MICROPHYSICAL AND CHEMICAL PROPERTIES

OF

NANOPARTICLES EMITTED BY FLIGHT ENGINES

Results from German PAZI Project

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- **Motivation**

  Aircraft Gas turbine and combustor tests / fuel kerosene

- **Aircraft Piston engine tests / fuel: AVGAS leaded and unleaded**

  Scanning Mobility Particle Sizer SMPS

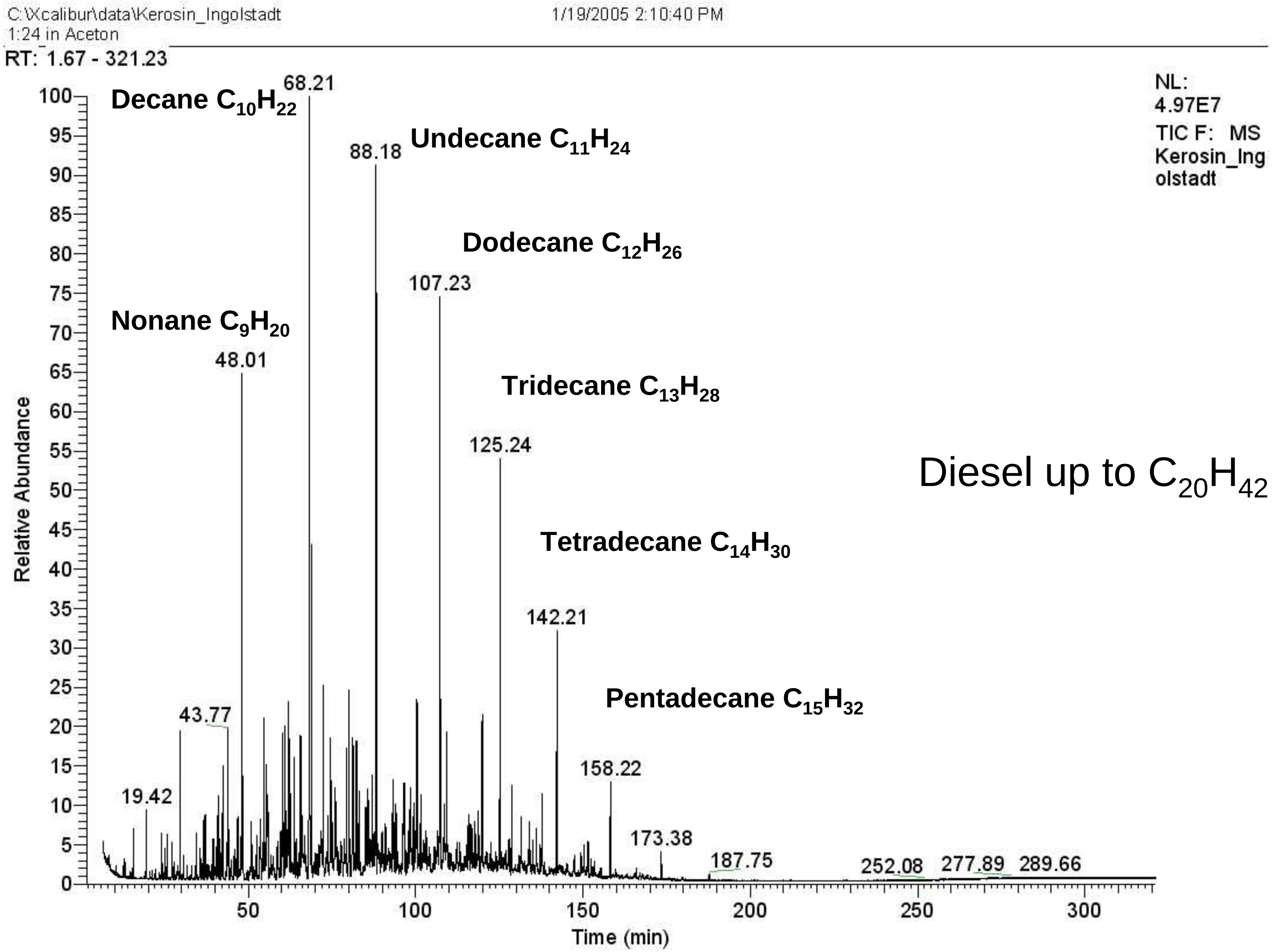
  Scanning Electron Microscopy SEM

  Energy Dispersive X-ray spectroscopy EDX

  Aldehyde tests DNPH Method

- **Conclusion**

Kerosene JET-A1 (PAZI II HBKS)



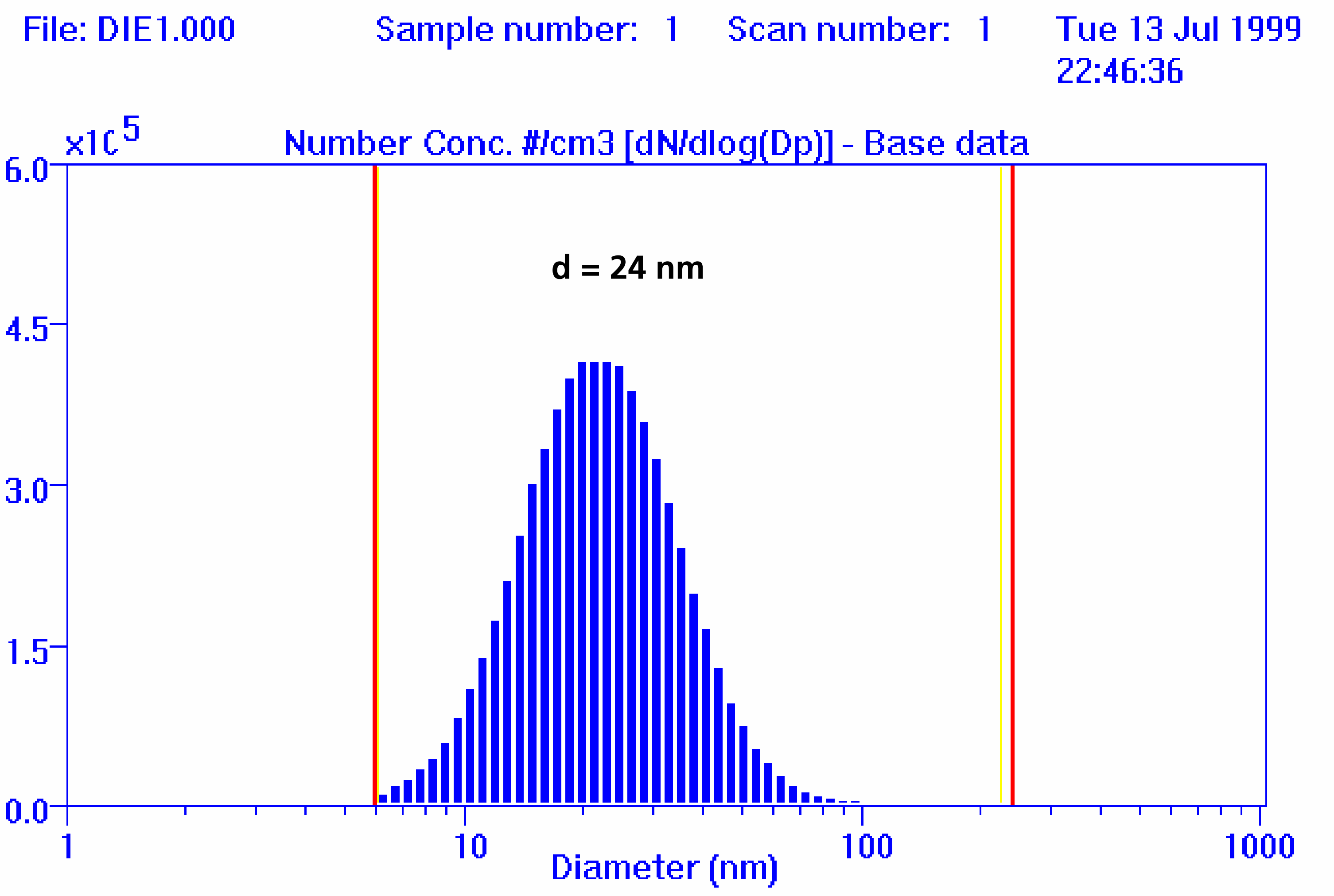
Diesel up to $C_{20}H_{42}$

Kerosene or diesel combustion can produce soot nanoparticles.

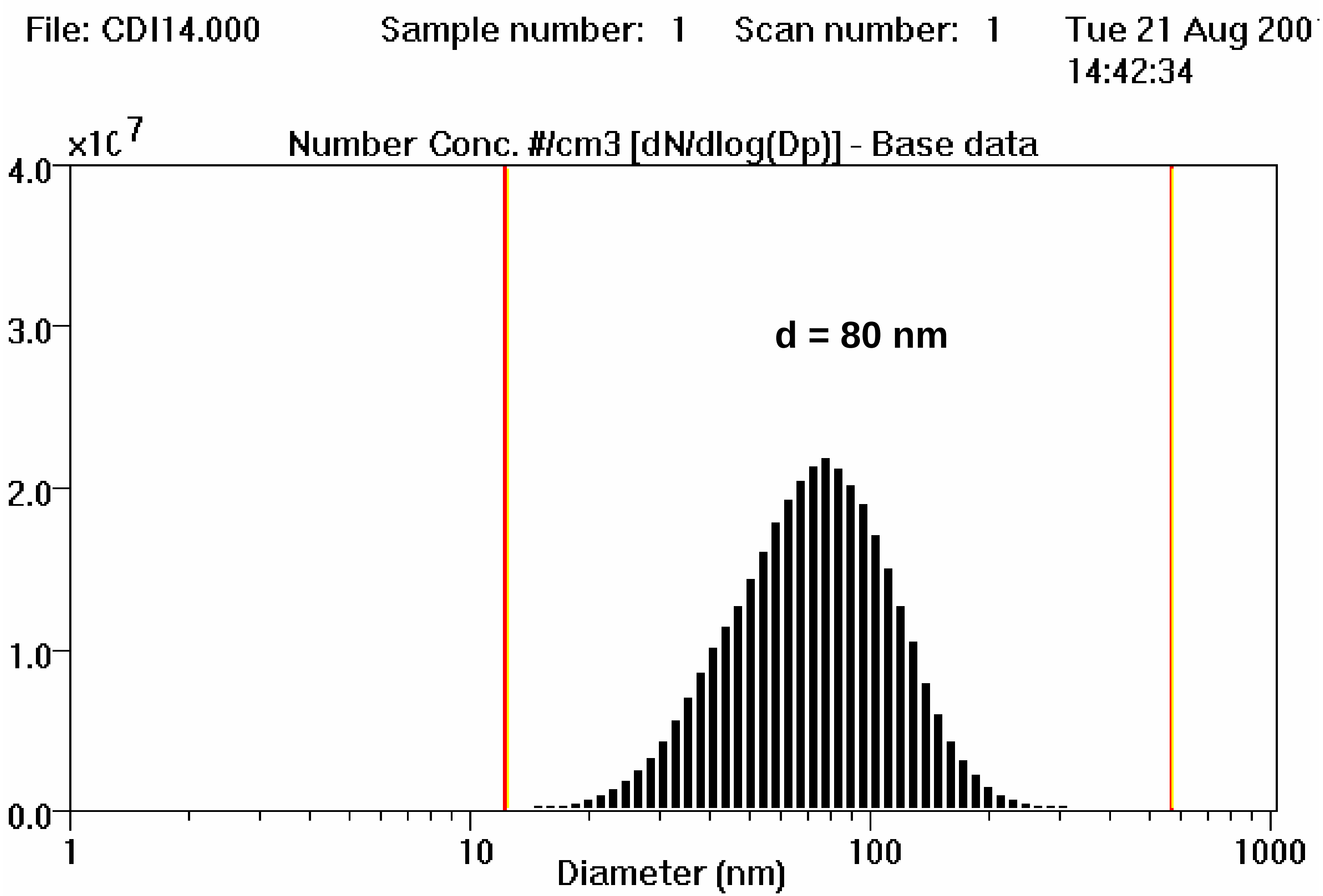
Mean diameters are between 25 – 80 nm

e.g. flight gas turbines or diesel cars

PSD of a Flight Gas Turbine / ICAO IDLE / fuel: JET-A1



Diesel Passenger Car CDI 2000 rpm (increased idle)



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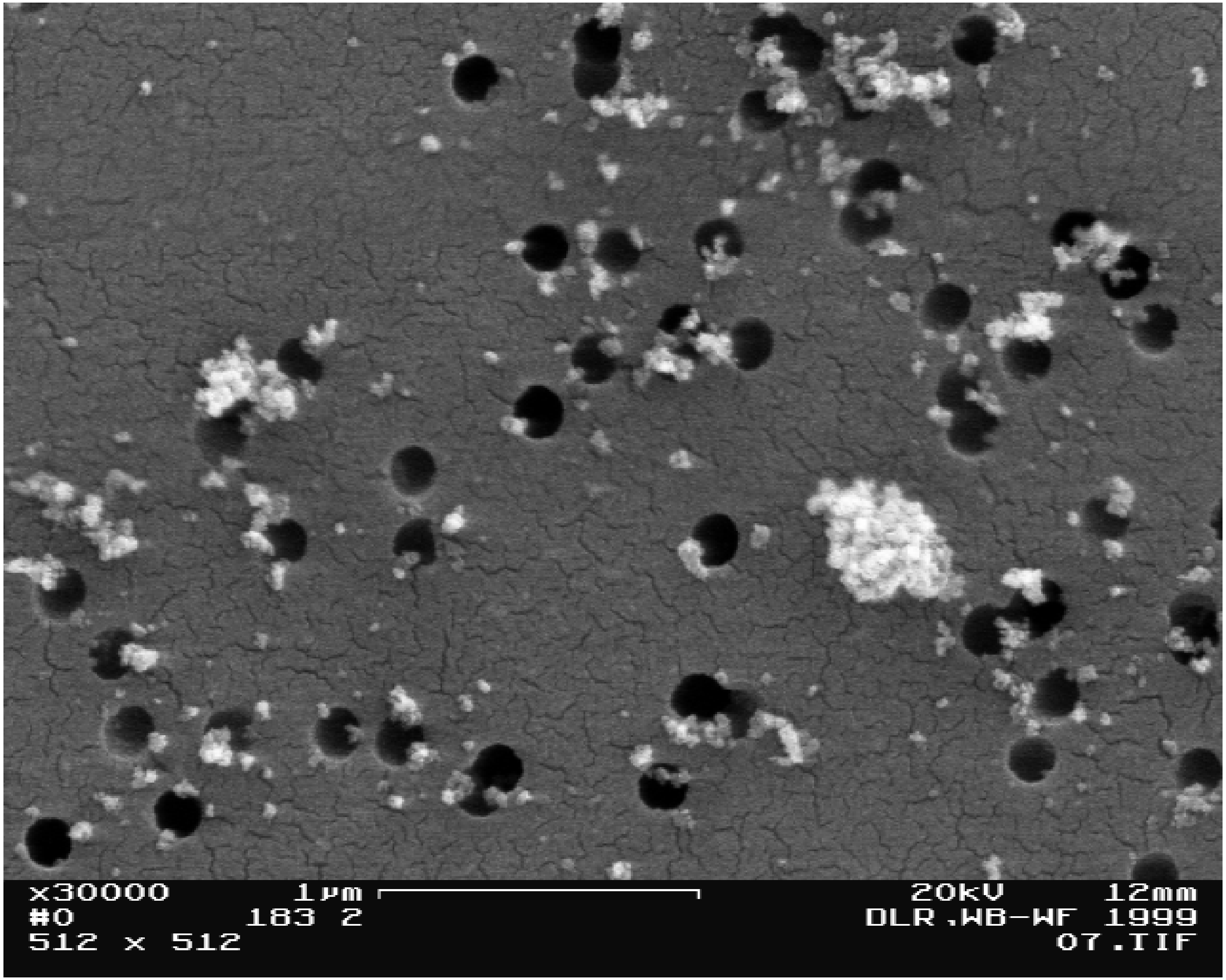
SEM X30 000 Soot from staged combustor test / fuel: JET-A1



Motivation for the Piston Engines Tests

Soot particles are not expected by combustion of gasoline or aviation gasoline

However:

A lot of small aircraft piston engines have to ***run under fuel rich conditions*****,**

in order to keep the engine temperatures low.

Fuel rich combustion can form soot nanoparticles.

Piston Engines Ground Tests at DLR Oberpfaffenhofen

Aircraft Piston Engine - Ground Tests at DLR Oberpfaffenhofen

Aircraft: HB-EYS	- Robin DR400 Federal Office for Civil Aviation, Bern (Switzerland) - Lycoming O -360 180 HP Carburettor
Aircraft: SE-KEI	- Piper 28 Warrior II Hjelmco Oil (Sweden) - Lycoming O-320-D3G 160HP Carburettor

Fuel: - **AVGAS 100LL** 212mg lead/gallon (maximum, ASTM D 910)
56 mg lead / liter

- **AVGAS 91/96 UL** unleaded

Test Equipment:

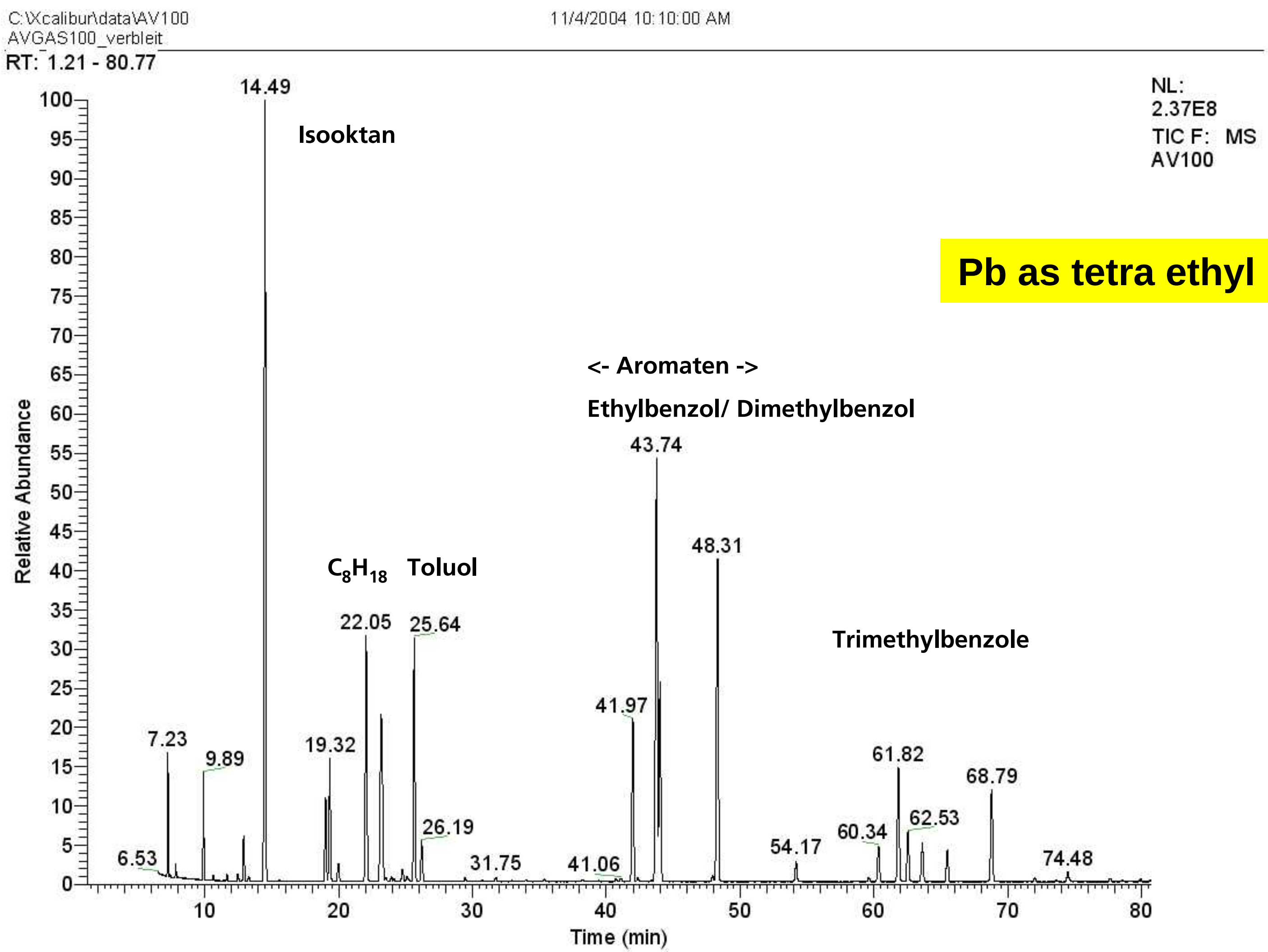
- Microprocessor controlled gas sampler (aldehydes, SEM)

-SMPS System:	TSI 3080, long DMA, 3022A CPC
-Diluter:	DEKATI 8.4x
-Sampling line:	4.5 m stainless steel, 6mm id , 150°C
-probe:	stainless steel 6 mm inner diameter

Stainless Steel Probe   (6mm tube)


-ELRS

AVGAS 100LL 212mg lead /gallon (56mg Pb / liter)



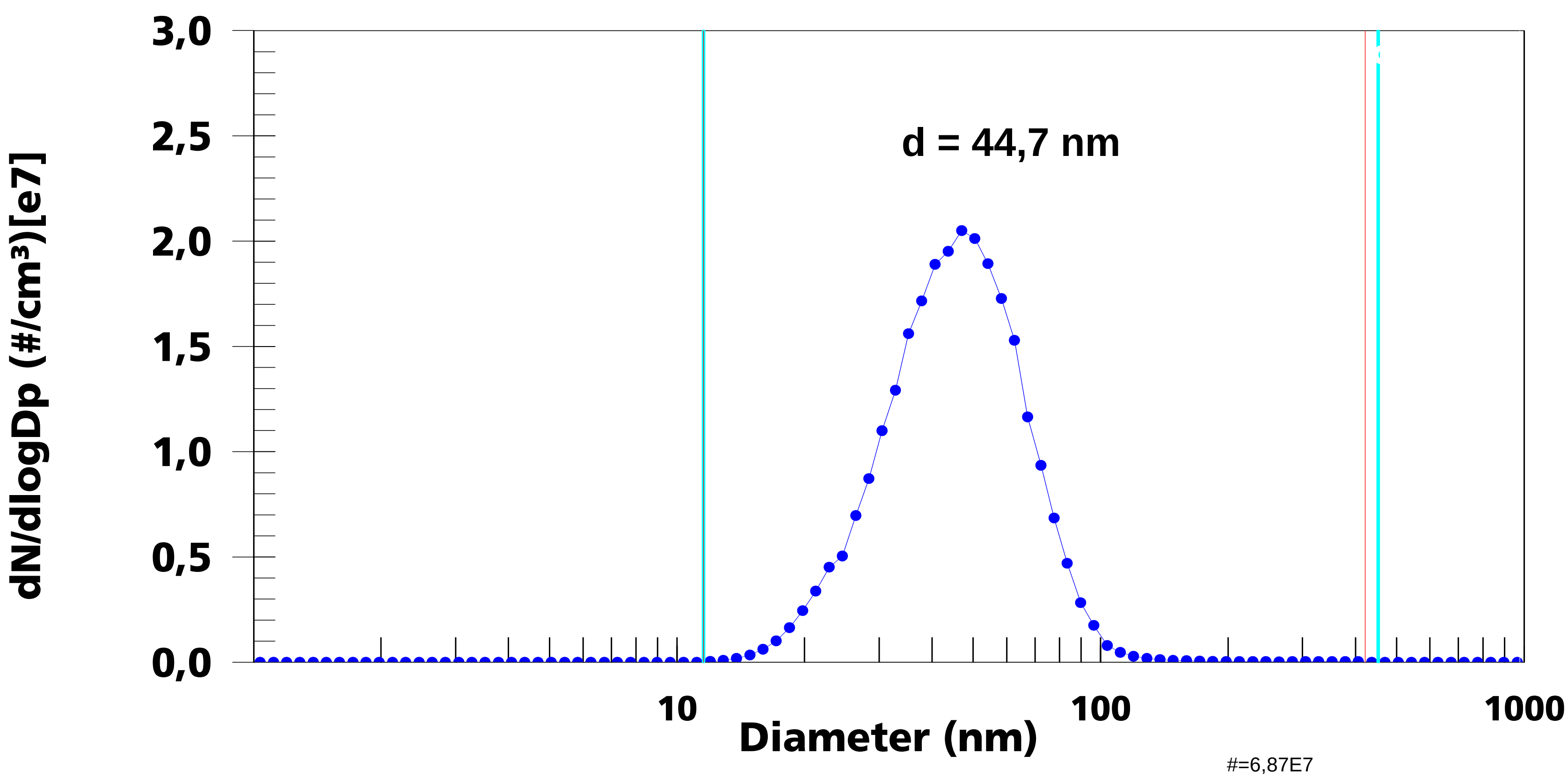
Pb as tetra ethyl lead

Engine power settings

ICAO test points + Cruise

	power
Taxi	**7 %**
Approach	**30 %**
Cruise	***65 %***
Climb	**85 %**
Take Off	**100 %**

HB-EYS AVGAS 100LL 212 mg lead / gallon Cruise



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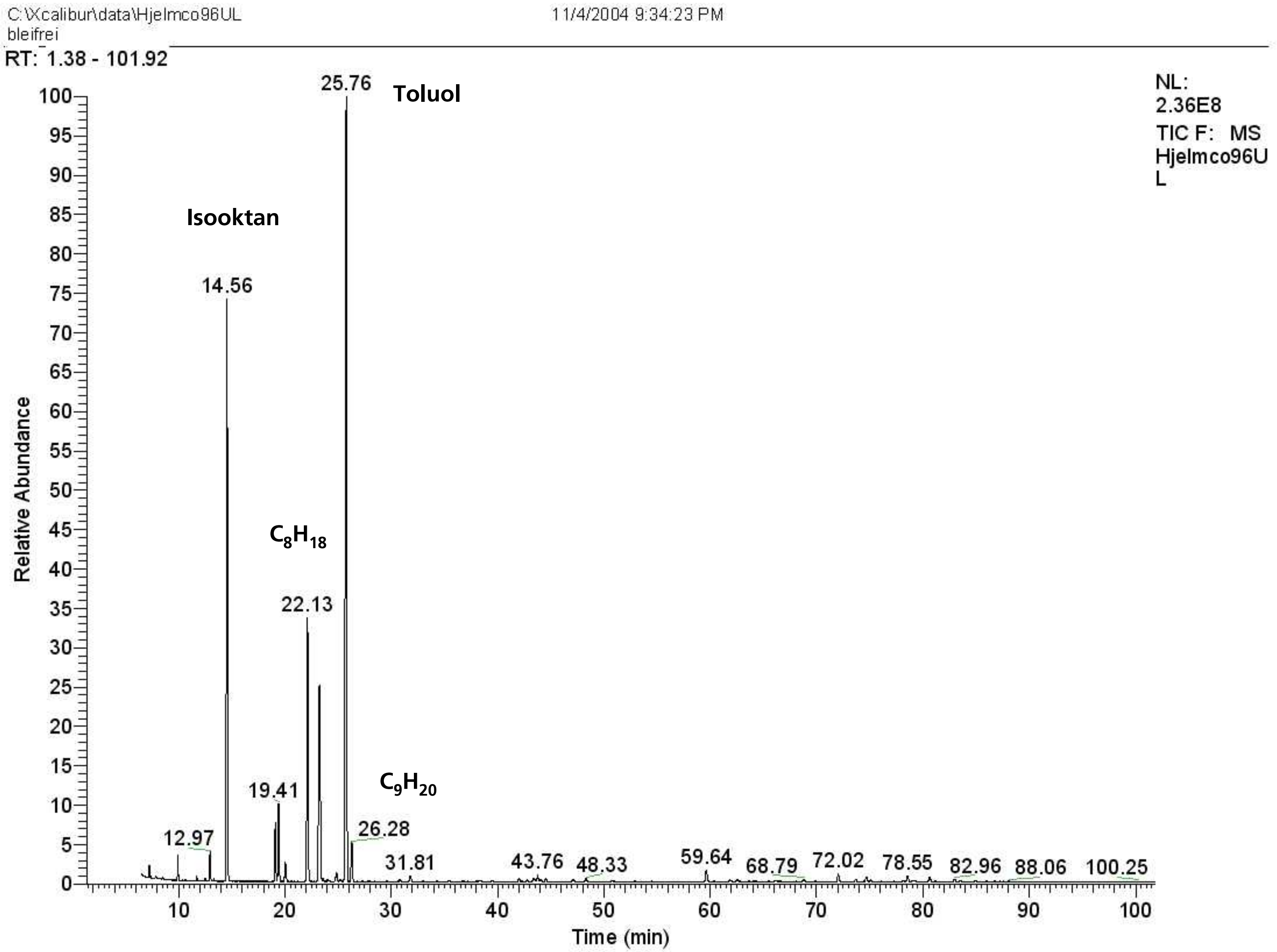
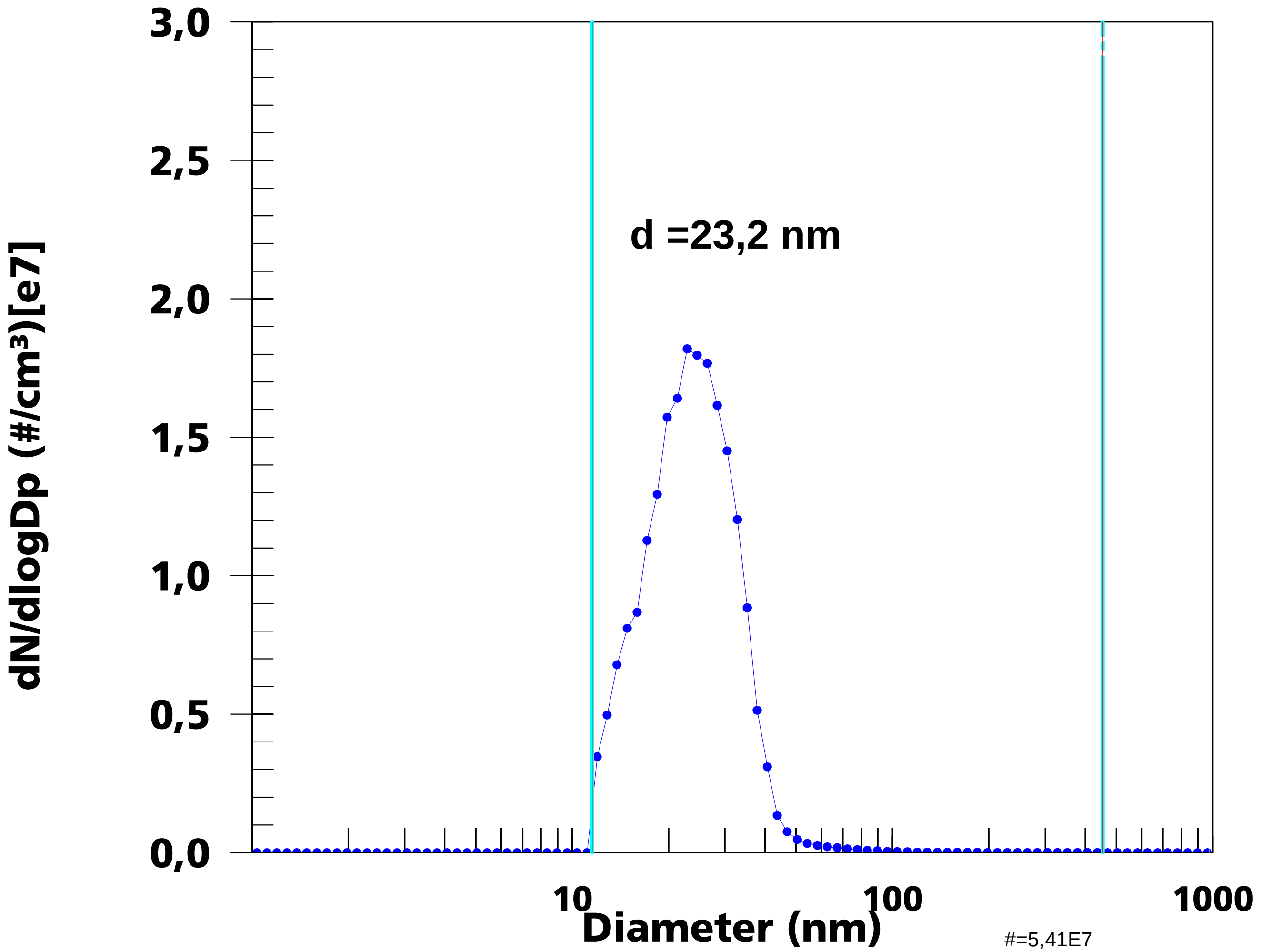
MINIMUM
AVGAS 91/96 UL
HIGHLY INFLAMMABLE
INHALATION DANGEROUS
DANGEROUS TO HEALTH WHEN INHALED OR INGESTED, ON SKIN CONTACT AND WHEN SPLASHED INTO THE EYES. DO NOT USE FOR ANY PURPOSE OTHER THAN ENGINE FUEL.
TAKE PRECAUTIONS AGAINST STATIC ELECTRICITY. TO BE STORED APART FROM SOURCES OF IGNITION – SMOKING FORBIDDEN. USE SAFETY GLOVES. IN CASES OF SKIN CONTACT, IMMEDIATELY WASH CAREFULLY WITH SOAP AND WATER. IF DROPS GET IN THE EYES WASH INSTANTLY WITH LARGE QUANTITIES OF WATER. SEEK MEDICAL AID IF IRRITATION PERSISTS. WITHOUT A FULL-FACE MASK AND CONTAINED BREATHING APPARATUS, HANDLE ONLY OUT OF DOORS AND AVOID SPLASHING DROPS AND/OR INHALING FUMES. IF INGESTED DO NOT FORCE VOMITING. SEEK IMMEDIATE HOSPITAL CARE. WHEN FIGHTING FIRE, USE POWDER, FOAM OR CARBON DIOXIDE. DO NOT USE WATER. MAY NOT BE EMPTIED INTO THE DRAINAGE SYSTEM. CONTENTS: COMPLEX MIXTURE OF HYDROCARBONS, OF WHICH AROMATIC HYDROCARBON MAX. 20 VOLUME %. IMPROVED-FUNCTIONING ADDITIVE: ANTIOXIDANT.
SUPPLIER: HJELMCO OIL AB

AVGAS 91/96UL unleaded

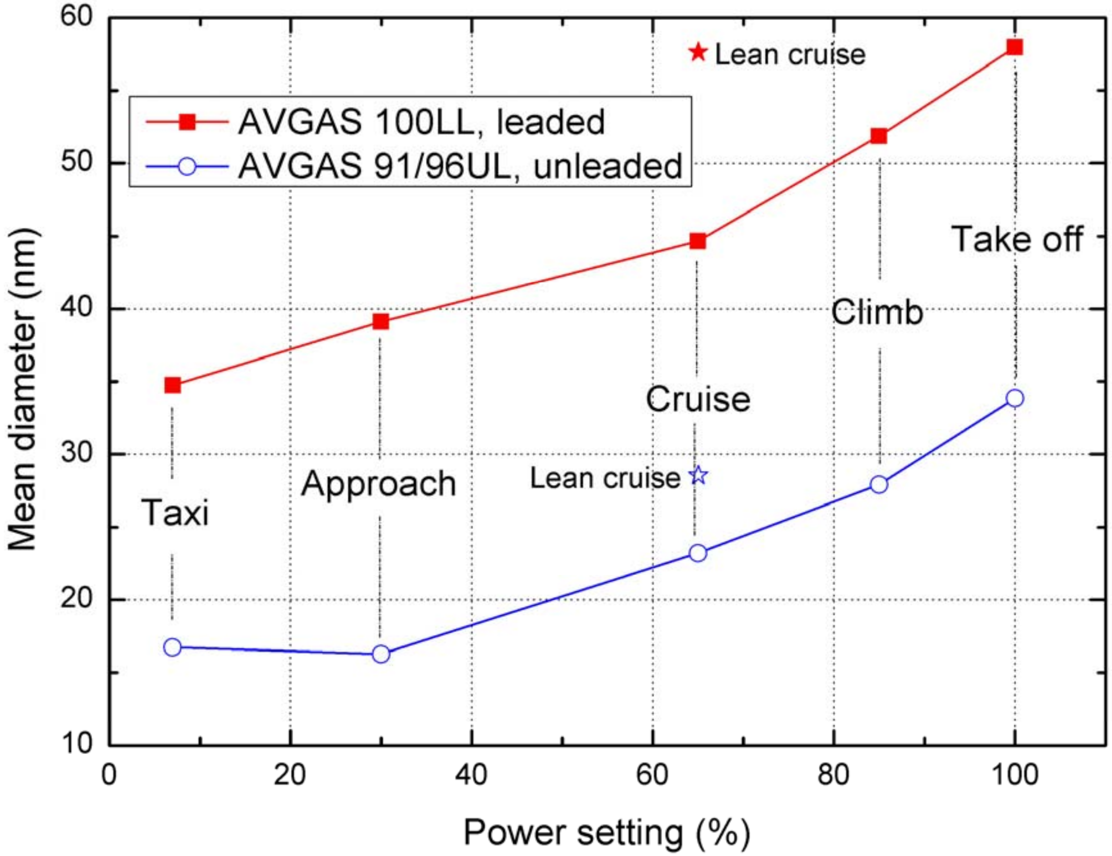



MARINE POLLUTANT

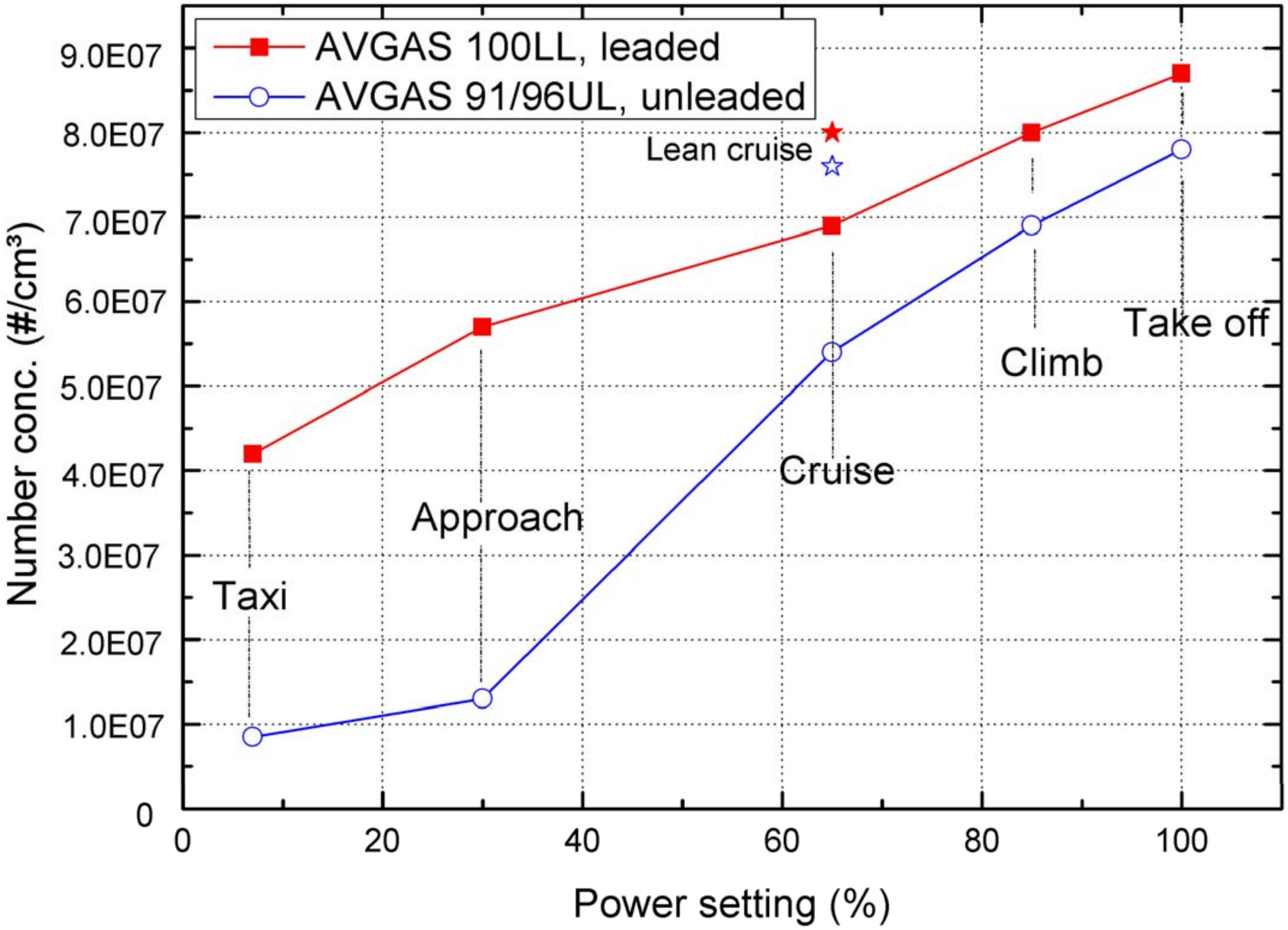
HB-EYS AVGAS 91/96UL unleaded Cruise



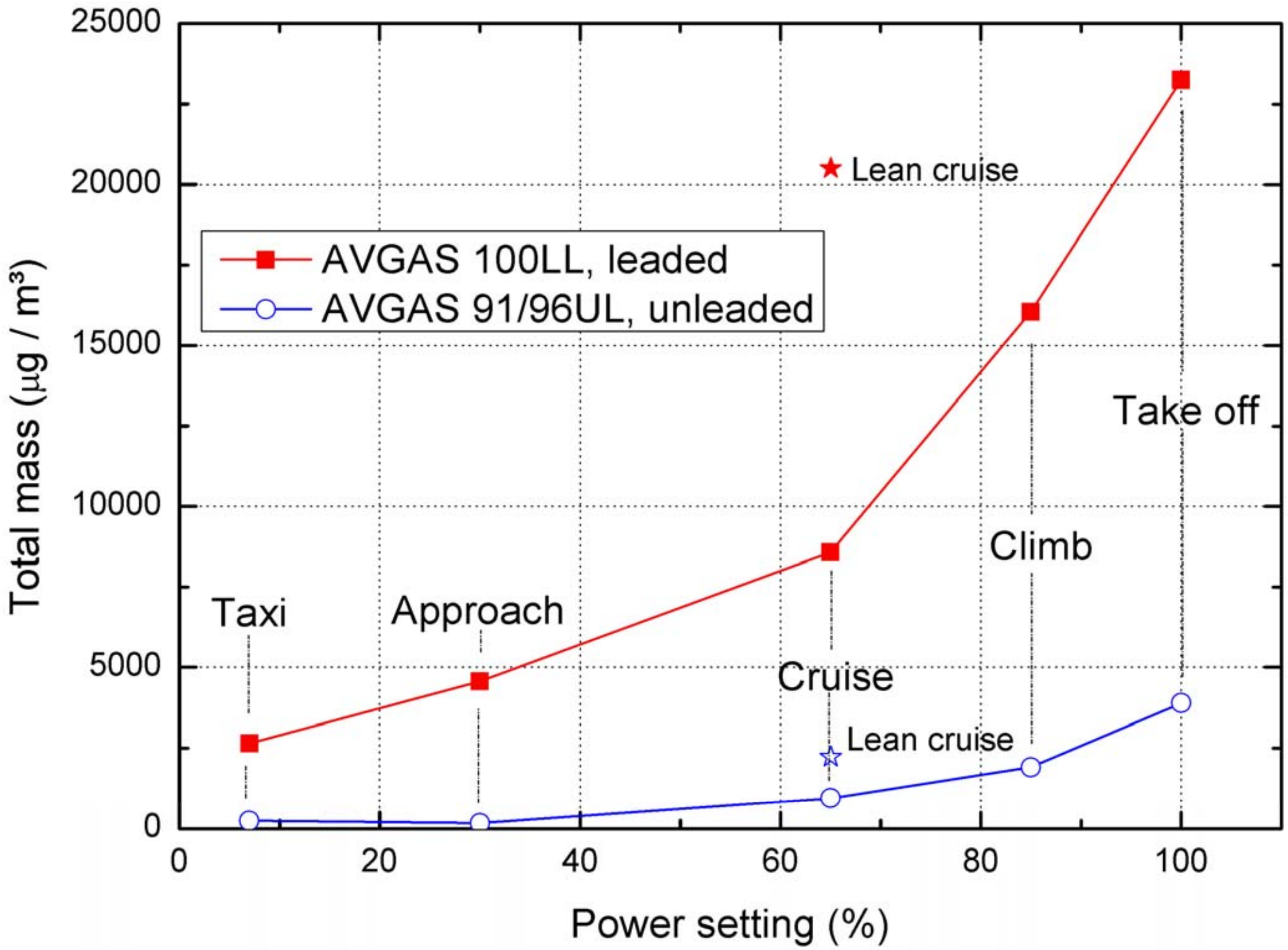
HB-EYS   Mean diameter = f (power)



HB-EYS number conc. = f (power)



HB-EYS total mass = f (power)

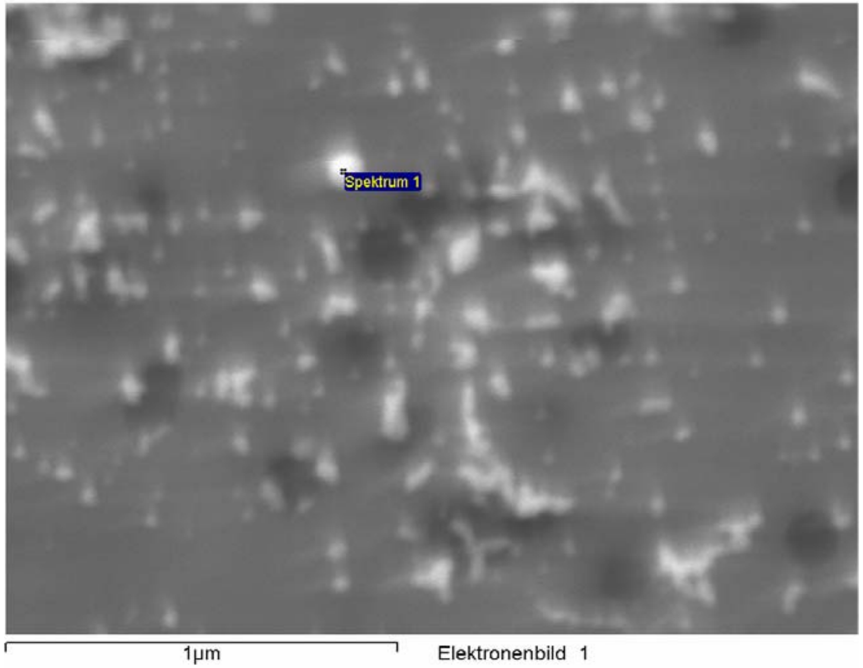


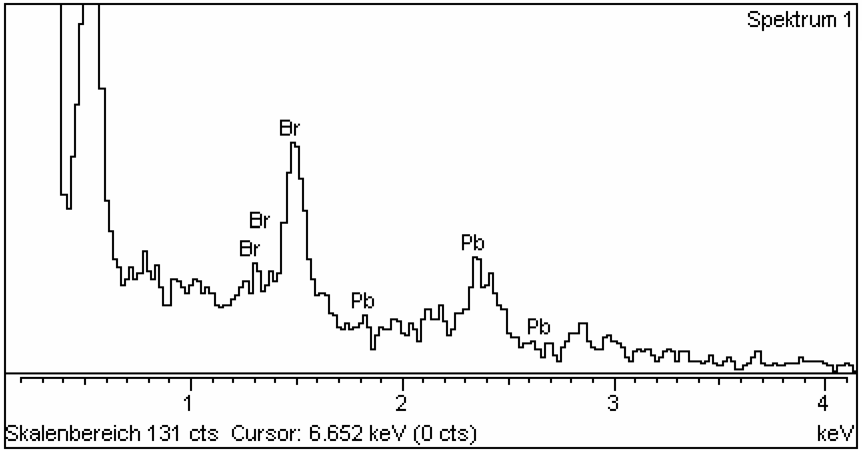
EDX – Spectra HB-EYS

AVGAS 100LL

Verarbeitungsoption : Alle Elemente analysiert (Normalisiert)
Anzahl Iterationen = 2
Standard :
Br KBr 1-Jun-1999 12:00 AM
Pb PbF2 1-Jun-1999 12:00 AM

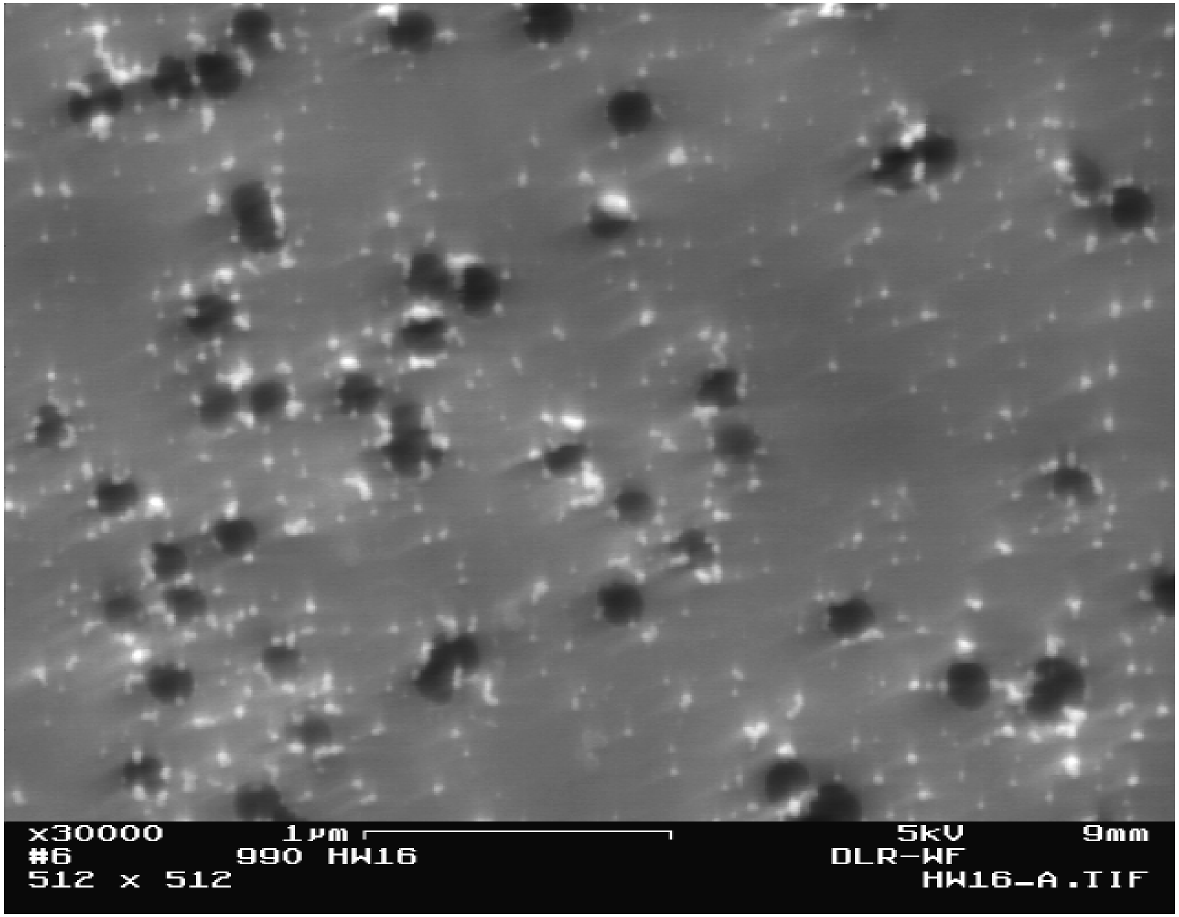
Element	Gewichts %	Atom %	
Br L	36.52	59.87	
Pb M	63.48	40.13	
Insgesamt	100.00		





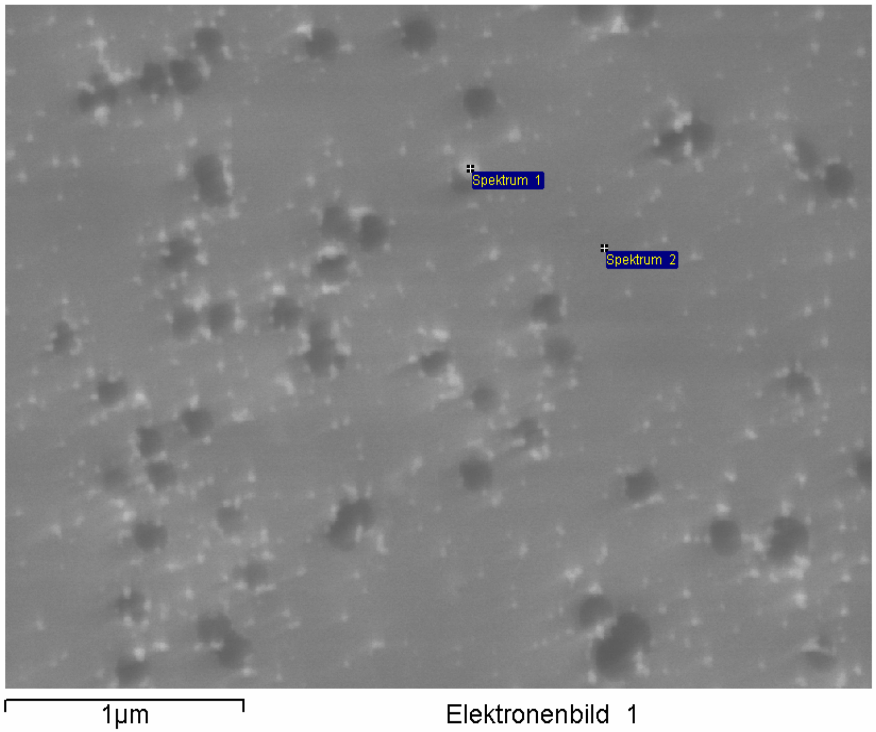
Projekt 990 Probe2 H4_A.doc

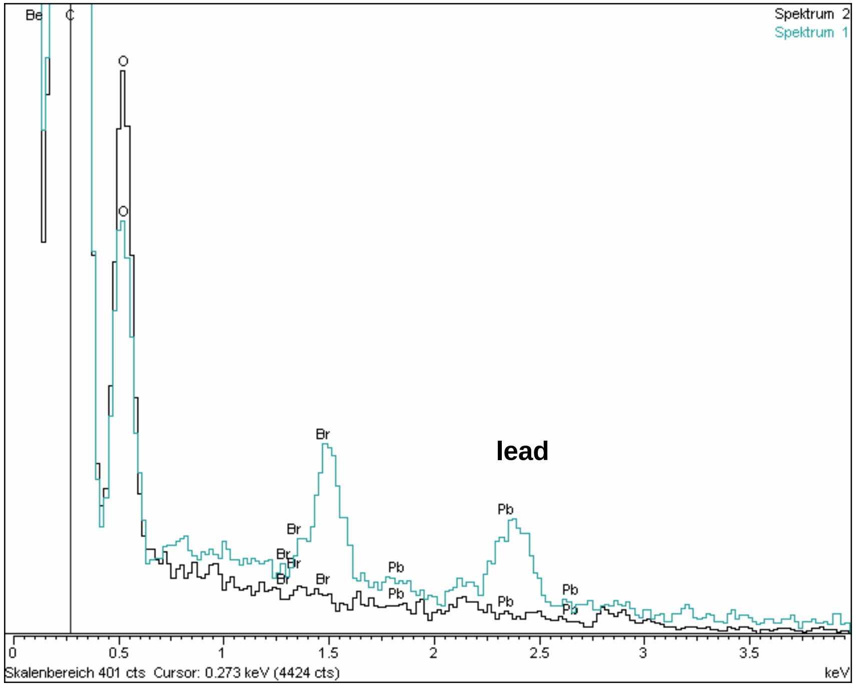
HB-EYS SEM Cruise lean unleaded fuel



EDX HB-EYS Cruise lean unleaded fuel

There are still residual lead bromide particles !





Projekt 990 - Probe 3, 5keV

Results of “Swiss Airplane test” **HB-EYS**:

-AVGAS 100LL (leaded) forms soot and lead bromide particles.

-There are bromide scavengers in AVGAS 100LL

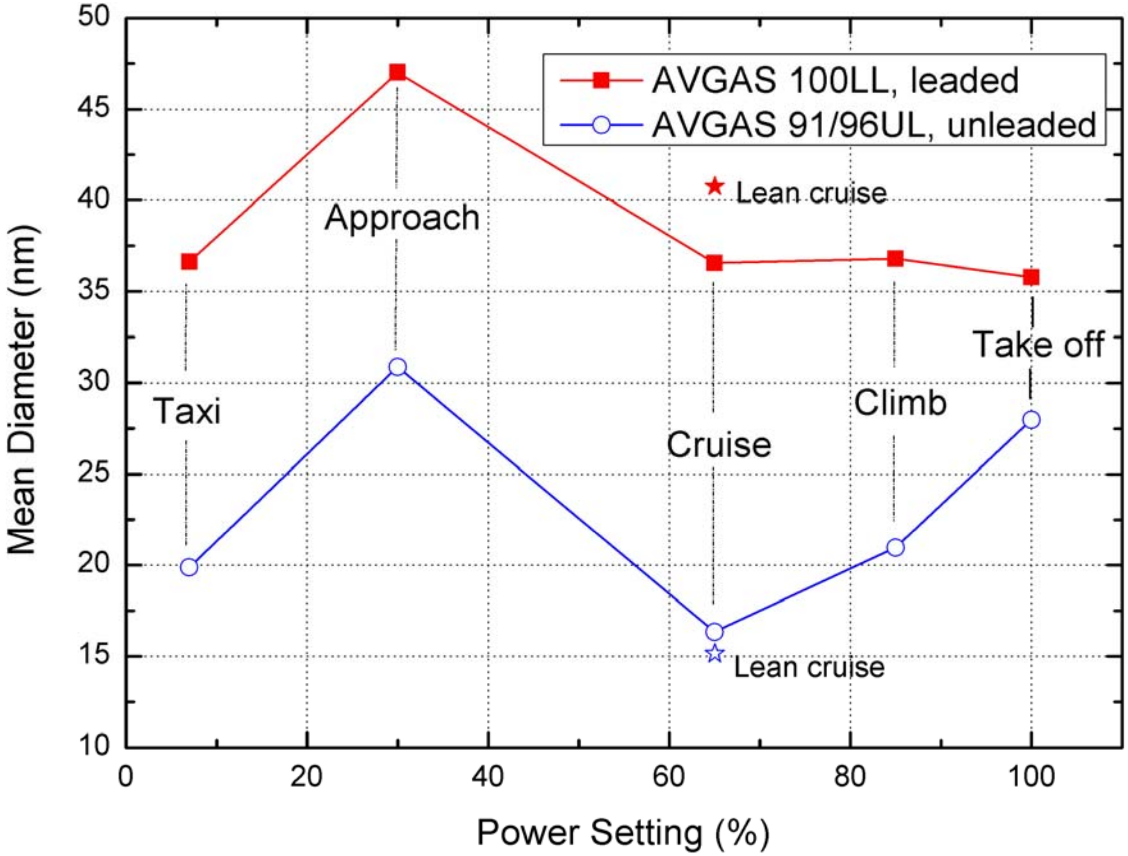
-AVGAS 91/96UL gives a significant reduction in number concentration,

mass and diameter

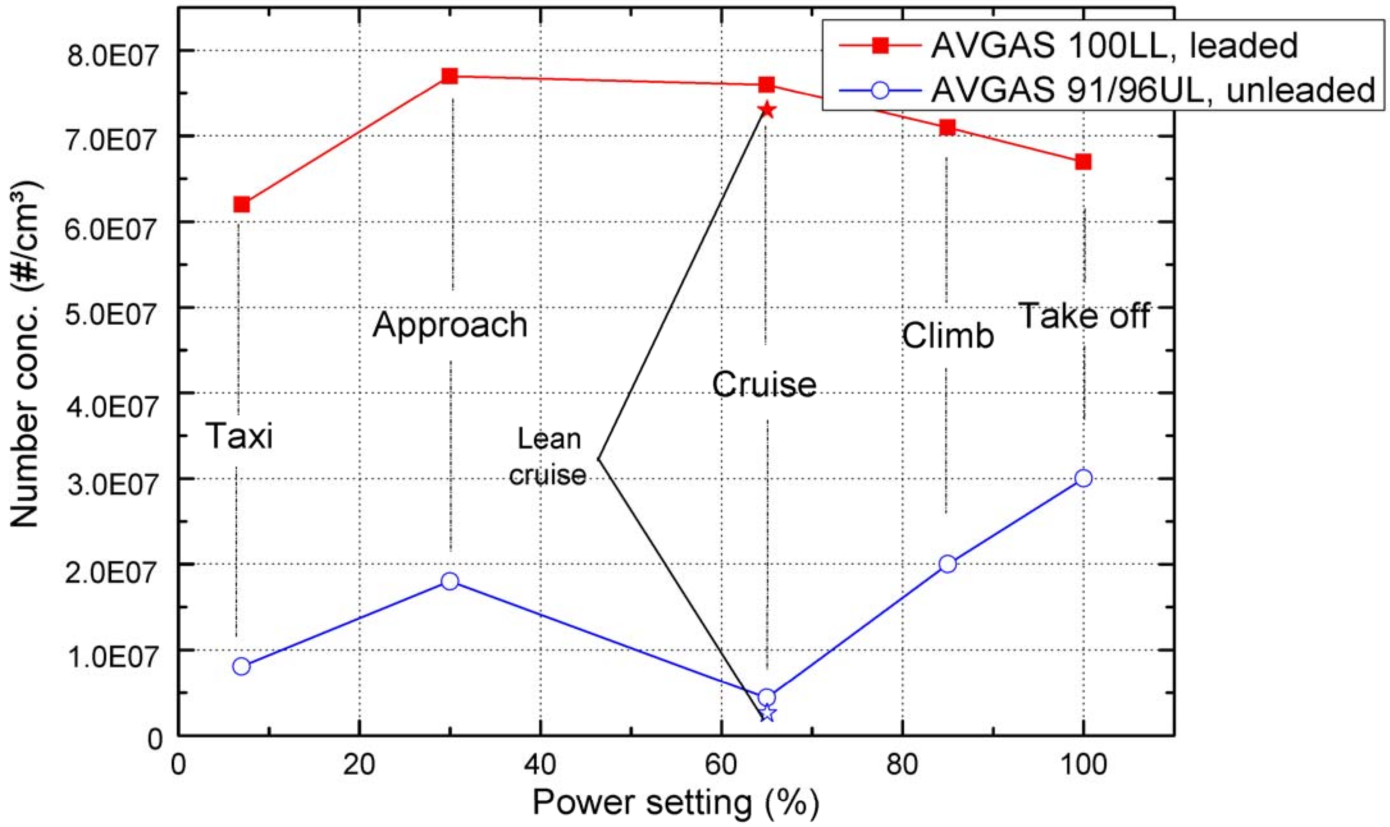
-Running the HB-EYS with lead free fuel gives still some lead bromide emissions (The aircraft was running its hole life with leaded fuel)

Fortunately not all lead is emitted, you can find huge lead deposits in the oil pan of the engine

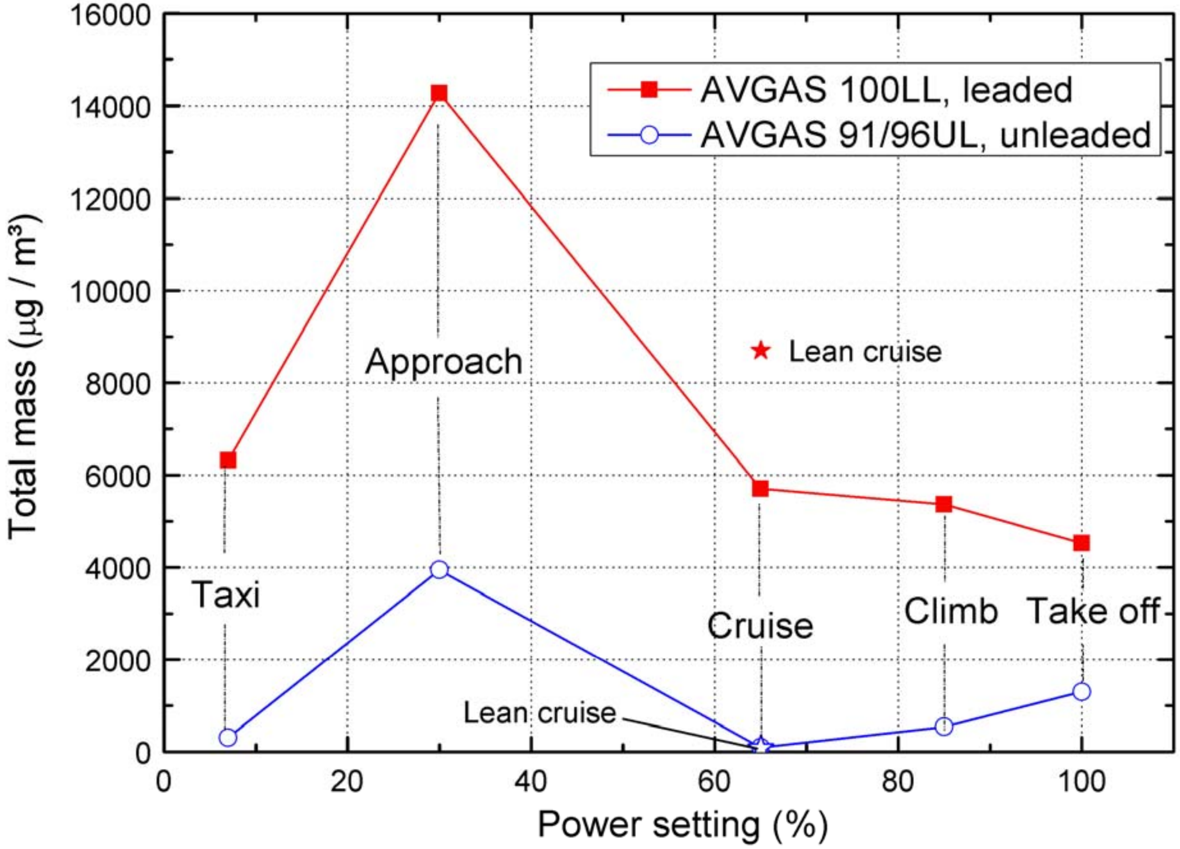
SE-KEI Mean Diameter = f (power)



SE-KEI Number conc. = f (power)



SE-KEI Total mass = f (power)

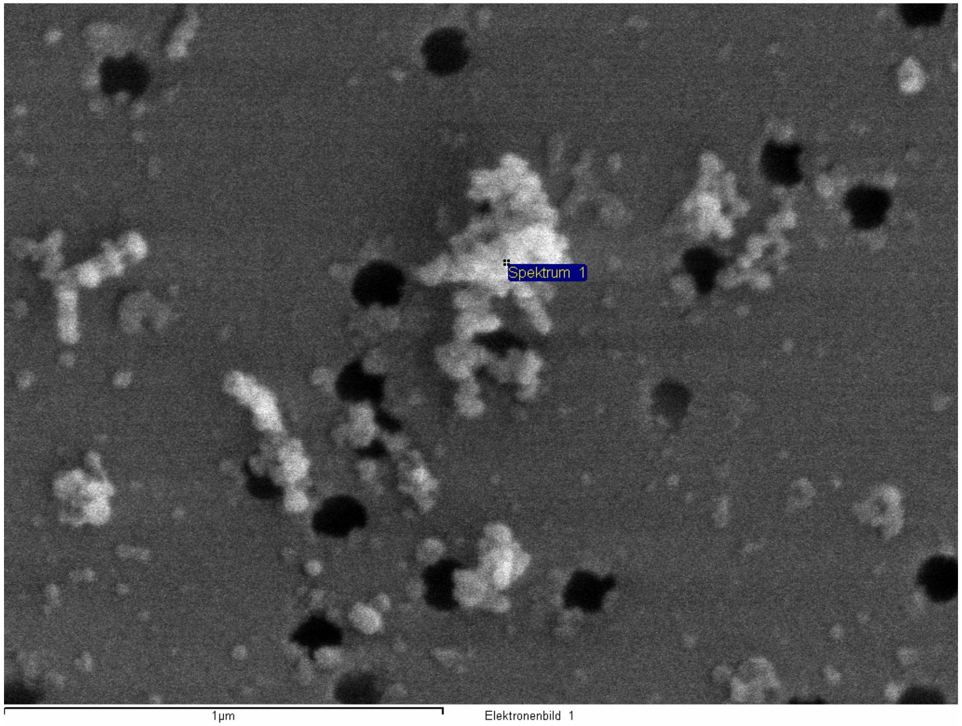


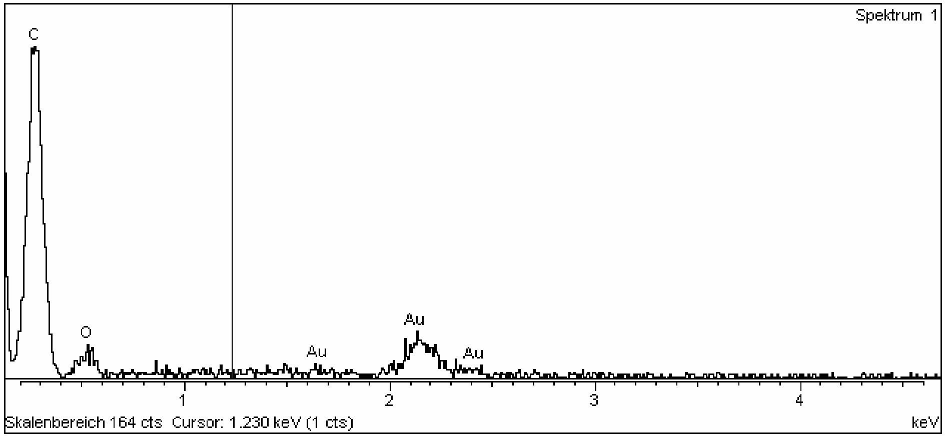
SE-KEI

Approach

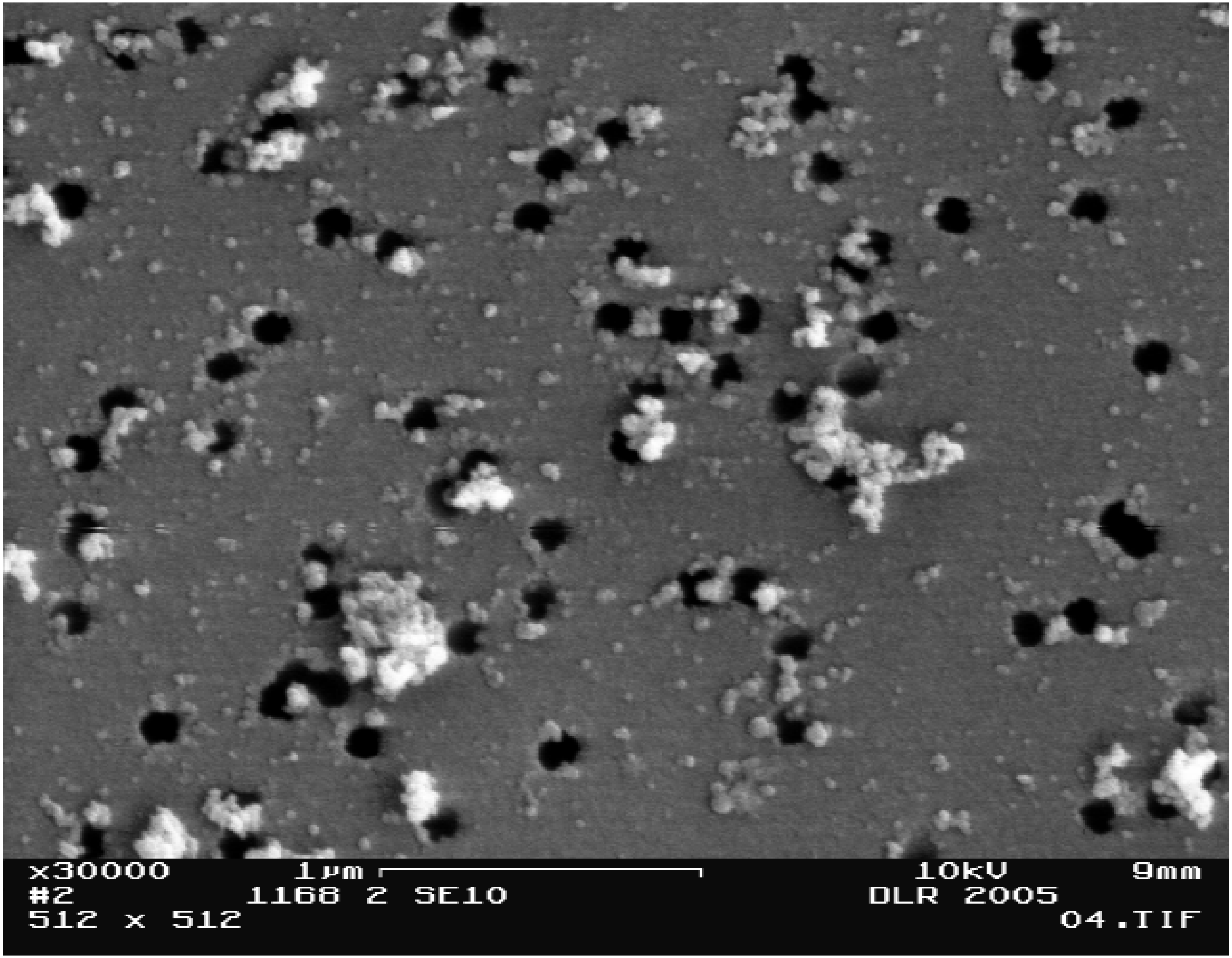
SE10 Probe2

Projekt 1168 - Probe 2

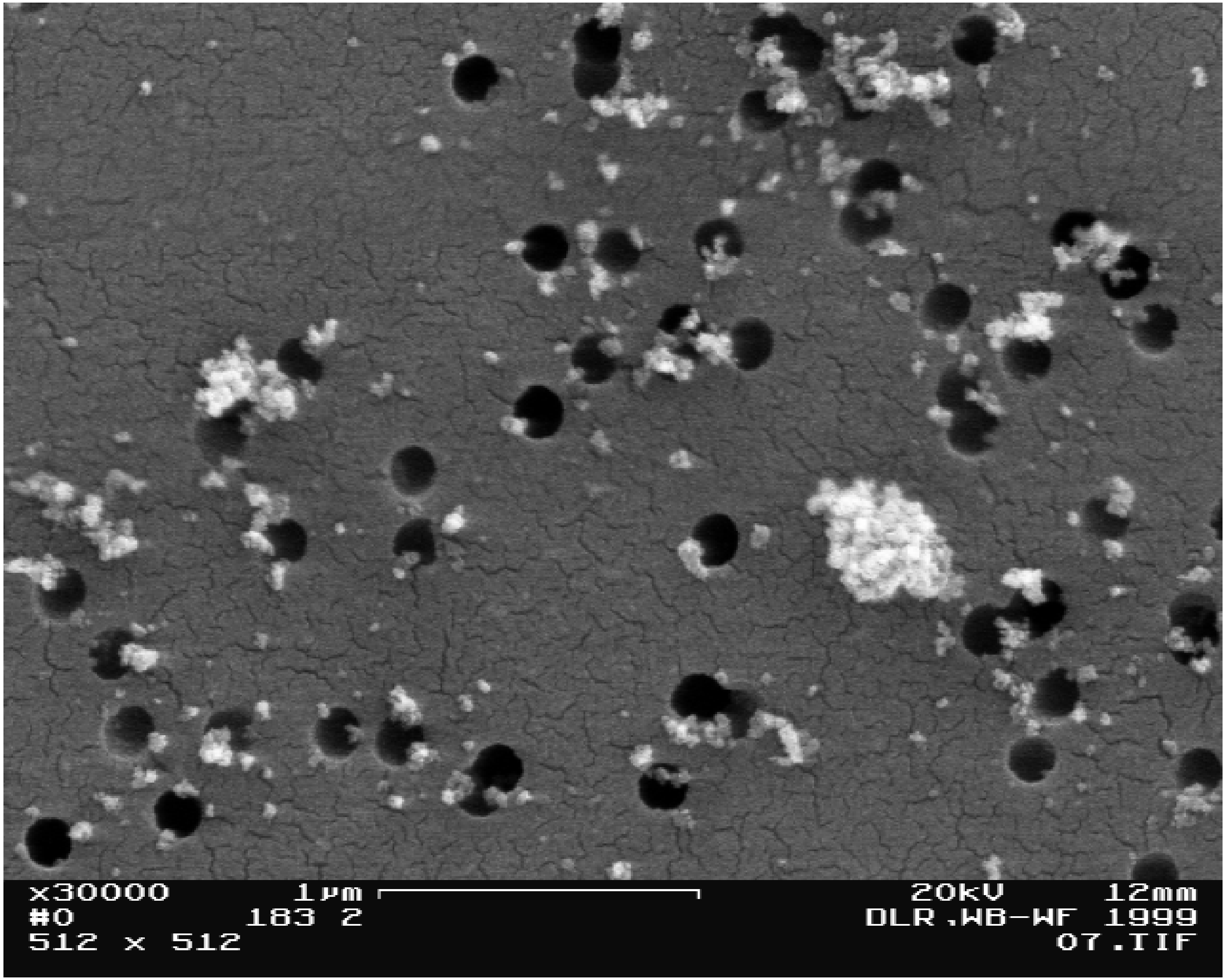




SEM x 30000 Soot SE-KEI APPROCH / fuel: AVGAS



SEM X30 000 Soot from staged combustor test / fuel: JET-A1



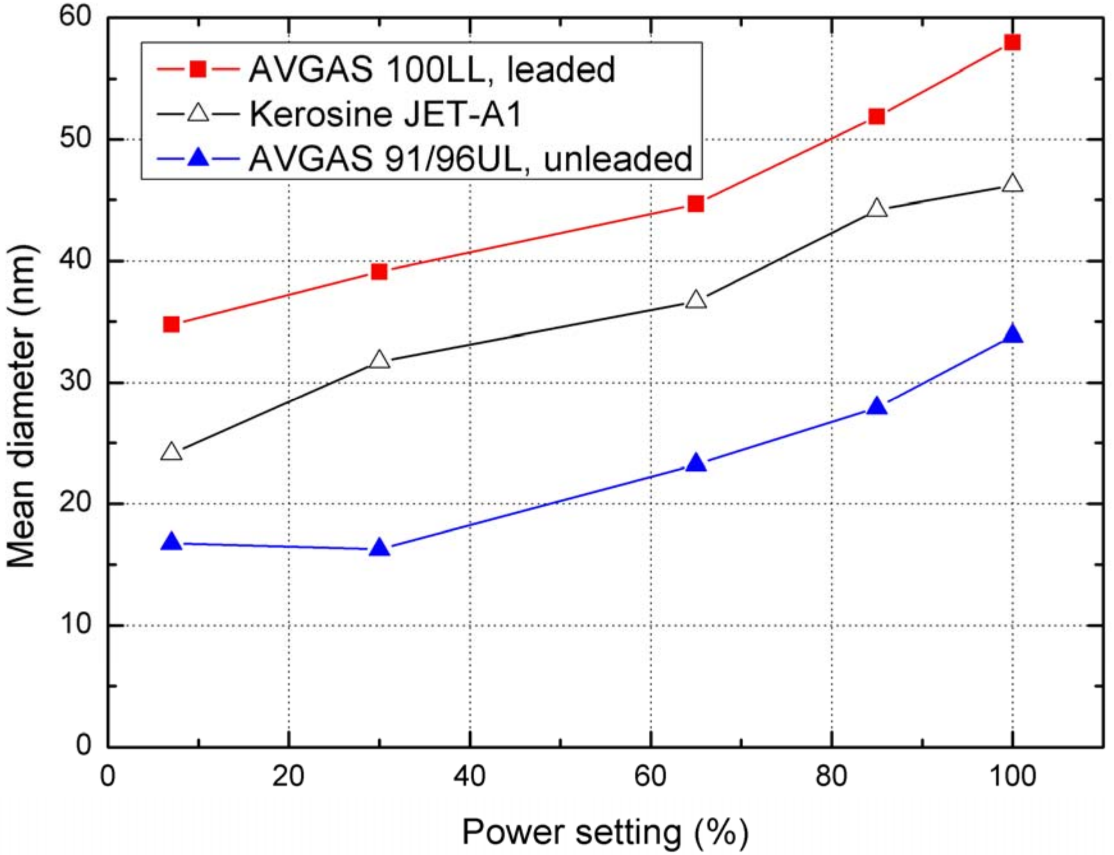
Results of “Swedish Aircraft test” **SE-KEI**:

-Again AVGAS100LL shows significant higher emissions than unleaded fuel

-Maximum emissions found at approach conditions
(perhaps the carburettor by itself is automatically set to rich condition?)

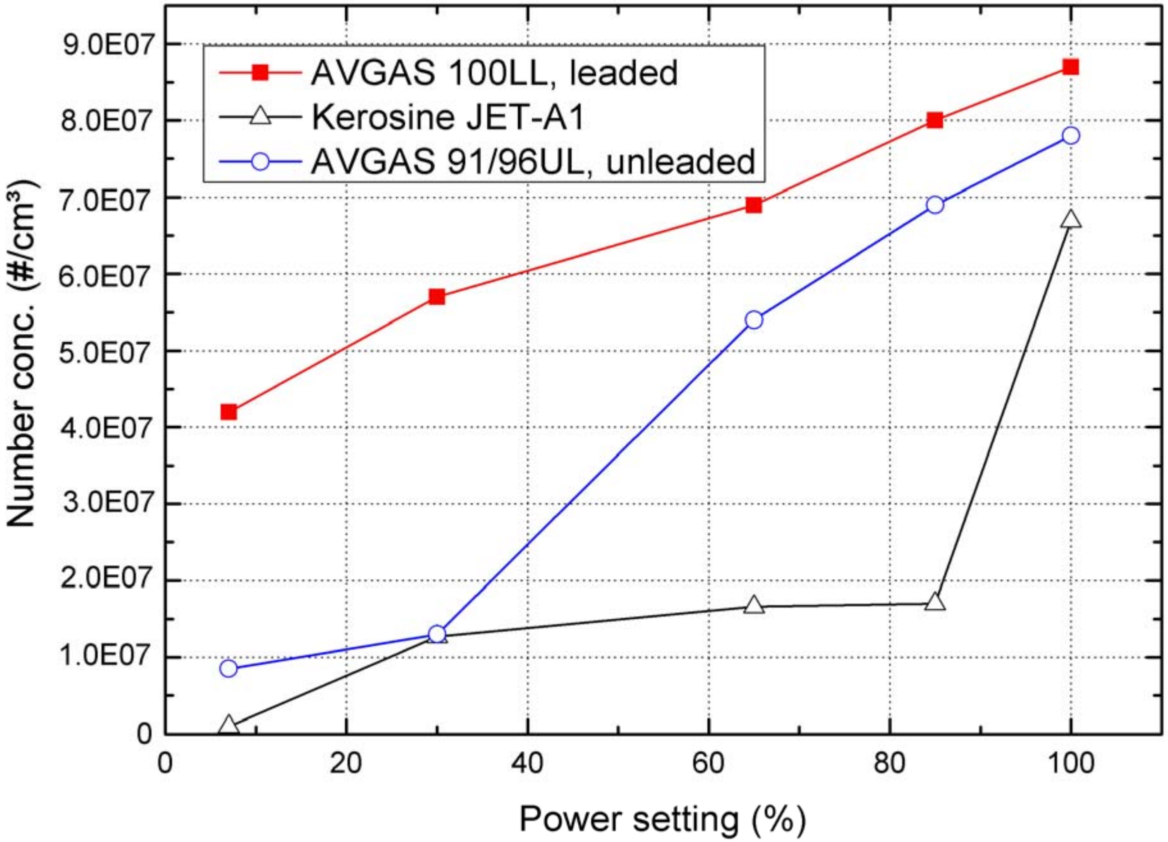
-Shape of the particles is similar to kerosene soot

Comparison of HB-EYS piston engine test with modern flight gas turbine emissions

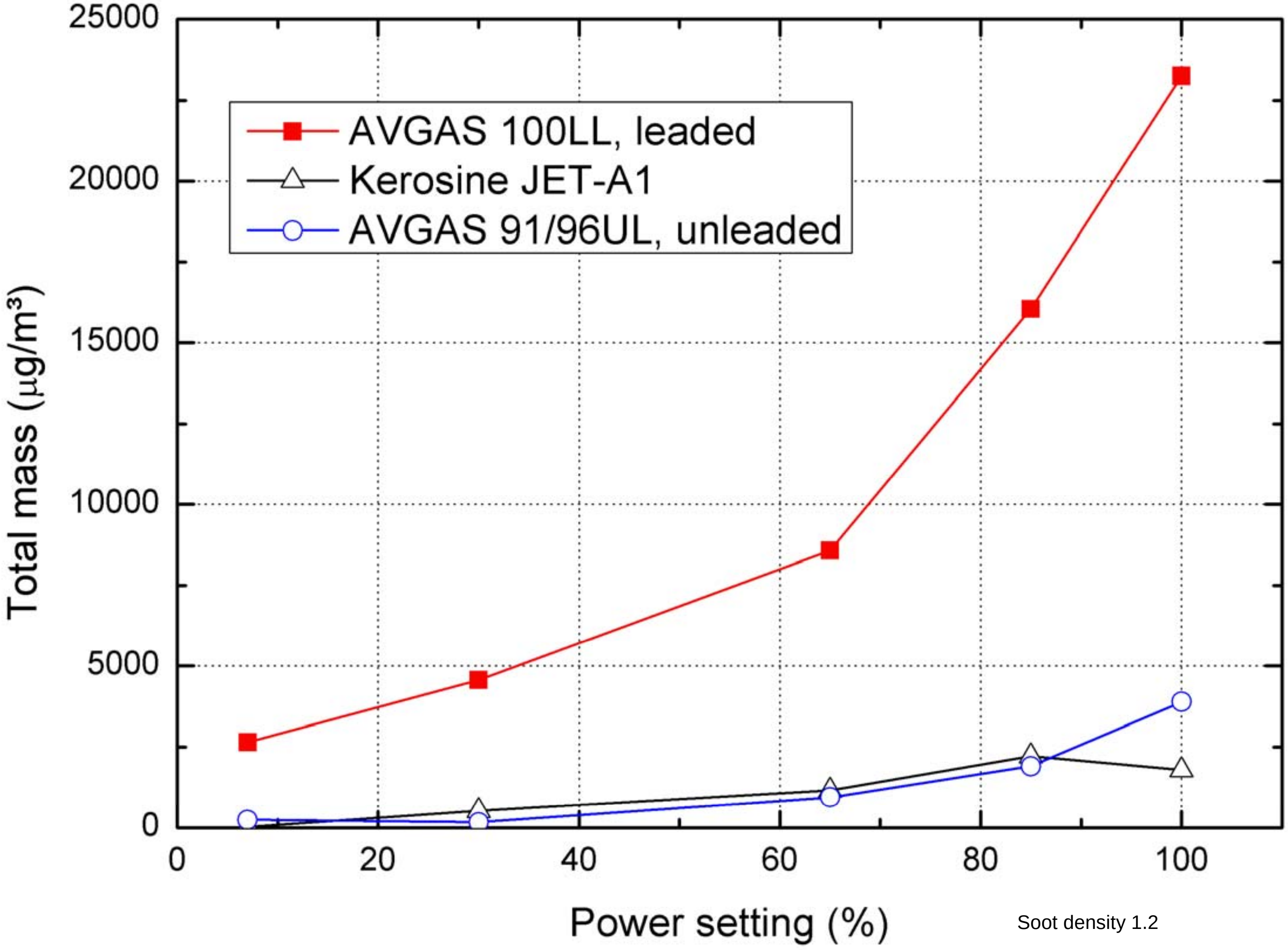


ASME / GT2003-38797

HB-EYS piston engine compared with flight gas turbine



HB-EYS piston engine compared with flight gas turbine

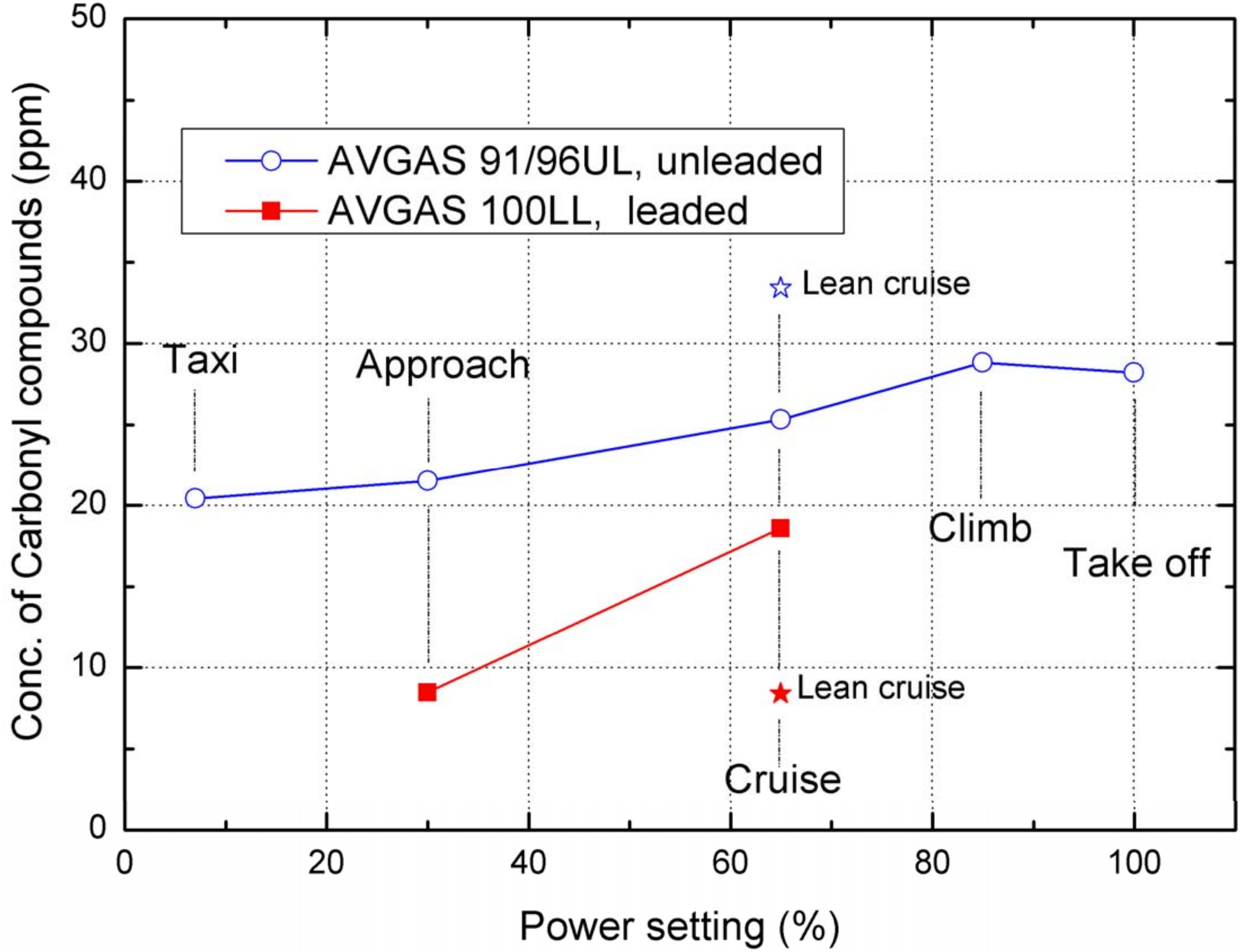


Soot density 1.2

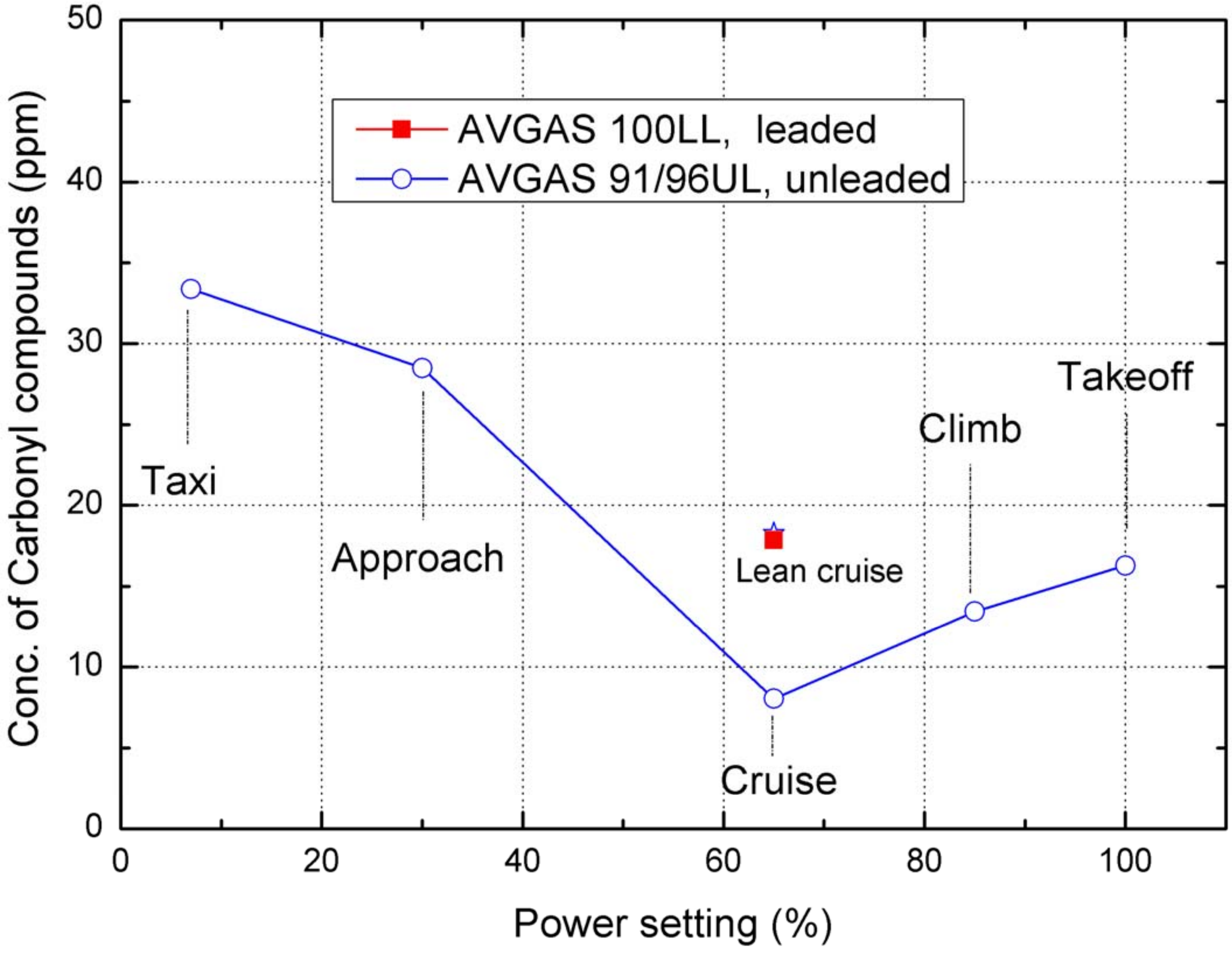
Carbonyl Compounds identified by DNPH - HPLC Method

** Formaldehyde	CH_2O
* Acetaldehyde	CH_3CHO
Propargylaldehyde	CHCCHO
Acetone	CH_3OCH_3
* Propionaldehyde	CH_3CH_2CHO
Crotonaldehyde	$CH_3CHCHCHO$
i-Butanale	$i\text{-}C_3H_7CHO$
* Benzaldehyde	C_6H_5CHO
Methylglyoxal	CH_3COCHO
o-Toluene – aldehyde	$CH_3C_6H_4CHO$
m-Toluene – aldehyde	$CH_3C_6H_4CHO$
p-Toluene – aldehyde	$CH_3C_6H_4CHO$

SE-KEI Carbonyl compounds vs. power setting



HB-EYS Carbonyl Compounds vs. power setting



Conclusion

- AVGAS powered flight piston engines emit nanoparticles!

-Size, concentration, mass and shape is similar to modern staged gas turbines

-AVGAS 100LL give soot and lead bromide particles $PbBr_2$

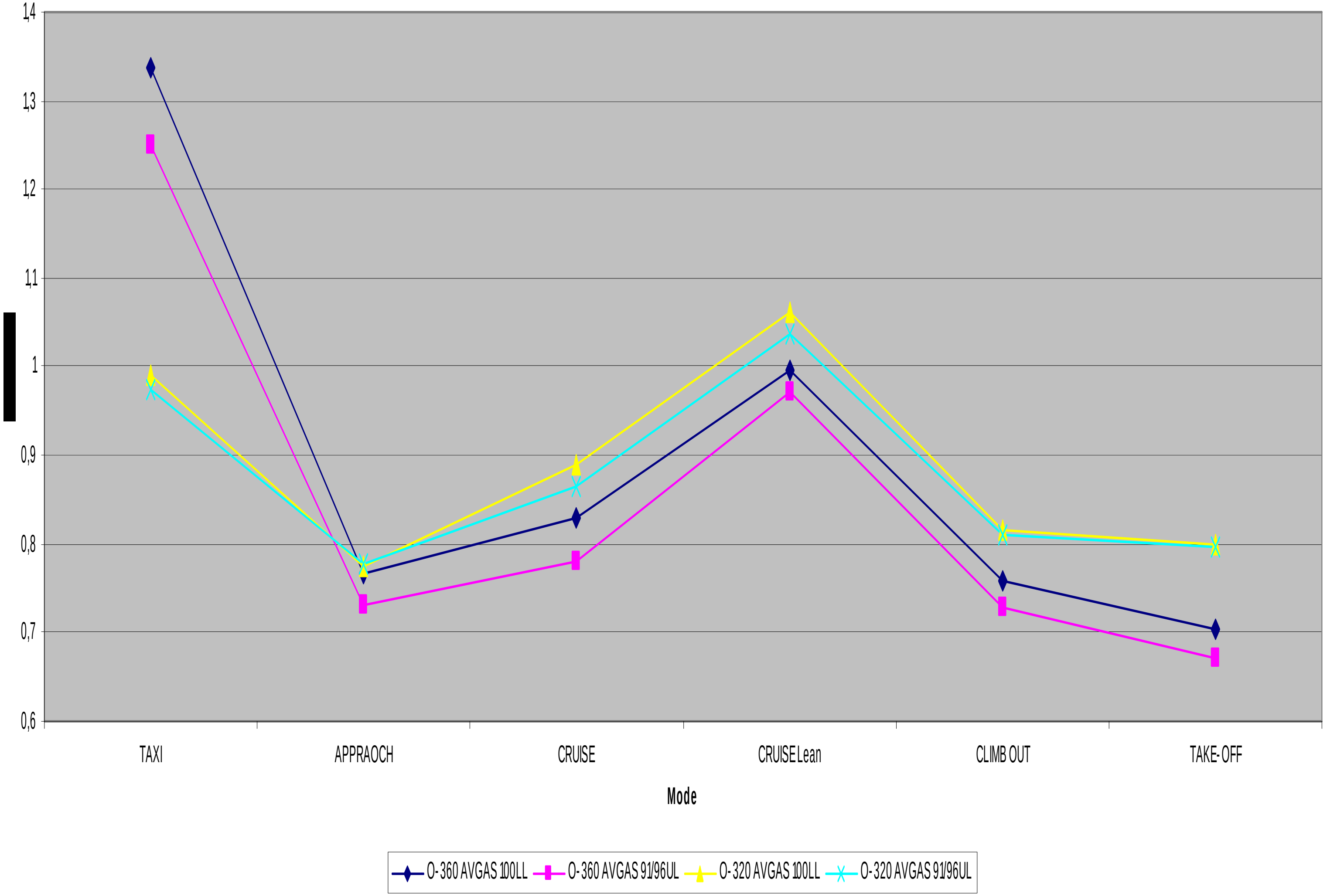
- unleaded AVGAS 91/96UL gives **significant lower emissions** (diameter, number conc.# and mass!), than leaded AVGAS

-AVGAS 91/96UL has no lead and no bromide emissions!

-The engine manufacturer Textron Lycoming has included AVGAS 91/96 UL as an approved alternate aviation gasoline for a large number of their engines already in year 1995. The engines with type numbers are listed in their service instruction No. SI 1070”


ROBIN

Lambda Comparison HB-EYS and SE-KEI



Lambda-Comparison HBEYS and SEKEI

		Lambda O-360		Lambda O-320	
MODE	Approx.%Power	100LL	91/96UL	100LL	91/96UL
TAXI	10	1,338	1,251	0,99	0,975
APPRAOCH	30	0,767	0,731	0,774	0,778
CRUISE	65	0,829	0,781	0,89	0,864
CRUISE Lean	65	0,997	0,97	1,062	1,036
CLIMB OUT	85	0,759	0,727	0,815	0,809
TAKE-OFF	100	0,704	0,671	0,798	0,797