UT-BATTELLE

Detailed HCCI Exhaust Speciation – ORNL Reference Fuel Blends

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Purpose of research

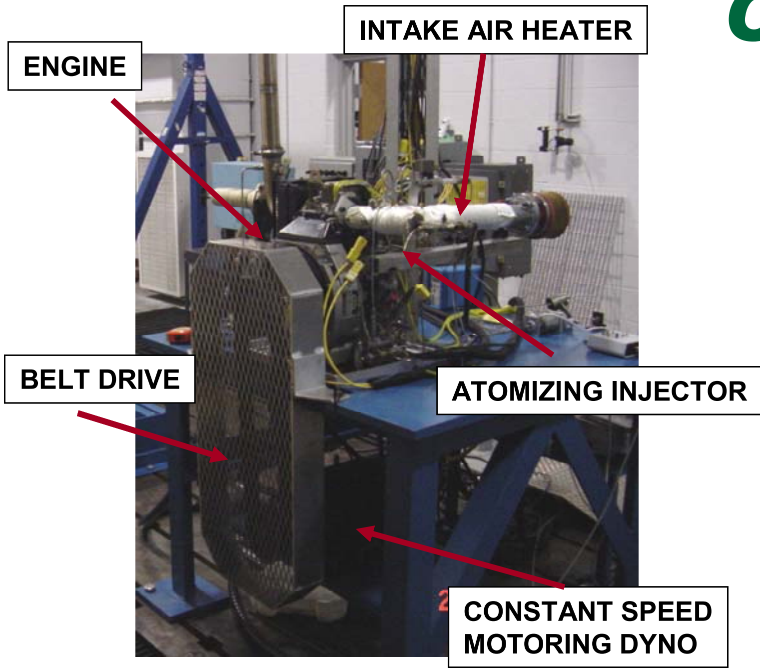
- Accurately measure exhaust profile from an HCCI engine with a variety of fuels
  - PRF, TRP, and PRF-E gasoline surrogates presented here
  - Diesel + diesel surrogates just completed
  - More measurements planned, based on these results
- Create a better understanding of HCCI engine emissions
  - Regulated, particulate and unregulated
- Supply experimental data to the Model Fuels Consortium to help verify mechanisms and engine models
- Supply experimental data to the Model Fuels Consortium for the purpose of developing particulate precursor and particulate formation models

Fuels evaluated for this study

- **Experimental Design**
  - 3 fuels
  - ≈9 gm/min fuel rate
  - 6 IMTs for each fuel
- **Engine information**
  - HCCI
  - 14.5 C/R
  - PFI, premixed
  - NA, un-throttled

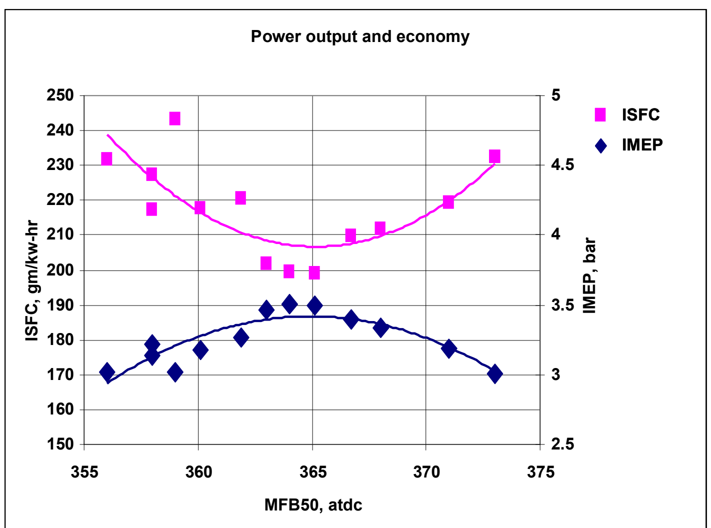
	PRF	TRF	PRF+E
iso-octane (%-mass)	87	0	58.32
n-heptane (%-mass)	13	27	8.71
toluene (%-mass)	0	73	0
ethanol (%-mass)	0	0	32.97
LHV (btu/lbs)	19065	17912	16871
H/C	2.255	1.433	2.313
O/C	0	0	0.119
RON	87	87	105
Intake Temp (°C)	175-190	182-198	175-197

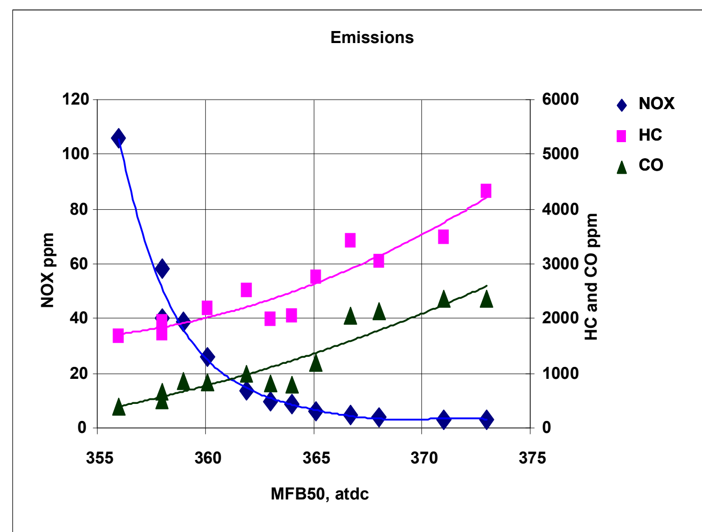
ORNL HCCI engine



- Derived from Hatz single cylinder diesel
- Fully premixed, dilute, with ignition controlled by intake heating
- Simple platform for fuels research
  - Performance dominated by fuel effects
- Recently upgraded with boost, throttle, improved HR

EMISSIONS AND ECONOMY TRADEOFFS VS. COMBUSTION PHASING

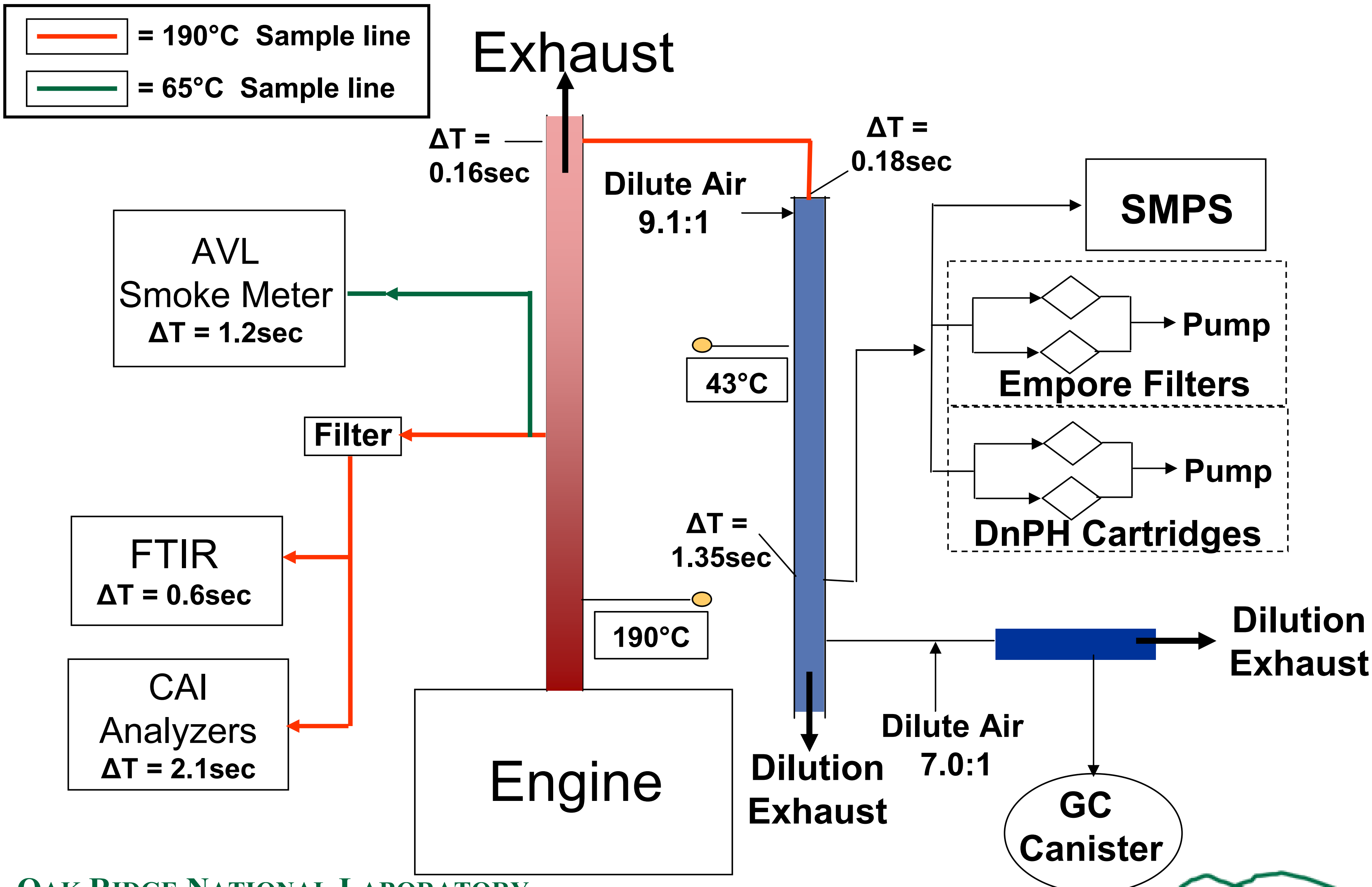




Data taken

- **Engine Data**
  - Pressure trace data
    - Heat release, work, efficiency
  - Cylinder Wall Temperature
  - Intake/Exhaust P and T
- **Gas Analysis**
  - Traditional emissions analyzers
  - FTIR
  - Canister - GC analysis
- **Particulates**
  - AVL smoke meter
  - SMPS
    - Particle size distribution
- **Extraction**
  - Empore Filters (>C-8,18)
  - DNPH Filters
    - Aldehydes, ketones

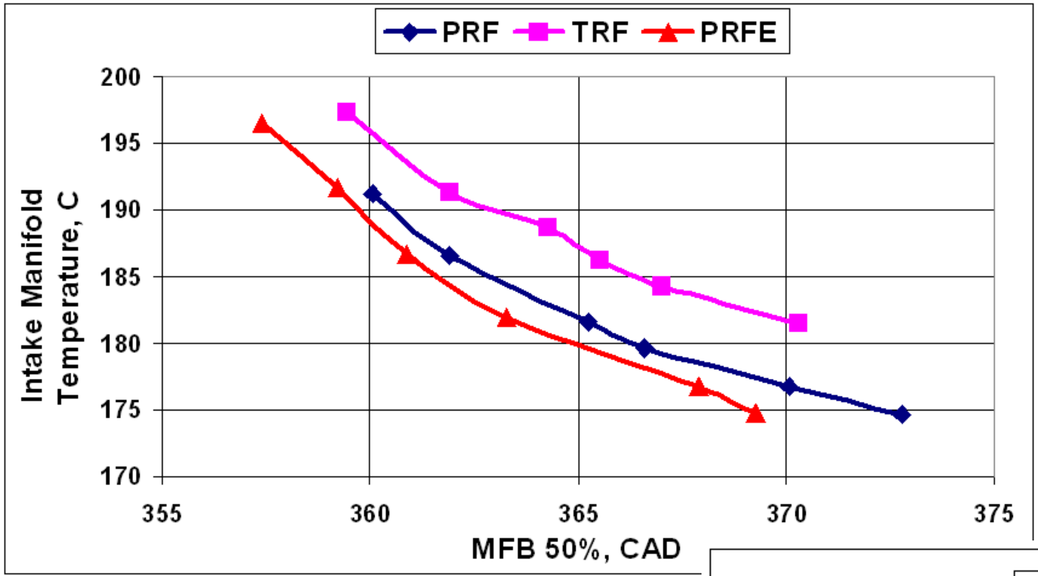
Overall sampling diagram



Conventional emissions measurements

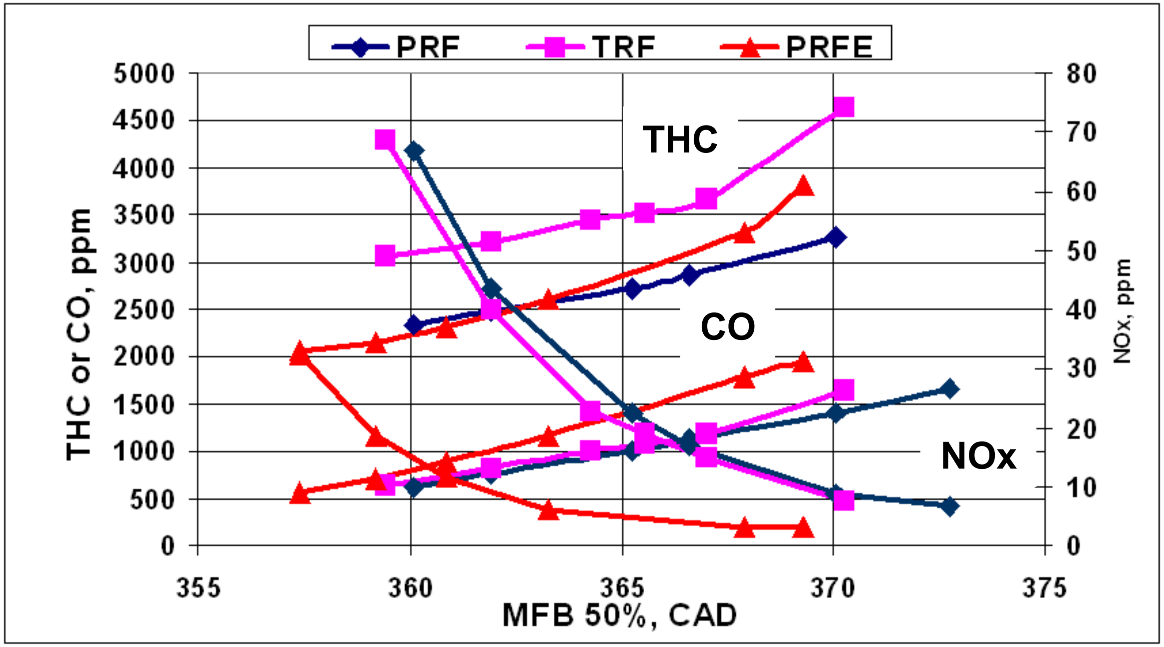
Method	Measurement	Range of Measurements		
		PRF	TRF	PRF + Ethanol
NDIR	CO (ppm)	600 - 1650	600 - 1650	550 - 2000
NDIR	CO_2 (%)	4.7 - 5.1	5 - 5.5	4.1 - 4.7
Chemiluminescence	NO_x (%)	5 - 65	5 - 70	5 - 35
FID	THC_1 (ppm)	2300 - 3850	3050 - 4650	2050 - 3800
Paramagnetic	O_2 (%)	13.4 - 14.0	13.7 - 14.3	14 - 14.9
AVL smoke meter	Smoke Number	0.02 - 0.05	0.02 - 0.06	0.02 - 0.04

Fuel related operational differences



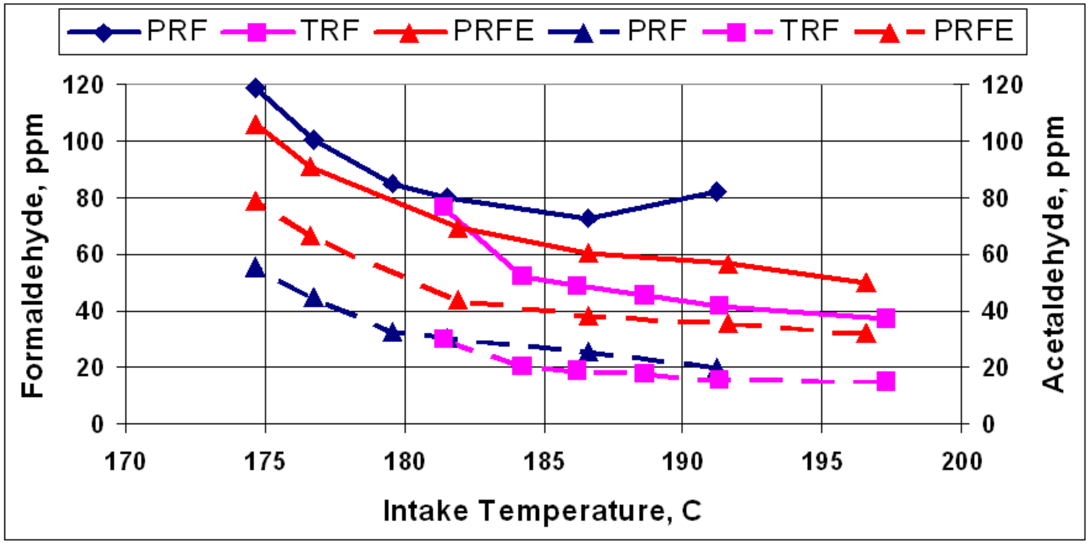
IGNITION CHARACTERISTICS

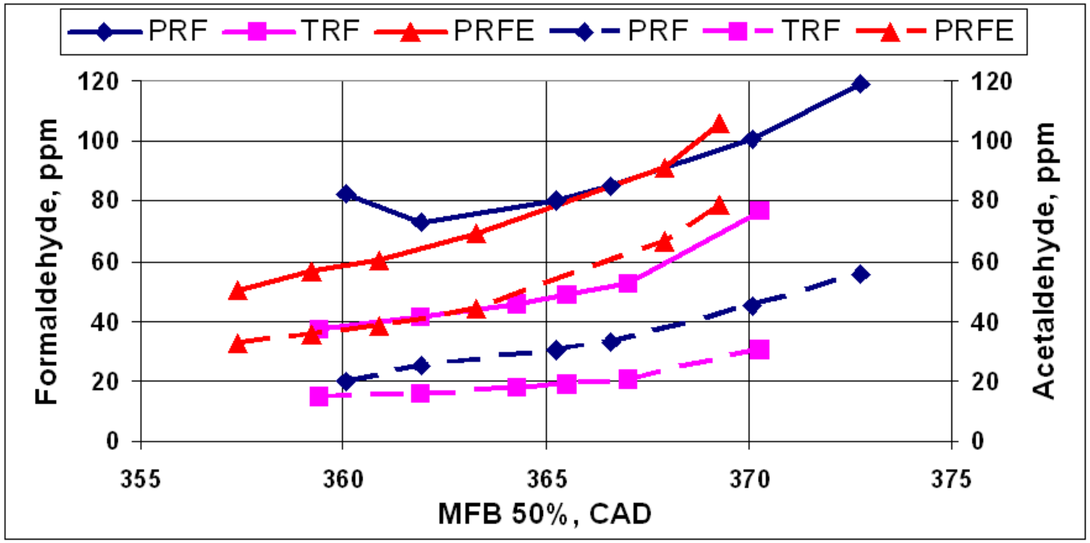
REGULATED EMISSIONS



Aldehyde measurements by FTIR

- **Formaldehyde and Acetaldehyde are dominant oxygenated species**
- **Formaldehyde always higher by ratio of about 1.5 to 3**
- **Aldehyde emissions increase with lower intake temperature and resulting phasing retard**

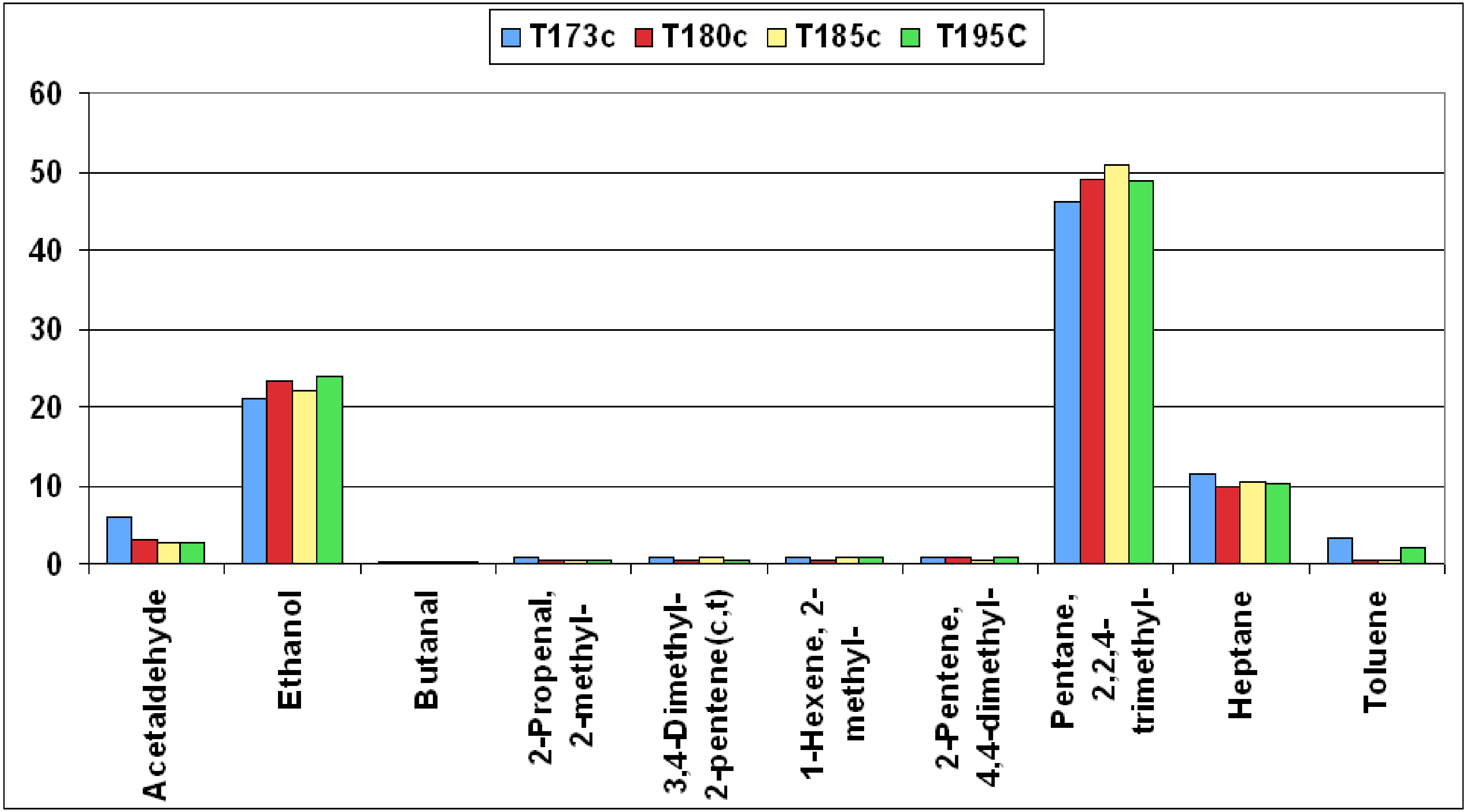




Canister – GC

- Dilute sample collected from exhaust and then analyzed off line by GC-MS
  - Dilution Ratio of 63.9:1
- Results presented as % of calculated area
  - Not exact ppm measurement
- High fuel bleed-through
  - Possible saturated detector

Canister – GC (PRF + ethanol)



Fuel profile from canister GC measurements - average of all runs -

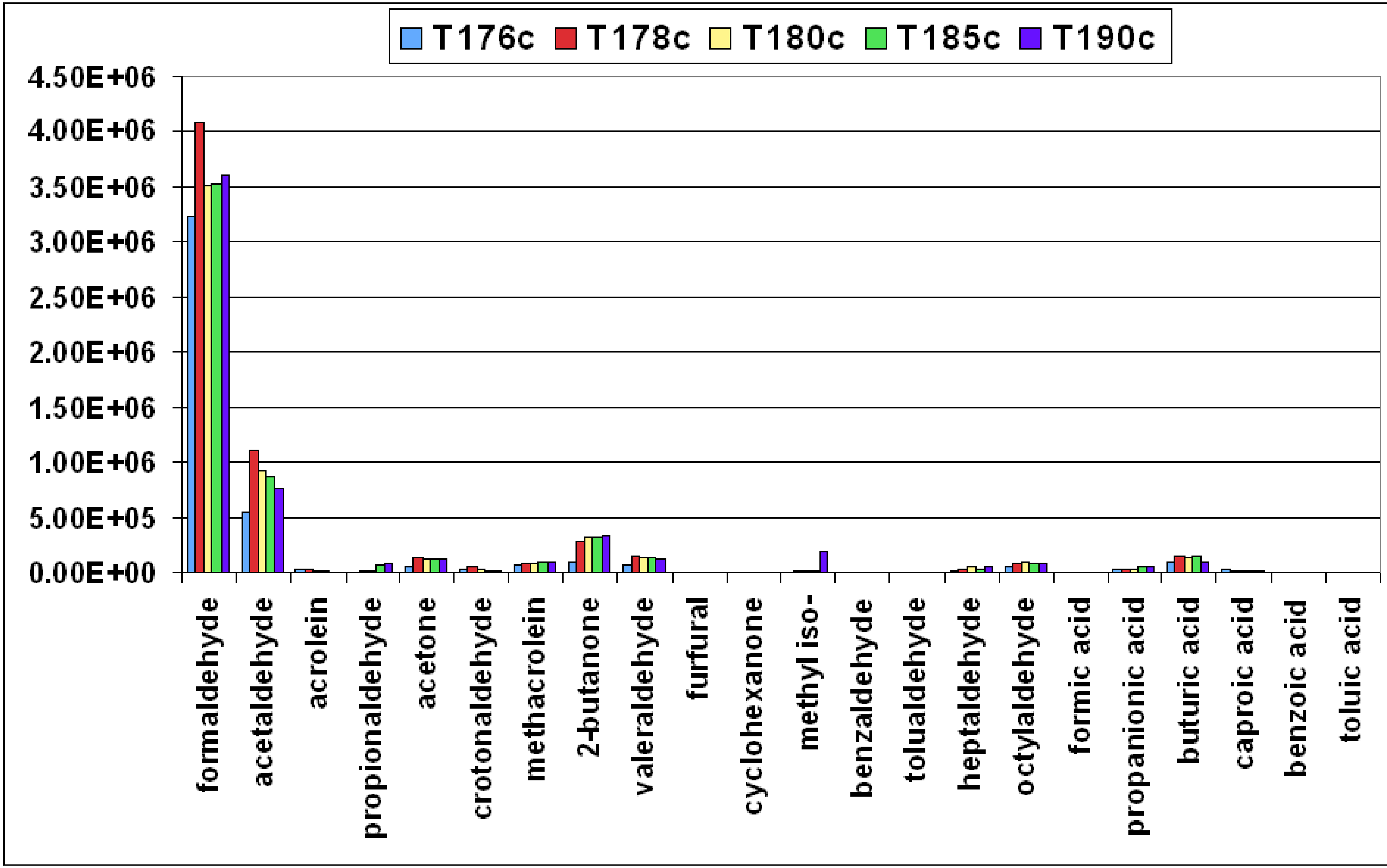
FUEL	COMPONENTS COUNT % OF TOTAL CANISTER	MEASUREMENT	n-heptane	iso-octane	toluene	ethanol
PRF	87%	WT% IN FUEL	13%	87%	na	na
		WT% IN FUEL PORTION OF CANISTER	16%	84%	na	na
TRF	87%	WT% IN FUEL	27%	na	73%	na
		WT% IN FUEL PORTION OF CANISTER	33%	na	67%	na
TRF-E	91%	WT% IN FUEL	9%	54%	na	33%
		WT% IN FUEL PORTION OF CANISTER	13%	60%	na	28%

- **Unburned fuel is about 90% of HC emissions**
- **Profile of fuel components is maintained in exhaust**

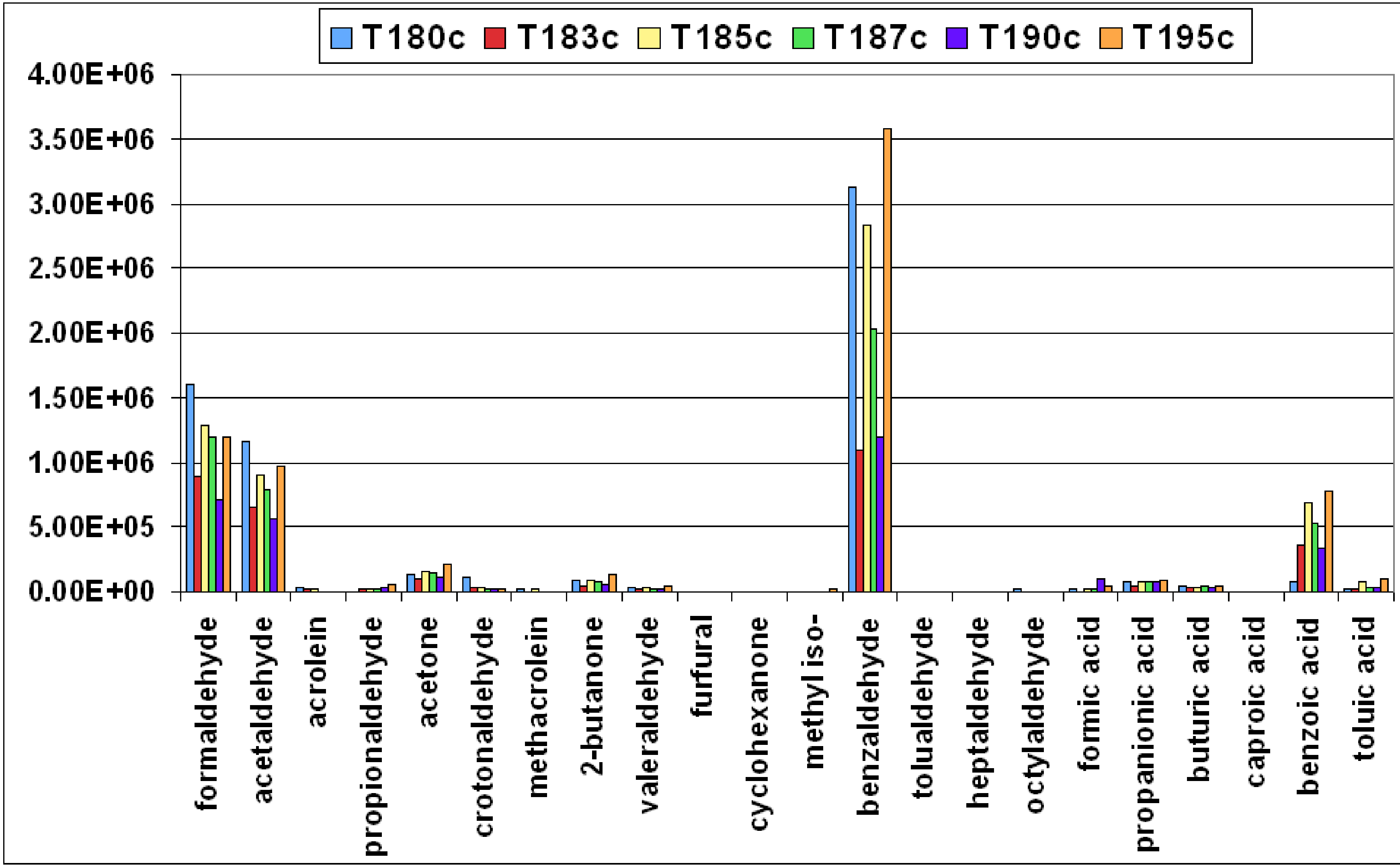
DNPH cartridge

- Dilution ratio of 9.1:1
- Cartridges are heat treated to ensure complete reaction of carbonyls and carboxylic acids with DNPH
  - Provides profile of above species
  - This method reduces background because other compounds, including saturates, do not derivitize
- Cartridge typically have 80% collection efficiency
- Analysis by LCMS

Raw DnPh cartridge – (PRF)



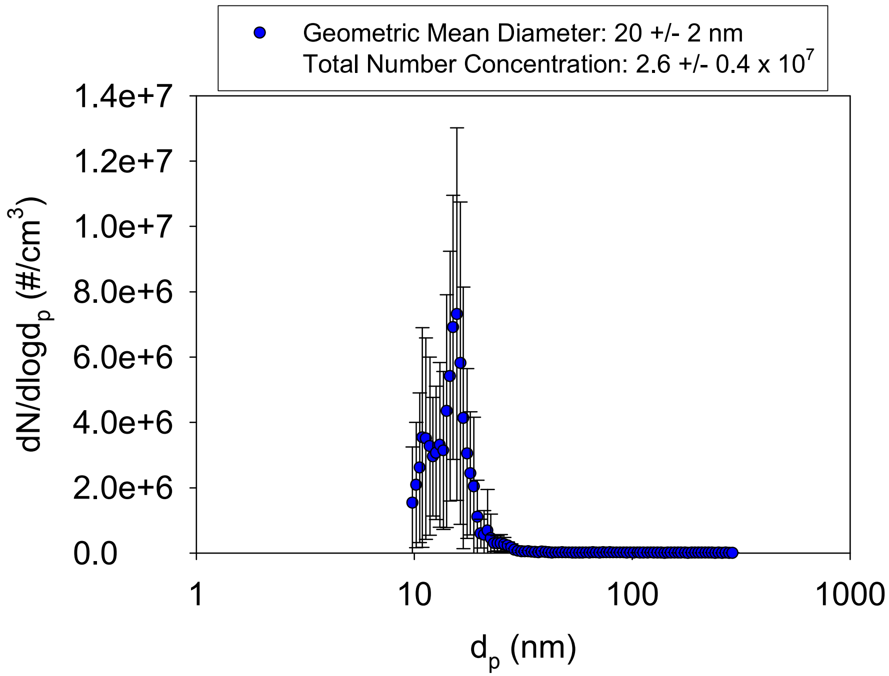
Raw DnPh cartridge – (TRF)

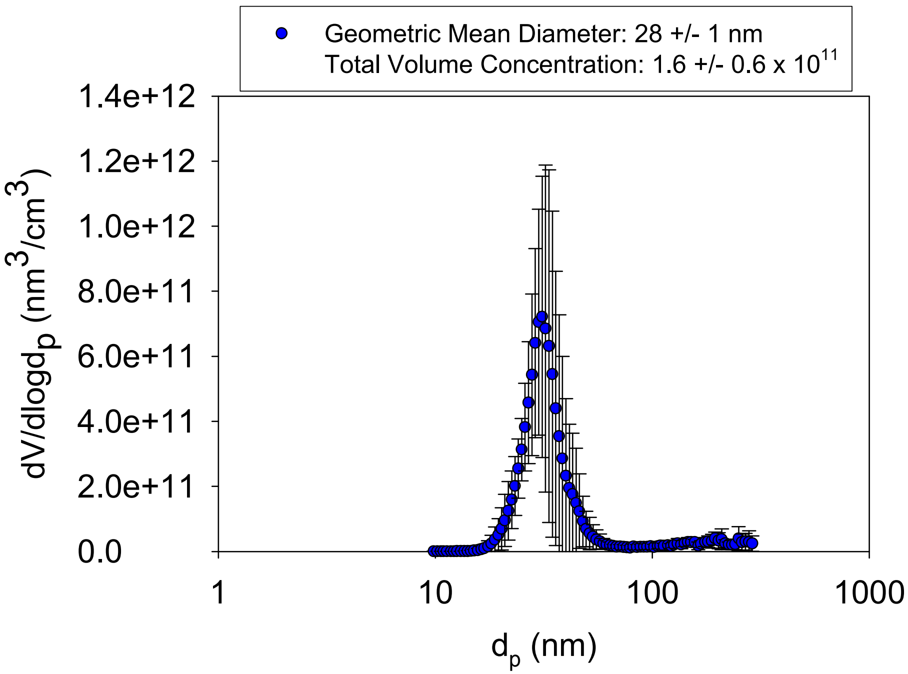


SMPS – particle size distribution

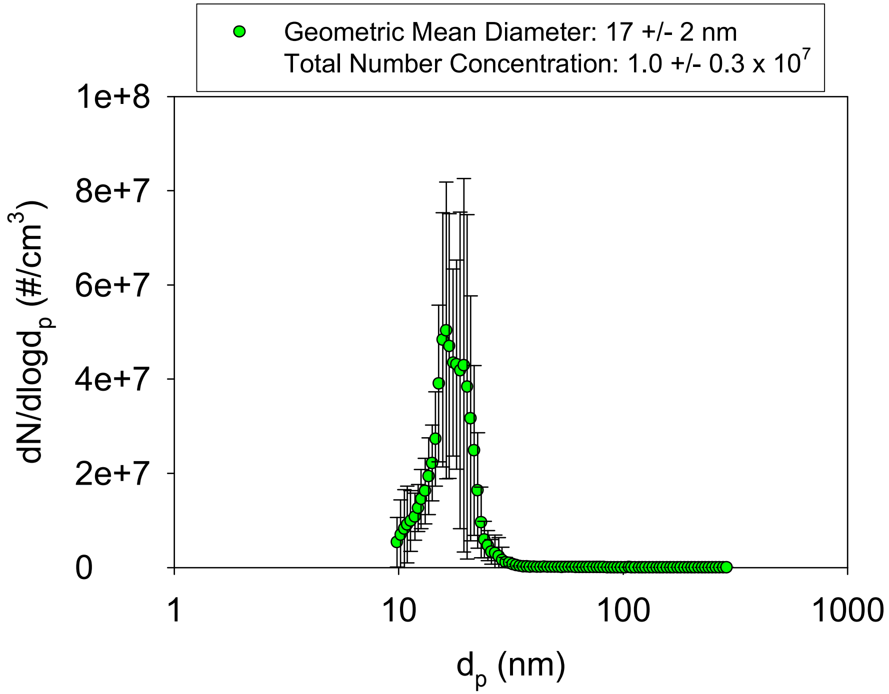
- Dilution ratio of 9.1:1
  - Low dilution ratio used may promote aerosol formation
- Residence time of species to detector is approximately 1.7 seconds
- 15 scans taken at each condition
  - Average results presented
- Data presented two ways to define particle size distributions
  - Number concentration – (counts/cm^3)
  - Volume concentration – (nm^3/cm^3)
- Only limited data will be shown

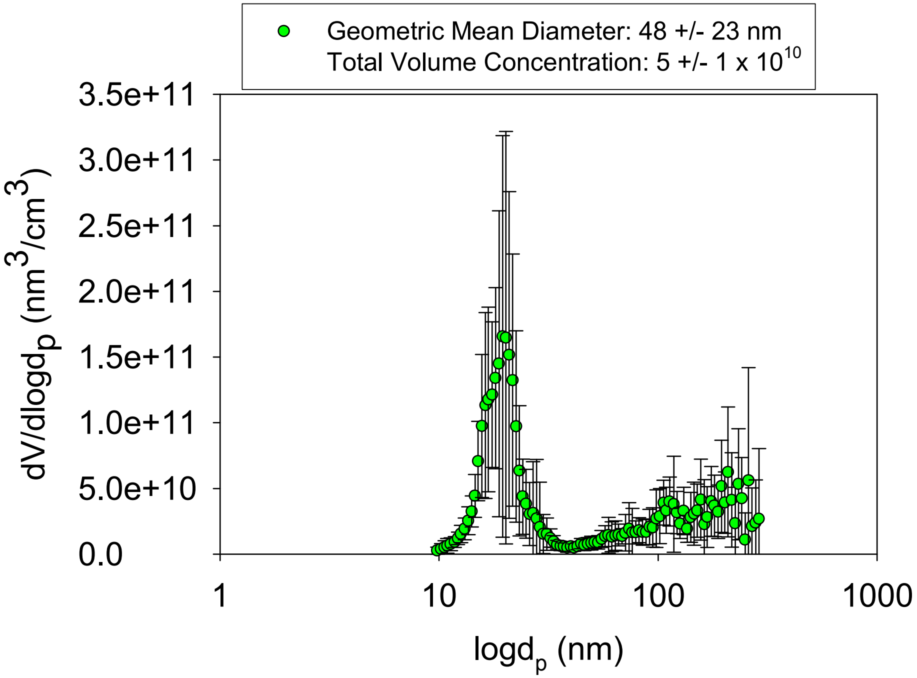
SMPS – Typical particle size distribution (PRF at 190C intake)





SMPS – typical particle size distribution (TRF at 190C intake)





Conclusions

- Raw fuel surviving combustion is a significant source of HC emissions
  - Fuel profile is maintained in exhaust
- Aldehyde emissions are high
  - Mainly formaldehyde and acetaldehyde
- TRF fuel also forms benzaldehyde and benzoic acid
- Particle emissions depend on combustion phasing and fuel type
  - Likely to be largely aerosols in these samples
  - Mainly in 13-30nm range
  - With TRF, larger particles are emitted at retarded phasing, indicating possible formation of soot precursors
  - TEM grids taken in diesel series
- Measurements are a challenge, but ORNL has long experience with these methods

Future work

- Analyze and present data for diesel fuels and surrogates recently completed
- Further define time, temperature, and pressure profiles in sampling system and instrumentation to allow modeling of particulate condensation and growth processes
- Plan additional fuel sets based on results and interest