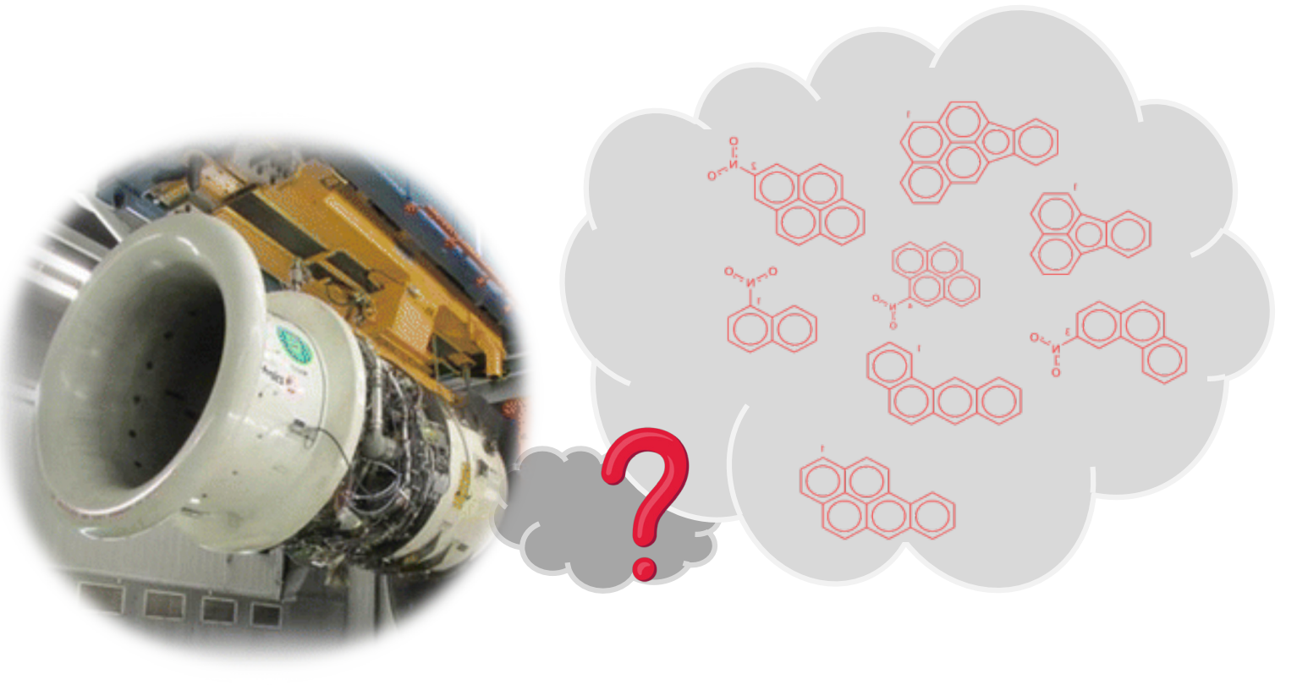
Thrust-dependent PAH emissions of an in-service turbofan jet engine

M. Muñoz[1,*], B. Brem[1], L. Durdina[1], M. Elser[1], R. Haag[1], S. Wyss[2], J. Mohn[2] and N. Heeb[1]
[1] *Advanced Analytical Technologies*, [2]*Air Pollution/Environmental Technology, Empa, CH-8600 Dübendorf*
Corresponding author: maria.munozfernandez@empa.ch

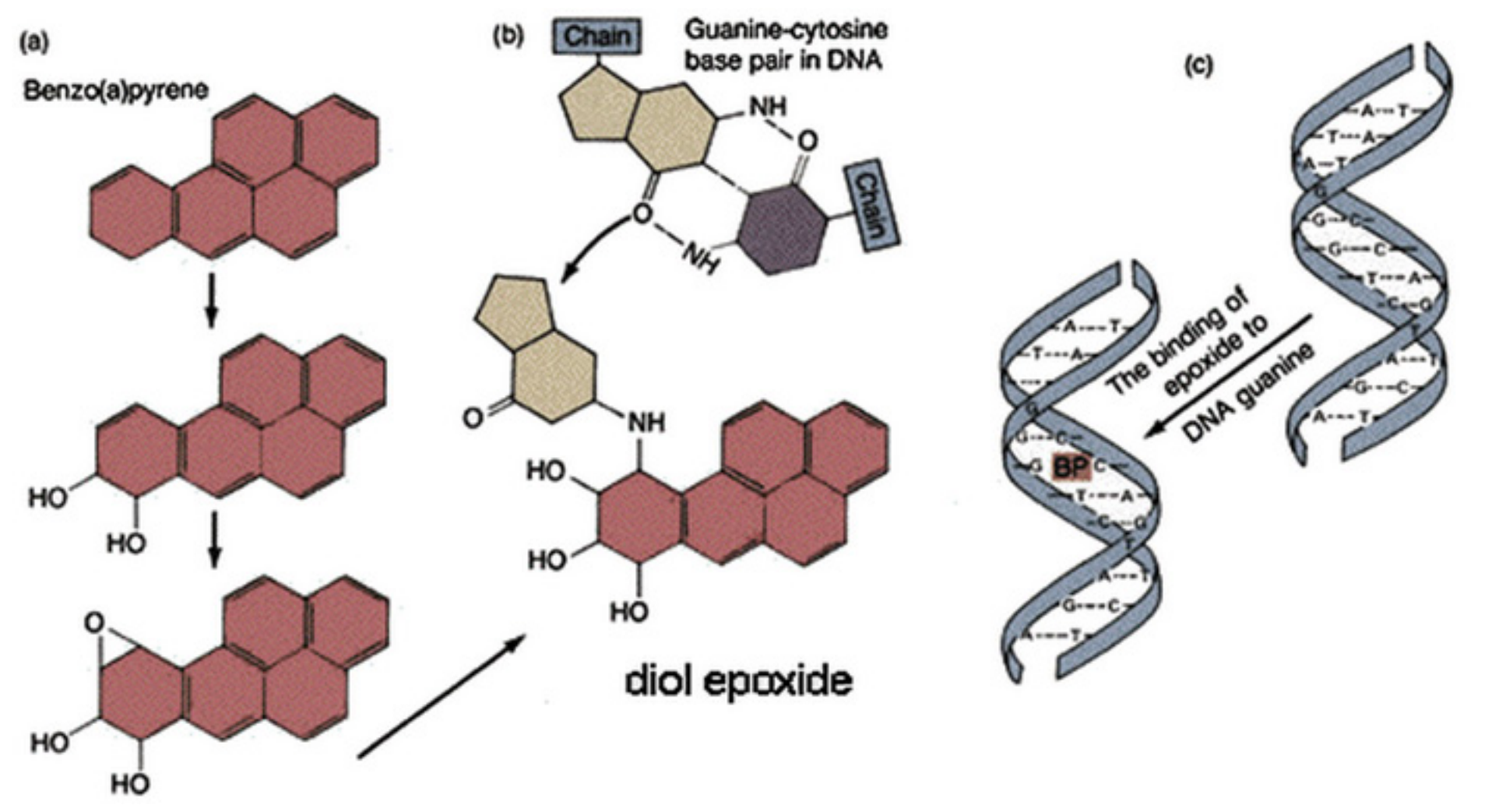
Background and motivation

- Aviation is a substantial and a fast growing emissions source. Impacts on local and regional air quality are poorly understood because emission inventories lack representative data.
- Large numbers of soot nanoparticles (**2.8-8.7x10^{14} #/kg fuel**) with mean diameter of **5-100 nm**, even smaller than diesel particles are emitted from jet engines (Masiol et al 2014, Durdina et al. 2017).
- It remains to be proved if these jet engine particles and exhausts also contain with **genotoxic PAHs**. A group of 16 PAHs are considered as priority pollutants and 8 of them are genotoxic (Fig. 4).
- In 2012, the WHO classified non-treated diesel exhausts as a class 1 carcinogen inducing lung cancer in humans. We hypothesized that jet engine particle exhausts resemble those of diesel engines.

Genotoxic effect of benzo(a)pyrene (Group 1 carcinogen)



IS JET ENGINE EXHAUST GENOTOXIC?



Methodology

Sampling diagram at SR Technics → Sampling train for PAHs → Laboratory analysis

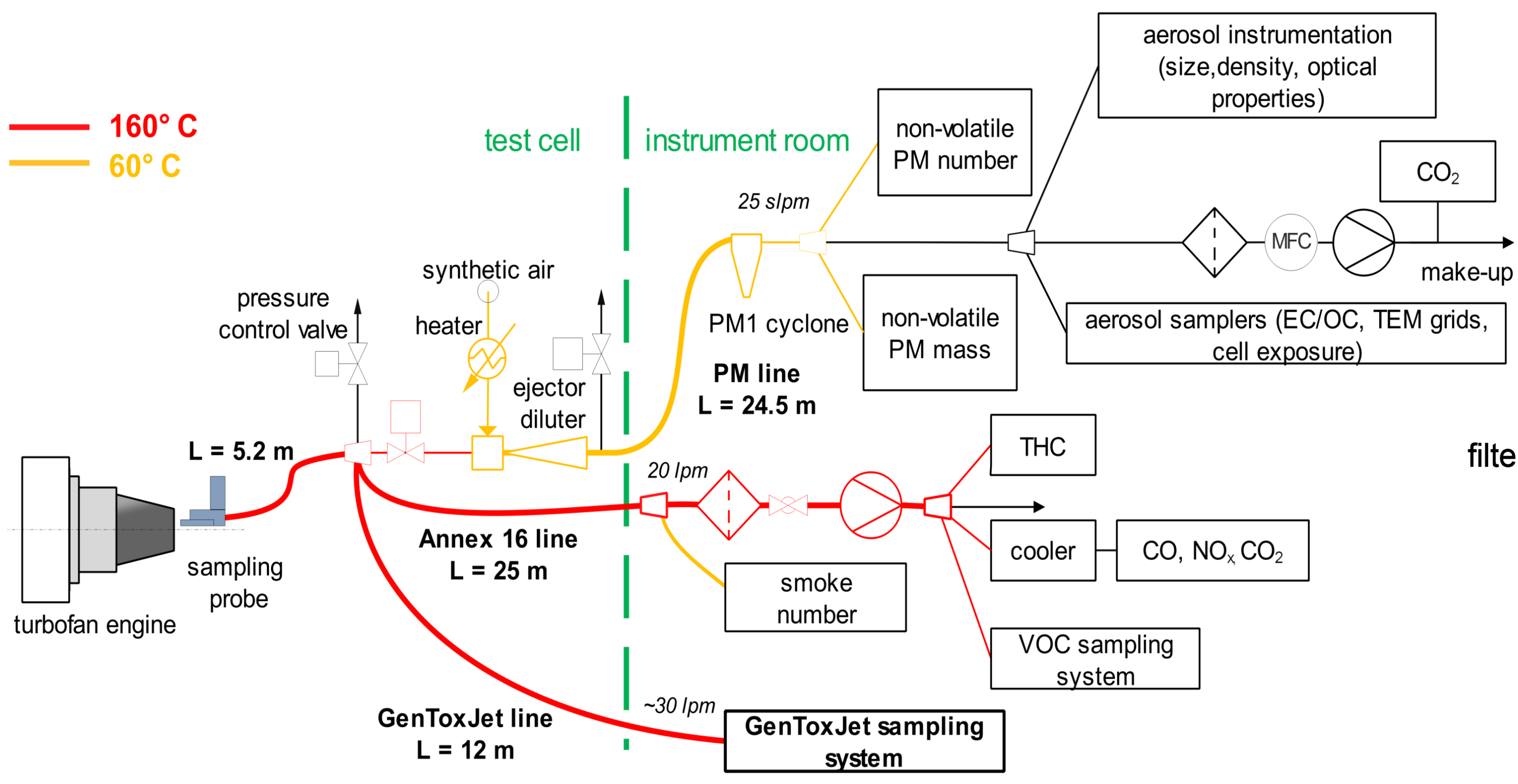


Fig. 1. Scheme of the sampling system in the test cell of SR Technics in Zürich airport. The GenoTox Jet sampling system (bold) corresponds to the line where our measurements were done.

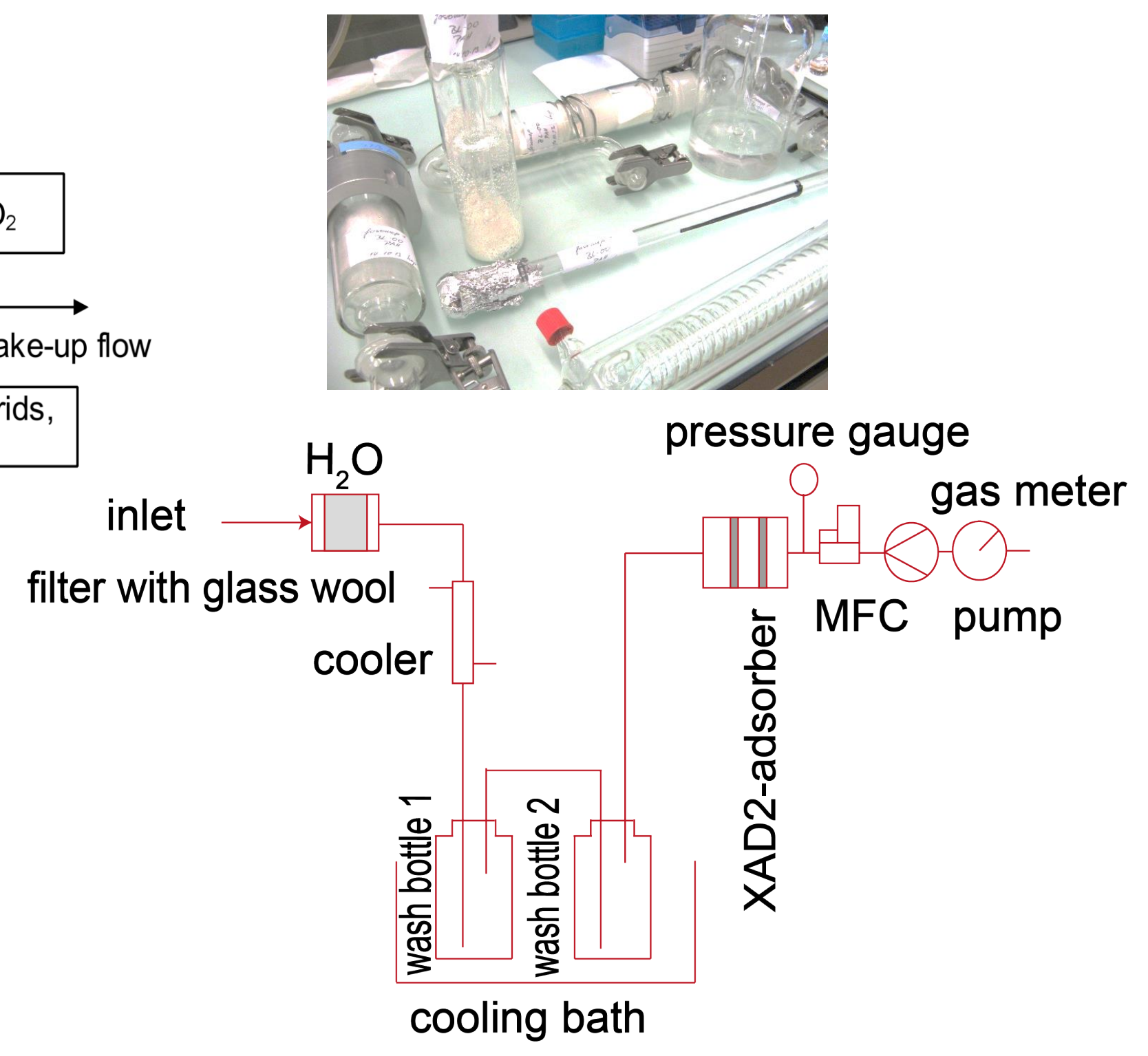


Fig. 2. Scheme of the sampling system (LAGA train) connected to the GenTox Jet line used to collect PAHs. Example of all fractions collected from a sample above.

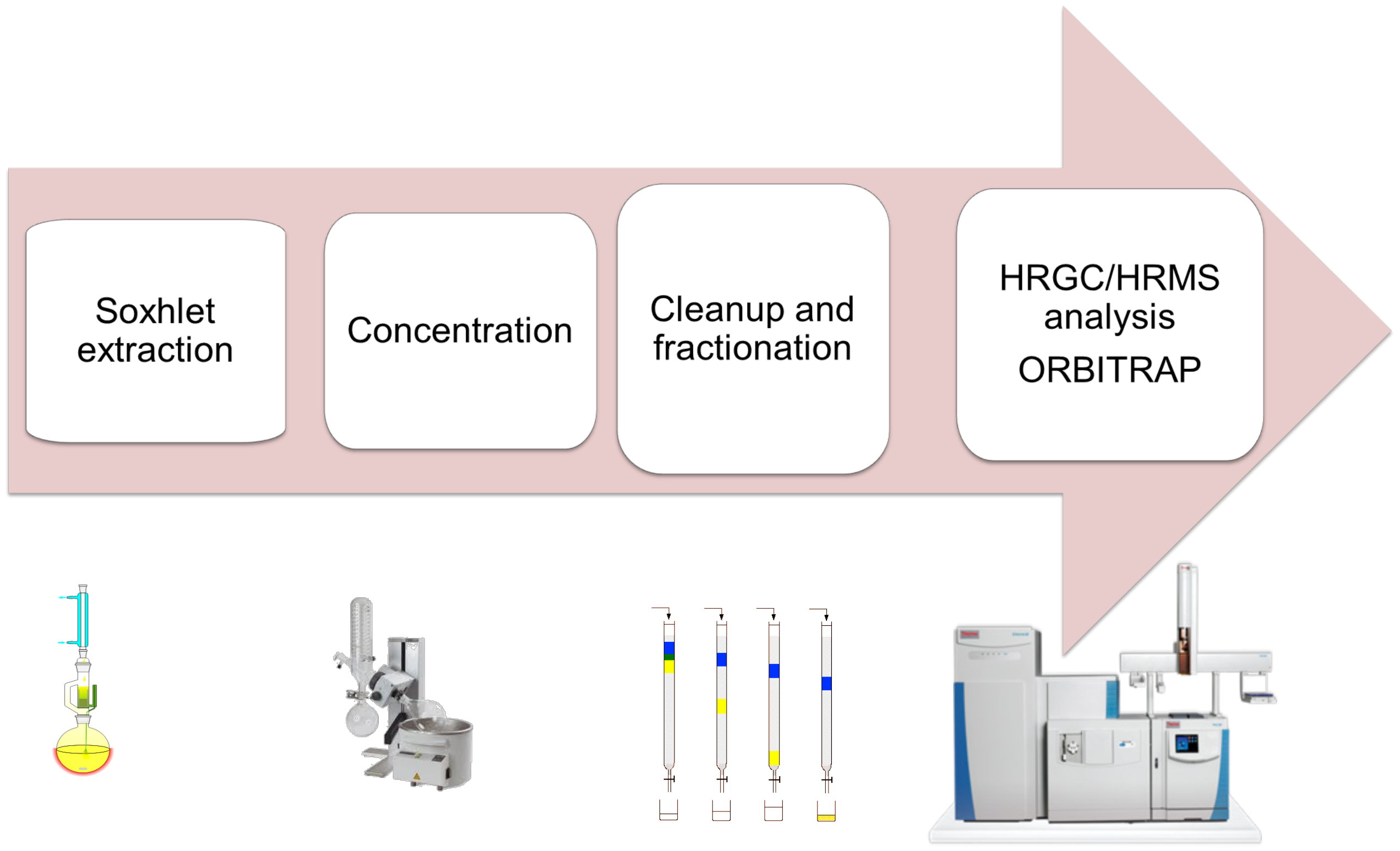


Fig. 3. Scheme of the laboratory cleanup and mass spectrometry analysis (MAT95 and Orbitrap).

Results

- **1-2 order higher concentrations of genotoxic PAHs at idle than at high thrust**
- **Naphthalene predominant at idle. Less volatile PAHs dominate at high thrust**
- **Highest PN emissions at high thrust**
- PAHs collected from raw exhaust included solid, liquid and gaseous fractions. Schemes of the sampling and analytical steps are shown in Fig. 1-3.
- Lowest PAH concentrations (2100 ng/m^3) were detected at high thrust (85%) and 530-times higher concentration at idle (mean idle = 1.1x10^6 ng/m^3).
- Naphthalene and their alkylated derivatives (Fig. 8) account more than 50% of the PAH emissions at idle and low thrust (7%). Phenanthrene is the most abundant PAH at high thrust.
- Fig. 5 shows concentrations of the sum of genotoxic PAHs in ng TEQ/m^3 = [concentration (ng/m^3)] x [toxic equivalency factor (TEF)] (Group 1, 2A and 2B carcinogens). Highest genotoxic PAH concentrations were observed at idle and low thrust.
- At idle and low thrust, volatile PAHs dominate while semivolatile and toxic PAHs dominate at higher thrust (Fig. 5, pattern)
- This correlates with the HC results (Fig. 6) meaning that probably more partially or non-oxidized hydrocarbons are released at idle, while more soot-like particles are released at higher thrust.
- PN (#/m^3) and CO_2 emissions show the opposing trends with respect to thrust (Fig. 6).

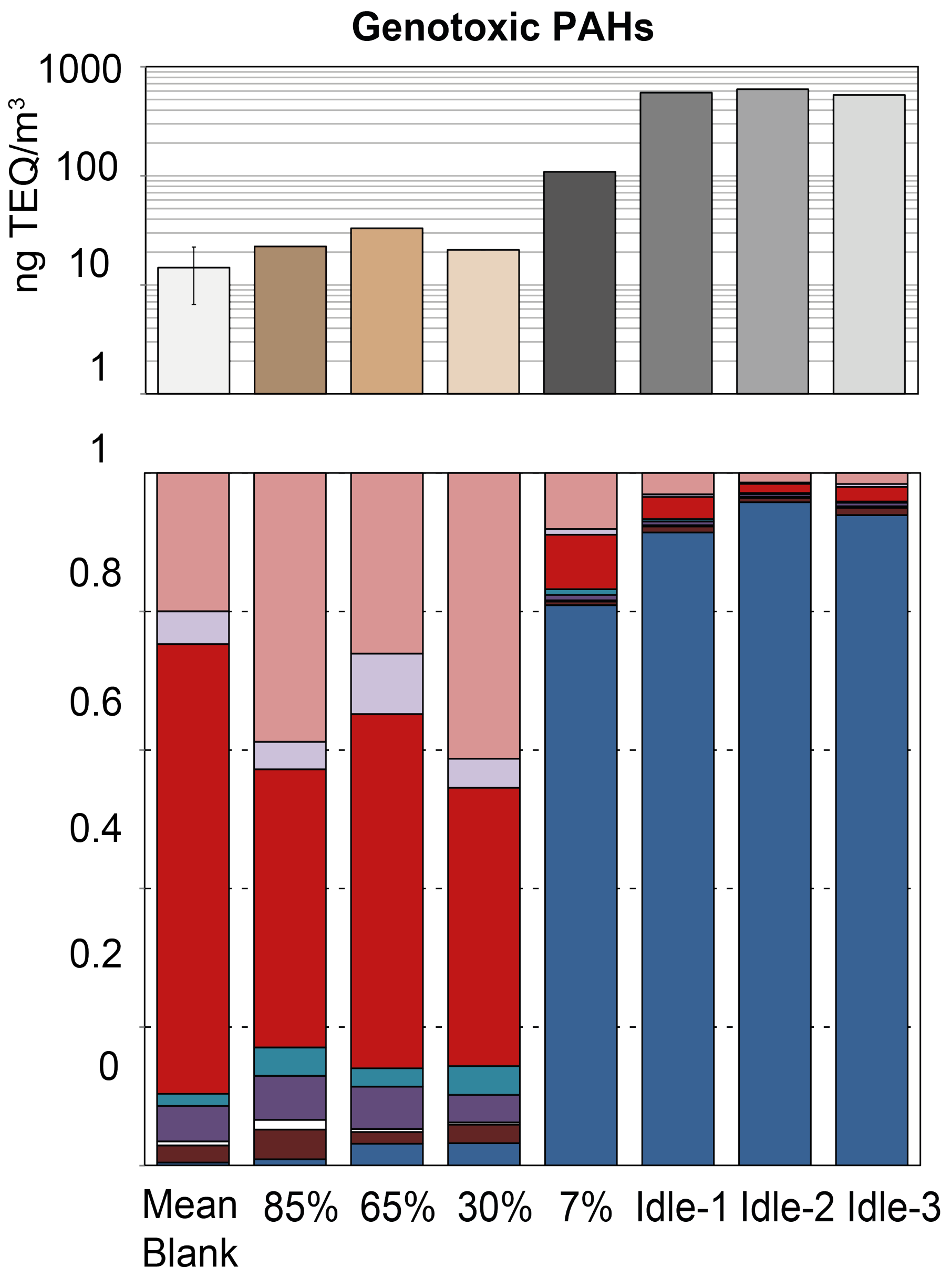


Fig. 5. Concentrations of 8 genotoxic PAHs in ng TEQ/m^3 at the different thrust levels. Patterns of individual PAHs given below.

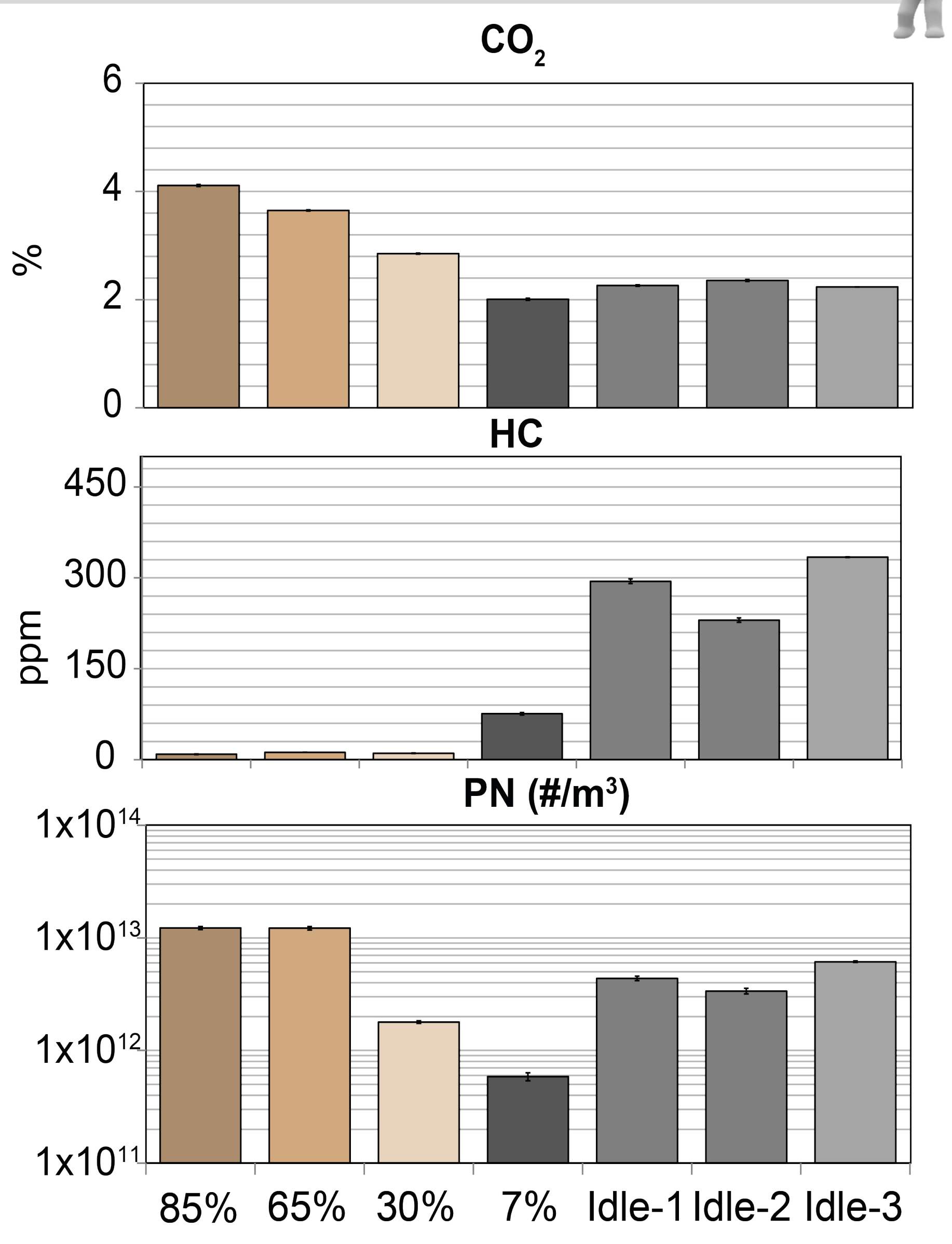


Fig. 6. Concentrations of major pollutants (CO_2, HC and PN) at different thrust levels.

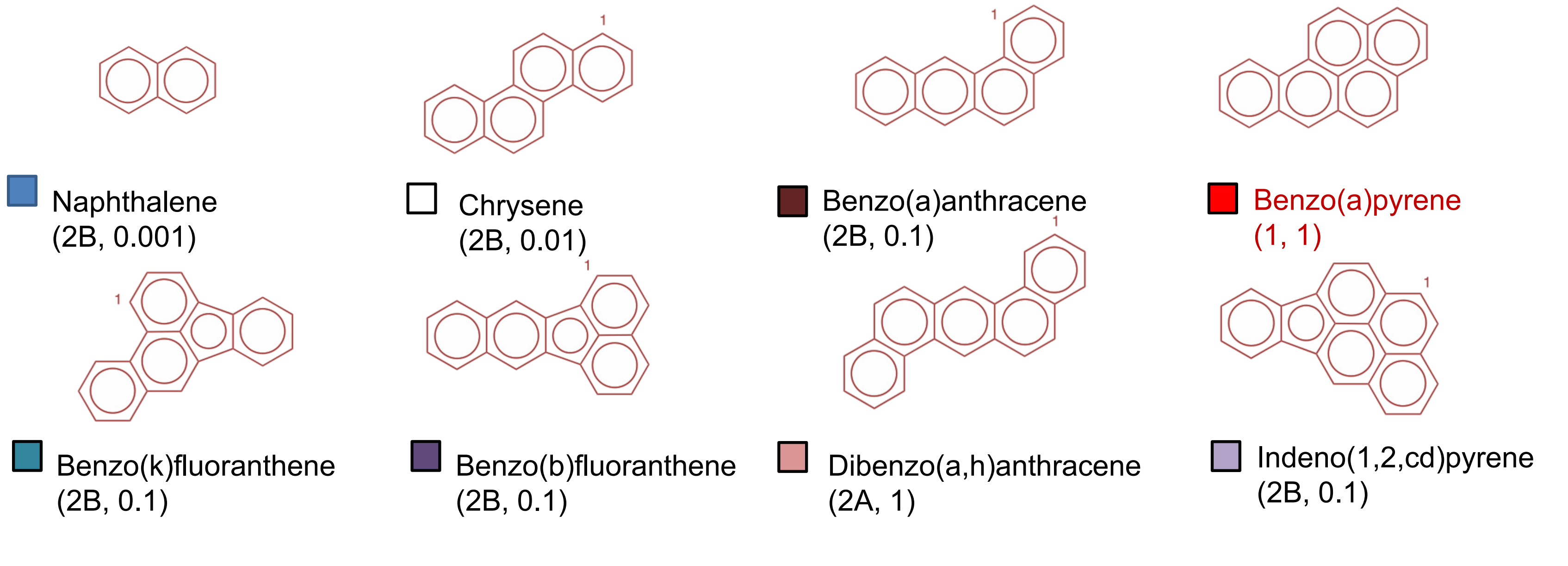


Fig. 4. Chemical structures and names of 8 genotoxic PAHs. IARC carcinogen group and TEFs are indicated in brackets according to I.C. Nisbeth, P.K.L. Regul Toxic Pharmacol. 16:290-300; 1992.

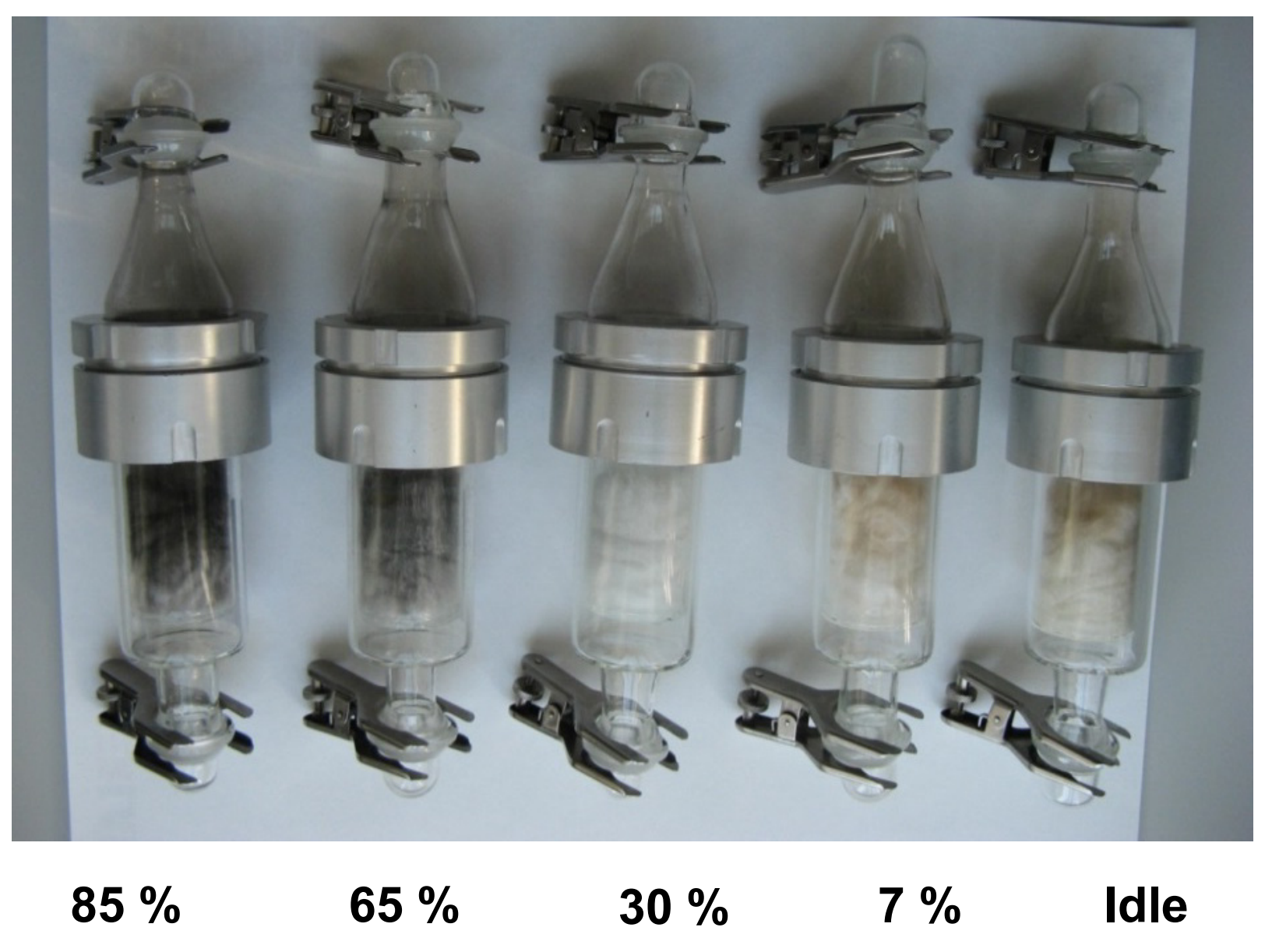


Fig. 7. Concentrations of the naphthalene and their alkylated derivatives.

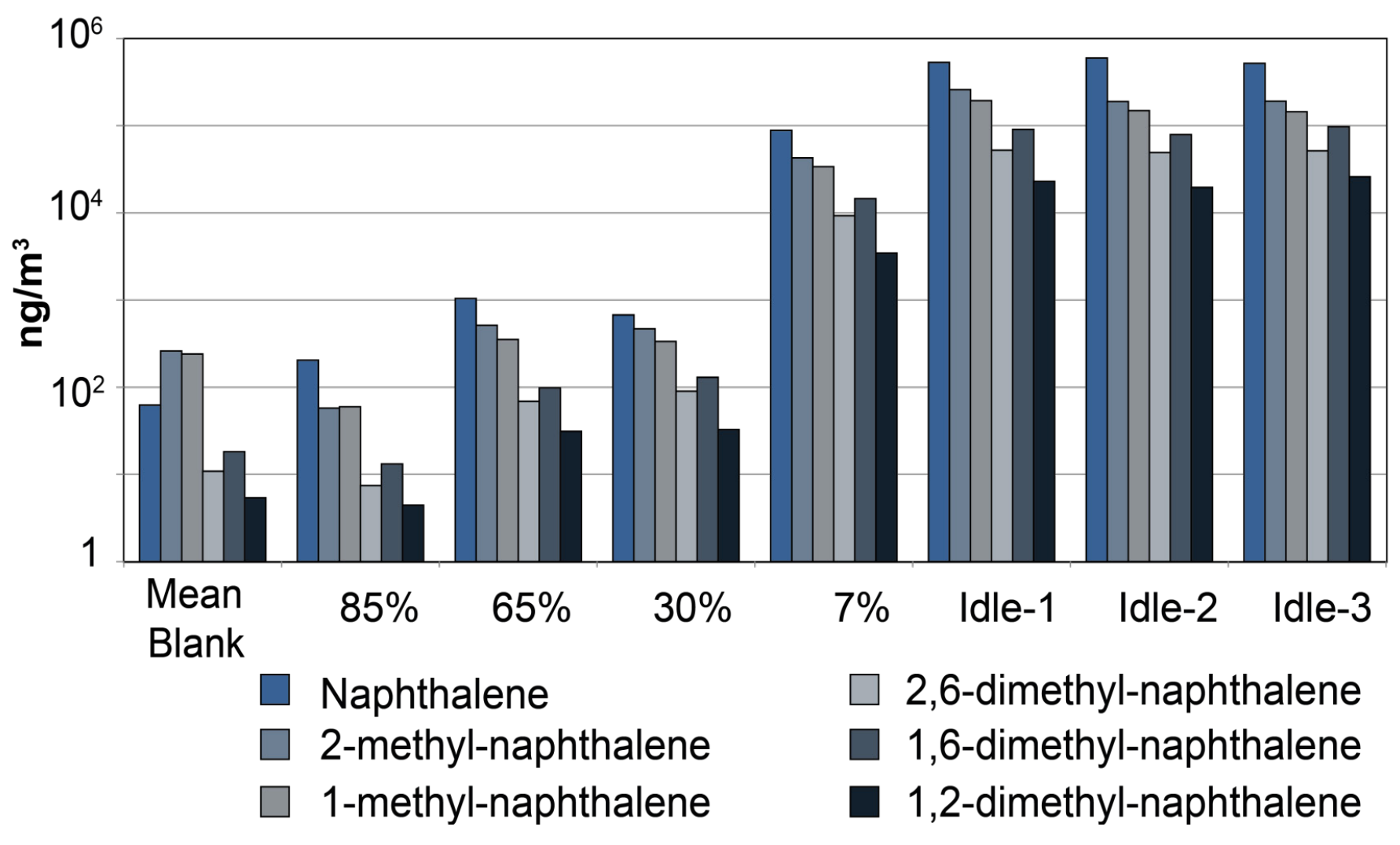


Fig. 8. Concentrations of naphthalene and their alkylated derivatives.

Conclusions

- Genotoxic PAHs are found in jet engine exhausts, mostly at ground idle and low thrust conditions
  - → Thus jet engine exhausts contribute to the genotoxicity of ambient air at or nearby airports.
- benzo(a)pyrene mean levels of 13 ng TEQ/m^3 were found at ground idle, exceeding the EU air quality limit value of 1 ng /m^3 by a factor of 13.
- Other genotoxic PAHs also present in jet engine exhausts further contribute to the genotoxic burden, like those showed in Figures 5 and 8.

Acknowledgements

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
BAZL Bundesamt für Zivilluftfahrt

SR Technics

REFERENCES:
Masiol, M. and R.M. Harrison, *Aircraft engine exhaust emissions and other airport-related contributions to ambient air pollution: A review.* Atmospheric Environment, 2014. **95**: p. 409-455.
Durdina, L., et al., *Assessment of Particle Pollution from Jetliners: from Smoke Visibility to Nanoparticle Counting.* Environmental Science & Technology, 2017. **51**(6): p. 3534-3541.