate your data folder, and double click on the CT Pro 3D icon, which will open the data using CT Pro 3D software. The interface window will look like the image below:



1. Image Tab
    - Check Sample Movement
      In the image tab, use the keyboard arrow keys to move back and forth between the first and the extra image to make sure that the sample has not moved between images as well as there is no change in brightness between images.

    - Fix Variation in Image Brightness (rarely required)
      Within the image tab, variation in brightness can be fixed by applying flux normalization to a small region of the image, where the part does not rotate through. To perform this action, follow the steps shown in the image below.

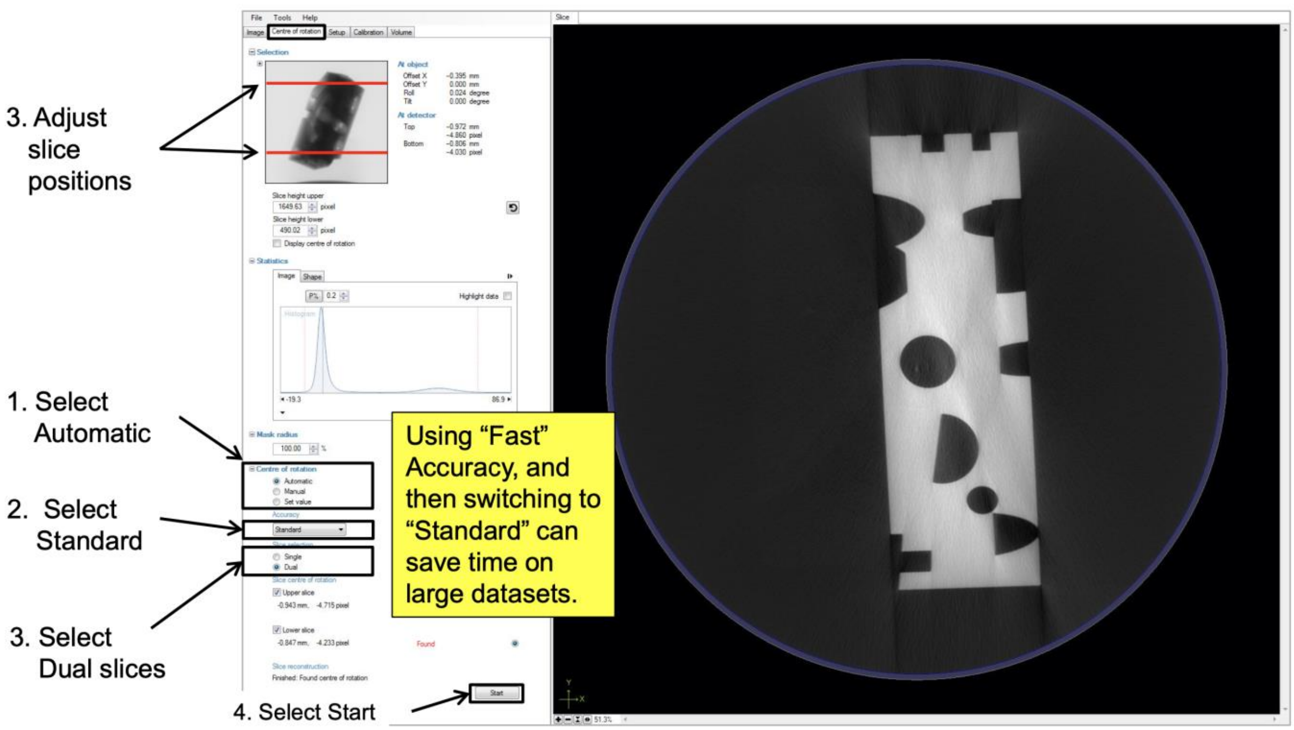


Changes in brightness may also be minimized by warming up the system prior to the scan.

2. Center of Rotation Tab

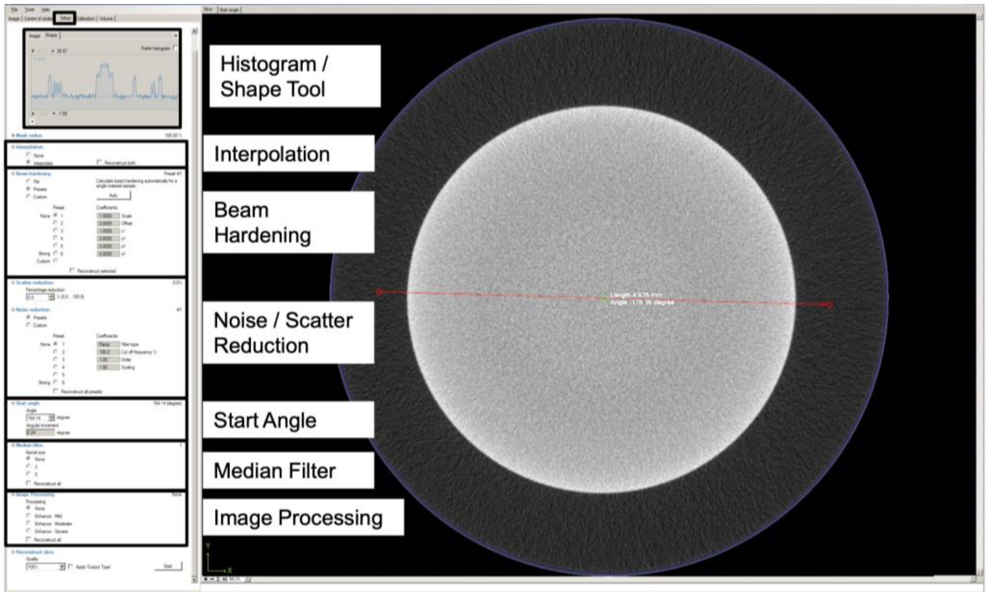
   The center of rotation is calculated using eighter a single or dual slice setting. This step can also be done in the automatic mode, through which the software finds the pixel shift based on the selected row(s) of pixels from the tiff images. It is recommended to use a dual slice setting for tall samples. Using a single slice will not correct for angularity in the panel alignment.

   Follow the steps below to calculate the center of rotation:

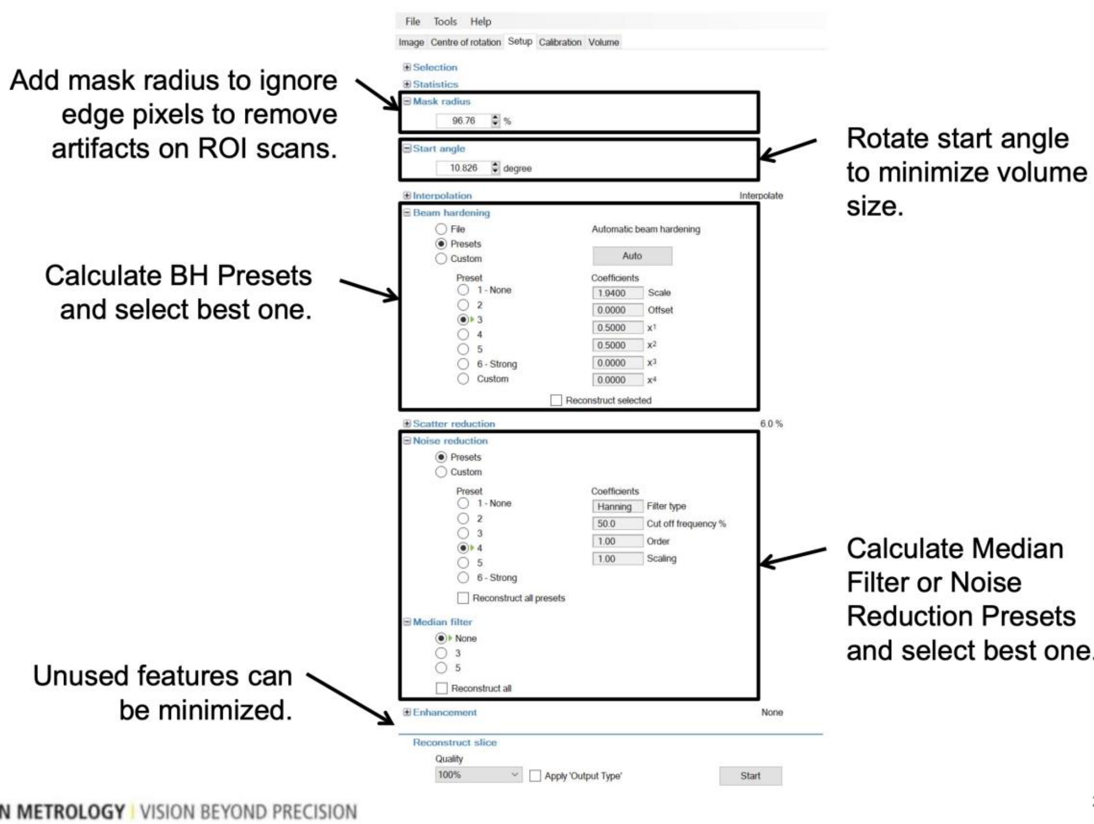


3. Setup

The “Setup” tab includes many features as shown in the image below. However, unused features are usually minimized, and the most used features are shown in the following images.

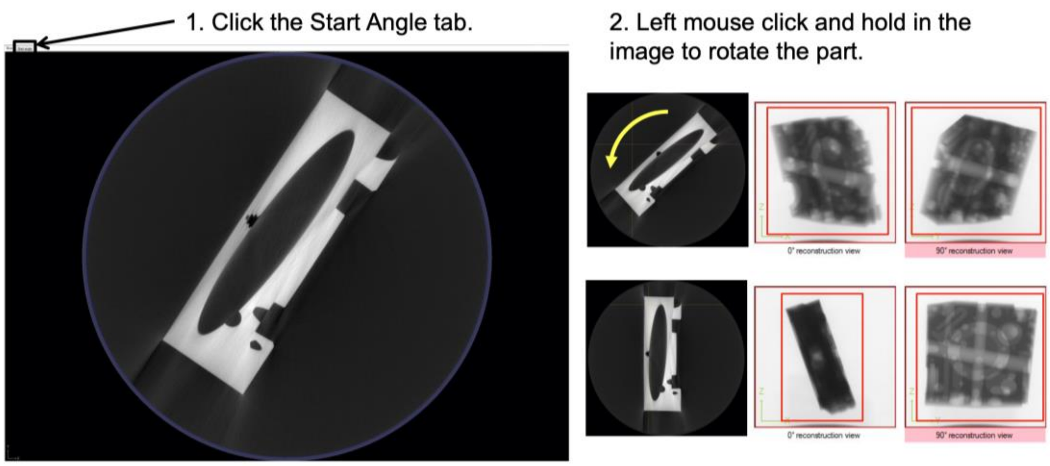


Below are the most used features (details follow on the next page)



- Minimize Volume Size (not necessary if you have a big storage)

Adjusting the Start Angle of the sample will allow the volume to be cropped more closely in the Volume tab, which will reduce the volume size.



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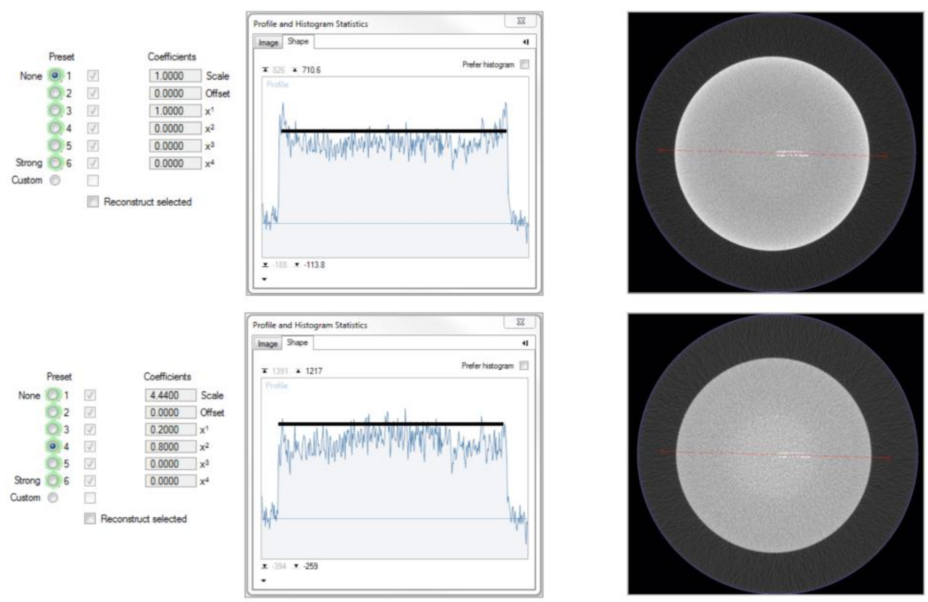
- Fix Beam Hardening
  For beam hardening, select "reconstruct selected" to perform all beam hardening preset (apply different attenuation curves).

Draw a line across the image and use the Shape Tool to help determine which Beam Hardening preset is most appropriate.



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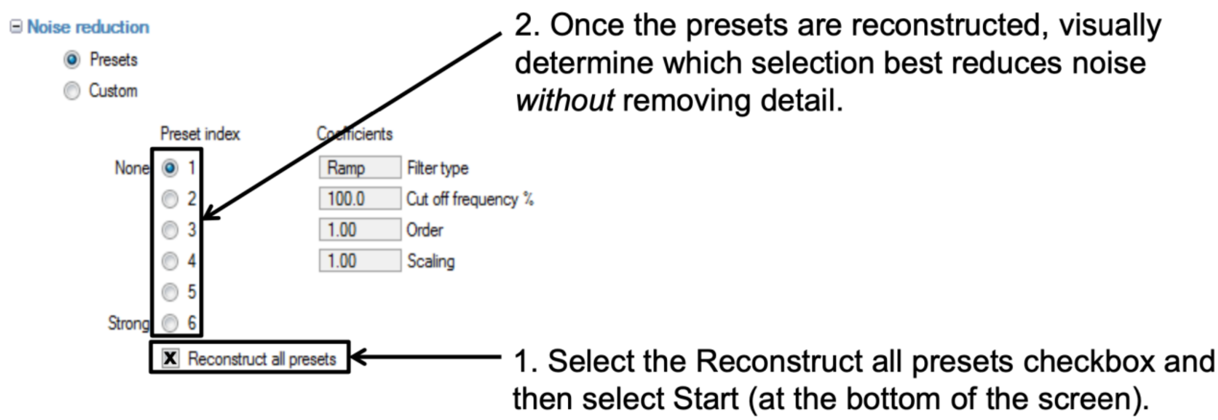
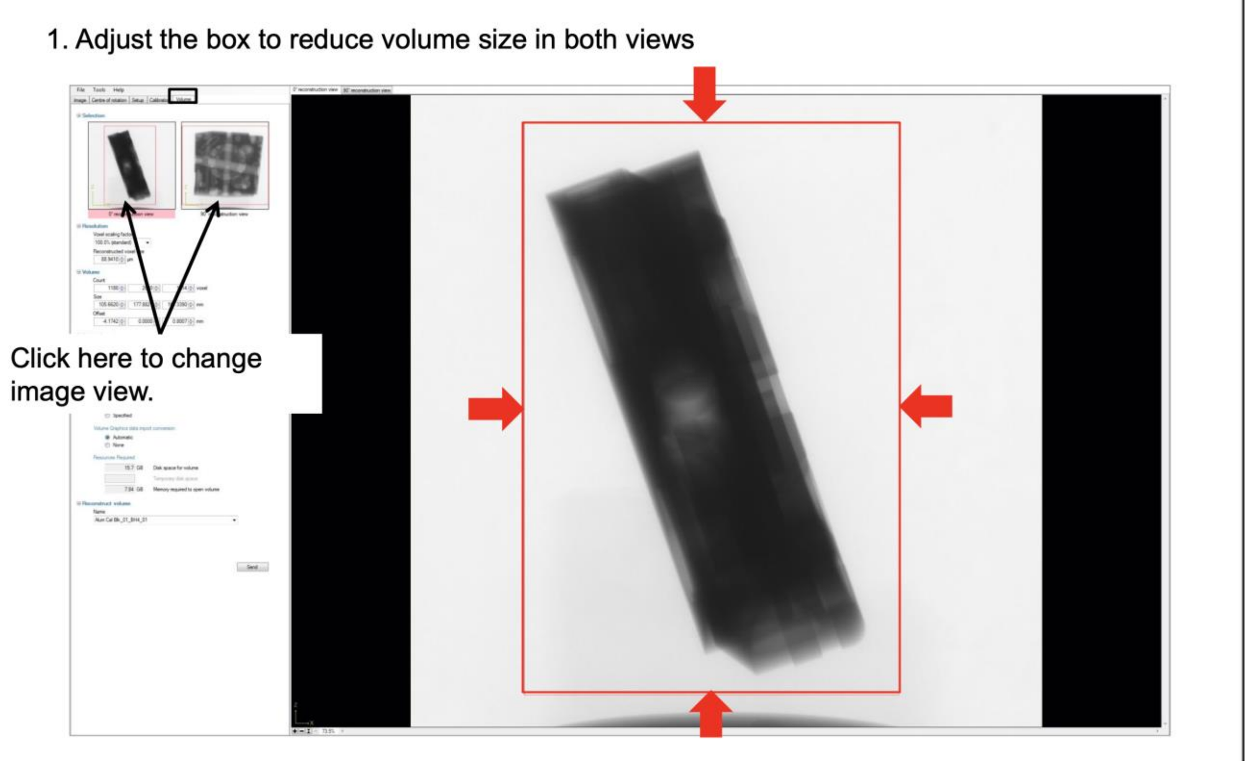
- Reduce Noise
  Not always needed, but it can be easily done as follows:

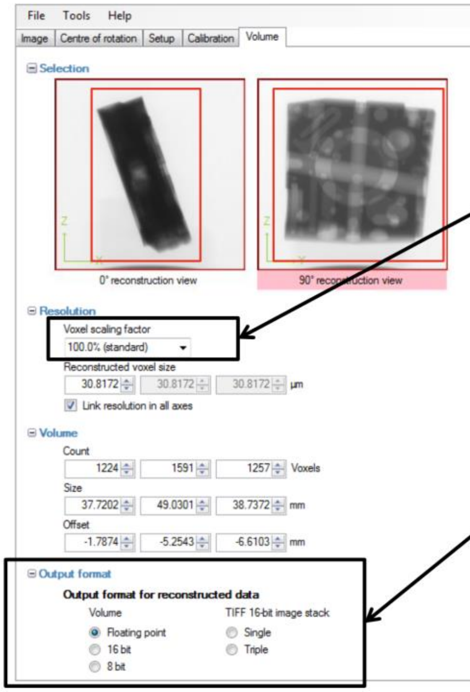


The preset filtering options give a sliding scale between preserving detail and removing noise. Most scans use preset 1 or 2 – Less is better!

4. Calibration Tab
   Calibration is only used in medical field (This tab is deactivated on our CT Pro 3D)

5. Volume Tab
   The default settings are the optimized settings for most scans. The only setting that needs to be adjusted is the volume box to reduce the size or choose the part of the scan that you need to process.





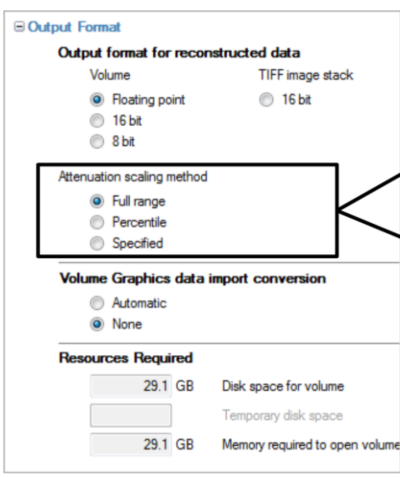
2. Verify Resolution Quality is set to 100% for final volume reconstruction for a 1:1 voxel size. Using 50% will combine voxels (some 3D printers have voxel size requirements), whereas 150% will split the voxels for greater resolution (interpolation).

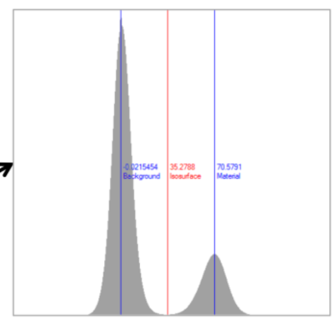
3. Output Format can be set to Floating Point for maximum quality, but is generally set to match the panel bit depth (16 bit). File size can be reduced further by setting the format to 8 bit:

16 Bit = ½ Floating Point size.

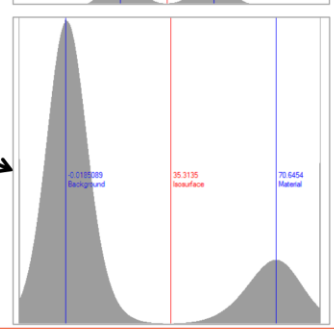
8 Bit = ½ 16 Bit size

4. Most people use Full Range for multi-material samples and then crop the grey scale range in VGStudio.



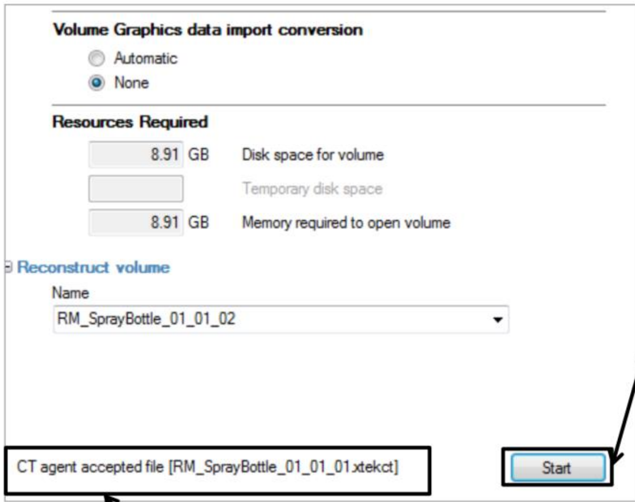


Full Range



Percentile (1%, 99%)

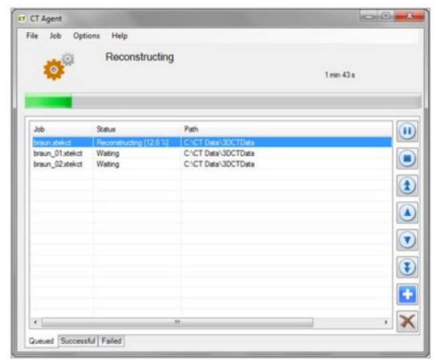
Percentile can be used for single material samples, but should not be used when looking for inclusions, as cropping the dataset can inadvertently hide more dense materials.



5. Once all parameters have been set, select Start to begin reconstruction.

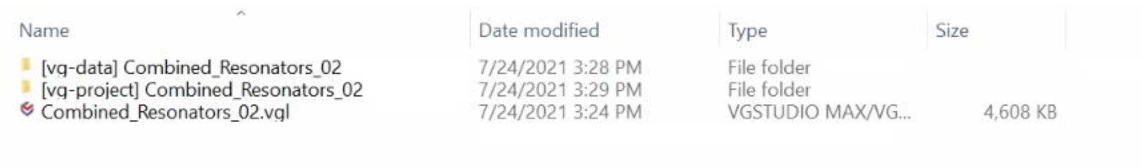
This message will appear if the file is sent successfully to CT Agent. Clicking Start multiple times will send the file to CT Agent multiple times.

6. Open CT Agent to view the status of the reconstruction.

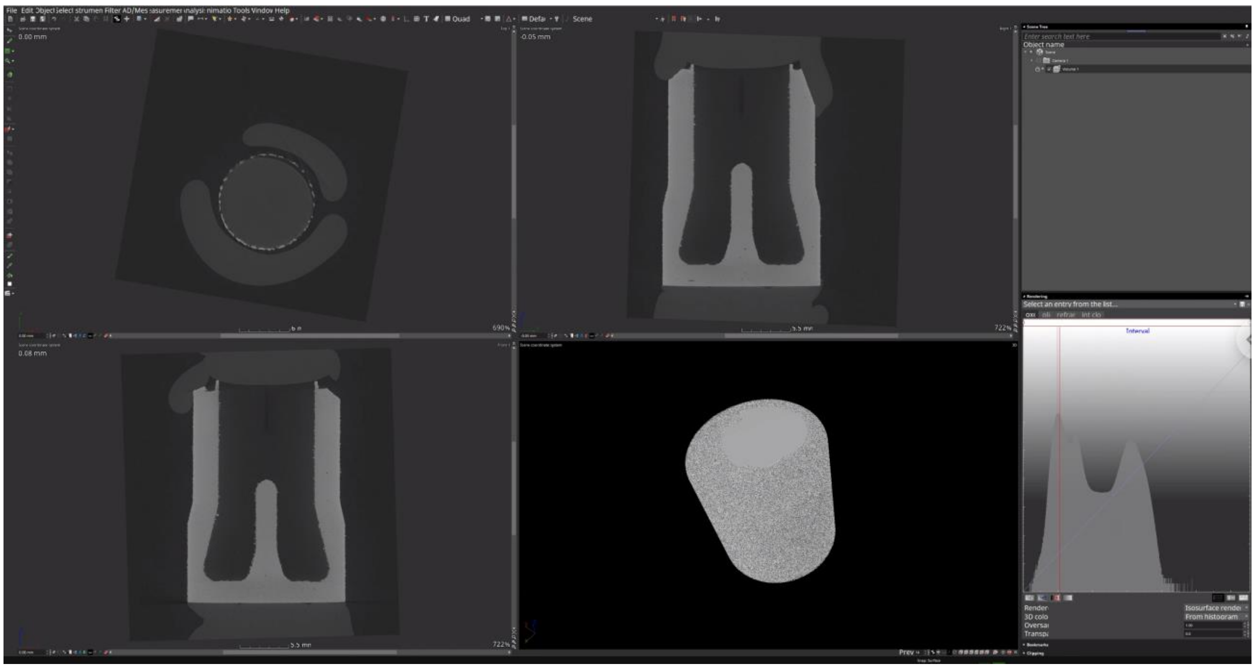


III. VGStudio

After the reconstruction is done and the data are converted, a new folder will be added to the data. The new folder is VGStudio compatible and VGStudio icon will appear in the folder as shown below:

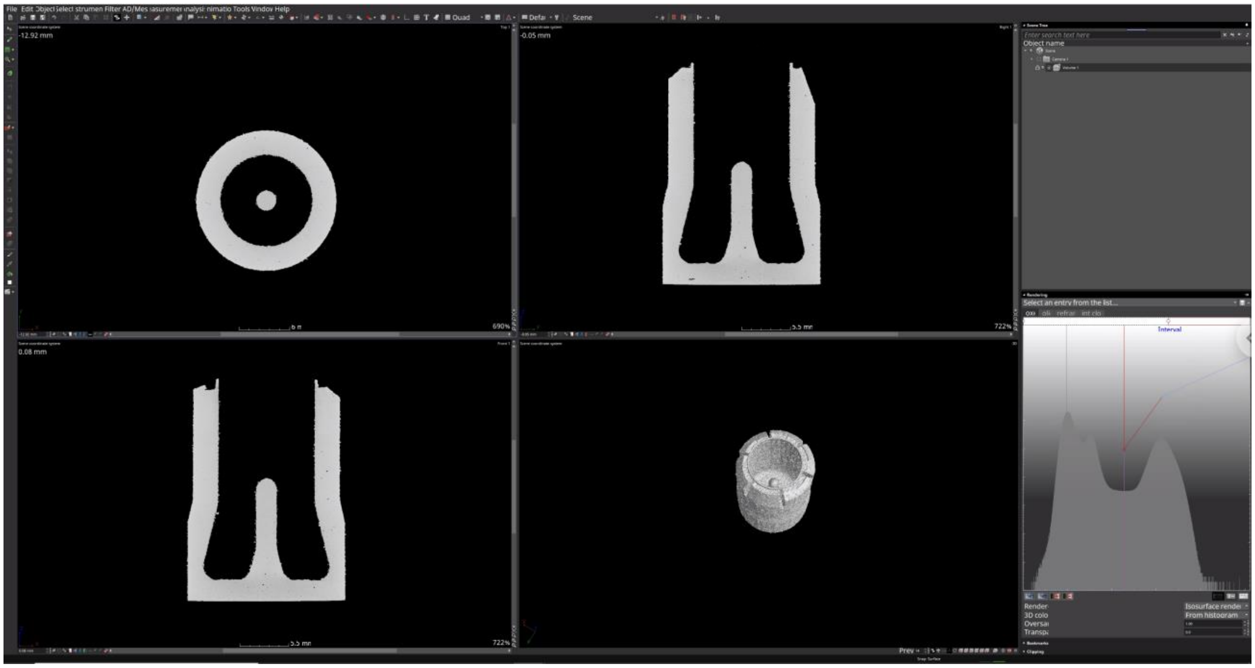


1. Double click on the VGStudio icon and you should see the following window:

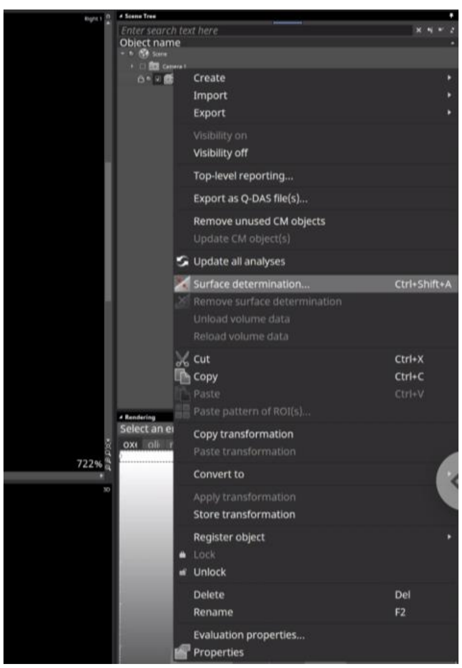


2. In the rendering window, you will find two lines as shown in the image. Move the red vertical line "isosurface line" to the mid-distance between the two humps to separate material from the background and the blue diagonal line to adjust opacity. You may add a couple more joints to the opacity line by clicking "+" sign at the bottom for convenience.

   In the image bellow both lines are adjusted, and the background of the slices is changed to Black for better visualization.



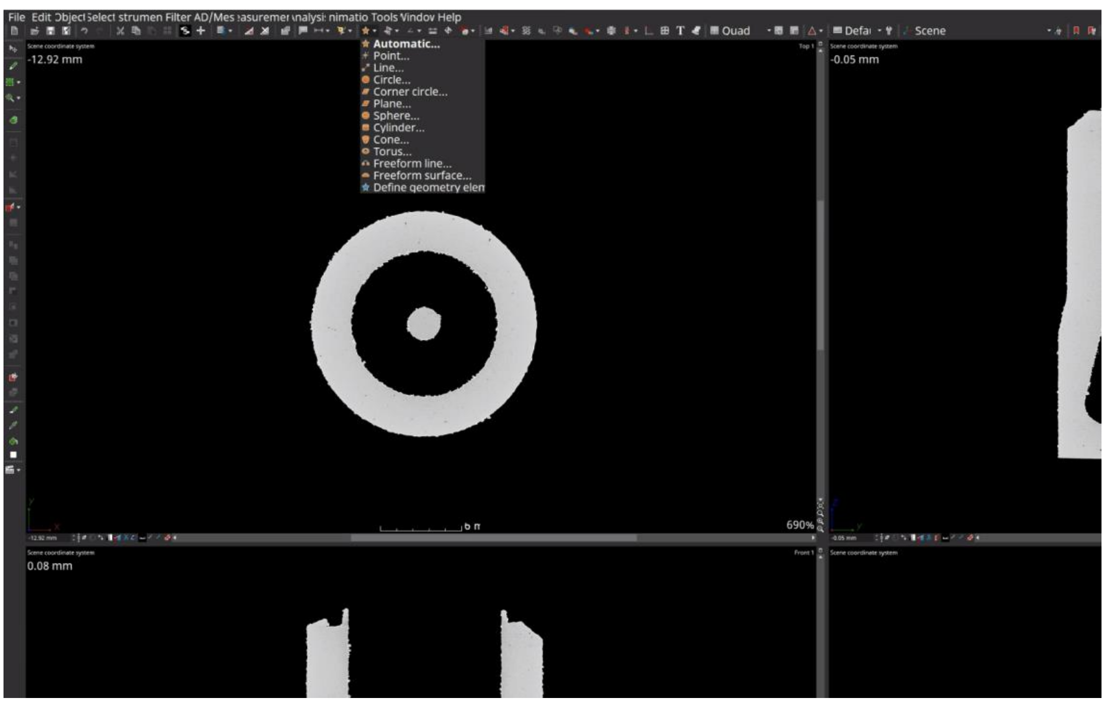
3. Perform surface determination. Right click on the volume and choose surface determination as shown below:



In the surface determination window, set the Approach to “advanced classic” and material determination to “manual” or “automatic”, depending on your analysis. Then, in the options at the bottom of the window, set starting contour healing to “Remove all particles and voids” and click finish.

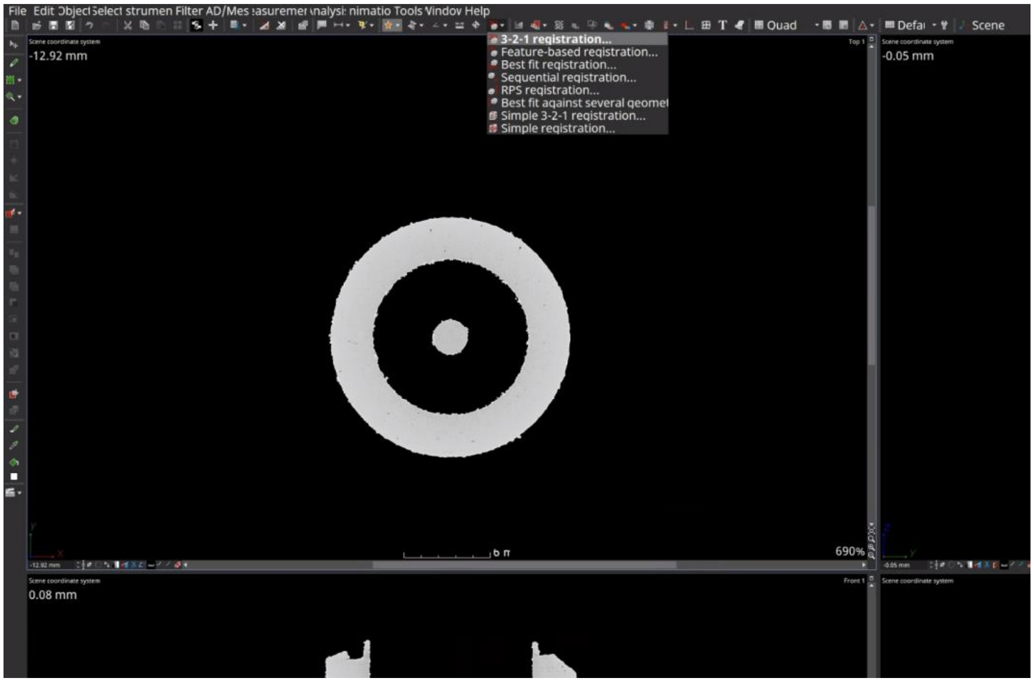
The new surface determination window with all the above settings will look like the image below:

4. Fit three geometries to your object to use as references for its registration. This step can be skipped if you have a CAD model to use for registration or if you decided to use simple registration.

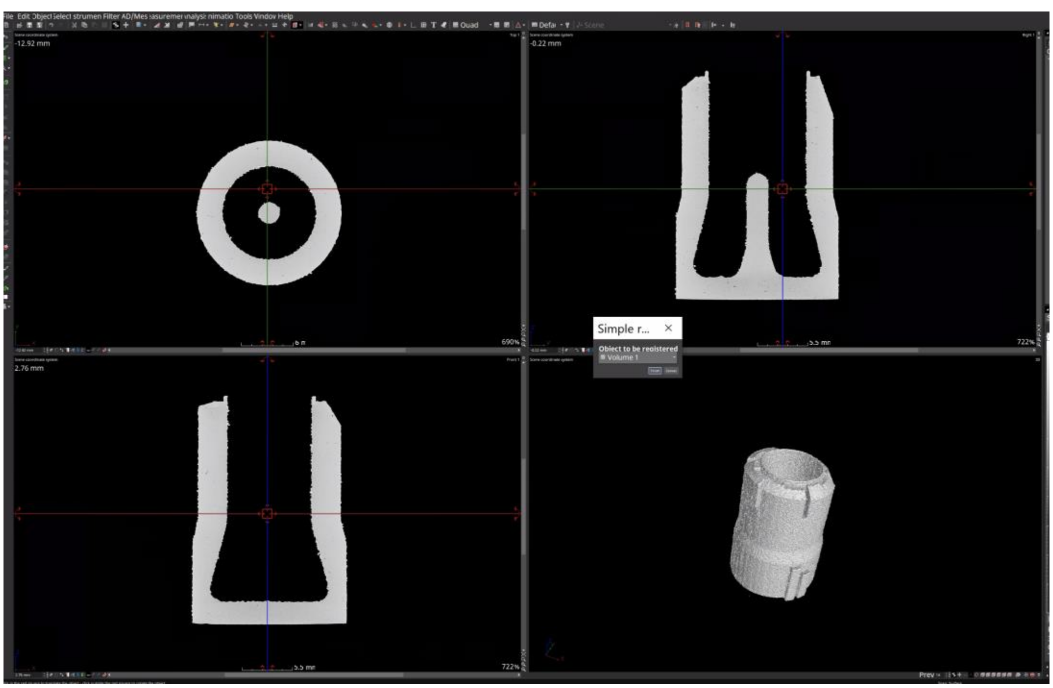


5. Registration

Registration is required for analysis, so it is necessary to register your object. Use one of the registration methods from the list by clicking on the registration icon shown in the image. For example: “3-2-1 registration” is usually used when you have fitted three geometries to the object. “Best fit registration” is used when you have a CAD model.



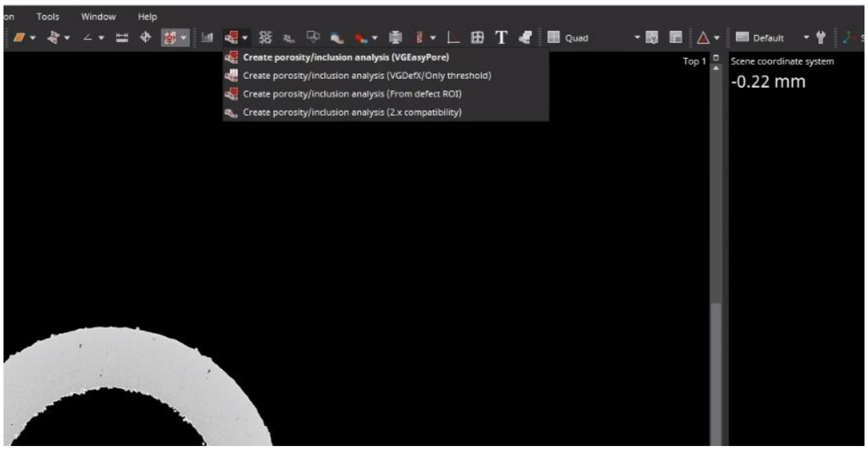
Below is an example of simple registration window. Grab the middle red square shown in the window below to move the object up and down while click the object and hold to rotate the object. When you have aligned your object, click finish to complete the registration.



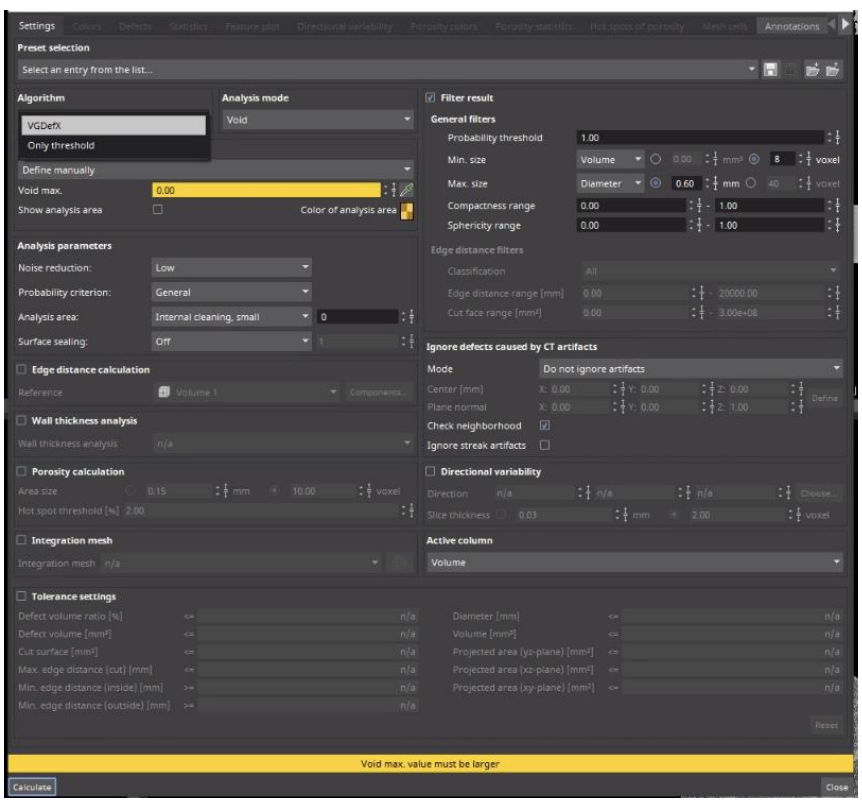
6. Analysis

Now you are ready to perform analysis. As an example, porosity analysis is explained blow.

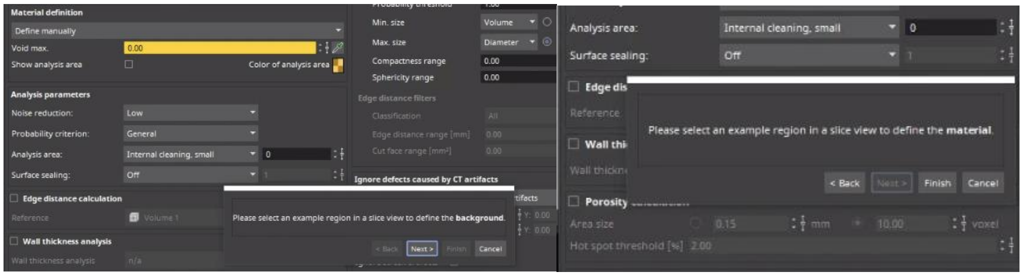
- Click the porosity analysis icon shown below and choose the type of porosity analysis. The second in the list is used for this example.



- In the next window, choose your algorithm (VGDefx or only threshold). “Only threshold” is a very fast algorithm in comparison with the other algorithms. However, some algorithms do better than the others depending on your scan.



- For defining the “Void max.”, highlighted in yellow, use the eye dropper to select the background and the actual material. First, select a small area of the background in one of the slice windows, which will appear as a line in the other windows. Drag the line to extend the selected area to a small volume and click “Next”. Do the same for defining the material. It is necessary to avoid pores as you select your material.

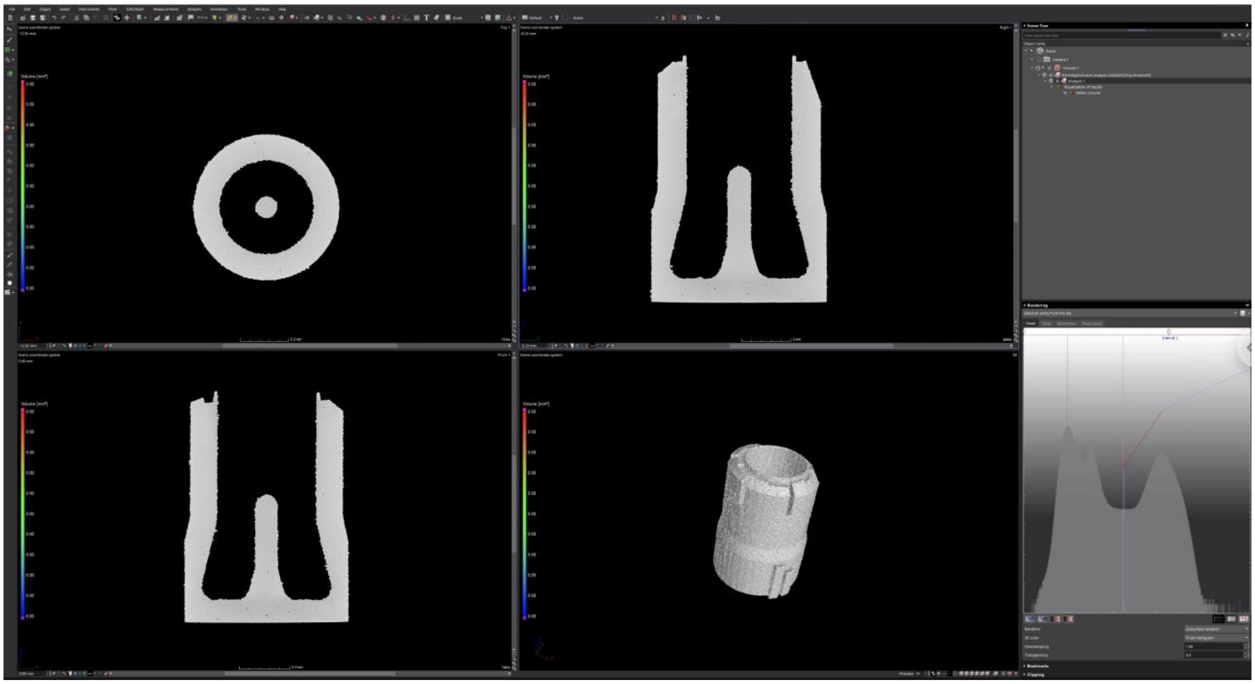


- Adjust the rest of the settings as required and click “Calculate”.

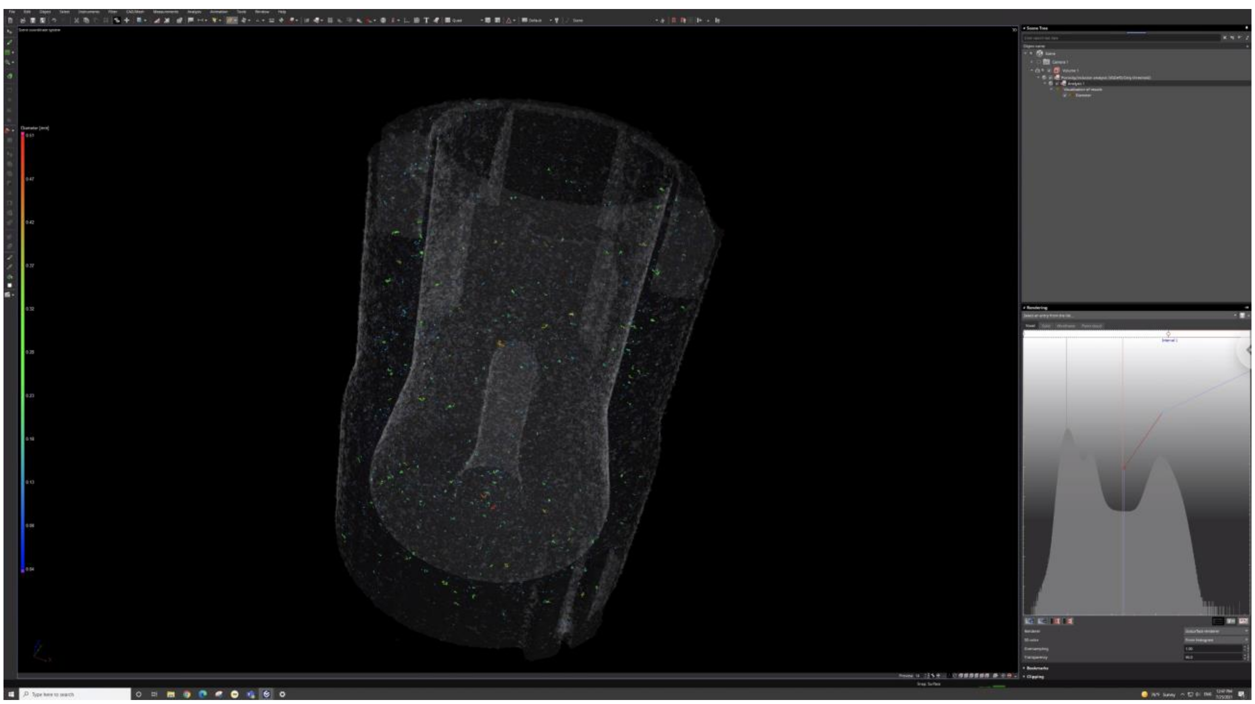
- The analysis window of this example is shown below.

  Zoom any area in or out by scrolling the middle roller of your mouse while holding down the control key on the keyboard.

  Scroll the middle-roller of the mouse to move through the slices in any of the windows.



- Change the transparency in the histogram window to view the volumetric porosity content in the 3D object as shown.



Please note that VGStudio is a very powerful software, which requires additional training for advanced analysis. What has been presented here is only to get you started and do only basic analysis.