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Non-thermal plasma based
technologies for the aftertreatment of
diesel exhaust particulates and NOx

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DEER 2003, Newport, Rhode Island
28th August 2003



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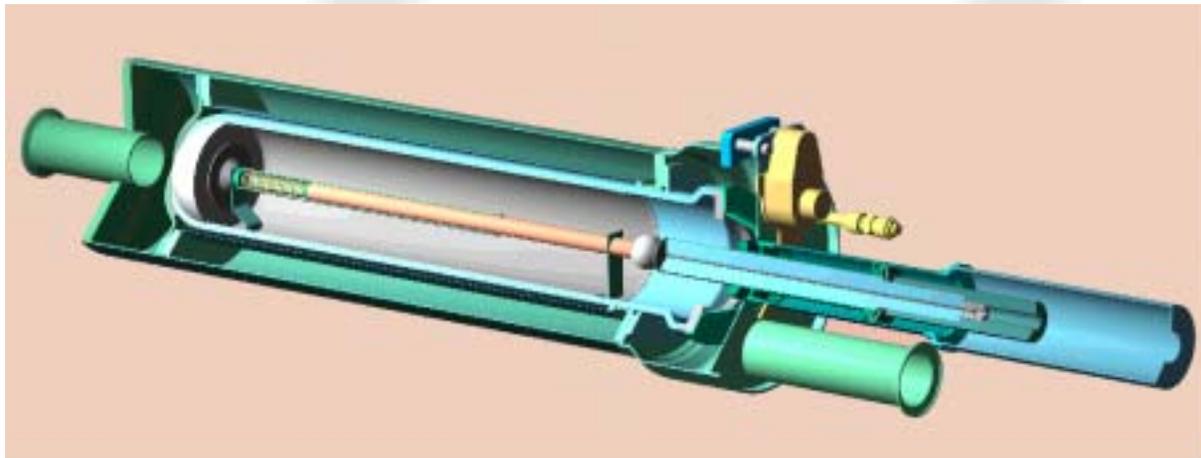
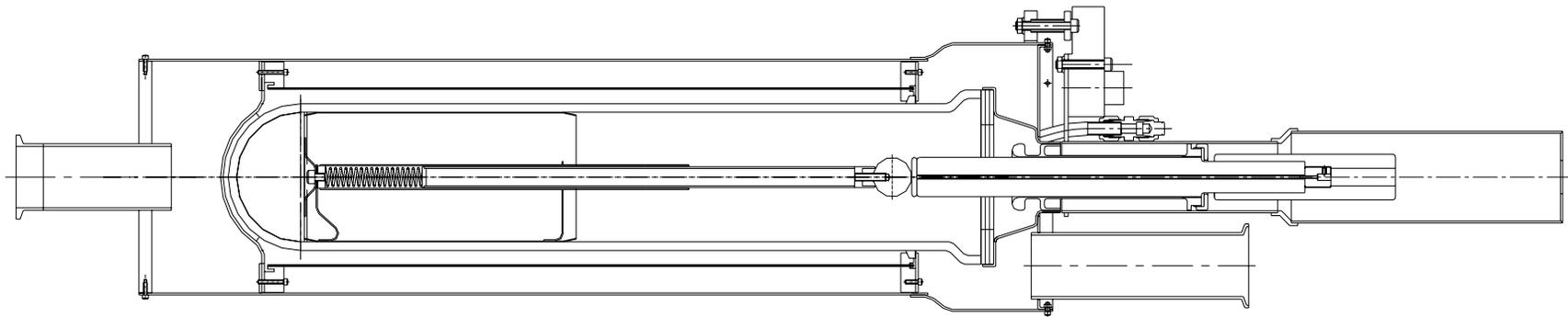
Overview

- Passenger car application
 - Diesel Particulate Filter
 - trapping efficiency
 - testing
 - In partnership with Eberspächer
- Marine diesel exhaust application
 - Plasma Assisted Catalysis of NOx
 - drivers
 - programme overview
 - In partnership with Ministry of Defence - Warship Support Agency



Electrocat™ DPF

Dielectric barrier discharge



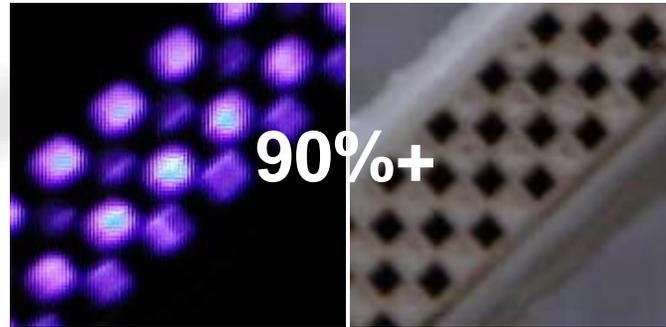
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Improved Filtration

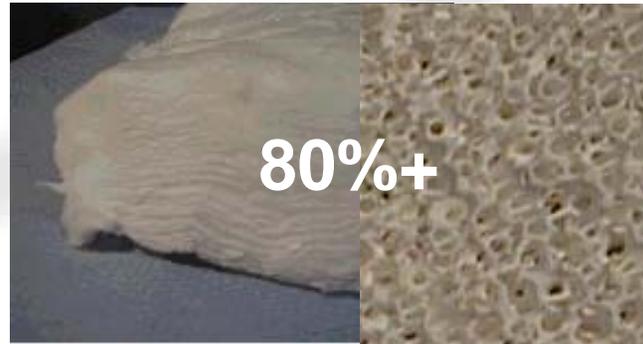


Pellets
50-60% filtration

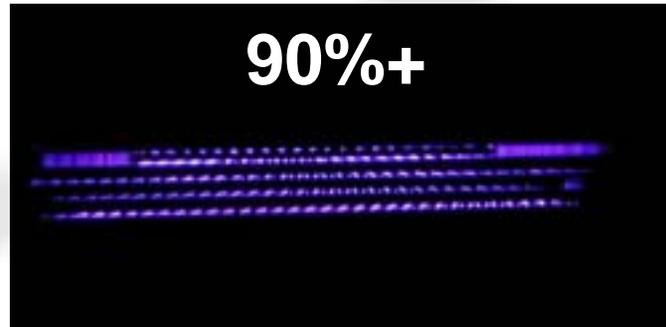
Improved
→
Filtration



Cordierite
Monoliths

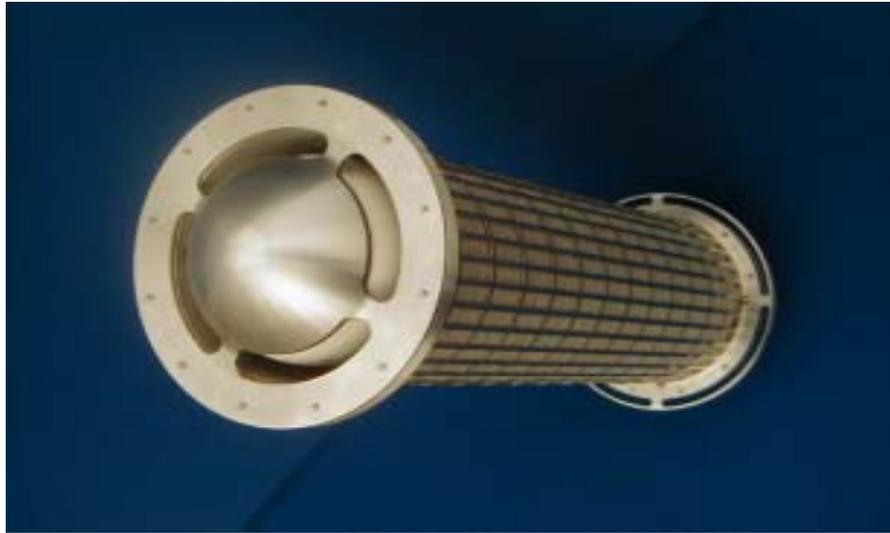


Ceramic Fibres
and Foams

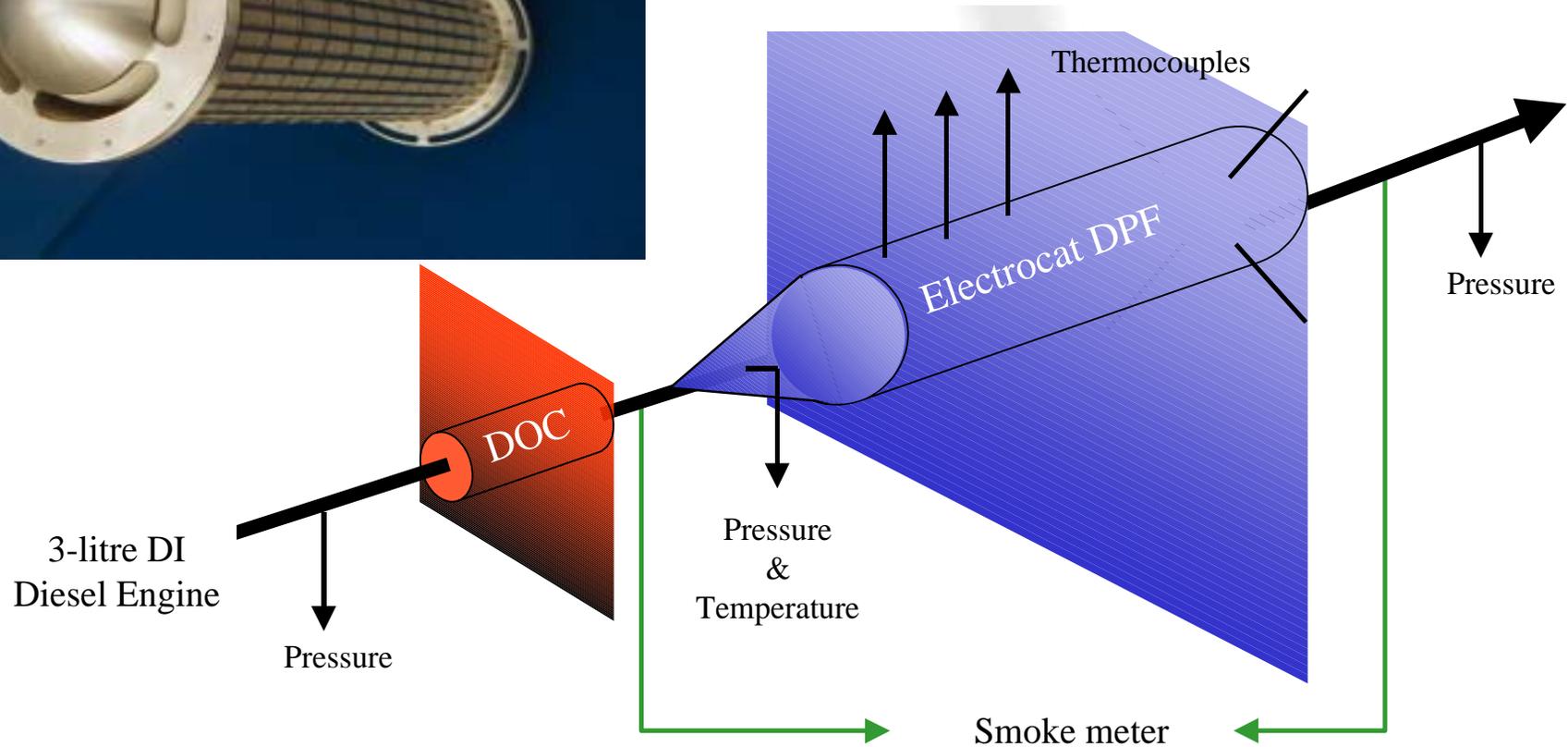


Meshes &
Sintered Metal

Electrocat™ DPF

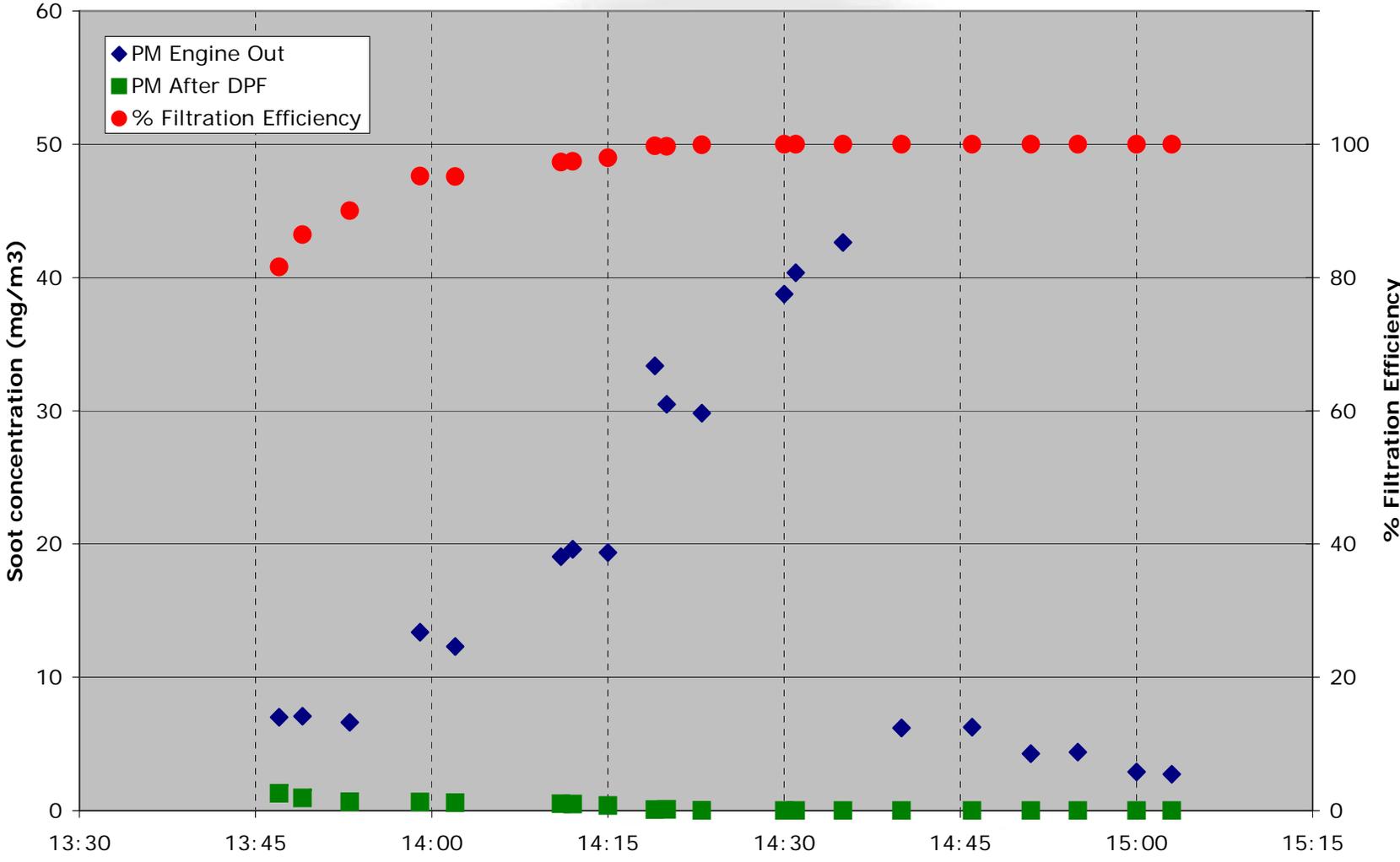


Testing of plasma regenerated sintered metal fibre filter



Filtration efficiency

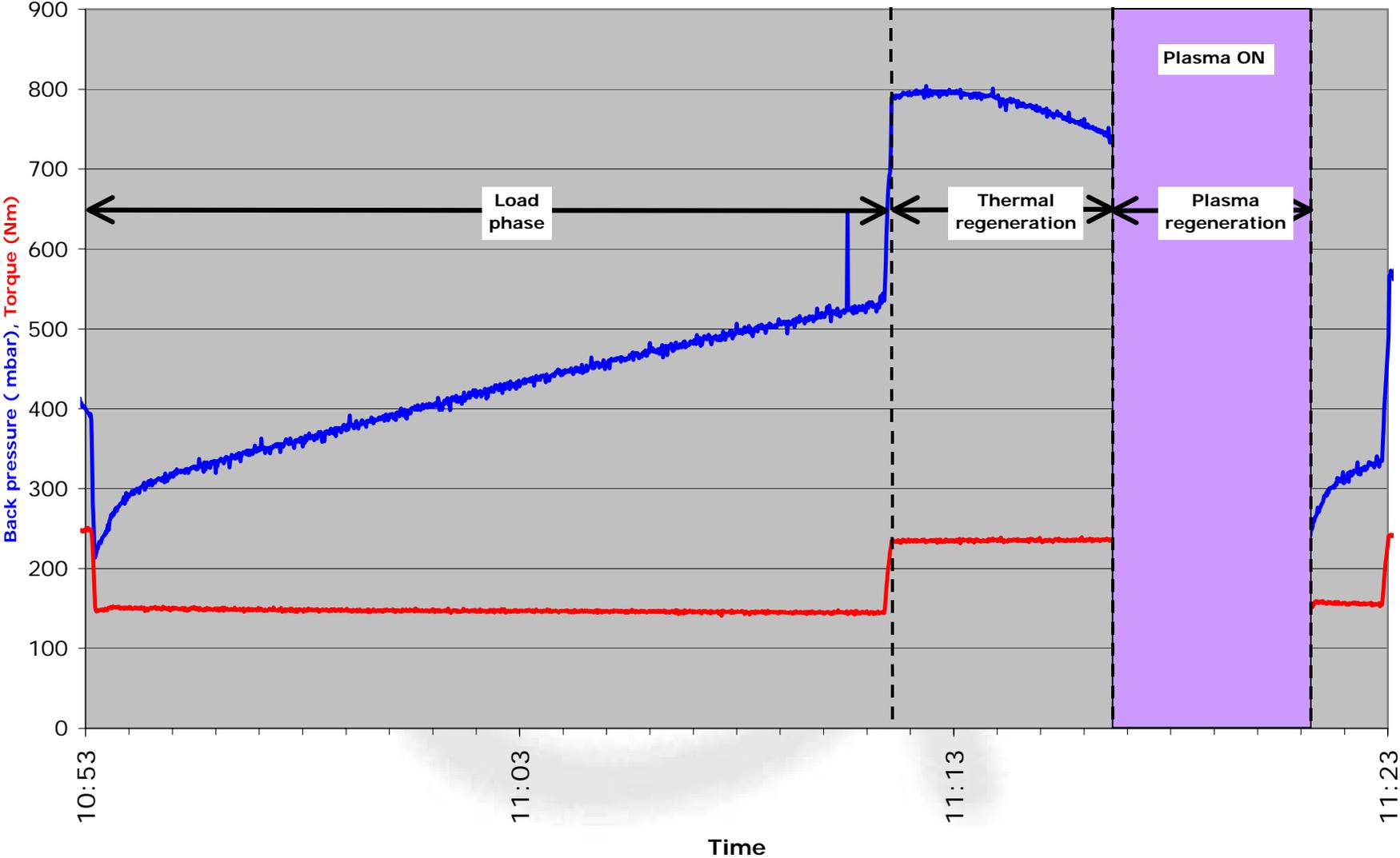
Filtration efficiency tested from clean condition



Speed 1500rpm
Torque 60-260 Nm
in 30Nm steps

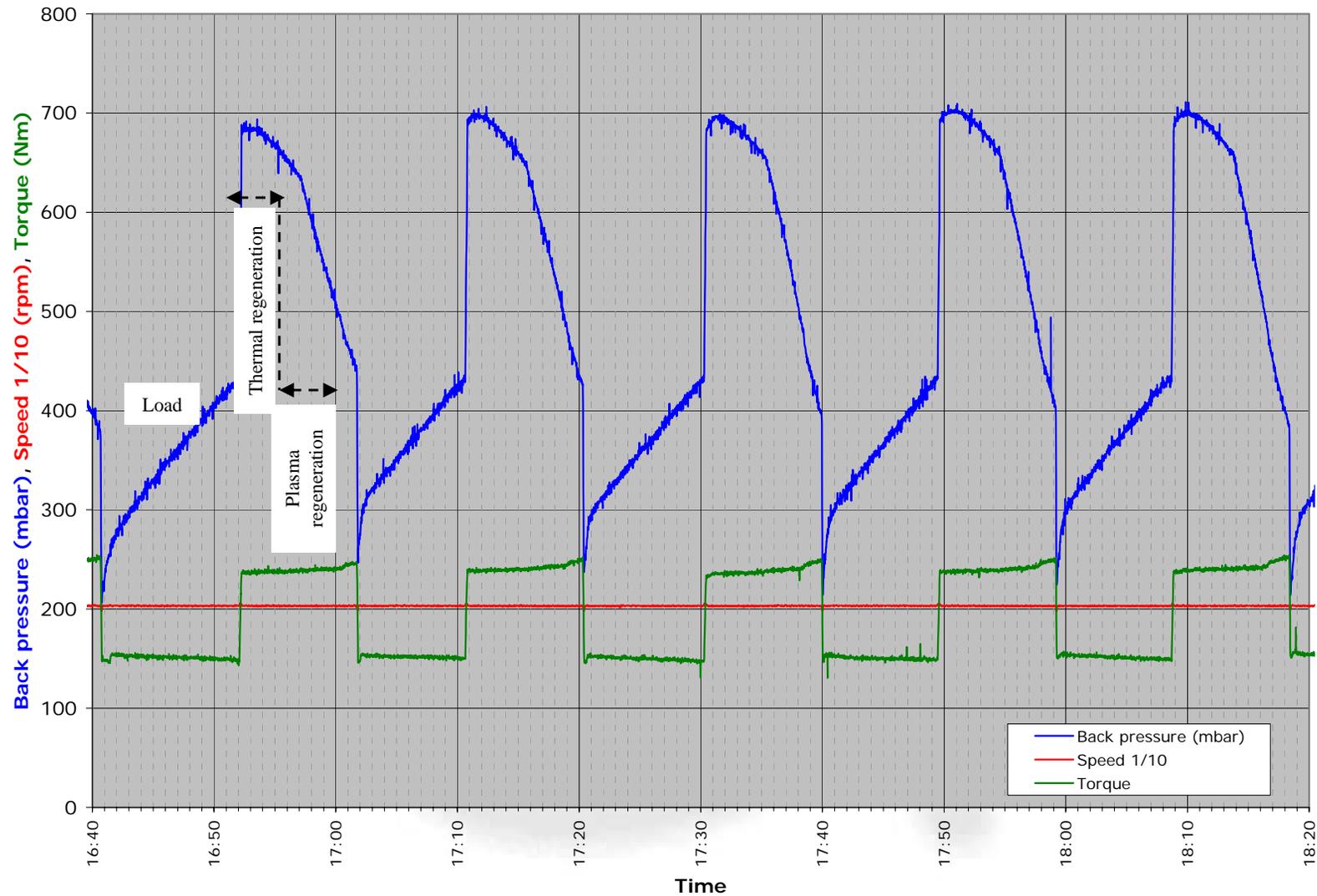


Regeneration



Load 2000rpm 150Nm
Regen 2000rpm 237Nm
Inlet temp ~375-400°C

Cyclic regeneration



DPF Current status

- Highlights
 - 95-100% filtration efficiency
 - Filter regeneration demonstrated at powers down to 500W
 - Rapid initiation of filter regeneration on application of plasma
 - Regeneration demonstrated over lower temperature range ~90-200°C
 - Flexible operating strategy demonstrated
- Future development
 - Increased capacity of system e.g. filter surface area
 - Improved performance and power efficiency

Emissions drivers for marine diesels

- **Present legislation**

- MARPOL ANNEX VI (1997)*
 - NOx emissions
 - met by on engine methods
- Fairway & port differential fees (e.g. Sweden, Hamburg)
 - Probably not presently cost effective for Royal Navy to use aftertreatment

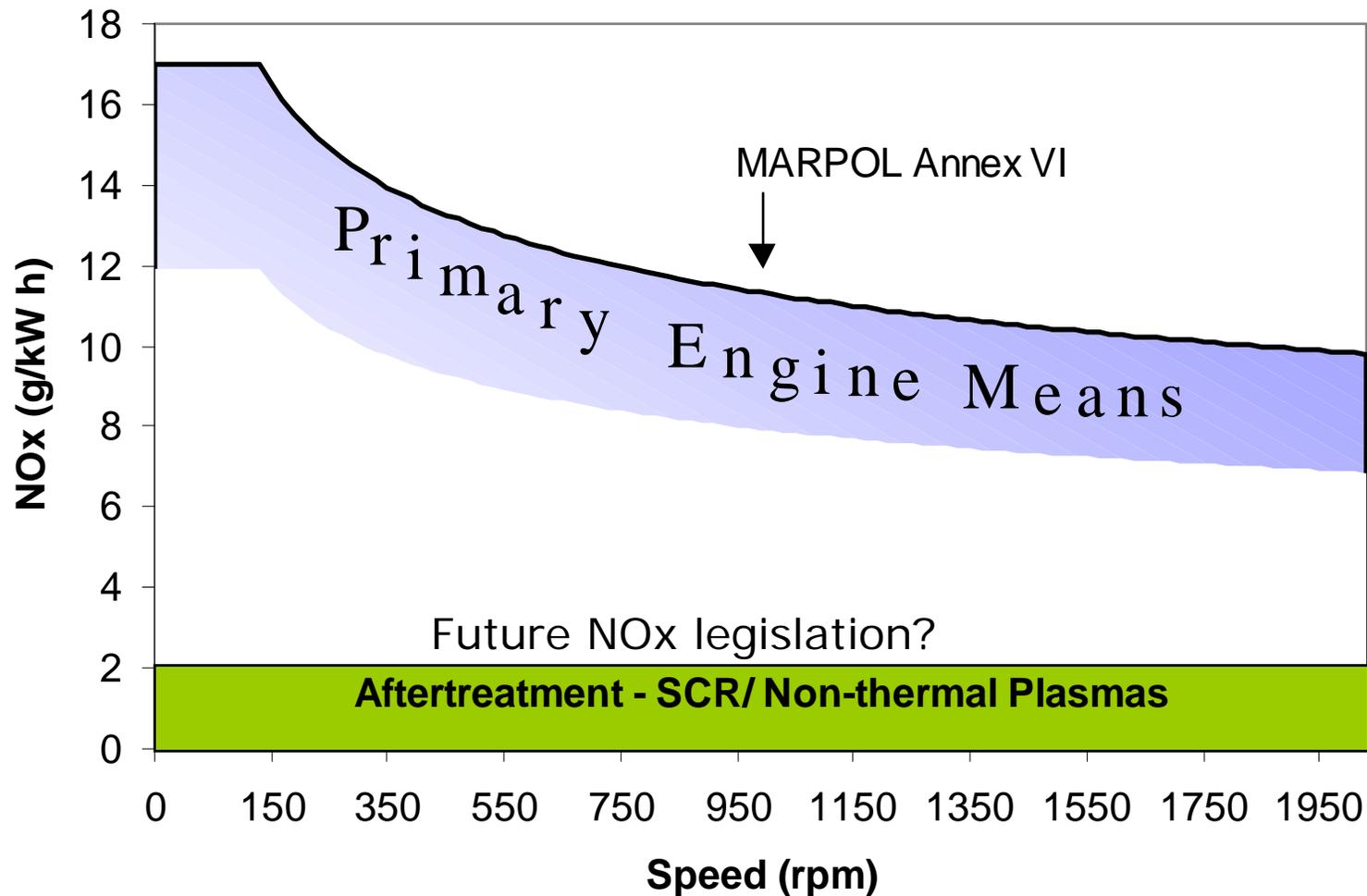
- **Future legislation**

- NOx - further reduction
- Particulate matter (PM)
- Others (Poly-Aromatic Hydrocarbons)
- Timescales?

* This Annex will enter into force 12 months after being ratified by at least 15 States whose combined fleets of merchant shipping constitute at least 50% of the world fleet. At the time of writing this report 10 States (Bahamas, Bangladesh, Denmark, Greece, Liberia, Marshall Islands, Norway, Panama, Singapore and Sweden) whose combined tonnage represents 52.56% of the world tonnage have ratified the Annex. (Source: <http://www.imo.org>).

NOx emissions limits

MARPOL ANNEX VI and the future

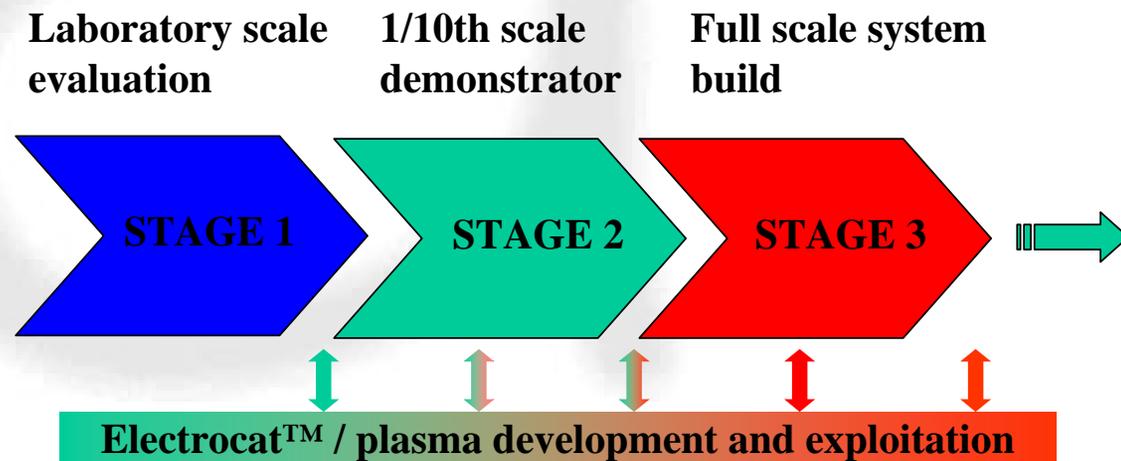


SCR - Impact on operational capability

- Royal Navy have tested full scale SCR system
 - 1.4MW Paxman Valenta
- Liquid urea storage
 - Type 23 Frigate: estimate converted 35 m³ fuel tank of urea solution would last 4 months
- Urea purchased as solid
 - storage before mixing - where on vessel?
 - impact on water supply
- World-wide bunkering/availability?
 - Bunkered as aqueous solution (6 month shelf life)?
- Additional manpower requirements
 - Royal Navy moving to Reliability Centred Maintenance

Non-Thermal Plasma NOx reduction

- Non-thermal plasma
 - well placed to meet future legislation
 - potential for combined NOx/particulate
 - diesel fuel reductant
 - already available on board
 - fuel penalty 2 - 5% over operating cycle
 - low load potential & shock tolerance
- Programme
 - 1/10th scale
 - build
 - test
 - evaluate
 - retest



NTP Target specifications

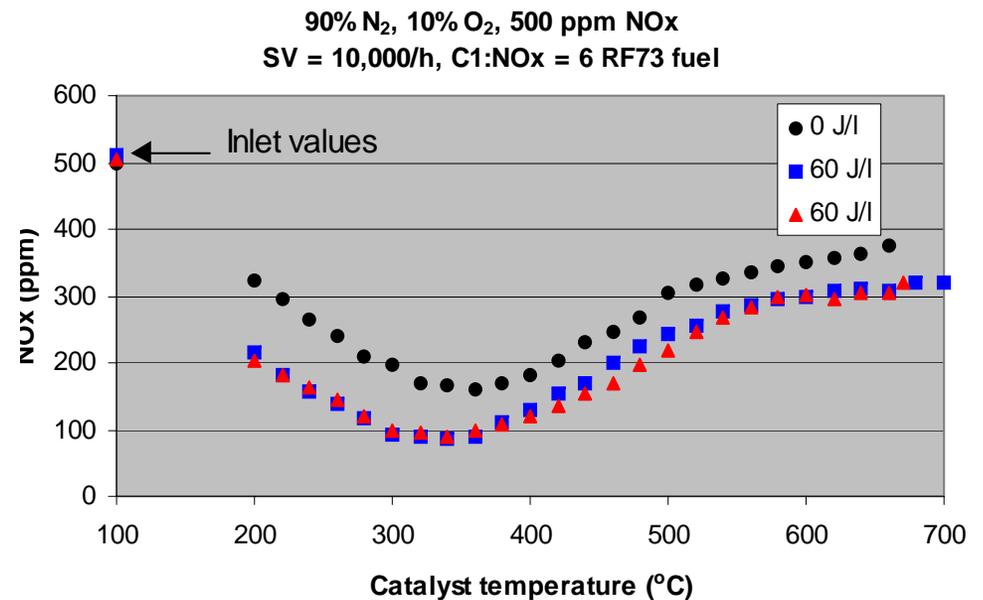
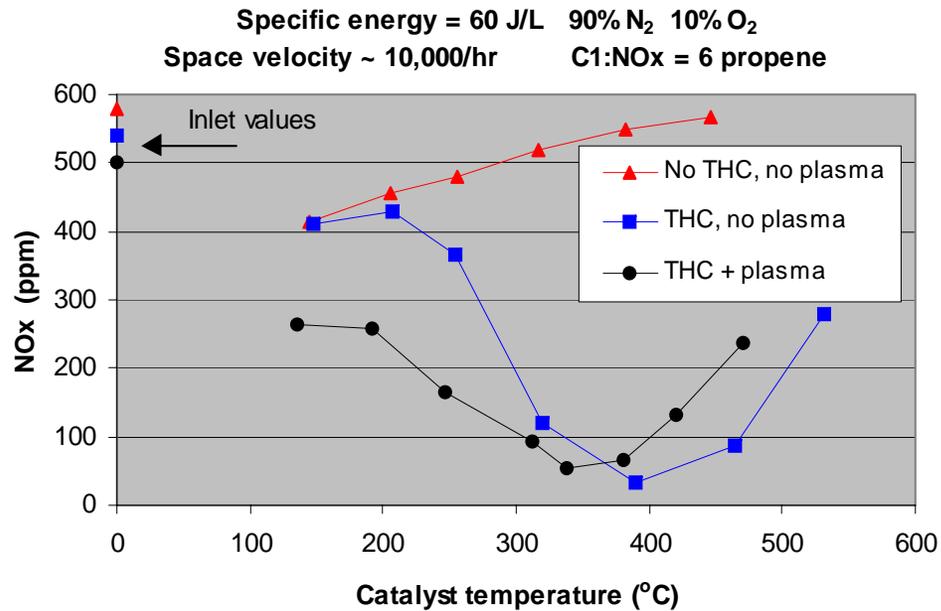
- NOx reduction >90%
- Noise attenuation >25 dB(A)
- Weight 20-50% additional to silencer
- Space requirement equivalent to silencer
- Power increase <5%
- Lifetime of mean engine overhaul



Plasma assisted NOx reduction

NOx catalyst in synthetic exhaust

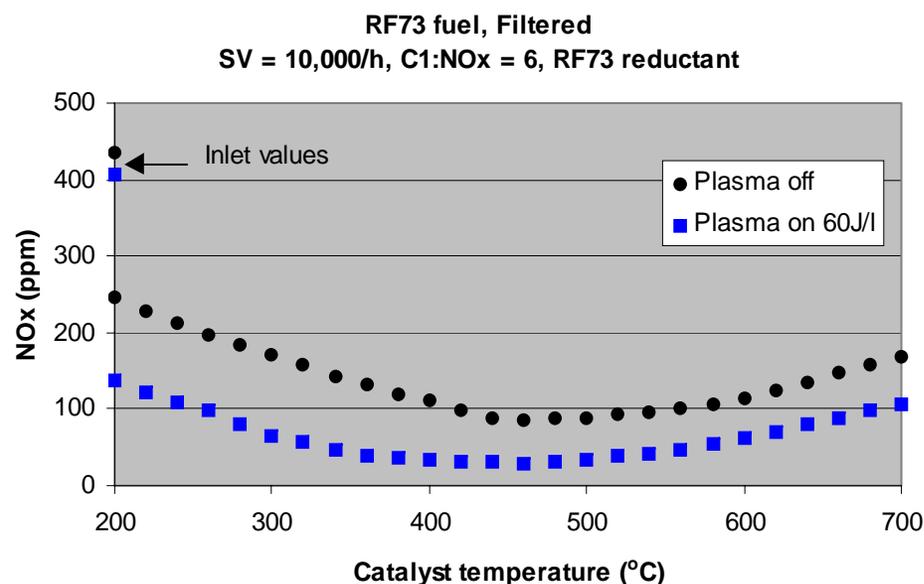
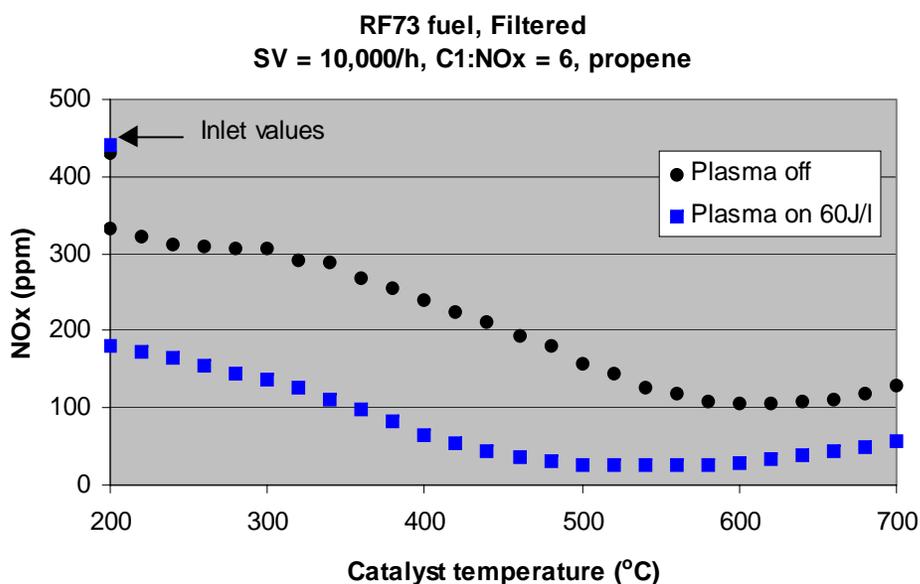
- 2% Ag/Al₂O₃ with propene or RF73 fuel reductant



NOx reduction in genset exhaust

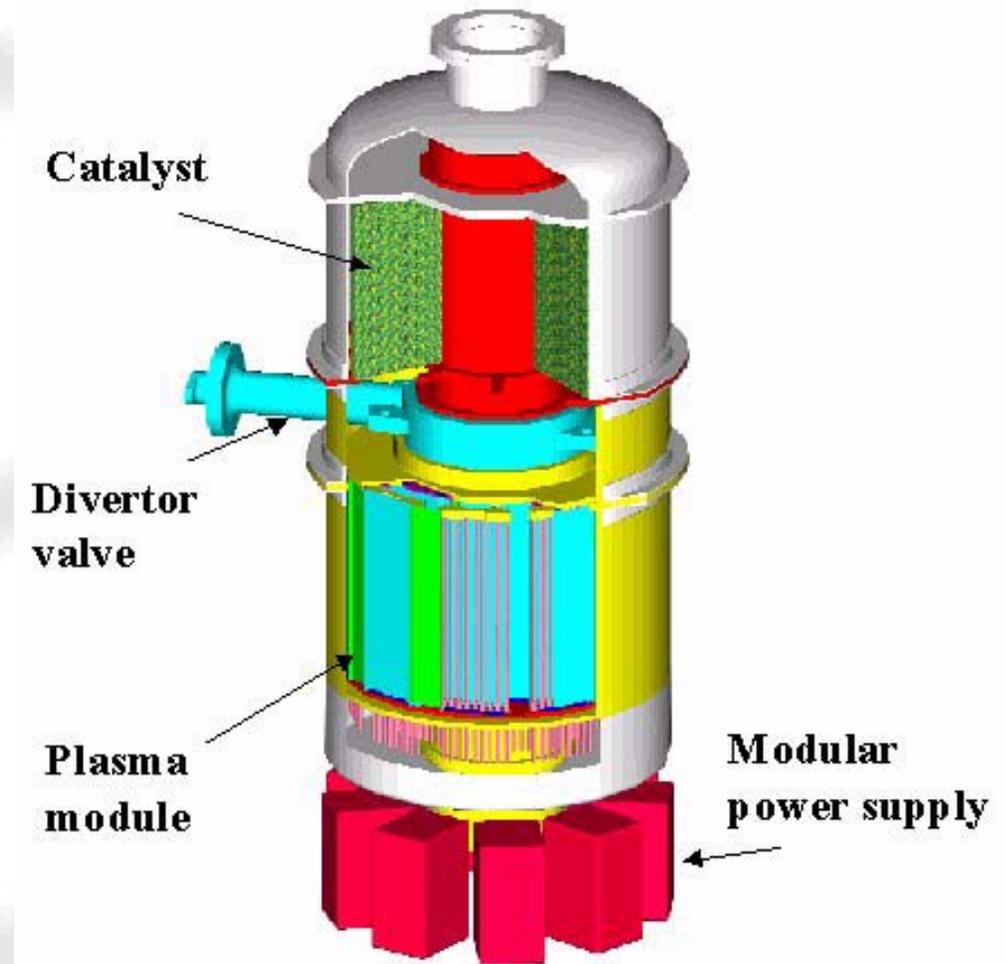
NOx catalyst in genset exhaust

- RF73 (~0.043% sulphur) fuel in genset

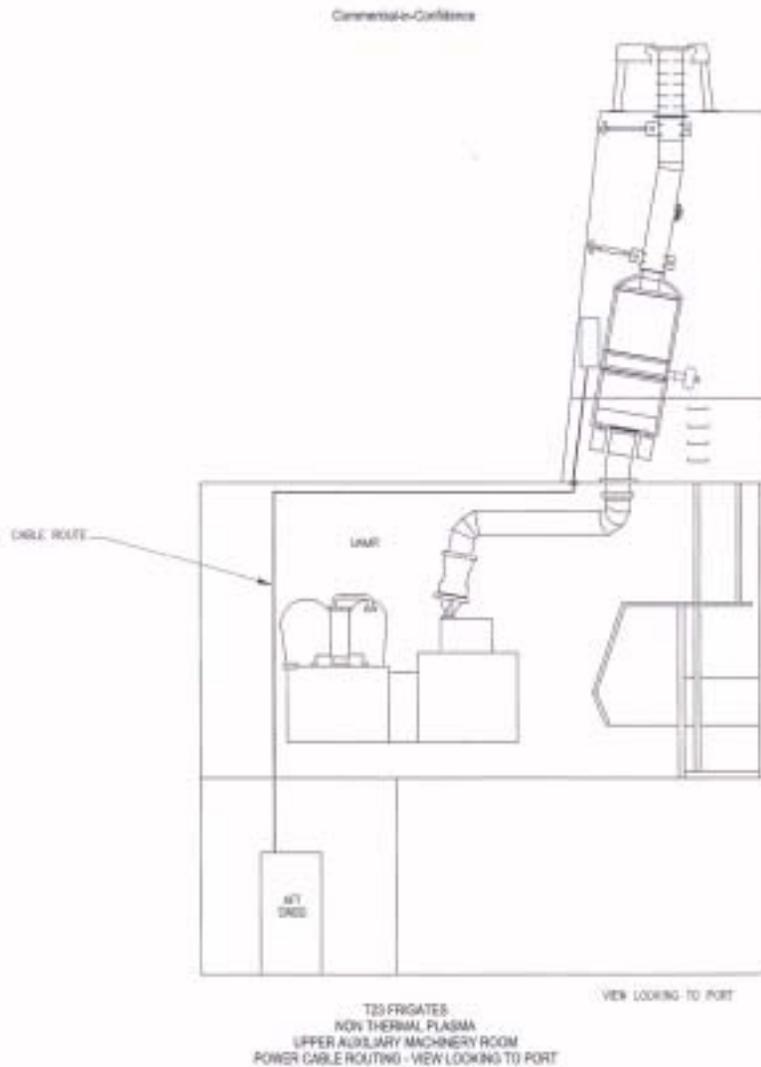


Full scale concept to 1/10th scale system

- 1/10th scale system design
 - treat 1/10th flow from indicative engine
 - based on (evolving) full scale concept
 - minimises potential for new development issues
 - full scale concept will match predefined envelope for an example Type 23 fit
 - ship integration/safety needs accounted for
 - maximise flexibility to address other fits as easily as possible
 - modularity



Type 23 Frigate fit



Commercial-in-Confidence



- Notional fit within both UAMR and FAMR

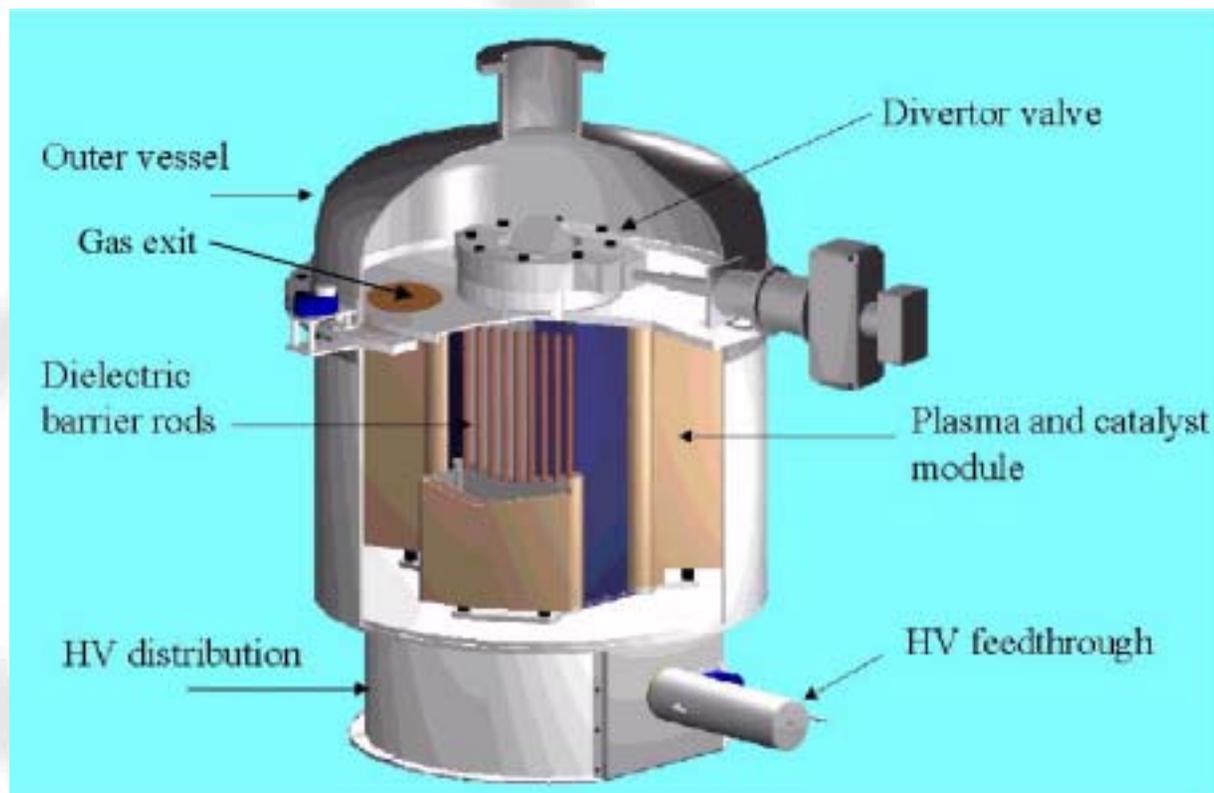
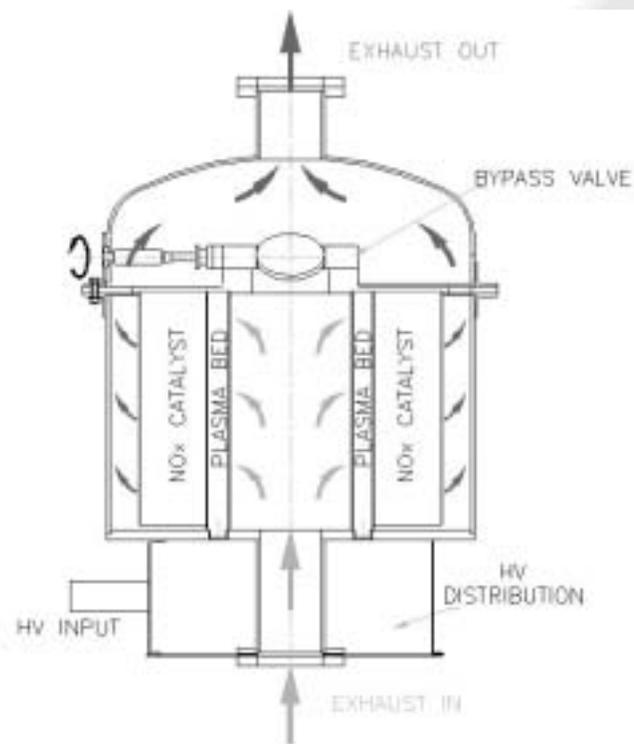
Integrated 1/10th scale system

- Type 23 Frigate gensets
 - 4x Paxman Valenta 1.4 MW
 - exhaust ~ 8200 kg/hr @ rated speed and power
- 1/10th scale system
 - 10kW capability (>5% at 1/10th scale)
- Functional testing before trials
 - power
 - diagnostics
 - EMC (radiated and conducted)



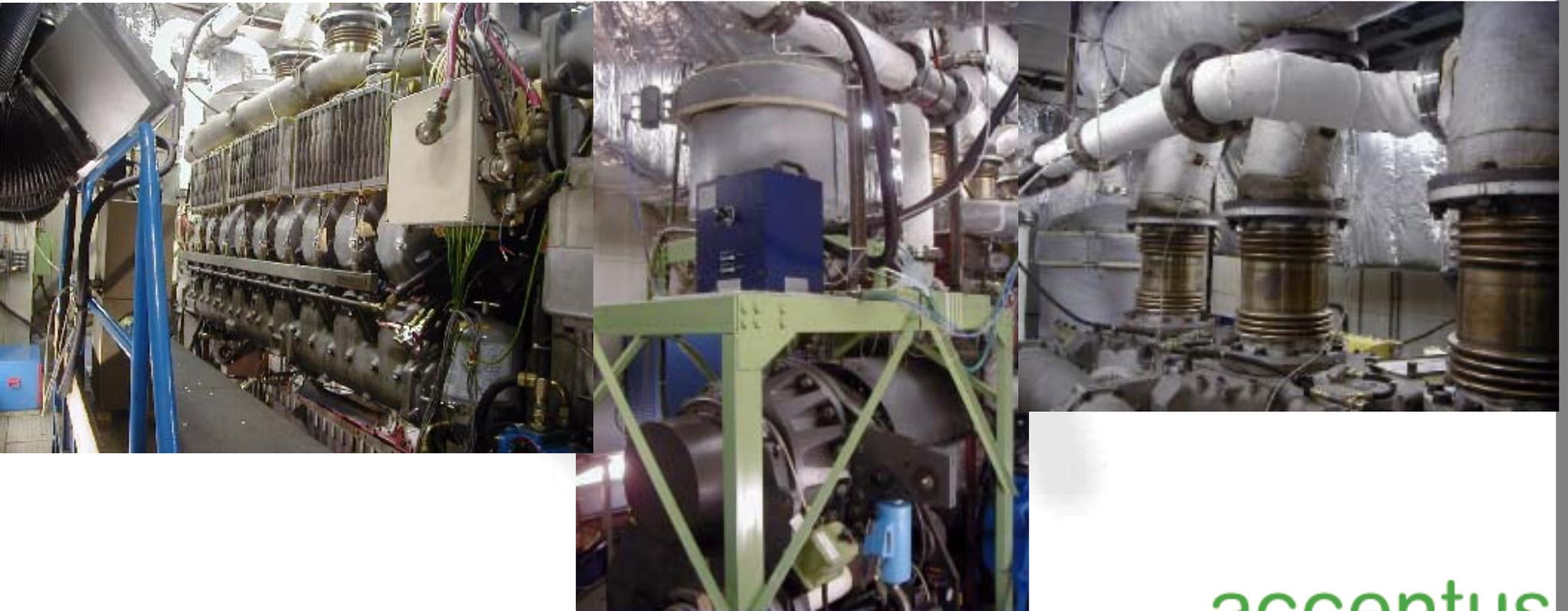
Plasma and catalyst system

- Flow through plasma and catalyst controlled by divertor valve



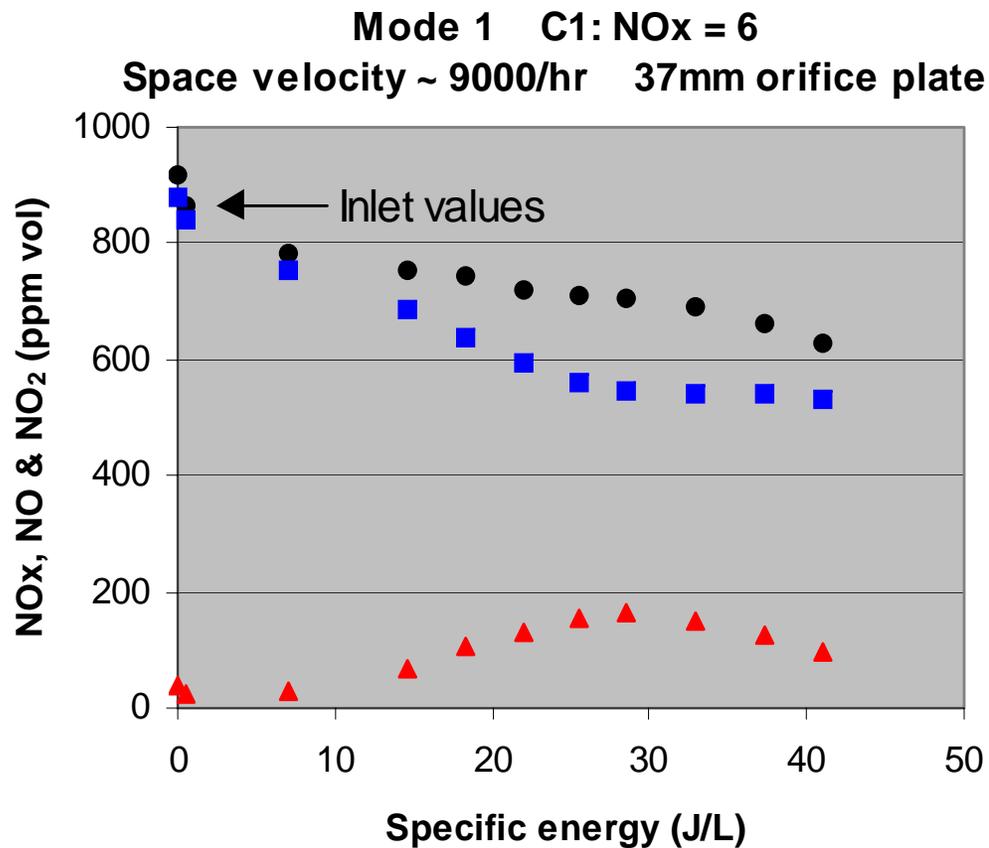
Initial test cell trials

- Carried out at MAN B&W Paxman site, Colchester, Essex
 - Development 18VP185 engine (0.1%S fuel)



Plasma/catalyst performance

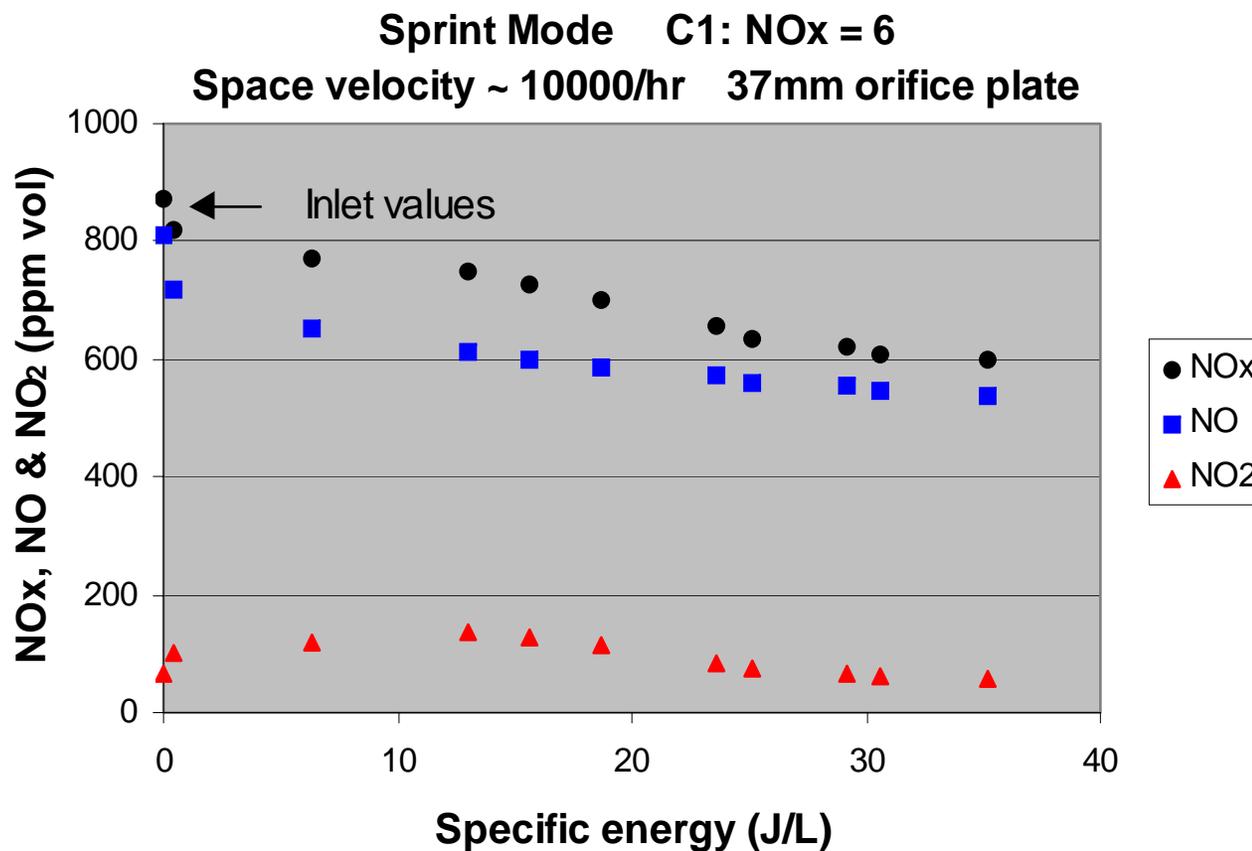
- D2 Cycle Mode 1
 - rated power and speed (3.25MW, 1800 rpm)



Flow ~ 300 m³/hr

Plasma/catalyst performance

- “Sprint Mode”
 - 4MW, 1950 rpm - hotter exhaust gas



Performance enhancement

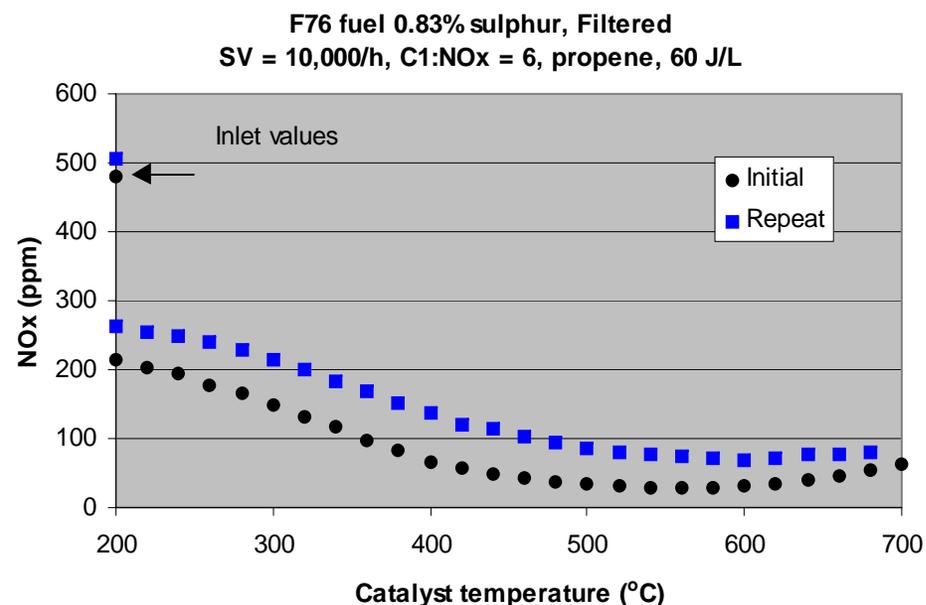
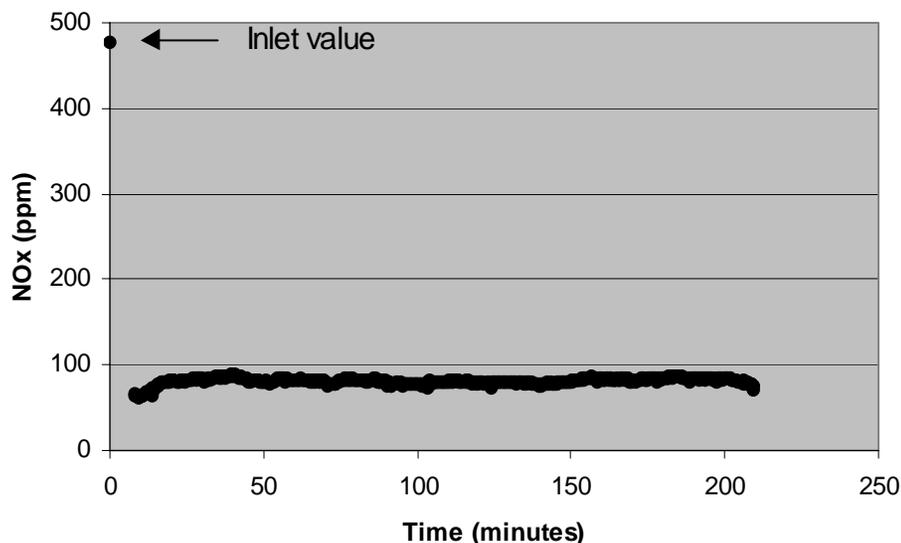
Lab scale vs 1/10th scale

ISSUE	EFFECT	STATUS	COMMENT
Power measurement	Specific energy error	Checked	Power measurement
Flow measurement	Specific energy/space velocity error	Checked	Flow measured independently Catalyst volume varied Flow varied
Catalyst temperature low	Lower NOx reduction	Checked	Temperature measurement in catalyst module
Flow distribution through modules	Lower specific energy/ higher space velocity	Initial check	Use of alternative catalyst modules with simpler, known flow distribution CFD?
Fuel sulphur level	Catalyst poisoning	Being checked	Sulphur measured on used catalyst Catalyst testing at various sulphur levels
Particulate build up in plasma module	Lower hydrocarbon activation	To be checked	Effect on waveforms? Testing at module or system level in air or diesel exhaust without particulates
Particulate build up on catalyst	Catalyst deactivation	To be checked	Carbon measured on used catalyst Testing at module or system level in air or diesel exhaust without particulates

Sulphur tolerance of catalyst

- Used varying sulphur level fuels
 - F76 is Royal Navy fuel specification
 - typically 0.1%S but can be up to 1%S

F76 - 0.12% sulphur fuel, Filtered, Catalyst temp ~ 420 °C,
SV = 10,000/h, C1:NOx = 6, propene, 60 J/l



Ongoing / Future work

- Optimising system performance - ongoing
 - catalyst development and sulphur tolerance
 - identify performance limitations
- Further test cell trials of 1/10th scale system
 - early 2004
- Project **HERCULES** (start early 2004)
 - **H**igh **E**fficiency **R**&**D** on **C**ombustion for **U**ltra-**L**ow **E**missions from **S**hips - diesel engines
 - EU VIth Framework programme-33M €-43 partners
 - Technology showcase