SkyScan 2214

- Multiscale X-Ray Nanotomograph

MICROTOMOGRAPHY

Innovation with Integrity

SkyScan 2214
Multiscale X-Ray Nanotomography System

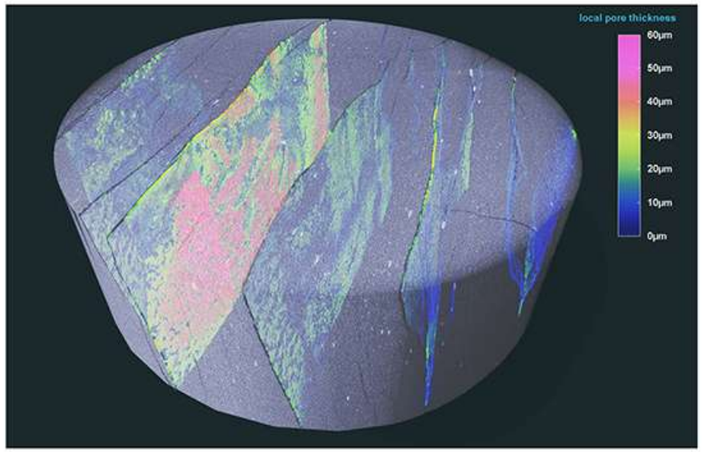
2214

The SkyScan 2214 Multiscale X-ray nanotomograph covers the widest range of object sizes and spatial resolutions in one single instrument. It opens unique possibilities for non-destructive 3D imaging, analysis, and exact modeling of materials in a number of applications, such as oil and gas exploration, composite materials, lithium batteries, additive manufactured parts, pharmaceutical products, electronic assemblies, etc.

From micro to nano

- X-ray source with diamond window, 20 to 160 kV accelerating voltage, < 500 nm focal spot size
- Unique versatility by combining up to four highly optimized X-ray detectors in one system:
  - CCD1: 8 Mp high-resolution cooled CCD with zoom-in fiber-optic taper
  - CCD2: 11 Mp standard-resolution cooled CCD with 1:1 fiber optics
  - CCD3: 11 Mp large field of view cooled CCD with zoom-out fiber-optic taper
  - Flat-Panel: 6Mp large format active CMOS flat-panel with largest field of view
- 60 nm smallest voxel size, submicron voxels for large objects
- Round and helical scanning trajectories, patented (licensed) exact helical reconstruction
- GPU-accelerated and patented (licensed) world's fastest hierarchical (InstaRecon®) 3D reconstruction
- Up to 8000 x 8000 pixels in every virtual slice, thousands of such slices can be reconstructed after a single scan with output file formats as TIFF, JPG, BMP, PNG, DICOM and AVI-format movies
- Maximum scanning diameter of 140 mm, maximum sample size of 300D x 400H mm, weight up to 26 kg
- Integrated anti-vibration granite platform with pneumatic leveling
- Automatically adjusted variable scanning geometry for the fastest scan at any magnification
- Ultra-precision rotation stage with <50 nm accuracy, integrated micro-positioning stage
- Export of reconstructed results to phones and tablets for 3D volume rendering (iOS and Android)

Best results for any application



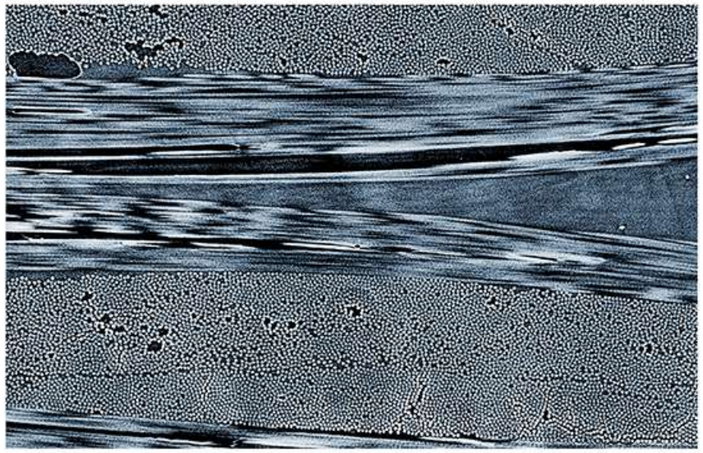
Geology, oil and gas exploration

3D volume rendering of a shale showing the pore network with color-coded local pore thickness

3000 x 3000 x 1300 pixels

6 µm isotropic resolution

volume of interest reconstruction inside 4 x 5.5 cm sample

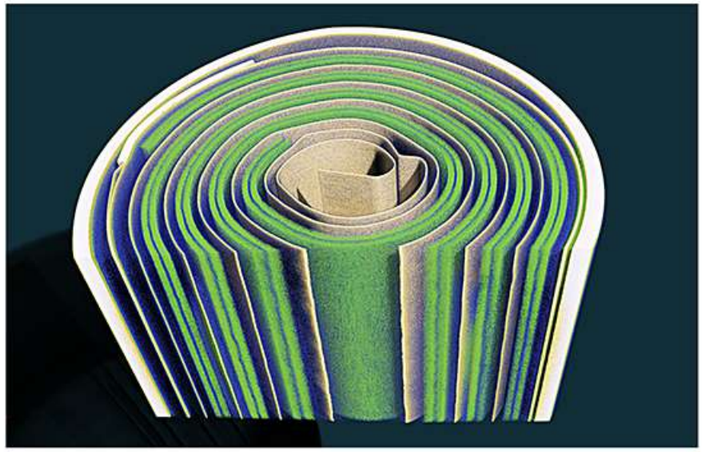


Composites

Carbon-fiber reinforced polymer (CFRP)

One of virtual slices from 4032 x 4032 x 1420 pixels reconstructed volume

450 nm isotropic resolution



Energy storage, Lithium batteries

3D volume rendering of a Lithium-Ion battery with virtually removed front part

4032 x 4032 x 2290 pixels

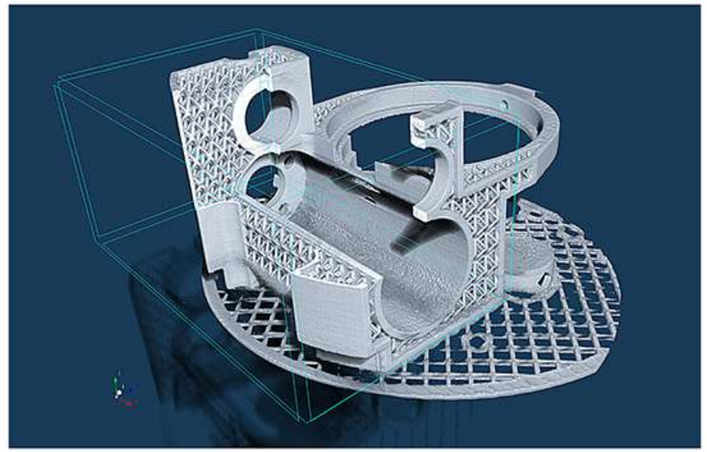
900 nm isotropic resolution

Additive manufactured parts

3D volume rendering of an additive manufactured (3D-printed) metal part with virtually removed left top corner

2908 x 2908 x 1420 pixels

26 µm isotropic resolution

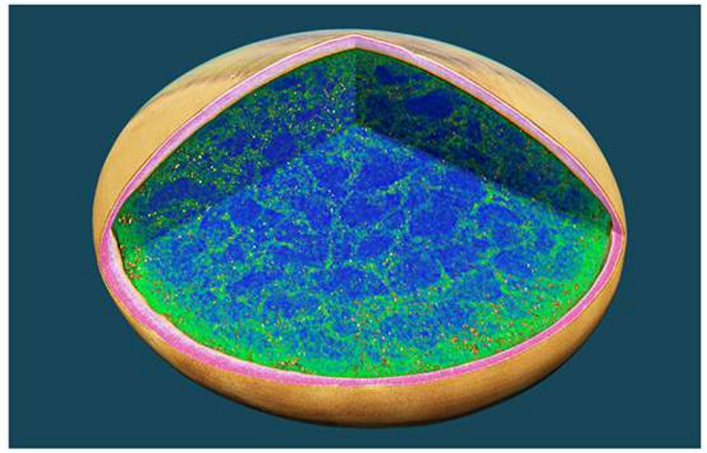


Pharmaceutical products

3D volume rendering of a pharmaceutical tablet with virtually removed front top corner

4032 x 4032 x 1910 pixels

3.9 µm isotropic resolution



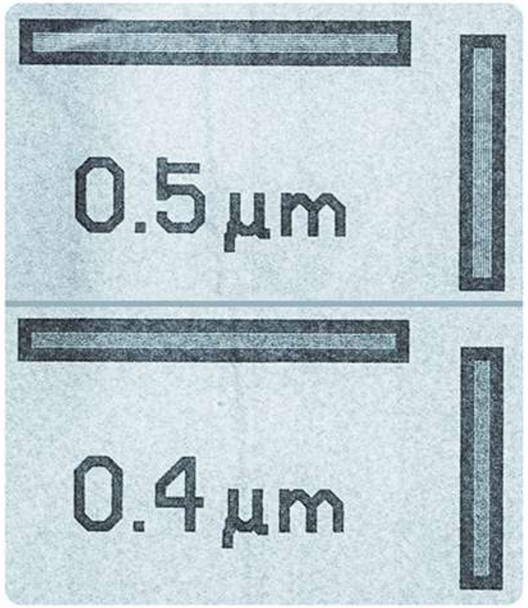
Mouse lungs

3D volume rendering of a mouse lungs with virtually removed front part

4032 x 4032 x 1918 pixels

3 µm isotropic resolution

Advanced key components for uncompromised image quality



High performance X-ray source

The SkyScan 2214 has an open type (pumped) nanofocus X-ray source with diamond window. It produces an X-ray beam with peak energy from 20 to 160 kV. The system is supplied with two type of cathodes for the X-ray source. The Tungsten (W) cathodes operate in the full range of accelerating voltages up to 160 kV and provide a spot size of X-ray beam down to 800 nm. The Lanthanum Hexaboride (LaB_6) cathodes can be used for accelerating voltages from 20 to 100 kV and provide a spot size of X-ray beam smaller than 500 nm to achieve the highest resolution in imaging and 3D reconstructions. The spatial resolution is proved by imaging a special test pattern, for example - JIMA resolution charts. The image on the left indicates that 500 nm structures can be easily resolved while 400 nm structures can be seen with significant contrast. For long-term stability of the focal spot size and position of the emission point, the X-ray source is equipped with a liquid cooling system which contains a re-circulator providing precise temperature stability of the cooling fluid.

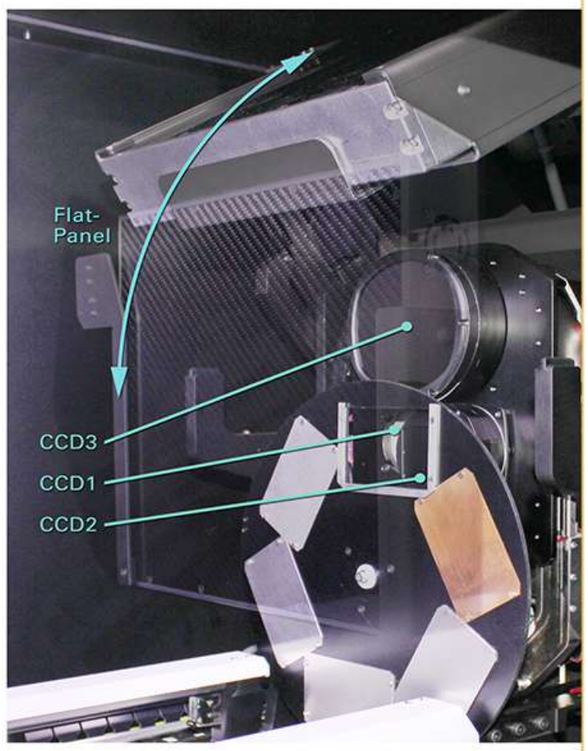
Unique versatility with up to four X-ray detectors

The SkyScan 2214 can be equipped with one to four different X-ray detectors:

- CCD1: high resolution 8Mp cooled CCD
- CCD2: standard resolution 11Mp cooled CCD
- CCD3: large field of view, 11Mp cooled CCD
- Flat-Panel: active CMOS 6Mp detector

The detectors can be switched by a simple mouse click. During switching the selected CCD will move to the central position and the filter wheel will place the selected filter in front of the CCD. While imaging with CCD detectors, the flat-panel stays above the CCD assembly. In case of flat-panel selection, the flat-panel flips down in front of the CCDs to the central position of the X-ray beam. All calibrations and flat-field reference maps for the selected filter-detector combination will be loaded automatically and the image format will be reconfigured to the format of the selected detector. All three CCDs can take images in the central beam position and in two offset positions to double the field of view. The images in the two offset positions are automatically stitching together with compensation of the shifts and possible intensity differences.

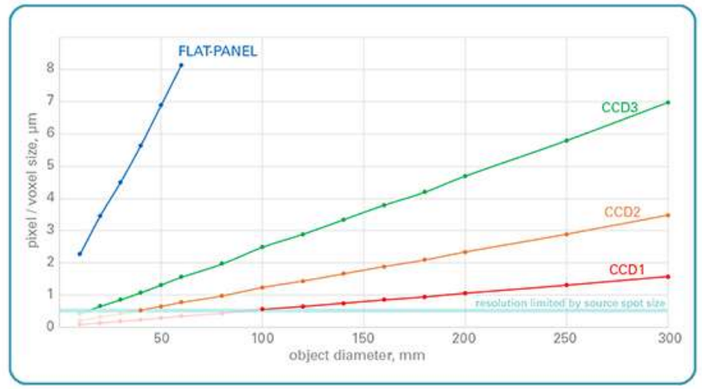
Detector	Nominal Resolution (image pixel size)	Field of View central position	Field of View two offsets
CCD1	60nm...2.5µm	8mm	15mm
CCD2	130nm...5.6µm	22mm	42mm
CCD3	270nm...11.5µm	45mm	88mm
Flat-Panel	2...50µm	140mm	



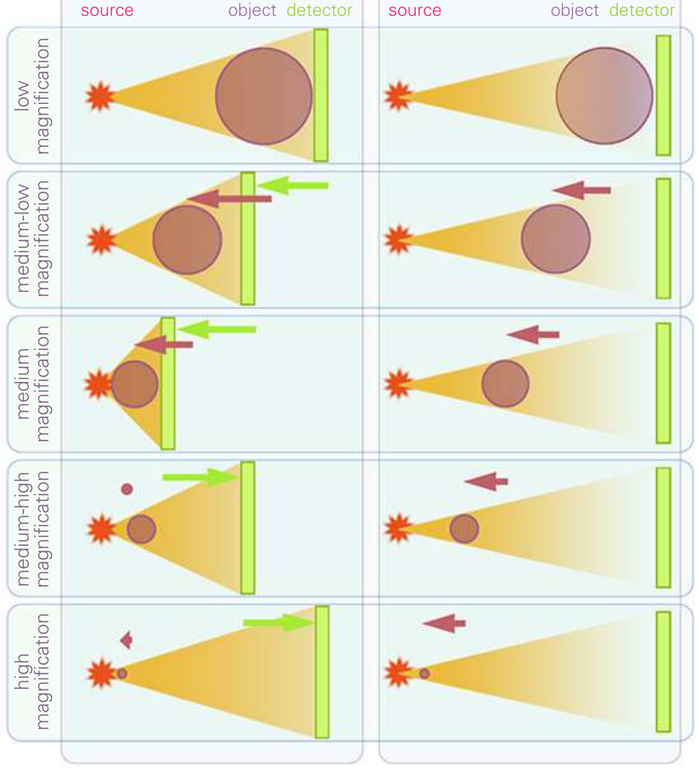
Highest resolution with fast scanning for any samples

High magnification for small and large objects

Using CCD detectors with small pixel size allows extending high-resolution imaging and 3D reconstruction to large objects. With proper selection of the CCD camera or flat-panel detector, the user can adjust the necessary field of view and spatial resolution according to the object size and density. An advanced reconstruction from a volume of interest provides scanning for a selected part of a large object with high resolution without compromising image quality. Additionally the field of view can be increased horizontally and vertically by using offset camera positions and vertical object movement.



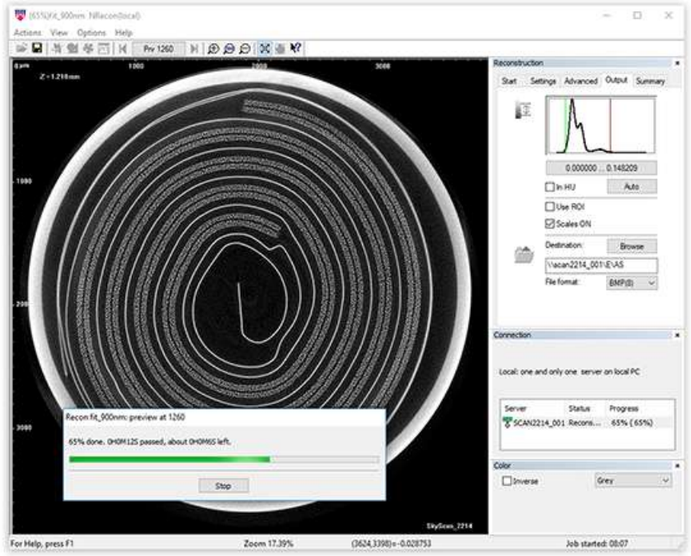
Automatically variable scanning geometry for the best scan at any magnification



When making tomographic scans with any of the CCD cameras, the SkyScan 2214 utilizes the automatically variable acquisition geometry invented by Bruker microCT to reduce the scanning time and to increase the scanning quality. Most other commercially available micro-CT systems use a static acquisition geometry where the X-ray source and X-ray detector are separated by a fixed distance and the image magnification is adjusted by moving the object between them. Increasing the source-detector distance, to extend the magnification range, reduces quadratically the intensity of the X-ray beam at the detector and thereby increases the scan time drastically. This is avoided in the SkyScan 2214 by using automatically variable scanning geometry. At high and low magnifications, the distance between the source and the detector is set to its maximum. At intermediate image magnifications, both the object and the detector are moving towards the source until they reach the most compressed geometry possible for the selected pixel size. Such an adaptive scanning geometry allows an improvement in image quality or reduction of the scan time compared to a traditional fixed scanning geometry.

Software suite for reconstruction and 2D / 3D image analysis

NRECON: Multithreaded GPU-accelerated reconstruction



The supplied reconstruction program **NRecon** supports several reconstruction engines including the world's fastest InstaRecon® hierarchical reconstruction. It can reconstruct circular and helical scans, objects larger than the field of view as well as volume of interest, and automatically merges partial scans. Additionally, NRecon allows correction of common micro-CT related atrifacts including beam-hardening, misalignment, ring artifacts, thermal drifts, etc. Futhermore **NRecon** features allow batch reconstruction of multiple datasets with individually adjusted settings, fifth order polynomial beam-hardening correction, fine tuning of reconstructing parameters for best possible results, etc. The results can be saved in conventional formats, such as 8-bit BMP, 16-bit TIFF, lossless compressed PNG, 24-bit JPG, as well as in DICOM format.

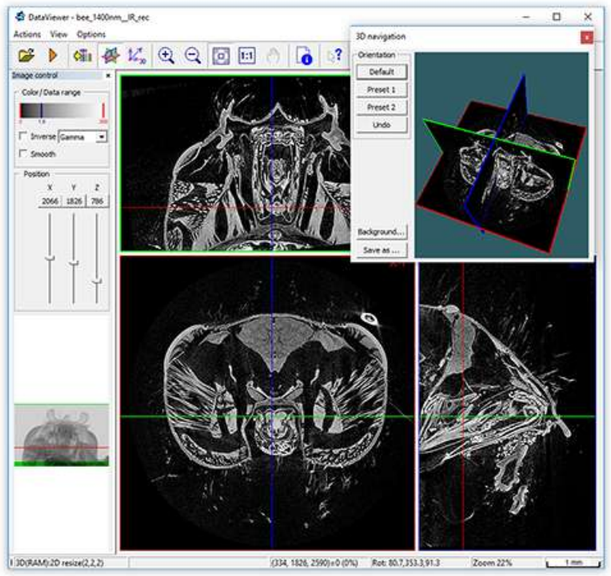
reconstruction time: full volume / per slice	1K (615 slices)	2K (1229 slices)	4K (2459 slices)	8K (2255 slices)
NRecon (CPU)	2m 46s / 0.270s	24m 28s / 1.194s	4h 16m / 6.233s	15h 42m / 25.075s
GPURecon (GPU: NVIDIA Quadro P4000, 8 GB)	39s / 0.063s	6m 4s / 0.296s	1h 48m / 2.635s	5h 12m / 8.302s
InstaRecon® (CPU)	16s / 0.026s	1m 15s / 0.061s	8m 2s / 0.196s	1h 13m / 1.952s

DATAVIEWER: Slice-by-slice movie, three virtual slices intersecting at any point in the reconstructed volume

DataViewer displays reconstructed results as a slice-by-slice movie or as three orthogonal sections, centered at any selected point inside the reconstructed volume. One can rotate and resample reconstructed volumes in any direction and save a new repositioned dataset or volume of interest. Additional features include 4D animation of time-resolved tomography and compression or tensile *in-situ* examination, variable smoothing options, measuring distances in 3D and intensity profiles.

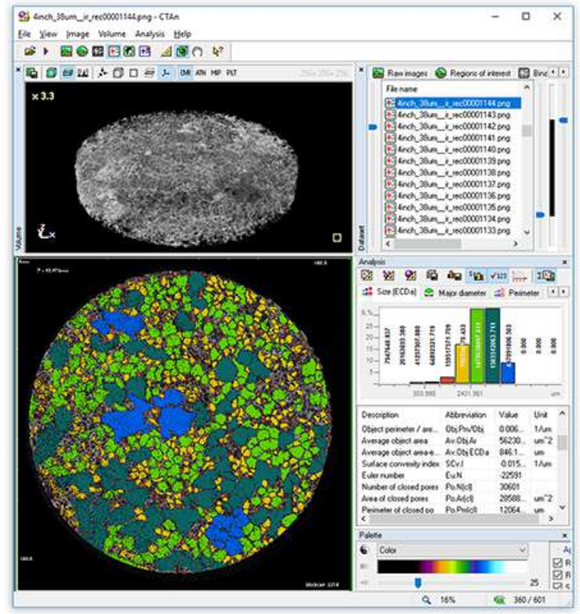
DataViewer also allows detailed examination inside volumes of interest. It can apply different grayscale linear and non-linear transformations and use colour coding with several look-up tables.

DataViewer includes automatic co-registration of several datasets in position and spatial orientation and output of differential image data.



CTAN: 2D / 3D image analysis; CTVOL: realistic visualization by surface rendering

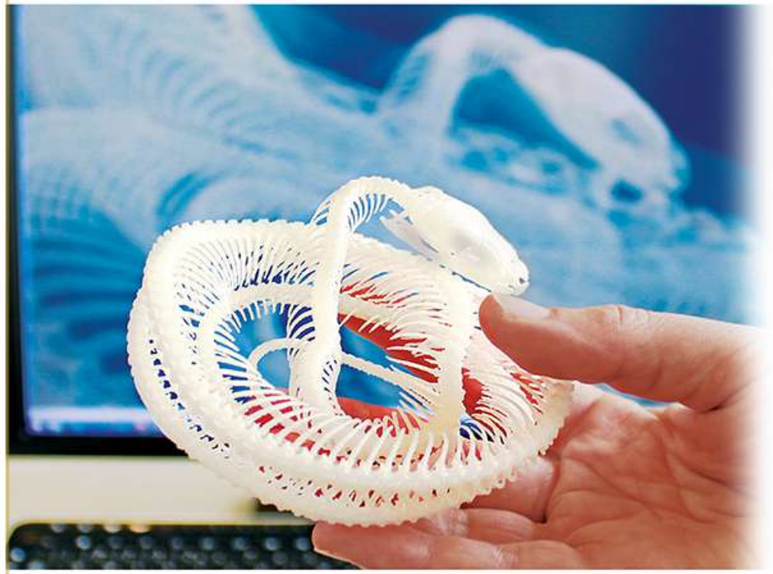
CT-Analyser or **CTAn** allows accurate and detailed study of micro-CT results for morphometry and densitometry. Powerful, flexible and programmable image processing tools allow a wide range of image segmentation, enhancement and measurement functions for analyses ranging from porosity to contact surface around high-density insertions to complex architectures. Versatile volume of interest selection tools are included. "CT-Volume" or CTVol uses surface triangulated models from **CTAn** and provides a virtual 3D viewing environment, flexible and rich in features, to give you a wide range of options for 3D presentation of micro-CT results.



The main features of **CTAn** are:

- Import of dataset in tiff, bmp, jpg, png, DICOM, etc.
- Global, Otsu, multi-level and adaptive segmentation
- Advanced region/volume of interest selection tools
- Creates max. and min. intensity projection images
- Measures 3D distances and angles
- Calibrates density as HU, BMD or attenuation
- Smooth, sharpen, despeckle, Boolean operations
- 2D/3D analysis of integrated structures within VOI
- 2D/3D analysis of all individual objects within VOI
- Parameters measured (including 2D and 3D):
  - Object (pore, particle, etc.) volume
  - Object surface
  - Structure thickness
  - Structure separation, number
  - Structure Model Index (SMI)
  - Fragmentation index (trabecular pattern factor)
  - Euler number, eccentricity
  - Degree of anisotropy, eigenvalues, eigenvectors
  - Fractal dimension (Kolmogorov)
  - Moments of inertia (x, y, polar, product)
  - Detailed analysis of porosity
- Automated batch analysis
- Connects to user-created plug-ins
- Creates 3D models by several rendering algorithms
- Export triangulated models in STL and PLY formats

STL file export for 3D printers, finite element analysis and 3D CAD

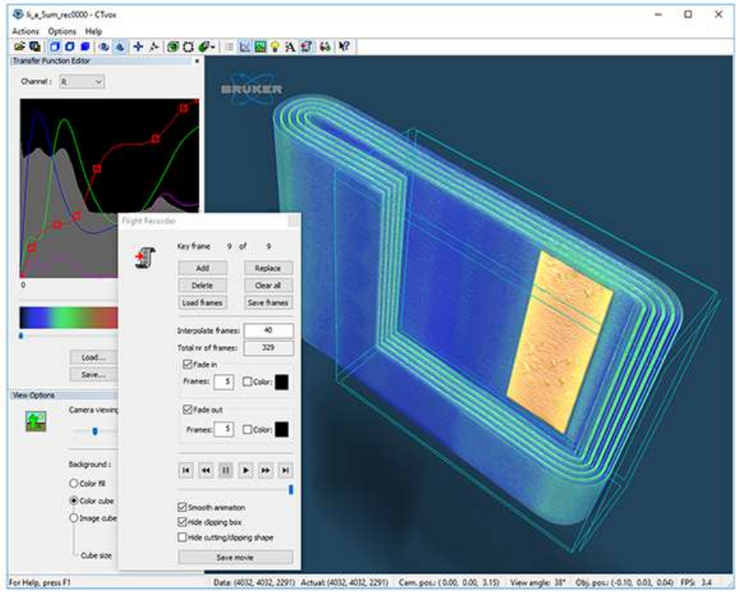


The **CTAn / CTVol** programs can create and visualize triangulated models of object surfaces. Such models can be saved in STL file format which is widely used in numerous applications. The STL files can be sent to a 3D printer to build a magnified physical copy of the scanned objects in different materials. Using a volume of interest created in **CTAn,** the physical model may be partially opened to get access to internal object details. The STL file format is also used as input information for FEA (Finite Element Analysis) software packages which can analyze the impact of mechanical load on internal microstructure of objects. It is also a common file format for data import into 3D CAD software packages, such as SolidWorks. Importing STL files from the scanned results into 3D CAD packages allows direct comparison of the scanned object with the CAD model used to create the object.

Volume rendering for desk-tops and mobiles

CTVox: Realistic visualization by volume rendering

The volume rendering program **CTVox** displays reconstructed results as a realistic 3D object with intuitive navigation and manipulation of both object and camera, flexible clipping tools to produce cut-away views and an interactive transfer function control to adjust transparency and colors. The lighting and shadowing with selection of material surface properties produces fully realistic visualizations. A "flight recorder" function allows fast creation of "fly around" and "fly through" animations based on simple selection of several key frames with automatic interpolation in between. Imaging possibilities include displaying multiple datasets obtained from the series of *in-situ* scanning during applying force or temperature variations.



Volume rendering on mobile phones and tablets

The volume rendering program **CTVox** also has its mobile versions, which can be freely downloaded from the AppStore for iPhone / iPad / iPod or from the Google Play for Android devices. Any 3D results obtained by SkyScan 2214 system can be sent to a mobile device for realistic visualization by real-time rendering with 3D object manipulation, virtual cutting, adjustment of opacity and colors, etc.

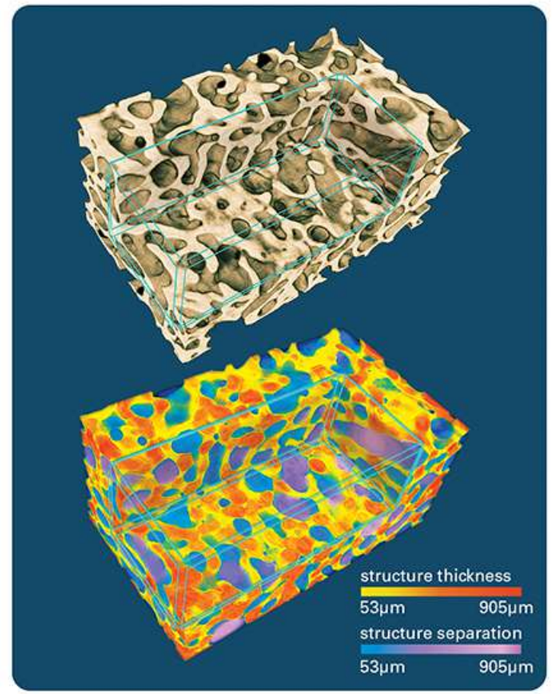
The results can be sent to a mobile device through a cable connection or wireless network. The exported rendered data and color schemes are stored in the local memory of the mobile device and do not require any connection or downloading during manipulation. A large number of reconstructed datasets can be loaded to the memory of a mobile device, allowing you to study image results while travelling and demonstrate them at meetings or scientific conferences.

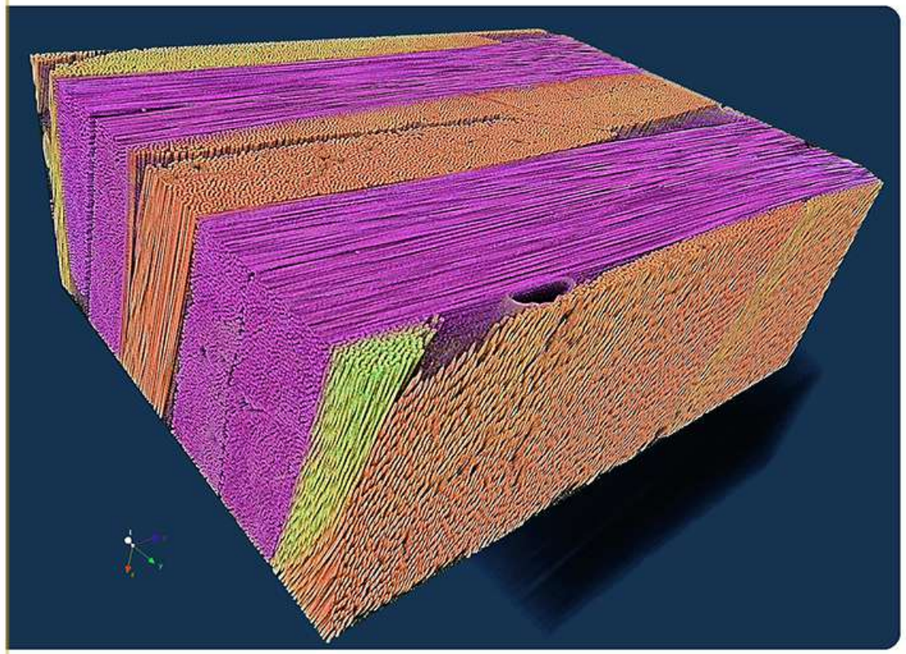
Displaying 3D measurements

Visualization of 3D analysis results

Combining the power of 3D numerical analysis of micromorphology in **CTAn** with the imaging capability of **CTVox** allows visualizing the 3D distribution of morphological parameters across the scanned volume.

Calculation of local 3D numerical parameters, such as structural thickness or structural separation, in **CTAn** is based on growing a spherical probe in every point of the object's 3D space until the maximum diameter which fills structural features. The obtained local information on 3D structural thicknesses and structural separations can be saved as a spatial intensity map. **CTVox** converts such maps of measured morphological parameters to color-coded 3D images, which reflect the local distribution of numerical characteristics of the object. The possibility to work with multiple datasets in **CTVox** helps to display the 3D distribution of several measured parameters simultaneously. For example, local structural thickness and local structural separation (pore size distribution) can be coded in complementary color schemes and displayed simultaneously.





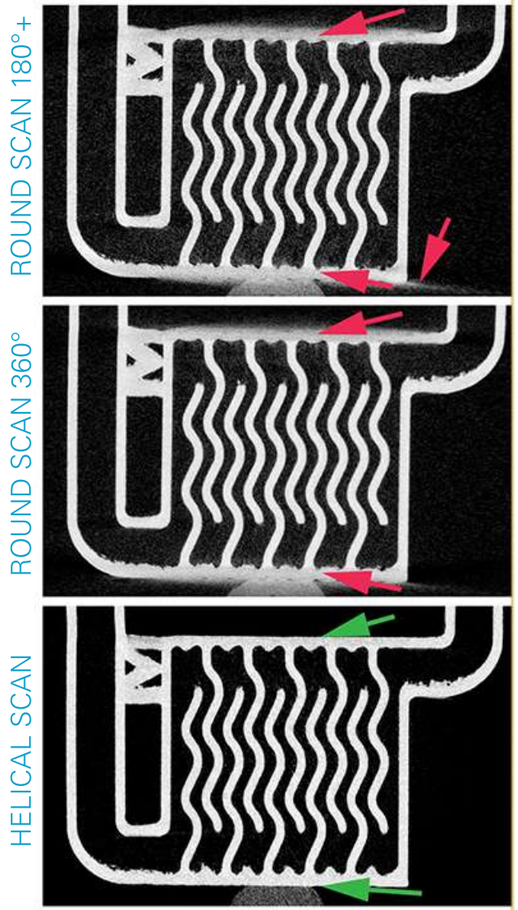
Several analysis functions in **CTAn** are able to provide specific morphological data based on information from half-tone reconstructed slices without image segmentation. It allows performing local 3D analysis in densely packed objects or in objects with similar X-ray absorption in different components. Such analysis is often based on 3D calculation of local signal gradients in original half-tone reconstructed data.

For example, the color-coded image on the left shows the local orientation distribution of every fiber in a densely packed carbon-fiber reinforced polymer (CFRP). The results of the orientation analysis are overlayed with the morphological image of the sample.

Helical scanning, exact reconstruction, metrology

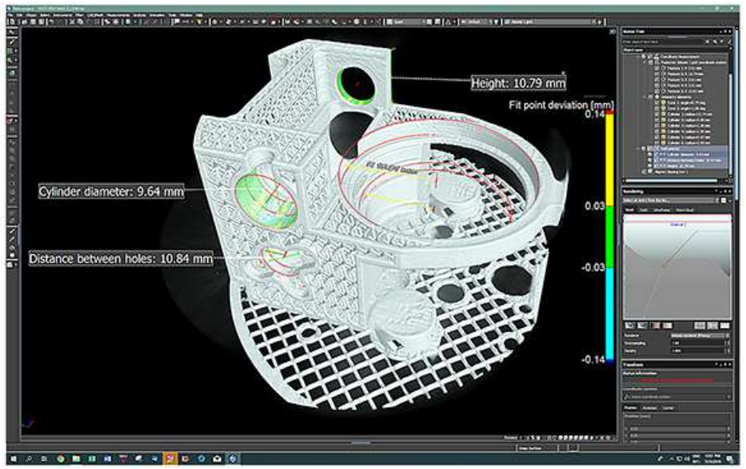
Round and helical scanning, exact reconstruction algorithm

Most micro-CT systems are using a round scanning trajectory where the object rotates between the X-ray source and the camera inside a conical primary beam. This type of scanning is well-supported by the industry-standard Feldkamp reconstruction algorithm with visually good results in many practical cases. The Feldkamp algorithm for cone-beam geometry is an approximate algorithm, which produces significant unsharpness for planar structures perpendicular to the rotation axis in the top and bottom of the reconstructed volume due to insufficient data obtained during scanning with a round trajectory.



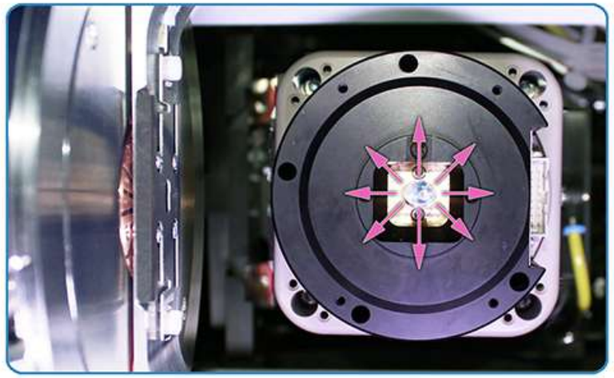
In the reconstruction examples of the 3D printed cooling element shown in the two top images on the right hand side, the typical loss of information from horizontal surfaces is marked by red arrows. In the case of a 180°+ scan, it can be seen as unsharpness in the reconstructed surfaces and tails aside the edges. The middle example after 360° scanning shows better results, but horizontal surfaces are still unsharp and metrological analysis using such reconstructions is practically impossible because the result will depend on the object orientation. Getting sufficient data for accurate reconstruction of any object shape anywhere in the field of view requires scanning with simultaneous rotation and linear movement, for example - by using a helical (spiral) scanning trajectory. Such scanning needs a different reconstruction algorithm. The SkyScan 2214 can perform scanning with both round and helical trajectories. The supplied reconstruction uses a patented (licensed) exact reconstruction algorithm to get geometrically correct results. The bottom image on the right shows the result of a helical scan and exact reconstruction. It produces perfectly sharp information at any place of the object. Obtaining exact information opens the possibility for accurate metrological measurements.

External and internal 3D metrology



Obtaining geometrically perfect information from helical scans with exact reconstruction allows accurate dimensional measurements of the scanned objects. In the case of 3D printed parts with limited or no access to internal structures, micro-CT is the only method for metrological analysis of the internal parts of objects. The results from the SkyScan 2214 and other SkyScan systems can be directly imported by Volume Graphics software VGSTUDIO MAX or VGMETROLOGY for geometric dimensioning, tolerancing, comparison to 3D CAD design and other metrological measurements.

Object stages for *in-situ* examination



Integrated micropositioning stage

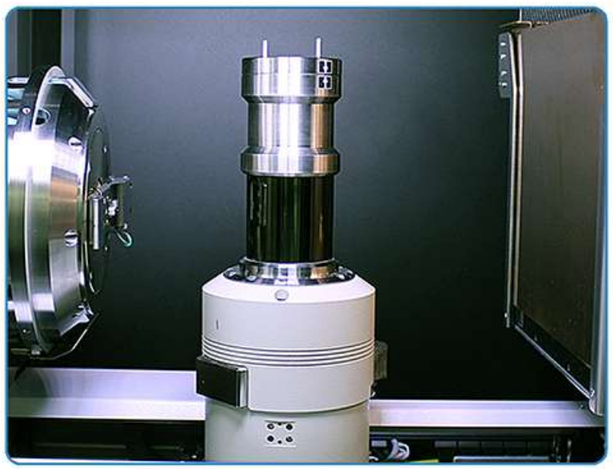
The SkyScan2214 system includes an integrated micropositioning stage. It helps the user to precisely center the object on the rotation axis to get the largest field of view and best quality of the scanning results. The micropositioning stage also allows selection of truncated scan regions within samples that are larger than the field of view. Together with the vertical object movement, lateral movement of the stage is controlled by simple drag and drop positioning of the image on the screen in the acquisition software independent of the object magnification and orientation.

Material testing stages

The material testing stage symmetrically applies a controlled compression or tension to both ends of an object. Symmetrically applied force keeps the central part of the object in a static position during scanning. An internal microprocessor controls the load and reads out the displacement as well as the applied force. The stage can be equipped with different load cells for maximum force of 42 N, 210 N or 440 N. The material testing stage is supplied with several sample chambers for objects up to 24 mm in diameter and 24 mm in length for compression or 20 mm wide and 17 mm long for tension. The software for the material testing stage works in handshake with the main control software of the scanner to perform multiple scans with selected forces or at predefined deformations. A special version of the stage (MTS3) can apply 2200 N or 4400 N forces with asymmetrical load (compression only, 5.5 mm travel).

Heating and cooling stages

The heating and cooling stages provide environments for micro-CT scanning under controlled object temperature above or below ambient. The heating stage keeps an object at a temperature up to +85°C. The cooling stage keeps an object at sub-zero temperatures down to 30-40°C below ambient. An internal microprocessor controls a solid-state cooling or heating system keeping an object under a selected temperature with 1°C accuracy.



Adapter for Deben stages

The SkyScan 2214 system can be supplied with an adapter for the CT5000RT tensile stage produced by Deben company in UK. All necessary connections for the stage are done through preinstalled slip rings and cables. It allows mounting and unmounting of the stage without any additional connections and supports multiturn rotation necessary for helical scanning.

Simple control, safe and easy data access

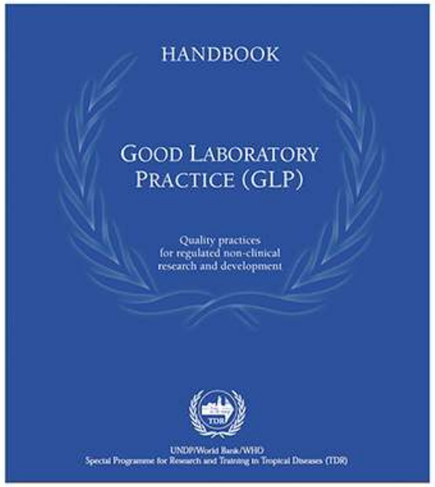
Touchscreen control panel

The embedded touchscreen in SkyScan 2214 allows precise object positioning and indicates the applied voltage and current in the X-ray source. It also displays information on the progress of the ongoing scan. Apart from the touchscreen, the front control panel also includes indicators of the compressed air and cooling fluid statuses as well as a single button control of the automatic vacuum system in the X-ray source. During filament exchange, a simple push to this button starts the ventilation sequence, which takes less than one minute. After releasing the vacuum control button, the air starts pumping out and reaches an operatable vacuum again in 15-20 minutes. The automatic vacuum system ensures the shortest down time during filament exchange with the simplest operator control.

Good Laboratory Practice (GLP) software

The SkyScan 2214 is supplied with a GLP module, which when activated allows administration of user rights and the implementation of necessary data protection according to GLP requirements. Access to the control software will be protected by a user's name - password combination. Several levels of access can be granted: standard users, advanced users or supervisors. Standard users' rights allow scanning, saving and loading of results and switching of scanning protocols, but do not allow to erase or modify results or change scanner settings. The users with advanced access rights can access all functions of the system.

When the GLP-module is activated, the control software duplicates every scan log-file with all scan parameters and system settings, in an encrypted copy, which cannot be directly accessed or modified. When necessary, encrypted log files can be restored to text for QA audit, to ensure the secure storing of critical scan information.



Flexible image formats

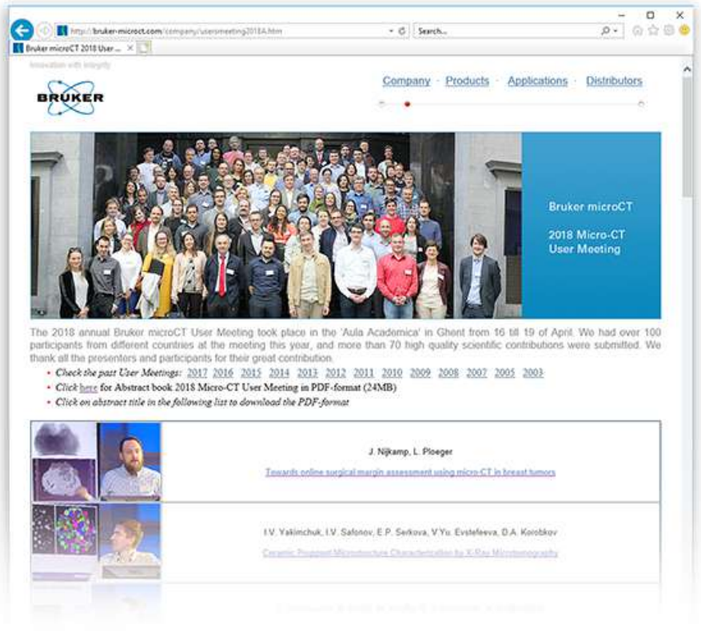
The SkyScan 2214 software provides results in Windows readable formats such as PNG, BMP, JPG and TIFF images, and AVI movies. The reconstruction and analysis software additionally use a DICOM format. The 3D models of scanned objects can be saved in STL, PLY and other formats. Numerical results of image analysis can be exported as a plain text or in Excel-compatible formats.

If required, images can be converted between formats using the supplied Format Converter. This allows the user to easily rename, resize, rescale and renumber individual images or full datasets, as well as combine multiple sets of reconstructed slices.

Comprehensive support and training

Training courses

After installation of every SkyScan system, the new users will receive first an initial and later an advanced training, either on-site or by course attendance. A five-day system and software advanced training course at the headquarter is also available. It covers a number of major topics including image acquisition, image reconstruction, data analysis and realistic visualization of results. This course combines the basic theoretical background of microCT scanning with as much hands-on experience as possible.



Micro-CT annual meetings

Bruker microCT also organizes annual MicroCT Meetings in the form of a 3-day scientific conference combined with training workshops. Intensive exchange of knowledge and experience helps new as well as skilled users to find the way to get the best results from their microCT system. An invitation to the next MicroCT Meeting and the abstracts of contributions from the previous meetings can be found at www.bruker-microct.com

'Bruker MicroCT Academy'

The "Bruker microCT Academy" is an efficient educational network for hundreds of groups who are using SkyScan instruments. It includes a monthly newsletter with application and technical tips and keeps users updated on new methods, developments and company news. By subscribing to Academy Newsletter, our users will gain access to a database with detailed application and technical notes and provide feedback with questions and suggestions for improvements of the instruments and software.

TECHNICAL SPECIFICATIONS

X-ray source	20...160 kV, <500 nm spot size, Tungsten target on diamond window, open (pumped) X-ray source with W and LaB_6 cathodes
X-ray detectors	Up to four detectors: 8 Mp high-resolution cooled CCD, 11 Mp standard resolution cooled CCD, 11 Mp large format cooled CCD, 6 Mp active pixels CMOS flat panel, 6-positions filter changer for CCDs, 2 filters for flat-panel.
Reconstructed image formats	*Flat panel:* 3072 x 3072 pixels *CCD (11Mp):* 4032 x 4032 pixels (central position) 8000 x 8000 pixels (two offset positions)
Spatial resolution	Better than 500 nm low-contrast resolution (>10% contrast), 60 nm smallest pixel size at maximum magnification (hi-res CCD)
Object positioning	10-axis manipulator, all stepping motors use microstepping, object rotation - by direct drive air bearing with <50 nm accuracy,
Vibration isolation	Granite platform with pneumatic leveling
Scanning volume	Max. scanning diameter: 140 mm, scanning length: 80...130 mm, max. object diameter: 300 mm, maximum object weight: 26 kg
Radiation safety	<1 µSv/h at any point 10 cm from the instrument's surface
Power supply	100-240 V AC, 50-60 Hz, 10 A max.

The system is supplied with closed loop water chiller, necessary particle filters and air dryer to use industrial-grade compressed air, 8...12 bar. The oil-free compressor can be supplied optionally.

Bruker microCT is continually improving its products and reserves the right to change specifications without notice.

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