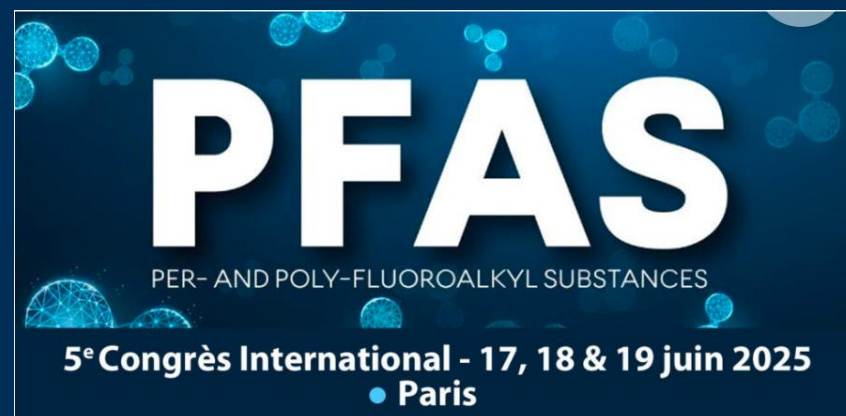


Characterizing PFAS in air emissions; monitoring methods & remediation challenges

Jelle Hofman

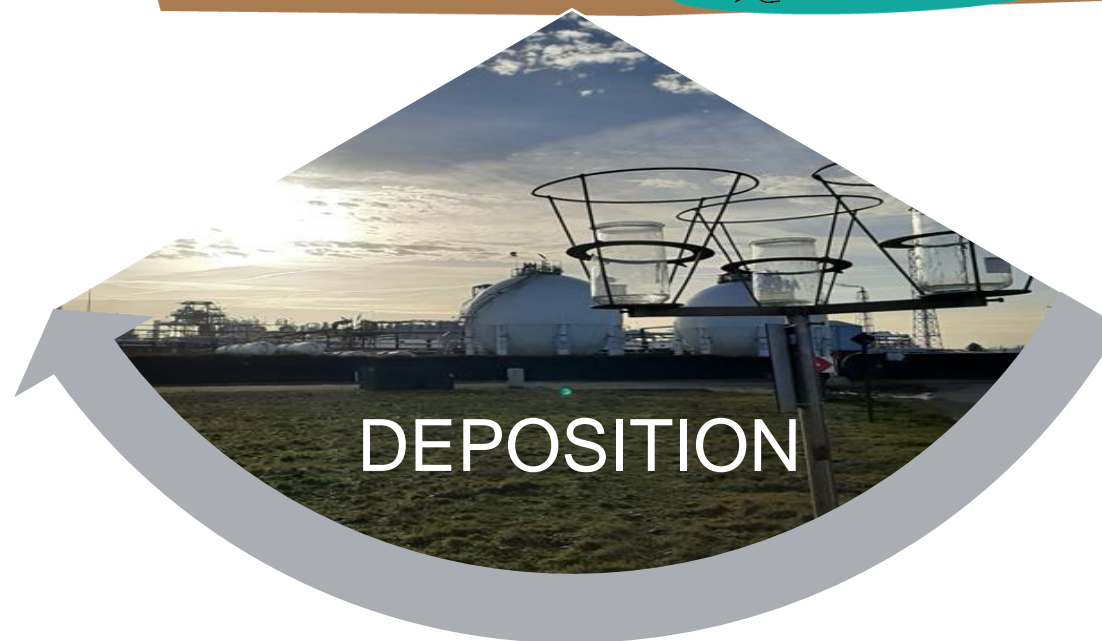
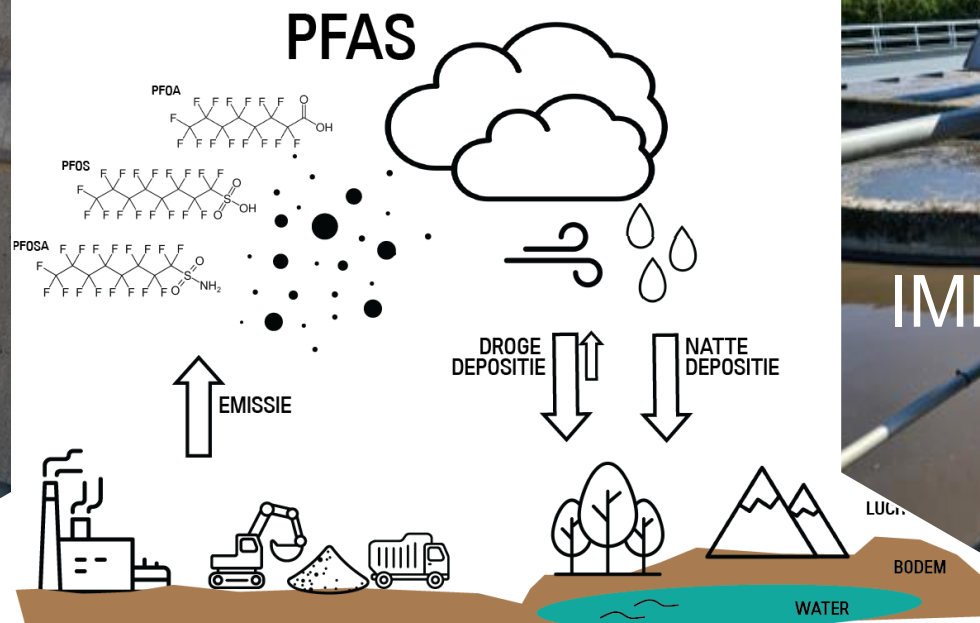
jelle.hofman@vito.be



Turning fundamental research into solutions

Creating value and increased competitiveness for companies and governments

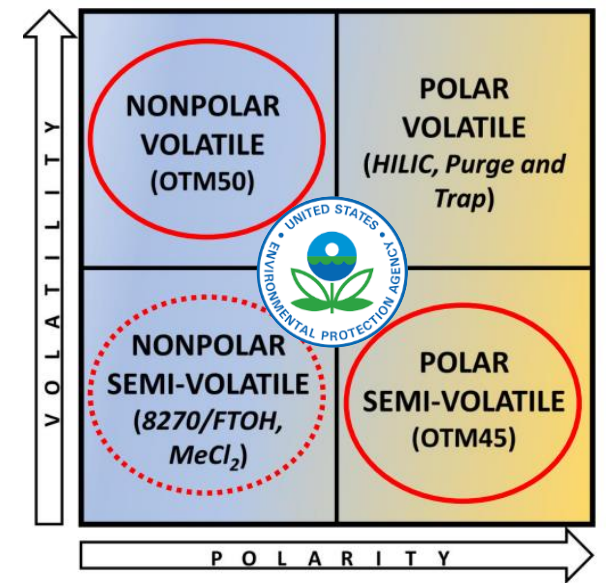




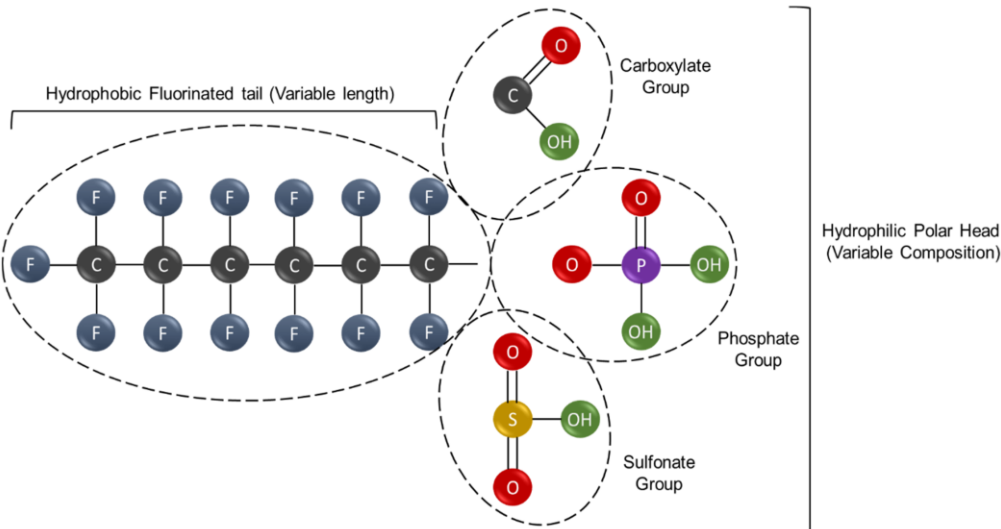
PFAS DIVERSITY

WHAT?

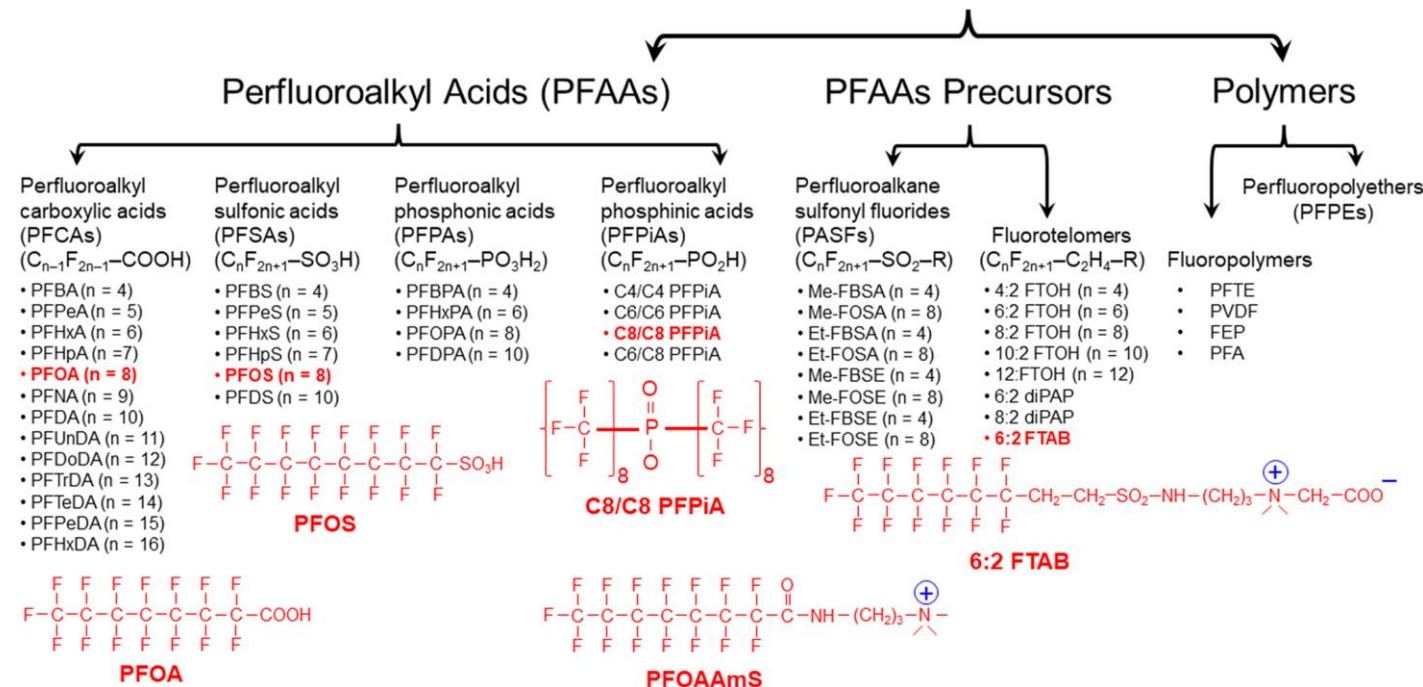
- Molecules with varying (i) carbon chain length, (ii) functional groups and (iii) number of fluor atoms
- PFAA + Polymers + Precursors
- Particle-bound, semi-volatile and volatile



Per- and Polyfluoroalkyl Substances (PFAS; C_nF_{2n+1}-R)



<https://doi.org/10.3390/toxics10020044>



<https://doi.org/10.1029/2021RG000765>



2021-2023

Development & validation LUC/VI/003



Oct 2023

Publication LUC/VI/003



Jan 2024

Visit + NDA US EPA



Feb 2024

Interlaboratory comparison (ILC)



Jun 2024

Publication LUC/VI/003 revision



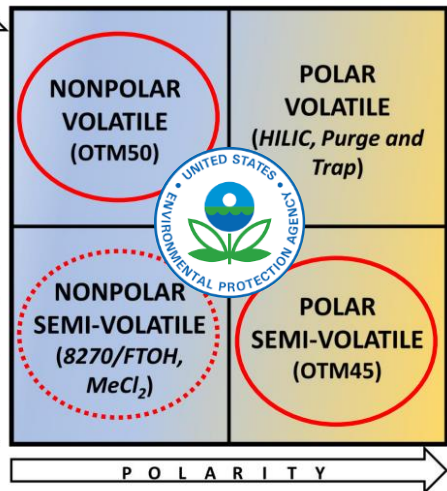
Jun-Dec 2024

Lab audits TAUW, SGS & Eurofins
Corrective actions



>March 2025

Accreditation ongoing



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C. 20460

MUTUAL CONFIDENTIALITY AGREEMENT

Between the U.S. Environmental Protection Agency and Vlaamse Instelling voor
Technologisch Onderzoek



Full length article

Quantifying per- and polyfluoroalkyl substances (PFAS) in air emissions:
Lab & field experiences from a hazardous waste incinerator

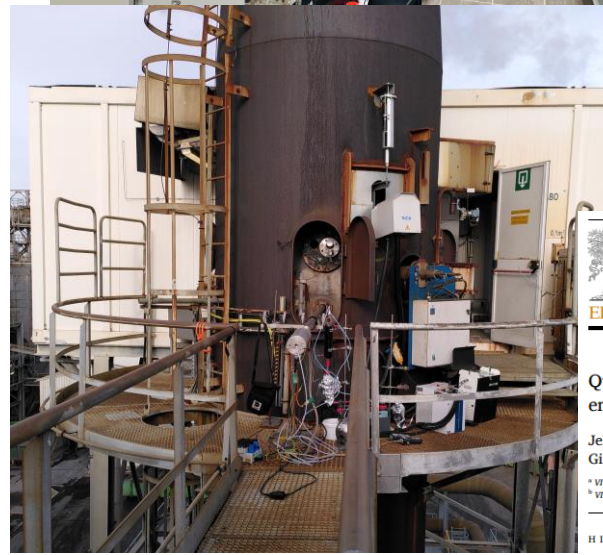
Jelle Hofman^{a,*}, Griet Jacobs^b, Bart Baeyens^a, Aline Reis De Carvalho^b, Wim Aerts^a,
Stefan Voorspoels^b, Gill Van den Bergh^b, Masha Van Deun^b, Patrick Berghmans^a,
Andres Van Brecht^c, Gert Otten^a



Quantification of per- and polyfluoroalkyl substances (PFAS) in air
emissions: An interlaboratory comparison

Jelle Hofman^{a,*}, Bart Baeyens^a, Wim Aerts^a, Griet Jacobs^b, Aline Reis de Carvalho^b,
Gill Van den Bergh^b, Stefan Voorspoels^b, Gert Otten^a

^a VITO Air Quality Management Systems (AQMS), Flemish Institute for Technological Research (VITO), Boeretang 200, 2400, Mol, Belgium
^b VITO GOAL, Flemish Institute for Technological Research (VITO), Boeretang 200, 2400, Mol, Belgium



HIGHLIGHTS

GRAPHICAL ABSTRACT

Standardized
experiments
in air
was ob-
served to-
rent lab
quantifi-
15th,
ation
need for
of PFAS
g. more

LUC/VI/003

SAMPLING TRAIN

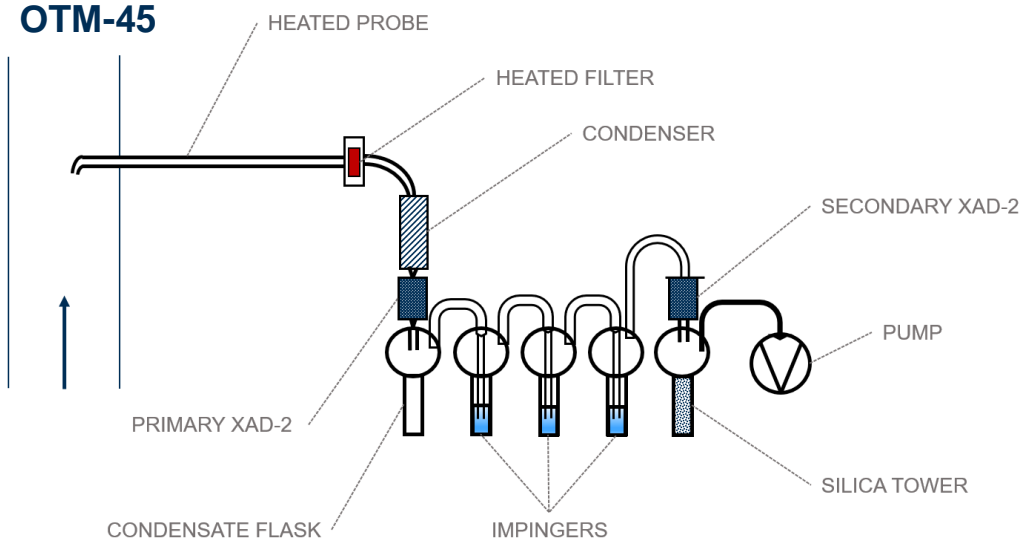
- Principal sampling train (OTM-45)
 - 2 additional variants (OTM-45 variant + cooled probe)
- Procedure (~5-6 hours):
 - 5 medium blanks
 - Leak test + Field blank collection (6)
 - Isokinetic sampling (min. 3 hours (~2 Nm³))
 - Leak test + Collection Field samples (7)
 - Post-rinse blank collection (2)
- Sample aggregation
- Sample extraction
- LC-MS/MS ([WAC/IV/A/025](https://doi.org/10.1016/j.envint.2025.109541))



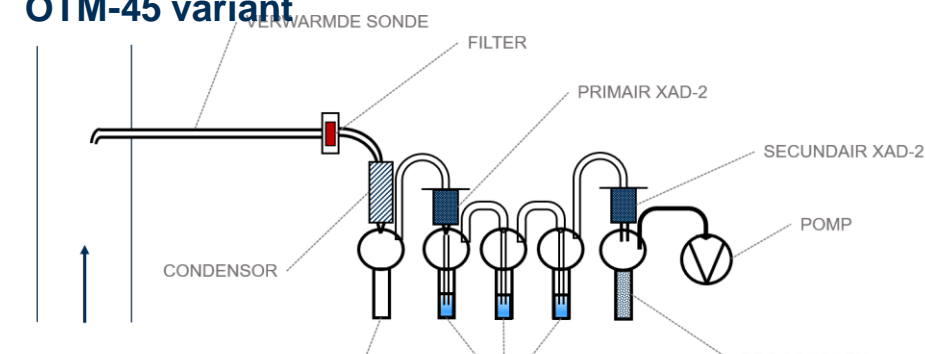
Government
of Flanders



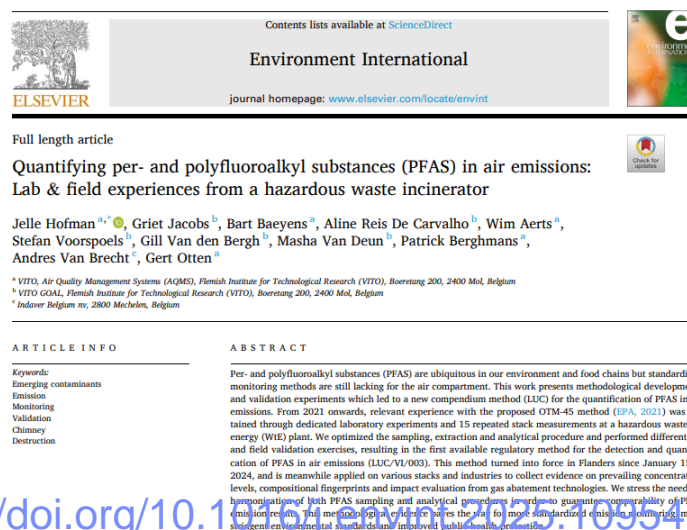
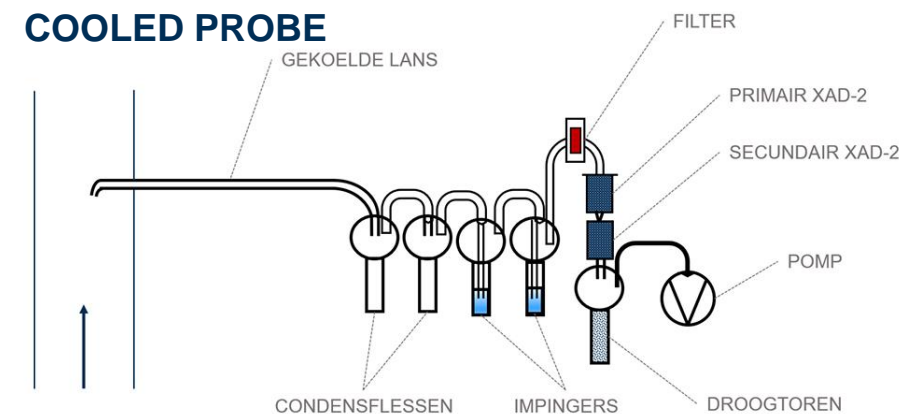
OTM-45



OTM-45 variant



COOLED PROBE

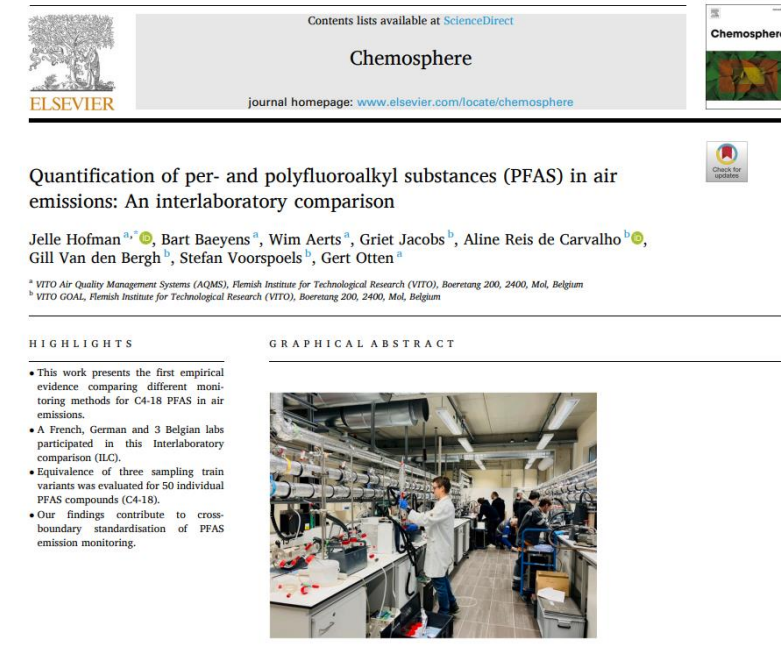
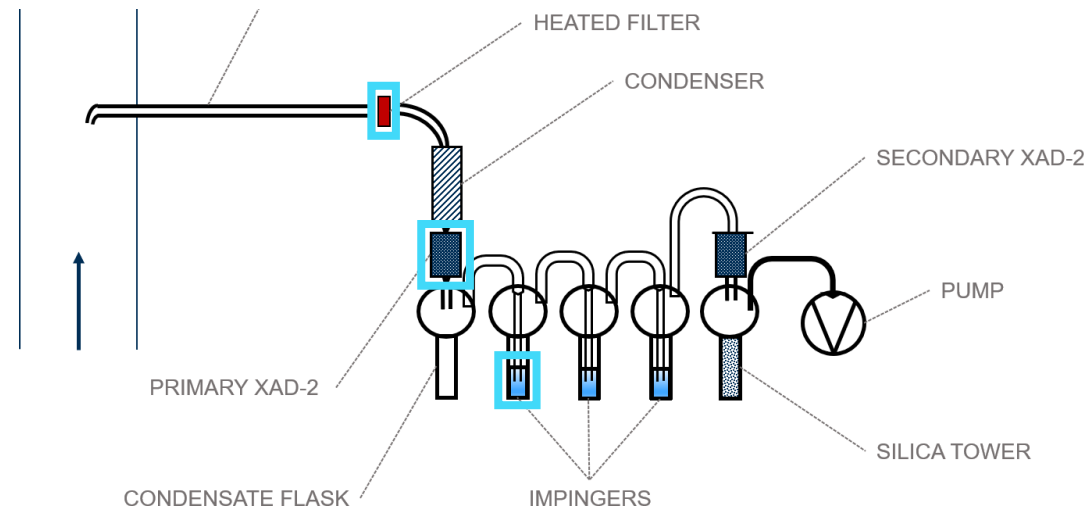




VALIDATION

ILC, Feb 2024

- AIM: test equivalence sampling train variants + determine reliability method
 - Validation sampling + analytical procedure
 - Preconditioned air (temp/RH) + spiked media (filter, water, XAD2)
 - Evaluation:
 - Sampling Standard (SS) Recoveries (%): 50-130%
 - Internal Standard (IS) Recoveries (%): >20% (*13C-8:2diPAP and 13C-PFHxDA* $\geq 10\%$ (WAC VI/A/003))
 - Breakthrough (%): <30%
 - **Native PFAS Recoveries (%): 70-120%**
 - **Observed uncertainty (U, k=2): <50%**

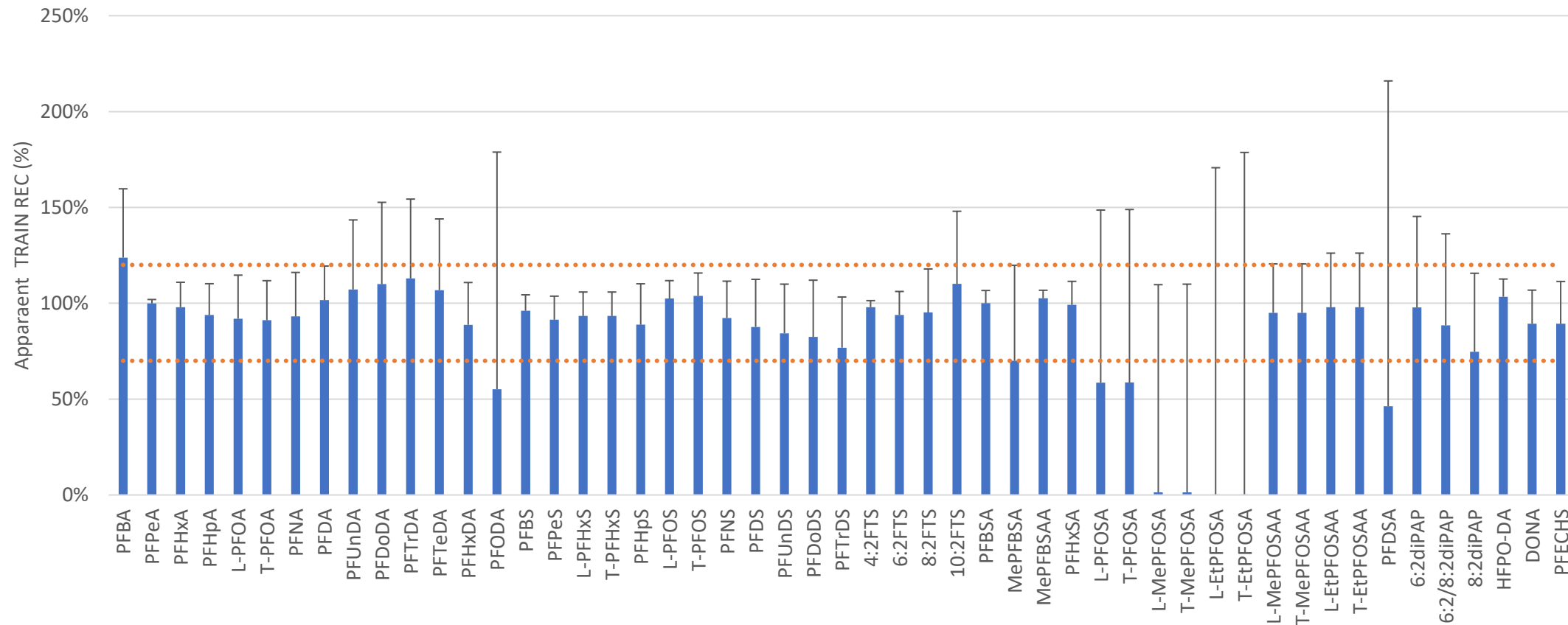




VALIDATION

ILC2024

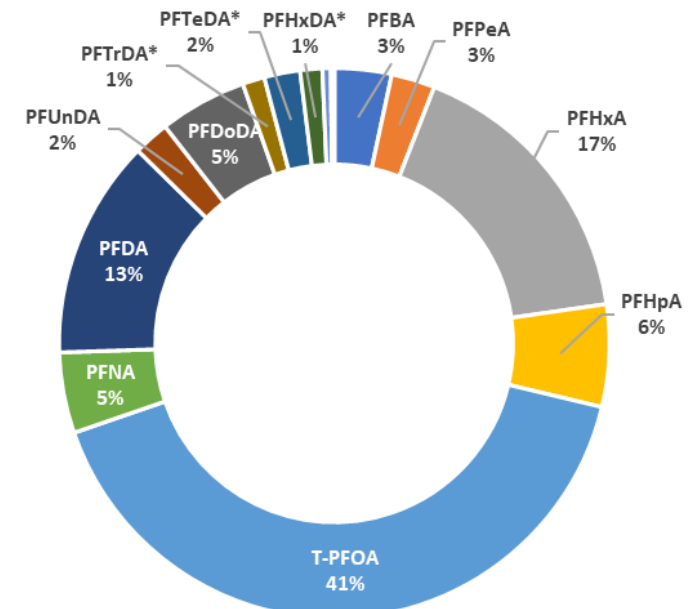
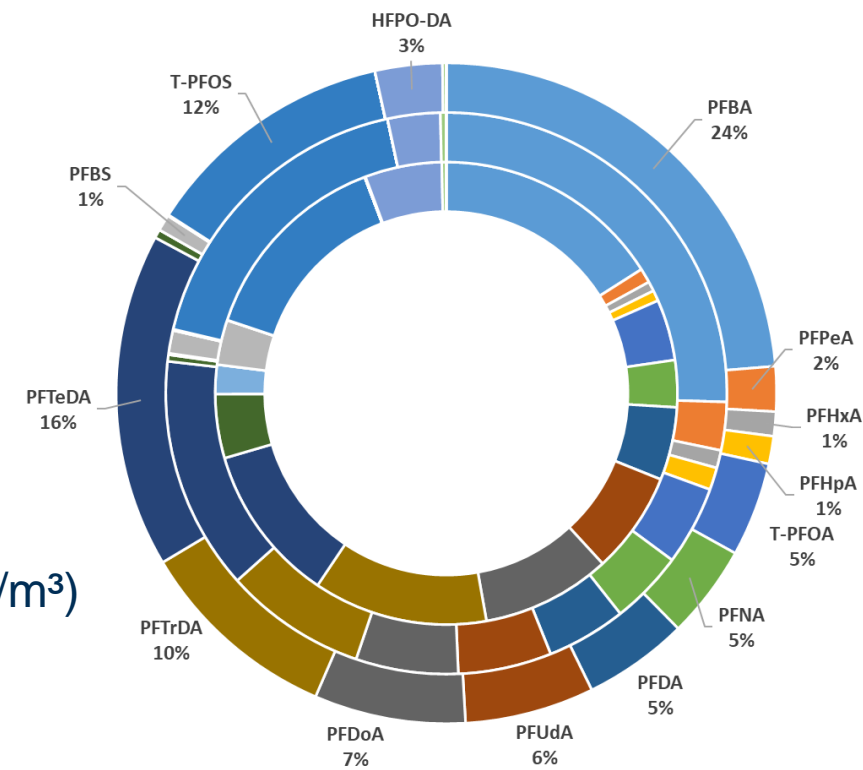
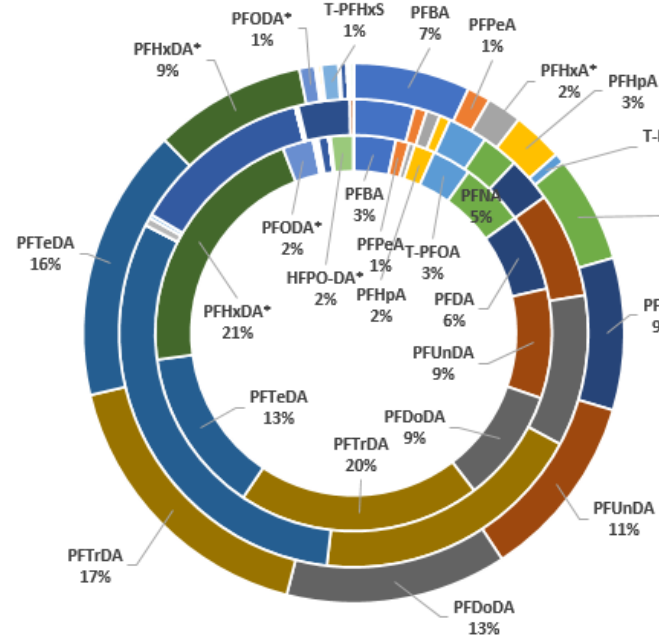
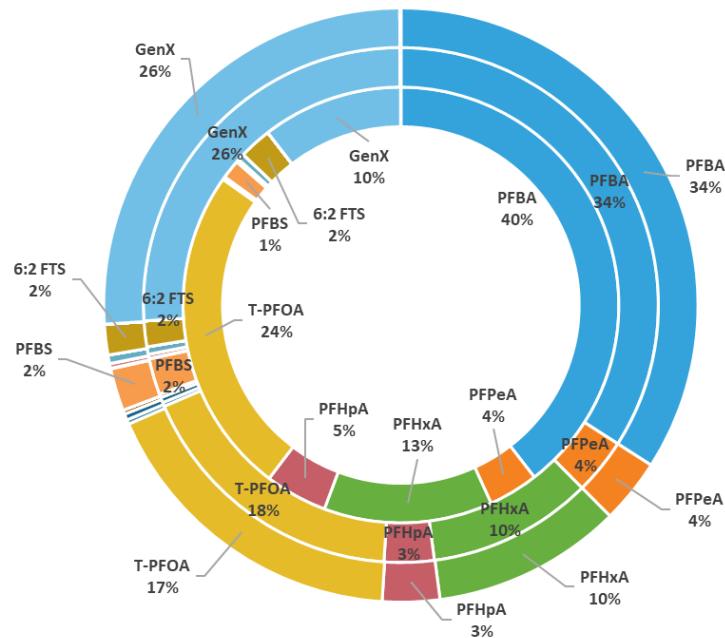
VITO (42 QUANTITATIVE CPDS)



FIELD EXPERIENCES

STACK FINGERPRINT

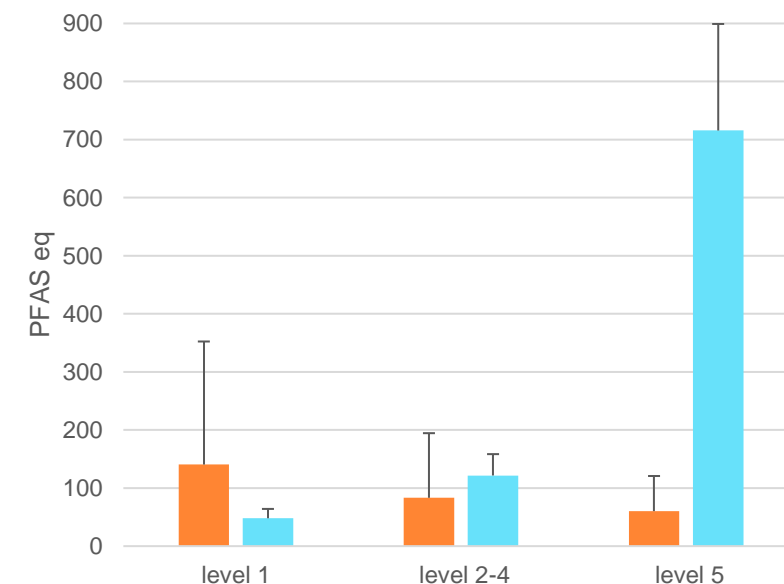
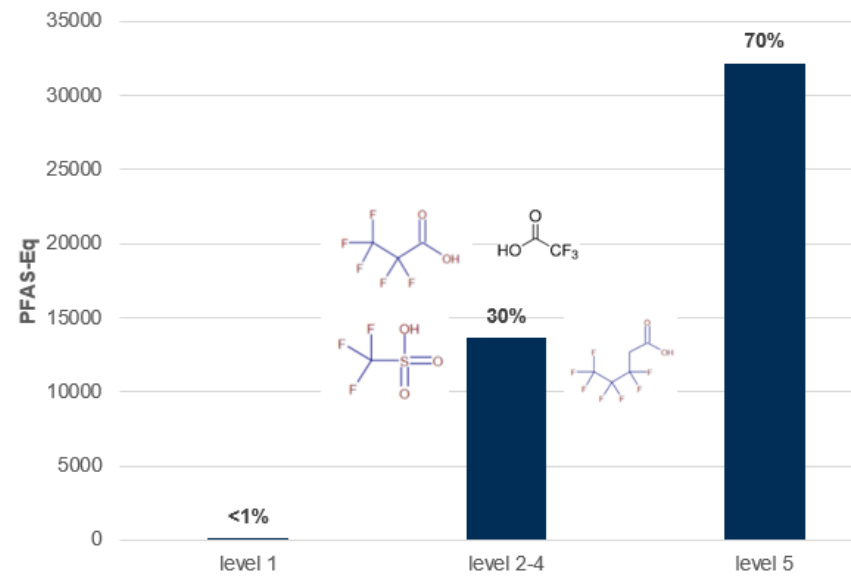
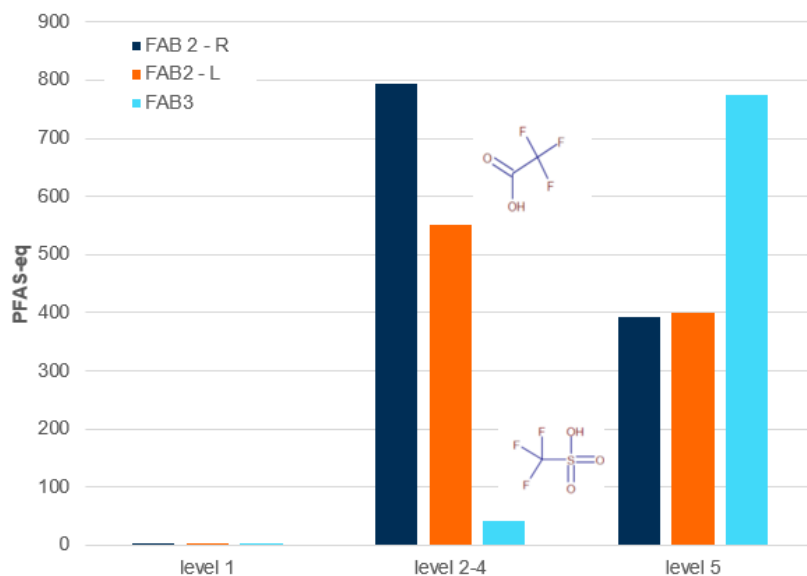
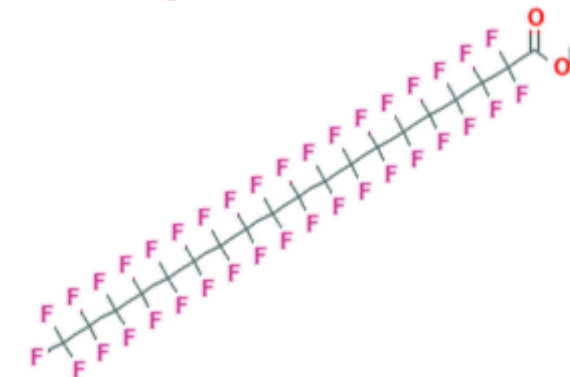
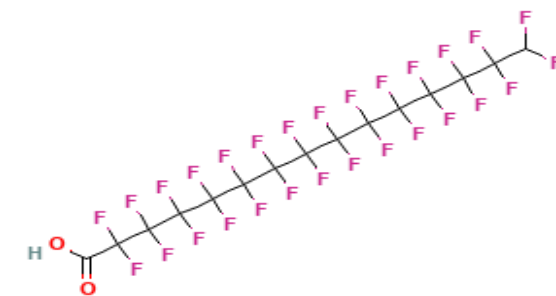
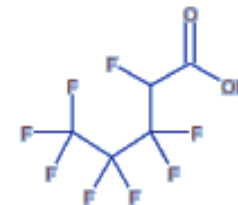
- Various chimneys/processes in Flanders
 - 11 ng/Nm³ – 43 mg/Nm³ (Σ PFAS)
 - 2.5 ng/Nm³ - 6.7 mg/Nm³ (Σ EFSA)
- <ELV (Netherlands), EFSA4 ambient air framework Belgium (0.3 ng/m³)
- Thermal transformation PFSA \rightarrow PFCA
- Impact flue gas cleaning: AC, wet scrubbers



FIELD EXPERIENCES

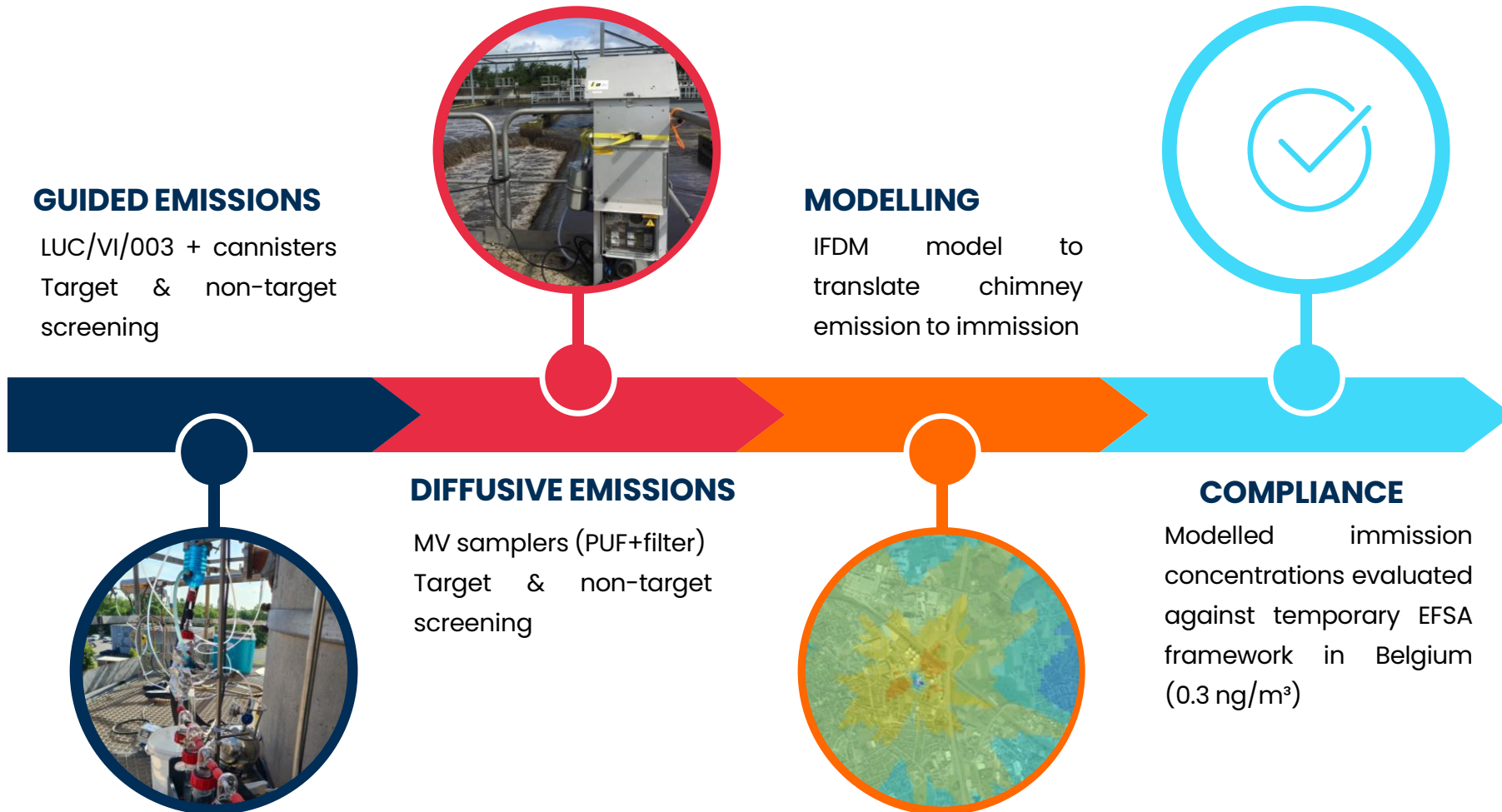
OUT OF ANALYTICAL/LEGAL SCOPE (BUT PRESENT!)

- Identified via NTA (HR-MS, DART-MS):
 - Ultra-short chain (<C4), e.g. PFPrA, TFA, TFMS,...
 - Poly-/H-substituted
 - Long-chain PFCA's up to 20C
- Ratio target vs unknown cpds varies strongly
- When relevant and analytical standards available
 → inclusion in LUC/VI/003 target scope?



PFAS EMISSIONS

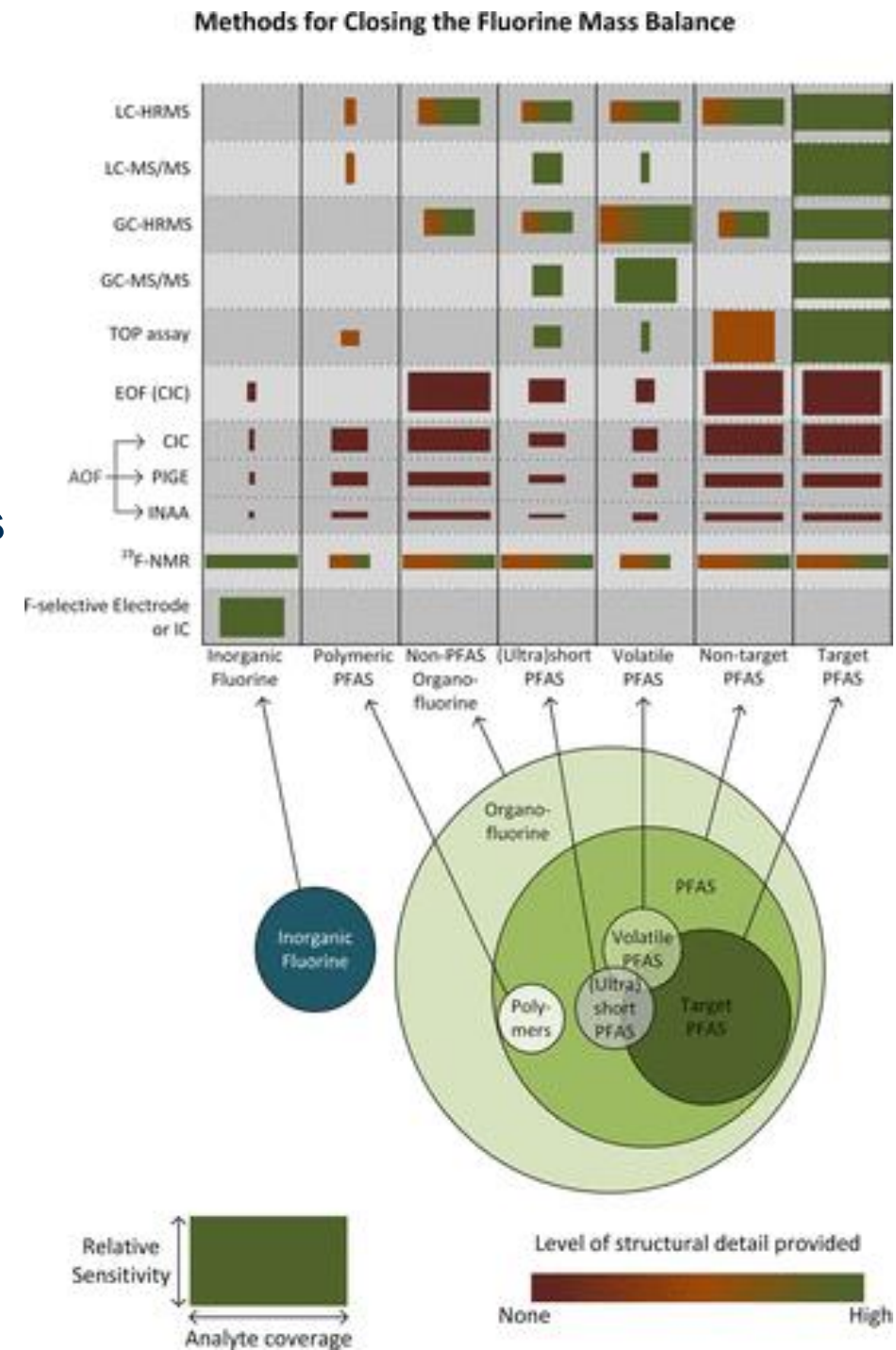
WHAT IS POSSIBLE TODAY?



DESTRUCTION vs MINERALISATION

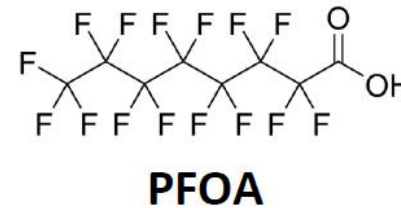
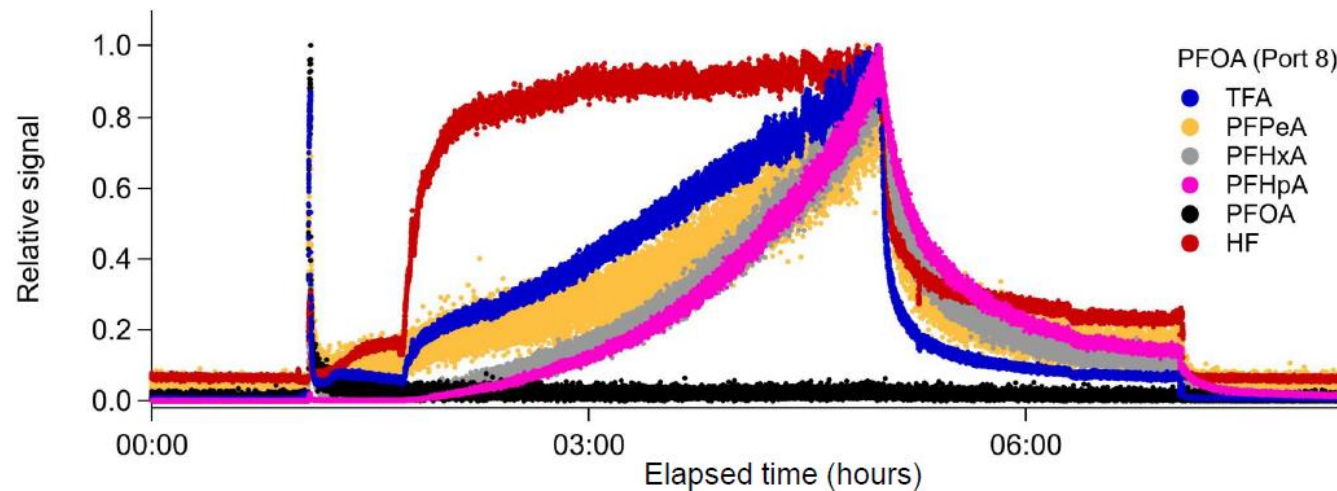
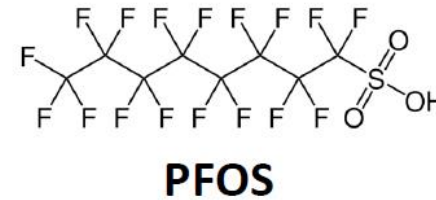
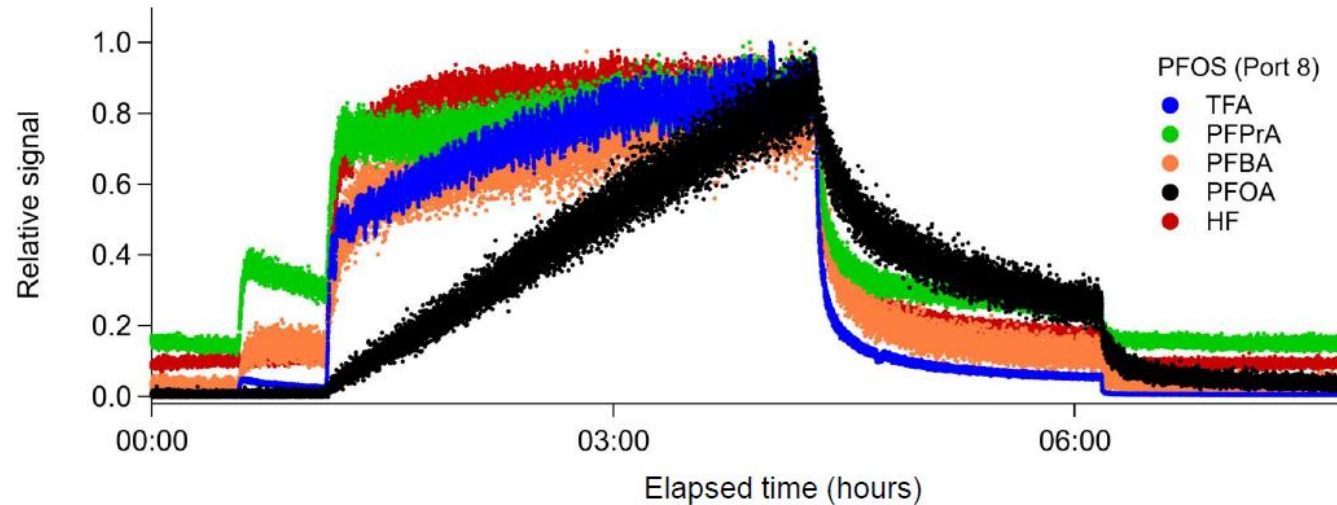
- AIM: close the fluorine mass-balance
- In practice very hard due to **high LOQ's**, **representative sampling** and **extraction procedures** of different media:
 - Waste
 - Flue gases
 - AC
 - Scrubber water
 - Bottom ash
 - Flue gas salts
 - ...

<https://pubs.acs.org/doi/10.1021/acs.est.3c10617>



PICs

Incomplete destruction of PFOS and PFOA yields smaller PFAS



ENVIRONMENTAL
Science & Technology

pubs.acs.org/est

Article

Characterizing Volatile Emissions and Combustion Byproducts from Aqueous Film-Forming Foams Using Online Chemical Ionization Mass Spectrometry

James M. Mattila,* Jonathan D. Krug, William R. Roberson, R. Preston Burnette, Stella McDonald, Larry Virtaranta, John H. Offenber, and William P. Linak

 Cite This: *Environ. Sci. Technol.* 2024, 58, 3942–3952

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Metrics & More

 Article Recommendations

Supporting Information

ABSTRACT: Aqueous film-forming foams (AFFFs) are used in firefighting applications and often contain per- and polyfluoroalkyl substances (PFAS), which can detrimentally impact environmental and biological health. Incineration is a potential disposal method for AFFFs, which may produce secondary PFAS and other air pollutants. We used online chemical ionization mass spectrometry (CIMS) to measure volatile PFAS emissions from incinerating AFFF concentrate solutions. We quantified perfluorinated carboxylic acids (PFCAs) from the incineration of legacy and contemporary AFFFs. These included trifluoroacetic acid, which reached mg m^{-3} quantities in the incinerator exhaust. These PFCAs are likely arose as products of incomplete combustion of AFFF fluorosurfactants with lower peak furnace temperatures yielding higher PCFA concentrations. We also detected other short-chain PFAS, and other novel chemical products in AFFF combustion emissions. The volatile heads above AFFF solutions contained larger ($\text{C} \geq 8$), less oxidized PFAS detected by CIMS. We identified neutral PFAS resembling fluorotelomer surfactants (e.g., fluorotelomer sulfonamide alcohols) and perfluorinated alcohols in contemporary AFFFs. We compared the distinct chemical spaces of AFFF volatile headspace and combustion byproducts as measured by CIMS provides insight toward the chemistry of PFAS during thermal treatment of AFFFs.

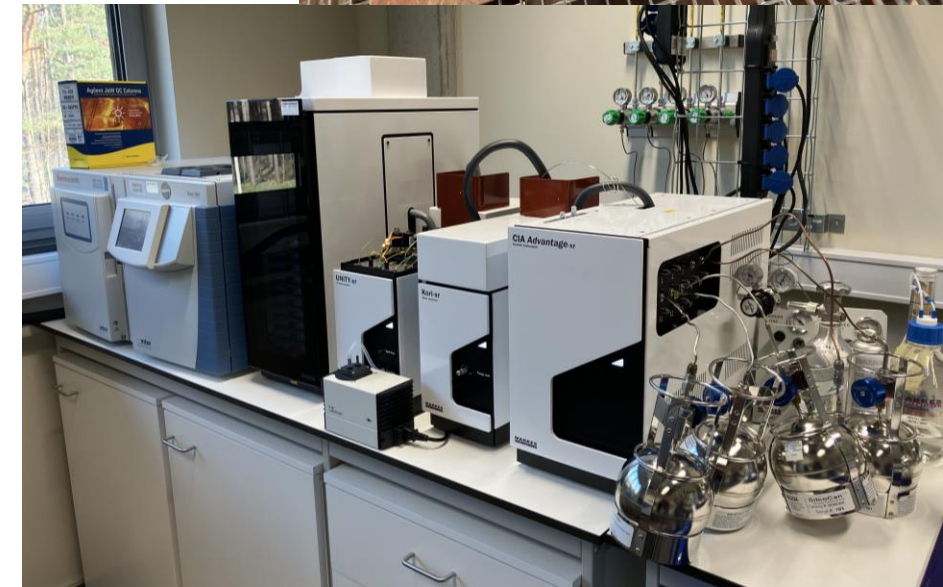
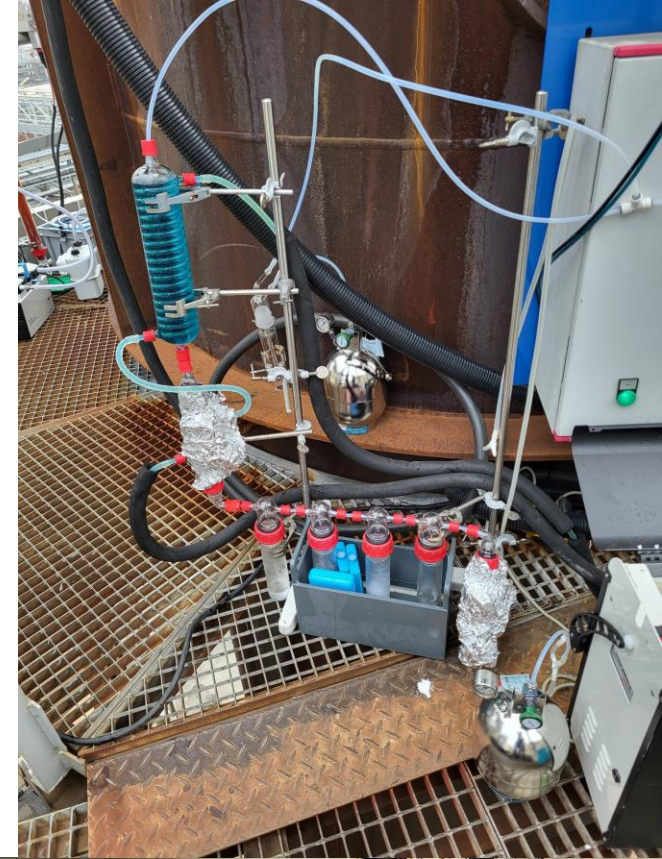
KEYWORDS: PFAS, AFFF, online mass spectrometry, thermal oxidation, forever chemicals, headspace

vito.be

<https://doi.org/10.1021/acs.est.3c09255>

>2025

- New method for non-polar USC/PICs (canister + GC) ~OTM-50
- Comparative ILC with accredited labs on stack
- Optimization LUC/VI/003
- *Extension target scope USC polar compounds, alignment LOQs, simplification sampling train/cost price, ...*
- Standardization!
 - **CEN/TC 264 WG48**
 - Convenor: Marc Coleman (NPL)
 - Secretary Ljuba Woppowa (VDI)
 - **EURAMET MetZeroPol**
 - Start EU standardisation



RESOURCES

- LUC/VI/003 method C4-18 polar compounds:
https://reflabos.vito.be/2026/LUC_VI_003.pdf
- LUC/VI/003 development: <https://doi.org/10.1016/j.envint.2025.109541>
- 2024 ILC: <https://doi.org/10.1016/j.chemosphere.2025.144449>
- BAT study/inventory on reducing PFAS emissions to air:
<https://emis.vito.be/nl/bbt/publicaties/bbtbref-en-andere-publicaties/pfas-emissies-lucht>
- Review of per- and poly-fluoroalkyl treatment in combustion-based thermal waste systems in the United States (2024) <https://doi.org/10.1016/j.scitotenv.2024.172658>
- A systematic review for non-targeted analysis of per- and polyfluoroalkyl substances (2025): <https://doi.org/10.1016/j.scitotenv.2024.178240>

“An increased NTA in the atmosphere and marine environment would help improve our understanding of the global fate and transport of PFAS.”

“you can only find what you search for”

jelle.hofman@vito.be