Physikalisch-Technische Bundesanstalt
National Metrology Institute

Into the Future
with Metrology

The Challenges of Our Environment and Climate

The Challenges of Our Environment and Climate

sustainable – global/local – quantitative – interdisciplinary – connected

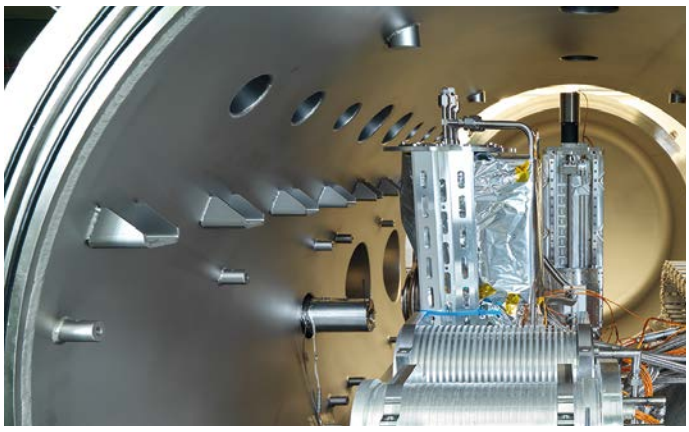
When it comes to climate and the environment, in many cases, the eleventh hour is already upon us. But to make reliable statements about climate change, quantitative, accurate and reliable measurements are needed – and this in a highly complex system with a very large number of relevant physical and chemical measurement parameters. As environmental and climate processes know no boundaries, one of PTB's most important partners in climate monitoring is the World Meteorological Organization (WMO), which operates, among other things, the Global Atmosphere Watch (GAW) Programme and the Global Climate Observing System (GCOS). The latter defines, for example, 54 essential climate variables (ECVs), i.e. physical, chemical and biological measurement quantities designed to describe the global state of the climate. Changes in these quantities are small; in order to recognize developments unambiguously, long-term, highly accurate and reliable measurements (i.e. measurements that are traceable to the International System of Units SI) are necessary. Therefore, PTB has increased its participation in the traceability of these measurements.

When it comes to environmental protection, the German Environment Agency (UBA) is an important partner of PTB; the legal framework is provided by European framework directives for air and water, among other things. PTB is also responsible for the traceability and certification of vehicle exhaust gas and particle measurements and is continuously expanding its capabilities in this field. Within the framework of the radiation protection network, PTB maintains close contact with the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), the control centers of the Integrated Measurement and Information System (IMIS), which monitors radioactivity in the environment, as well as with the measuring stations of the federal and state governments. PTB is very active in European research programs such as EMPIR and is highly involved in the European Metrology Networks (EMNs) which are derived from these programs. PTB communicates intensively with the various stakeholders in legislation, standardization, industry and research in order to achieve and support continuous improvement and expansion of these activities. Please feel free to contact us!

Climate

Satellites: the view from space

How much does the greenhouse effect heat up the earth? Which rainforests are being cut down? Where are CFCs still being released into the atmosphere? In order to answer such questions, data from measuring instruments installed on satellites are continuously evaluated and made freely available within the framework of the ESA-SENTINEL missions and the planned EnMAP mission of the German Research Center for Geosciences (GFZ) and the German Aerospace Center (DLR). Future missions will make it possible to make reliable statements about the complete energy balance of the Earth. The planned ESA mission TRUTHS measures the solar irradiance. For the emitted radiation of the Earth, the planned ESA Earth Explorer FORUM will be in charge. PTB is involved in its characterization even at this early stage to a great extent. Other essential climate variables which are measured from space by radiation thermometry or radiometry are the temperatures of water surface and atmosphere as well as the concentrations of trace gases and aerosols. PTB ensures that the respective measuring instruments and the detector and radiator standards are traceable to the International System of Units before they are used. PTB has been supporting ESA for many years, for example by means of its Reduced Background Calibration Facility, a measuring facility that is unique in Europe for the calibration of instruments in remote sensing in the infrared spectral range. With its measurement capabilities in the far infrared range, PTB is unique in the world. With a new spectral comparator measurement setup, PTB will, in the future, also be able to meet the specific requirements of remote sensing in the spectral range from the UV to the infrared.



The interior view of the source chamber of the Reduced Background Calibration Facility 2. In the foreground: the reference blackbody radiators against which, for example, the FORUM and GLORIA reference sources are calibrated.

An accurate view of the Sun

The radiation of the Sun is partially absorbed by smaller components of the Earth's atmosphere that are among the most essential climate variables (such as ozone, nitrogen oxides,

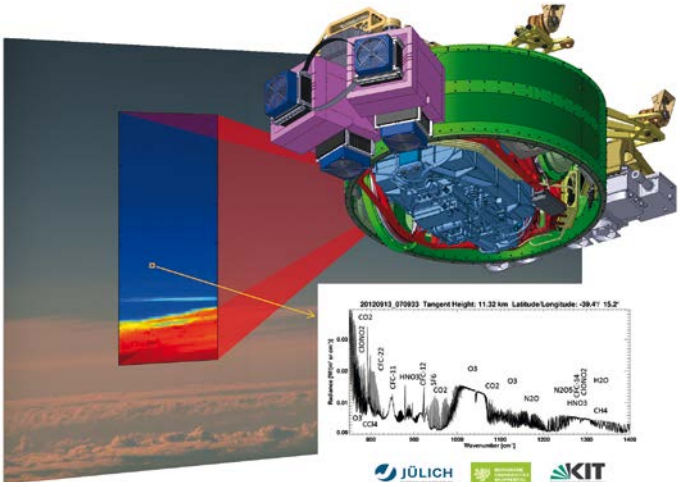
water vapor and aerosols) or partially reflected back into space. On the basis of radiometric measurements of terrestrial solar radiation, the respective essential climate variables can therefore be determined. And furthermore, the effects on health (UV radiation) or on the energy production in PV systems can be quantified. PTB has been cooperating closely with the Physical Meteorological Observatory Davos/World Radiation Center for many years to enable the traceability of solar measurements and of derived quantities such as the ozone column and the column-integrated optical properties of aerosols to the SI with the smallest possible uncertainties. For this purpose, the national standard for the spectral irradiance (a high-temperature blackbody radiator) as well as the spectrally tunable laser systems of PTB are used to calibrate the required spectrally resolving and spectrally integrating measuring instruments.

An array spectroradiometer characterized at PTB faces the rising sun at the Izaña Atmospheric Observatory (IZO) in Tenerife during an international comparison measurement campaign to determine the ozone column.

The atmosphere: the air around us

A key task of climate monitoring is the observation of the most important atmospheric components that influence the greenhouse effect. In addition to using ground stations and satellites, the WMO's Global Atmosphere Watch (GAW) Programme also takes measurements in the atmosphere, for example using aircraft, balloons and drones. In all of these fields, PTB provides metrological support. PTB is active in the SI traceability of the measurement of H_2O, CO_2, CH_4, N_2O, volatile organic compounds (VOCs) and soot aerosols. It develops national standards and measurement procedures for this purpose, for example, on the basis of optical-spectroscopic measurements with tunable lasers or Fourier Transform Infrared Spectrometers (FTIRs). Another important topic is innovative aerosol metrology up to primary particle number standards or the traceability of black carbon measurements. Where the calibration of optical spectrometers is not possible (or where stable, SI-traceable reference gases are not available), PTB offers the most important input quantity for spectroscopic remote sensing measurements by measuring spectral reference data of the important molecules. At the same time, PTB develops accurate, calibration-free laser spectrometers as metrological transfer standards that, if required, can also be designed in such a way that they can be used in the field – for example, on research aircraft such as HALO. It is intended to further expand the fascinating possibilities of spectroscopic transfer standards, absolute spectral data and aerosol metrology.

For many years, PTB has also ensured the traceability of airborne remote sensing measurements with regard to the composition and dynamics of the atmosphere. These measurements are performed during the various missions of the GLORIA imaging infrared Fourier spectrometer of Forschungszentrum Jülich (FZJ) and the Karlsruhe Institute of Technology (KIT) on the HALO research aircraft. For the global ground-based measurements of the infrared reflection of the atmosphere performed within the framework of the worldwide Baseline Surface Radiation Network (BSRN), PTB has developed and implemented a traceability concept in cooperation with the World Radiation Center in Davos, thus allowing it to continue ensuring the comparability of these measurements in the future.



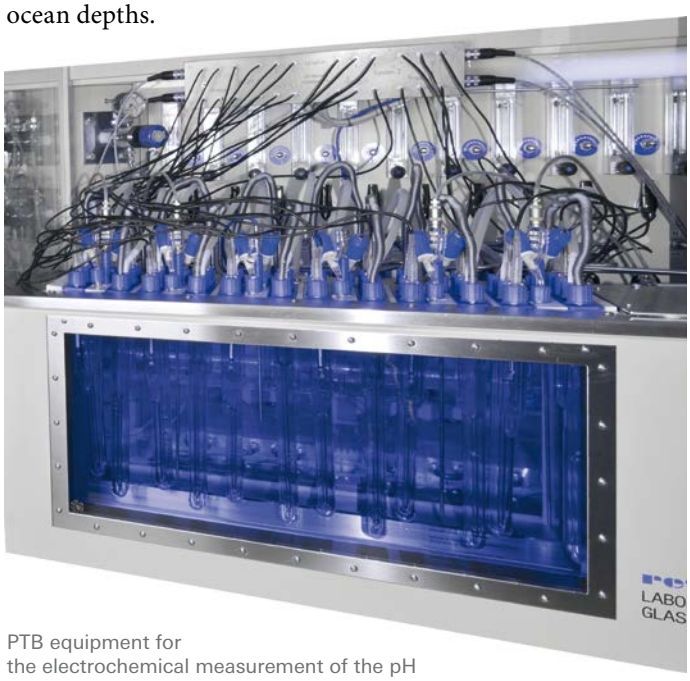
The GLORIA infrared Fourier spectrometer is regularly taken on the various missions of the German Aerospace Center's HALO research aircraft. It can carry out more than 16,000 spatially and spectrally resolved atmospheric observations simultaneously and is regularly recalibrated by PTB.

Oceans: saltier and more acidic

Within the scope of climate research, researchers measure several important properties of the world's oceans, two of which are salinity and pH. Climate change is changing the density and salinity of seawater. As a result, the major ocean currents (such as the Gulf Stream) which have a major impact on the climate themselves may change (albeit very slowly). For this reason, measurement results must be comparable over long periods of time and must have measurement uncertainties that are as small as possible. Within the framework of a European research project, PTB has implemented the traceability of salinity measurements to the SI system with suitable measurement uncertainties.

In a joint project with the Leibniz Institute for Baltic Sea Research in Warnemünde, PTB has, for the first time, made optical measuring methods (which are most frequently used in oceanography) traceable to the metrologically sound, electrochemically measured pH value. This will make it possible

to measure the pH values in oceans in such a way that they are comparable in the future, which is of particular interest for quantifying the acidification of the oceans caused by anthropogenic CO_2. This acidification influences the diversity of marine microbes and coral growth. PTB is planning to further expand its primary measuring stations in the future, e.g. for applications at high pressure as is prevalent in great ocean depths.



PTB equipment for
the electrochemical measurement of the pH

How humid, how warm?

Everyone talks about carbon dioxide – but plain water in the form of humid air is one of the strongest greenhouse gases. In other words, it is an essential climate variable. PTB is one of the main participants in the broad introduction of the metrological principle of traceability for the measurands of water content and gas humidity, thus making the measurements more reliable and comparable. With the HAI and SEALDH laser hygrometers, it has developed the world's first airworthy, calibration-free H_2O transfer standards – in addition to its existing primary standard – and has successfully used them on renowned research aircraft such as HALO and LEARJET. HAI is an extremely fast hygrometer developed especially for use on airplanes even when traveling through clouds. It is the only instrument in the world that can simultaneously and precisely determine which part of the water is present in the atmosphere as droplets or ice particles and which part is present in the gas phase. This data helps to better understand natural and man-made cloud formation processes and their influence on the climate. PTB is working (beyond the radiation-thermometric and radiometric methods of remote sensing) on measurement concepts that can be used to determine the temperatures of atmospheric layers better than before by means of high-resolution molecular spectra.

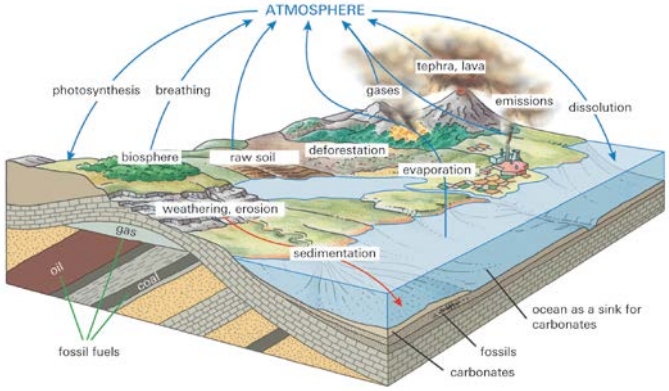
DLR's HALO research aircraft above the rainforest. Also on board: HAI, PTB's highly accurate humidity measuring instrument specifically developed for use in airplanes and in clouds.

Human influences on the greenhouse gas cycle

Human civilization disturbs the natural cycle of the greenhouse gases (GHGs) like CO_2, CH_4, N_2O and H_2O. The concrete anthropogenic impact can be determined using various methods. When measuring GHG isotope signatures, advantage is taken of the fact that the ratio of different isotopes of an element can differ according to their origin. For example, the CO_2 produced during combustion of plants and fossil fuels (= ancient plants) has a different ratio between ^{12}C and ^{13}C than the CO_2 in the atmosphere. Methane is a greenhouse gas 30 times stronger than CO_2 which comes from thawing permafrost, natural gas production, leaks in natural gas pipelines and intensive livestock farming. Here, different C/H isotope signatures are found. The same is true for the N isotopes in N_2O, which is mainly influenced by intensive agriculture and traffic emissions, or for the H/D and $^{16}O/^{18}O$ isotopedistribution in water. The latter is an important indicator of transport processes between the oceans, the atmosphere and the biosphere, and for condensation processes in clouds. In order to determine such isotope ratios on a global scale in the long term and with high accuracy, new reference materials and primary isotope ratio measurement methods for the different molecules are needed. In addition, optical transfer standards for traceability and mobile spectroscopic isotope measurements (e.g. on airplanes and balloons or at remote measurement sites) need to be developed or improved. Under field conditions, isotope ratios are currently determined mainly by optical/spectroscopic methods (laser or FTIR), which requires a robust metrological link between the optical measuring methods and the mass spectrometers, which are usually only operated in stationary mode. PTB works intensively with both methods. In EMPIR projects such as SIRS and STELLAR, PTB's work aims at supporting the Global Atmosphere Watch Programme of the WMO and of the European Metrology Network (EMN), "Climate and Ocean Observation (COO)".

Another innovative method is the radon tracer method. This method uses the naturally occurring radioactive noble gas isotope ^{222}Rn (radon), which originates from the soil and is therefore, in deeper layers of the atmosphere, found in higher concentrations than in higher layers. ^{222}Rn can therefore be used to obtain data for transport calculations (e.g. of CO_2) and to validate models for calculating dispersion in the atmosphere.

In this way, data for climate models will be available in the future with smaller uncertainties, allowing a distinction to be made between natural and anthropogenic greenhouse gases. For this purpose, "traceRadon", a European model project coordinated by PTB, is offering traceability to the SI for the first time for the rapidly growing number of users of flux measurements around the world such as ICOS or ANSTO. In addition, outdoor air measurements of ^{222}Rn provide a valuable database for efficiently improving the radiation protection of the European population without driving up the costs involved.

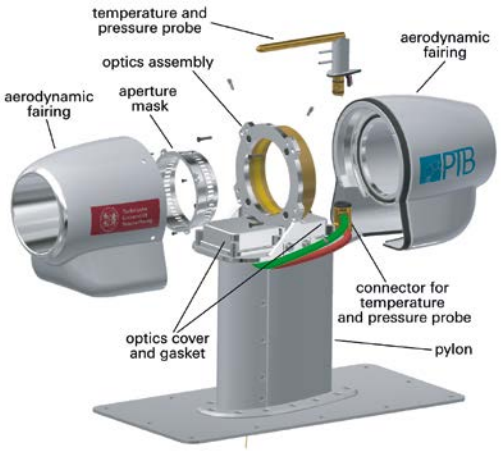


The global cycle ensures a constant change between bound and re-released carbon dioxide. (Fig.: Ernst Klett Verlag, Stuttgart, Wolfgang Schaar, Grafing, based on Barbara W. Murck et al.: Dangerous Earth. John Wiley & Sons Inc. 1997, p. 25)

Climate / Environment

Global greenhouse gas fluxes: Local sources and sinks

Anyone who wants to understand climate change and the effects of environmental pollution must do more than just record the current state by measuring the local CO_2 concentrations, for example. It is necessary to quantify the sources and sinks of the problematic substances: of water vapor, greenhouse gases (CO_2, CH_4, N_2O), pollutants such as N_2O from fertilization, NH_3/CH_4 from intensive livestock farming or NO_x and aerosols/fine dust from traffic. What must be measured is how much substance is exchanged, how fast and where between air/soil/ocean/biosphere, how large these substance fluxes are and how they change. The essential tool for this is the eddy covariance (EC) technique, where the temporal fluctuation of the substance concentration, the gas temperature and vertical wind speed is determined simultaneously and rapidly. For this purpose, PTB and TU Braunschweig are developing a new, very fast laser hygrometer transfer standard for use on their new research aircraft. The aim is to investigate – in cooperation with further partners – in which way, for example, the decline of polar sea ice affects the Arctic heat balance. Projects on CH_4 release from landfills or bogs are also planned. Further methods for the determination of substance fluxes aim to record spatial concentration gradients by means of spectroscopic methods in combination with dedicated gas release and detection studies as have been investigated in the IMPRESS and IMPRESS2 projects on PTB's 600 m reference measuring section. It is envisaged to further develop these methods.



Laser hygrometer transfer standard for flux measurements on the new research aircraft of TU Braunschweig. (Figure: Felix Witt, TU Braunschweig)

"Thick air" in the cities

Pollutants, for example from car exhaust gases such as nitrogen oxides or soot particles/fine dust, are harmful to human health, the environment and the climate. PTB ensures that measuring instruments for exhaust gas measurement or for monitoring air quality are reliable. PTB cooperates closely with the Federal Ministries of Transport and Environment and the Verification Offices of the German Federal States on the subject of traffic emissions and with the German Environment Agency, which is the German EU reference laboratory for air pollution monitoring, on the subject of environmental pollution. The Directive on Ambient Air Quality and Cleaner Air in Europe (2008/50/EC) stipulates the monitoring of priority air pollutants in Europe. As new pollutants that are classified as priority substances or as limit values (e.g. for NO, CO or fine dust) are defined more strictly, PTB is constantly faced with new metrological challenges. For example, it is involved in the "MessBAR" project, which is financed by the Federal Ministry of Transport and Digital Infrastructure. The basic idea behind this project is that determining the vertical distribution of pollutants is currently a very time-consuming and laborious process. However, it plays an important role in the transport and distribution of particles and other air pollutants such as

The ALICE quadrocopter takes air samples that can then be further analyzed in the laboratory. In addition, it measures temperature and humidity profiles up to 1000 m altitude. (Photo: Astrid Lampert, TU Braunschweig)

nitrogen dioxide. In order to improve predictions, validate transport models and verify measures for pollutant reduction, TU Braunschweig, PTB, the German Environment Agency and other partner organizations are developing and validating in MessBAR a flying, drone-based measurement system. Three quadrocopters will be equipped with miniaturized sensor technology for fine dust, soot, nitrogen oxides and ozone and are designed to determine the spatially resolved 3D pollution levels in and around cities and conurbations up to a height of one kilometer.

Environment

What comes out of the exhaust pipe?

The Diesel scandal, nitrogen oxide limits, driving bans in German city centers – all these topics are currently causing a lot of discussion. PTB monitors pollutants in vehicle exhaust gases on behalf of lawmakers, carries out conformity tests for exhaust and particle measuring instruments and calibrates measuring instruments as well as transfer standards for verification authorities and testing institutions. One focus of PTB's work is the development of primary and secondary particle number standards to ensure the traceability of (nano-)particle number measurements to internationally recognized standards. In the near future, the traceable measurement of the particle number concentration in the exhaust emission test (AU) will be required by law; for this purpose, PTB is building several aerosol research and testing laboratories. The traceable measurement of nitrogen oxides is also being discussed intensely by lawmakers. PTB is therefore also preparing for the introduction of a NO_x-AU (exhaust emission test for nitrogen oxide). In addition, it is conducting research on an improved traceability in mobile emission measurements (RDE, PEMS) within the framework of manufacturer vehicle approvals.Exhaust gas measurements that measure limit values reliably (i.e. traceably to the SI) and comply with the necessary specifications, even in everyday driving or car repair centers, are indispensable for the AU (the bi-annual national exhaust emission test) and, in the future, for vehicle type approval. PTB accounts for this as the initiator/coordinator of European metrology research projects such as "PartEmission", "Autopart" or "METROPEMS".

The new PTB laboratory building for the type examination of automotive exhaust gas measuring instruments

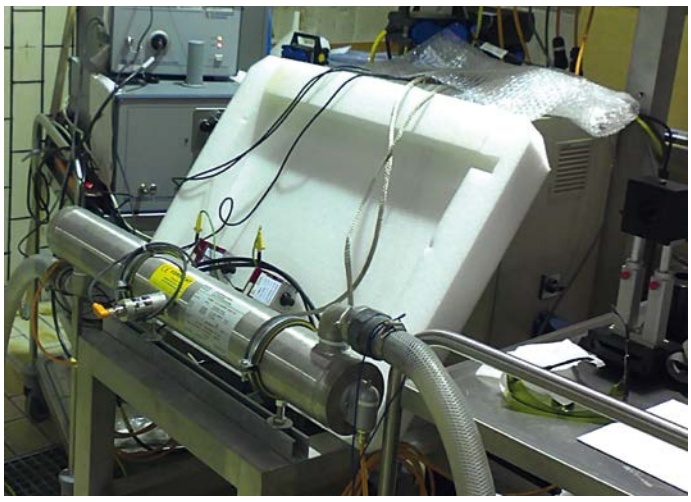
Pollutants in water and soil

The EU is very concerned about its waters. The Water Framework Directive 2000/60/EC and the Marine Strategy Framework Directive 2008/56/EC name the measurement quantities, the relevant measurement ranges and the measurement uncertainties which take priority. Furthermore, these directives stipulate quality assurance according to ISO 17025. Within the framework of the Network for Metrology in Chemistry in Germany, the BAM Federal Institute for Materials Research and Testing and PTB maintain the necessary standards and organize interlaboratory comparisons. At PTB, the focus is on heavy-metal measurements. For this purpose, monoelement solutions are prepared as reference solutions for the SI-traceable determination of heavy metals (Cd, Ni, Pb, Hg) in drinking water as national standards. For the measurement of further pollutants, structures still need to be constructed; this applies, for example, to drug residues in order to account for the growing problem of resistance to antibiotics. A national reference laboratory – such as the German Environment Agency is for air pollutants – would make sense here.

Taking a water sample from the Oker river in Braunschweig

UV therapy for safe drinking water

Drinking water disinfection with UV-C radiation plays an increasingly important role in water treatment in order to reduce water pollution with chlorine, the substance most frequently used for this purpose worldwide. Due to the close cooperation between PTB and the *Technologiezentrum Wasser* (TZW) (the certification body responsible for Germany), traceable measuring and calibration methods have been established and laid down in standards (DIN 1294). Today's technology used to this end is mainly based on the use of mercury vapor lamps whose strong

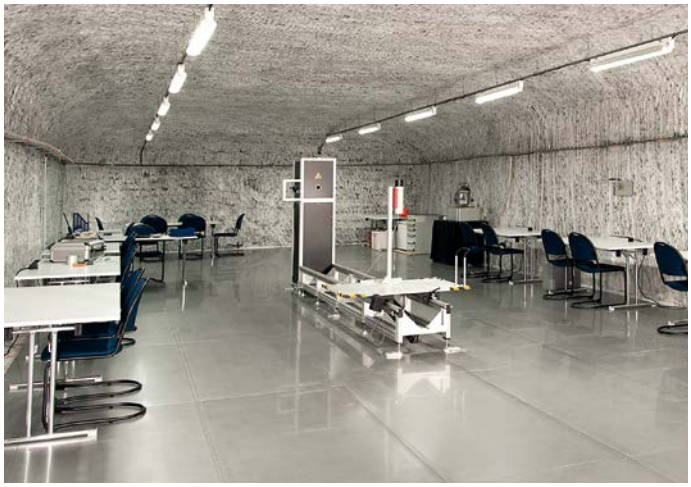


Measurement campaign at the DVGW test laboratory in St. Augustin-Meindorf for the validation of the calibration methods developed by PTB

emission lines in the UV-C are close to the maximum of the action function for killing microorganisms. However, as the Minamata Agreement on mercury – which was initiated by the United Nations Environment Programme and ratified by all members in 2017 – provides for worldwide bans and restrictions on the manufacture, trade and sale of mercury-containing products from 2020, a technological change from mercury vapor lamps to LED-based energy-saving UV-C sources will take place in the coming years. Nevertheless, the new technology also requires a comprehensive adaptation of regulations and standardization and the acquisition of new scientific knowledge. For example, the spectral action function for killing microorganisms by UV radiation must be determined very precisely in order to adapt to it the spectrum of the UV LEDs that have to be used in the best possible way. Here, again with its partners and DIN, PTB is in the process of defining the metrological boundary conditions for appropriate sources.

What's radiating here?

Concerning ionizing radiation, the focus can be on two different aspects: either on the radiating object itself, or on the dose a person receives. In both cases, the German Radiation Protection Act applies and PTB is active when precise measurements are needed. In the first case, looking at the object itself, the unit of the becquerel is involved. Here, PTB ensures the traceability of radioactivity measurements on environmental samples from Germany, Europe and beyond. Besides conventional environmental samples (water, soil, food, etc.), industrial products are also analyzed (building materials, residues and waste); both artificial and natural radionuclides are relevant. PTB's focus is on calibration measurements for comparison and reference materials. When considering – in the second case – the dose, the unit of measurement is the sievert. PTB is mainly active in the field of low dose rates. It operates the UDO II underground laboratory (with a minimum area dose rate), a reference measuring station on water (a floating platform without the terrestrial radiation component) and a reference measuring area which records cosmic radiation in addition to the terrestrial dose rate (caused by natural radioactivity). The above-mentioned components can be separated via comparative measurements. In the future, PTB will, among other things, further develop the measurement of alpha-emitting nuclides in the environment by means of optical methods in order to be able to detect contaminations from great distances.



Low-dose calibration facility in PTB's underground laboratory UDO II

Too bright and too loud

"Light pollution" does not mean that the light is dirty, but that artificial light sources are making the night sky brighter and brighter. This leads to an unnecessary waste of energy and disturbs the day/night rhythm of living beings; moreover, there are only very few truly dark places left on Earth that are suitable for astronomical research. Much light pollution comes from poorly designed or inefficient light sources. PTB is active in the characterization of energy-efficient light sources. There are no generally valid regulations for the limitation of light immissions, which is also due to the fact that neither a binding measurand nor a traceable measurement technique for the quantitative determination of light pollution exists. PTB is working on advancing metrology and legislation in this field.

Light pollution in Europe at night (Fig.: NASA Earth Observatory / NOAA NGDC)

Noise is a significant environmental factor. The World Health Organization classifies noise as one of the leading health risks that are due to the environment. To combat noise, it must be quantified on site. This requires measuring instruments that provide accurate, reliable results that are traceable to national standards. PTB offers comprehensive services in the field of calibration of microphones, sound level meters and additional equipment. The type approval of sound measuring instruments ensures confidence in a quantitative analysis. At the same time, PTB conducts research on infrasound, which emanates, for example, from wind turbines, and on airborne ultrasound. Here, in addition to the development of new measurement and calibration methods, the aim is to better understand how infrared and ultrasound are perceived.

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The texts of these Info Sheet and further information can be found in the internet: www.ptb.de > Research & Development > Into the Future with Metrology > The Challenges of Our Environment and Climate

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