

ACTRIS Standard Procedures for In-Situ Aerosol Sampling, Measurements, and Analyses at ACTRIS Observatories

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Center for Aerosol In-Situ Measurement

European Center for Aerosol Calibration and Characterization (CAIS-ECAC).

Preface

The Topical Center CAIS-ECAC has established standard procedures for observatories (ACTRIS NFs) to ensure high-quality ACTRIS measurements and facilitate consistent aerosol in-situ measurements. These standard procedures are crucial in preventing any issues or misunderstandings during the implementation and operation phases of ACTRIS. It is essential to harmonize the sampling configuration, physical and chemical aerosol in-situ instrumentation, and the analysis methods applied to comply with ACTRIS requirements.

CAIS-ECAC offers a list of instrument models for certain aerosol in-situ variables (not all variables) that have undergone testing to ensure compliance with ACTRIS requirements for aerosol in-situ measurements. This list comprises instrument models that are ACTRIS compliant and remains open to new instruments that meet ACTRIS requirements and have been tested by ECAC for specific variables.

In-situ aerosol instruments from various manufacturers, including microphysical, optical devices, and chemical are required to undergo performance testing at CAIS-ECAC to demonstrate compliance with ACTRIS requirements and target uncertainties. The measured aerosol data must fall within the specified target uncertainty ranges and be traceable to reference instruments or standards established by CAIS-ECAC.

Online in-situ aerosol instruments are required to undergo regular calibration workshops, the frequency of which is determined by CAIS-ECAC based on the instrument type.

- CAIS-ECAC schedules the calibrations for the specific instrument types for all NFs.
- CAIS-ECAC provides regular training workshops for the scientists and operators of the respective instruments.

Offline in-situ aerosol measurements must undergo regular round-robin tests organized by CAIS-ECAC, with a defined frequency for each measurement type.

These standard procedures are derived from existing guidelines, standardization documents, and project reports, including:

- CEN Technical Specifications, EU standards, and ISO standards
- WMO-GAW guideline, report 227
- Deliverables from ACTRIS-related research projects such as EUSAAR, ACTRIS-I, and ACTRIS-II, the COST Action COLOSSAL, ACTRIS-PPP, ACTRIS-IMP, and RI-Urbans

as well as from over a decade of experience within various CAIS-ECAC units and individuals within the European research community. These standard procedures will be updated annually in collaboration with the ACTRIS NF Technical and Scientific Forum, providing all National Facilities the opportunity to participate and express their opinions, and in collaboration with manufacturers.

All guidelines for aerosol in-situ measurements can be found under:

<https://www.actris-ecac.eu/actris-gaw-recommendation-documents.html>

ACTRIS aerosol in-situ variables

Five out of the 12 ACTRIS aerosol in-situ variables are obligatory for NFs (observatories). The number of obligatory variables for exploratory and mobile platforms may differ and is explained elsewhere.

Obligatory ACTRIS aerosol in-situ variables for observatories:

- Particle number concentration $D_{P50} = 10 \text{ nm}$ (EN-16976)
- Particle number size distribution – mobility diameter 10 to 800 nm (CEN/TS-17434)¹⁾
- Particle light scattering & backscattering coefficient - multi-wavelength²⁾
- Particle light absorption coefficient and/or equivalent black carbon concentration²⁾
- At least one additional variable from the list below, preferably a variable on particle chemical or elemental composition, considering the scientific program of the NF.

Other ACTRIS aerosol in-situ variables:

- Nano-particle number concentration ($D_{P50} < 10 \text{ nm}$)
 - Nano-particle number size distribution $< 10 \text{ nm}$
 - Particle number size distribution - aerodynamic diameter 0.8 to 10 μm ³⁾
 - Cloud condensation nuclei number concentration
 - Mass concentration of particulate organic tracers²⁾
 - Mass concentration of particulate organic and elemental carbon⁴⁾ (
 - Mass concentration of non-refractory particulate organics and inorganics within PM1 fraction^{5,6)}
 - Mass concentration of particulate elements²⁾
1. PM2.5 selection in case of a significant influence of coarse particles such as mineral dust or sea salt
 2. PM10 size fraction must be employed, except in cases where a whole air inlet is required.
 3. Optical Particle Size Spectrometers are excluded from ACTRIS Observatories
 4. PM2.5 is required by the EU standard (EN-16909)
 5. A preliminary cut-off at a diameter of 2.5 μm is preferred in front of the dynamic lens
 6. This variable might be measured within the PM2.5 fraction (after a preliminary cut-off at about 4 μm) using ad hoc dynamic lens and capture vaporizer, when needed, considering the scientific program of the NF and after discussions with CAIS-ECAC.

General Recommendations

Aerosol inlets

- **A PM10 inlet** should be generally used at ACTRIS observatories. This cut-off is harmonized with the WMO-GAW network.
- **A whole air inlet** must be used, if the observatory is more than 10% of the time in cloud or fog (activated droplets either by convection (cloud) or ground temperature inversion (fog)). This is important for continuous aerosol in-situ measurements.
- Classical PM10 or PM2.5 inlets are not recommended for these sites, because they cut into the droplet number size distribution and provide thus only a fraction of activated particles.
- **A PM2.5 inlet** can be only used for certain applications as described above.
- **An interstitial inlet** might be used for observatories, which are additionally interested in measurements of the interstitial aerosol.
- **Nano-particle measurements** (1-3 nm) should be preferably done at a separate inlet with minimized diffusion losses.

General sampling recommendations

- **Reduce diffusional losses** for ultrafine particles. The optimum **Reynolds number** of the sampling flow is **about 2000 (or slightly below)**.
- **Stainless-steel sampling pipes** are preferred (short parts of the sampling lines can include silicone carbon tubing where necessary, except for ACSM and AMS).
- **Individual pipes** to the instruments should be kept **as short as possible**.
- At least **50% penetration efficiency** through the inlet is recommended at the lowest measurement size.
- The sampling can utilize **by-pass flow** to reduce the residence time in the sampling line.
- **Center line** core sampling is recommended.
- **Vertical pipes** are preferred to avoid losses of supermicrometer particles by impaction and sedimentation.
- Employ an adequate **isokinetic flow splitter** of PM10 related variables to avoid over- or under-sampling of supermicrometer particles.

We would also like to refer to existing guidelines & publications, which can be found under:

<https://www.actris-ecac.eu/measurement-guidelines.html>

Aerosol conditioning (drying)

Aerosol microphysical and optical measurements shall be performed at RH < 40%. This is necessary to obtain comparable data, independent of the hygroscopic behavior of the aerosol particles.

Note: No conditioning is needed for nano-particle measurements going down to 1-3 nm in particle diameter (to prevent excessive losses of nano-particles).

Generally, two different methods can be employed to achieve a relative humidity (RH) below 40%.

- **Nafion dryer: This drying method is recommended** in ACTRIS using **single tube** Nafion dryers. Different Nafion dryer designs are available for low flow rates (~1 l/min) and larger flow rates (up to ~8 l/min).
- **Dilution with dry air: This drying method is recommended for subtropical and tropical sites** in ACTRIS. A dilution with dry particle-free air behind the inlet head can be employed in tropical and subtropical regions with high dew point temperatures ($T_{\text{dew}} > 20^{\circ}\text{C}$). The dilution by dry air should be done according to the description of Annex E in the CEN/TS 17434 document.

The following techniques **shall not be used** to decrease the sample flow RH at ACTRIS NFs:

- **A Nafion bundle dryer must not be used** for microphysical, optical, and mass spectrometer measurements. Existing bundle dryers must be replaced.
- **Aerosol diffusion dryers: This method must not be used** in ACTRIS. These dryers are based on silica gel and cause high diffusion particle diffusional losses.
- **Heating of the sampling pipe: This method must not be used.** However, a moderate heating of the inlet head is allowed for stations at low ambient temperatures to avoid freezing or to evaporate droplets in a whole air inlet.

We would also like to refer to existing guidelines & publications, which can be found under:

<https://www.actris-ecac.eu/aerosol-inlets-and-conditioning.html>

Additional considerations

Following additional recommendations are also obligatory:

- The overall **data coverage should be > 90%** (excluding the time when the instruments are participating in the calibration workshops).
- The **volumetric aerosol flow rate** should be determined **at the inlet of the instrument** (does not need to be continuously measured, but has to be checked/verified frequently).
- The **actual pressure** should be measured with a high time resolution at a central point, such as **at the aerosol splitter** inside of the measurement room.
- The **actual relative humidity and temperature** should be determined also with a high time resolution **at the inlet of each individual instrument** (or within the instrument measurement cell, e.g., for nephelometers). The pressure and temperature are needed for the calculation of the concentration at “Standard Temperature & Pressure” (STP; defined to 273,15K and 1013 hPa)
- If a common sampling inlet and a common drying is used for more instruments (with suitable isokinetic subsampling), one sensor for relative humidity, temperature and pressure can be used for this set of the instruments (but only if these variables do not vary between the inlets of the individual instruments due to some additional sampling line parts).
- The uncertainty of the RH/T sensors should be **maximum 5% in RH and 0.5°C for the temperature.**

Near-Real-Time data (NRT)

ACTRIS aerosol in-situ online instrumentation must be ACTRIS-NRT compatible. The specifications of the requirements for NRT compatibility can be found on CAIS-ECAC web pages (still in progress). The ACTRIS-NRT logging software is provided by CAIS-ECAC after the initial acceptance of the individual NF.

Microphysical variables

Particle number concentration $D_{p50} = 10$ nm (WCCAP, PACC)

Particle number concentration (PNC) measurements using a stand-alone Condensation Particle Counter (CPC) should be conducted concurrently with Mobility Particle Size Spectrometer (MPSS) measurements to facilitate Near-Real-Time (NRT) quality control (QC) checks.

The CPC should not be utilized for other purposes, such as calibrating other instrumentation, to prevent contamination. The CEN264/32 working group developed CEN/TS 16976 for ambient PNC measurements, which will be adopted as an **EU standard (EN-16976) in 2024**, and is mandatory within ACTRIS-ERIC. In EN 16976, the lower detection efficiency diameter (D_{p50}) is adjusted to 10 nm to align with the lower end of the size range in CEN/TS 17434 for MPSS measurements.

It is essential for the CPC to be traceable, meaning that the PNC reading from an Ethernet/USB/serial port must match the calculated PNC from the primary output of the photodetector (pulse output). This includes the CPC-specific calibration factor and coincidence corrections. A "pulse output" port is mandatory in ACTRIS. Additionally, a full-flow CPC (where the aerosol inlet flow rate equals the flow rate through the detector) is required in ACTRIS to minimize potential uncertainties, ensuring no internal flow split and no optical focusing in the detector.

The provision of following diagnostic parameters of the CPC is obligatory:

- RH, T, p at inlet of the instrument (one sensor can be used for more instruments if they are under the same conditions - i.e. after a common dryer)
- Saturator T
- Condenser T
- Optics T
- Liquid level

The provision of following diagnostic parameters of the CPC is useful as additional information to monitor the condition of the instrument:

- nozzle pressure at the inlet to optical cell
- critical orifice pressure (if the CPC flow is controlled using critical orifice)
- laser current

Nano-particle number concentration $D_{p50} < 10$ nm (CCC)

The PNC starting from sizes smaller than 10 nm (Nano-PNC) can be measured using a CPC with low D_{p50} such as a Nano-CPC (Ultrafine CPC) or a dual-stage CPC consisting of a particle growth device such as a Particle Size Magnifier (PSM) or a Nano-Enhancer, followed by a regular CPC. This measurement is voluntary.

For the Nano-PNC measurement, it is important that the D_{p50} and operation of these instruments is carefully and regularly verified using a calibration system designed for sub-10 nm particles. Measurements of Nano-PNCs require special attention to minimizing particle diffusion losses in the sampling line. It should be noted that Nano-PNC measurements cannot be always executed by using the same setup (inlet, drying) that applies for $D_{p50} > 10$ nm PNCs. For instruments measuring down to 1-3 nm sizes a separate inlet is recommended or at least the fast delivery of the sample must be taken into account when designing the sampling line. The instrument must not be used for other purposes such as the calibration of other instrumentation to avoid contamination.

The instrument D_{p50} should be between 1-10 nm for solid, non-soluble particles (preferably either 3 nm or 1.7 nm for single-stage and dual-stage CPCs, respectively, for achieving comparable data between different stations). The D_{p50} and type (composition and polarity) of the calibration particles

should be reported alongside the measurement data. In the case of an UCPC with cut-off size 3 nm or larger, the instrument testing/verification can be performed at WCCAP or PACC. Dual-stage CPCs or other Nano-CPCs, whose cut-off size is expected to be 1-3 nm, shall be tested/verified at CCC.

Regarding sample drying, for Nano-CPCs with a D_{p50} of 3 nm or larger, a Nafion drier shall be used with proper correction for losses. For instruments working in the size range 1-3 nm, drying is NOT recommended due to high particle losses. Drying by dilution with dry air is possible. We expect no significant hygroscopic growth of the smallest particles and thus, we can allow exceptions from the general rule of $RH < 40\%$ for aerosol measurements in this case.

The provision of following diagnostic parameters is obligatory:

- RH, T, p at inlet of the instrument
- volumetric flow rates describing the mixing ratio (if applicable)
- instrument internal temperatures (saturator, condenser, optics, growth tube)
- liquid level
- nozzle pressure at the inlet to optical cell
- critical orifice pressure (if the CPC flow is controlled using critical orifice)
- laser current
- flow rates of the dilution/core sampling system

The existing measurement guidelines & publications can be found under:

<https://www.actris-ecac.eu/nano-pnsd-1-to-10nm.html>

Particle number size distribution - mobility diameter 10 to 800 nm (WCCAP, PACC)

- For the particle number size distribution (PNSD) of the submicrometer size range, the CEN264/32 working group developed the **CEN/TS-17434** to harmonize ambient PNSD measurements in Europe.
- The CEN/TS 17434 for MPSS is obligatory for NFs in ACTRIS-ERIC.
- This MPSS must not be used for other purposes such as the calibration of other instrumentation to avoid contamination (the only exception is using the DMA and the CPC for calibration of ACSM or AMS instruments under the condition that both will be checked and cleaned afterwards).

Following MPSS criteria are recommended:

- The obligatory **particle size range** is defined to **10 - 800 nm** (the size range could be extended to larger particle sizes, if the MPSS allows this). Exceptions are allowed for observatories at elevations above 4000m a.s.l. (see below).
- The CEN/TS 17434 does not specify an aerosol to sheath flow ratio of the DMA. The recommendation is to employ a ratio between 1:10 and 1:4 to obtain comparable measurements.
- **Krypton 85 and Nickel 63 are preferable** radioactive nuclides for **bipolar diffusion chargers**. The activity should be sufficient to provide the bipolar charge equilibrium. Please contact the responsible ECAC unit for advice.
- Bipolar chargers based on **X-ray, corona discharge, or plasma are not recommended** yet (lacking knowledge of long-term stability and the bipolar charge distribution among the different models).
- MPSS based on **unipolar charging are not qualified**, since the uncertainty due to the inversion matrix might be too large for the atmospheric aerosol.
- **Makeup/bypass flows** before or after the DMA **are not allowed** (CPC aerosol flow is the DMA

- aerosol inlet and sample flow).
- The CPC should follow the CEN/TS 16976 or EN 16976 (see also section 2.1)
 - The provision of diagnostic parameters of the CPC is obligatory as described above.
 - The recommended **particle size resolution** is **16 to 32 bins/decade**. We do not recommend a higher particle size resolution due to the poor counting statistics for atmospheric measurements.
 - The recommended time resolution for MPSS measurements is **5-10 min**.
 - A **positive High Voltage power supply for the DMA** is preferred to optimize the comparability among the measurements.

Special recommendations for MPSS measurements:

- A PM2.5 impactor or cyclone is generally useful in front of the regular MPSS (10-800 nm) and recommended for observatories with significant mineral dust or sea salt in the coarse particles range. This is important to avoid multiple charged particles of the coarse mode in the MPSS measurement.
- An inlet for MPSS measurements with minimized diffusion losses is recommended for observatories using a dual MPSS (3-800 nm) and/or a Nano-MPSS.
- For observatories at high altitudes above 4000m a.s.l., the upper size can be lowered to 500 nm to avoid sparking in the DMA.

The provision of the following additional diagnostic variables is obligatory:

- Volumetric aerosol inlet flow rate
- Volumetric sheath air flow rate
- Aerosol inlet flow
- Aerosol inlet RH, T, p (one sensor can be used for more instruments if they are under the same conditions - i.e. after a common dryer)
- Sheath air flow RH, T

We would also like to refer to existing guidelines & publications, which can be found under:

<https://www.actris-ecac.eu/pnsd-10-to-800nm.html>

Nano particle number size distribution (CCC)

Measurements of the particle number size distributions below 10 nm can be done using several commercially available or custom-made instruments such as a Nano-MPSS optimized for sub-10 nm particles, the PSM/nCNC or a NAIS (Neutral cluster and Air Ion Spectrometer).

The lower size limit of the instrument size range should be preferably 3 nm or lower. The upper limit of the size range depends on instrumentation, however, an overlap with the regular MPSS measurement (10-800 nm) is recommended to ensure comparability and allow a combined data inversion.

All instrument types (and all custom-made instruments) need to be tested/verified by the CAIS-ECAC. Dual-MPSS (i.e. instruments that are used both for 10-800 nm PNSD and <10 nm PNSD measurements with lower range typically >3 nm) calibration will be performed at the WCCAP and PACC. All other instruments measuring < 10 nm particle size distribution will be calibrated at the CCC. Regarding sample drying, for a Dual-MPSS, a Nafion drier must be used with proper correction for particle losses.

For instruments going down to 1-3 nm sizes drying with diffusion/membrane driers or heating of the inlet is NOT recommended due to high losses. Drying by dilution with dry air is possible. Particle losses in a dilution system must be minimized and characterized. We expect no significant hygroscopic growth of the smallest particles and thus, we can allow exceptions from the general rule

of RH < 40% for aerosol measurements in this case.

Specific recommendations for a Nano-MPSS:

- A bipolar diffusion charger is recommended as charger/neutralizer as described before. X-ray, corona discharge, or plasma can be only used with careful characterization.
- A positive High Voltage power supply for the Differential Mobility Analyser (DMA) or the measurement of both polarities is preferred to minimize uncertainties.
- DMA resolution and penetration need to be sufficient.
- Flow rates need to be monitored.
- The flow ratio must be between 1:4 to 1:10.
- For Dual-MPSS, follow the recommendations given above for $D_{p50} > 10$ nm PNSD measurements.

The existing measurement guidelines & publications can be found under:

<https://www.actris-ecac.eu/nano-pnsd-1-to-10nm.html>

Particle number size distribution - aerodynamic diameter 0.8 to 10 μm (WCCAP, PACC)

We recommend employing an Aerodynamic Particle Size Spectrometer (APSS) to determine the particle number size distribution in the upper accumulation mode and coarse range. As the counting efficiency of the APSS drops rapidly and becomes unstable below 0.8 μm aerodynamic diameter, it is advisable to **consider only data from the particle number size distribution greater than 0.8 μm .**

The APSS can be connected to the sampling line just with the inner nozzle (sampling 1 l/min) from the common sampling line, while taking the additional sheath flow (4 l/min) from the air in the measurement container. However, it is crucial to dry this sheath flow, sourced from room air, to below 40% RH. This approach not only reduces the requirements for aerosol dryers but also minimizes the total flow through the sampling head when using a common inlet for multiple instruments.

It is important to note that an Optical Particle Size Spectrometer (OPSS) should not be used at an ACTRIS observatory (NF) due to the lack of traceability in the supermicrometer size range. The measured optical diameter cannot be converted to a volume-equivalent diameter because of the unknown particle shape and light-absorbing particle composition in the coarse size range.

Cloud condensation nuclei number concentration (WCCAP)

The standard operation procedures for Cloud Condensation nuclei concentrations measurements using a Cloud Condensation Nuclei Counter (CCNC) are described in detail in the ACTRIS SOP. Additionally to this recommendation, the RH of the sampling flow should be also kept below 40% to be operated as the same RH as the MPSS.

We would also like to refer to existing guidelines & publications, which can be found under:

<https://www.actris-ecac.eu/ccn-nc.html>

Optical variables

Particle light scattering & backscattering coefficient - multi-wavelength (WCCAP, PACC)

The recommendation here is to use an integrating nephelometer. The instrument should fulfill the following criteria.

- The instrument must be a **multi-wavelength Integrating Nephelometer (IN)**.
- **Total scattering and backscattering** should be determined.
- The sampling flow rate should be set to a constant value of about 5 L/min under the consideration of drying.
- The response time of the nephelometer should not be longer than 5 minutes (especially for the zero calibration).
- The time resolution of the level-0 data should not be longer than one minute. The internal averaging time should correspond to this time and no further data filtering should take place.
- Capability of calibration with two gases. The preferred calibration gases are particle free air (low span gas) and CO₂ (high span gas).
- Automatic measurement of the baseline at regular intervals (minimum once a day) with particle free air (low span gas). This flow rate must not differ more than 20% compared to the fixed regular sampling flow rate.
- We recommend using an external pump (including HEPA filter and a needle valve or a critical orifice) to regulate and keep the flow rate. It must be ensured that the flow at the aerosol inlet is rather stable (+/- 1 L/min), even during automatic zero measurements.
- It is sufficient to measure T, RH, and p in the cell of the integrating nephelometer.

The processing of scattering raw data (including truncation error correction and the illumination function correction) is performed centrally at the EBAS database. This includes following correction methods:

- Tabulated correction function as function of the scattering Ångström exponent. This method only is applicable to multi-wavelength integrating nephelometers.
- For cases when the Ångström exponent has an increased uncertainty (low concentrations): Mie scattering calculations based on knowledge of the truncation angles and light source characteristics. This method also requires measuring the particle number size distributions.

We would also like to refer to existing guidelines & publications, which can be found under:

<https://www.actris-ecac.eu/particle-light-scattering.html>

Particle light absorption coefficient (WCCAP, PACC)

Specifications for instruments measuring the particle light absorption coefficients are given for **filter-based Absorption Photometers (AP)**.

Filter-based APs are simple in their technical construction. Therefore, the list of hardware requirements is rather short.

- The **sample flow through the filter must be measured**. Since an uncontrolled flow decreases when loading a filter may occur, it is recommended to regulate and measure the sample flow.
- The **attenuation or transmission of light must be recorded**.
- When exceeding an instrument specific maximum attenuation, the filter must be changed either automatically or manually. The station user must estimate how long the device can operate unattended.
- The sample spot size must be regularly checked. Diffuse edges indicate a problem with the closing mechanism.
- The filter type must have been calibrated for use in that instrument. Calibration factors are

needed for data evaluation.

- Instruments often report black carbon (BC) concentrations. The conversion formulas of measured quantities in optical units to BC concentrations used by the instrument software during the measurement must be known.
- The instrument must record housekeeping numbers and the measured raw intensities.
- The zero (noise) test should be performed together with the span check of the integrating nephelometer.

Other instruments:

- For an "Photo-Acoustic-Sensor" (PAS) no recommendation exist yet.
- The method "extinction minus scattering" is not recommended to determine the light particle absorption coefficient for the ambient aerosol, because of the high measurement uncertainty for a high single scattering albedo.

We would also like to refer to existing guidelines & publications, which can be found under:

<https://www.actris-ecac.eu/particle-light-absorption.html>

Chemical variables

Mass concentration of particulate organic tracers (OGTAC-CC)

The Organic Tracers and Aerosol Constituents – Calibration Center (OGTAC-CC) is within its implementation phase. Besides training of operators and scientists in good practice related to filter sampling, sample transport and storage, sample preparation until final data analysis, the calibration center is focusing on the harmonization of these different analytical steps. Therefore, technical requirements are currently defined. Additionally, measurement guidelines will be set up based on the technical requirements that will be later used as SOP (standard operating procedure) template, available for each individual technique. These templates need to be finalized in a later stage by each NF individually together with the calibration center. Finally, the NF individual SOP needs to be approved by the calibration center.

Details on the organic tracer target compounds, recommended analytical techniques, the technical requirements and the measurements guidelines will be provided by the calibration centre to the NFs as soon as the documents are finalized (not part of the present document). The implementation phase will be further used for inter-laboratory comparisons to test measurement guidelines for different (groups of) target compounds, enabling an appropriate analytical measuring strategy. All steps will be evaluated in collaboration between OGTAC-CC and the NFs.

Mass concentration of particulate organic and elemental carbon (OGTAC-CC, ERLAP)

ACTRIS recommendation is to follow the **CEN standard - EN 16909:2017**: “Ambient air - Measurement of elemental carbon (EC) and organic carbon (OC) collected on filters”. The reference method described in EN 16909 is the off-line thermal-optical method, applying the thermal protocol EUSAAR-2.

The following points of EN 16909 are particularly important:

- **At least one field blank** shall be collected **every 14 samples**.
- **Samples** should be **stored at temperature below 5°C**, if not analyzed within 28 days from sampling.
- Instruments shall be **regularly calibrated for TC** (multi-point calibration) **at least once every 12 months and after any major maintenance/modifications**.
- The calibration should be checked at least every measurement day, e. g. by the analysis of a sucrose spiked filter. Better use a certified sucrose solution for this.
- To verify the instrument’s long-term stability, at least one punch of a large control filter shall be analyzed on each measurement day or for each sample batch. Control filters can be obtained from ECAC on request.
- Temperature probe calibration shall be checked at least every 12 months and after any major maintenance/modification.
- Laser signal noise and drift shall be checked during instrument blank analysis on each measurement day or for each sample batch.

On top of EN 16909, ACTRIS recommendations include:

- The participation of NFs in the ACTRIS annual inter-laboratory comparison for the determination OC and EC loading ($\mu\text{g}/\text{cm}^2$) in test filter samples is compulsory.
- Except if technically not feasible (see next bullet point), a carbon monolith denuder shall be installed downstream of the sampling head and upstream of the filter holder. The dimension of a denuder should be such that the residence time in the denuder is about 1s. A denuder should be regenerated at least every 3 months or 2000 m^3 . The use of denuder is particularly important at remote or rural background sites where the relative contribution of positive sampling

artifacts is higher.

- At an observatories where the use of a denuder is not possible (e.g., extreme weather conditions, hi-vol sampling plus lack of technical solutions to have several denuders in parallel, ...), positive artifacts shall be assessed across a whole year using one of the techniques described in e.g. *“Methods to Assess Carbonaceous Aerosol Sampling Artifact for IMPROVE and Other Long-Term Networks”*.
- Field blanks shall be sampled for ca. 30 to 60 s (which is not specified in the EN16909 standard).
- The response of the instrument in the helium and in the helium/oxygen modes shall be checked on each measurement day (or sample batch) by injecting a fixed amount of calibration gas in the two analytical modes and should not differ by more than 5%.
- The laser correction coefficient shall be ≤ 1 but ≥ 0.9 .
- The transit time shall be regularly verified (at least once a year).
- The available integration options (such as the initial laser signal value determination, baseline, laser and detector slope corrections) leading to optimal determinations of the peak areas and split point shall be selected. Be sure to record the applied options in your Metadata.

Until further notice, the use of alternative methods for determining OC and/or EC under ACTRIS is **NOT** prohibited. This includes the thermal-optical **on-line** analysis of OC and EC, for which best practices are described in *“Semi-continuous measurement of elemental carbon (EC) and organic carbon (OC)”* available at www.actris-ecac.eu/pmc-oc-ec.html.

In any case, **users of alternative methods shall demonstrate their equivalence with the reference method described in EN 16909** according to international standards (see e. g. EN 16450).

Mass concentration of non-refractory particulate organics and inorganics (ACMCC)

Based on a less sensitive but more robust technology than state-of-the-art and well-advanced aerosol mass spectrometer (AMS), the aerosol chemical speciation monitor (ACSM) has been designed to provide continuous measurements of the main non-refractory chemical species within submicrometer aerosols ~~over~~ for years, which is particularly well-suited for ACTRIS observatory platforms.

There is currently only one company providing such devices. This company is proposing two models of ACSM: one equipped with a Quadrupole detector, and the other with a time-of-flight mass spectrometer. The Quadrupole ACSM is to be chosen by default, notably because it is less expensive and easier to use. The Time-of-Flight ACSM, having lower detection limits, is suitable for NFs located at remote (or altitude) sites.

At ACTRIS observatory platforms, ACSM measurements should be preferentially conducted using so-called PM1 lens and standard vaporizer. ACSM equipped with PM2.5 lens and/or capture vaporizer are not recommended yet (except for peculiar situations to be discussed with ACMCC).

It is expected that all instruments are ~~be~~ calibrated and intercompared at the ACMCC at least once every three years. Recommended installation, calibration, sampling, and data processing procedures have been discussed and agreed within the corresponding research community in the frame of ACTRIS-related research projects and of the COST Action COLOSSAL.

Although, the ACTRIS MPSS should not be used for other purposes (to avoid contamination), an exception is to use the DMA for bi-annually calibrations of the ACTRIS aerosol mass spectrometers (ACSM or AMS). If the staff is instructed to clean the DMA at least annually. However, a separate DMA set-up is preferred for the calibration.

Existing guidelines & publications to be followed for ACSM measurements at ACTRIS observational platforms are available under:

<https://www.actris-ecac.eu/pmc-non-refractory-organics-and-inorganics.html>

Mass concentration of particulate elements (EMC2)

Offline filter-based measurements could be done within the PM₁₀, PM_{2.5} or PM₁ size fractions alike. Specific recommendations that update what given in the quoted guidelines are the following. It must be noted that currently no explicit recommendations for online elemental analysis are given, such as those using the Xact 625 or 625i Ambient Multi-Metal Monitor device, other than to follow the specific instructions from the instrument manufacturer.

Filters

The best filters for elemental analysis of aerosol samples using PIXE (or IBA techniques in general), XRF or ICP techniques:

- Should not contain the elements one wants to detect (so filters made of light elements alone, atomic number $Z < 10$);
- Should be clean, with low contamination, however if impurities are present, their concentrations should be stable and homogeneous across filter batches.
- Should be thin (possibly lower than a few micrometers or 1 mg/cm^2); for PIXE and XRF measurements this is important in order to reduce the background in the spectra, but in general it is suggested to reduce the contribution of residual bulk contaminants.
- Should collect the particles on the filter surface, avoiding in-depth penetration of the particles, for PIXE and XRF measurements.

EMC2 recommends mainly the use of pure ring-supported stretched thin polytetrafluoroethylene (PTFE) filters, or, as a second choice, porous polycarbonate membrane. However, polycarbonate filters could pose some problems during sampling (clogging). Both PTFE and polycarbonate filters can acquire an electric charge. The possible electrostatic charging of filters does not pose any problem for elemental analysis. If a preliminary gravimetric determination of the total aerosol sample mass is performed, possible interferences of electrostatic forces shall be properly addressed. The use of quartz fiber filters is allowed only for ICP measurements.

Sampling

The sampling should produce as much homogeneous aerosol deposit as possible. The ACTRIS Elemental Mass Calibration Centre recommends choosing/using proper filter supporting grids, and not to have a checkered pattern of the deposit on the filter.

Sample storage

The ACTRIS Elemental Mass Calibration Centre recommends that after the sampling the filters should be stored in Petri slides, in order to avoid that the filter surface with the aerosol deposit on it could get in contact with materials that could result in loss of the aerosol deposit or in contamination. The use of small ziploc plastic bags or wrapped aluminum foils should be avoided.

Detected elements

EMC2 recommends the following list of suggested elements to be measured according to the different analytical techniques.

- For PIXE and XRF: Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Zr, Mo, Ba, Pb, Cd.
- For ICP: Fe, Al, Cu, Pb, Mn, Cr, Ni, V, As, Cd (see e.g. EN 14902 for the measurement of Pb, Cd, As and Ni in the PM₁₀ fraction)

We would also like to refer to existing guidelines & publications, which can be found under:

<https://www.actris-ecac.eu/pmc-elements.html>