Internal Combustion Engines – MAK 493E

MIXTURE PREPERATION in CI ENGINES

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Mixture Preperation

- Introduction
- Atomization of fuel, sprays
- Fuel systems - in-line systems, distributor systems
- Common-rail systems, unit pump and unit injector systems

Fuel Atomization

In Diesel engines, fuel-air mixture is prepared as a result of fuel injection into the cylinder at the end of compression stroke (usually before TDC) during a limited time (crank angle) interval.

The purpouse of fuel injection is to provide good mixing of air and fuel in the limited time available, by increasing the surface area of the liquid fuel as a result of atomization

Dividing unit fuel volume into droplets of 100×10^{-6} [m] diameter would increase the total surface area by 10,000 times.

Liquid Atomization

Liquid atomization is effected by internal and external forces.

controlled by Reynolds number defining the balance between inertia effects and viscous effects

$$Re = \rho\ u\ D / \mu$$

Atomization at Low Speeds

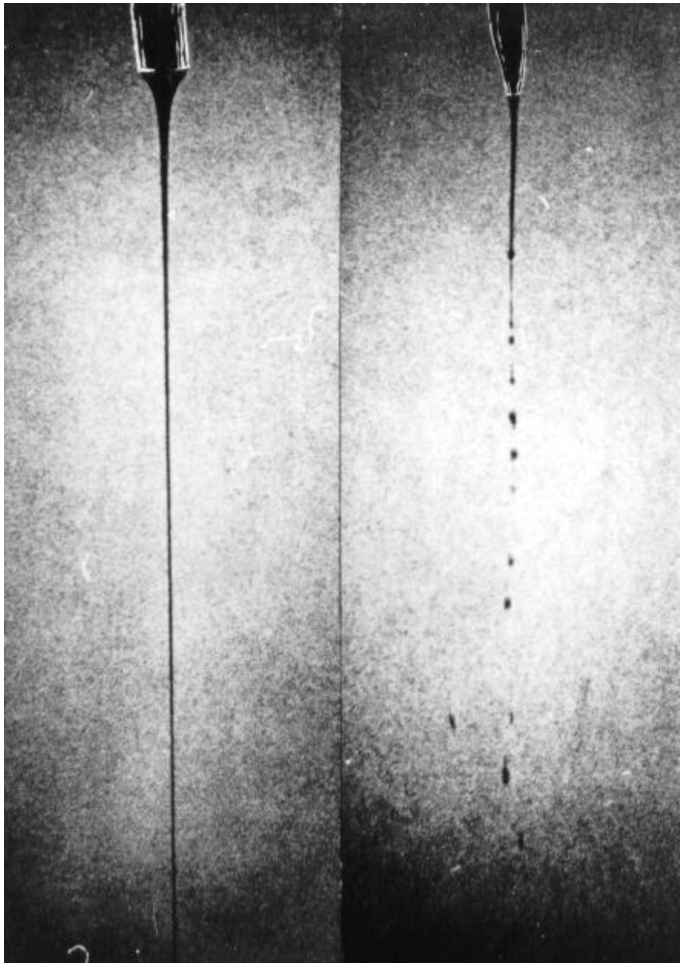
Rayleigh regime : internal effects are dominant

surface tension, fuel density, liquid column diameter

Any disturbance produces break-up of liquid column

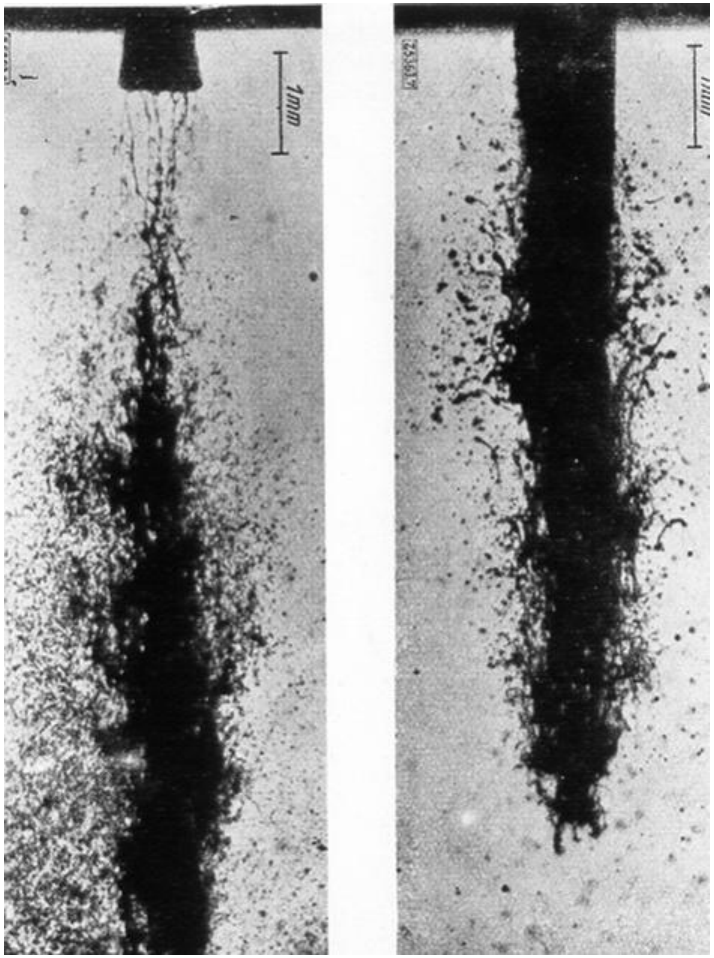
Weber : indicated the importance of viscous effects

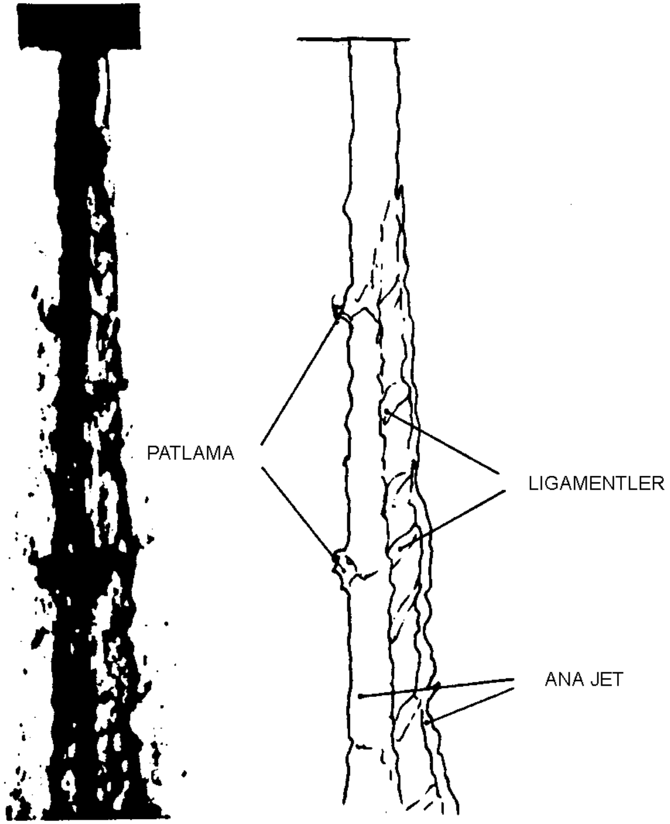
Heavy fuel, (left) 5000 cS
Diesel fuel (right) 6 cS



Atomization at High Speeds

Atomization at High Speeds

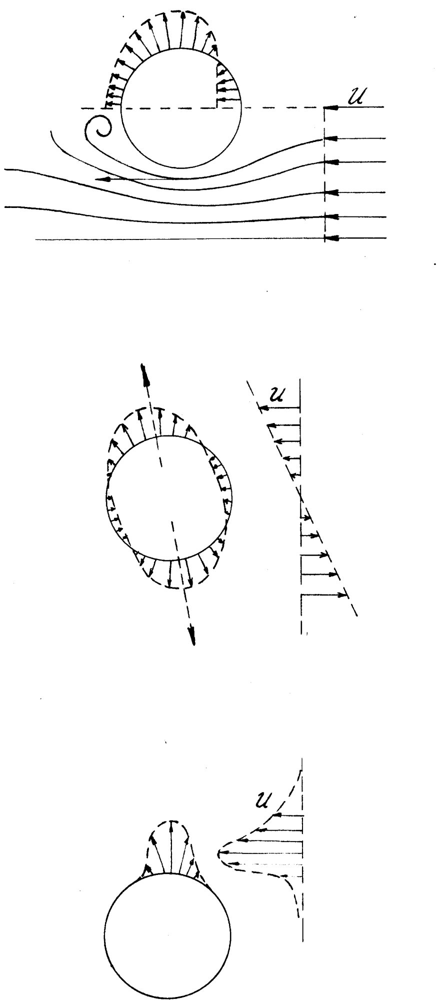




Secondary Atomization

Weber number

$$W_e = \frac{\rho_h u^2 D}{\sigma}$$



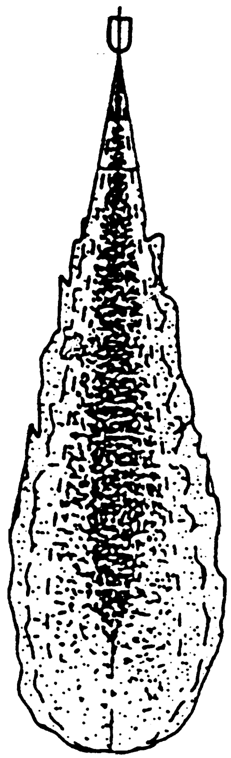
Spray Structure

In difusion flames, combustion is controlled by the mixing rate of the fuel and air.

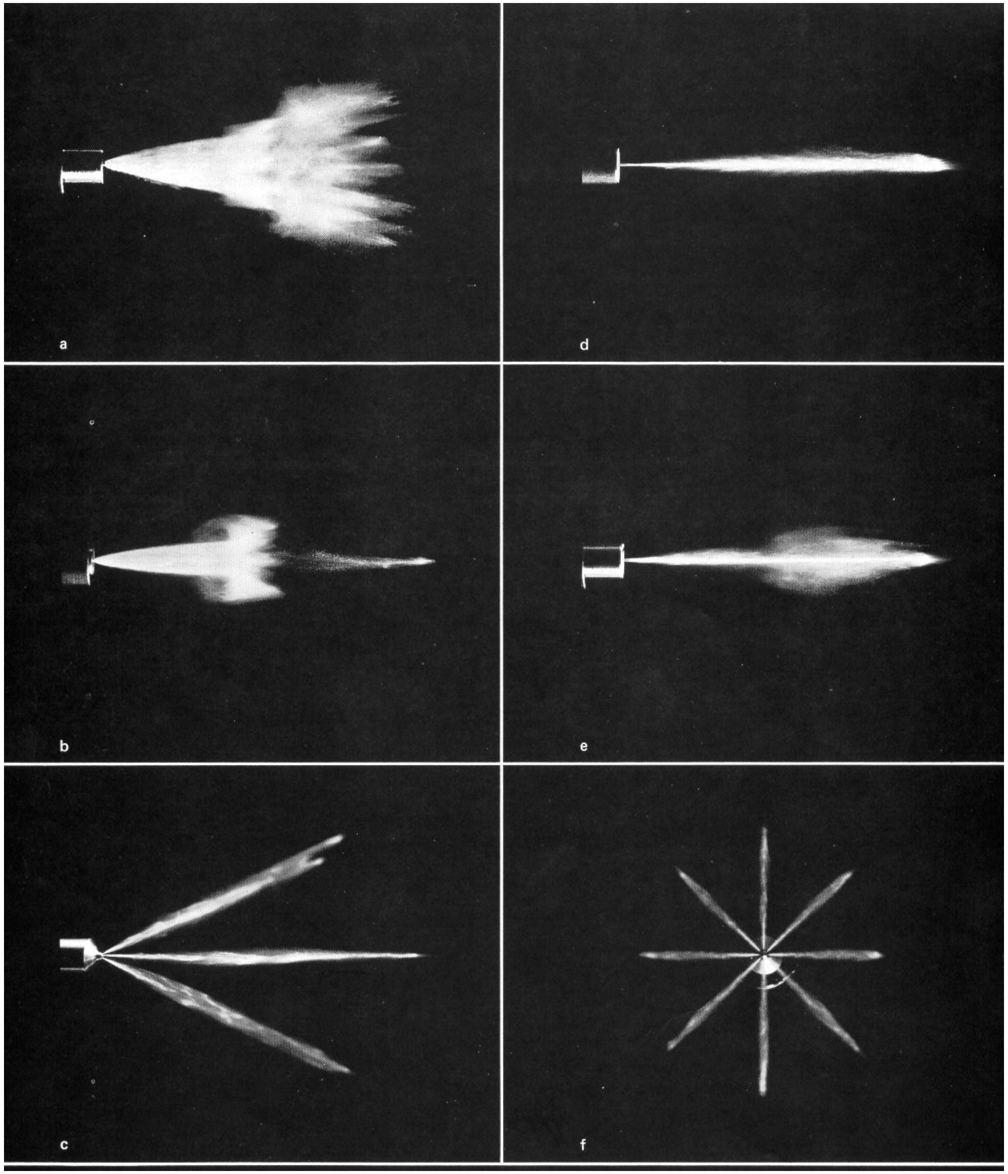
The local conditions in the combustion chamber such as the air-fuel ratio, temperature, pressure control the ignition of the fuel and the combustion process. Heat and mass transfer in the combustion chamber and the fluid flow (air flow) also effects this process.

Spray structure,

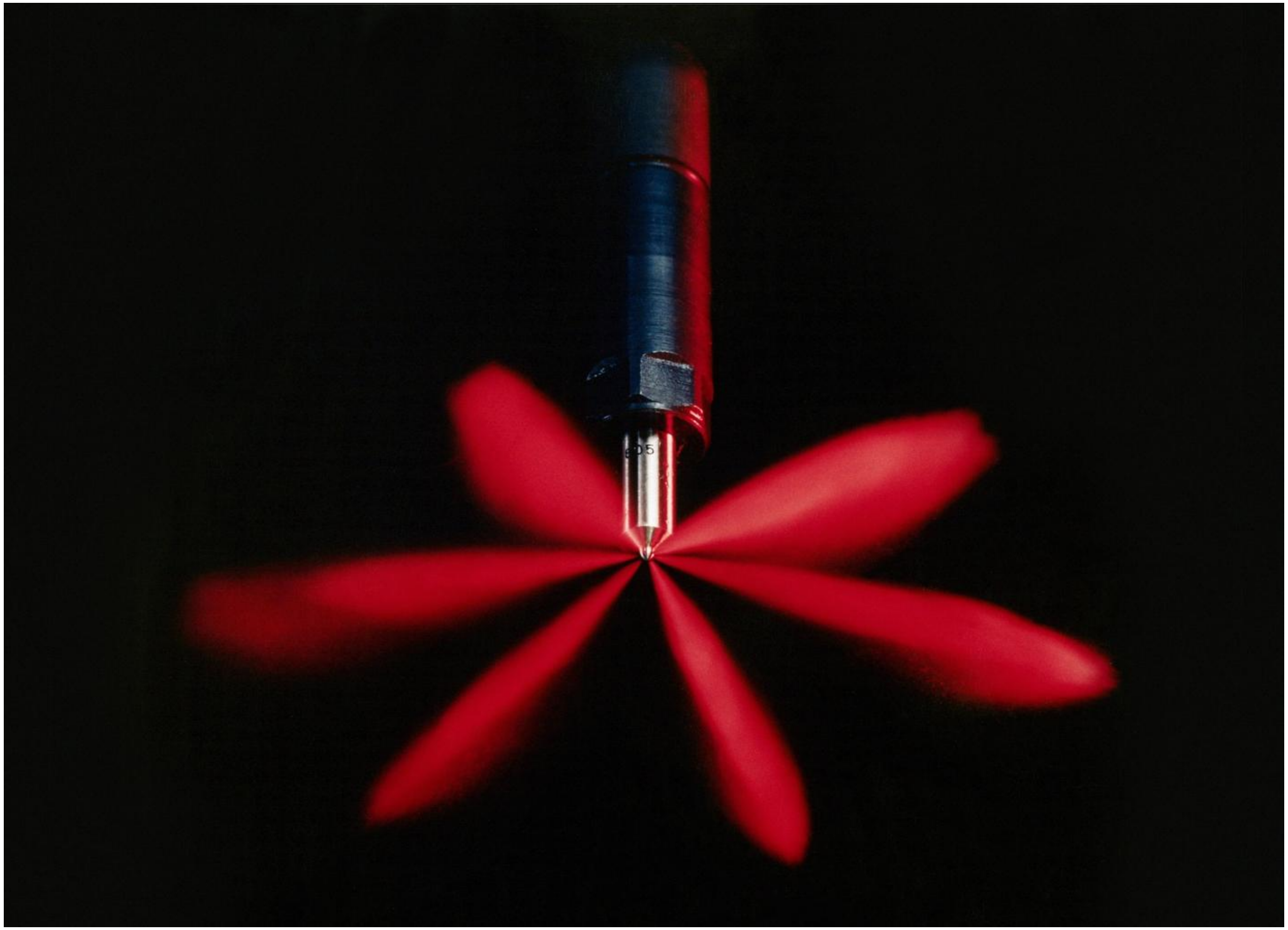
- core
- breakup length
- spray tip penetration



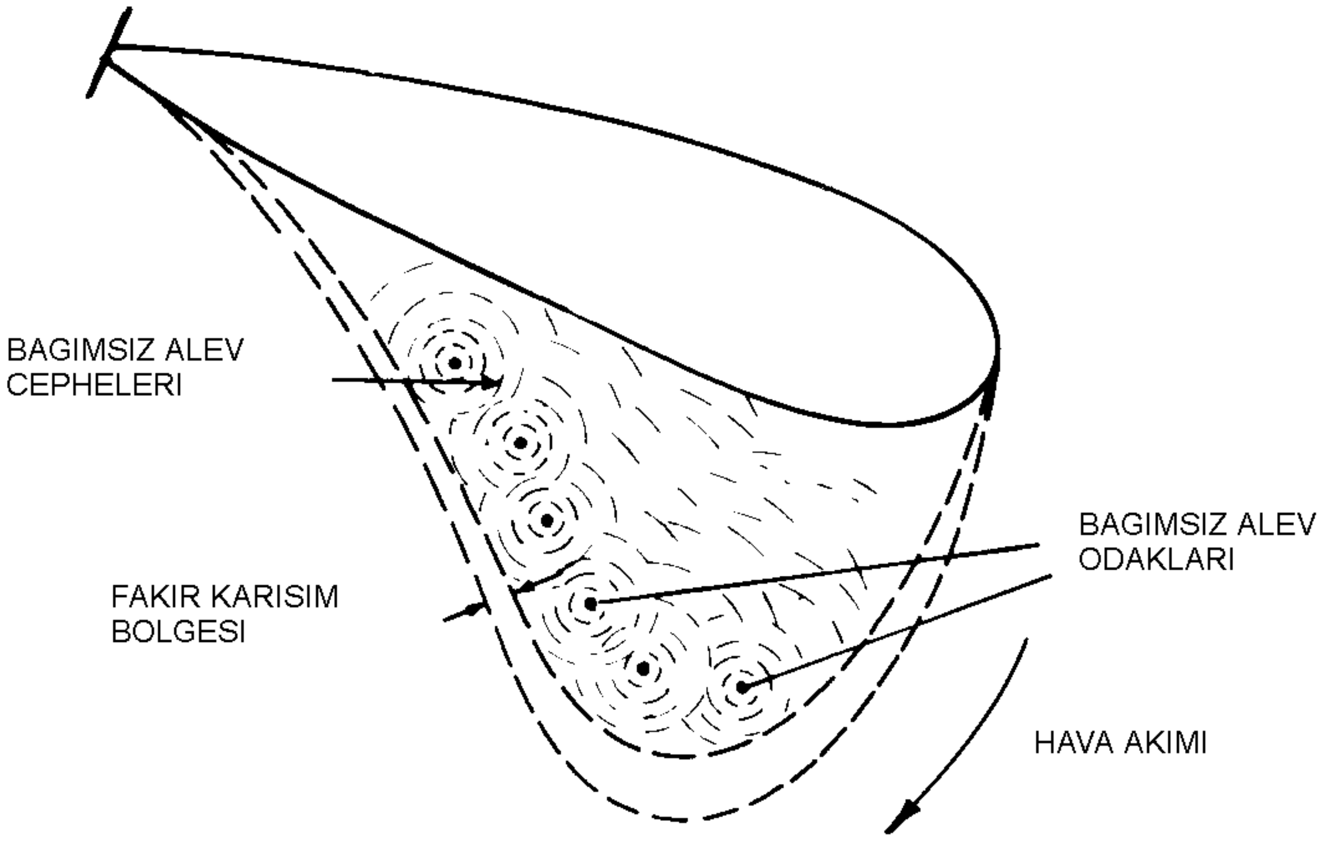
Fuel Sprays



Fuel Sprays

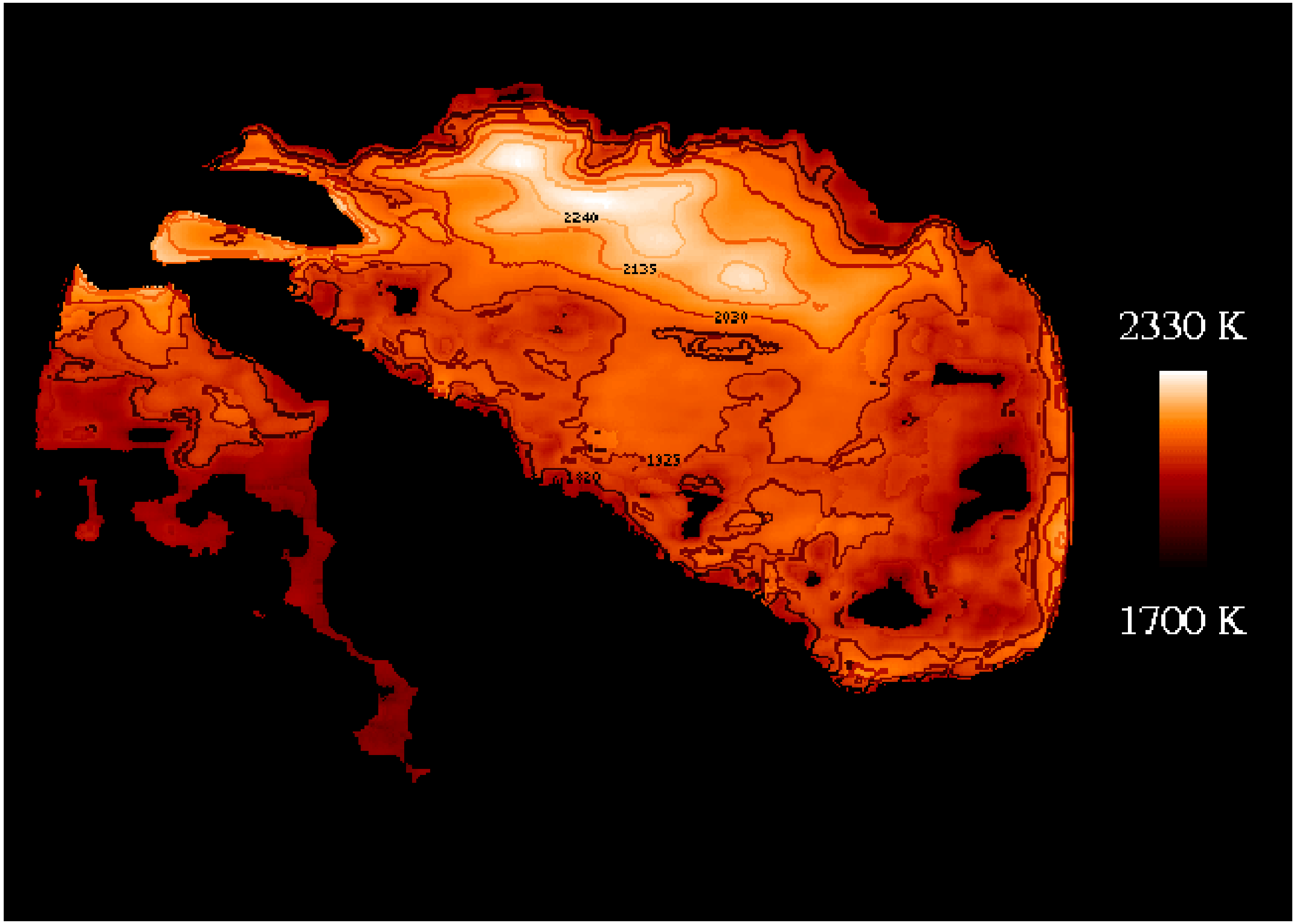


Fuel Sprays



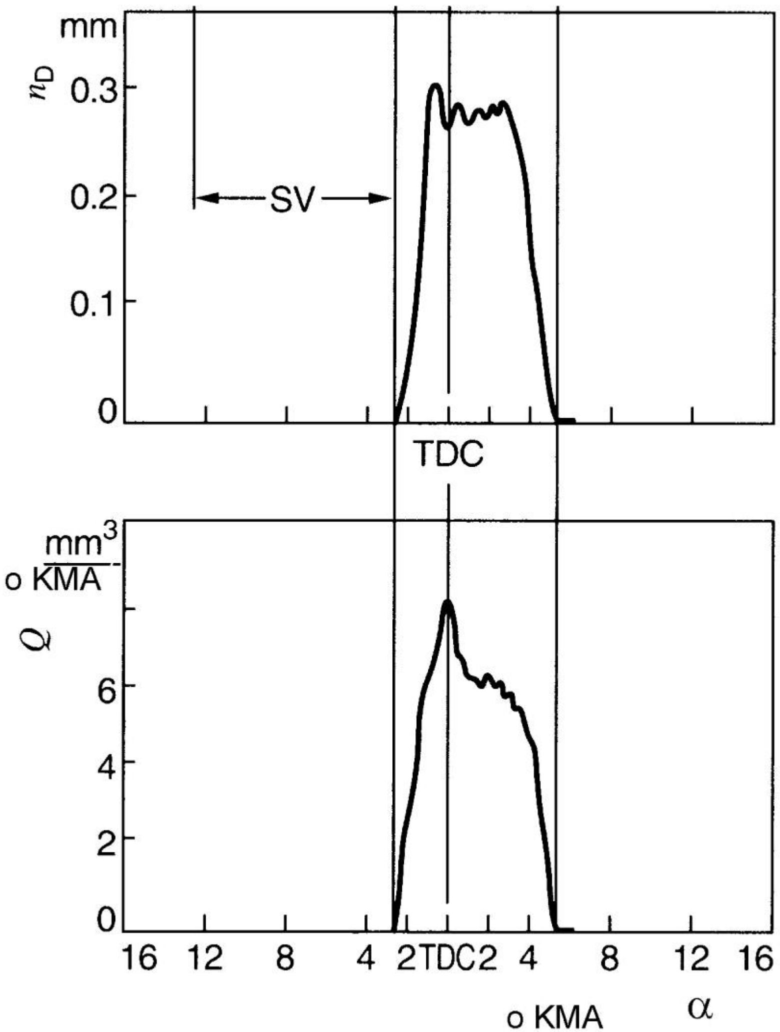
BAGIMSIZ ALEV
CEPHELERI
FAKIR KARISIM
BOLGESI
BAGIMSIZ ALEV
ODAKLARI
HAVA AKIMI

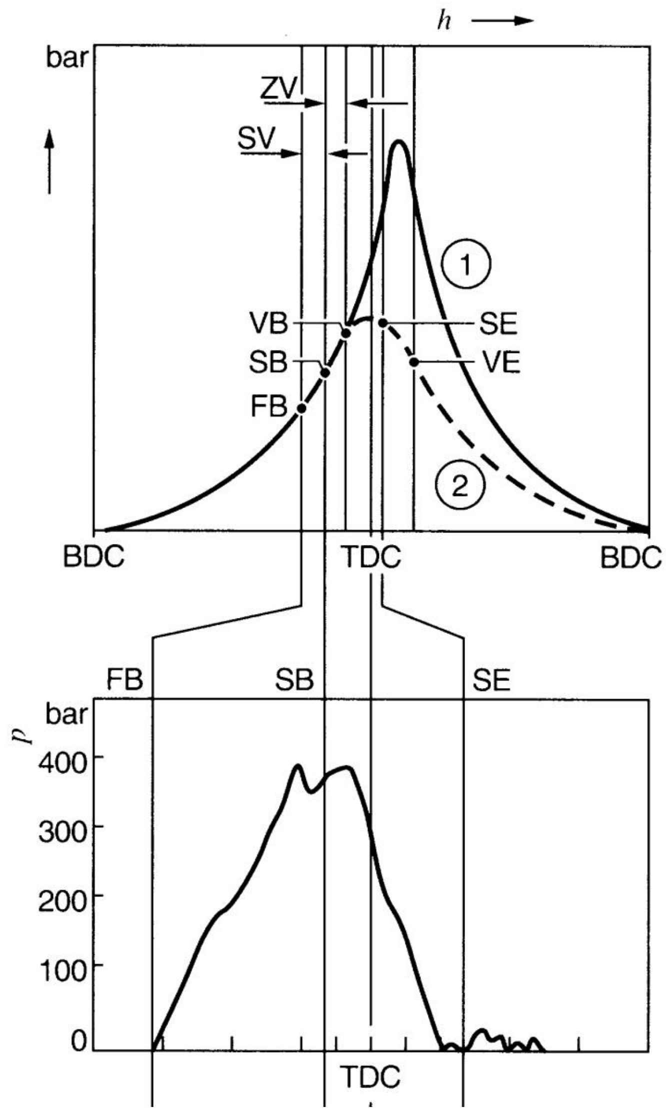
Temperature Contours



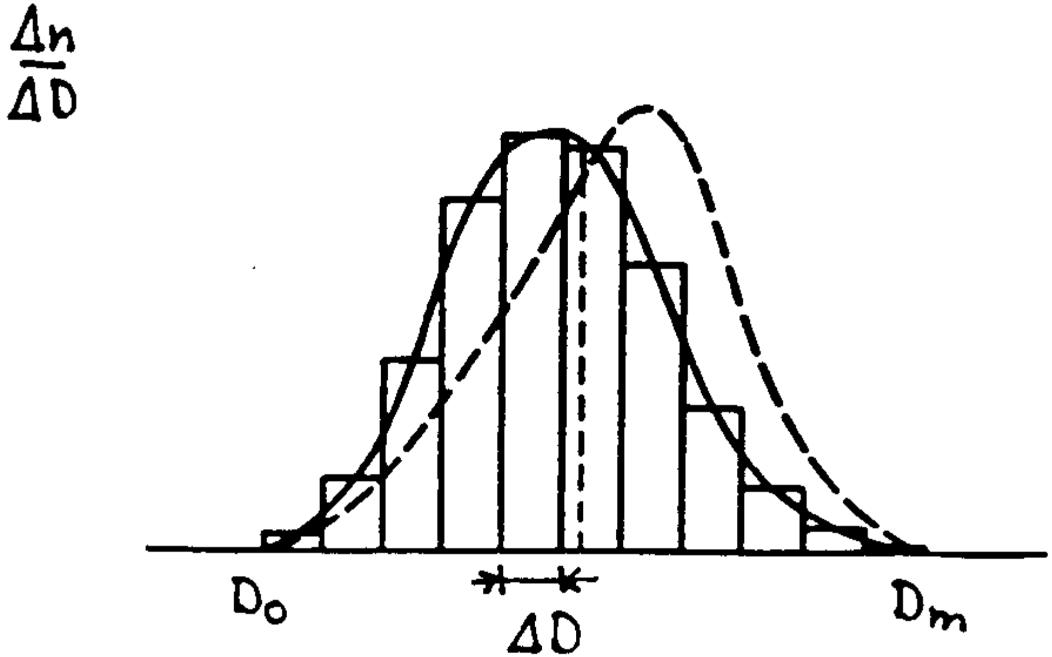
Temperature distribution inside the cylinder

Diesel Combustion Phases

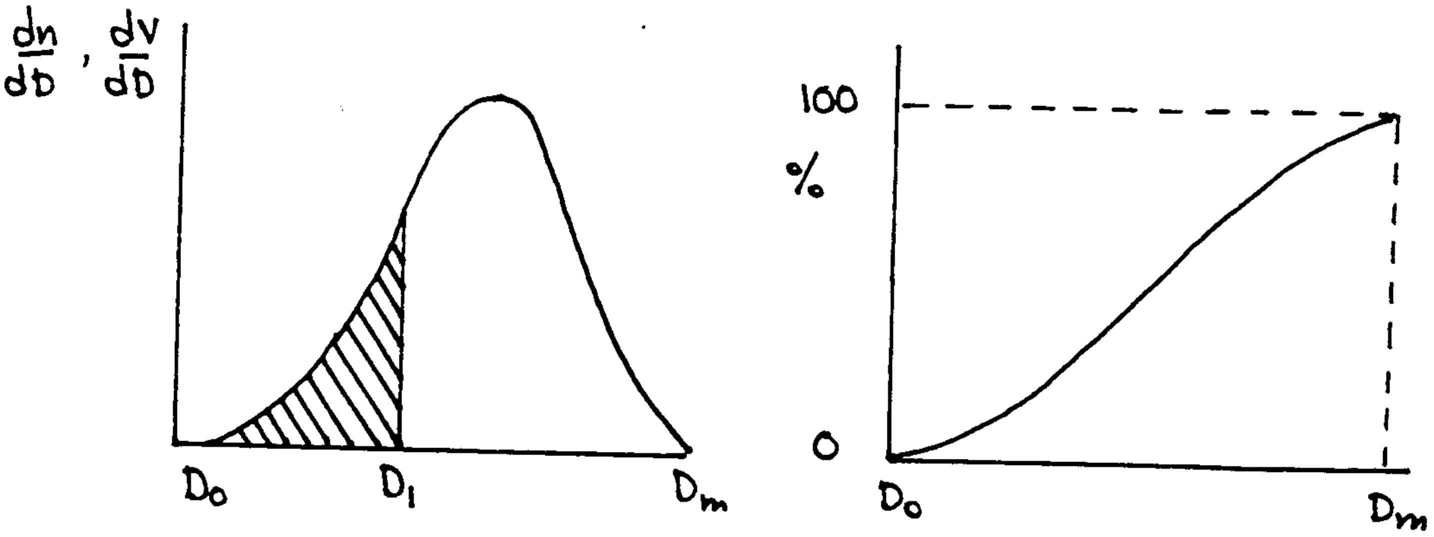




Droplet Size Distribution



Droplet Size Distribution



Sauter Mean Diameter

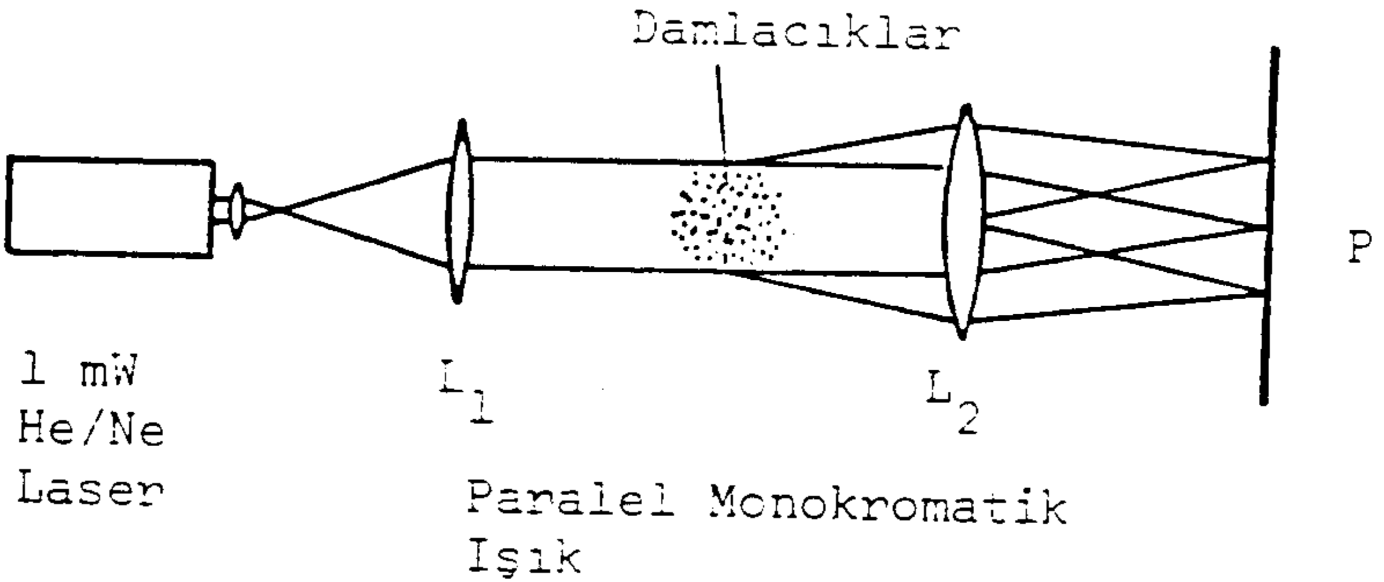
$$D_{qp}^{q-p} = \frac{\int_{D_m}^{D_o} D^q \frac{dn}{dD} dD}{\int_{D_m}^{D_o} D^p \frac{dn}{dD} dD} = \frac{\int_{D_m}^{D_o} D^{q-3} \frac{dV}{dD} dD}{\int_{D_m}^{D_o} D^{p-3} \frac{dV}{dD} dD}$$

p = 2 and q = 3 : Sauter Mean Diameter

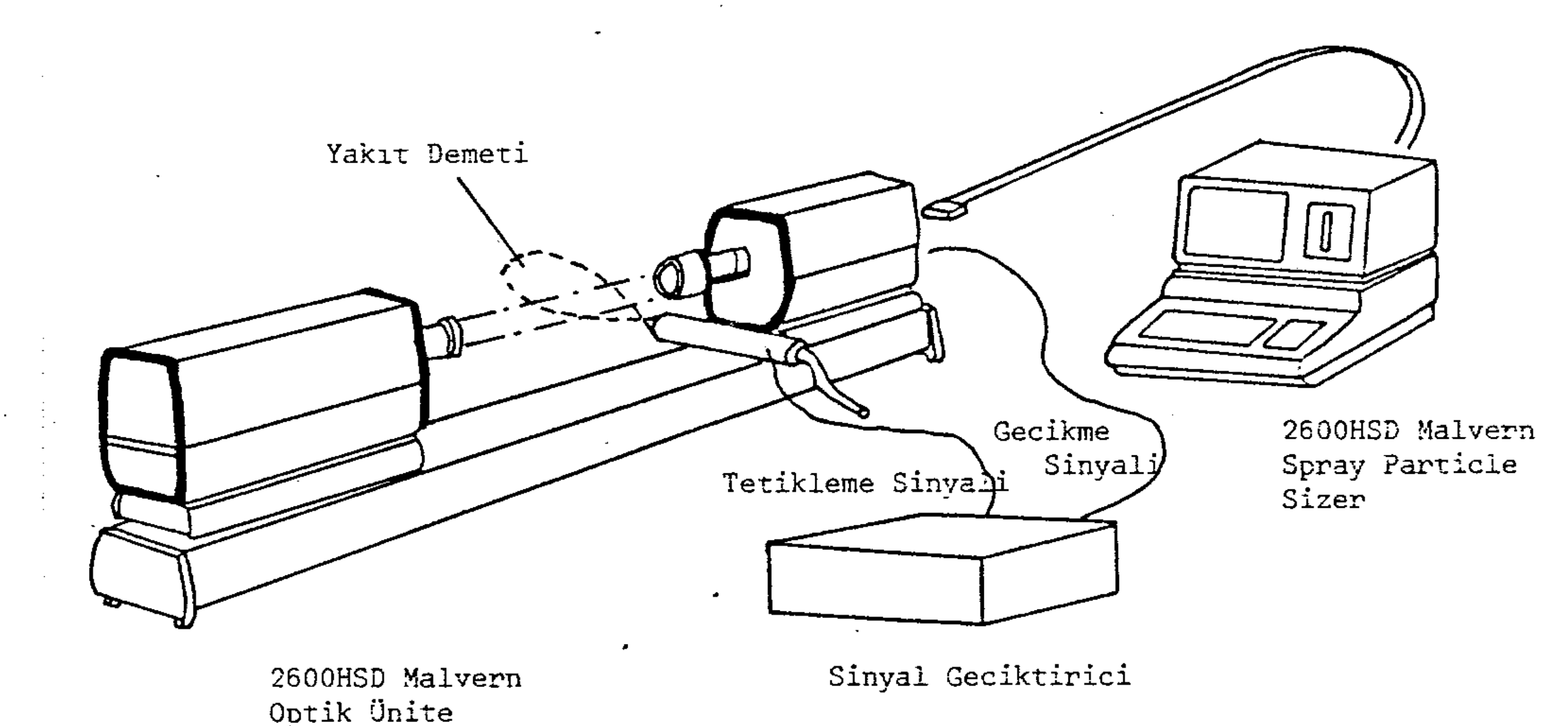
indicates the total Area-to-Volume ratio applicable for the whole spray

$$D_{32} = \frac{\sum D_i^3 n_i}{\sum D_i^2 n_i}$$

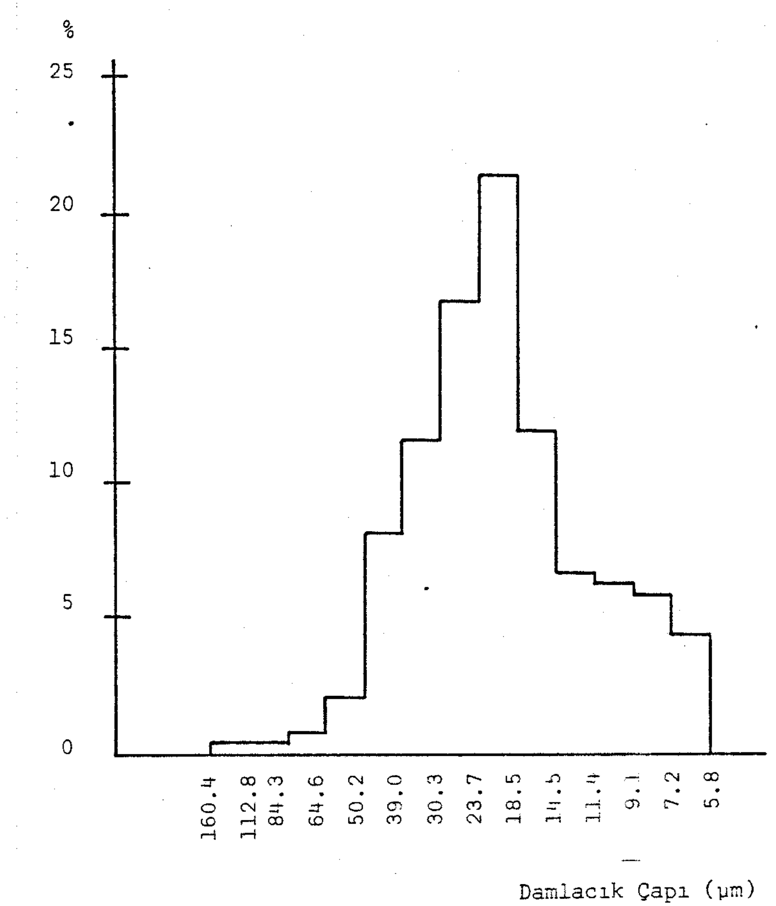
Droplet Size Measurements



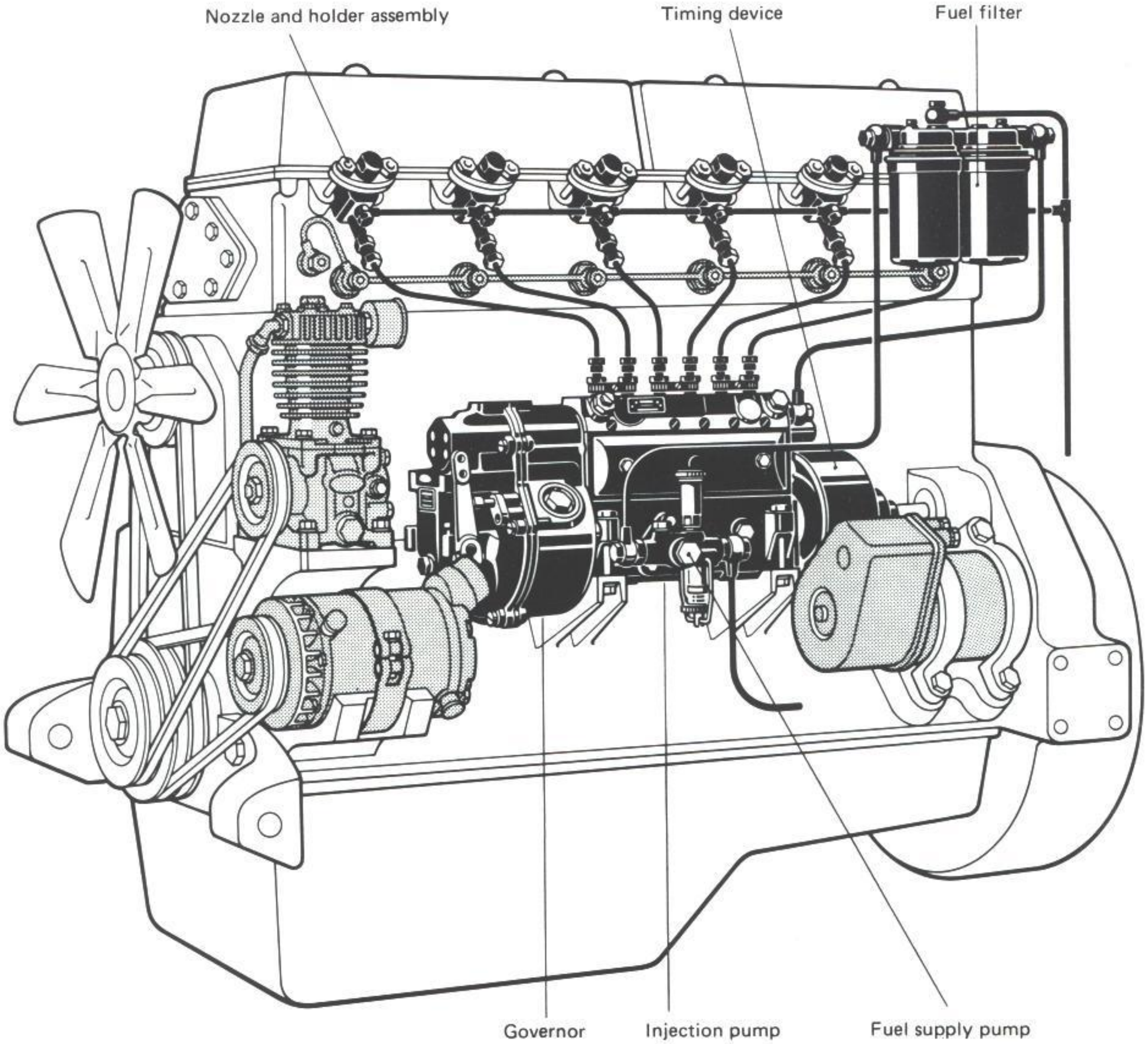
Droplet Size Measurements



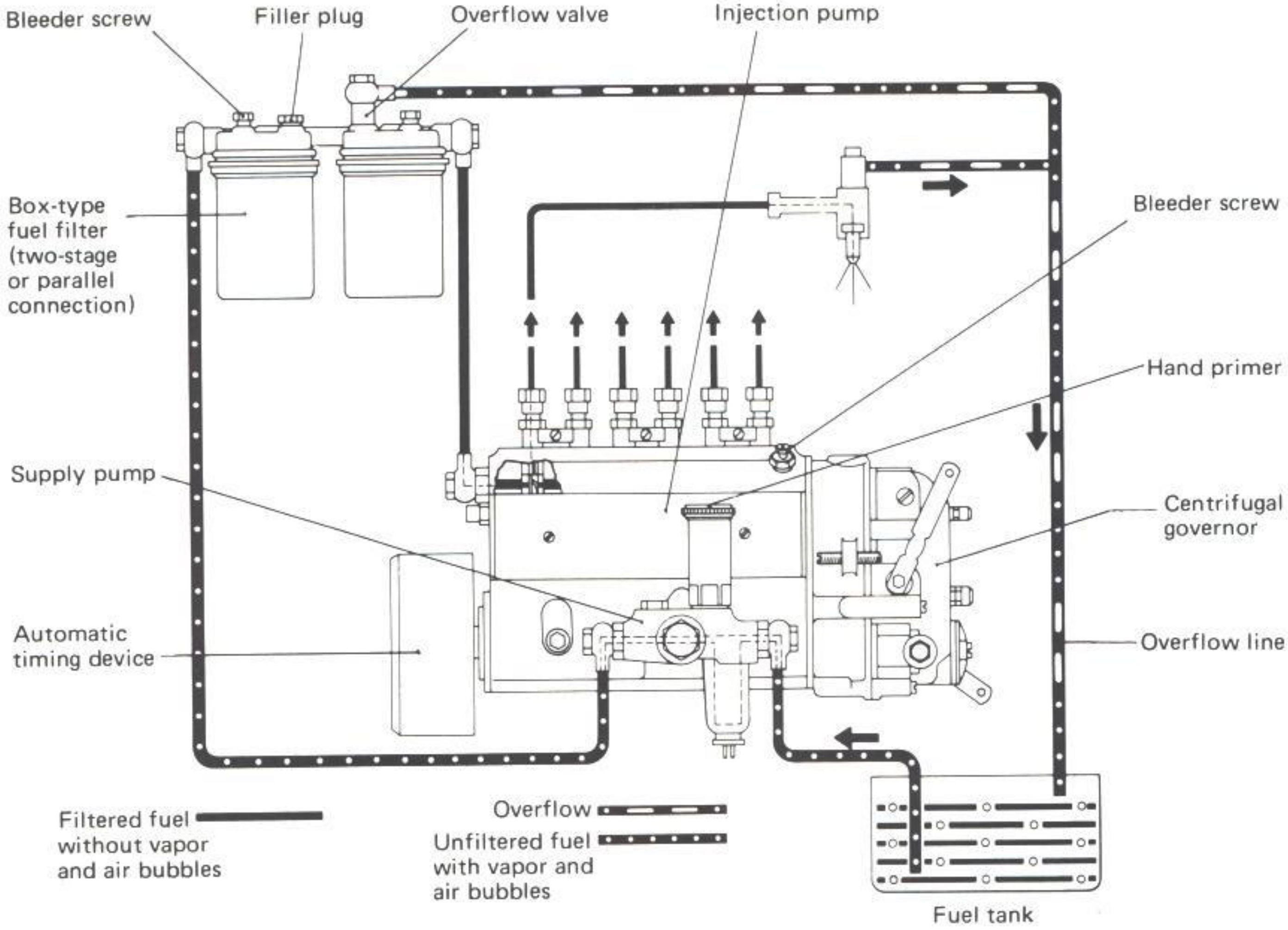
Droplet Size Measurements



Diesel Engines

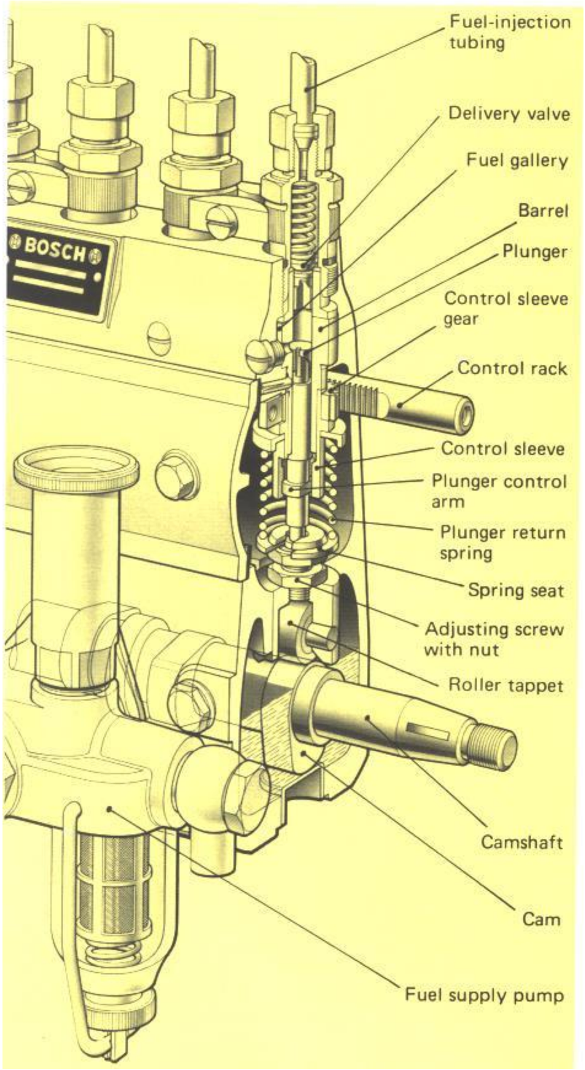


Fuel system

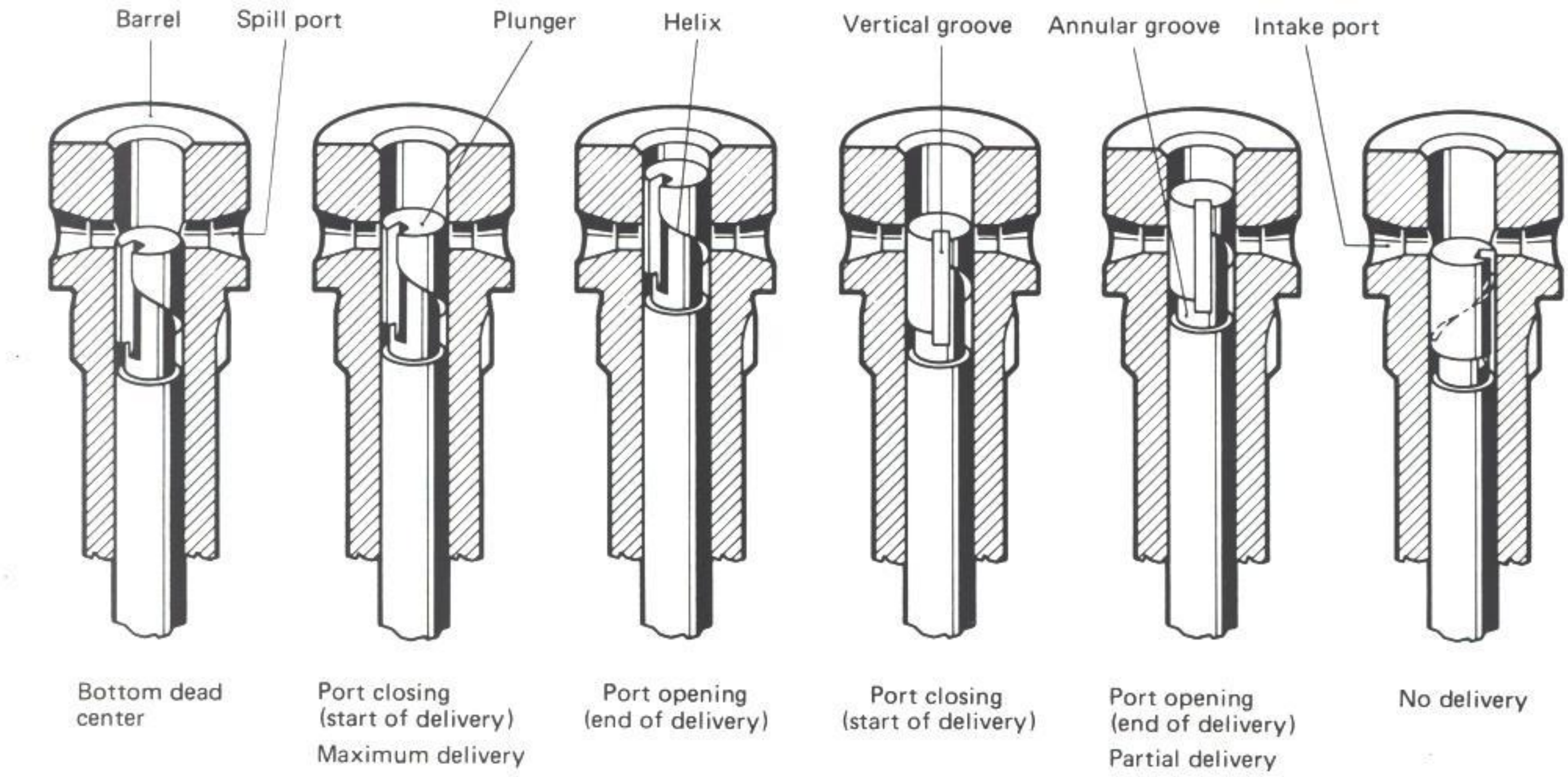


Bleeder screw
Filler plug
Overflow valve
Injection pump
Box-type fuel filter (two-stage or parallel connection)
Bleeder screw
Hand primer
Supply pump
Centrifugal governor
Automatic timing device
Overflow line
Filtered fuel without vapor and air bubbles
Overflow
Unfiltered fuel with vapor and air bubbles
Fuel tank

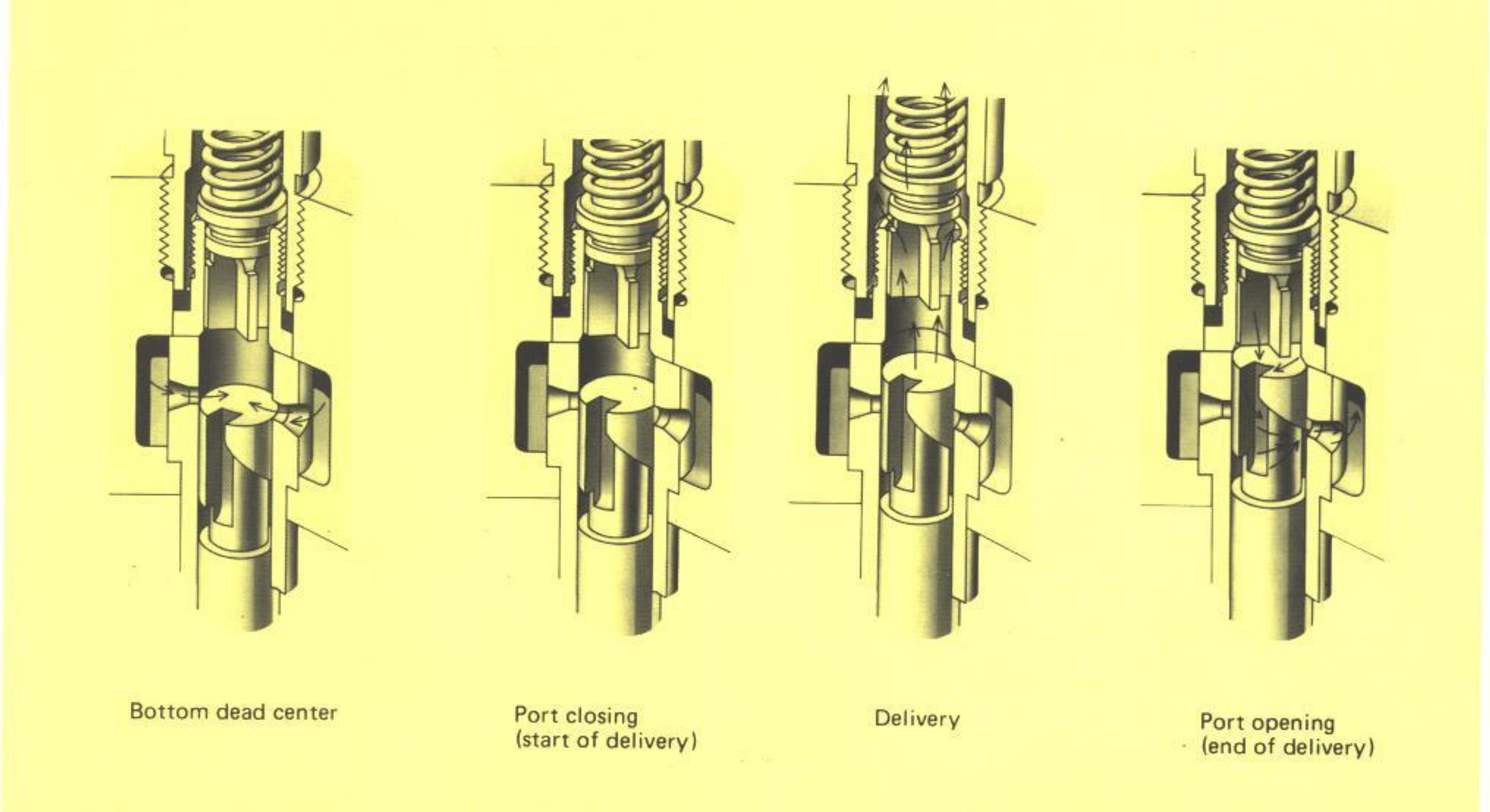
Injection Pump – in line system



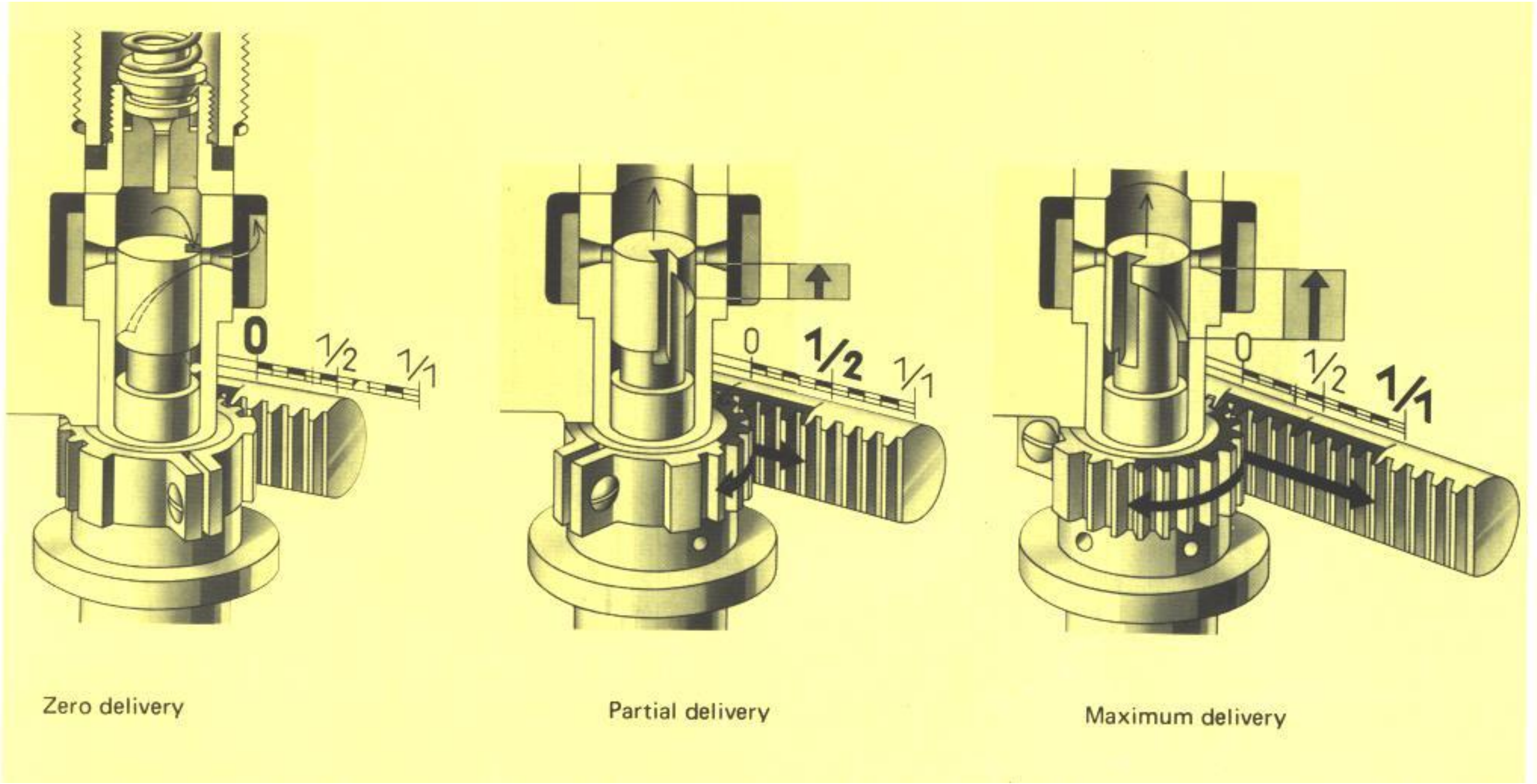
Injection Pump



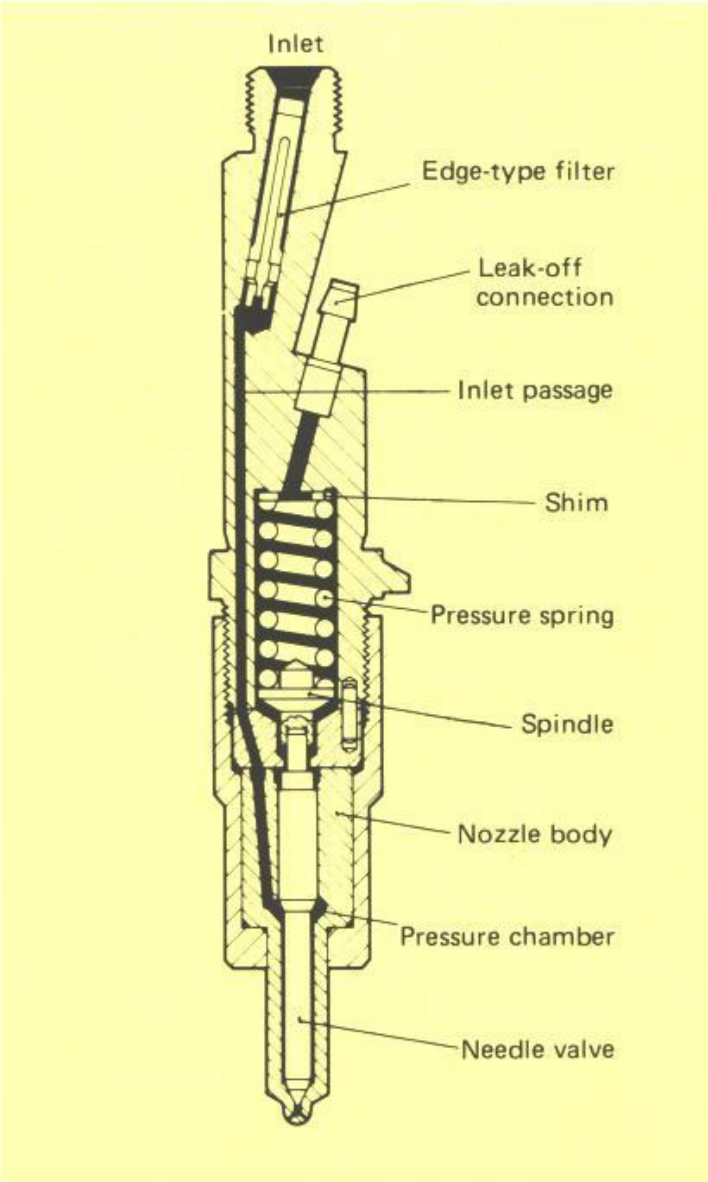
Injection Pump



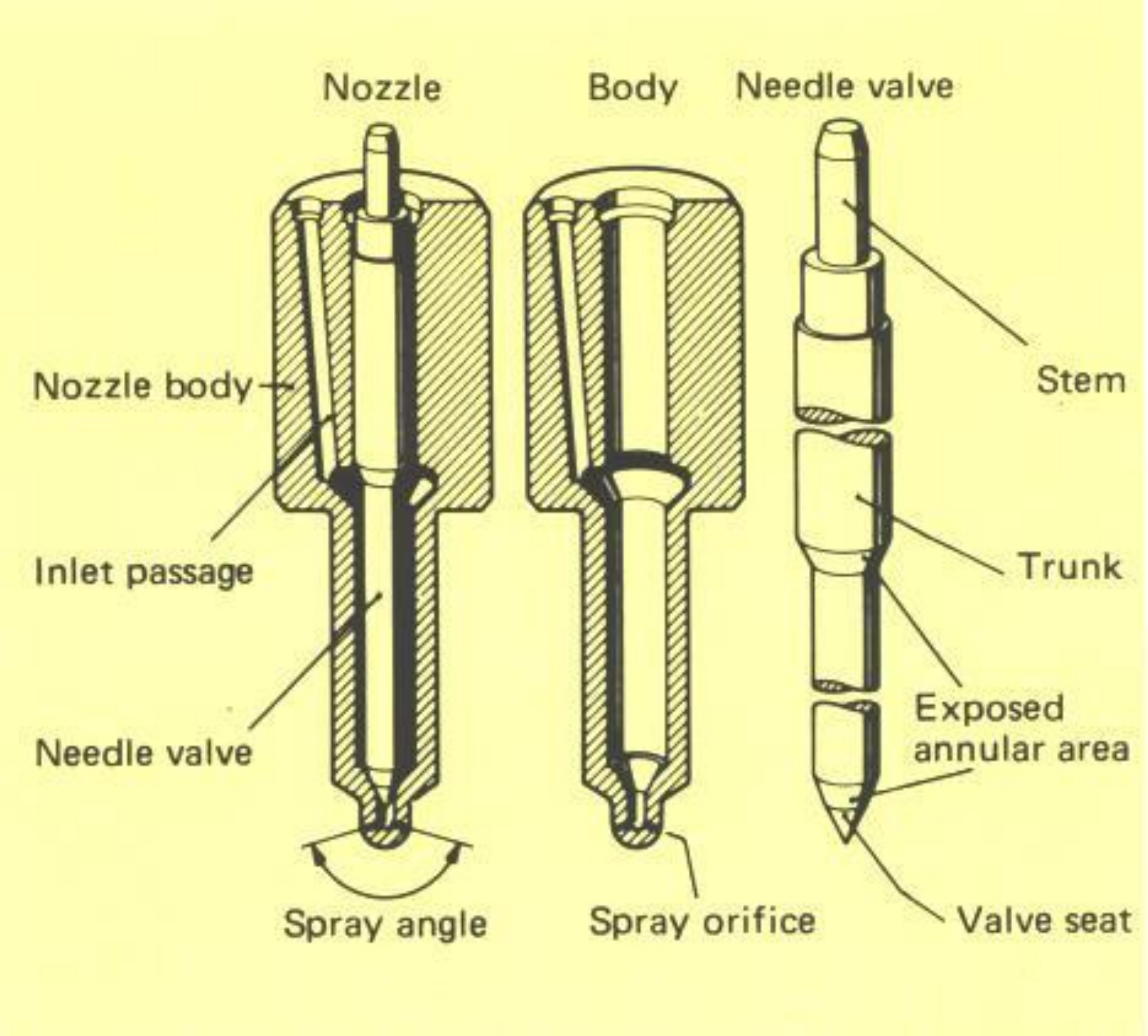
Injection Pump – fuel metering



Injector


Inlet
Edge-type filter
Leak-off
connection
Inlet passage
Shim
Pressure spring
Spindle
Nozzle body
Pressure chamber
Needle valve

Injector



Nozzle
Body
Needle valve
Nozzle body
Inlet passage
Needle valve
Stem
Trunk
Exposed
annular area
Spray angle
Spray orifice
Valve seat

Nozzles

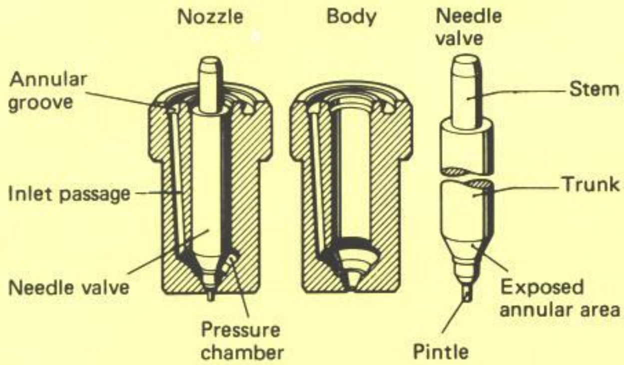


Fig. 48 Pintle nozzle

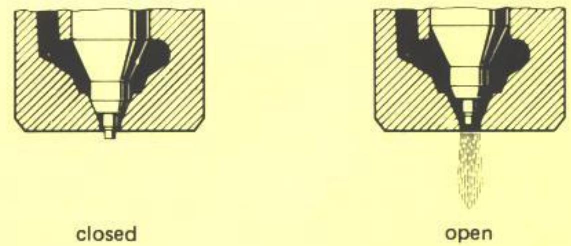


Fig. 50 Pintle nozzle (DN..), with cylindrical pintle (narrow spray)

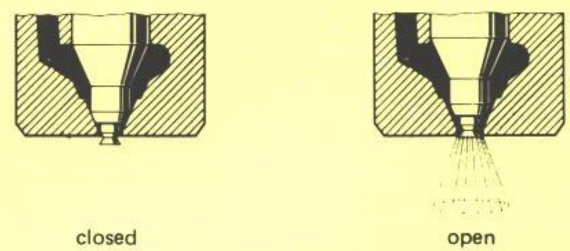
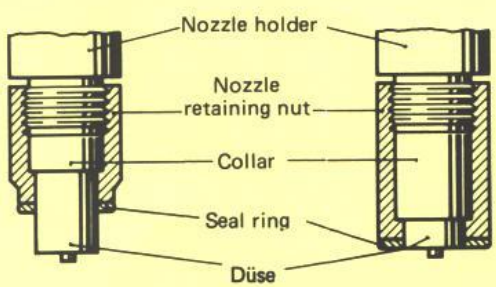
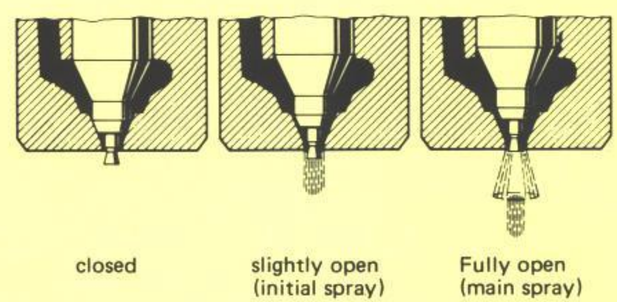


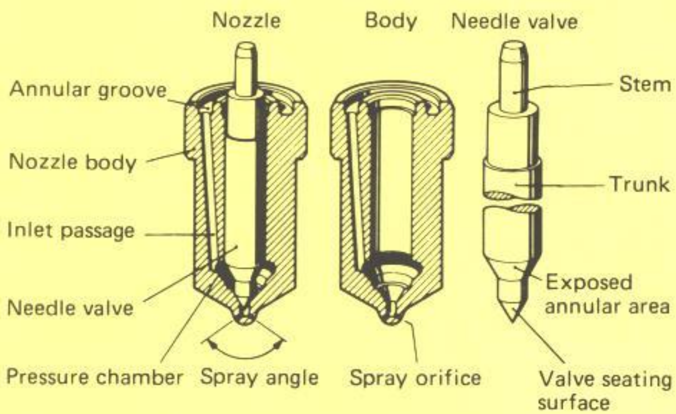
Fig. 51 Pintle nozzle (DN..), with conical pintle (wide spray)

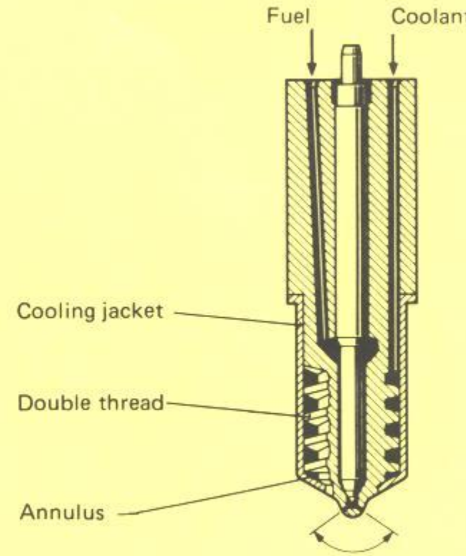


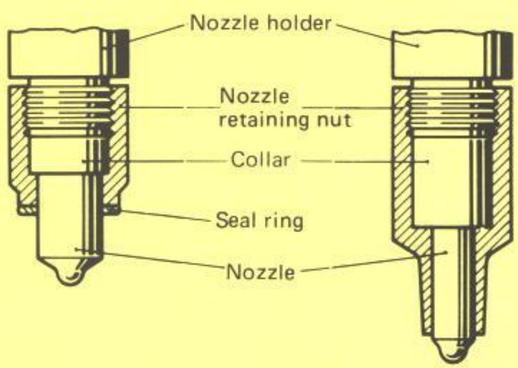
Standard pintle nozzle Roller-type nozzle

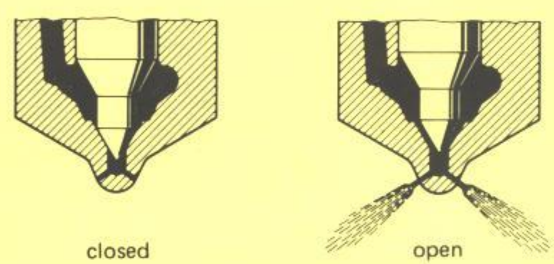


Nozzles

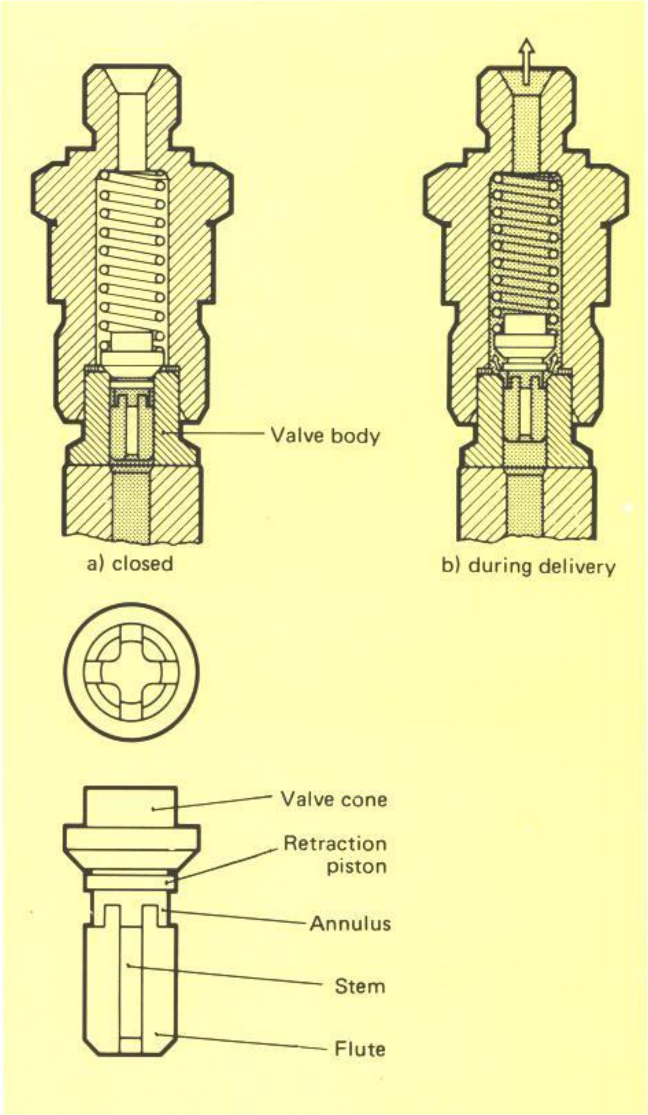

Nozzle
Body
Needle valve
Annular groove
Nozzle body
Inlet passage
Needle valve
Pressure chamber
Spray angle
Spray orifice
Stem
Trunk
Exposed annular area
Valve seating surface


Fuel
Coolant
Cooling jacket
Double thread
Annulus

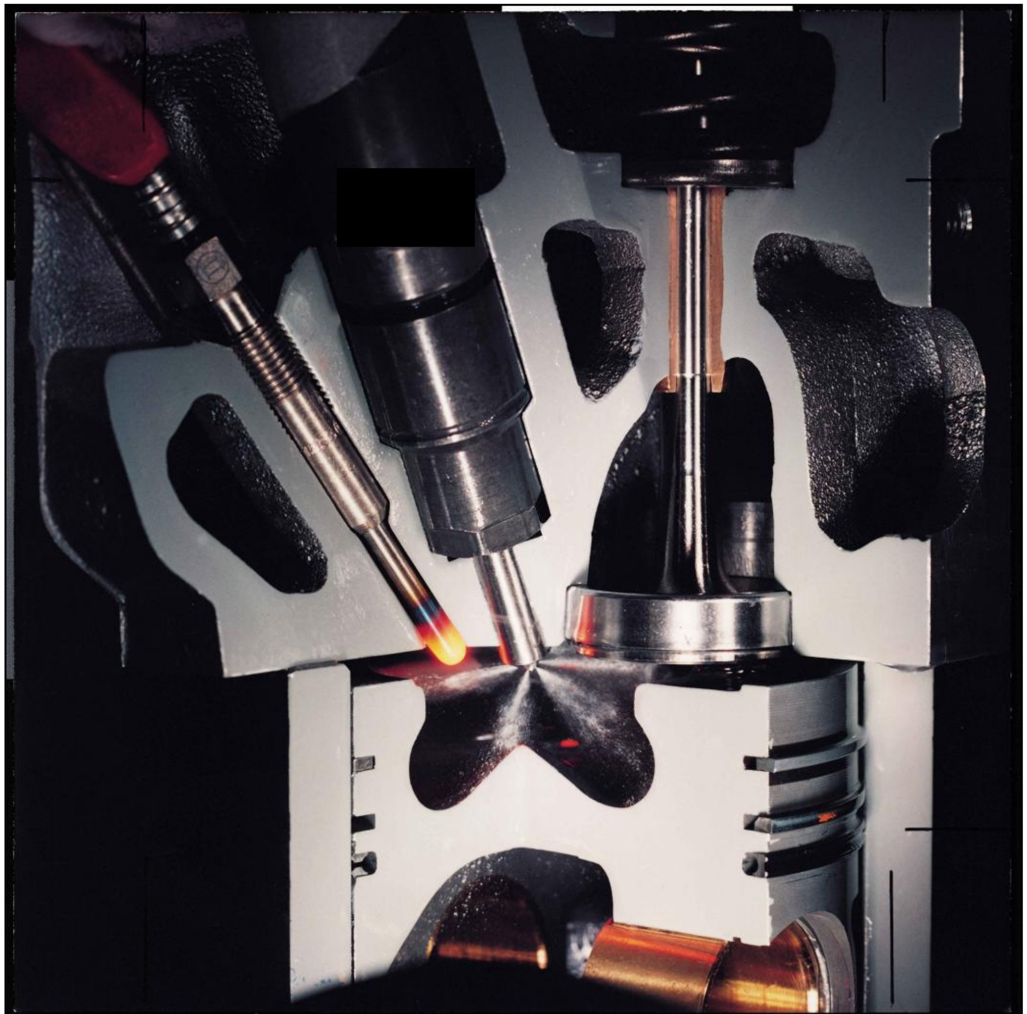

Nozzle holder
Nozzle retaining nut
Collar
Seal ring
Nozzle


closed
open

Delivery Valve

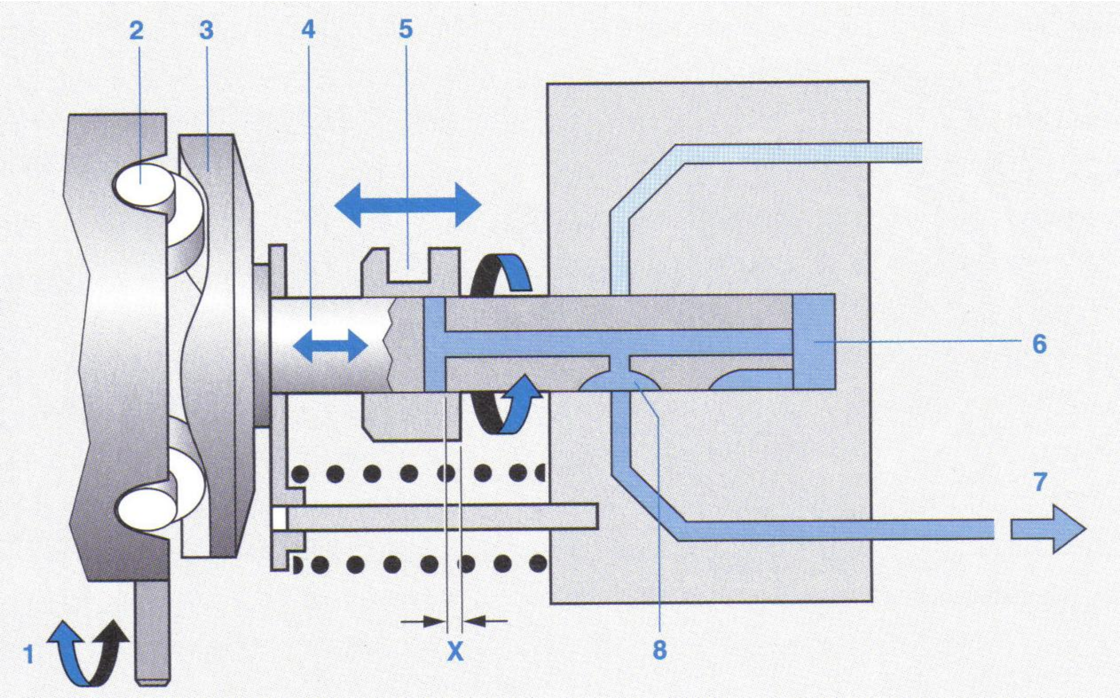


Direct Injection Diesel Engine



Indirect Injection Diesel Engine

Distributor-Type Injection Pump

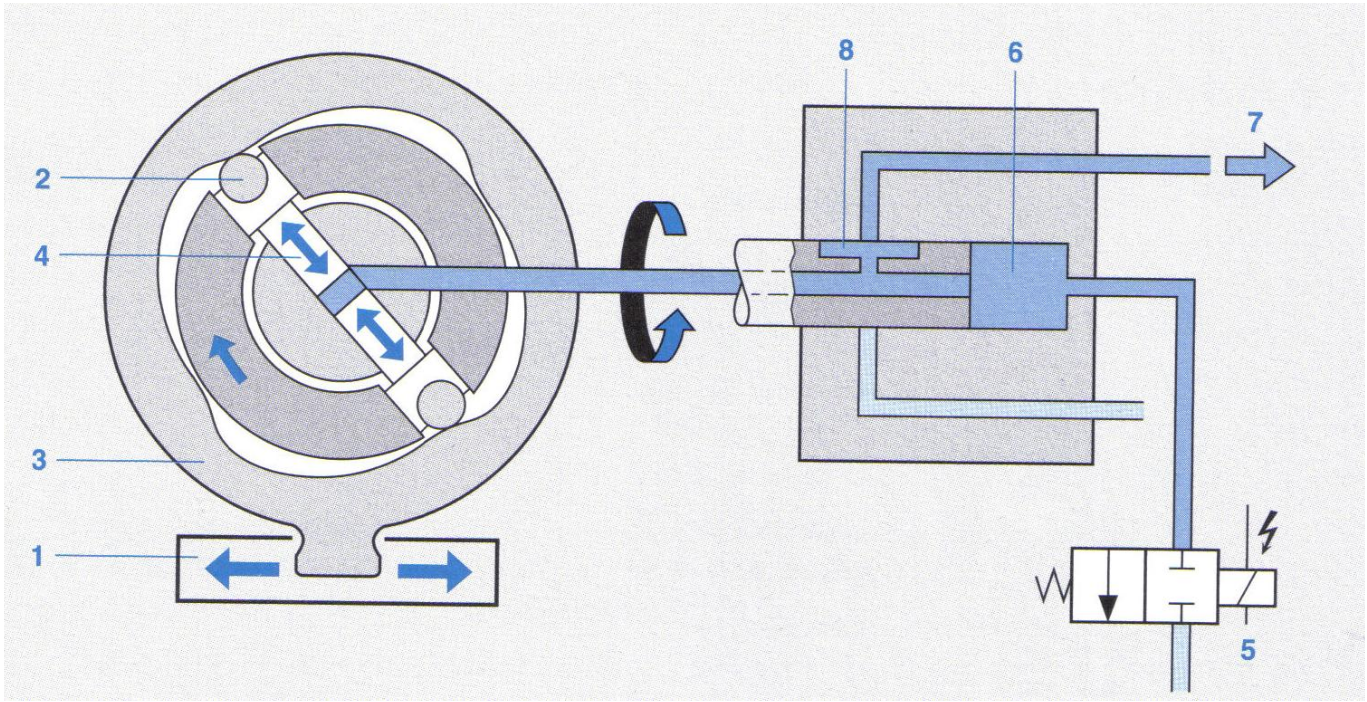


1. Injection Timing Adjustement
2. Roller
3. Cam Plate
4. Axial Piston
5. Control Sleeve
6. High-Pressure Chamber
7. Fuel Outflow to Nozzle
8. Leak-Off

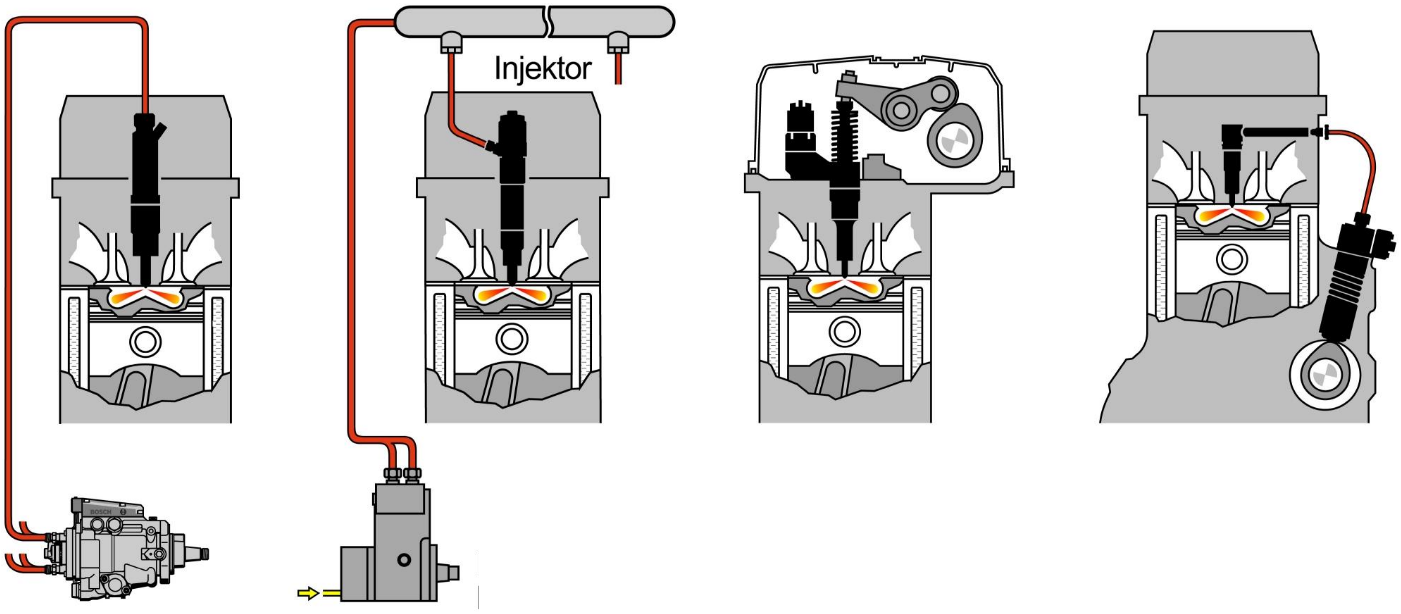
x. Effective Stroke

Yıldız pompa
Distribütör tipi pompa

Distributor-Type Injection Pump

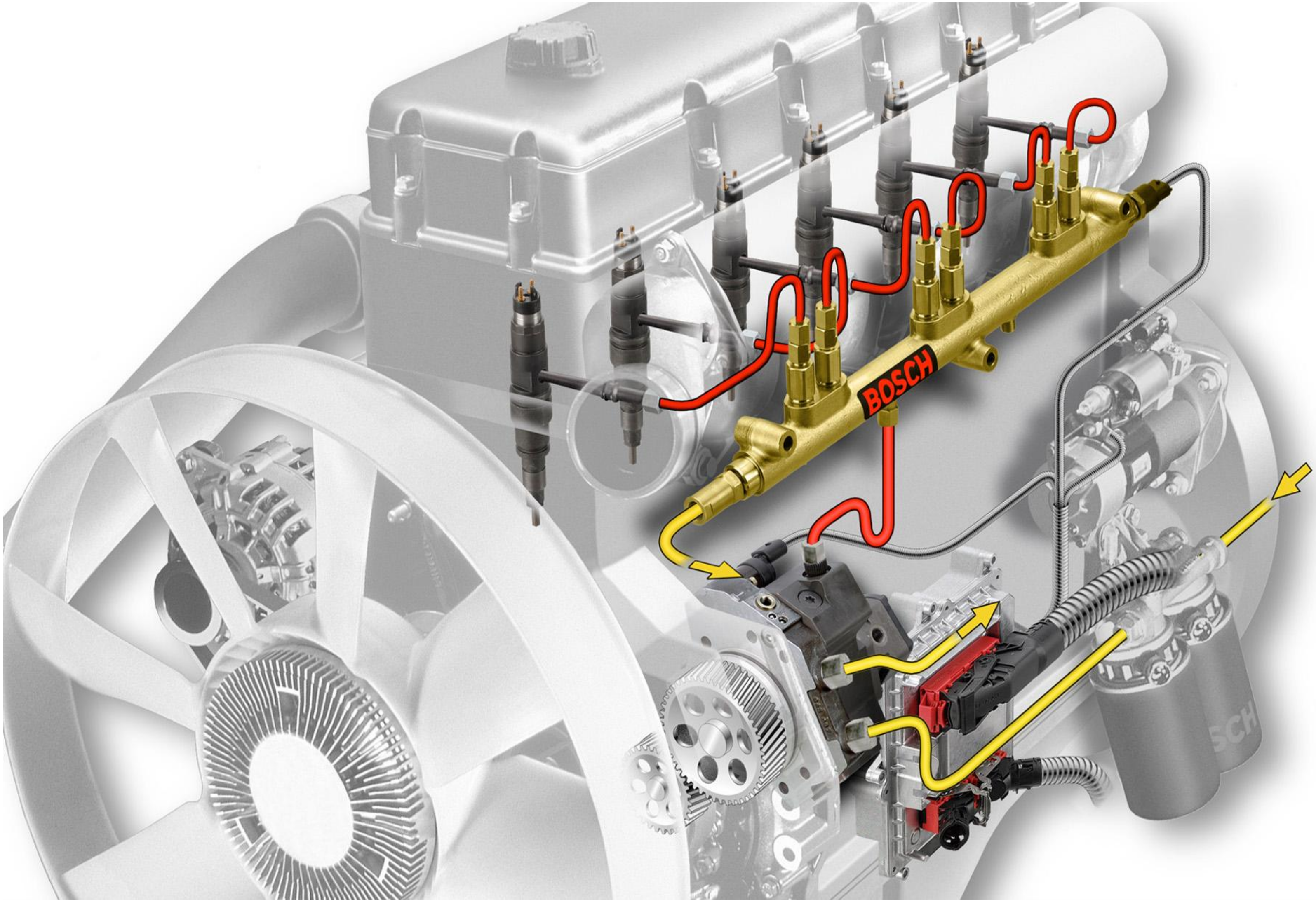


Diesel Fuel Systems



In-line pumps Common Rail Unit-injector/pump

Common-Rail System (Truck engine)



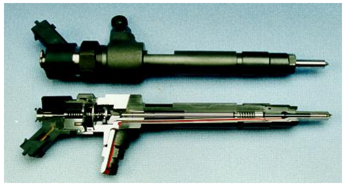
CR-System Production Location Bursa

Products

Nozzles

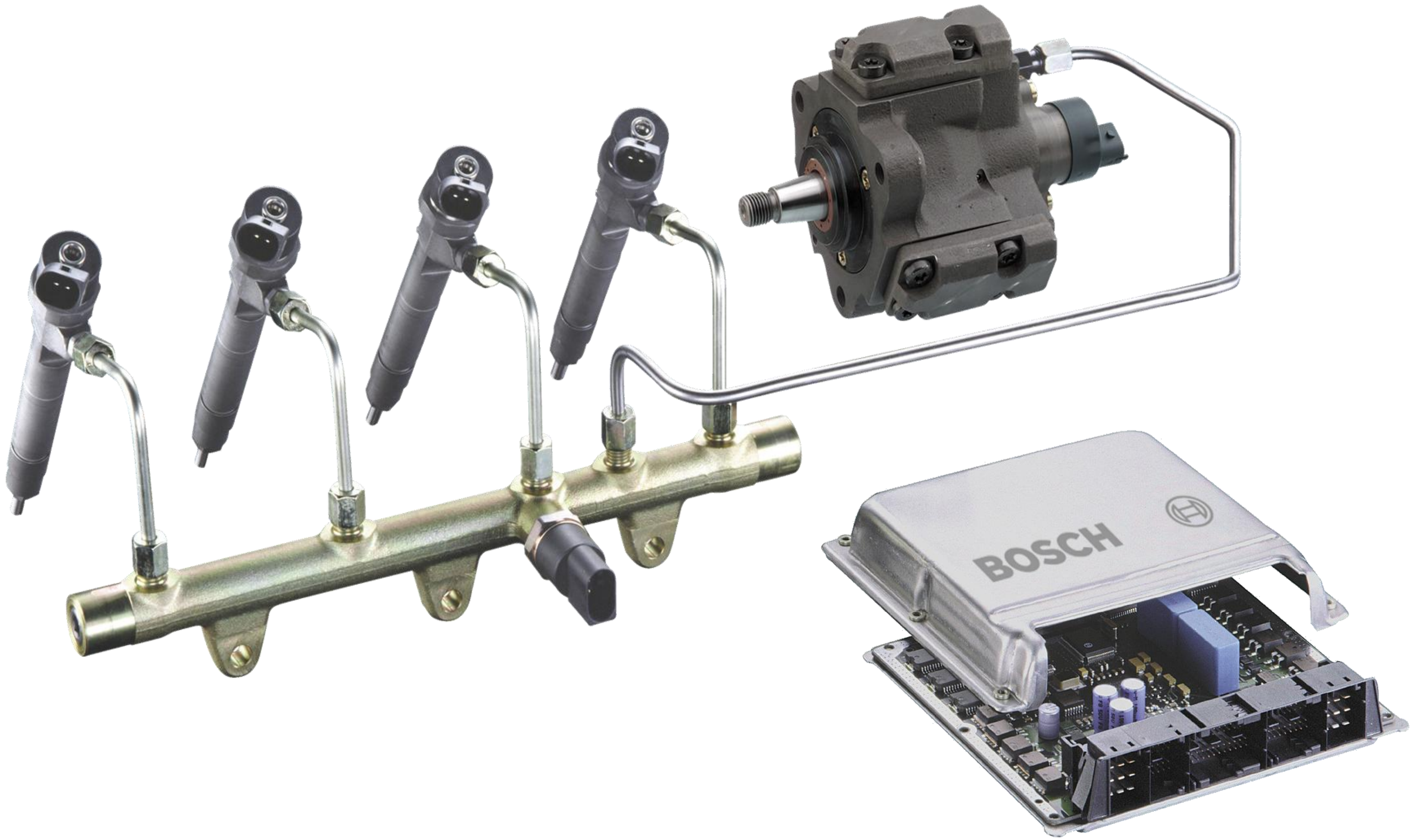
Nozzle Holder Assemblies

Pump Elements

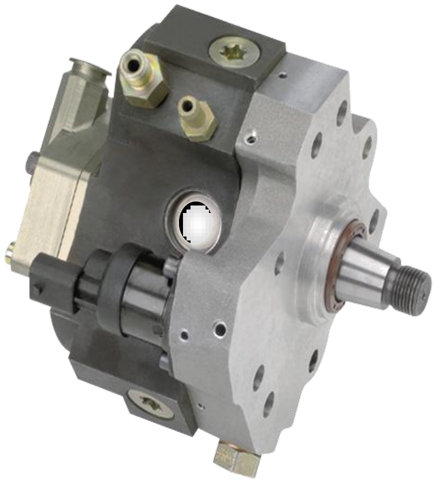


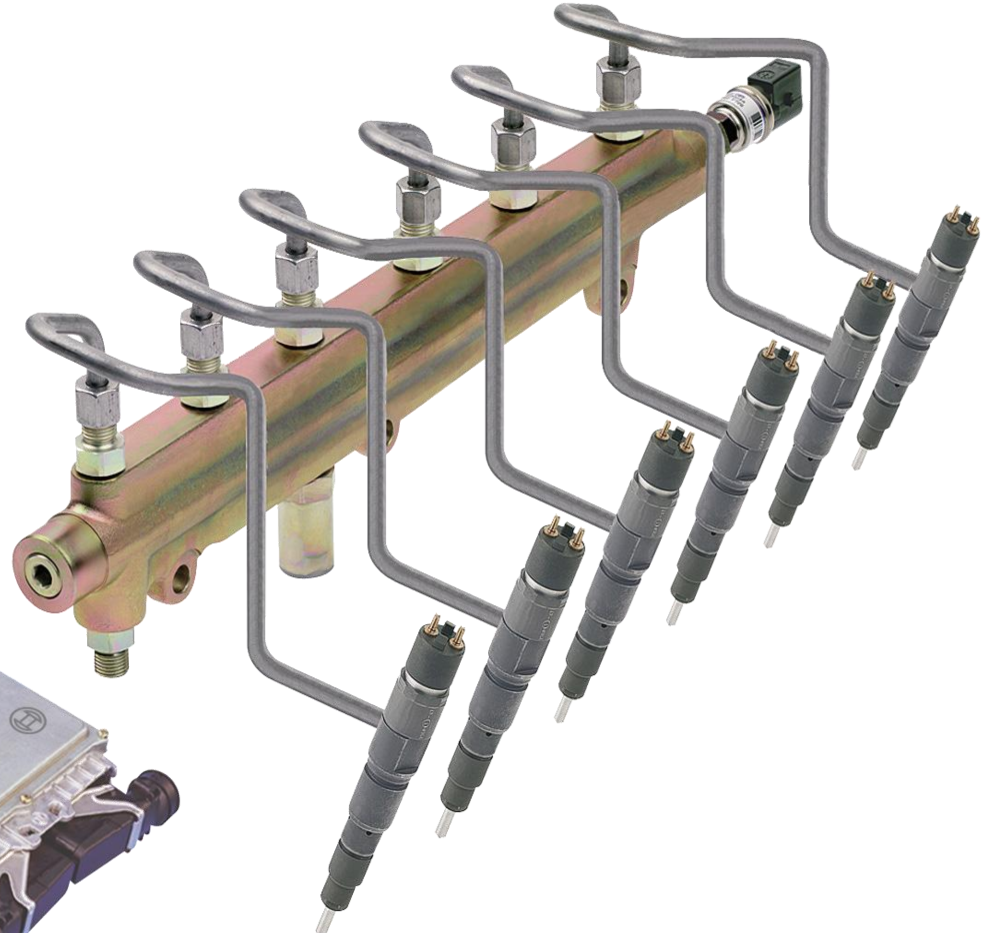
Common Rail Injector

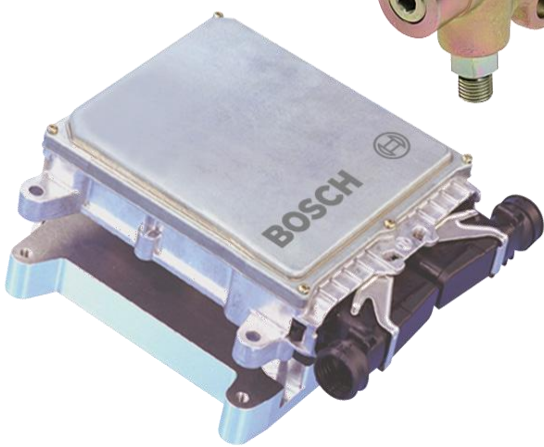
Common Rail System for Passanger Cars



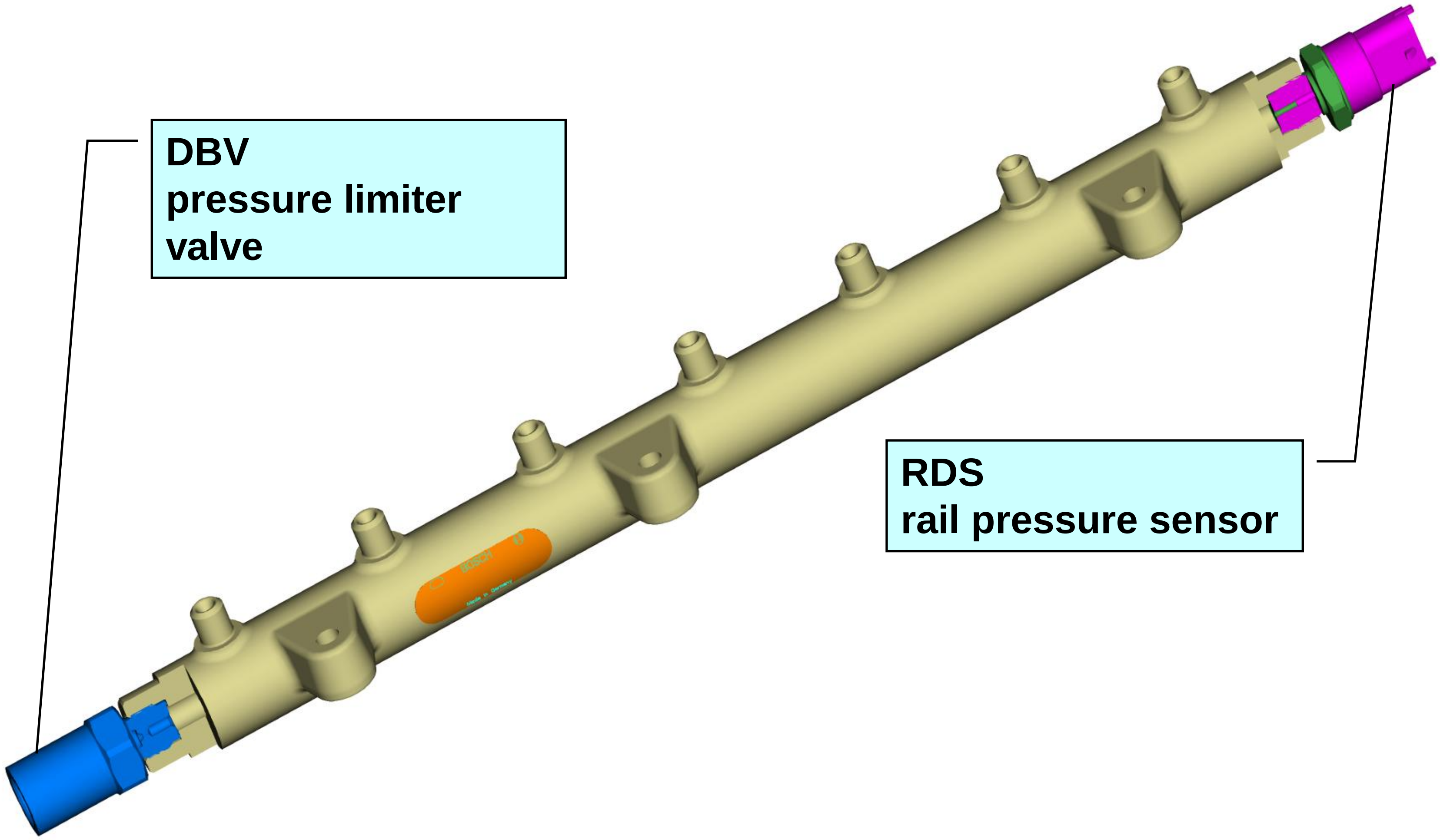
Common-Rail System for Heavy Duty Engines



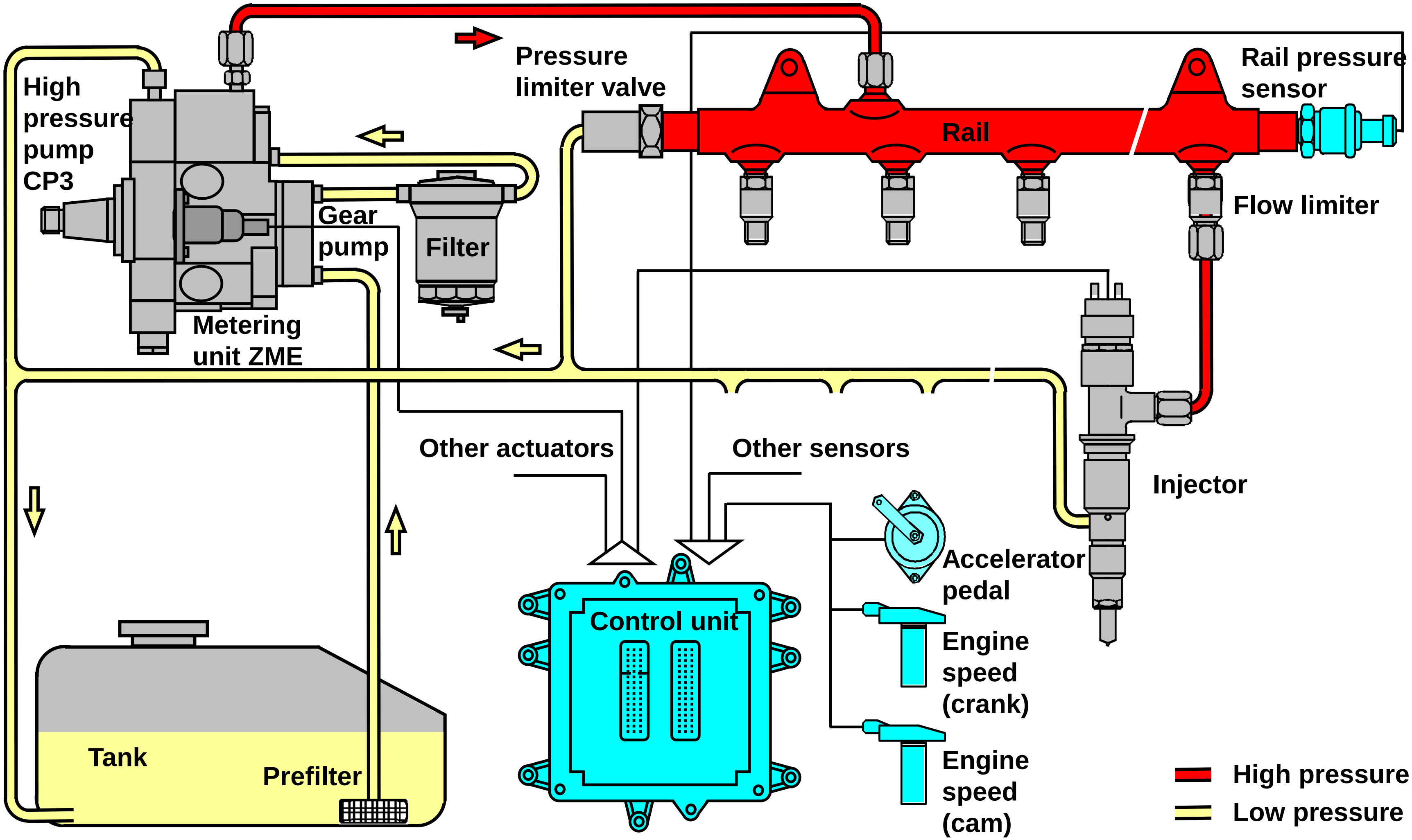




Common-Rail (Truck Rail Basic Design)

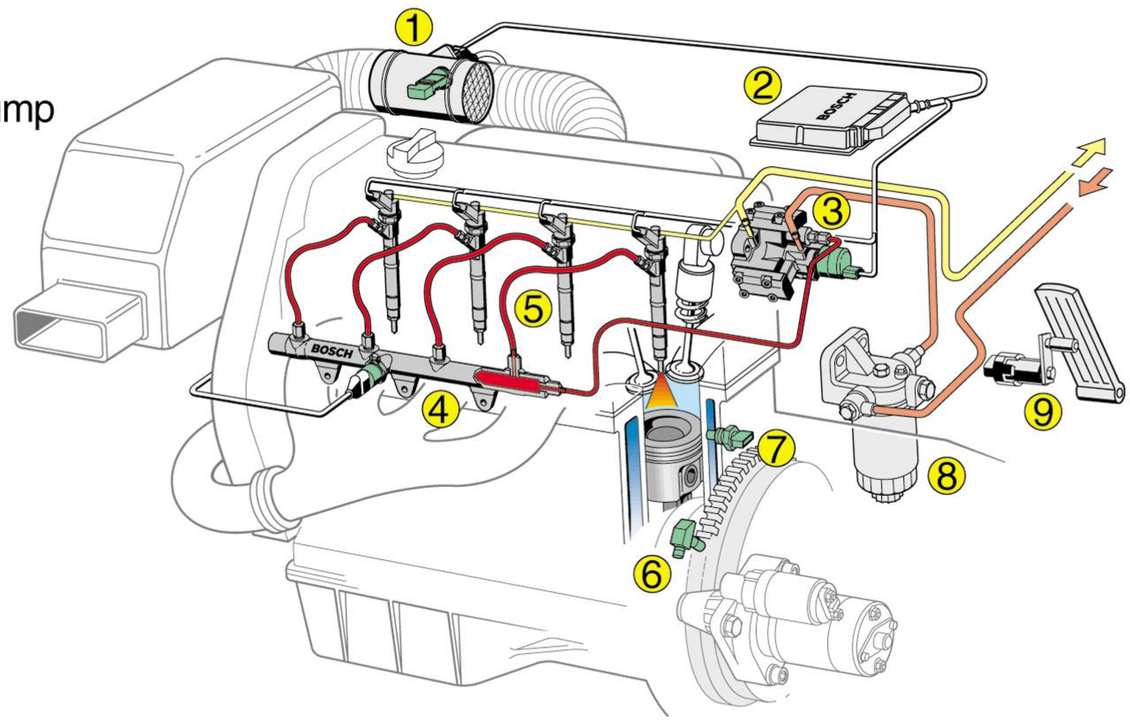


Common-Rail System

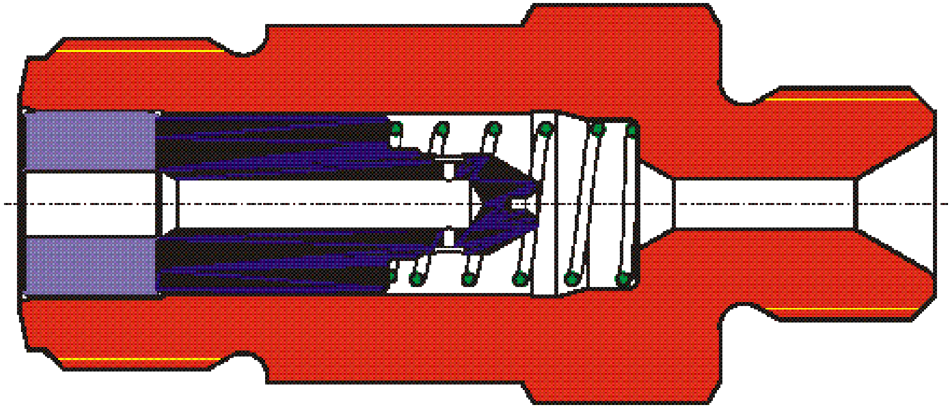


Fuel System Control

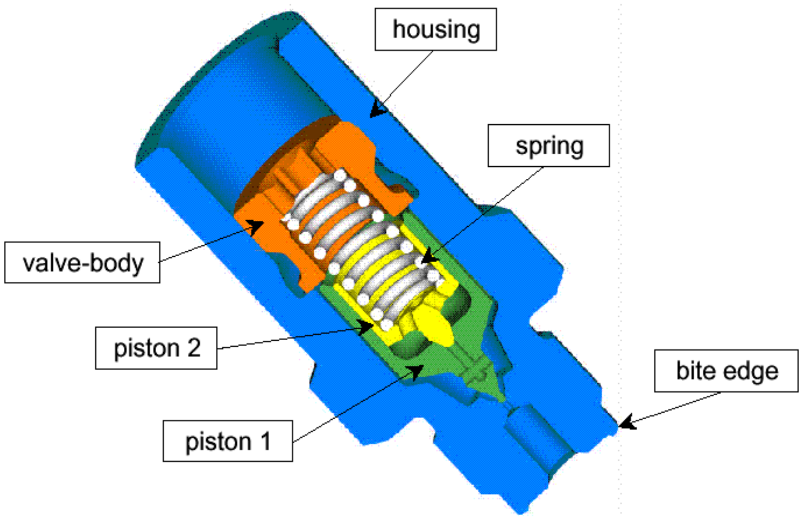
1. Air mass meter
2. Engine ECU
3. High pressure pump
4. Common rail
5. Injectors
6. Engine speed sensor
7. Coolant temp. sensor
8. Filter
9. Accelerator pedal sensor



Flow Limiter



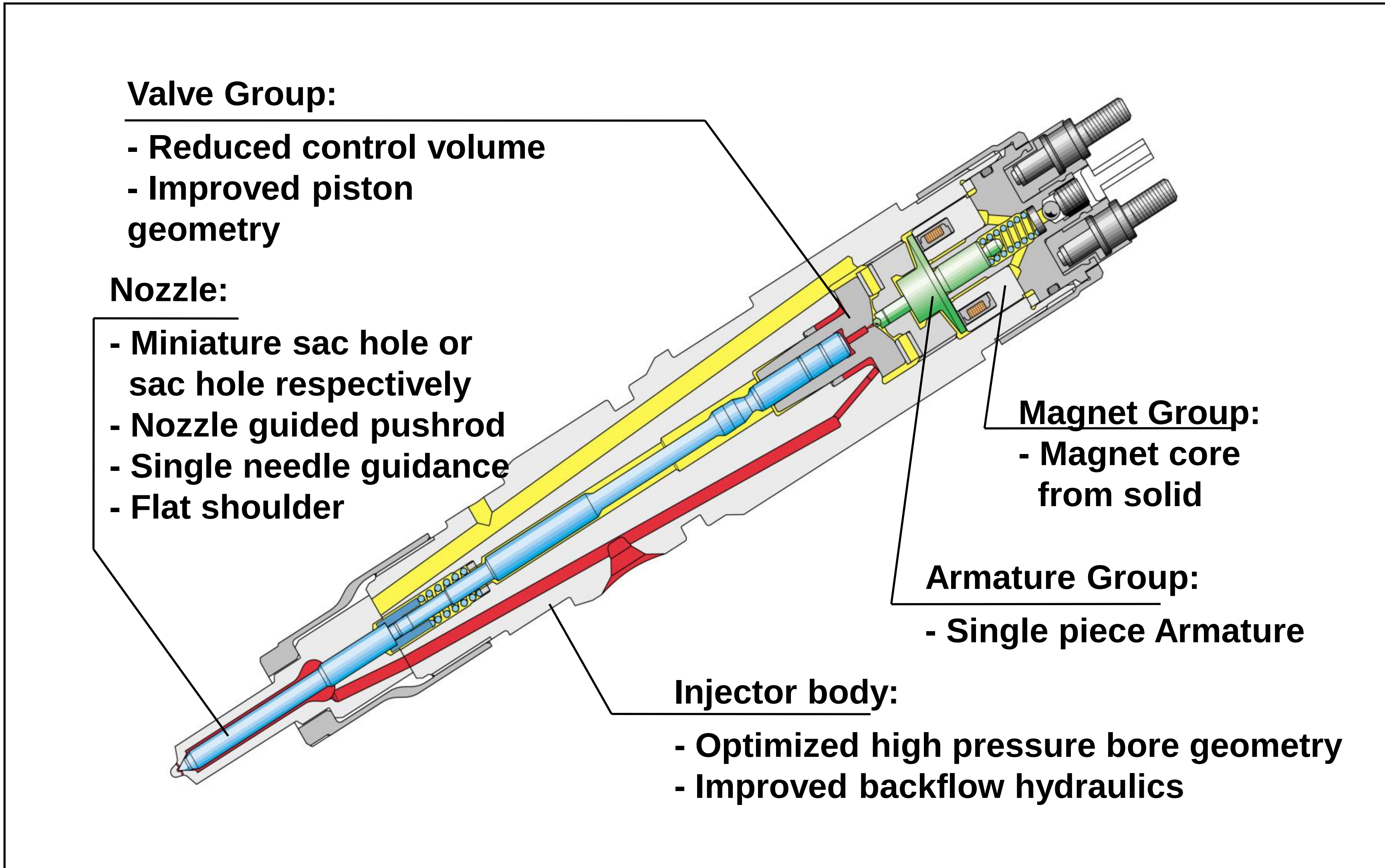
Two-step Pressure Limiting Valve



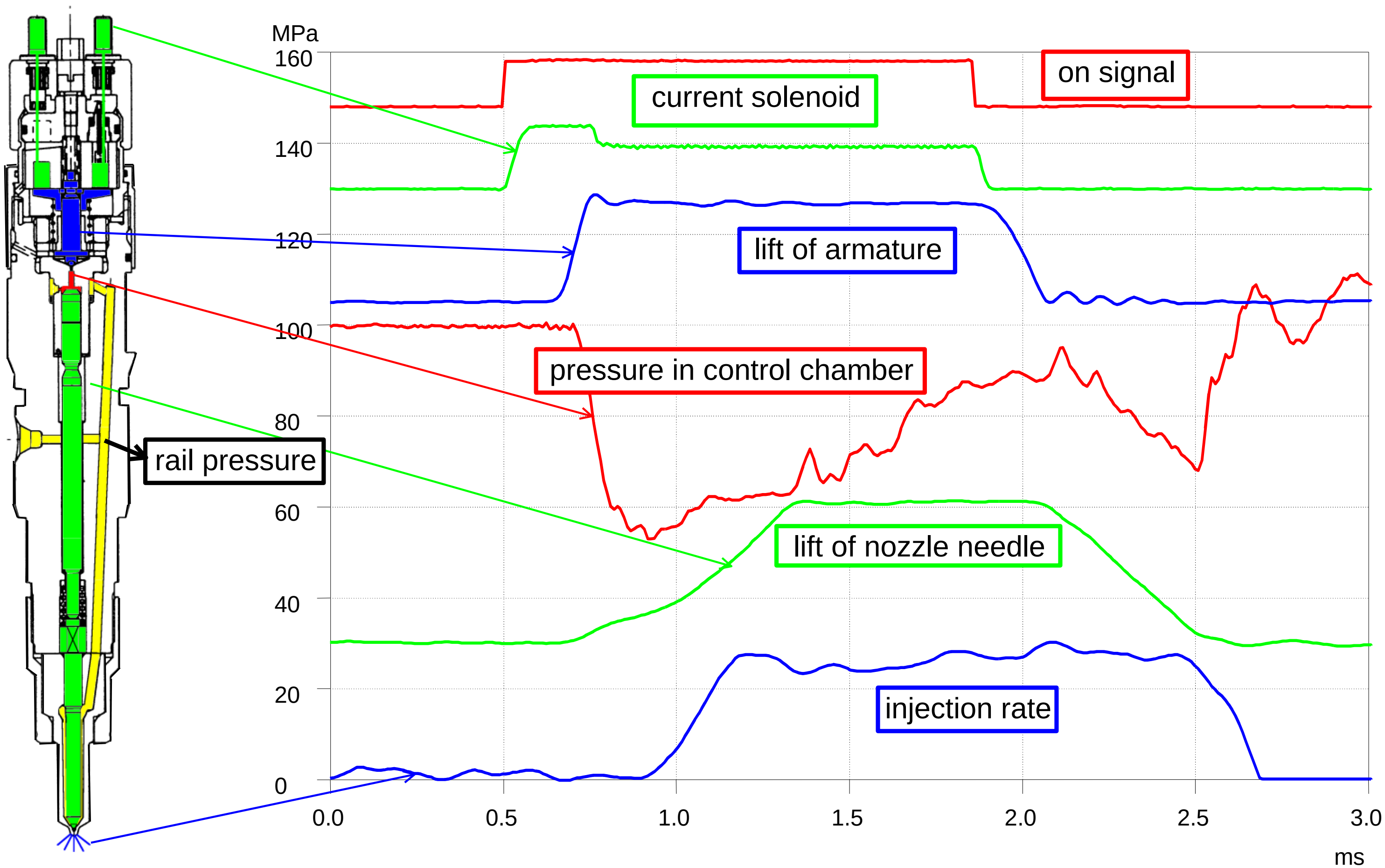
Rail Pressure Sensor Features

- Stainless-steel diaphragm with thin-film
- Complete separation of medium and electronics
- Compact, rugged, resistant against vibration
- Pressure ports:
  M12 x 1,5 with sealing ring
  M18 x 1,5 with self sealing edge
- Operating range: 0-150/180 MPa
- High accuracy: ±1,2% FS (over life time/main op. range)

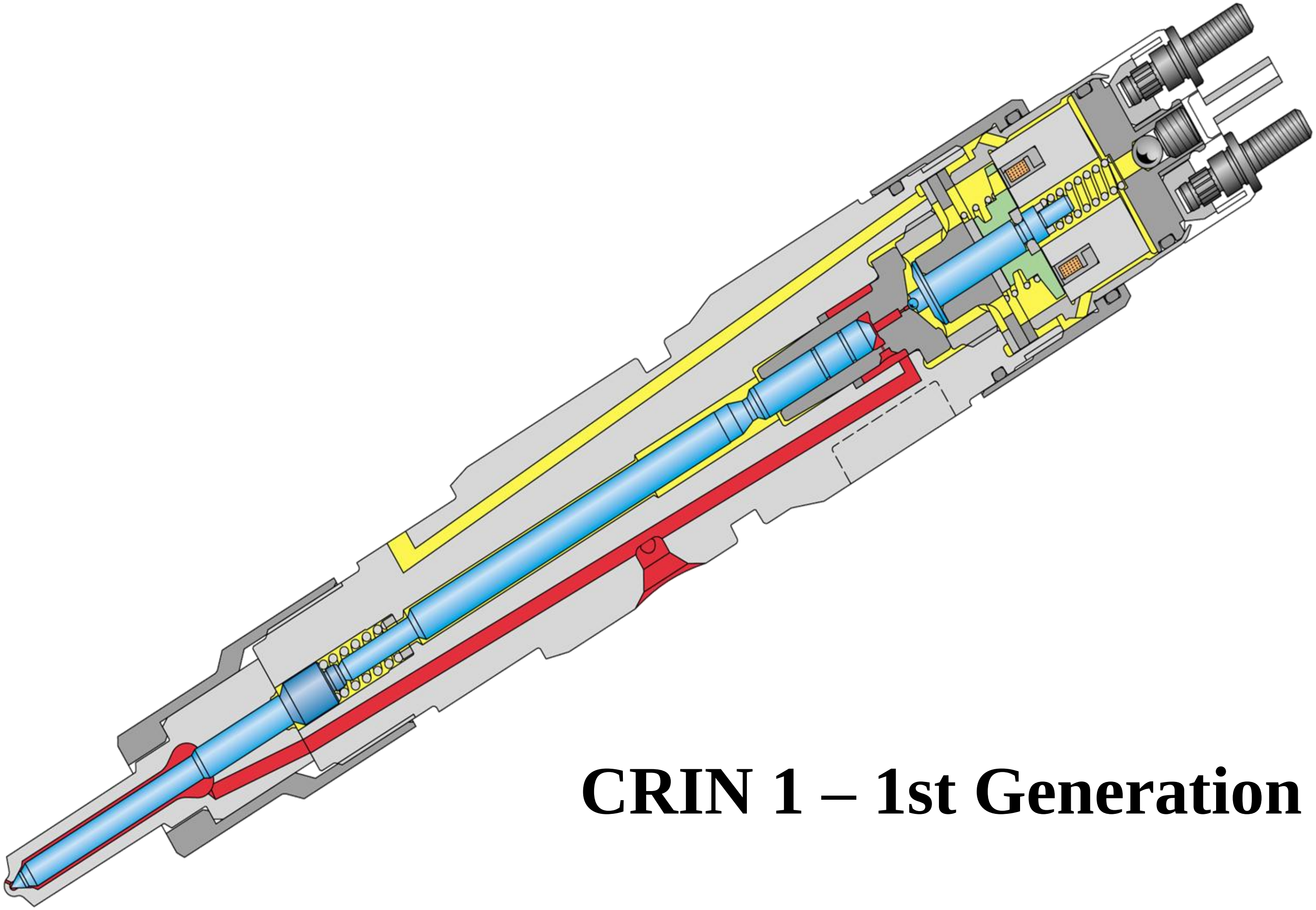
Common Rail Fuel Injector (Heavy Duty)



Common Rail Fuel Injector

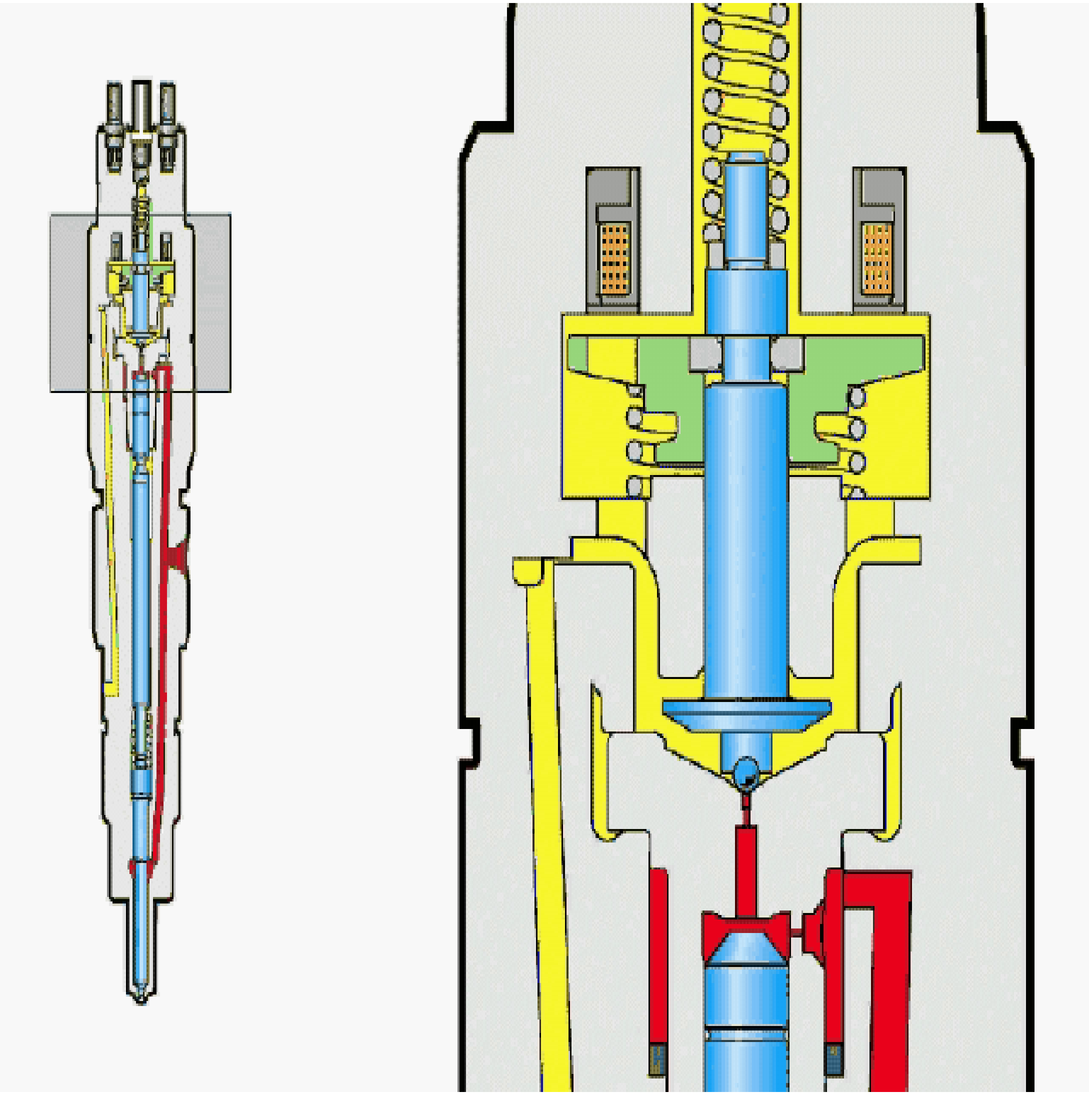


Common Rail Fuel Injector – First Generation



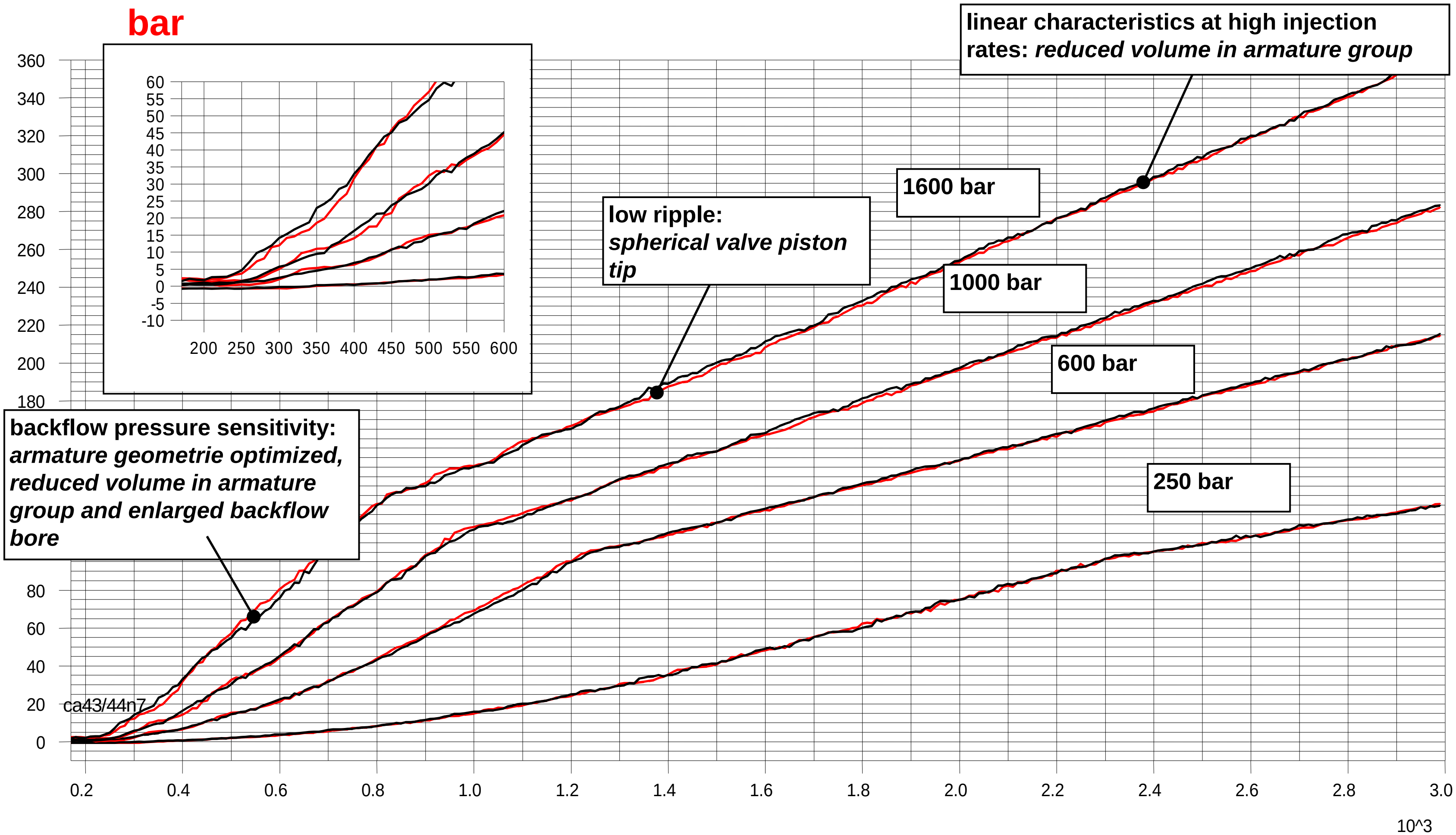
CRIN 1 – 1st Generation

CR Injector – Principle of Function

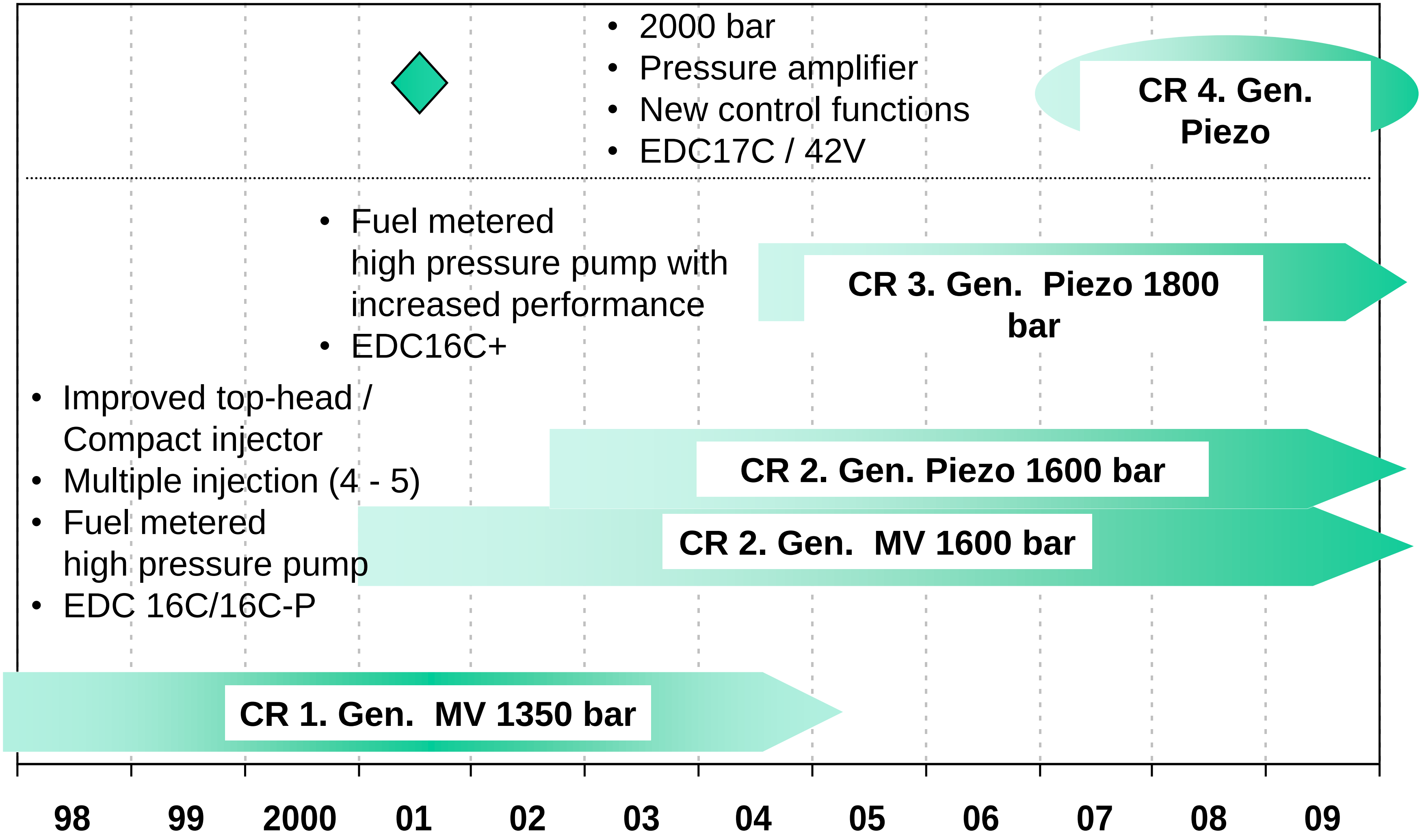


CR Injector Map

backflow counterpressure: 0 bar and 0.5 bar

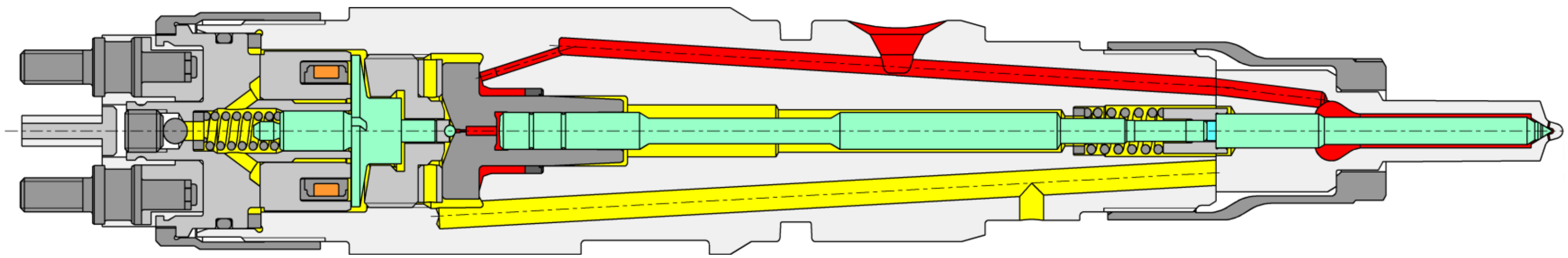


CR System Roadmap (P Cars and Light DutyTrucks)



CR Fuel Injector – Comparison

2. Generation

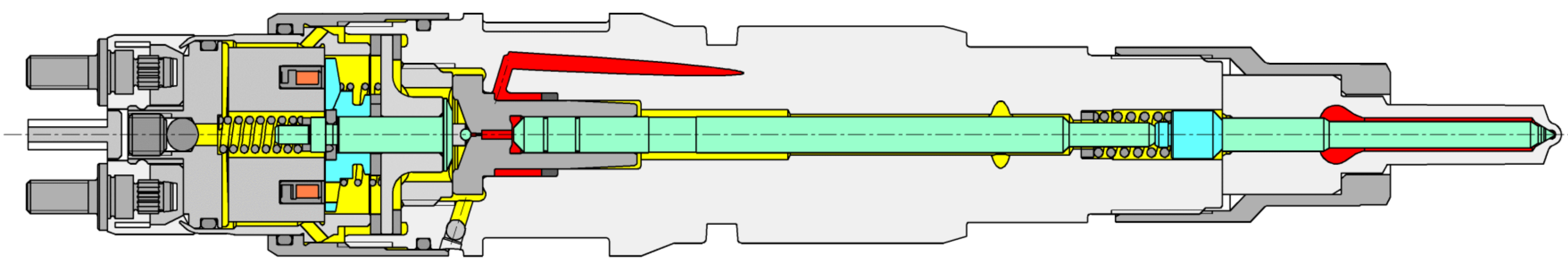


magnet core **armature**

control chamber geometry

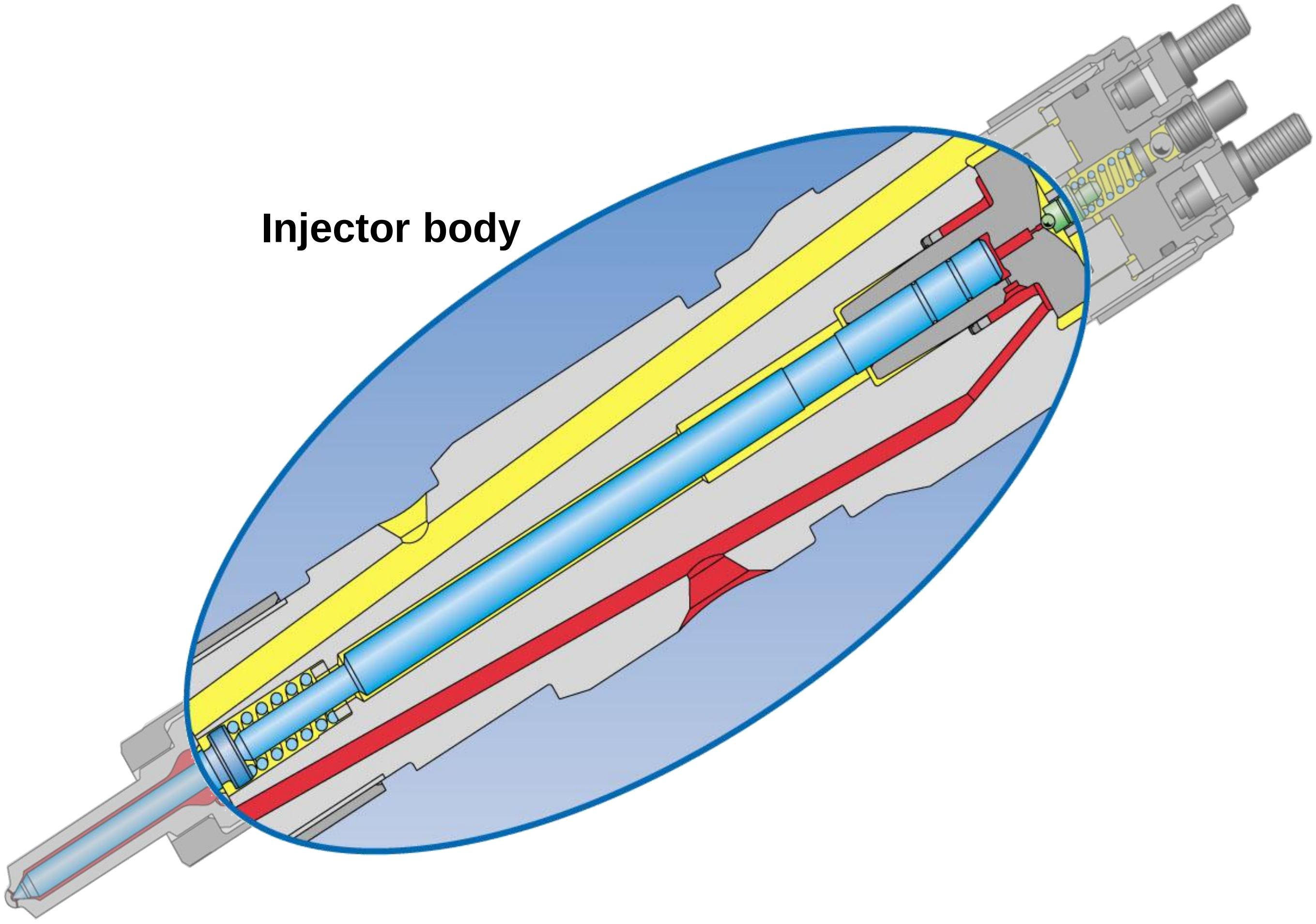
high pressure bore design

DGV intermediate pin

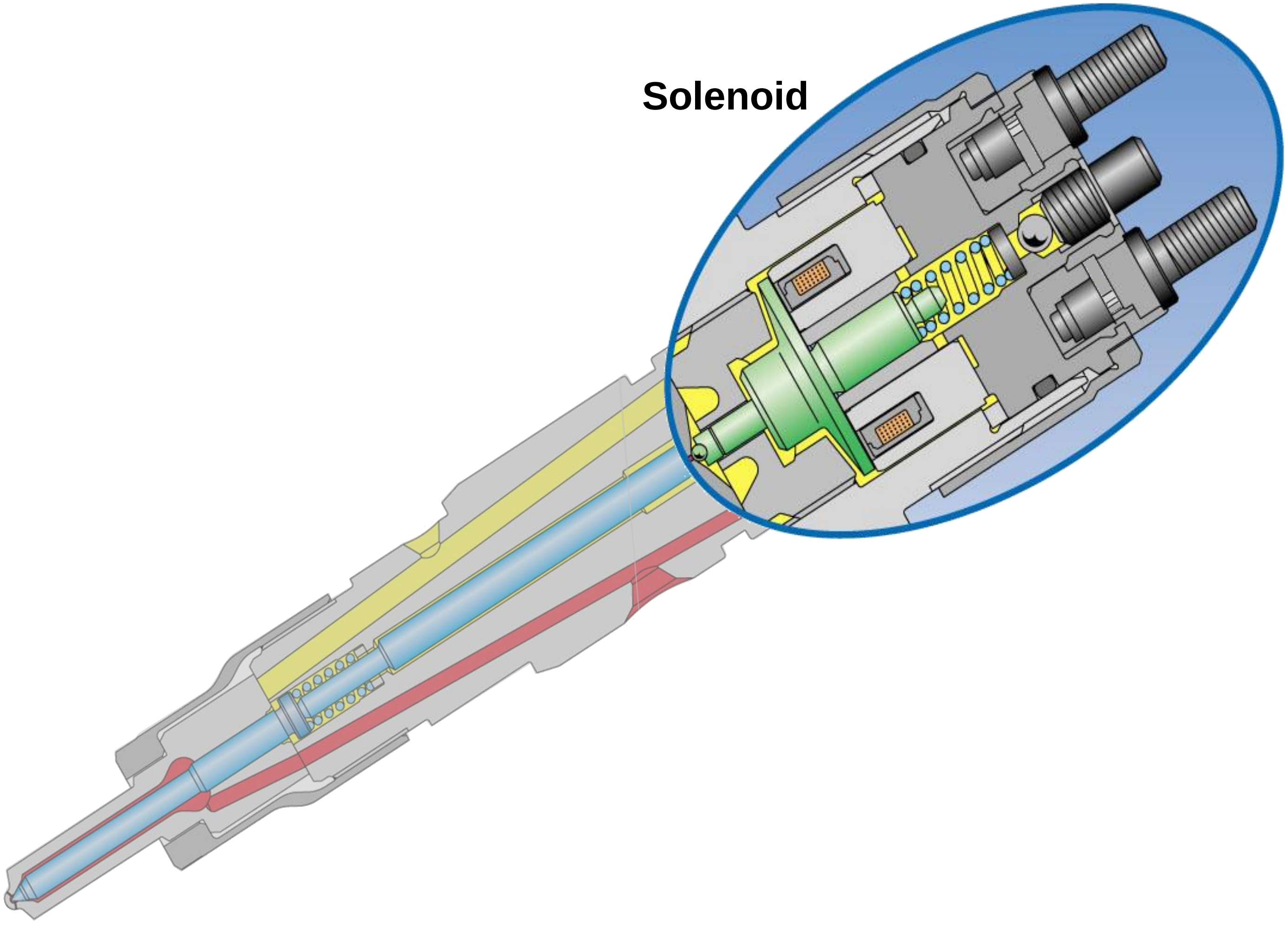


1. Generation

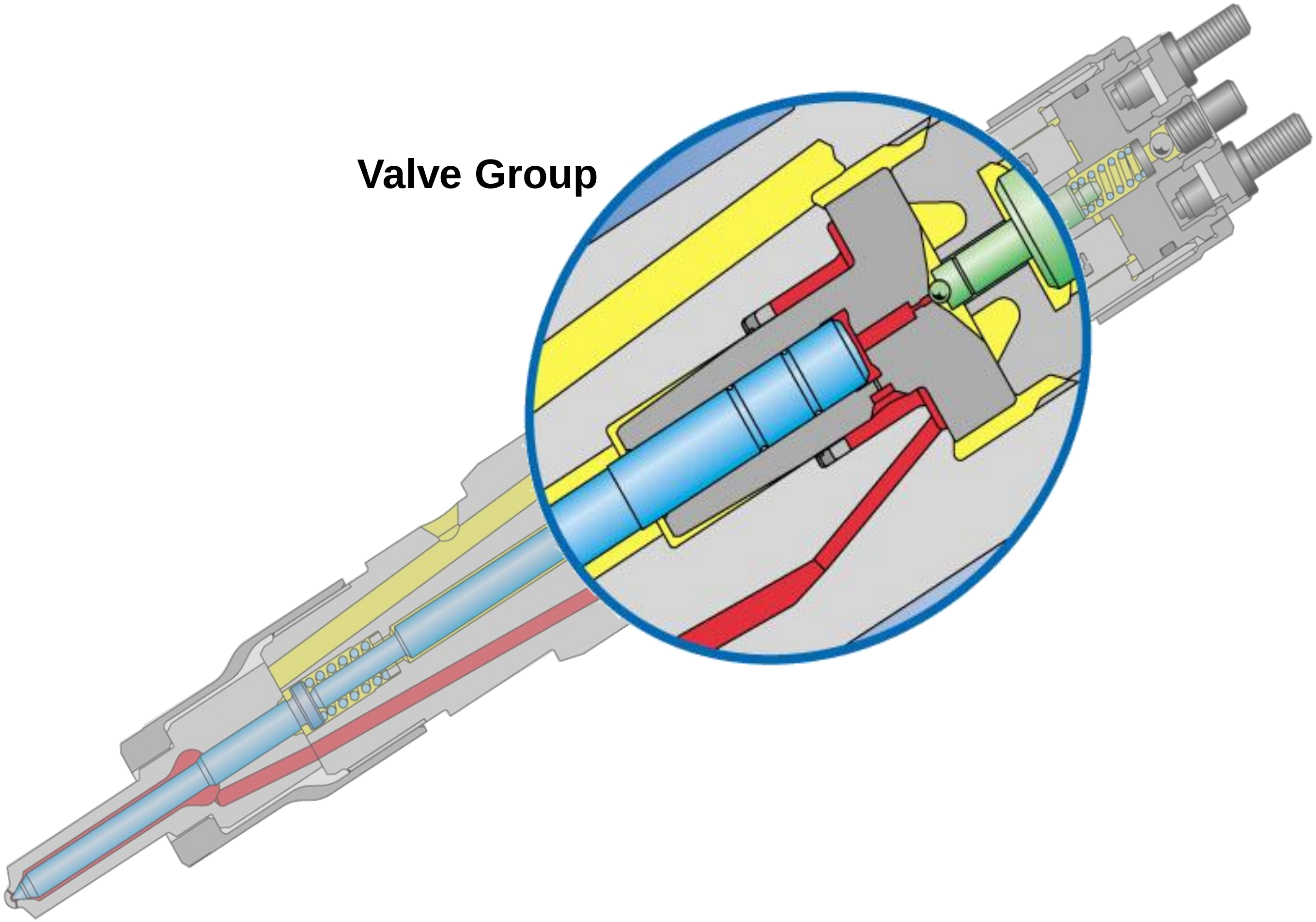
CR Fuel Injector – 2. Generation (for Trucks)



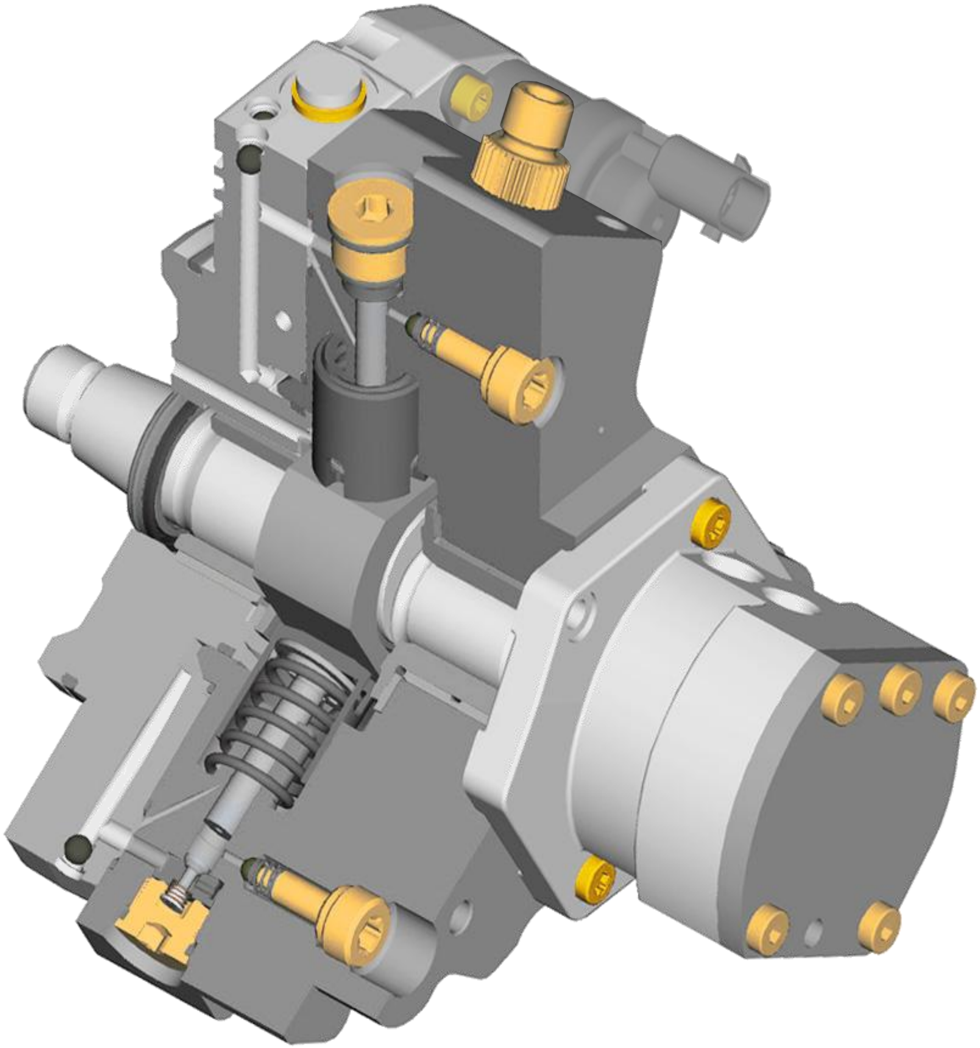
CR Fuel Injector – 2. Generation (for Trucks)



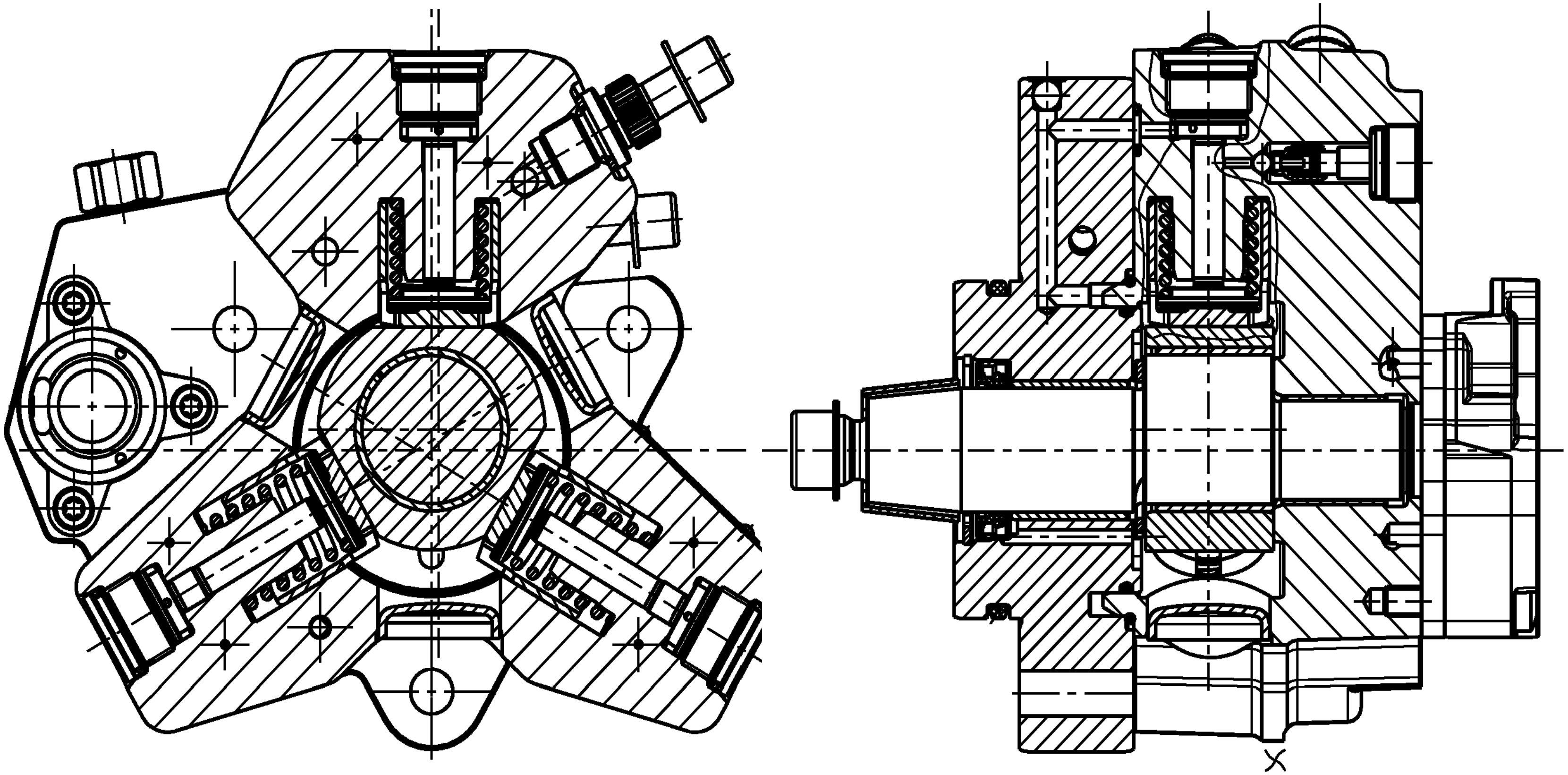
CR Fuel Injector – 2. Generation (for Trucks)



High Pressure Pump



High Pressure Pump



CR Systems Status

1. Generation, 1350 bar systems

   Euro III achieved with different applications

   Low combustion noise with pilot-injection

   Production of different applications (3 to 8 cylinders)

2. Generation, 1600 bar

   Euro IV achieved with different applications

   Combustion noise further reduced with 2 pilot-injections

HD Diesel Engine – EURO IV

Advanced combustion characteristics
- combustion chamber, swirl, number of nozzle holes

Advanced air management system
- high excess-air ratio, $\lambda \geq 1.8$ (steady state and transient)

Advanced supercharging system
- "super" VGT or electronic powered charger

Close loop EGR system with VGT and linear EGR valve
- efficient charge air cooling and EGR cooling

Application with retarded SOI for low EGR Rate

High injection pressure $\geq$ 1600 bar

Oxidation Catalyst for soluble fraction

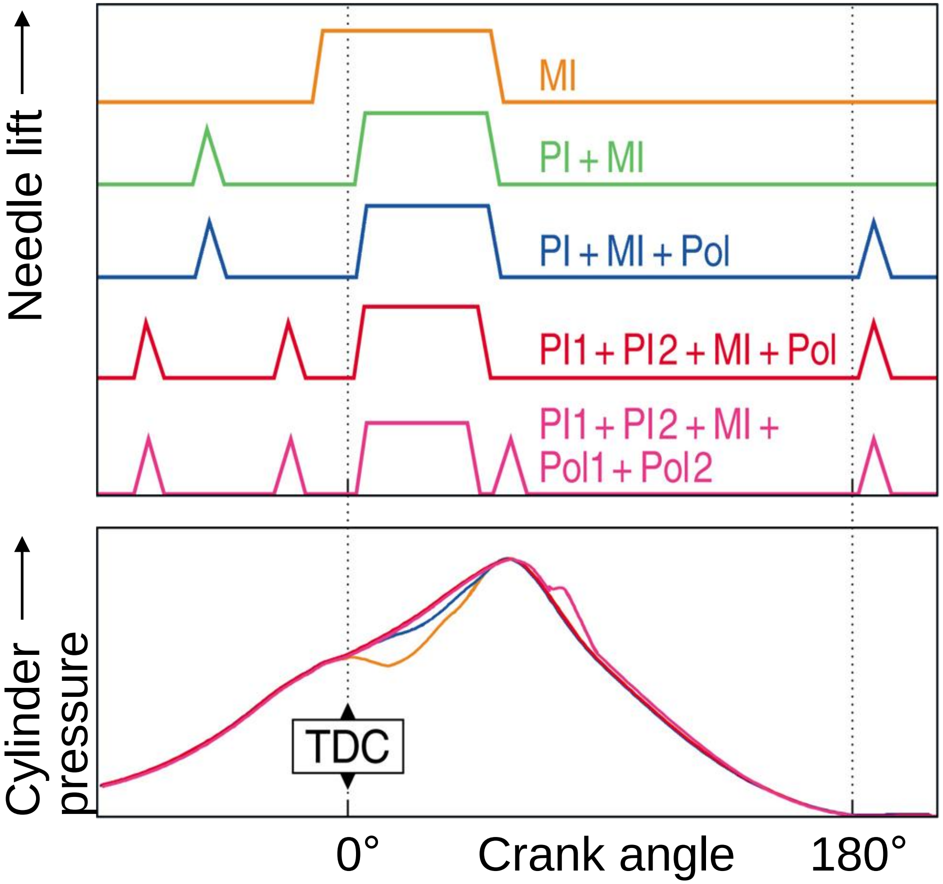
Sulphur free fuel

Conclusion:

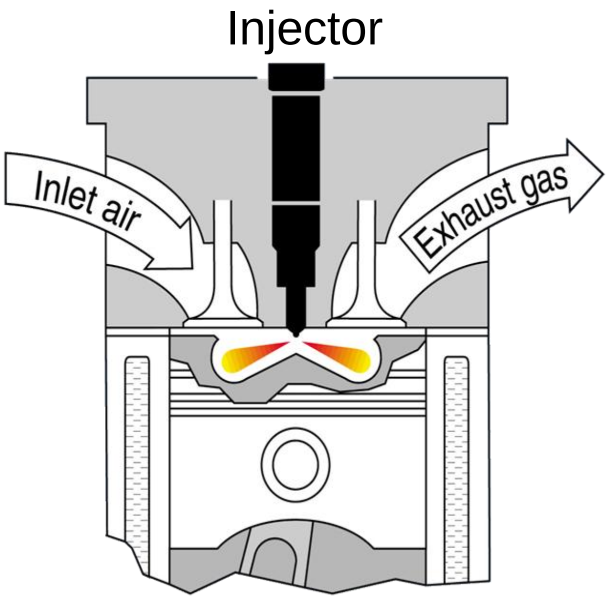
steady state test ESC possible

transient test ETC only possible with all mentioned measures

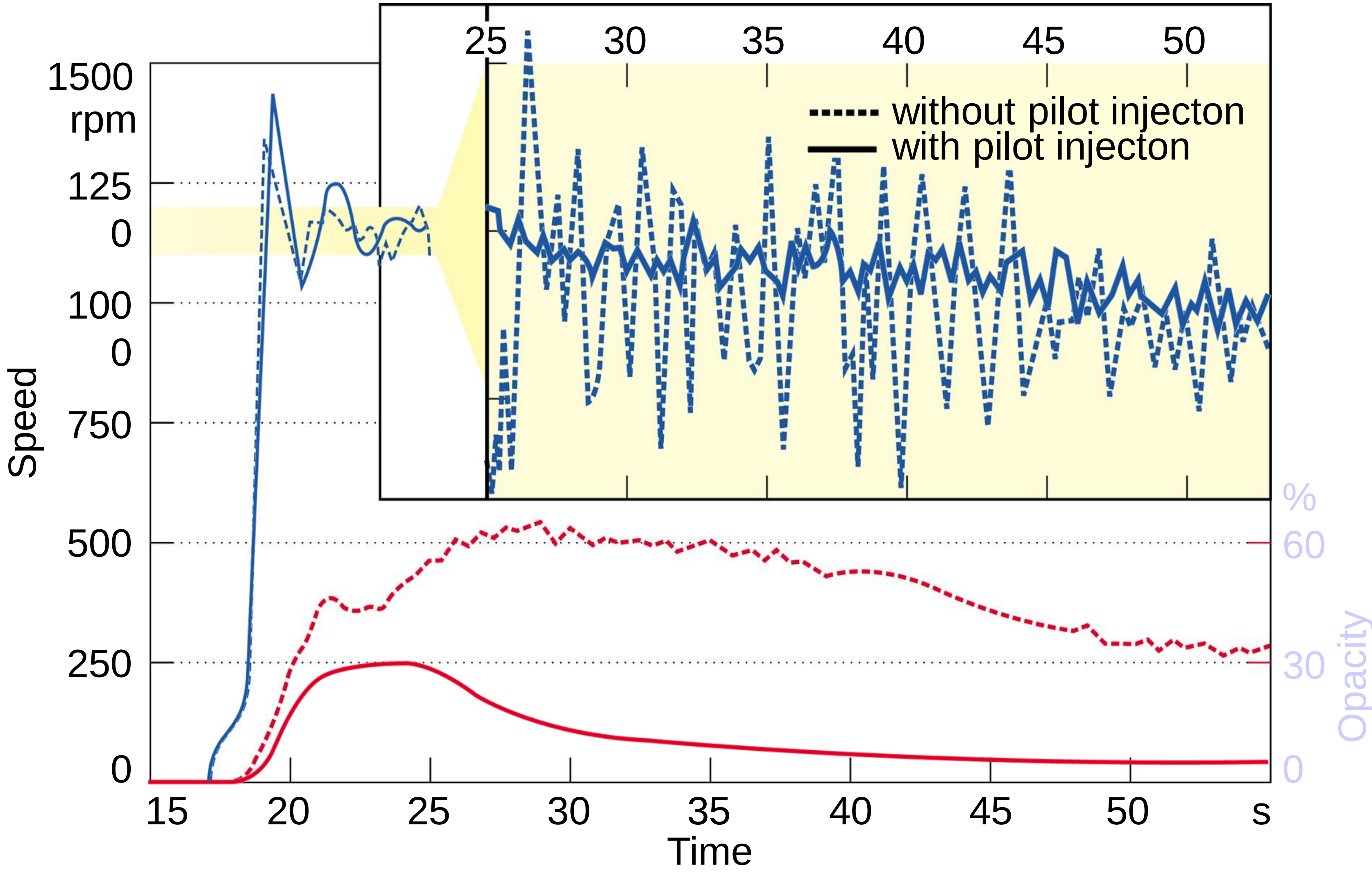
CR System – Comparison of Injection Strategies



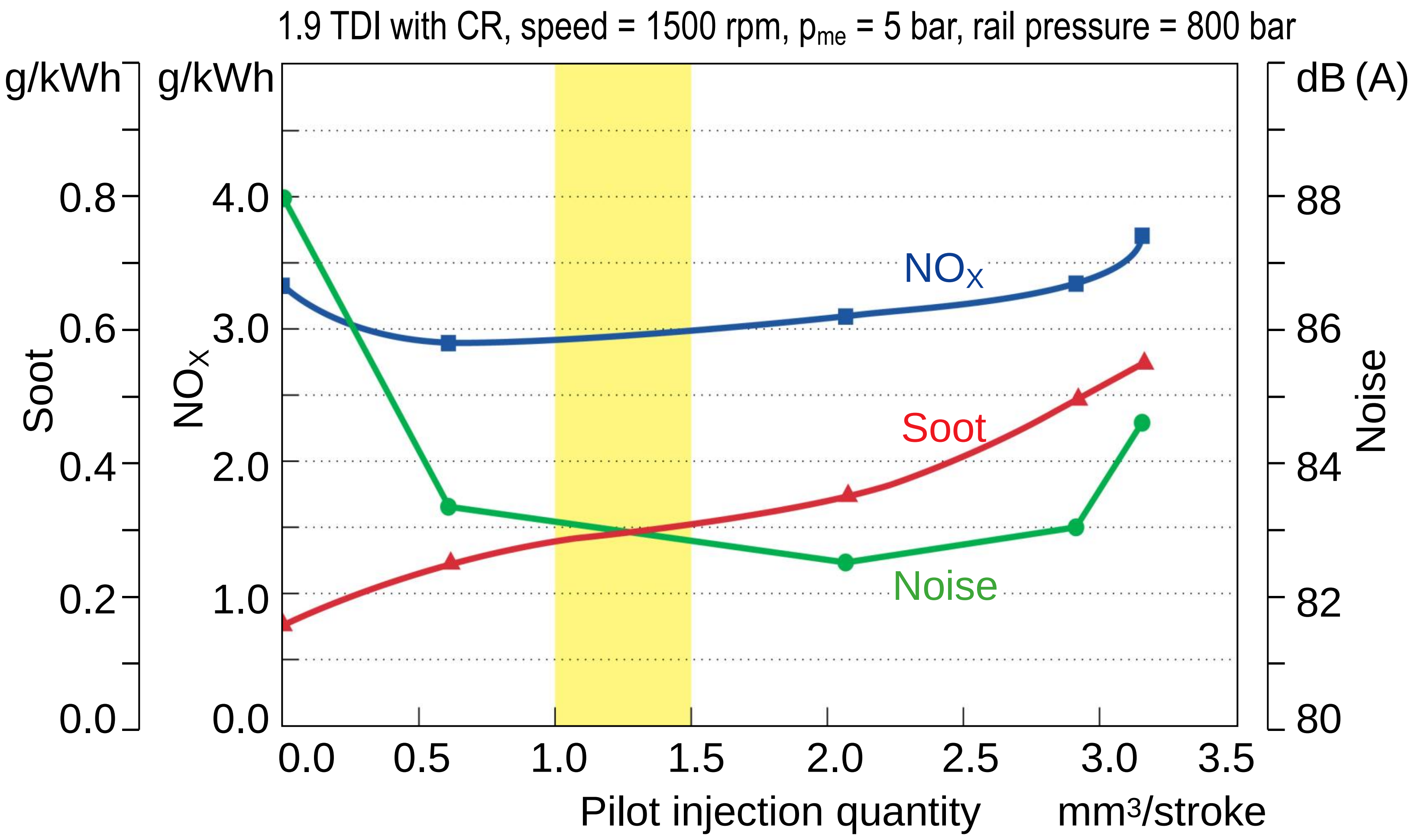
PI Pilot injection
MI Main injection
PoI Post Injection



DI Engine – warm up after cold start at -20° C

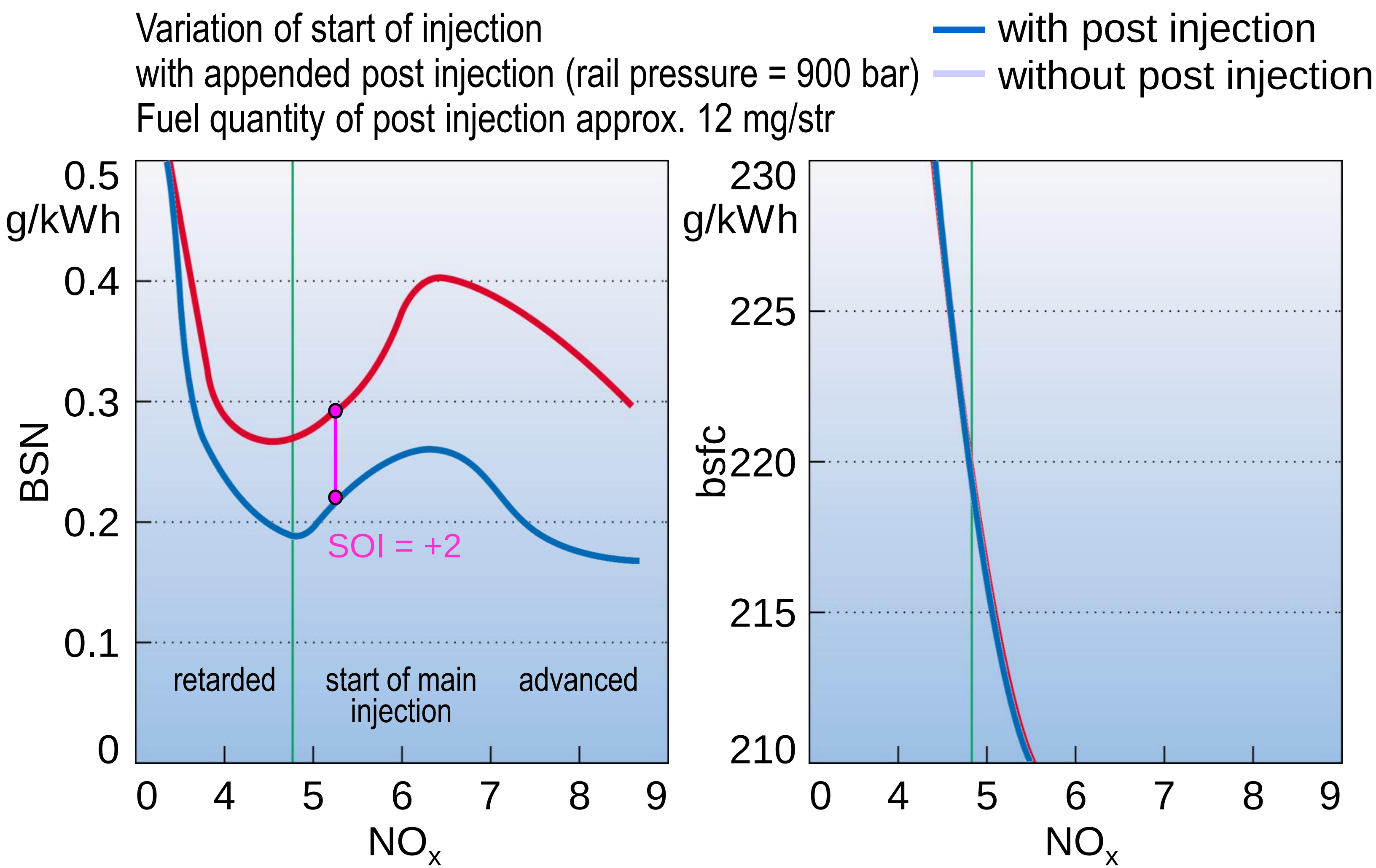


Influence of Pilot Injection on Noise and Emissions



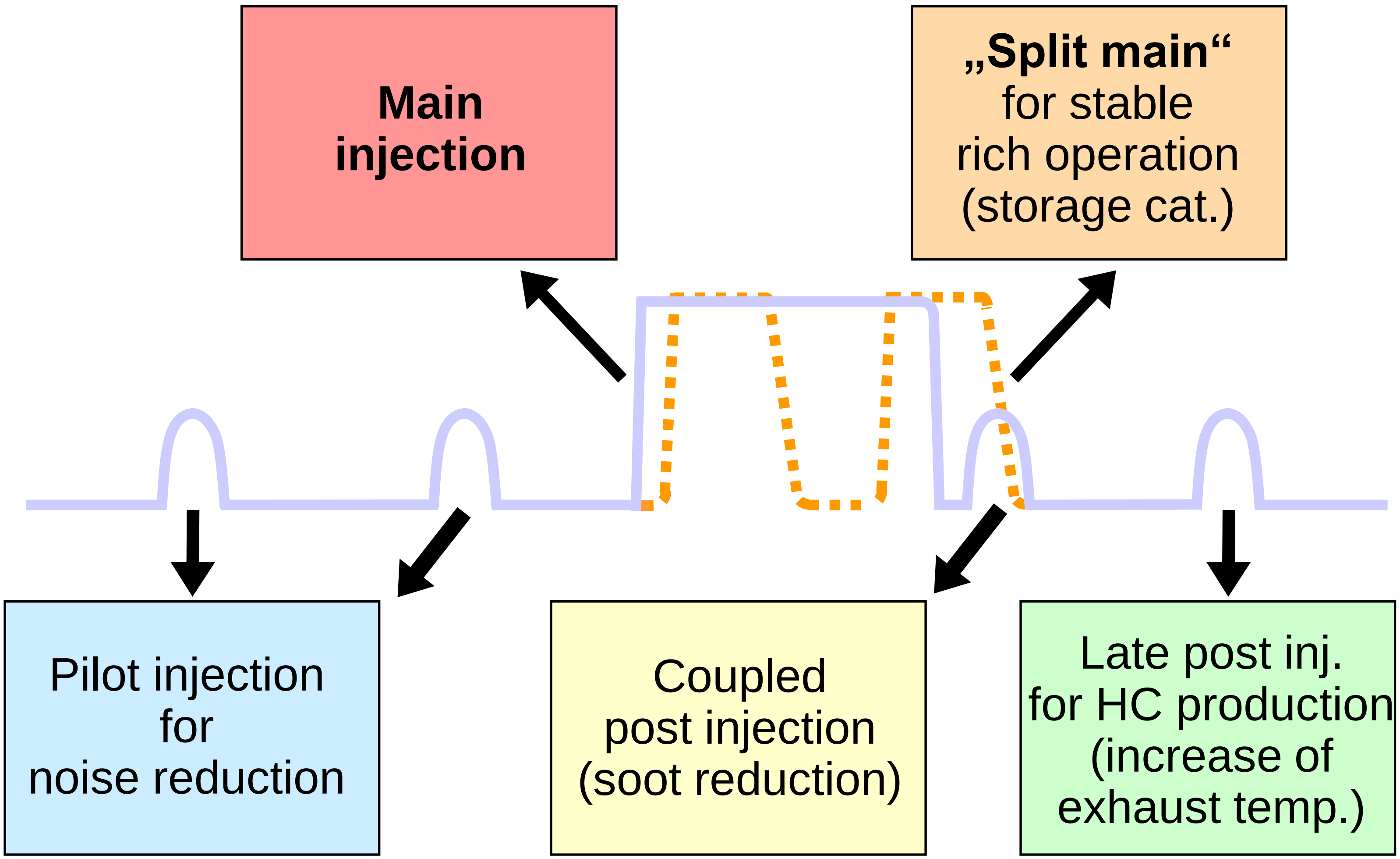
HD Diesel Engine – Post Injection

Variation of start of injection
with appended post injection (rail pressure = 900 bar)
Fuel quantity of post injection approx. 12 mg/str

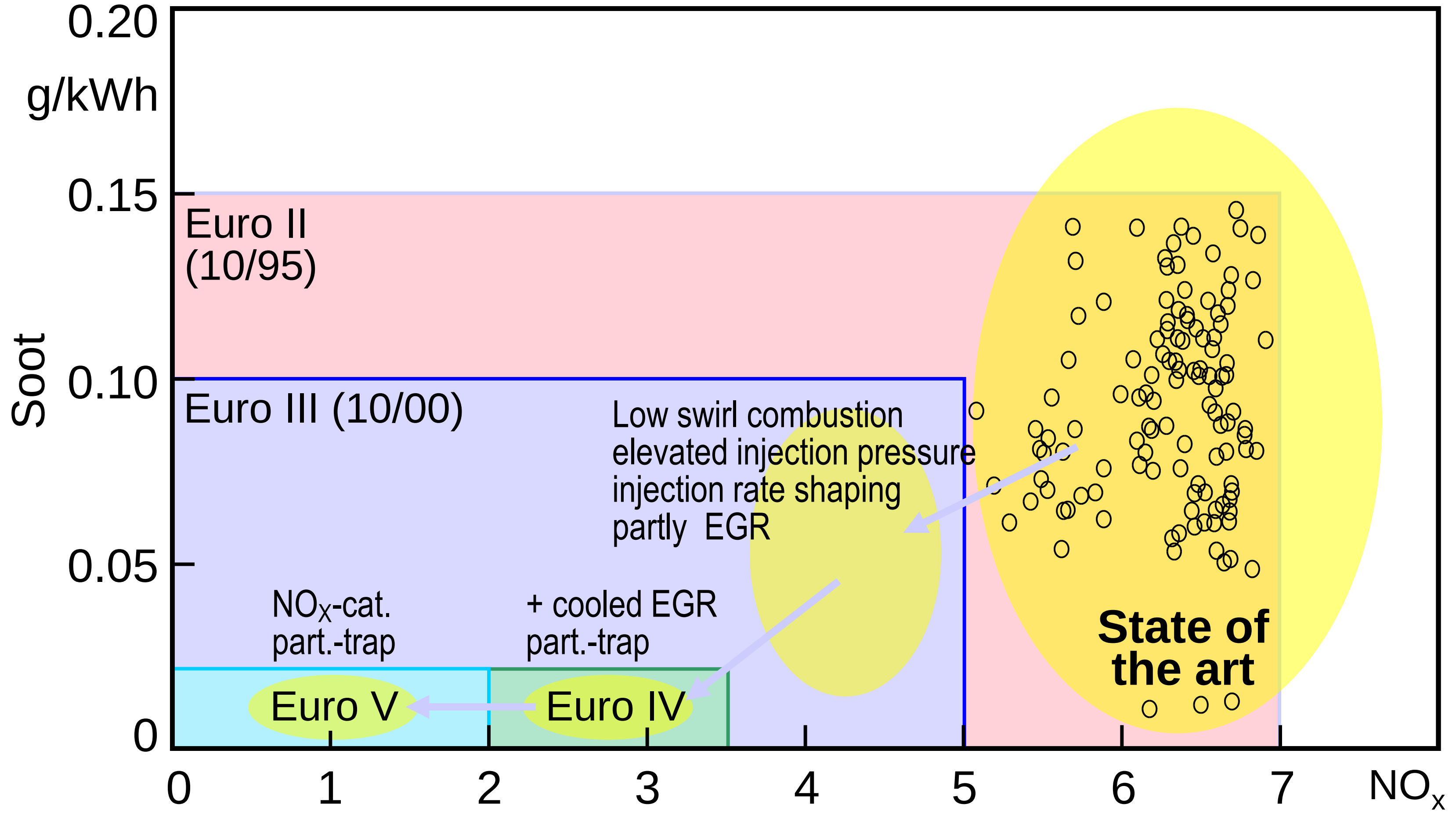


1400 rpm, 75% Load

Common Rail System – Passenger Car



Type Approval Data of HD Engines (> 85 kW)



Exhaust Gas Aftertreatment for P Cars

Assessment of aftertreatment for Diesel-PC, EURO IV and up

Priority I (PM Reduction):

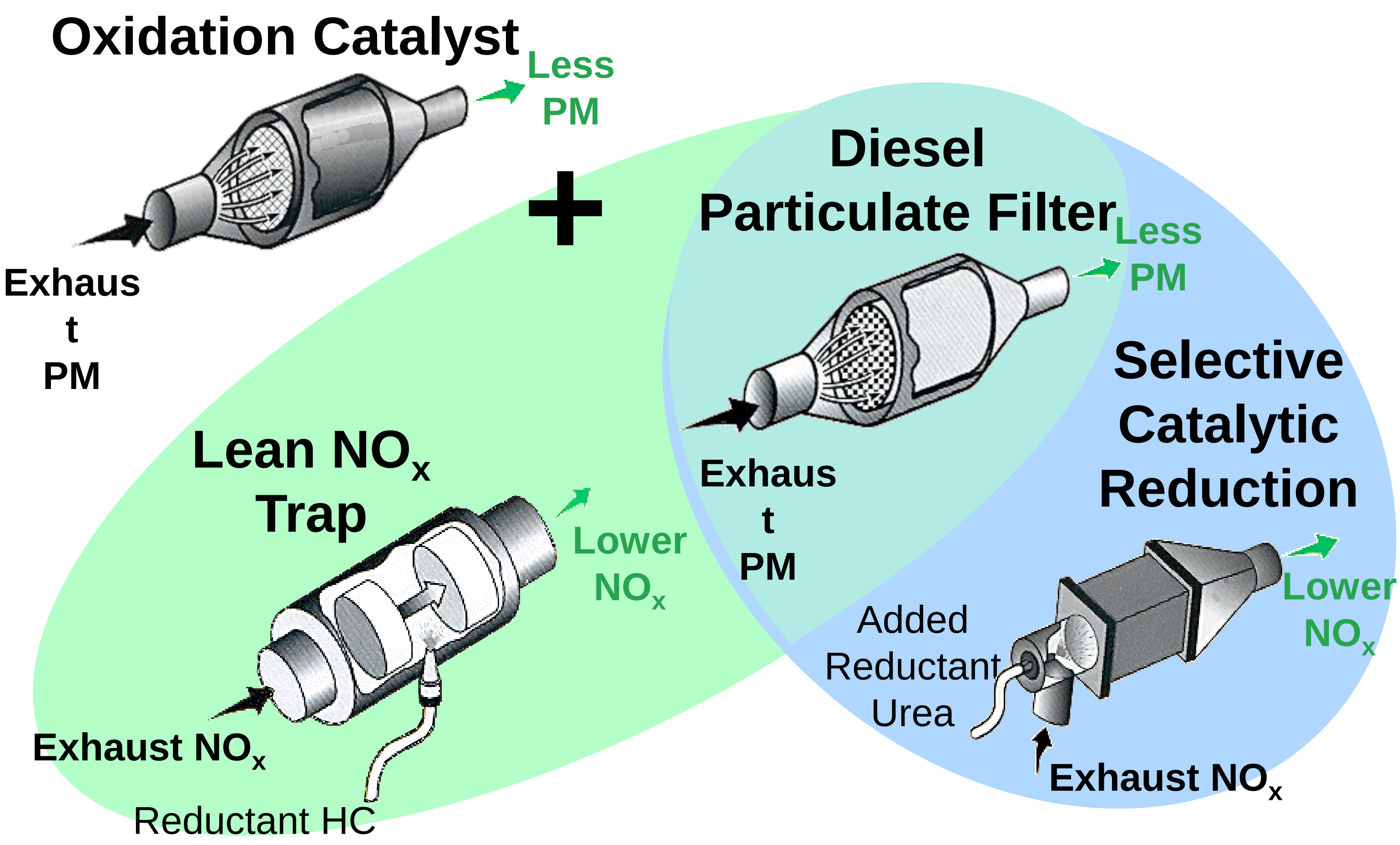
Particulate trap technology is politically necessary and technically suggestive; short-term market release

Priority II (NOx Reduction):

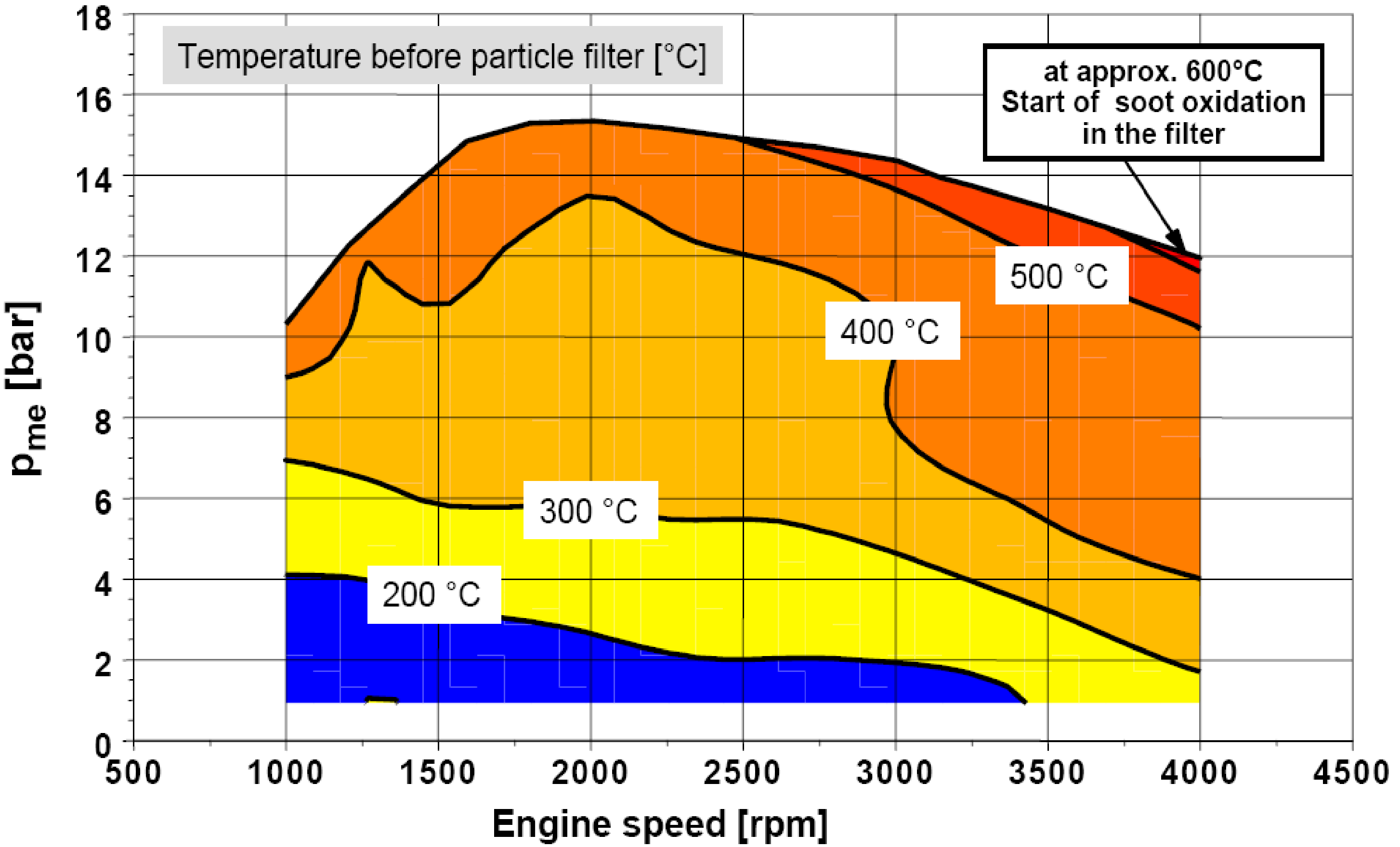
With market release of low-sulphur fuel NOx trap has high potential; further development necessary; medium-term market release

NOx reduction with urea/water remains an individual solution

Diesel Emission Reduction Technologies – P Cars

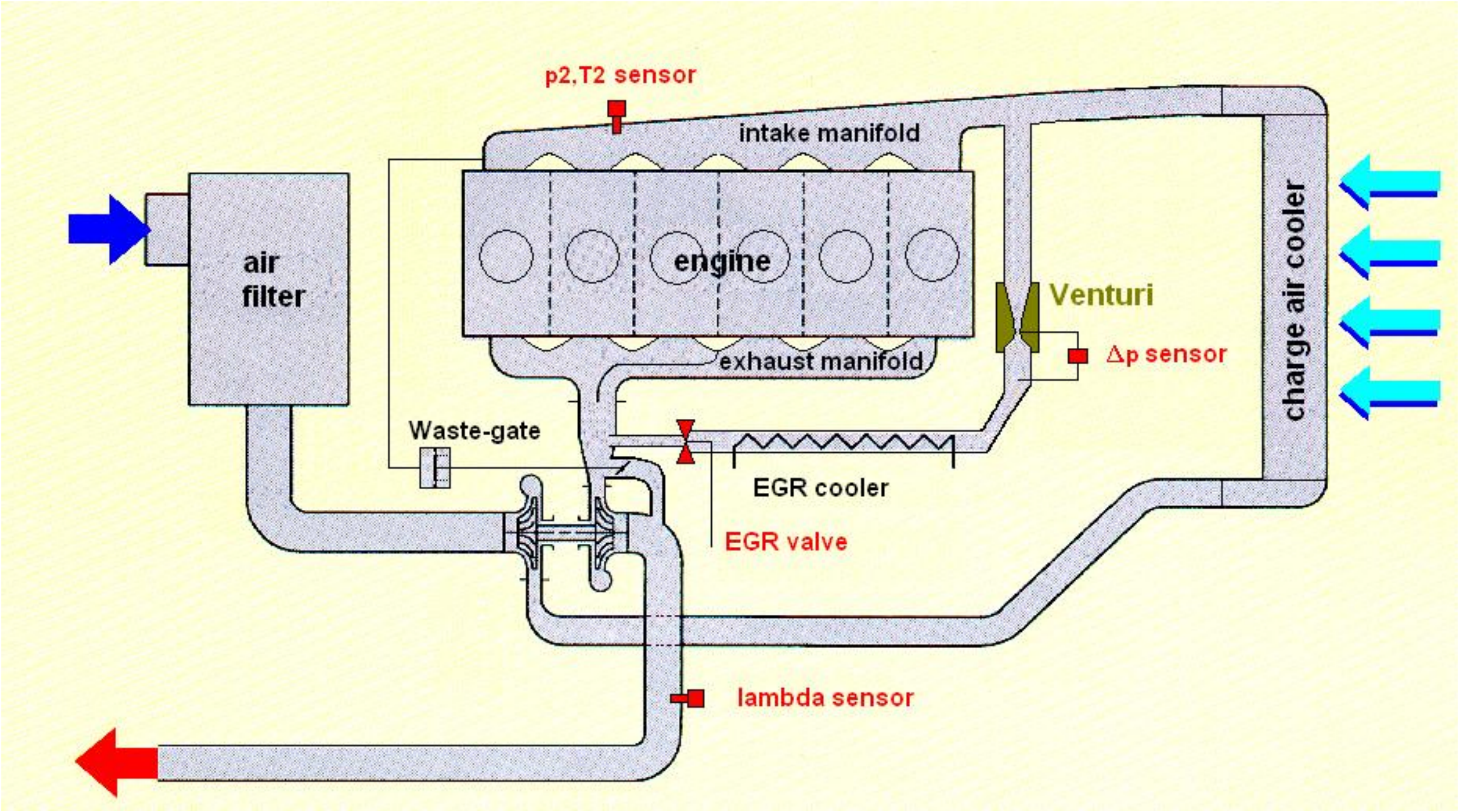


Influence of Pilot Injection on Noise and Emissions

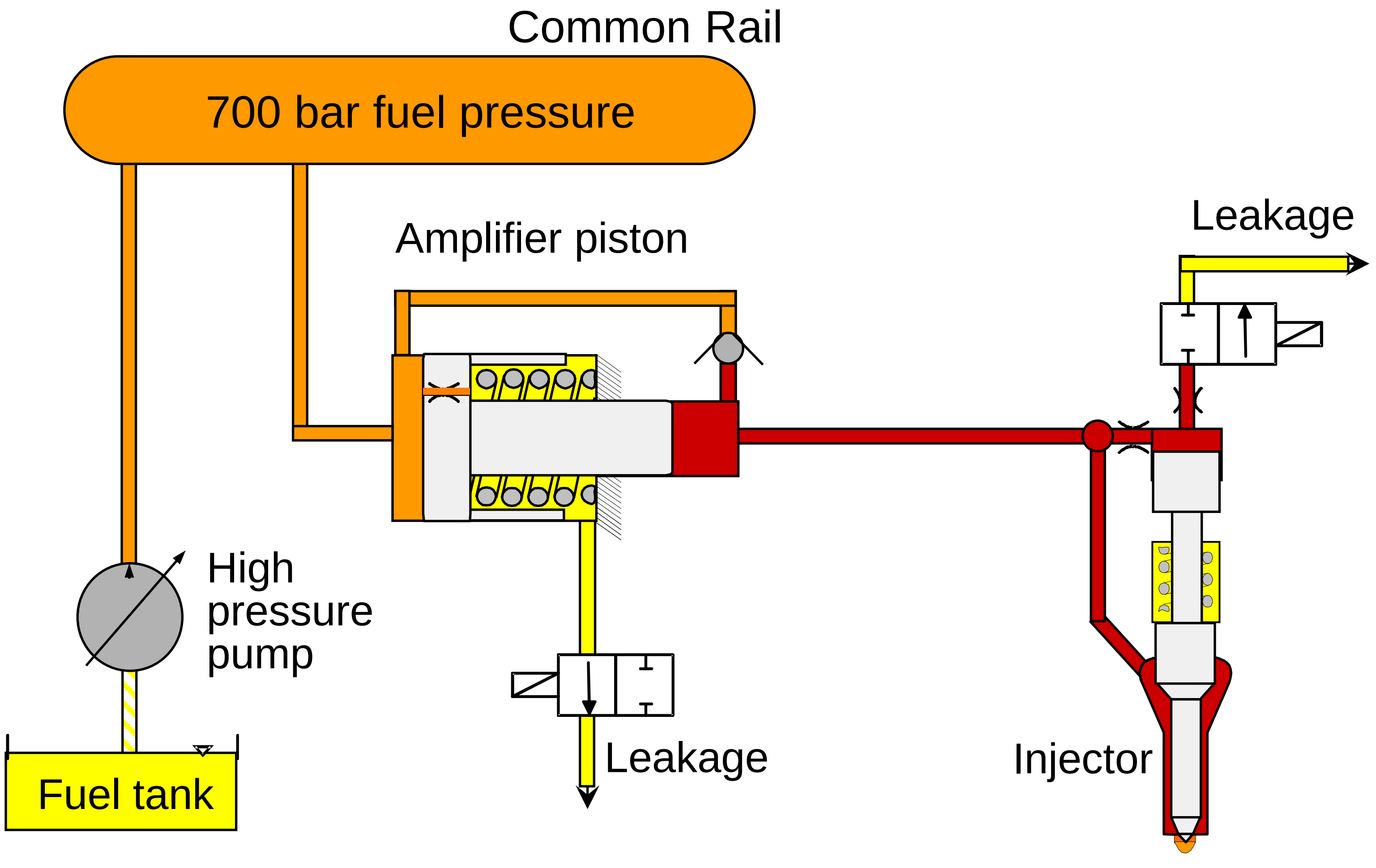


Regeneration of the particle filter is the challenge!

Diesel Emission Reduction Technologies - EGR

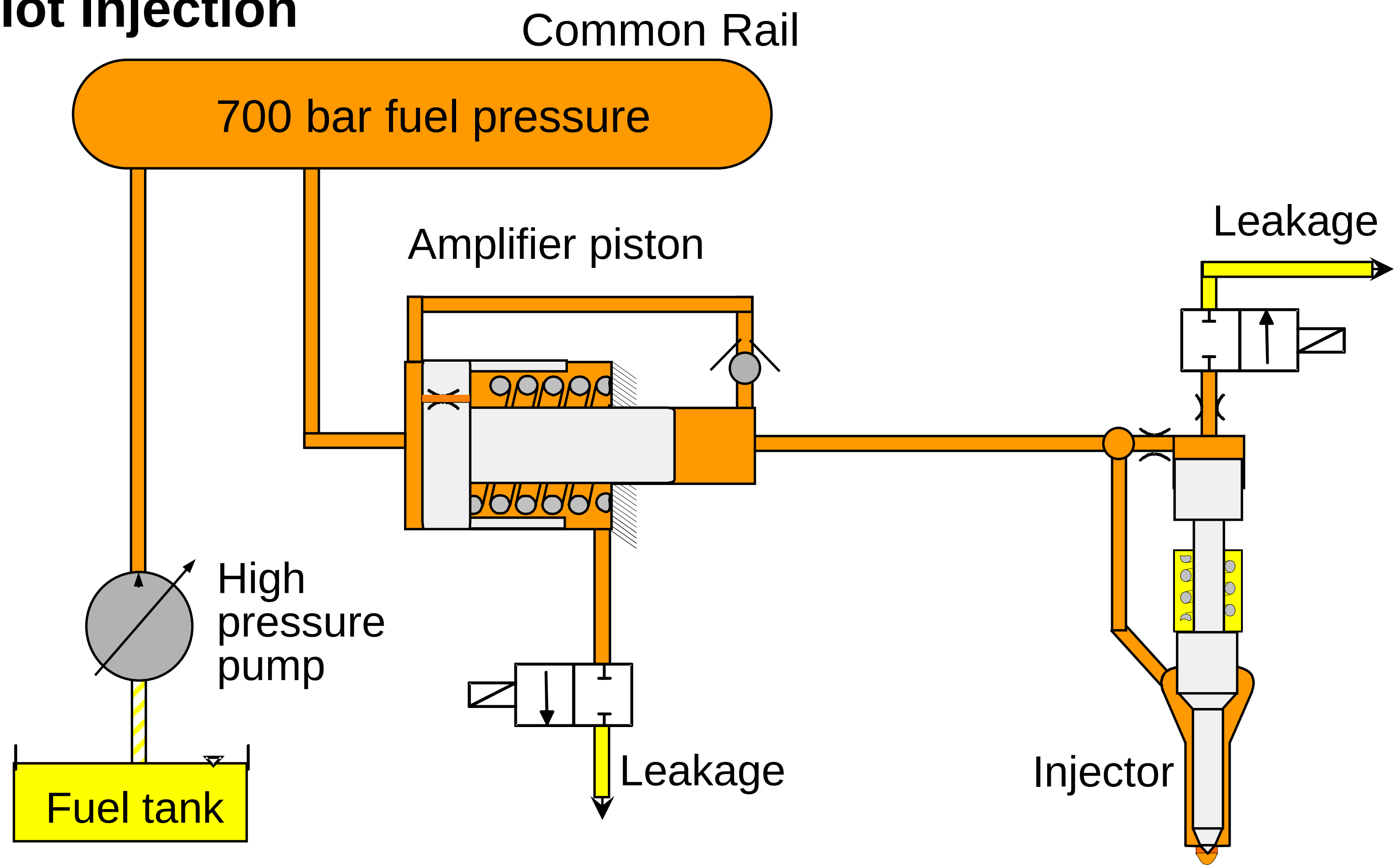


High Pressure Amplifier Piston CR System APCRS – Schematic View



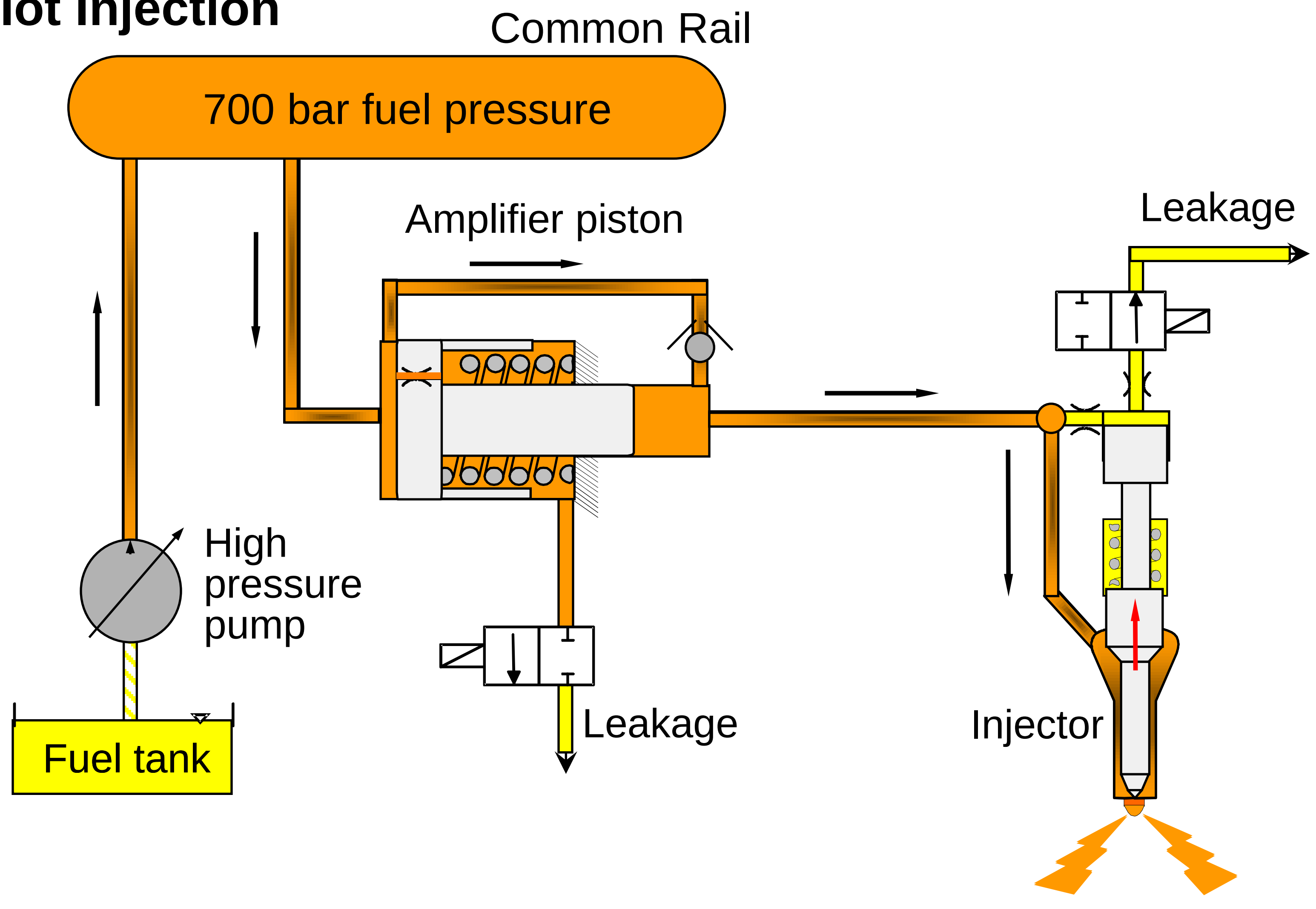
High Pressure Amplifier Piston CR System APCRS – Schematic View

Pilot Injection



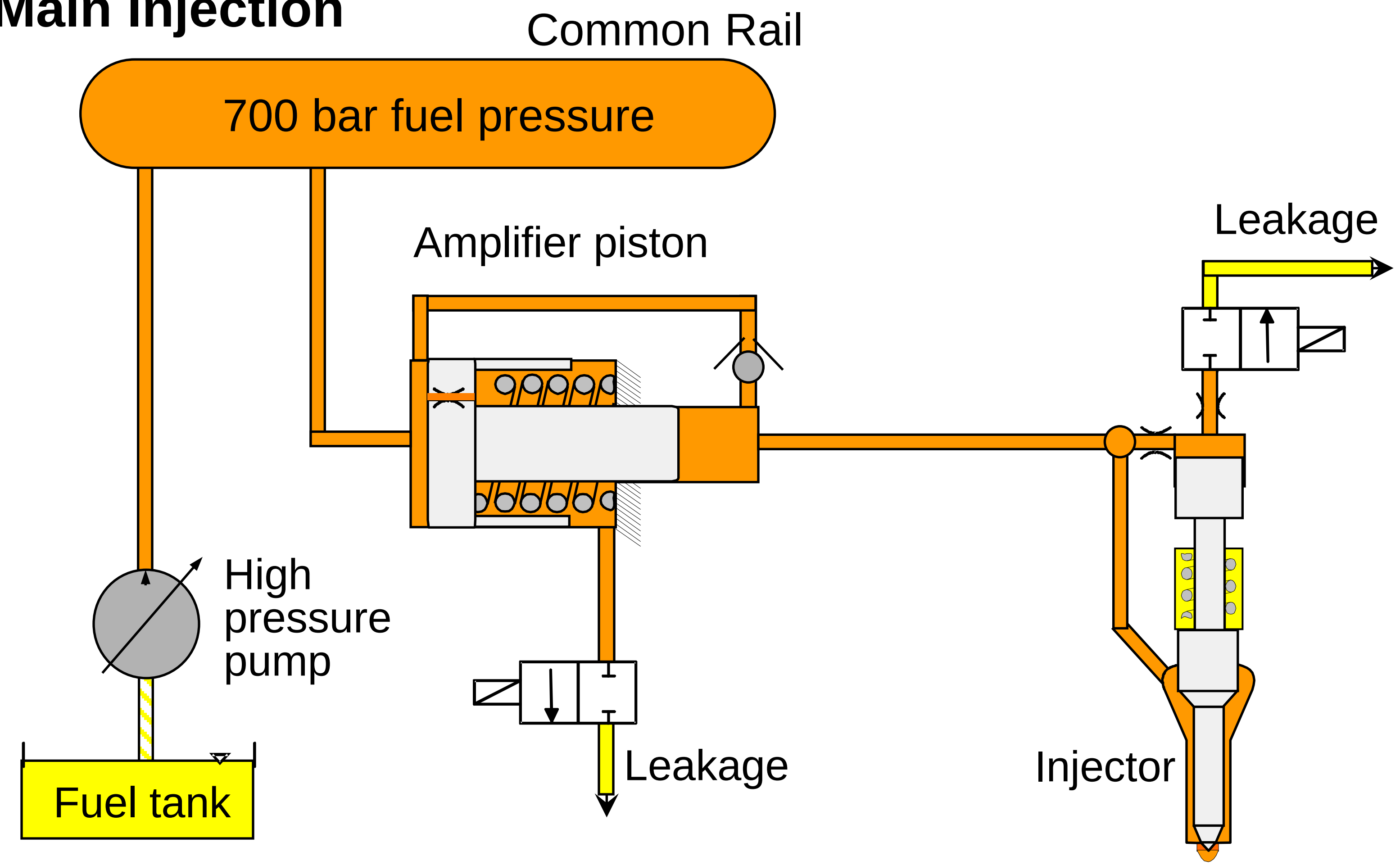
High Pressure Amplifier Piston CR System APCRS – Schematic View

Pilot Injection

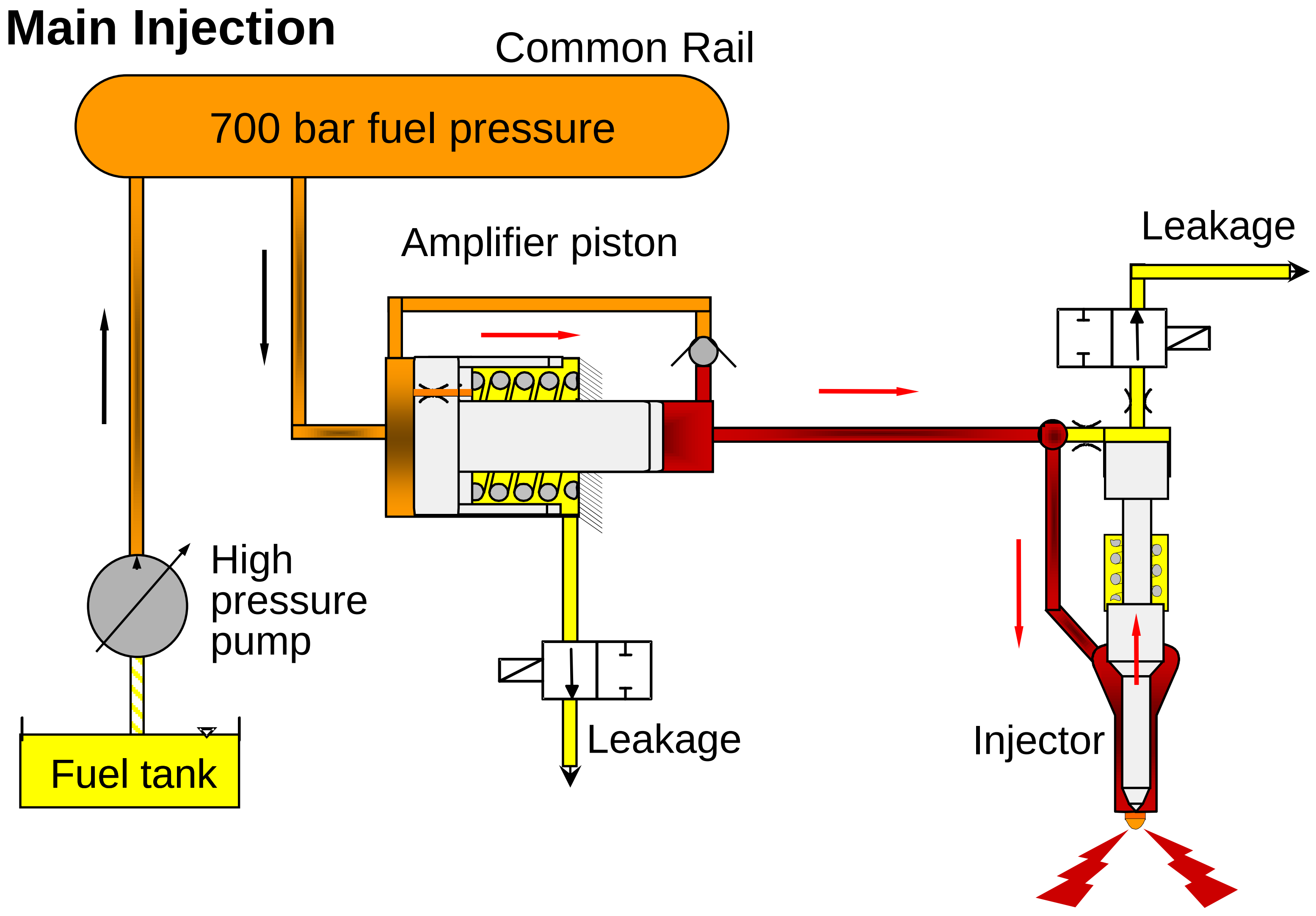


High Pressure Amplifier Piston CR System APCRS – Schematic View

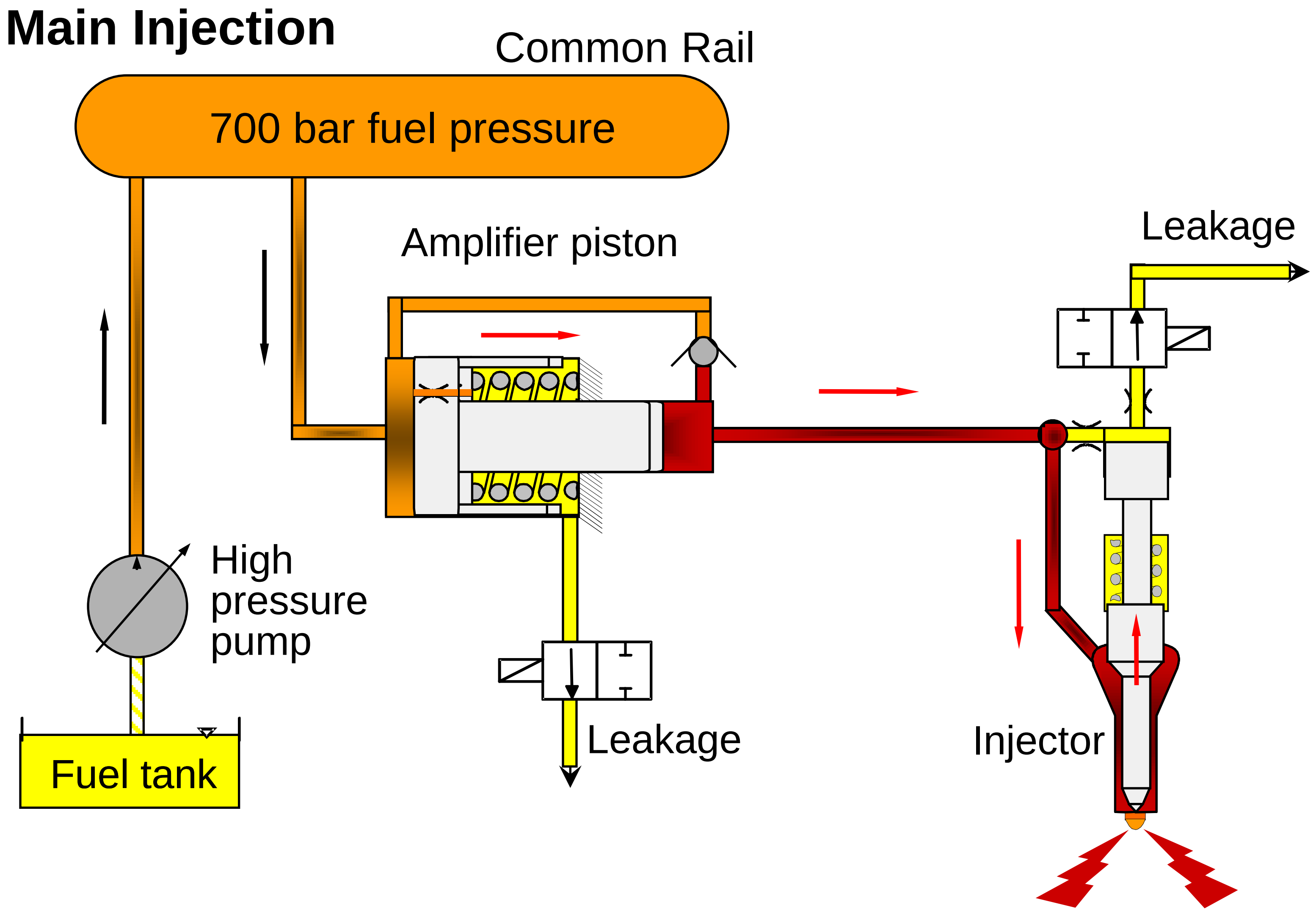
Main Injection



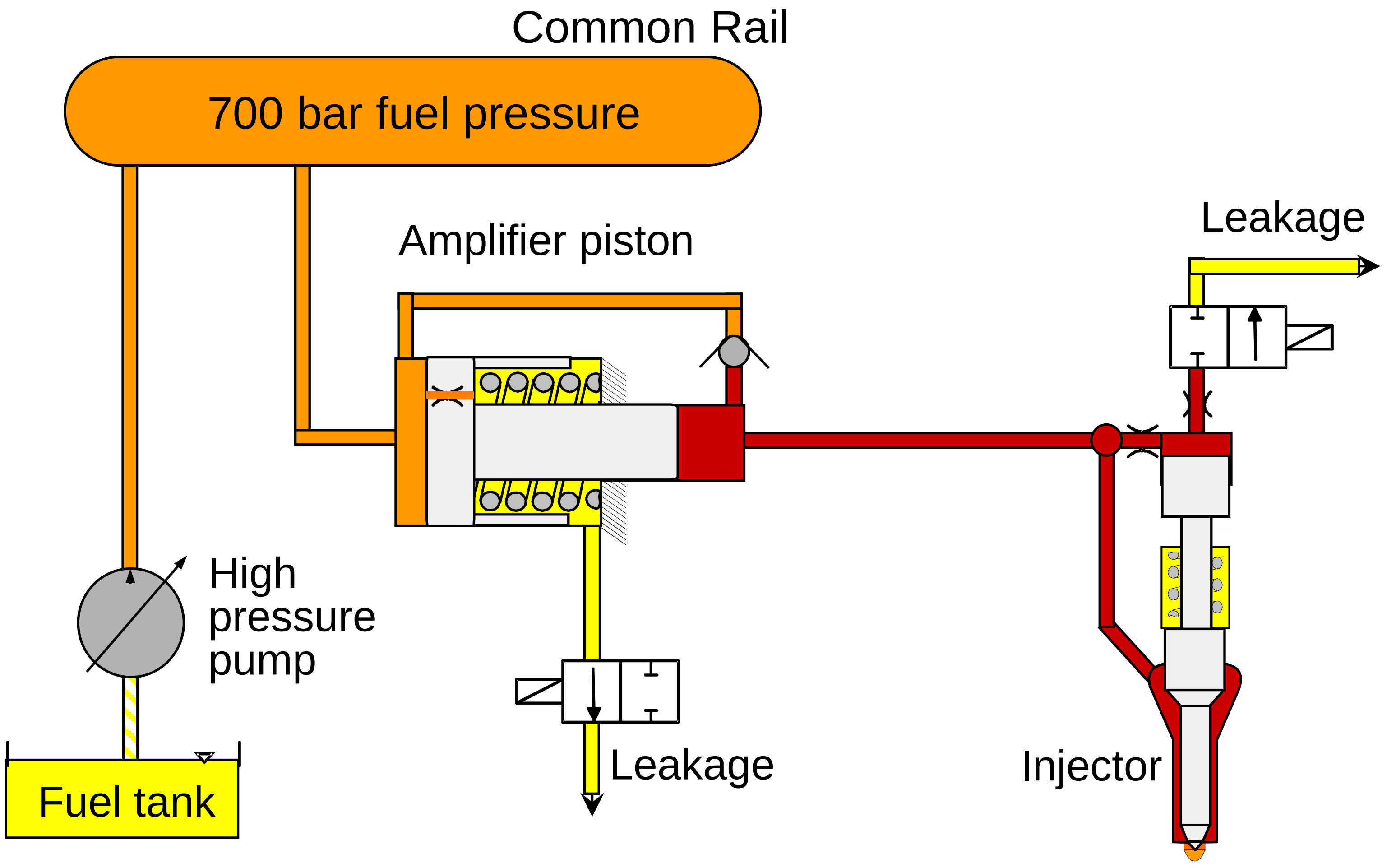
High Pressure Amplifier Piston CR System APCRS – Schematic View



High Pressure Amplifier Piston CR System APCRS – Schematic View

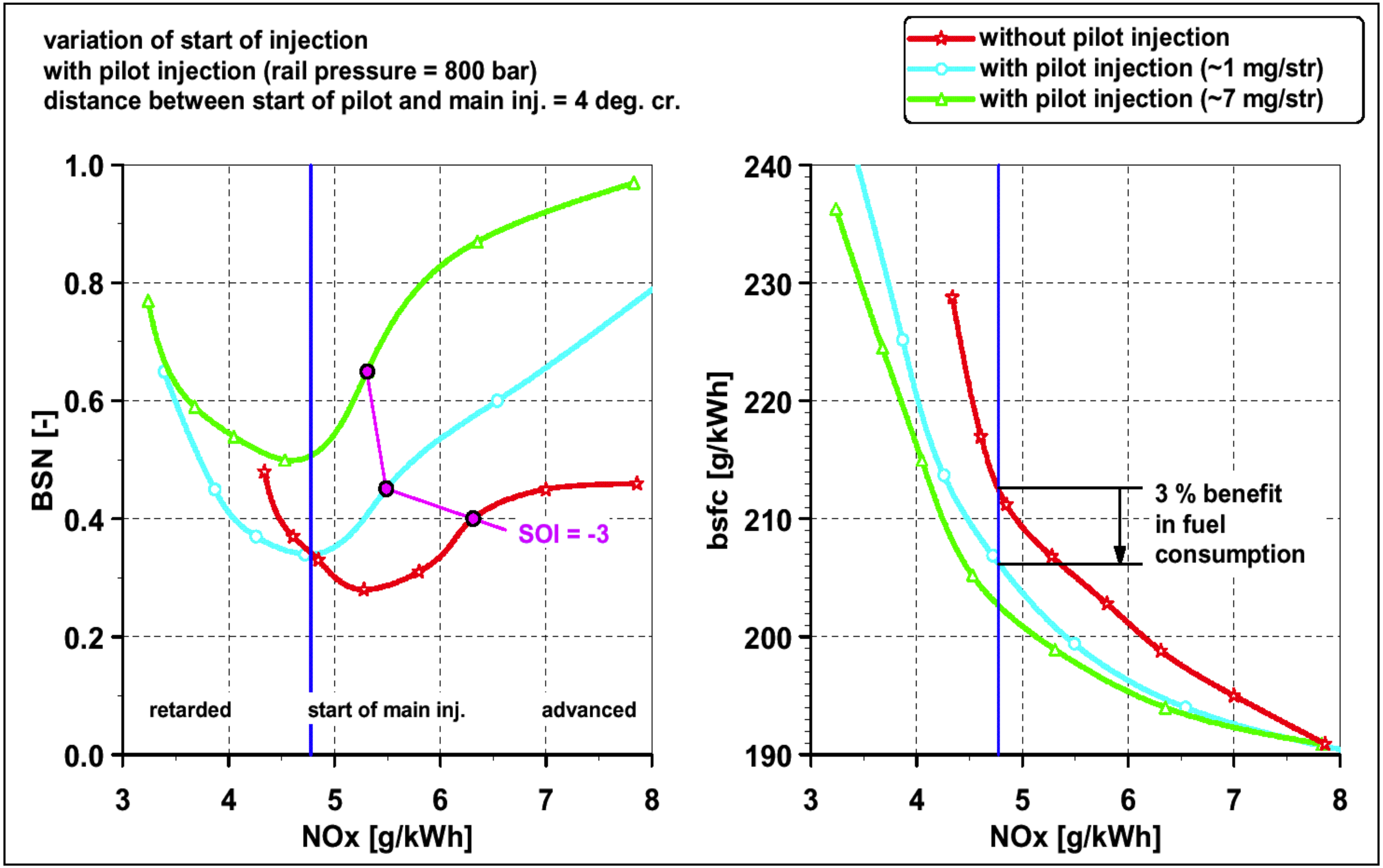


High Pressure Amplifier Piston CR System APCRS – Schematic View

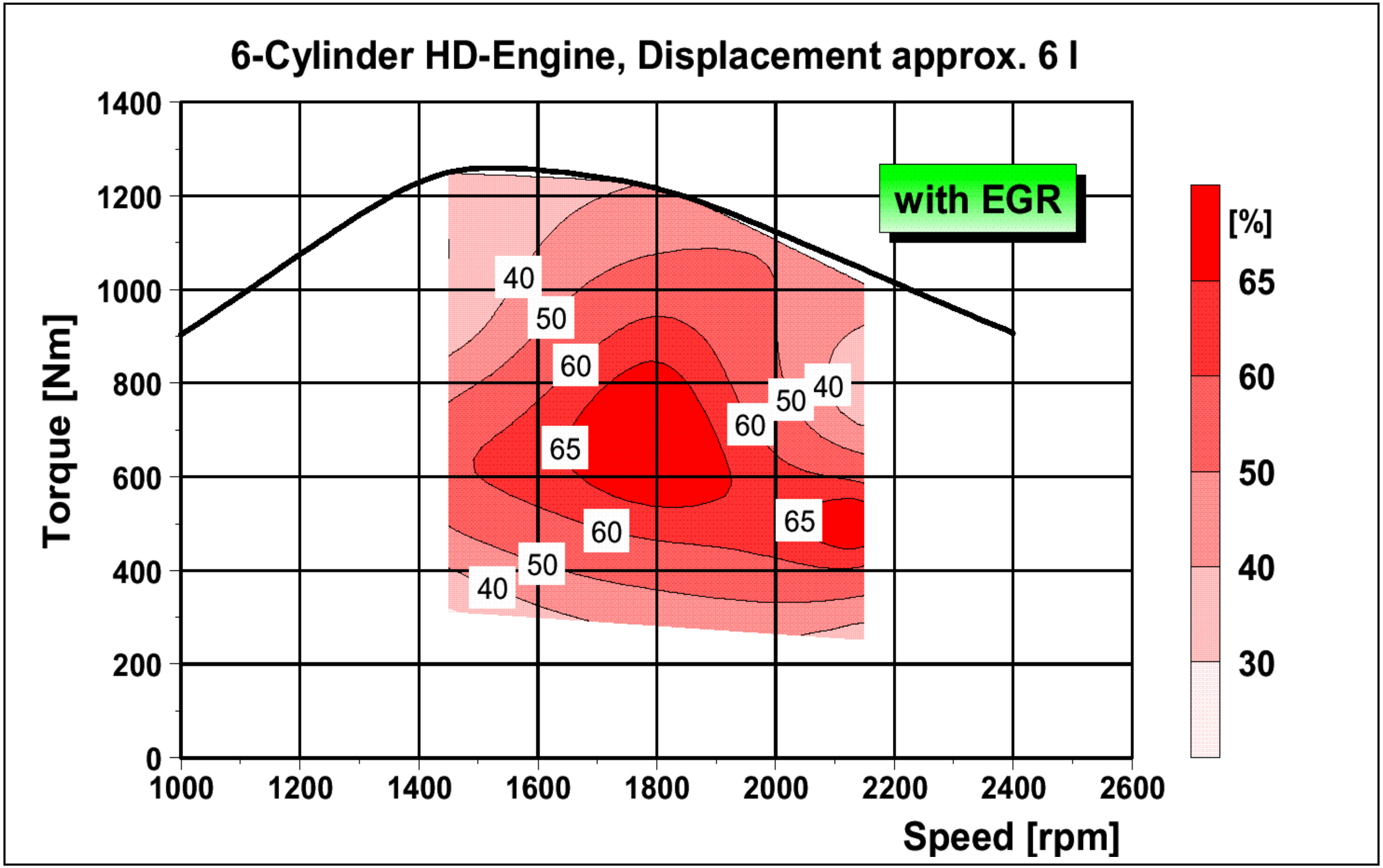


HD-Engine with CRS, Pilot Injection

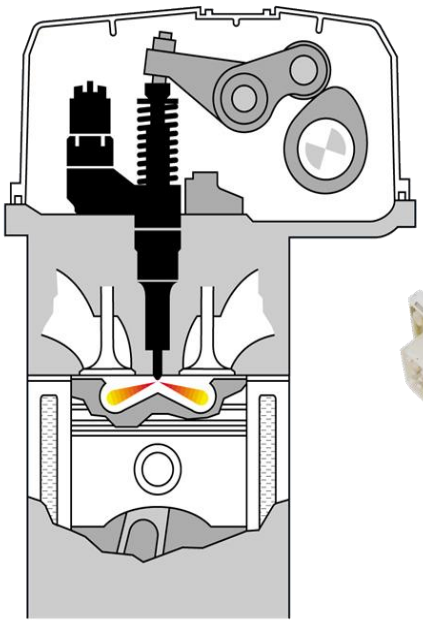
n = 1200 rpm, full load

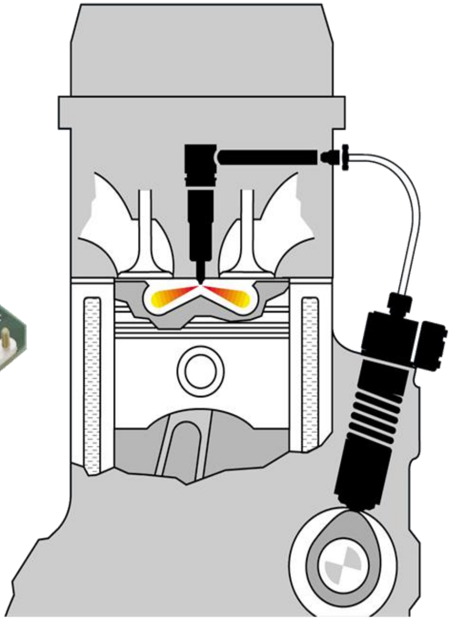


Possible Black Smoke Reduction with Post-Injection

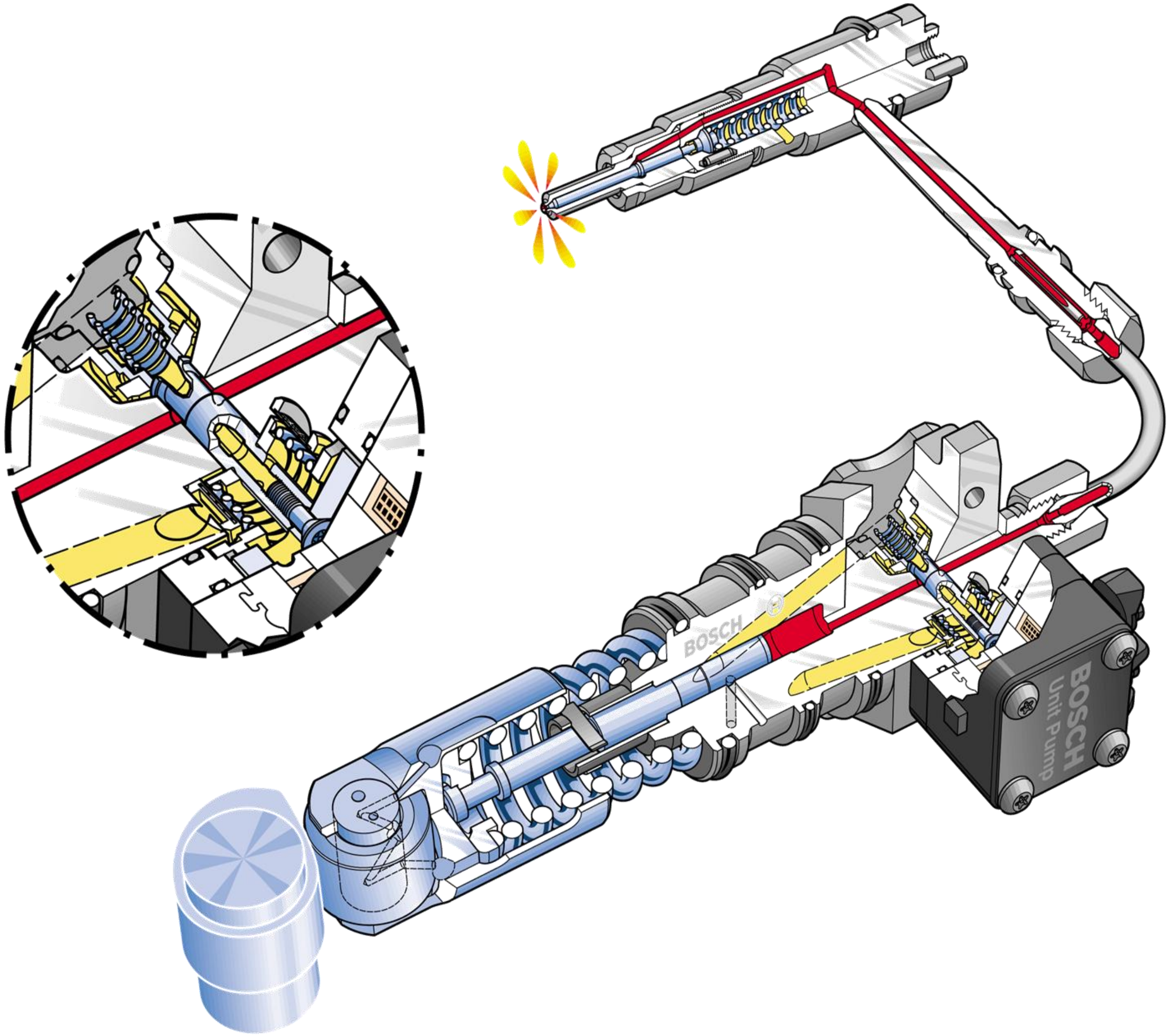


Unit Injector and Unit Pump for Commercial Vehicles

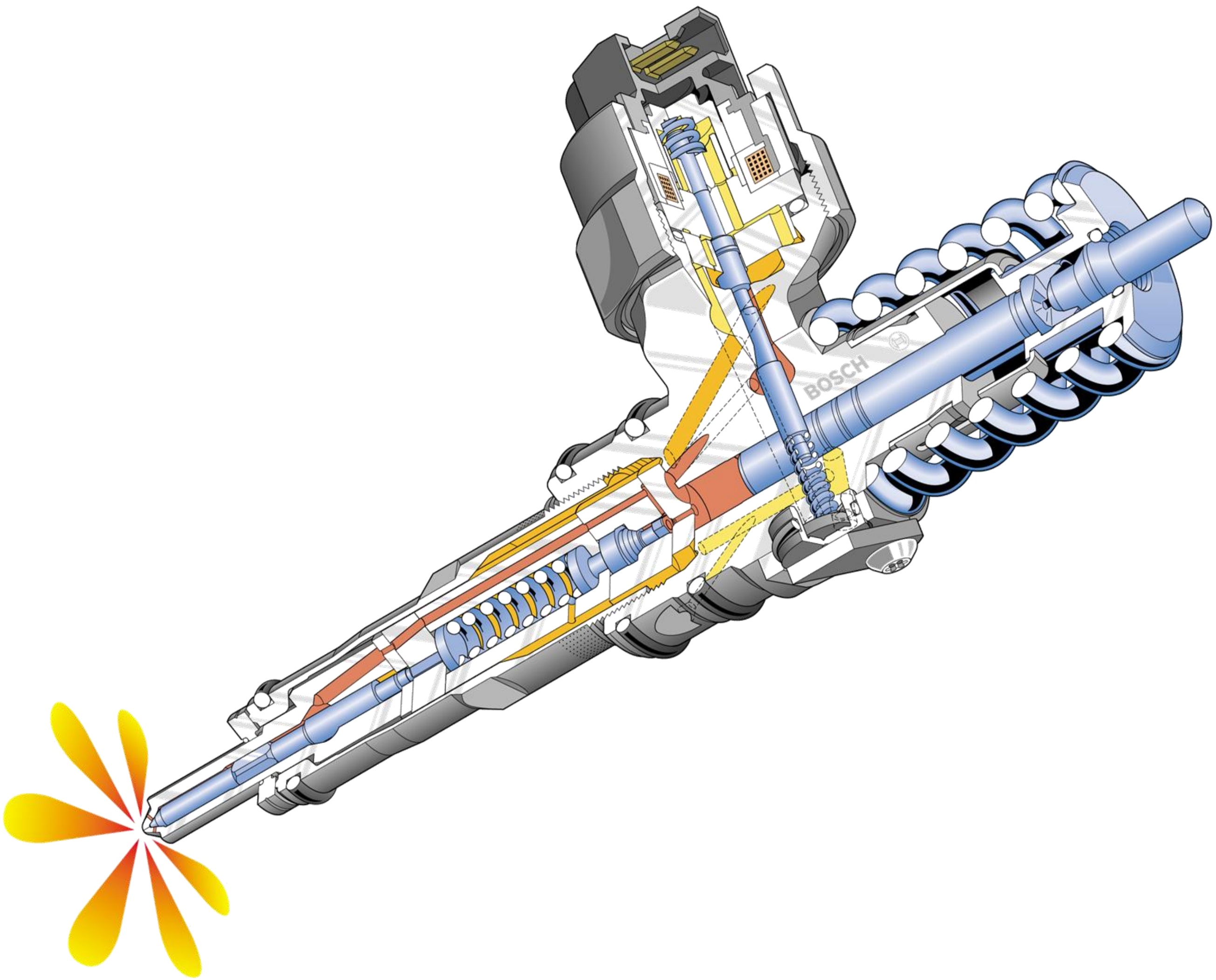




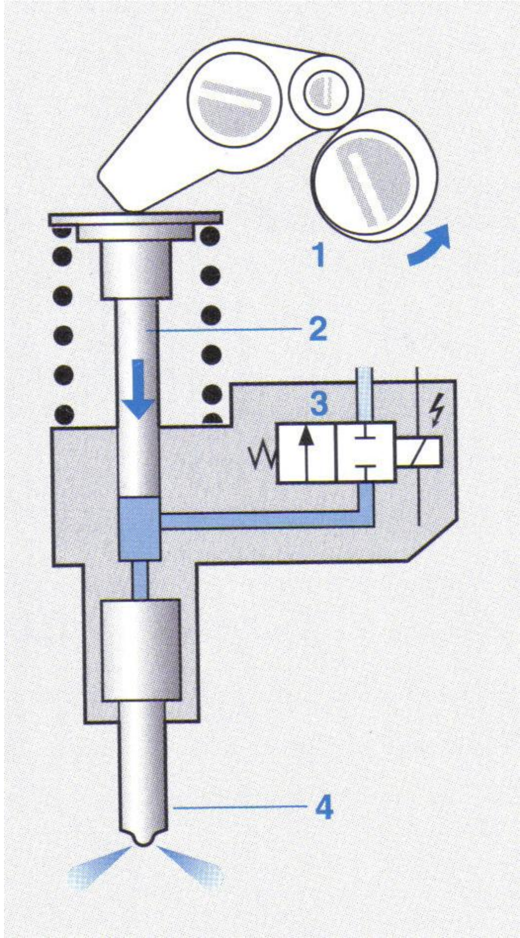
Unit Pump for Commercial Vehicles



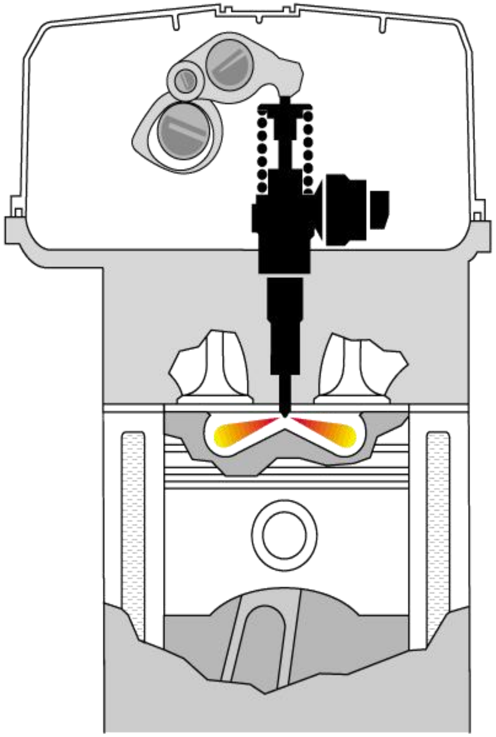
Unit Injector for Passenger Cars

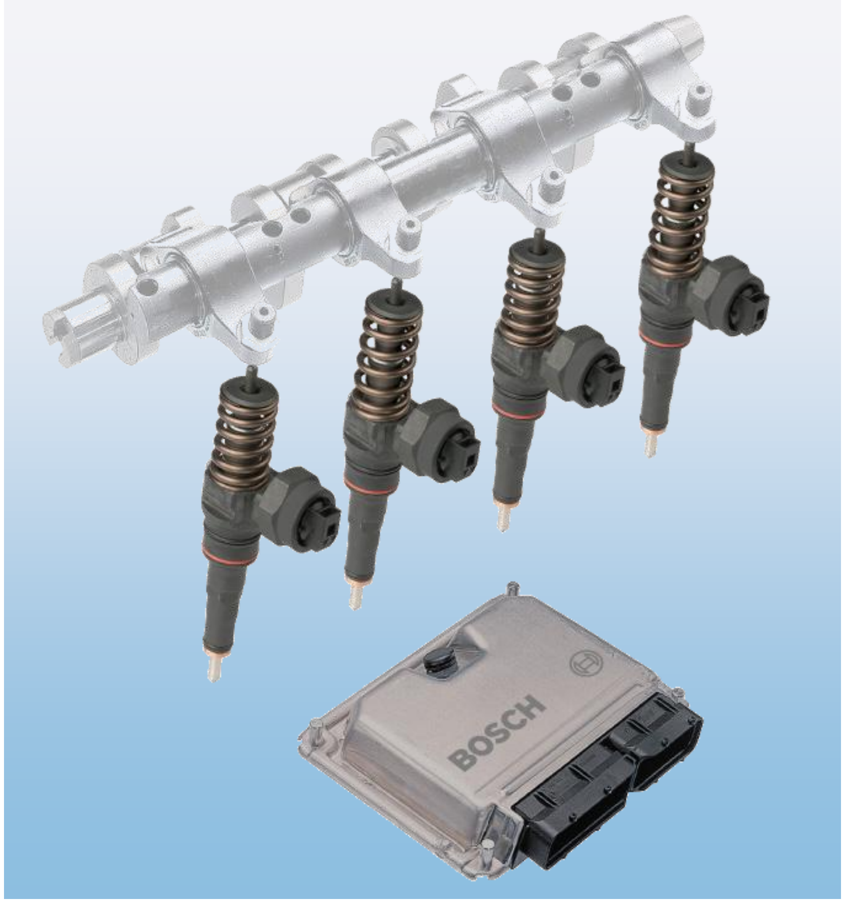


Unit Injector for Passenger Cars

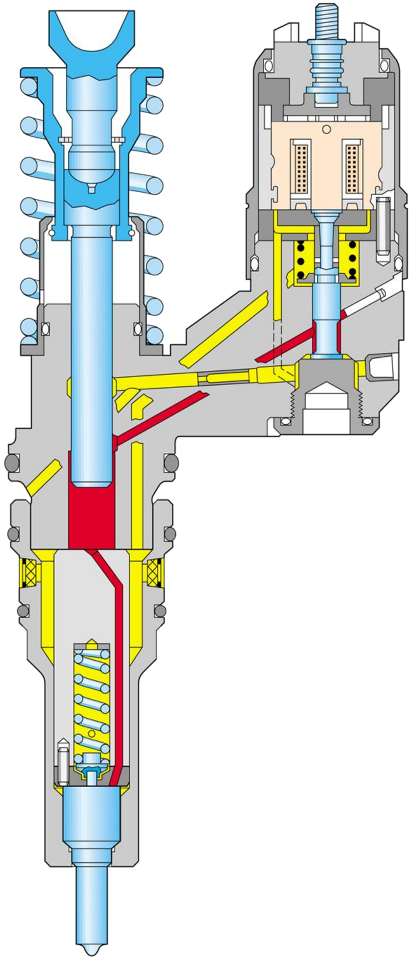


Unit Injector System for Passenger Cars



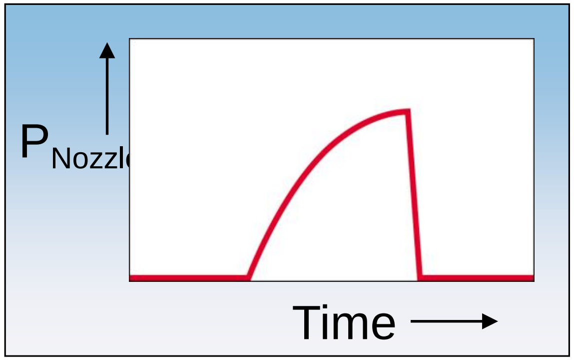


Unit Injector System – Generations G1 and G2

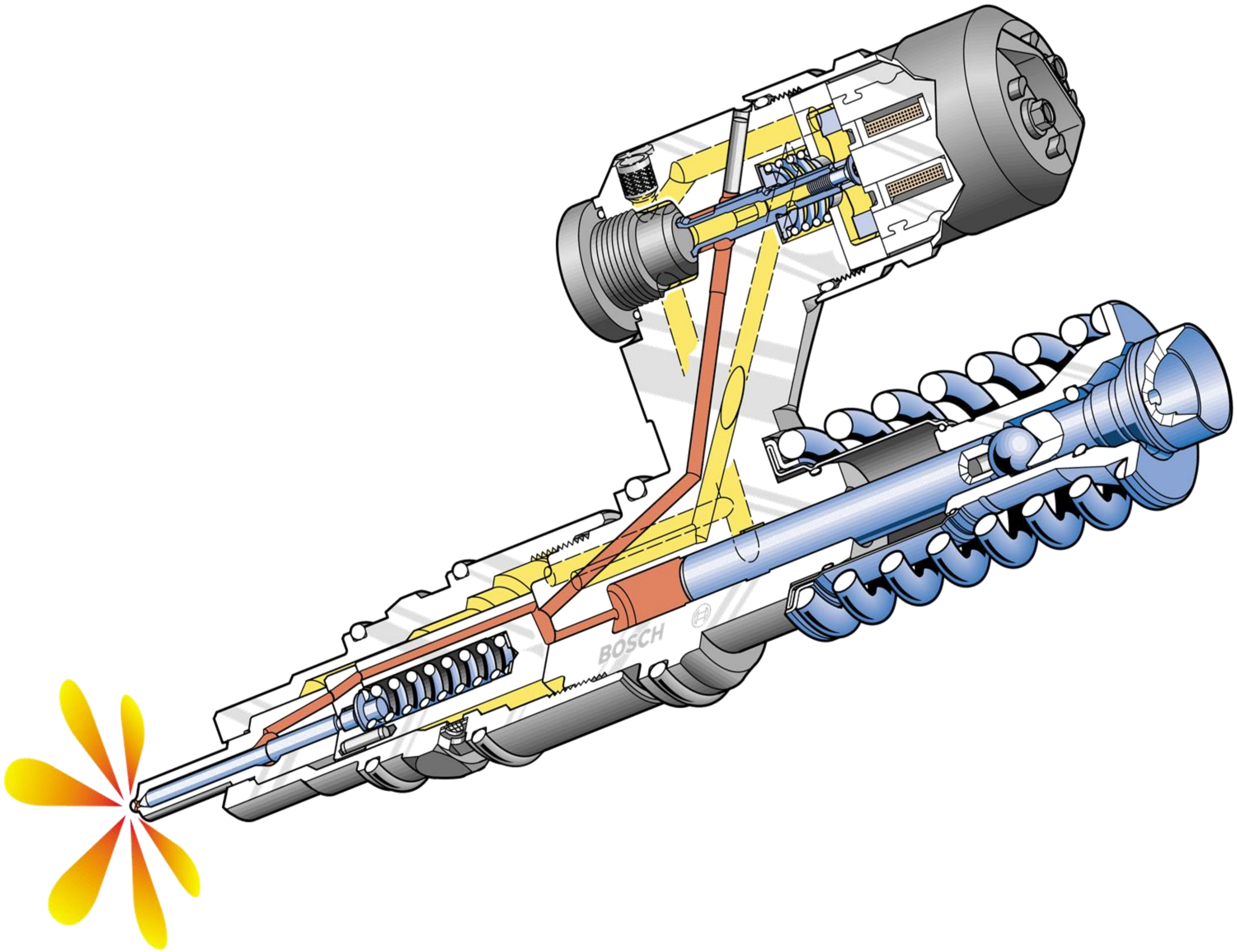


Generation N1 : 1600 bar

Generation N2 : 1800 bar



Unit Injector for Commercial Vehicles



Applications of Diesel Fuel-Injection Equipment