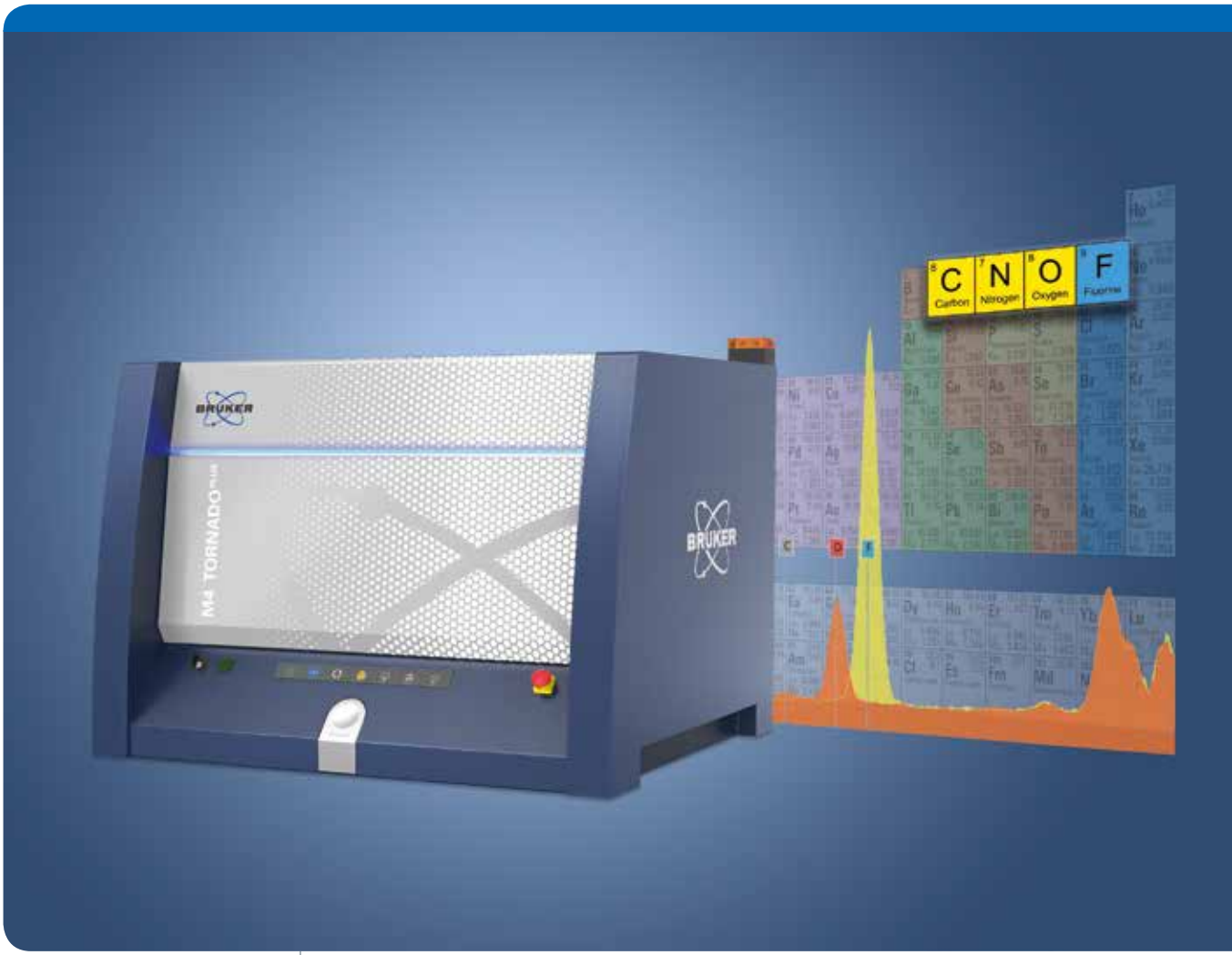


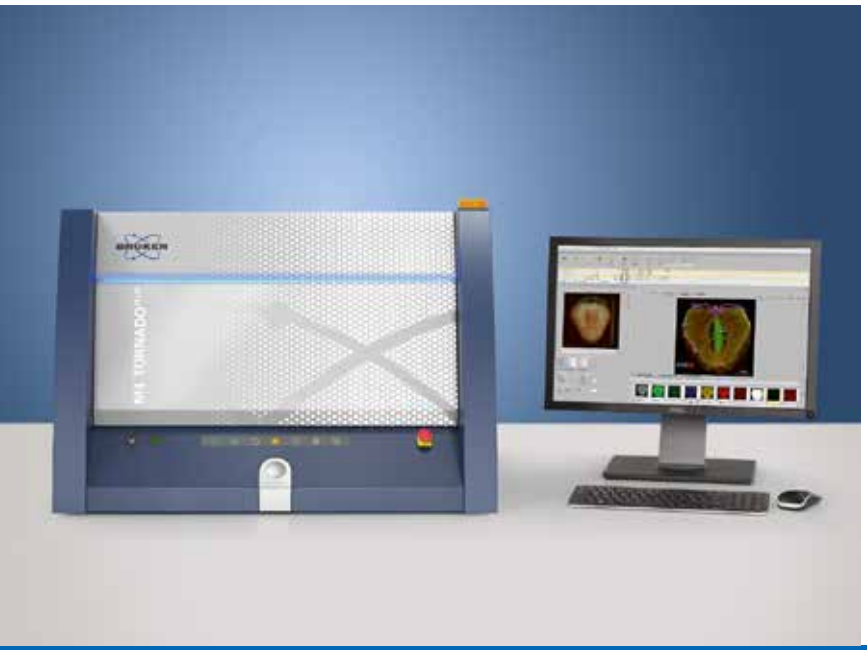
M4 TORNADO^{PLUS}

- Super Light Element Micro-XRF Spectrometer

Micro-XRF

Innovation with Integrity

M4 TORNADO^{PLUS} - A New Era in Micro-XRF



M4 TORNADO^{PLUS} is the world's first Micro-XRF spectrometer that enables the detection and analysis of the entire element range from carbon to americium.
As the latest member of the proven, market leading family of M4 TORNADO Micro-XRF analyzers, the M4 TORNADO^{PLUS} also offers additional unique features, such as an innovative aperture management system, an ultra-high throughput pulse processor and a flexible quick-change sample stage.

Unique Features and Benefits of the M4 TORNADO^{PLUS}

Features	Benefits
Dual, large-area silicon drift detectors (SDD) with super light element window	Detection and analysis of light elements down to carbon
High throughput pulse processor	Reduced acquisition time, increased productivity
Innovative Aperture Management System (AMS)	High depth of field to keep more features and details in focus when investigating topographic samples
Quick-change stage with optional specimen holders	Reduced sample exchange and setup time
Second X-ray tube with automatic four position collimator changer (optional)	More flexibility for the analysis of high energy lines
Programmable He-purge system (optional)	Light element analysis at atmospheric pressure

Lighter, Faster, Deeper

The M4 TORNADO^{PLUS} enables the detection of light elements down to carbon by using large-area silicon drift detectors (SDD) with super light element window and offers vastly increased acquisition speed by performing ultra-high throughput pulse processing. Its patented aperture management system (AMS) provides an unmatched depth of field and allows analysis of samples with highly topographic surfaces.

Super Light Element Detection down to Carbon

Using two large-area silicon drift detectors with super light element window and a specifically optimized Rh X-ray tube, the M4 TORNADO^{PLUS} is the first Micro-XRF spectrometer ever to enable the analysis of light elements.

Unlike common Micro-XRF systems, which are suitable to detect elements from sodium up, the M4 TORNADO^{PLUS} allows to also measure elements with atomic numbers $Z < 11$, such as fluorine, oxygen, nitrogen and carbon, without compromising the performance and sensitivity in the higher energy ranges.

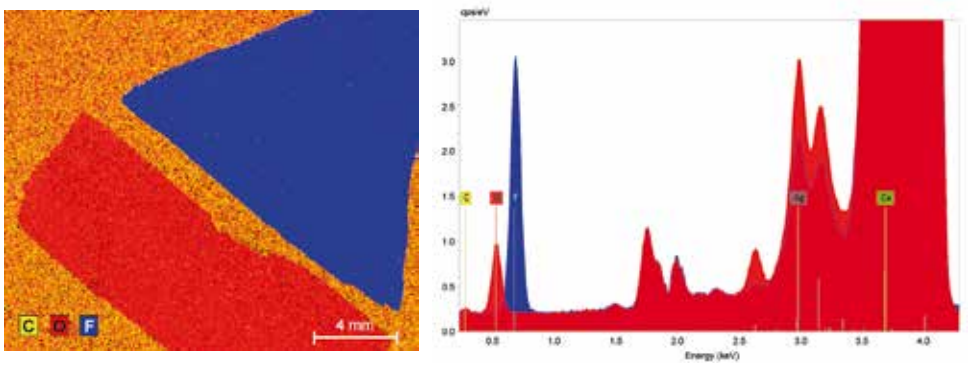
With this performance enhancement, new applications are opening up for Micro-XRF, e.g. in geoscience and mining, biology, polymer research or semiconductor industry.

Application Example - Differentiating Fluorite and Calcite

Both fluorite (CaF_2) and calcite ($CaCO_3$) are minerals with calcium as a main component. What differentiates them is the presence of the light elements fluorine and oxygen/carbon, respectively. Due to their inability to detect elements with $Z < 11$ (sodium), common Micro-XRF systems cannot distinguish between these two minerals, as both the fluorite and calcite spectrum would show the calcium line only.

With its super light element detectors and the light element X-ray tube, the M4 TORNADO^{PLUS} can detect fluorine, oxygen and carbon and thus reliably identify the two minerals.

Differentiating fluorite and calcite



Left: Element map of calcite (red) and fluorite (blue); image size: 20 x 12 mm^2; scan resolution: 800 x 460 pixels; step size: 25 µm; dwell time: 25 ms/pixel; excitation: Ag LE tube, 50 kV, 500 µA.
Right: Light element spectrum region of the two minerals fluorite (blue) and calcite (red).

Lighter, Faster, Deeper

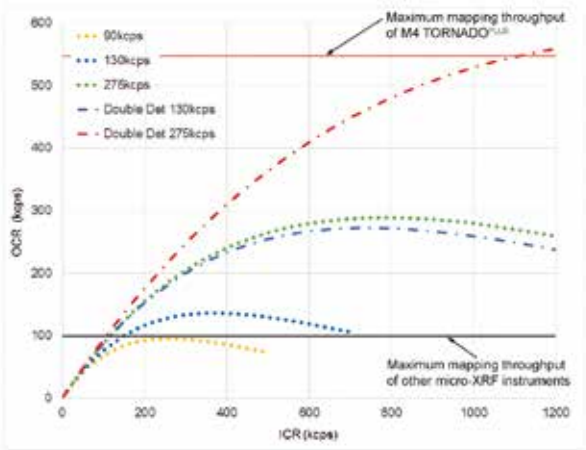
Ultra-High Throughput Pulse Processor for Fastest Measurements

While the highly brilliant micro-focus X-ray sources of most modern Micro-XRF systems are capable of generating very high X-ray fluorescence intensities, detectors and pulse processors limit the output count rate to typically 90–100 kcps.

Already the previous dual detector versions of the M4 TORNADO have been trendsetting in this regard, providing up to 260 kcps output count rate with excellent energy resolution.

With its unique ability to process up to 1,200 kcps and to deliver an output count rate of up to 550 kcps, the M4 TORNADO^{PLUS} pushes these limits significantly further, enabling unmatched acquisition speed and productivity.

Input vs. output count rate for the M4 TORNADO^{PLUS} pulse processors



Even if the nature of the sample does not allow the generation of correspondingly high X-ray fluorescence intensities, the pulse throughput will be superior due to the low pulse processor dead time. That means, in any measurement situation the M4 TORNADO^{PLUS} delivers more data in the same time, or produces a result with the same amount of data in less time, compared to competing instruments.

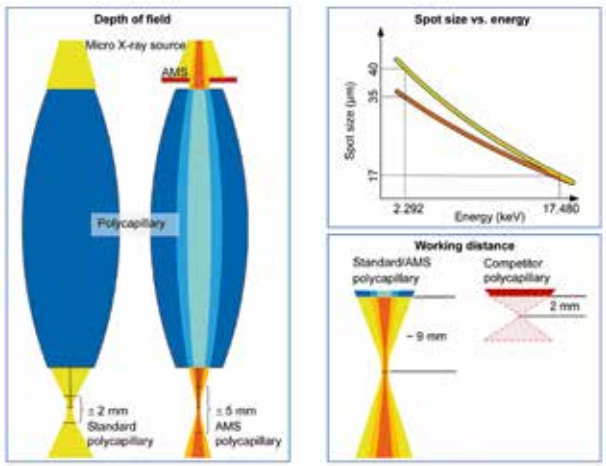
Aperture Management System (AMS) - Increasing Depth of Field and Spatial Resolution

Many specimens to be investigated using Micro-XRF have topographic surfaces, rather than being perfectly flat. Therefore, just like in photography, the depth of field becomes an important parameter for the X-ray optical system used to generate the small excitation spot on the sample surface.

Usually, in Micro-XRF analyzers with high spatial resolution X-ray optics (7 µm), the working distance needs to be as small as 2 mm and the achievable depth of field is less than 1 mm.

The innovative, software-controlled aperture management system (AMS) of the M4 TORNADO^{PLUS} enables a working distance of approx. 9 mm and provides a depth of field of up to ± 5 mm. That means, the spatial resolution does not get lost, and sample features are kept in focus, even if the sample surface varies over several millimeters. This makes the M4 TORNADO^{PLUS} the instrument of choice for the analysis of specimens with strong topography, e.g. in electronics, forensics, or geoscience.

AMS principle - Narrow beam, high depth of field and low energy dependence

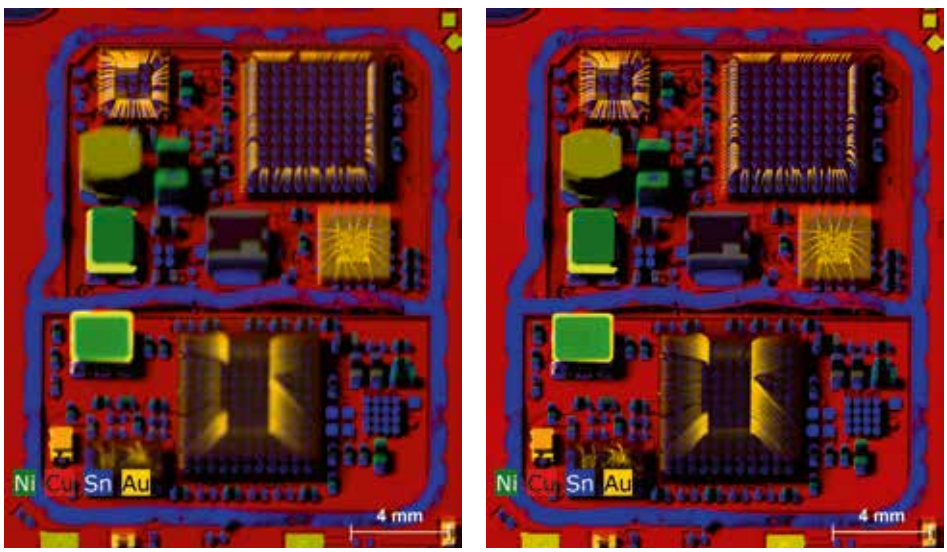


The reduction of the radiation entrance angle into the polycapillary results in a significantly larger depth of field. With polycapillary and AMS, the energy dependent variation of the spot size becomes negligible.

Application Example - PCB Mapping

Due to the extremely deep depth of field with AMS, the corresponding X-ray image of a mobile phone circuit board has far more details in focus than the image of the same circuit board acquired without AMS. In addition, the energy dependence of the spot size becomes less pronounced because of the reduced entrance and exit angles of the excited X-ray photons.

Circuit board analyzed without and with AMS



Left: The standard polycapillary spot was focused on the board level of the PCB, hence the tall components and bond wires are out of focus and appear blurred. Right: AMS image showing high depth of field with all components in focus over a larger depth range.

Easing, Expanding, Extending

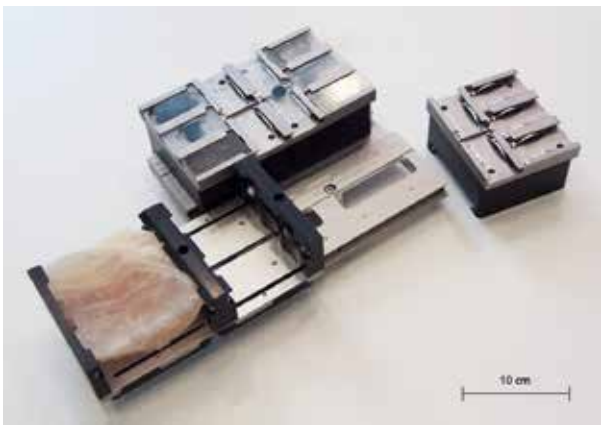
The M4 TORNADO^{PLUS} eases the exchanging, positioning and fixing of samples with the quick-change stage, expands the spot size and intensity range of the (optional) second X-ray tube with a collimator changer and extends the range of application in the light element analysis even for sensitive or hydrated specimens using He-purging.

Quick-Change Stage for Fast and Easy Sample Exchange

In most analytical labs, there is pressure on the analyst to maximize the sample throughput and to minimize the time the instrument sits idle. Besides that, the secure attachment of large, irregularly shaped specimens, or of a large number of thin sections in a repeatable manner, can be challenging and time-consuming tasks.

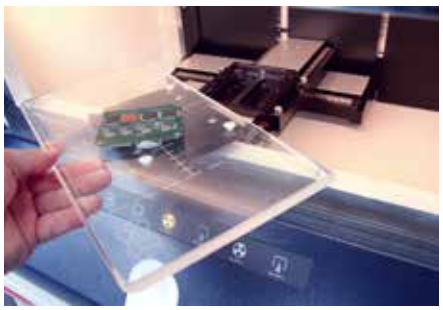
The M4 TORNADO^{PLUS} comes with a modular quick-change stage interface. The dovetail coupler enables the stage plate to be removed and reinserted easily and quickly without any tools, providing for convenient and secure placement of samples onto the stage plate.

Quick-change stage interface with drill core holder and thin section holders



Adjustable sample holder with whole, half or quarter plugs for drill cores and other irregular shaped samples as well as for thin sections.

Standard quick-change stage interface



Standard quick-change stage interface for easy placement of a sample outside the sample chamber.

Optionally, there is an additional base plate, which supports drill core holders or thin section carriers.

The drill core sample holder is configurable and can be adjusted to hold up to HQ sized (2.5 inch) drill cores. It can be set up with one or two halves, each being able to hold two or three half or quarter drill cores, as well as end pieces or plugs. Alternatively, the base plate can be equipped with up to four thin section carriers, each being able to hold five thin sections, secured by two wave springs.

Regardless if using drill core holders, thin section carriers or a combination of both, the measuring plane is always the same, meaning less time spent with setting up measurements. The entire stage load can be analyzed without changing focus.

Second X-ray Tube with Collimator Changer for Intensity Gain at Higher Energies

In order to effectively excite the high-energy lines of heavy or Rare Earth Elements (REE), an X-ray source with collimator is the better choice as it does not suffer from the attenuation of the higher energy portion of the tube spectrum that can be observed with polycapillary lenses.

For the analysis of larger specimen volumes, it may also be beneficial to have a larger spot size.

The M4 TORNADO^{PLUS} can therefore be equipped with a second (fine-focus) X-ray tube (W) combined with a fully software-controlled four position collimator changer. The collimator changer can be set to spot sizes of 500 µm, 1 mm, 2 mm, and 4.5 mm, enabling either a small spot analysis, albeit with lower intensity, or close to bulk XRF analysis with a large high intensity spot.

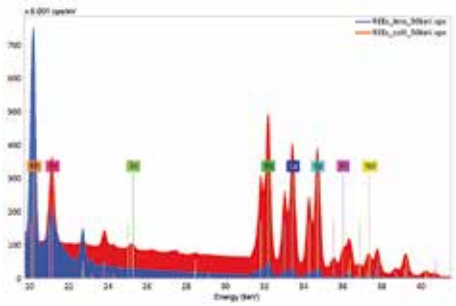
He-Purge System for Increased Intensity at Lower Energies

For certain specimens, measurement under vacuum poses an issue because they are sensitive to pressure variation or may dry out. Even though working at ambient air is always possible, X-ray fluorescence from the light elements below Ca is strongly attenuated or even completely absorbed. In order to detect light and super light elements down to carbon also in vacuum-sensitive samples, the M4 TORNADO^{PLUS} offers an optional, computer-controlled He-purge system to extend the analysis range under atmospheric pressure.

Two different purging modes can be employed, depending on the specific analytical requirements. For a quick single or multi-point analysis, local high-flow purging of the measurement position is sufficient to reliably acquire the low energy X-rays.

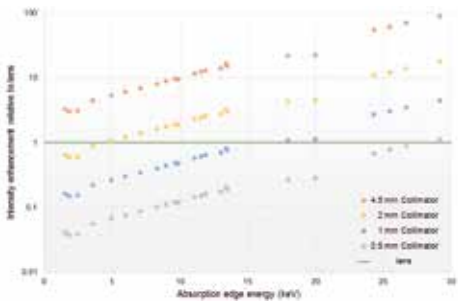
When performing X-ray mapping however, stage movement may cause turbulences, resulting in instable detection conditions for light elements. In this case, a second purging mode is available in which the entire measurement chamber is filled with He, ensuring constant and repeatable conditions for the detection and analysis of light elements during the acquisition process.

Collimator vs. lens sensitivity on REEs



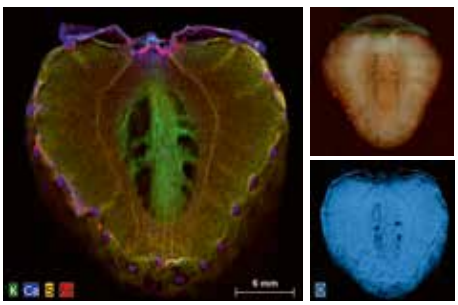
Comparison of rare earth element lines excited with polycapillary lens (blue) and collimator (red). The excitation with collimator yields higher sensitivity for the high energy lines.

Intensity gain with collimator



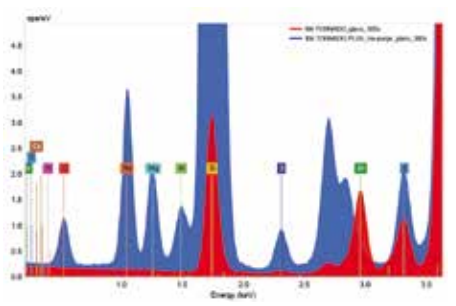
Gain of the primary X-ray intensity for the different collimator sizes in comparison to a polycapillary lens (line at 1).

Element map with He-purge



Mosaic image and single element maps of a strawberry. Image size: 31.2 x 30.5 mm^2, scan resolution: 1560 x 1525 pixels; step size: 20 µm; dwell time: 10 ms/pixel; excitation: Rh tube, 50 kV, 600 µA.

Spectra comparison of NIST glass



Spectra comparison of NIST 620 glass samples measured with a standard M4 TORNADO in air (red) and a M4 TORNADO^{PLUS} with He-purge (blue).

Technical Specifications

Sample types	Solids, particles, liquids
Sample chamber size	WxDxH: 600 mm x 350 mm x 260 mm
Stage	WxD: 330 mm x 170 mm, Max. weight load: 7 kg
Measurement media	Air or oil free vacuum, 20 mbar in 2 min, optional He-purge system
Sample travel Max. travel Mapping travel Travel speed	 WxDxH: 200 mm x 160 mm x 120 mm WxD: 190 mm x 160 mm Up to 100 mm/s with TurboSpeed stage
Sample view	2 simultaneous live images from above with different magnifications for sample overview and precise positioning Lateral fisheye camera for the sample chamber overview
Excitation	High brilliance, light element micro focus X-ray tube with polycapillary X-ray optics and aperture management system (AMS) Optional: 2nd fine focus X-ray tube with four position collimator changer from 0.5 to 4.5 mm
Excitation parameters Target material Tube parameters Spot size AMS filters Filters	 1st tube: Rh (optionally Ag), 2nd tube: W (optionally Rh, Mo, Cu, Cr) 50 kV, 30 W (40 W for collimator) Less than 20 µm for Mo Kα (17.5 keV) with polycapillary lens 500 µm and 1 mm apertures, plus 6 filters 8 filters for collimator
Detection	XFlash® super light element silicon drift detectors, detection from C to Am, simultaneous use of two detectors
Detector parameters Sensitive area Energy resolution Throughput	 2 x 60 mm² < 145 eV at 600,000 cps input count rate up to 550,000 cps output count rate
Instrument control	State-of-the-art PC, Windows 10
Instrument control functions	Complete control of tube parameters, filters, optical microscopes, sample illumination and sample positioning
Spectra evaluation	Peak identification, artifact and background correction, peak area calculation, FP quantification, calibrated quantification with standard-based and standardless models using XMethod
Distribution analysis	"On the fly" measurement, HyperMap capability
Result presentation	Quantification results, statistical evaluation, element distribution (line scan, mapping)
Power requirements	100–240 V (1P), 50/60 Hz
Dimensions	WxDxH: 815 mm x 680 mm x 580 mm, 130 kg*
Quality & safety	DIN EN ISO 9001:2008, CE certified Fully radiation protected system; radiation < 1 µSv/h

*Depending on configuration