A Case for the Development of a Standardized Measurement System for Marine Black Carbon

Stéphanie Gagné
Jalal Norooz-Oliaee, Fengshan Liu, Prem Lobo

6th ICCT Workshop on Marine Black Carbon Emissions
Helsinki, September 18-19, 2019

Outline

A historical perspective on black carbon regulations in other sectors

Emission limits: why and how

Challenges specific to marine black carbon emissions

A historical perspective on BC regulations in other sectors

BC is regulated in the aviation sector

Objective: improve local air quality

First regulation: smoke, using the Smoke Number (SN) since 1983

SN not sensitive enough, not only BC → development of nvPM (BC) regulations
nvPM ≈ black carbon

Measurement procedures at ICAO in 2017, application: 2020/2023

Photos: courtesy of G. Smallwood

BC is regulated in the aviation sector

Basic principles of new measurement system:

- standardize system as much as possible
- **compatible** with existing gaseous and smoke number measurement to degree possible
- minimize particle losses
- **accommodate all engines**, from largest turbofans to small helicopter engines and auxiliary power units (APUs)

BC is regulated in the aviation sector

Smoke (1983)	nvPM and nvPN (2020/2023)
All emissions	Non-volatile at 350°C ≈ BC
Engine certification	Engine certification
Progressive emission limits	Progressive emission limits
Units: SN	mg/kg fuel and #/kg fuel over a test cycle (LTO)
Certification fuel	Certification fuel
Combustor tech improvements	???

BC is regulated in the automotive sector

Primary objective: tackling the smog problem
Nowadays: also health and climate

- **At first, PM was regulated, based on a traceable gravimetric method**
- **European Commission introduced PN as well as PM due to gravimetric methods reaching their sensitivity limit**
- **PN Solid Particles (EU)**
  - Between ~23nm and 4µm in diameter
  - Of sufficiently low volatility to survive evaporation after a residence time of 0.2s at 300°C.
  - Solid particles ≈ black carbon

BC is regulated in the automotive sector

- Type certification
- Progressive emissions limits e.g. Euro (Europe), Tier (US), LEV (California)
- Units: g/km over test cycles
- US, California → Fleet-based regulations, fuel-neutral
  Europe → Vehicle-based regulations (different categories), fuel-dependent
- Consequences: technological solutions to reduce emissions e.g. DPFs

Regulations in the rail sector

Purpose for the **International Union of Railways (UIC)**: harmonize emission requirements for rail locomotives. Applied in Europe and many other countries worldwide.

PM (g/kWh) regulated since 2002 (ISO 8178), **PN** (1/kWh) since 2019.

PM from ISO 8178 ≠ BC: diluted cold to mimic atmospheric PM.

Tests are done according to ISO 8178-4 test cycle F. Testing is generally done on a **test-bed** but can be applied in the field if the engine can produce the points specified in cycle F.

Regulations in the rail sector (US)

The **US EPA** regulates **PM** (g/bhp-hr) and **smoke (%)** for locomotives depending on their **manufacturing date**.

- Chassis-based testing, **production line** testing using 40 Code of Federal Regulations (40 CFR) and
- **in-use** testing using the Federal Test Procedure (FTP) at 50-70% of the useful lifetime.

PM ≠ BC (all particulate mass regardless of nature);
Smoke ≠ BC (opacity cause by all emissions, regardless of nature).

Photo: pixabay.com

Emission limits: why and how?

Arguments for BC emission limits
(instead of prescribing control measures)

A good Measurement System enables Policy Makers to focus on appropriate targets and policies:

- **Developed by an international group of technical experts from various backgrounds → credible**
- **Enables a progressive reduction of BC emissions**
- **Promotes R&D and creative solutions**
- **Leaves ship owners a choice of options they might consider a good fit to their operations**
- **BC reductions can be distributed between ship classes as deemed appropriate by policy makers**

BC emission limits vs prescribed measure

Instead of imposing prescribed control measures…

- **Pushes technology**: With tightening emission limits, it makes sense to choose an efficient method and be ready for the next step
- The measurement system is **universal**: applies to all engines and after treatment options
- **Results**: control measures don't need to rely on a limited database of BC reduction measurements
- **Flexible**: possibility to set different emission limits to different ship classes
- Diversity of products and **competition** between control measure manufacturers (and/or fuel designers), **reduced cost**, promotion of **innovation**

How to enable a BC emission limit

The way to make BC emission limits possible is by creating a standard measurement system compatible to MEPC 74-10-8:

> ***…develop a standardized sampling, conditioning and measurement protocol, including a traceable reference method and an uncertainty analysis, taking into account the three most appropriate Black Carbon measurement methods (FSN, PAS, LII), to make accurate and traceable (comparable) measurements of Black Carbon emissions.***

How to enable a BC emission limit

"…develop a standardized sampling, conditioning and measurement protocol, including a traceable reference method and an uncertainty analysis, taking into account the three most appropriate Black Carbon measurement methods (FSN, PAS, LII), to make accurate and traceable (comparable) measurements of Black Carbon emissions."

- Standardize sampling, conditioning and measurement so that the three "most appropriate measurement methods" all give consistent results in all foreseen conditions…
- Include all engine types, all modular technical control measures…

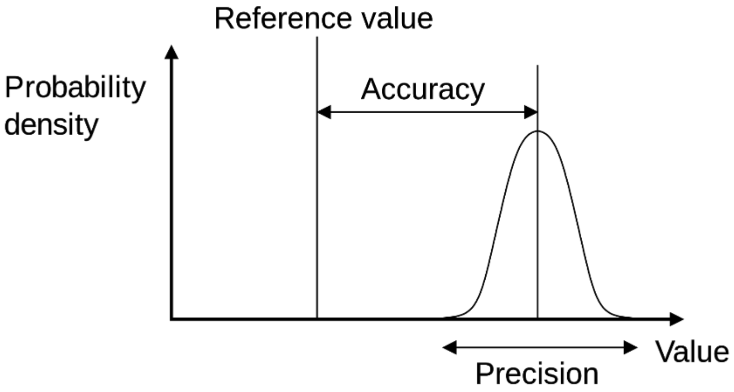
…as much as possible

Benefits of a standardized measurements system: Traceability

Measurement traceability is important because it establishes the **confidence** and **assurance** that the measurement results agree with international standards within the uncertainty of the measurement. It is **comparable** anywhere in the world.

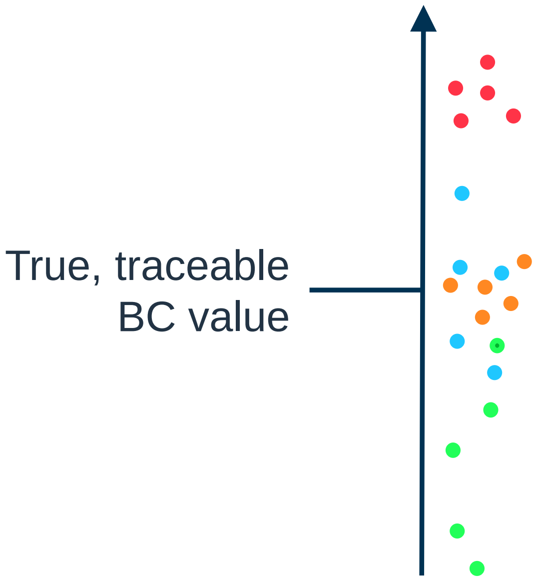
It is the **accuracy**!

Traceable
=
Comparable



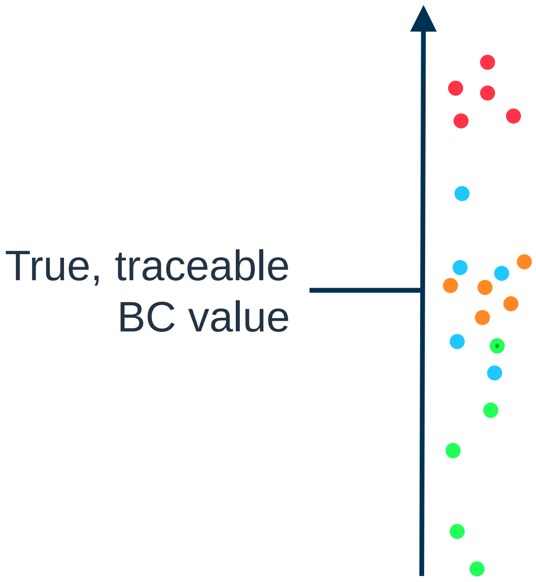
https://en.wikipedia.org/wiki/Accuracy_and_precision

Benefits of a standardized measurements system: Traceability



- Low accuracy, low precision
- Low accuracy, good precision
- Good accuracy, low precision
- Good accuracy, good precision

Benefits of a standardized measurements system: Traceability

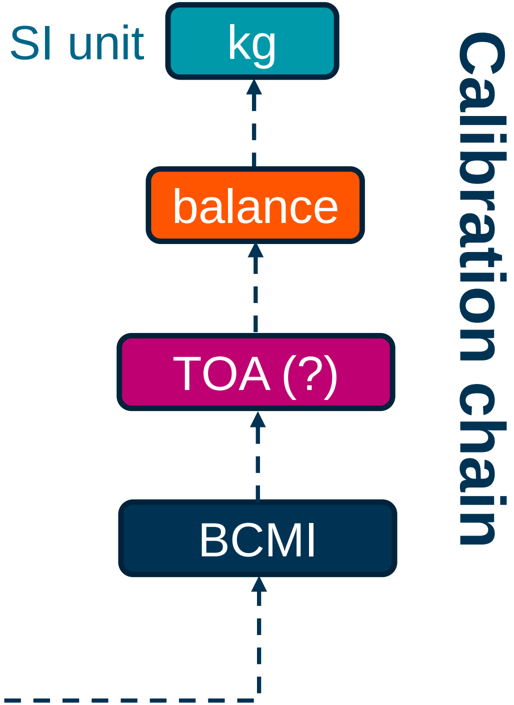


- Low accuracy, low precision
- Low accuracy, good precision
- Good accuracy, low precision
- Good accuracy, good precision

Traceability chain for BC

BC emissions measurement system

→ Sampling
→ Conditioning
→ BC measurement instrument (BCMI)



Benefits of a standardized measurements system: Standardized

A standardized measurement system aims to:

- take **all variables** into account (fuels, technology, engine size, etc.)
- get truly **comparable** measured values regardless of the conditions of the emissions
- set a recipe for good **repeatability** and **reproducibility**
- know the **uncertainty** of the measurement precisely

A standardized measurement system is a **central** repository for **best practices** and can be updated when necessary.

Benefits of a standardized measurements system: Standardized

Includes:

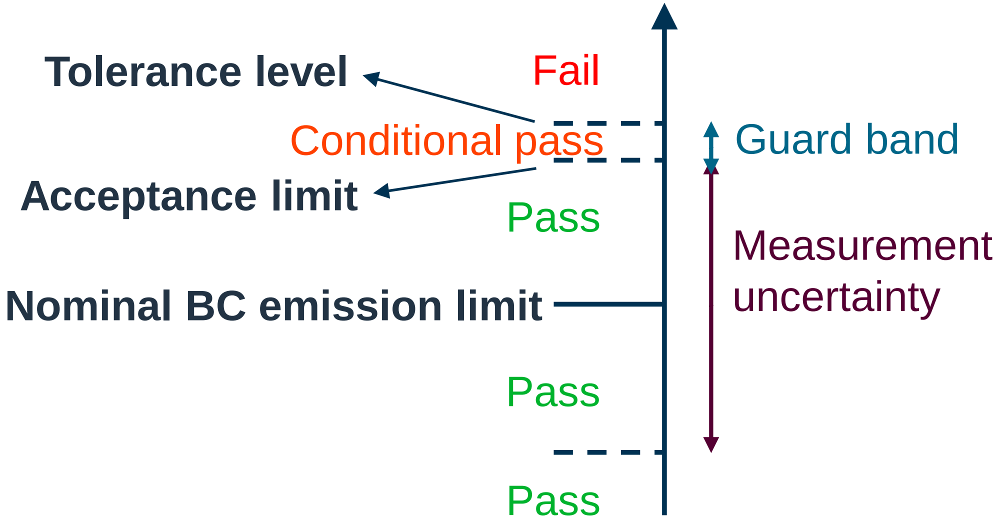
- **sampling, conditioning, and the measurement of BC;**
- **engine cycle, test fuels, etc.;**
- **when and how the measurements have to be taken e.g. on each individual ship, or on a test-bed (type certification);**
- **special instructions if a known technology or fuel changes the properties of BC in a way that affects its measurement.**

Benefits of a standardized measurements system: Uncertainty

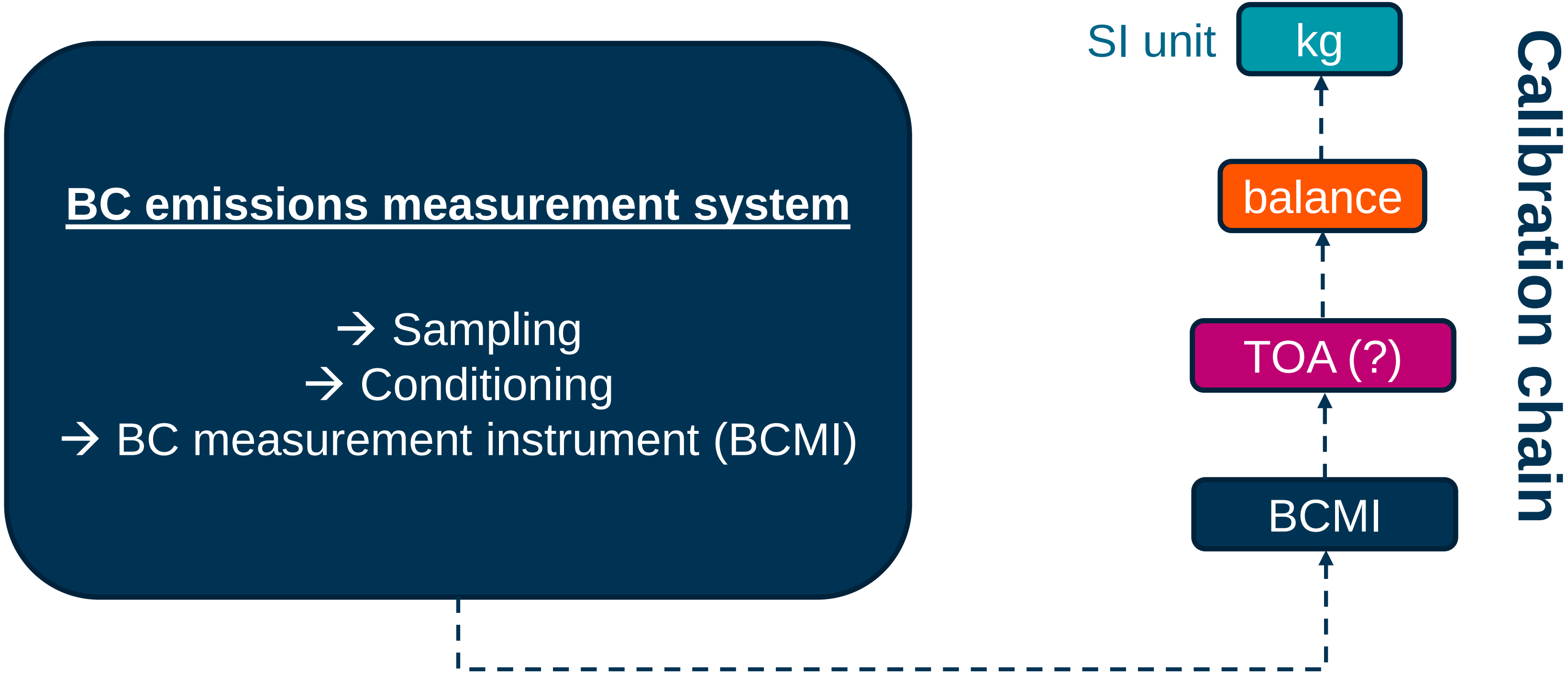
An **uncertainty analysis** allows for a **fair** comparison where it is acknowledged that the measured value may fall within a certain **range of the true emitted BC**.

Uncertainty means we make **sure** the measurements are **fair**

Decision model: non-binary statement with guard band



Traceability chain for BC



Benefits of a standardized measurements system: Uncertainty

The uncertainty comes from:

- Repeatability, reproducibility and resolution components (combined uncertainty) of the different contributors to the measurement system
- Uncertainty of the international/national standard-traceable calibration method for BC measurement instruments

→ All uncertainty components propagated to final result

Uncertainty means we make **sure** the measurements are **fair**

Photo credit: Prem Lobo

Challenges specific to marine BC emissions

Different fuels affect the measurement of BC for most measurement methods

- **Tar is co-emitted with BC when using HFO and other residual fuels → most BC measurement methods measure tar as BC.** ***Corbin et al., NPJ Climate & Atmos. Sci., 2019***

- **The sulphur content and vanadium affect some measurement methods, in particular Thermal-Optical Analysis (traceable method).** ***Aakko-Saksa et al., JAS, 2018***

- **Co-emitted ash can also affect BC measurements.** ***Gagné et al., in prep.***

Different fuels affect the measurement of BC for most measurement methods

- Tar is co-emitted with BC when using HFO and other residual fue … C.
  Co
- Th … n pa … *ko-*
  Sa
- Co … *l., in*
  pr

Solutions needed!

- Designate a distillate test fuel (go-around)
- Develop a method that can handle residual fuels
- ??

→ Input from **technical experts needed!**

Candidate reference method and marine engine emissions

Thermal-Optical Analysis (TOA) is traceable but affected by:

- **Sulphur**
- **Metals / ash**
- **Organic content (and its pyrolysis)**

Possible solutions:

→ **Calibrate based on a distillate test fuel (no such issues)**

→ **Develop a marine SOP for Thermal-Optical Analysis**

Candidate reference method and marine engine emissions

Thermal-Optical Analysis (TOA) is traceable but affected by:

- **Sulphur**
- **Metals / ash**
- **Orga**

Possib

→ Input from **technical experts needed!**

→ **Calibrate based on a distillate test fuel (no such issues)**

→ **Develop a marine SOP for Thermal-Optical Analysis**

Most ships' engine-to-exhaust systems are modular

- **Unless the engine alone meets the BC emissions requirement, certifying models alone as in aviation/automotive is not enough.**
- **Systems are often custom systems. Combinations of:**
  - engine
  - after-treatment system(s)
  - fuel
- **If the regulations are emission factors, measuring each ship may be very difficult. → Engine and after-treatment certification may be the best option.**

Most ships' engine-to-exhaust systems are modular

- **Unless the engine alone meets the BC emissions requirement, ce… …ough.**
- **Sy… C…**
  -
  -
  -
- **If … …o may be… …may be …**

Solutions needed!

- Certify engines and after treatment modules separately
- Measure exhaust-out on individual ships
- ??

→ Input from **technical experts needed!**

CONCLUSIONS

Summary

- **Other transportation sectors have measurement systems in place for BC → enables moving emission limits without redesigning the measurement system (focus on policy)**

- **Marine sector policy would also benefit from the flexibility brought by a standardized measurement system for BC**
  - A well thought out, universal and traceable measurement system developed by a group of international technical experts would be credible and likely accepted internationally

- **An emission limit has many historically proven advantages**

Advantages of emission limits enabled by standardized measurement systems

- **Pushes technology**: With tightening emission limits, technological development are likely to reduce emissions even further
- The measurement system is **universal**: applies to all engines and after treatment options
- **Results**: control measures don’t need to rely on a limited database of BC reduction measurements, the tolerance level will not be exceeded
- **Flexible**: possibility to set different emission limits to different ship classes
- Diversity of products and **competition** between control measure manufacturers (and/or fuel designers), **reduced cost**, promotion of **innovation**

Way forward

- Establish an international technical working group
- Take into account past research & literature and identify the gaps
- Internationally coordinate technical efforts and resources towards a clear goal (no coincidental duplication of the work)
- This work does not prevent a two-step policy approach where a control measure may be prescribed as a first step while the standard measurement system development is underway.

THANK YOU

Stéphanie Gagné, PhD • Research Officer
stephanie.gagne@nrc-cnrc.gc.ca