The Reference.

Switzerland's metrology magazine

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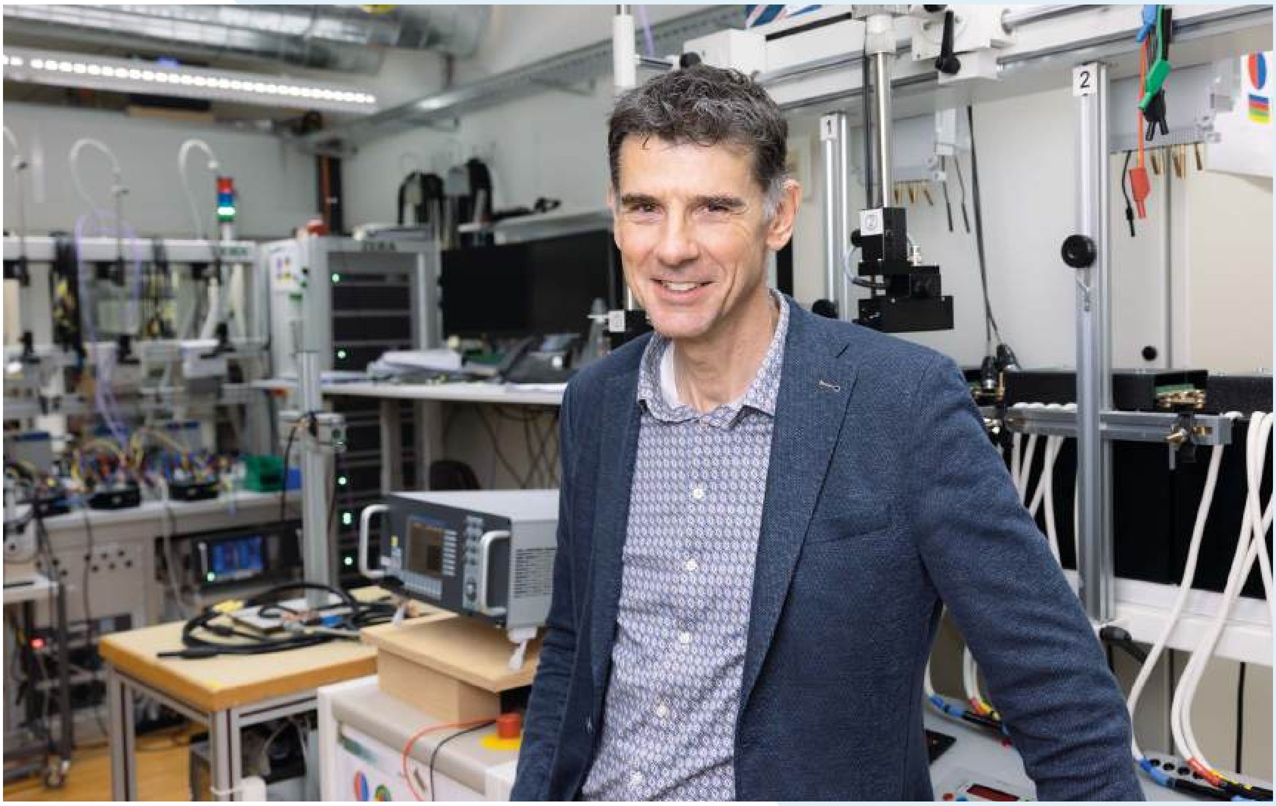
METAS



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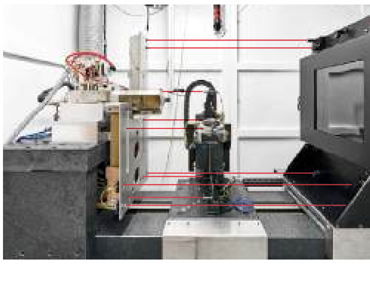
Cover
Calibration of a ZEISS METROTOM nano®
test specimen for monitoring the accuracy
of CT systems on the METAS micro-CMM.

Content



Editorial

Dear Reader,

Precision is the basis of comparability and trust – in the laboratory as well as in everyday life. Metrology usually works in the background and enables reliability, both now and in the future. This issue of our journal shows just how broad and at the same time deep this impact is – from the realisation of fundamental units and high-resolution measurement technology to analytical questions with high social relevance.

The focus is on contributions from length metrology as well as nanotechnology and microtechnology. They provide an insight into the realisation and transmission of the unit of length and show, using metrological computed tomography with sub-micrometre precision, how traceability and technological innovation interact.

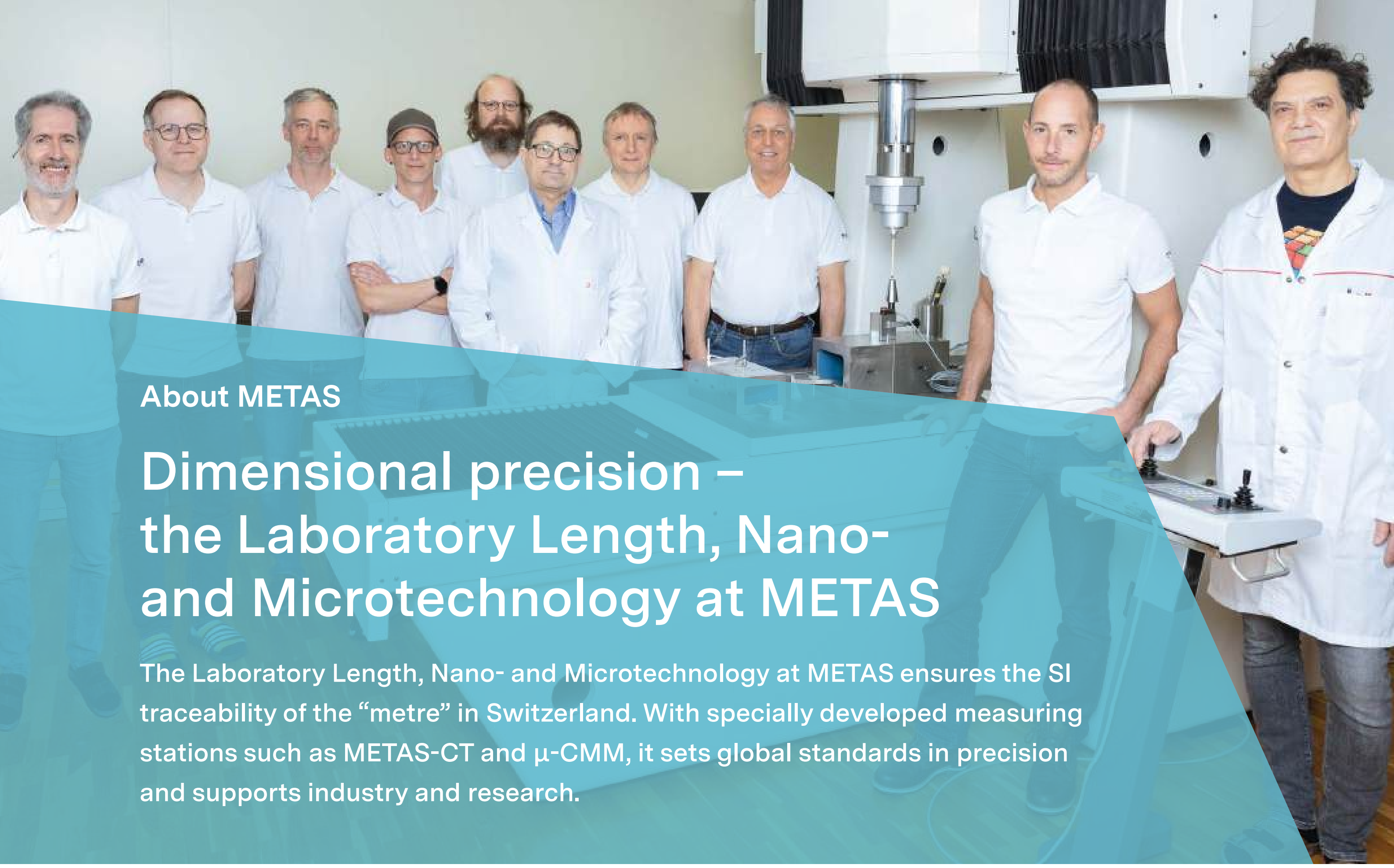
Another focus is on per- and polyfluorinated alkyl substances (PFASs). The articles on trace analysis in blood and food and on the harmonisation of analytical procedures illustrate the central role of reliable measurements for environmental and health protection as well as for regulatory decisions.

The new primary standard for flow calibration with hydrogen addresses a forward-looking topic.

The article on the future of metrology makes a deliberately playful statement: answers generated with the help of AI tools open up unfamiliar perspectives – and invite people to think about how metrology can continue to build trust in everyday life in the future.

We hope you feel stimulated after reading this issue.

Dr Fabiano Assi
Vice Director
Federal Institute of Metrology METAS



About METAS

Dimensional precision – the Laboratory Length, Nano- and Microtechnology at METAS

The Laboratory Length, Nano- and Microtechnology at METAS ensures the SI traceability of the “metre” in Switzerland. With specially developed measuring stations such as METAS-CT and µ-CMM, it sets global standards in precision and supports industry and research.

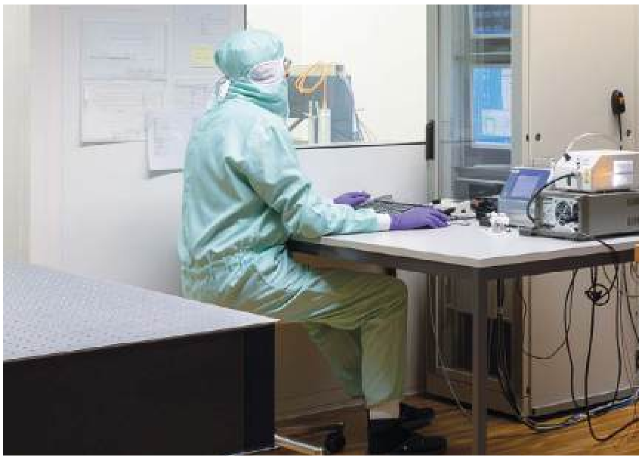
Philippe Chavanne

The Laboratory Length, Nano- and Microtechnology (LNM) of the Federal Institute of Metrology METAS is the national centre of excellence for dimensional metrology. It implements and distributes the SI unit of the “metre” in Switzerland and ensures that length measurements in industry, research and official control are carried out to the highest level of accuracy.

The laboratory comprises a dedicated team of ten specialists who not only perform calibrations and tests, but also actively work to refine the measurement technology. On average, the team oversees three ongoing research and development projects in close collaboration with industry partners and issues up to five scientific publications per year. In doing so, the laboratory makes a decisive contribution to innovation and international networking in the field of metrology.

With nine climate-controlled, low-vibration laboratories – including ISO class 7 and 3 clean rooms – and 32 high-precision measuring stations, the laboratory provides infrastructure that is unparalleled anywhere in the world. The traceability of all measurements to national standards and international recognition by the BIPM guarantee maximum reliability.

In addition to the calibration of measuring instruments and standards, the laboratory develops new measuring methods, carries out type tests and sup-



Daniel Schneeberger operating the mask-measuring machine located in the ISO class 3 clean room booth that can be seen in the background.

Figure 1: unique selling points of the Laboratory Length, Nano- and Microtechnology – expertise x infrastructure x precision.

ports industry with complex measuring tasks. With over 2,000 calibration certificates issued per year and 83 CMC entries in the international BIPM MRA KC database, the laboratory is an indispensable partner for precision in Switzerland.

Our five areas of expertise

The work of the LNM laboratory is divided into five core areas of expertise that cover the entire field of dimensional metrology:

1 Length – precision starting from the basics

The laboratory implements the SI unit of the "metre" (see the following article) and offers calibrations for gauge blocks, scales and complex length measuring systems. The infrastructure includes, among other things, a 50 m measuring bench for scales and laser distance measurers as well as interferometric systems for maximum accuracy in the calibration of final dimensions and diameters of different types.

2 Shape – geometric precision

Calibration of roundness, straightness, flatness and cylindricality for precision parts. Specially developed measuring machines such as the Talyrond 73 and Rondcom 65B make it possible to keep uncertainties in the nanometre range.

3 Multidimensional metrology – the heart of the laboratory

Unique measuring systems, most of which were developed in-house, are the laboratory's calling card and offer the industry measurement accuracy at the forefront of international metrology. It is where complex 2D and 3D geometries are captured with the highest precision – from micro-components for the watchmaking and pharmaceutical industries to complete assemblies for the aerospace sector.

Our core technologies:
micro-coordinate measuring instrument (µ-CMM)

- In-house development for tactile 3D measurements in the nanometre range.
- Measurement volume: 90 × 90 × 38 mm^3, Probe force: <5 mN, Repeatability: 5 nm.
- Measurement uncertainty: up to 27 nm + $2{\cdot}10^{-7}{\cdot}L$ (unidirectional).
- Supports single-point probing and free-form scanning for complex microgeometries.

Photomask-measuring machine

- Optical 2D coordinate measuring instrument for structures on photomasks and glass scales.
- Measuring range: 400 × 300 mm, uncertainty: 16 nm, $0.08{\cdot}10^{-6}{\cdot}L$ (Zerodur and quartz).
- ISO class 3 clean room, temperature stability ±0.02°C for maximum precision.

Realisation and Dissemination of the Length Unit

Length	Form	Multidimensional	Surface	Angle
· Gauge blocks · Line scale up to 50 m · Diameter	· Straightness · Roundness · Cylindricity	· 2D Photomasks · 3D Coordinate Metrology · Metrological micro-CT	· Roughness · Contour · Cutting edges	· Polygons · Encoders · Autocollimators
1	2	3	4	5

Metrological computed tomography (METAS-CT)

- This is presented in more detail in the following article “METAS-CT: metrological computed tomography with submicrometre precision”.

Atomic force microscope (AFM)

- For high-precision surface measurements in the nanometre range.
- Measuring range: 50 × 50 × 12 µm, uncertainty for step heights and particle sizes in the range of a few nanometres.
- Ideal for 1D and 2D structure distances, step heights and particle sizes (e.g. polymer, silica, metal).

4 Surfaces – quality of functional surfaces

Line profile calibration of roughness, waviness and contour standards as well as cutting-edge radii using the MarSurf LD 130 surface profile instrument. Currently measurement data evaluation is being expanded to fully comply with ISO 21920.

5 Angle – precision in rotation

Calibration of optical polygons, angle gauges and autocollimators. Air-bearing angle measuring tables and sine rulers enable accuracies of up to 0.001”.

Outlook for the future

The Laboratory Length, Nano- and Microtechnology does not stand still – on the contrary: the next milestone is the commissioning of the specially developed metrological 3D AFM (atomic force microscope). This highly innovative system combines the benefits of atomic force microscopy with interferometric monitoring in all three axes and will set new standards in precise surface and nanostructure measurement. In doing so, METAS is expanding its leading role in multidimensional metrology and laying the foundations for future applications in the fields of battery development, life science and the semiconductor industry.

Why is length metrology more important today than ever?

In a world where precision determines quality, safety and innovation, the precise determination of geometric quantities is essential. Whether in the semiconductor industry, mechanical engineering, or medical technology, the demands on accuracy are constantly increasing, driven by increasing miniaturisation, higher integration densities, and growing demands on system availability and process stability. METAS’s Length Laboratory ensures that Switzerland remains a global leader in this area.

Customer voice: Martin Wiederkehr, Head of Calibration Centre, Saphirwerk AG

“We have been impressed by the collaboration with the Laboratory Length, Nano- and Microtechnology at METAS for many years. The short delivery times, the extremely low measurement uncertainties and the high level of expertise in calibration services are crucial for us. METAS is a reliable partner for us when it comes to precision at the highest level.”

Metrology in general

Realisation and transmission of the unit of length

The metre at METAS is based on highly stable helium-neon lasers, which are precisely aligned with an atomic iodine transition in accordance with the *mise en pratique.* By calibrating laser interferometers, METAS ensures an internationally traceable, reliable calibration chain.

Dr Kurt Gunderson, Philippe Chavanne

Definition of the metre

The metre is defined as the length of the distance travelled by light in a vacuum in a time span of 1/299,792,458 seconds. Thus, the unit of length is directly coupled to a fundamental natural constant: the speed of light.

Realisation of the unit of length

At METAS, this definition is realised using lasers with a known and exceptionally stable frequency. Three helium-neon lasers are used as primary standards, whose optical frequency is tuned to an atomic transition, more precisely to an absorption line of iodine gas. These lasers serve as particularly stable and reproducible optical references and are suitable for continuous operation and the long-term assurance of the unit of length (figure 1).

Using a fibre-optic frequency comb, the optical frequencies of these lasers are directly linked to the realisation of the second. This achieves direct traceability of the unit of length to time. The relative uncertainty of metre realisation with iodine-stabilised helium-neon lasers is 2.5×10^{-11} *(mise en pratique*[1]*),* which – to illustrate this with an image – corresponds to a length uncertainty of about 1 mm in relation to the Earth's circumference.

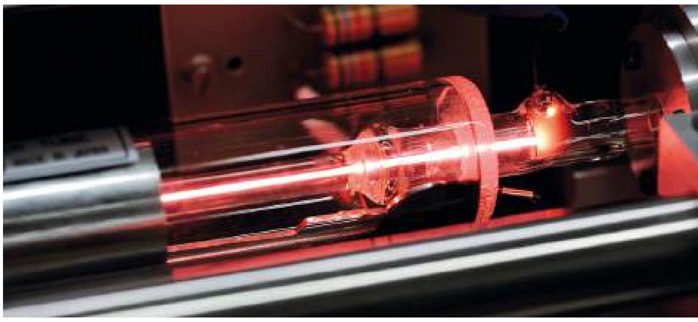
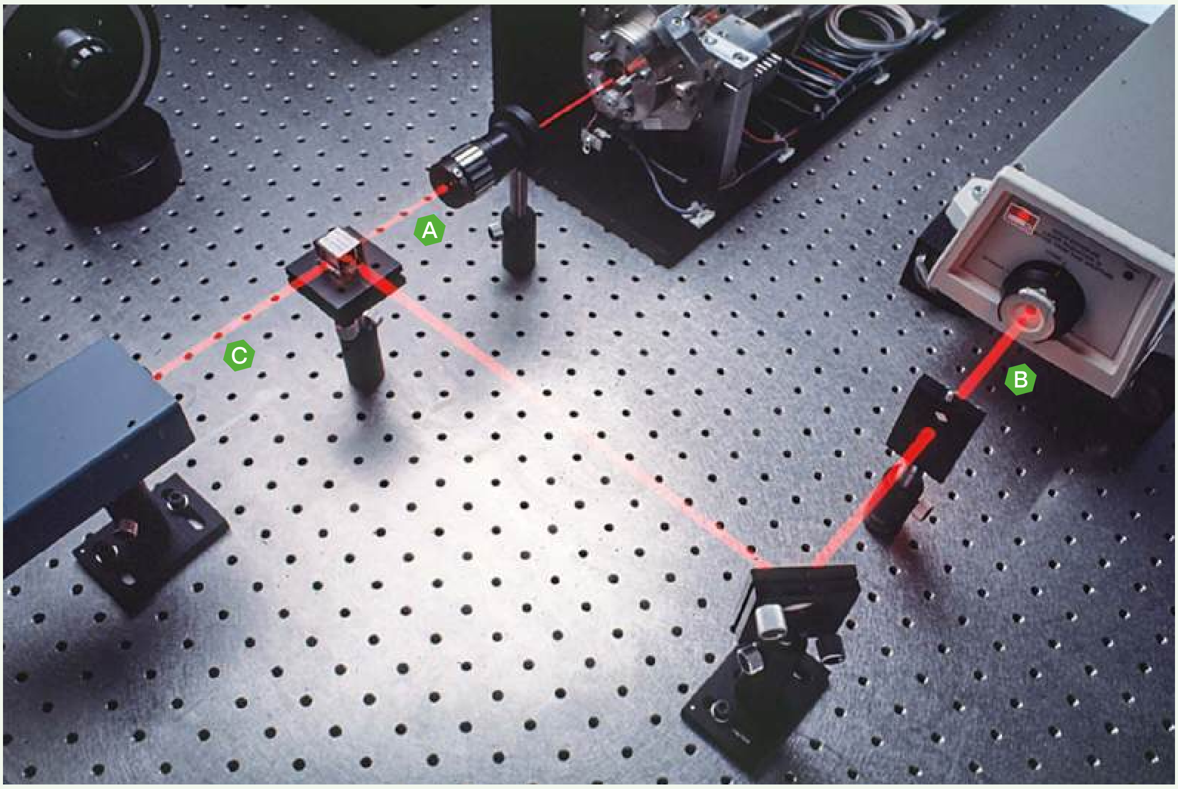


Figure 1: design of an iodine-stabilised helium-neon laser that will be used for the primary realisation of the metre at METAS.



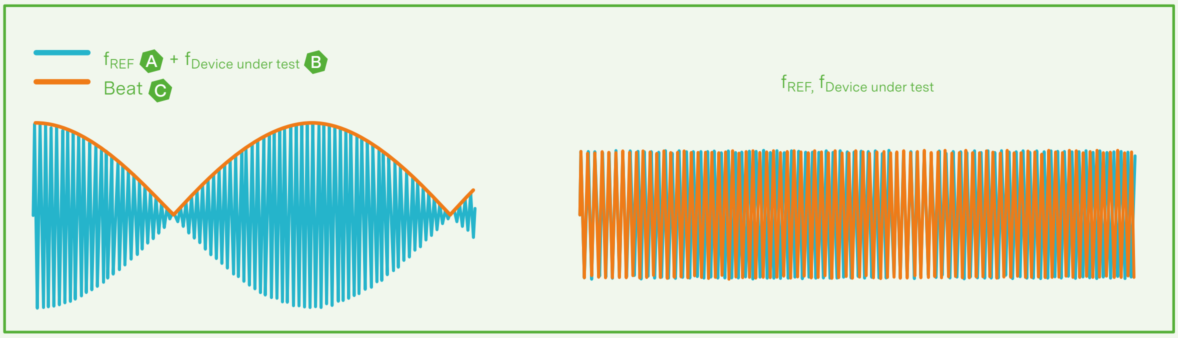


Figure 2: performing a laser calibration using a heterodyne measurement strategy in which the beam of the laser to be calibrated Ⓑ is superimposed with that of the primary realisation of the metre Ⓐ. The resulting beat Ⓒ corresponds to the frequency difference to be calibrated.

Transmission of the unit of length

The precisely known wavelengths of stabilised lasers – e.g. 0.633 µm in the case of the red helium-neon laser – form a “material-independent standard” for length measurement technology. They enable the direct comparison of measured dimensions with the realised unit.

In interferometric measuring systems, the wavelengths of the laser light along a travelled path are counted and interpolated via a material measure. This measuring principle enables an exceptionally large theoretical measuring range, extending from several tens of metres to the subnanometre range. In practical application, however, the refractive index of air limits the achievable accuracy to a few tens of nanometres, meaning that measurements in the subnanometre range can be carried out in an ultra-high vacuum.

An exactly known and stable laser wavelength is a prerequisite for precisely converting the detected interference signals into a clearly defined length.

Calibration of laser interferometers

Every calibration chain in length measurement technology starts with the calibration of laser interferometers. At around 474 THz, the optical frequencies of a helium-neon laser are far above the directly detectable range of conventional electronics. Such high frequencies therefore cannot be detected directly with electronic measuring instruments. For this reason, as shown in figure 2, a heterodyne measurement strategy is applied in which the beam of the laser to be calibrated is superimposed on that of the primary standard – an iodine-stabilised laser.

The resulting beat corresponds to the frequency difference of the two optical signals. The result is a low-frequency signal that reflects the difference between the two very high laser frequencies. Since this difference is typically less than 1 GHz, it can be measured directly after optoelectronic detection.

However, the calibration of laser interferometers at METAS involves more than just determining the optical frequency. It also involves the calibration of the refractive index compensation units, which take into account environmental influences such as atmospheric pressure, temperature and humidity and thus correct the change in the laser wavelength in air compared to the stable vacuum wavelength. ●

XRCD method: silicon crystal structure as an alternative primary realisation of the metre

In addition to classic optical interferometry, there is an alternative primary realisation of the metre based on the atomic structure of silicon:

- **Measurement principle:** determination of the Si {220} lattice constant of a high-purity silicon crystal by means of X-ray interferometry.
- **Derivation of the metre:** the length is determined by the number of grid levels on a defined route.
- **Independence:** works without optical interferometry or time-of-flight measurements.
- **Scope of application:** high-precision length metrology and fundamental analyses, e.g. in the determination of Avogadro constants.
- **Character:** considered an alternative **primary realisation,** as it is based directly on fundamental physical structures *(Bureau International des Poids et Mesures, 2019).*

Link

1 Bureau International des Poids et Mesures (2019). SI Brochure – 9th edition: Appendix 2 – *mise en pratique* for the definition of the metre in the SI. Retrieved from: https://www.bipm.org/documents/20126/41489670/SI-App2-metre.pdf

Service

METAS-CT: metrological computed tomography with submicrometre precision

METAS-CT, developed in-house, sets new standards in SI-traceable computed tomography. New corrections for temperature, beam curing and focus shifts reduce measurement uncertainty and enable significantly more reliable results.

Dr Alain Küng, Marc Trösch, Philippe Chavanne

METAS-CT at a glance

METAS-CT is not a conventional computed tomography system, but rather a high-precision metrological measuring instrument developed by the Length Laboratory specifically for the requirements of modern micro- and nanotechnology. At the heart of the system is a sub-microfocus X-ray tube with an effective spot size of around one micrometre, combined with a large-format flat-panel detector with 4096 × 4096 pixels. This system configuration enables the three-dimensional detection of even the smallest workpieces in the millimetre and sub-millimetre range with a resolution and measurement accuracy that was previously reserved primarily for tactile coordinate measuring instruments.

However, hardware alone is not enough: metrological traceability is determined by an in situ geometry measuring system. Eight fibre interferometers, five optical straightness sensors and three index sensors monitor the relative position of the source, rotating table and detector during each individual exposure. In this way, the projection geometry for each individual radiography is determined and directly integrated into the reconstruction. The system is complemented by a precisely designed temperature management system with several cooling circuits and a network of temperature sensors that detects and compensates for thermal drifts. The result is high long-term stability over many hours as well as a measurement accuracy in the submicrometre range in comparative measurements with multi-spherical standards.

Recent developments: from theory to practice

The last few years have been characterised by intensive research and development with the aim of elevating CT technology for dimensional measurement technology to a new level. One milestone is the expansion of in situ geometry compensation. While classic CT systems assume a static projection geometry, METAS-CT takes into account dynamic changes such as thermal drifts or minimal movement deviations during the measurement. For each projection, the actual geometry of the CT scanner is captured and integrated directly into the reconstruction.

Recent developments have placed particular emphasis on the precise characterisation of the detector geometry as well as the correction of the focus

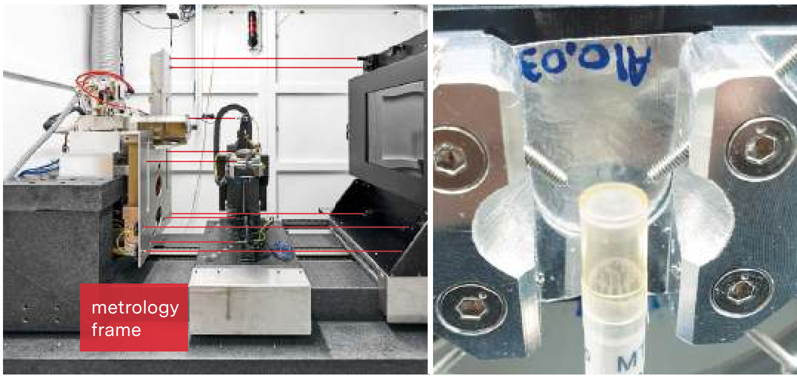


Figure 1: view of the METAS µCT as well as an enlarged representation of the reference spheres attached to the end of the tube to compensate for the focus point drift while scanning an artefact.

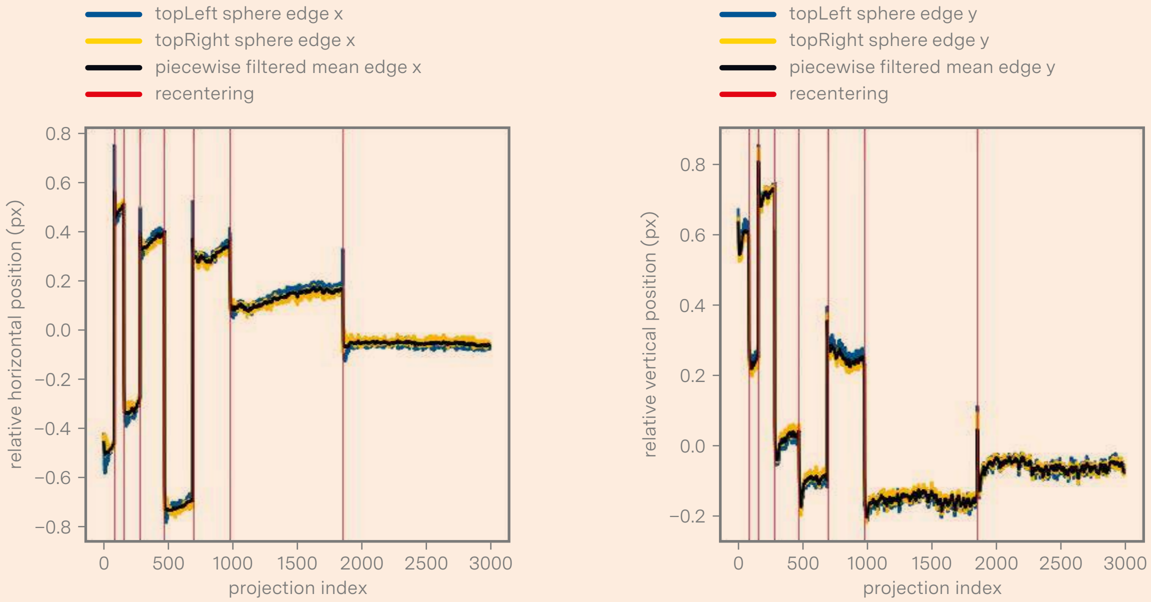


Figure 2: drift of the reference spheres and recentering of the focus point during a scan of our calibration artefact.

point drift. While a flat-panel detector theoretically constitutes a flat surface with perfectly regular pixels, this is not the case in practice. METAS has developed a method that captures and corrects geometric deviations for each pixel. The focus point of the X-ray tube also changes during the measurement due to thermal effects. Two reference spheres in the upper corners of the image (see figure 1, right) allow these position changes to be tracked in real time and corrected for each projection capture (figure 2). The result is a significant reduction in measurement uncertainty in the geometric evaluation of scan data.

Another key topic of computed tomography is reconstruction artefacts caused by cone beam geometry, among other things. METAS-CT addresses these effects by using additional scan trajectories. In addition to the classic circular orbit, vertical lines are used which, in combination with advanced reconstruction algorithms such as TIGRE, significantly contribute to a major reduction in typical distortions.

Ultimately, beam curing is a key issue. It leads to systematic measurement deviations because the X-ray spectrum is altered when the material is penetrated. METAS has developed an innovative method based on the analysis of image noise. The necessary correction is derived from the statistical distribution of the grey value fluctuations (figure 4) – an elegant solution that does not require complex material data. Figure 3 shows how beam hardening artefacts can be significantly reduced, especially in the case of strong contrast transitions between different materials.

These developments make it clear that METAS-CT is not just a piece of equipment, but rather a comprehensive concept that combines hardware, software and metrology. With continuous monitoring and compensation of all relevant influencing variables, METAS-CT enables significantly reduced measurement uncertainty when measuring test specimens – and thus redefines the limits of metrological computed tomography.

Use case: rethinking screw thread analysis

Screw threads are unassuming helices, but their geometry determines the functioning of entire assemblies. The correct interaction of a screw and nut depends not only on the diameter, but also on the flank angle, pitch and dimensional accuracy. This brings us to the comparison we are about to draw: between the classic three-wire method and modern CT analysis.

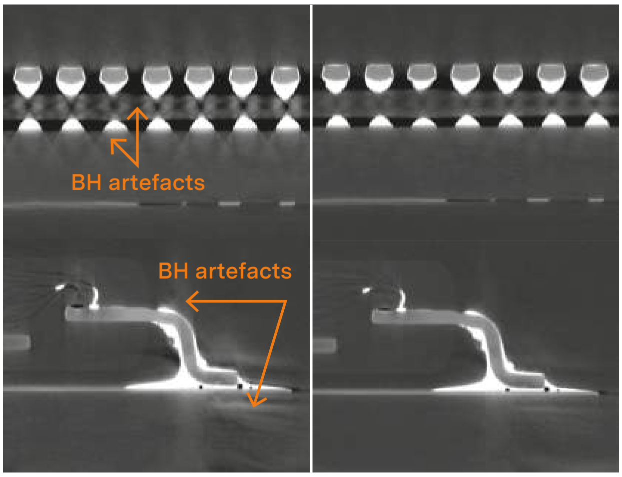


Figure 3: single projection of a USB stick on the right – with pixel beam hardening corrections; and on the left – without correction.

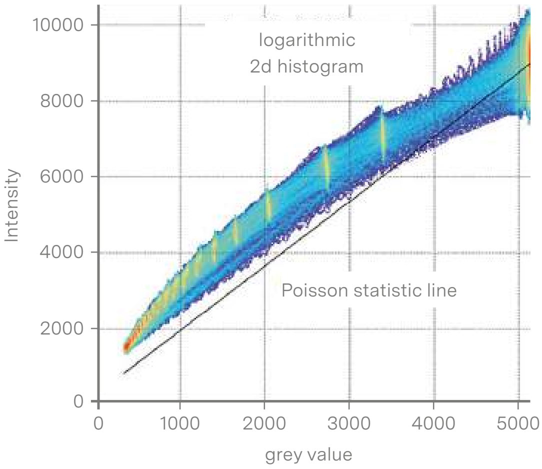


Figure 4: image noise as a function of the greyscale values of a step wedge standard.

The three-wire method has been a widely used measurement method for determining simple flank diameter for decades. Three precise wires are inserted into the thread flanks, the dimension "over the wires" is determined and the flank diameter is calculated based on this, assuming the nominal values for the pitch and flank angle (figure 5 left). The method is robust and delivers impressively accurate results. In a direct comparison, a value of 0.7586 mm with an extended measurement uncertainty of only 1.2 µm was determined for a NIHS S0.9 thread gauge. When measuring the "real" flank diameter, the pitch and flank angle are determined either with three wires of different sizes, which have a higher measurement uncertainty, or with a thread scanner.

But there are limits to this precision. The method makes its measurements at a defined point under ideal conditions. It gives no information about local deviations, asymmetric flanks or slope errors along the helix. In addition, the method is not suitable for internal threads for reasons of accessibility. Today's thread scanners can measure both external and internal threads, but they reach their limits with threads below M1.

This is where computed tomography comes in – and offers a wider range of possibilities. Instead of isolated pieces of information, it provides a complete volume model. After the scan, which achieves maximum accuracy using geometry and artefact corrections, the surface is extracted. Based on this, the actual analysis begins: helical fits along the profile flanks determine the pitch, axial sections provide the flank diameter, and profile analyses over the entire circumference allow the flank angle to be determined – including the smallest asymmetries (figure 5 right).

The advantage is that the CT not only captures the target dimensions, but also the real geometry with its deviations. Burr formation, chatter marks, pores or material inclusions become visible, even in concealed areas. For quality assurance, this means identifying potential problems at an early stage before they lead to malfunctions.

A typical example is a screw that runs stiff in the thread even though the flank diameter is within the tolerance according to the three-wire measurement. In this case, a CT scan reveals the cause, such as minimal fluctuations in the flank angle or periodic slope deviation due to tool vibrations. Such effects can only be detected to a limited extent with conventional measurement methods, especially in the case of small threads – and this is precisely where METAS-CT's strength lies.

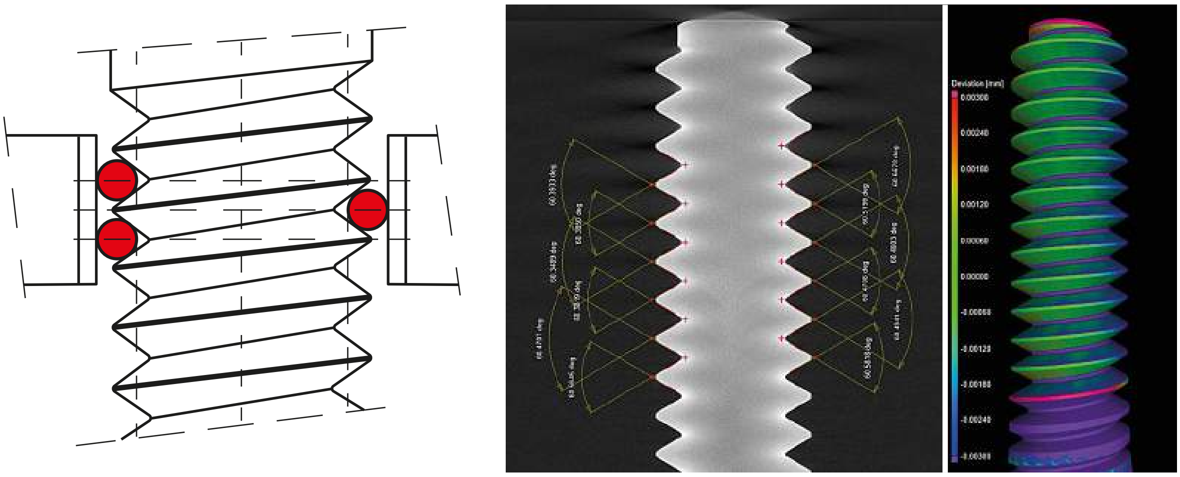


Figure 5: classic three-wire thread measurement (left) and characterisation using CT (right).

In conclusion, the three-wire method remains an indispensable standard for the calibration of threads. However, computed tomography offers decisive advantages for comprehensive geometric characterisation beyond the flank diameter. METAS-CT and the latest developments enable a complete, traceable analysis of threads – including flank angle and pitch – in the micrometre range. As well as marking a technological advancement, this also demonstrates a paradigm shift in industrial measurement technology, especially for extremely small threads. ●

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VDI/VDE 2630 Directives: Computed tomography in dimensional measurement technology.

METAS-CT is designed as a metrological reference system for the development, validation and traceability of CT measurement methods, while commercial metrological CT systems are primarily optimised for robust and efficient industrial measurement tasks.

Aspect	METAS-CT	Commercial CT
Use	Reference/research/troubleshooting	Industry/QA
Traceability	Direct and SI-based	Indirect/artefact-based
Uncertainty	Model-based, 0.3 µm + $2 \cdot 10^{-5} \cdot L$ (unidirectional)	Specification-based, typically reliably traceable in the range of 5–20 µm
System architecture	Open	Closed
Measuring efficiency	Low	High
Flexibility	Very high	Limited

PSI Connect at METAS: scientists in Wabern

In November 2025, the Federal Institute of Metrology METAS in Wabern opened its doors to around 30 young female scientists as part of PSI Connect. This PSI programme brings ambitious and highly qualified female scientists to exciting employers. METAS presented its role as a national metrology institute and demonstrated how scientific expertise, applied research and social responsibility interact.

In addition to insights into various career paths, the event offered practical workshops and direct dialogue with the METAS technical fields. The event underlined the good cooperation between the PSI and METAS in various areas as well as the importance of METAS as a platform for networking, talent development and sustainable dialogue between research and application.

METAS is participating in the NCCR project "Precision"

The State Secretariat for Education, Research and Innovation has approved new National Centres of Competence in Research. With its **Laboratory Photonics, Time and Frequency,** METAS is part of the NCCR Precision.

Together with partners from ETH Zurich, the University of Basel, EPFL, the Paul Scherrer Institute (PSI), the University of Neuchâtel and CSEM, METAS is pushing ahead with the development of a high-precision optical clock. In doing so, Switzerland is strengthening its international leading position in the precise measurement of time and frequency, thus creating new opportunities for research into fundamental physical phenomena. The applications also create a basis for innovation, research and technological sovereignty for Switzerland as a scientific and industrial hub.

More details:
https://www.sbfi.admin.ch/dam/en/sd-web/s2DtVF0Q6021/NFS_Precision_EN.pdf

Joint commitment to Swiss quality infrastructure

On 4 February 2026, METAS, the Swiss Accreditation Service SAS (SECO) and the Swiss Association for Standardization (SNV) signed a Memorandum of Understanding for enhanced cooperation within the Swiss quality infrastructure (QI). The aim is to exploit synergies and further increase the efficiency, visibility and benefits of QI for business, society and administration.

NB: In the next issue of *The Reference.*, we will report in depth on the Swiss quality infrastructure and its importance.

Cooperation agreement between the Azerbaijan Institute of Metrology and the Federal Institute of Metrology METAS

The Azerbaijan Institute of Metrology and the Swiss Federal Institute of Metrology METAS have signed a Scientific and Technical Cooperation Agreement (MOU). It creates a framework for the exchange of expertise, the joint development of metrological skills and the promotion of innovation. The agreement emphasises the key role of metrology for sustainable economic and technological progress.

Science Slam at METAS: science given a platform

The first Science Slam was held at METAS on 9 December 2025. The aim of the event was to communicate science and research in a creative, comprehensible and entertaining way. In a maximum of five minutes, the METAS participants presented their complicated work content from science and metrology and learned to leave out insignificant details and tell a clear story. The event took place in collaboration with the University of Fribourg. Thanks to its extensive experience in conducting Science Slam events, the team from the University of Fribourg was able to prepare METAS participants in the best possible way for the Science Slam and they also created a great atmosphere during the event. *Merci beaucoup* to everyone involved!

New laboratory managers in the field of metrology in chemistry and biology

In 2025, two management positions in the field of metrology in chemistry and biology were filled. On 1 September 2025, Dr Julie Tolu took over as Head of the Laboratory Organic Analysis and References. She has extensive experience in analytical chemistry, in particular in mass spectrometric methods for the detection of pollutants and elements in environmental and biological samples. She also has several years' experience in (co-)managing research projects, including master's students, doctoral candidates and postdocs. Dr Tobias Heck was appointed Head of the Laboratory Biological Analysis and References on 15 October 2025. He brings in-depth expertise in protein biochemistry as well as many years of experience from management positions in the pharmaceutical industry, including in the area of process-analytical technology.

Service

On the trail of PFASs in food and blood

Non-stick coatings for kitchen utensils, grease- and water-repellent textiles, coated paper and cardboard, pesticides or firefighting foams: PFASs are used in many industrial processes and products – but at what price?

Dr Alexandra Jaus

PFASs (***p**er- and poly**f**luoro**a**lkyl **s**ubstances*) are a group of persistent chemicals that have been produced for decades. Due to their water-, grease- and dirt-repellent properties, they are used in numerous industrial processes and products.

Due to the extremely strong carbon-fluorine bonds, PFASs are thermally and chemically extremely stable. While this is beneficial for many applications, PFASs are problematic in the environment where they are poorly degradable (see figure 1). PFASs are persistent and are therefore also referred to as *forever chemicals.* Combined with their often high toxicity and ability to accumulate, PFASs pose a major challenge for research, economy and policymakers.

Health effects of PFASs

PFASs enter the human body primarily via food and can accumulate there. According to current knowledge, some PFASs (e.g. perfluorooctanesulfonic acid, PFOS and perfluorooctanoic acid, PFOA, see figure 2) are known to have harmful effects on health. However, there are still major gaps in knowledge about many PFASs. Risk assessments by the European Food Safety Authority (EFSA) and the German Federal Institute for Risk Assessment (BfR) conclude that there is a correlation between PFAS levels in blood and decreased antibody levels after vaccination. Vaccinations may therefore be less effective. In addition, the two organisations highlight other possible negative effects of high levels of PFASs in the blood, such as on the liver, kidneys or birth weight.

PFASs in the blood of the Swiss population

As part of the pilot phase of the Swiss Health Study, which was initiated by the Federal Office of Public Health (FOPH), human biomonitoring was carried out on several hundred adults. Among other things, the impact of chemicals on health was investigated and various substances were measured in the participants' blood and urine. On behalf of the Federal

Figure 1: places where PFAS traces can be found.

Food Safety and Veterinary Office (FSVO) and together with other partners, the Laboratory Organic Analysis and References at METAS has recently issued a scientific publication[1] in which the levels of 30 PFASs in the serum of 630 persons from the cantons of Bern and Vaud were determined.

The exposure of the population of the two Swiss cantons determined for all substances was in the same range as in other European countries. As in other countries, exposure to PFOS was relevant to health, as almost 4% of participants exceeded the health-relevant threshold for PFOS. This substance was banned in the EU and Switzerland more than ten years ago, with a few exceptions, but is still found in the environment and in the human body due to its long lifespan and high mobility.

Details on this biomonitoring study can be found on the FOPH website[2].

Analysis of fish in Swiss lakes

In order to reduce the intake of PFASs, maximum levels for PFASs apply in particular to drinking water and certain foods of animal origin.

In this context, fish from various Swiss lakes have already been examined for PFASs in the FSVO Laboratory Organic Analysis and References, and METAS published the results in 2023 in a scientific communication[3]. Although fish from known contaminated sites were excluded, this study shows that wild-caught fish can be a source of PFASs in the human diet.

Ongoing projects

The Laboratory Organic Analysis and References is currently conducting a large monitoring study on PFASs in milk and dairy products as well as plant-based foods on behalf of the FSVO. The challenge is, on the one hand, to develop a sufficiently sensitive

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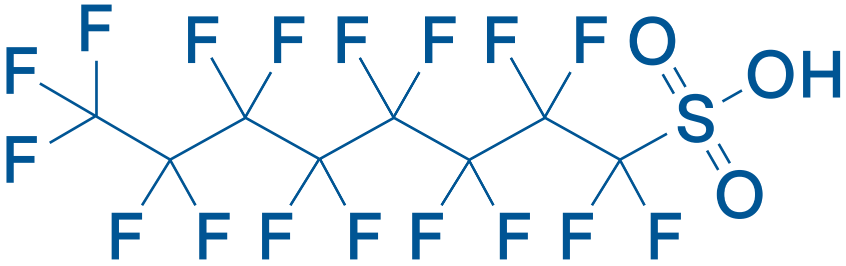
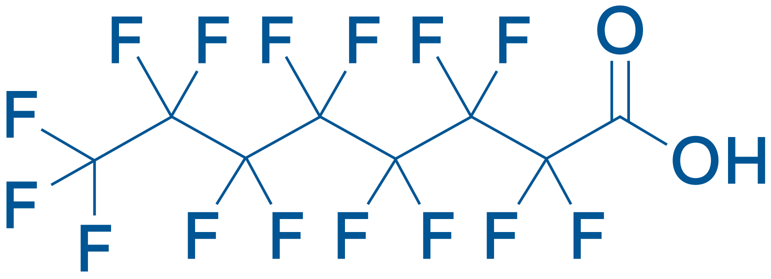
[1] Jaus, A., Fragnière Rime, C., Riou, J., Brüschweiler, B.J., Bochud, M., von Goetz, N. (2025). Serum biomonitoring of per- and polyfluoroalkyl substances (PFASs) in the adult population of Switzerland: Results from the pilot phase of the Swiss health study. *Environment International, 198,* 109382. https://doi.org/10.1016/j.envint.2025.109382

[2] https://www.bag.admin.ch/en/human-biomonitoring-projects-in-switzerland

[3] Jaus, A., Rhyn, P., Valentini, J. (2023). Trace Level Analysis of Per- and Polyfluorinated Substances in Fish from Various Regions in Switzerland. *Toxics, 11*(11), 909. https://doi.org/10.3390/toxics11110909



PFOS (perfluorooctanesulfonic acid)



PFOA (perfluorooctanoic acid)

Figure 2: chemical structure of the two PFASs: PFOS and PFOA.

yet robust method that can detect PFASs in the ultra-trace range. On the other hand, the method must not be extremely complex, in order to be able to efficiently process and analyse several hundred samples. The results for milk and dairy products, as well as results of other animal samples, were recently published by the Swiss Association of Cantonal Chemists and showed that foodstuffs on the Swiss market largely comply with the applicable maximum values. However, PFASs were also found to be widespread and detectable in all food categories at low concentrations: further investigations are therefore urgently needed.

In addition, the laboratory is currently conducting an analysis campaign on PFASs in serum samples from children and adolescents on behalf of the FSVO and in collaboration with the FOPH. The samples come from the menuCH-Kids study, a Swiss survey that aims to provide a better understanding of the eating habits of children and young people aged 6 to 17. Approximately 800 blood samples were collected in this study. These will be analysed in the first half of 2026, in order to quantify the PFASs levels. METAS therefore remains on the trail of PFASs.

Object

The silent layer – PFASs in your daily second skin

PFASs ensure that functional textiles repel water while still remaining breathable. But what happens when they are manufactured, abraded, used or disposed of? Which substances end up in the environment? The questions are complex and the available data is incomplete. One thing is clear: without precise, comparable measurements, the invisible remains blurred. Metrology provides the basis for detecting PFASs, setting limits and responsibly supporting technical innovation.

Research and development

PFASs: harmonising and improving analysis of these forever pollutants

PFASs, as substances associated with persistence and bioaccumulation, are attracting increasing interest because of their health effects. The Laboratory Organic Analysis and References at METAS has recognised the need for action and is participating in the European metrology project known as 23IND13 ScreenFood. It aims to develop metrological tools, including reference materials and analytical methods, in order to ensure reliable measurements and enable comparison of data at a European level.

Marina Chardonnens

A major research and regulatory issue

In recent years, PFASs have attracted increasing interest among the scientific community, health authorities and the general public. Because of their characteristics (persistence, bioaccumulation, adverse health effects), PFASs are now considered a major research and regulatory issue.

PFASs make up a very large family of more than 4000 different compounds. However, only a few of them have been sufficiently studied to provide complete toxicological and environmental data. This is why, to date, only four PFASs, known as PFOA, PFOS, PFNA and PFHxS, are regulated at a European level.

Regulations to protect public health

The European Commission (EC) has set maximum limits for these four compounds in certain foods (EU 2023/915) and limits of quantification (LOQ) (EU 2022/1431) to be observed during analyses. The LOQ is the smallest amount of a substance that any given method (including sample preparation and quantification of the substance) can reliably and accurately quantify. Below this limit, a presence can be detected, but the exact amount cannot be defined. These measures of the EC are aimed at protecting public health and harmonising the monitoring of these substances at member state level. Since 2024, Switzerland has partially adopted these European recommendations on maximum permitted levels.

The other PFASs are still unregulated, and new ones are appearing, known as “emerging PFASs”, in place of those that are regulated.

PFASs in the 23IND13 ScreenFood project

The ScreenFood project aims to develop the metrological tools needed for reliable analysis of PFASs in food. It includes development of robust analytical methods and production of certified reference materials, which are essential for traceability and comparability of laboratory measurements.

In line with European recommendations on PFAS monitoring, ScreenFood is helping to build a metrological network designed to support the harmonisation and international recognition of analytical results. The project, funded by the Euramet network, will run for three years from 2024 and brings together METAS, industry partners and academics, as well as several laboratories and foreign nationals.

The project is divided into several work packages (WPs), to be implemented as follows:

Figure 1: project logos.

METAS is mainly involved in developing certified reference materials (WP1), devising analytical methods (WP2) and organising an inter-laboratory test using the reference materials produced in WP1 (WP4). Since WP4 has not yet started and WP1 and WP2 are well advanced, this article focuses more on these two aspects.

Development of certified reference materials (CRMs)

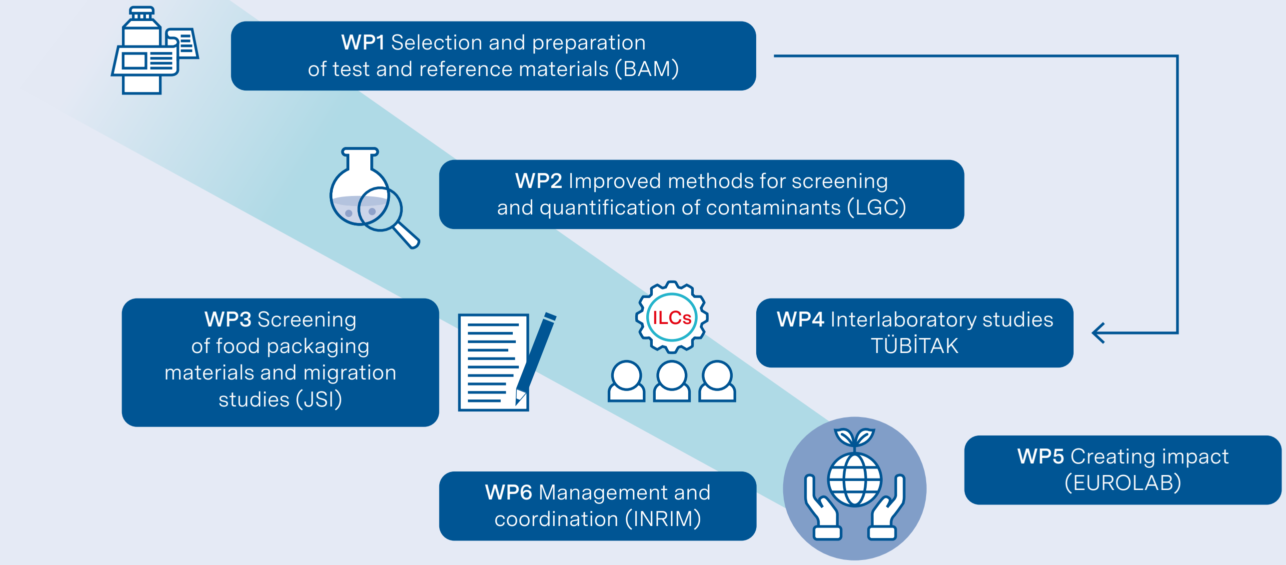
The matrices for the reference materials were selected with a view to meeting specific analytical needs. Two types of matrices were selected: a tomato sauce and a cereal-based product for use in baby food. These choices are based on several criteria. For one thing, there are to be no equivalent or similar materials on the market at the present time. In addition, these matrices are to complement each other in terms of their composition (e.g. different water, fat, starch, sugar contents), making it possible to cover a wide analytical range. Ultimately, these two matrices represent a major analytical challenge, as the LOQ imposed by European guidelines are particularly low for these types of products. This makes them ideal candidates, in a context of demanding development work for metrology purposes.

Once the matrices had been defined, the analytes were selected mainly based on current legislation and health concerns. A total of 24 PFASs were selected.

These two reference materials (tomato sauce and a cereal-based baby food product containing 24 PFASs) are currently being created by the Turkish National Metrology Institute TÜBİTAK. There is no one-size-fits-all method for designing reference materials in food matrices. The procedure differs greatly depending on the matrix chosen and the analytes targeted. In order to achieve quality reference materials, it is essential to ensure that the

Figure 2: measuring instrument: liquid chromatography (LC) coupled with a molecular mass spectrometer (MS/MS).

Implementation plan



WP1 Selection and preparation of test and reference materials (BAM)

WP2 Improved methods for screening and quantification of contaminants (LGC)

WP3 Screening of food packaging materials and migration studies (JSI)

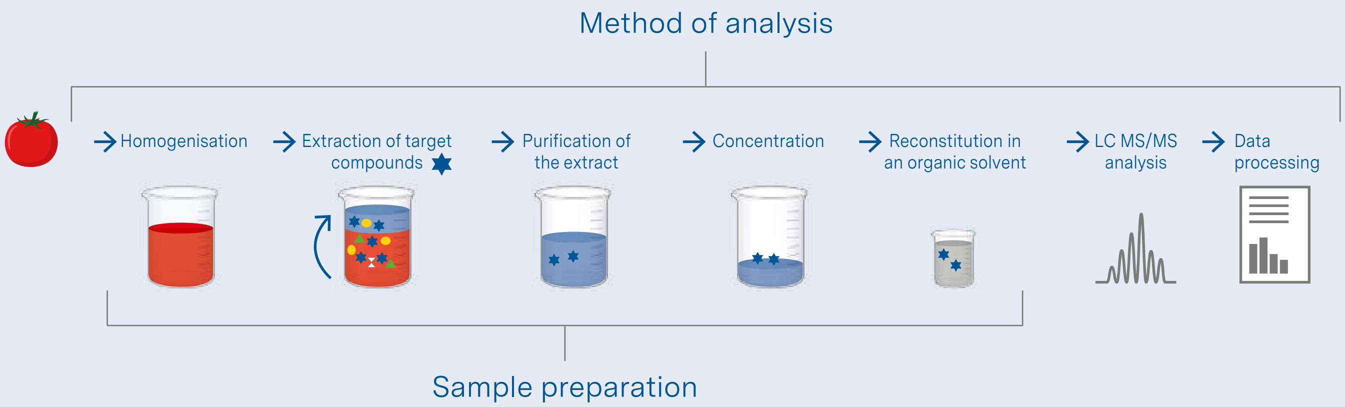
ILCs

WP4 Interlaboratory studies TÜBİTAK

WP5 Creating impact (EUROLAB)

WP6 Management and coordination (INRIM)

Figure 3: implementation of WPs in the ScreenFood project. The parties responsible for each WP are in brackets (slide inspired by INRIM).



Method of analysis

→ Homogenisation

→ Extraction of target compounds

→ Purification of the extract

→ Concentration

→ Reconstitution in an organic solvent

→ LC MS/MS analysis

→ Data processing

Sample preparation

Figure 4: standard procedure of a method for analysing PFASs in a food matrix.

compounds (PFASs) are not altered during the preparation process. Their specific properties, such as their respective volatility, photodegradation or tendency to adsorb to certain surfaces, must therefore be taken into account. This is why different experimental approaches are currently being tested by TÜBİTAK in order to identify the most suitable conditions. METAS and other partners are responsible for conducting preliminary tests on the reference materials created by TÜBİTAK in order to select the best materials.

These materials will subsequently be used for the inter-laboratory tests planned for WP4. The results of these tests will, among other things, establish the certified reference value and estimate the associated uncertainty in accordance with international metrological requirements.

Development of analytical methods

Method development is the process of devising and optimising an analytical procedure to reliably measure analytes, in this case PFASs, in a given matrix, namely tomato sauce and a cereal-based product for use in baby food. It involves identifying the necessary steps (extraction, purification, concentration, etc.), choosing the relevant parameters, and then gradually adjusting these conditions to obtain a method that is efficient in terms of sensitivity, selectivity, precision and robustness.

From an analytical perspective, the main challenge with this project is the ability of the method to achieve the required LOQ, while maintaining sufficient precision and accuracy. This requirement is crucial for the proper characterisation of reference materials.

Sample preparation is a key step in reducing LOQ and must be carefully optimised.

The process of PFAS analysis in food generally corresponds to figure 4.

First, the sample is homogenised. The procedure then consists of extracting only the compounds of interest (here PFASs), while limiting the coextraction of other constituents such as sugars or pigments. Finally, in order to measure such small amounts, the extract must be concentrated prior to analysis.

The compounds of interest are thus identified and quantified by liquid chromatography (LC), coupled with a molecular mass spectrometer (MS/MS) as illustrated in figures 2 and 6. In short, PFASs are separated over time by LC and are detected by MS/MS as peaks. Each peak corresponds to a compound, and its intensity is proportional to the amount present in the sample (see figure 5). The next step is quantification using a calibration line plotted on the basis of solutions of known concentrations (figure 6), which should ideally be certified.

Currently, METAS and the other partners are testing several approaches for 1) extraction of analytes (PFASs) from the matrix (tomato sauce) and 2) preconcentration and purification of the extract, in order to remove substances coextracted with PFASs that interfere with their detection and quantification. At METAS itself, liquid-liquid extraction and

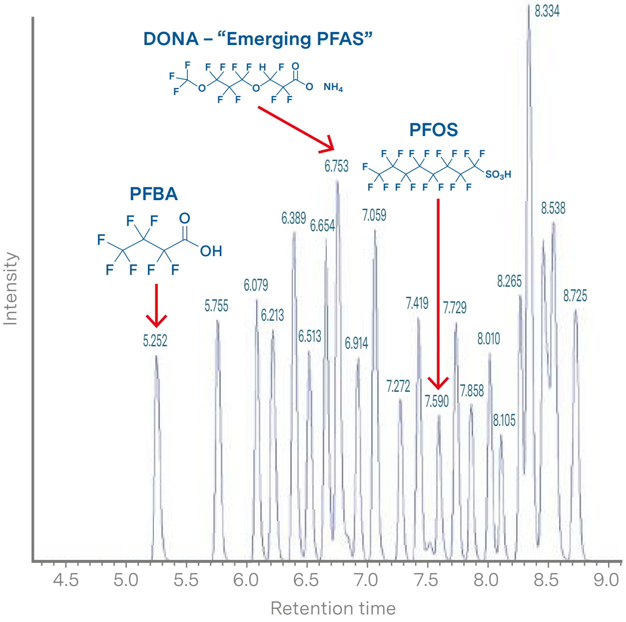


Figure 5: LC MS/MS chromatogram with the following PFASs: PFBA = perfluorobutanoic acid, DONA = perfluoro-4,8-dioxa-3H-nonanoic acid ammonium salt, and PFOS = perfluorooctanesulfonic acid.

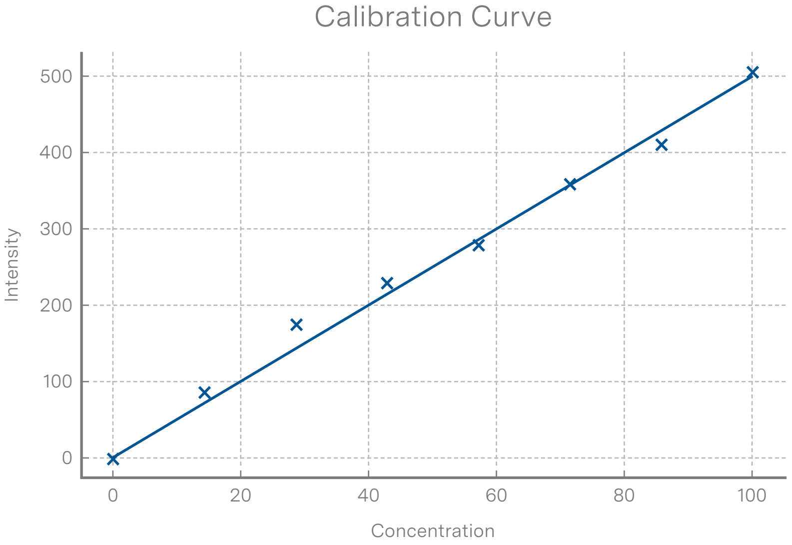


Figure 6: calibration line (or calibration curve), with the concentration of the analyte on the X axis and the intensity measured by the detector on the Y axis.

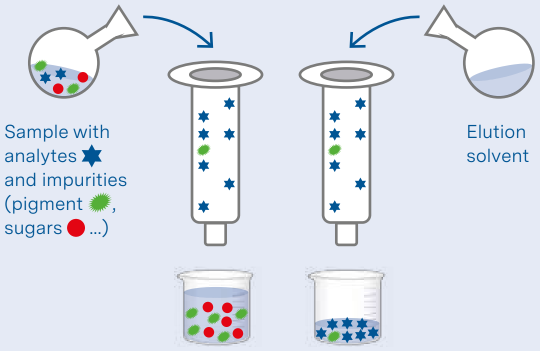


Figure 7: operating principle for SPE.

Figure 8: loading samples into an SPE cartridge.

Figure 9: purified extract after removal of impurities.

ion-pair extraction were evaluated for the extraction step, while QuEChERS (Quick Easy Cheap Effective Rugged and Safe) methods and the use of different SPE (solid-phase extraction) cartridges were studied for purification and preconcentration purposes. SPE involves passing the sample through a solid phase (resin), whose chemical properties allow for selective retention of the desired analytes before releasing them in a small amount of solvent, thereby allowing their isolation, purification and concentration prior to analysis (see figures 7, 8 and 9). As regards the actual process, the PFASs are first trapped on the resin, while sugars, pigments and other compounds that do not interact with the resin pass through the cartridge untrapped and are removed. Then, a specific solvent is used to break the interaction between the PFASs and the resin, which allows them to be eluted. A solution is then obtained containing the solvent and the PFASs, with the other undesirable compounds having been removed in the preceding steps.

Once the method has been developed (i.e. the optimal conditions have been determined), it will proceed to the validation phase. This step involves evaluating different parameters, such as robustness, precision and accuracy. It also determines measurement uncertainty, which is essential for the purpose of quantifying the substances analysed.

The validated method will be used to analyse reference materials during the inter-laboratory test (WP4).

Ensuring reliable measurements for PFAS quantification

The European project known as **ScreenFood** aims to improve the analysis of PFASs in food by developing **certified reference materials** and **robust analytical methods.** These tools ensure reliable measurements that are comparable between laboratories and comply with European regulatory limits. METAS is actively involved in the development of these materials and methods.

https://www.screenfood.eu/

The project 23IND13 ScreenFood has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

Service

New primary standard for flow calibration with hydrogen

METAS has developed a new primary standard for calibrating flow with hydrogen. The system is referred to as *pVTt* because pressure *(p)*, volume *(V)*, temperature *(T)* and time *(t)* play a key role. The system can be operated with both pure hydrogen and hydrogen-enriched natural gas and is used to calibrate critical flow venturi nozzles and gas meters.

Dr Hugo Bissig, Sven Hellmüller

The ideal gas equation $p\ V = n\ R\ T$ is an established relationship in physics and measurement technology between pressure *(p)*, volume *(V)*, quantity of substance *(n)*, absolute temperature *(T)* and the universal gas constant *(R)*. The measuring principle of the *pVTt* system uses this relationship to determine the amount of substance contained in a volume of a real gas, taking into account the compressibility factor.

The reference volumes in the water bath

Figure 1 shows the system. A water bath can be seen in the back right, in which five containers have been immersed. These containers are the reference volumes (three with 200 litres', one with 50 litres' and one with 10 litres' capacity) in which the gas flowing through the measuring section is collected. They have been placed in the water bath to ensure a stable and homogeneous distribution of temperature within the reference volumes.

The reason the water bath is needed is that the gas flowing into the container carries energy. This energy results in a temperature rise in the container, while the increasing amount of gas increases the pressure. In order to cool down the gas in the container

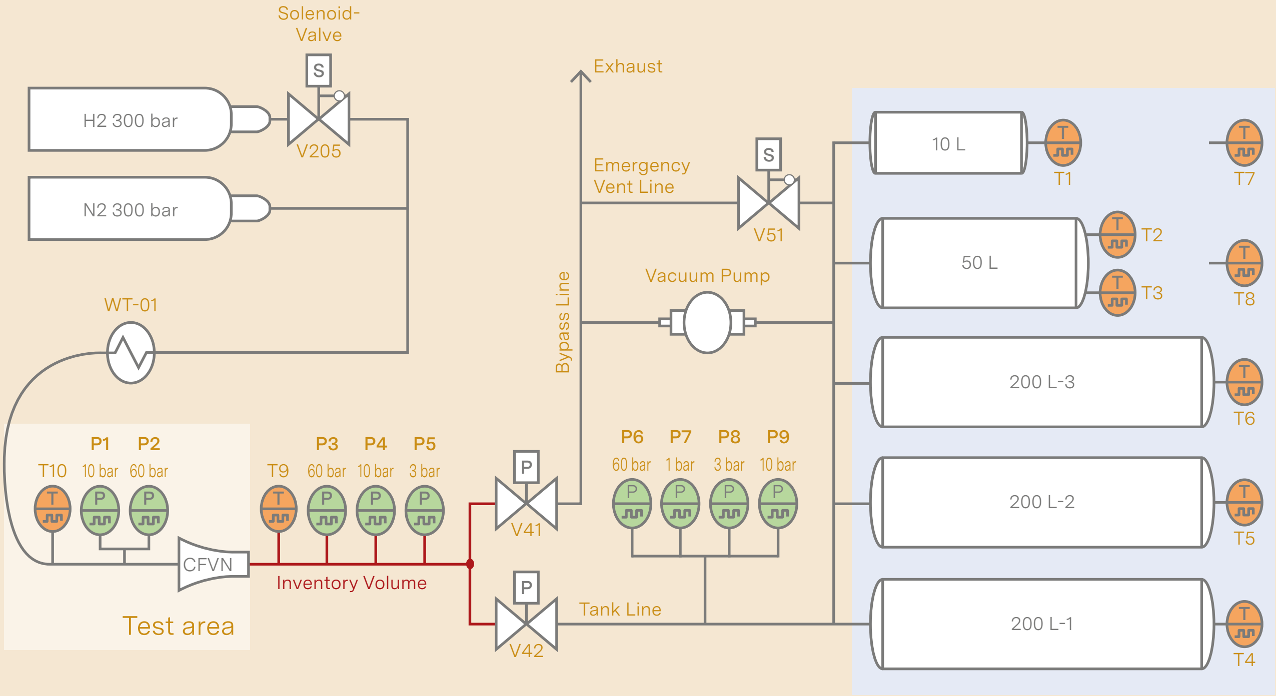


Figure 1: PID diagram of the system with measuring section and valves (centre) as well as water bath with containers (bottom right).

Figure 2: overview of the system with control PC (front left), measuring section with valves (rear left), water bath with containers (rear right) and electronics cabinet (front right).

again, heat must be extracted from the gas. The heat flows through the wall of the container into the cooler water, whereby the supplied energy is extracted from the water in the bath via a heat exchanger. In this way, the water and the gas in the container are cooled down to around 20°C and kept stable after the flow has been stopped.

How the amount of gas collected is determined

A vacuum is created in the reference volume before making a measurement, so that only a very small amount of gas remains in it. The pressure and the temperature are measured and the density of the gas can be determined under the conditions as at the start of the measurement. The gas is then diverted into the reference volume at a constant flow rate. The time of this diversion determines the timestamp of the start of the measurement. In the meantime, the gas flows into the reference volume, increasing the pressure and temperature.

As soon as the desired pressure is reached, the gas is directed away from the reference volume at a constant flow rate. This shift determines the timestamp of the end of the measurement; the difference between the two timestamps determines the measuring time. The temperature of the gas in the reference volume is then stabilised to prevent the pressure in the reference volume from changing in turn. After a certain waiting time, the data from the pressure and temperature sensors will show that no further changes are occurring. At this point, the pressure and the temperature of the gas can be determined and the density can be calculated.

The average mass flow is calculated using the densities at the start and end of the measurement, the measurement time and the calibrated volume content of the reference volume. If the volume flow is of interest, the mass flow is divided by the density at the measuring section.

What are critical flow venturi nozzles

Critical flow venturi nozzles are used in fluid technology to generate a constant gas flow. The geometry of the constriction is defined in the ISO 9300:2022 standard. If the pressure upstream of the nozzle is sufficiently high, the gas flows through the constriction at the speed of sound and this flow rate is maximum and independent of the pressure downstream of the nozzle (critical flow rate). The calibrated venturi nozzles are then used as a reference standard for calibrating measuring instruments.

Applied flow range

The system is designed for the calibration of household gas meters and reference meters of calibration systems. The targeted flow range is (0.1 to 250) g/min at pressures up to 40 bar, with an extended measurement uncertainty of 0.3% being aimed for. Extensive validation and characterisation measurements are currently being carried out to determine the main uncertainty components and their contributions. ●

Metrology in general

On the future of metrology

In 2025, the metrology community celebrated the 150th anniversary of the Metre Convention[1]. Can this historic step towards a harmonised system of units teach us anything about the metrology of the future? Or are there precursors from the future existing in the present that allow us to outline development scenarios for metrology?

This image was generated by AI.

Dr Hugo Lehmann

As science-minded people, metrologists are sceptical when it comes to predicting the future and would probably agree with Niels Bohr, who once famously remarked: “Prediction is very difficult, especially if it’s about the future.” But in specific areas – for example, when calculating planetary orbits – physicists allow themselves to make predictions, namely for descriptions of nature based on experimentally verified formulas. But the future of society, or even just the stock market, does not follow celestial mechanics!

Nevertheless, perhaps there are harbingers of future development that are already present in the here and now. Science fiction author William Gibson put this very aptly: *“The future is already here, it’s just not very evenly distributed.”* Such signals of the future exist in the present, but are not perceived as such or are only recognisable in specific social strata.

However, if the future is already here, this also means that well-trained artificial intelligence (AI) should be able to extract these signals from data. This is why we want to use various AI chatbots to generate a future scenario for metrology. We used Copilot[2], ChatGPT[3] and Perplexity[4] to test this idea.

AI as a detector for the signals of the future

The three AI chatbots were fed with the following prompt:

“Can you give me a few signals from the future that will significantly alter the field of metrology in 5–10 years’ time?”

The outputs of the AI chatbots are listed in the table 1-3, although the texts have been shortened.

Discussion

AI, digital twins, quantum technologies, metrology in the value chain and the networking of measuring devices were identified by all AI chatbots as key drivers of the future. Sustainability was only mentioned by Copilot and ChatGPT. It is interesting that ChatGPT mentioned social impacts such as trust in measurement results and the shortage of skilled workers, even without having been specifically asked (not listed in the table due to space constraints). Perplexity’s answers were somewhat more detailed.

[1] https://www.bipm.org/en/bipm-anniversary

[2] Microsoft. (2026). M365 Copilot (GPT-5 Chat Model), https://m365.cloud.microsoft/chat/

[3] OpenAI. (2026). ChatGPT (GPT-5.2), https://chatgpt.com/

[4] Perplexity AI. (2026). Perplexity AI – AI-supported search and answer platform, https://www.perplexity.ai

Answers from Microsoft Copilot to an open question on future signals from metrology (5–10 years):

Signal #		Copilot
1	Topic	**Quantum metrology**
	Signal	Advances in quantum computing and quantum communication
	Effect	Highly precise time, frequency and field measurements; possible new SI standards
2	Topic	**AI-supported measurement systems**
	Signal	Integration of machine learning into measurement processes
	Effect	Automated calibration and error detection; self-calibrating instruments
3	Topic	**Digital twins for measurement processes**
	Signal	Industry 4.0 and virtual models
	Effect	Real-time simulation and optimisation; less physical calibration
4	Topic	**Blockchain for traceability**
	Signal	Growing importance of data integrity
	Effect	Forgery-proof measurement data and digital certificates
5	Topic	**Sustainability-driven metrology**
	Signal	Climate change and resource conservation
	Effect	Central role for CO_2, energy and cycle measurements; new “green” metrology
6	Topic	**Nanotechnology and new materials**
	Signal	Advances in materials science
	Effect	More precise measurements at the atomic level; new sensors for extreme conditions
7	Topic	**Networked measuring systems**
	Signal	Increasing connectivity of devices
	Effect	Real-time measurement data from global networks; new challenges in data quality and security

Table 1: Copilot-generated responses to an identical prompt; editorially abbreviated.

Despite these differences, the responses appear consistent, with no hallucinations. In order to consolidate these three sets of information, Copilot was asked to merge the signals outlined above into the six most important fields. Here are the key points it provided:

Six key developments in metrology (5–10 years)

1. AI-supported, software-dominated measurement systems

Measurement chains are becoming data-driven; AI takes over detection, control and uncertainty models. Software reliability is becoming key. *Implications:* guidelines for AI in measurement chains, reference data, procedures for software validation and release control.

2. Digital traceability

Calibrations are becoming digital, automated and condition-based. Certificates are becoming machine-readable, test paths API-based. *Implications:* pilot testing of digital certificates, guidelines for digital traceability and continuous compliance.

3. Metrology in the process (in-line/edge) and IoT measurement networks

Measurement is moving directly to the machine/product; networked sensor fleets deliver real-time quality data. *Implications:* edge calibration, reference services for time/frequency, test beds for mobile/collaborative measurement systems.

Answers from ChatGPT to an open question on future signals from metrology (5–10 years):

Signal #		ChatGPT
1	Topic	**AI is transforming from analysis partner to measurement partner**
	Signal	Measurement systems make autonomous decisions (strategy, abort, recalibration)
	Effect	Traditional measurement specifications (static, standards-based) come under pressure
2	Topic	**Digital calibration chains**
	Signal	Cloud certificates, digital measuring instrument twins, blockchain-like traceability
	Effect	Metrology shifts from paper evidence to real-time proof of trust
3	Topic	**Metrology enters the process**
	Signal	More in-process/in-line measurement technology with lower individual accuracy but high data intelligence
	Effect	Traditional laboratory metrology loses monopoly position
4	Topic	**Measurement uncertainty becomes context-dependent**
	Signal	Measurement uncertainty is more dependent on application, risk and purpose of decision
	Effect	Metrology becomes more closely linked to decision and risk theory
5	Topic	**Software becomes the actual measuring device**
	Signal	Increasingly software-dominated measurement systems (sensor + model + AI)
	Effect	Metrology must actively integrate software engineering
6	Topic	**Quantum metrology leaves the research lab**
	Signal	Industrial applications of quantum-based sensors (time, gravity, magnetic field)
	Effect	Metrological expertise becomes even more specialised, but also more strategic
7	Topic	**Sustainability becomes a metric**
	Signal	Demand for carbon footprint of measurements, instruments and calibrations
	Effect	“Good metrology” becomes ecological metrology

Table 2: ChatGPT-generated responses to an identical prompt; editorially abbreviated.

4. Digital twins and virtual validation

Virtual images of measurement systems enable simulation, uncertainty analyses and targeted reduction of physical calibration.
Implications: validating models, criteria for virtual calibrations, interfaces to product life cycle management and manufacturing systems.

5. Quantum metrology and new sensor technology

Quantum-based time/frequency standards and new quantum sensor platforms are becoming practical.
Implications: university transfer programmes, infrastructure for distributed time services, guidelines for the traceability of new types of sensor technology.

6. Sustainability-driven metrology and focus on trust

Measurements for CO_2, energy and the circular economy are gaining in importance; trust and traceability are becoming the focus.
Implications: environmental assessment methods, remote calibration, “trust by design” framework.

Have we at METAS recognised these signals of the future?

From the writer’s perspective – with his sparse but natural intelligence – the consolidated future scenario makes sense on the whole. The topics that appear most likely from today’s perspective are mentioned, which is not surprising given the way AI works.

Answers from Perplexity to an open question on future signals from metrology (5–10 years):

Signal #		Perplexity
1	Topic	**Fully connected in-line metrology**
	Signal	Measuring systems are integrated directly into production lines, provide real-time data and control processes automatically
	Effect	Digital twins continuously use measurement data for calibration, monitoring and predictive quality control
2	Topic	**AI- and data-driven metrology**
	Signal	Use of deep-learning image processing in optical inspection; software that automatically generates measurement programmes and that models measurement uncertainty based on data
	Effect	Quality decisions become increasingly based on probabilistic, contextual assessments of large datasets
3	Topic	**Portable, robot-assisted and contactless**
	Signal	Trend towards portable 3D measuring systems and handheld scanners directly on the machine
	Effect	Metrology robots and collaborative measuring cells perform automated, repeatable measurements even on complex and large components
4	Topic	**New quantum sensors**
	Signal	Research projects on quantum-based norms that are already being tested as references in metrology institutes
	Effect	Quantum sensors enable standards and measurements with significantly higher accuracy and stability
5	Topic	**Service- and cloud-based metrology**
	Signal	Metrology is shifting to service and cloud models: evaluation, protocols and reference comparisons are increasingly carried out remotely
	Effect	Common data rooms ensure end-to-end traceability and enable process benchmarking along the value chain

Table 3: Perplexity-generated responses to an identical prompt; editorially abbreviated.

However, topics such as medicine, life science and biotechnology are missing. This may be due to the fact that metrological issues are not the focus in these specialist areas. The field of digitalisation seems to be more aligned with AI, and themes related to this are very much included in the overview. However, the improbable, coincidental but nonetheless possible, or even the interdisciplinary, remain beyond the grasp of AI. Nevertheless, the overview invites you to review the focus of research and innovation at METAS. A glance at our project portfolio shows that activities are currently underway in all the above-mentioned areas. Phew, so far so good, lucky again! Or is it just a self-fulfilling prophecy, since AI is only tapping into metrology sources for this task anyway, thus creating a vicious cycle?

> “The future is already here, it’s just not evenly distributed.”
>
> **William Gibson**

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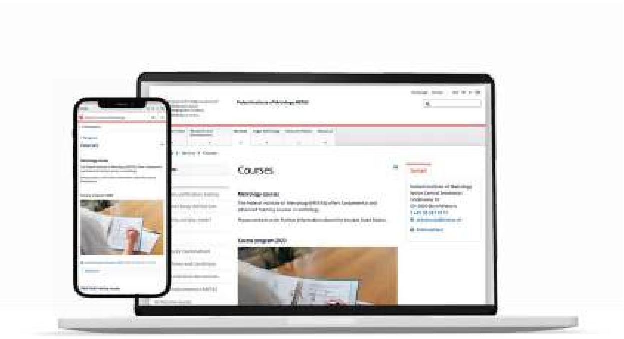

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