COMMERCIAL VEHICLES AND THEIR CONTRIBUTION TO ENVIRONMENTAL PROTECTION

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Environmental Protection and the Commercial Vehicle

The Mercedes-Benz Concept

Working for the Environment

Mercedes-Benz Commercial Vehicles

Low Emission Vehicle

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Foreword

Environmental protection and the motor vehicle is a topic which not only has a decisive impact on product policy within companies but which is also regularly featured in the media. What the general public often fails to realize is that this is in part an extremely complex issue. The partial views which are frequently shown lead to false conclusions and generate ill-feeling.

The automotive industry is - and has long been - favourably disposed towards the concept of protecting the environment, as concrete evidence shows. The industry began phasing in the reduction of pollutant emissions at an early stage, for example, and at its own initiative commissioned research into the dissemination and effects of airborne pollutants.

Mercedes-Benz was the first company to announce that a drastic reduction in pollutants in passenger car exhaust from petrol-engined vehicles was a real possibility in Europe with the aid of catalytic converters, provided that unleaded petrol was introduced and uniform European procedure agreed upon. Mercedes-Benz was then also the first company to offer its full range of petrol-engined passenger cars with catalytic converters as standard equipment on the German market, beginning in September 1986.

A further step was to introduce an improved combustion process for all passenger car diesel engines, leading primarily to a further clear reduction in what were already low particulate emissions.

The environmental strategy of Mercedes-Benz is based on three pillars:

Firstly, the development of innovative vehicle engineering to further reduce exhaust and noise emissions. This is the subject of the presentation.

Secondly, the creation of a concept of intelligent traffic management on which Mercedes-Benz is working for example within the "Traffonic" project.

Thirdly, the optimization of the commercial vehicle as a mode of transport in terms of its economic and ecological performance.

The environmental objectives of Mercedes-Benz for passenger cars and commercial vehicles are basically the same. There is however a degree of divergence, resulting from differences in engineering, applications, legal provisions, economic considerations, etc.

In the commercial vehicle sector, Mercedes-Benz is present at national and international levels with an exceptionally wide range of vehicles. This has made it important for the company to provide objective information on key aspects of the relationship between the commercial vehicle and the environment.

The primary aim has always been to make it clear that, for commercial vehicles too, an overall European concept must be developed.

The Mercedes-Benz Concept describes objectively the current state of the art and indicate the options available for the future.

Mercedes-Benz
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1. The role and significance of commercial vehicle transport

In any modern economy featuring the division of labour, the aspect of mobility is virtually as important in goods transport as it is in the passenger sector. In goods transport, structural change has come about as a result of changes in the nature and composition of the goods to be transported. This has been accompanied by local change, caused by a shift in the pattern of industrial locations. Of all conventional means of transport, the commercial vehicle with its loading and unloading techniques has proved best able to cope with the process of change sketched out below:

- The demand for mass mainstream transport over long distances has receded. This has been accompanied by an ongoing increase in the transport of high-value, fragile goods, requiring punctual, careful and flexible handling.
- Industrial and commercial locations have changed, too. Companies are to be found in increasing numbers in urban areas or even on country sites.

Together with a finely developed road network, modern commercial vehicles form the ideal link between various manufacturing sites, as well as between manufacturer, dealer and end-user. Despite all opinions to the contrary, the commercial vehicle is an integral, indispensable part of this system, replaceable only where sensibly bundled long-distance transport requirements which match the door-to-door logistical concept of the railways in full or at least in part, can be handled by rail.

But the commercial vehicle also has a major role to play in supplying municipalities and communities and dealing with waste disposal. Its wide specific range of applications is based on the manifold requirements which have led to the development of an extensive range of variants, adapting the commercial vehicle to the role of special-purpose transporter.

The continuing exceptional importance of the commercial vehicle is further illustrated by the following statistics:

- In the Federal Republic of Germany, recent years have seen a continuous increase in the commercial vehicle population, capacities, the volume of commercial vehicle traffic, volumes transported and distances covered. In 1990, the commercial vehicle population in the five new German states grew by 5.1 percent. For the whole of Germany the commercial vehicle population now stands at 3.1 million units.

- Just over 80 % of the overall volume of goods transported within Germany (1989: 100 % = 3.196 million tonnes) is carried by commercial vehicles, 72 % of which is accounted for by short distance runs (as defined in German Goods Traffic Law) with long-distance transport making up the remaining 28 %. In terms of actual trips, the ratio of local to long distance has been steady at 9:1 for a long time now. This demonstrates the continuing crucial role played by trucks in local goods traffic.

- In terms of tonne/kilometres, trucks account for 47 % of the total volume transported (1989: 100 % = 241 billion t/km).

But the significance of the commercial vehicle is not just the sum of transport capacity and performance figures but also lies in its importance for the economy as a whole.

- Of all modes of goods traffic the commercial vehicle is among the leaders in terms of covering directly attributable km-costs. Subsidies to cover operating losses are unknown in the road freight sector.

- The commercial vehicle industry plays a considerable role in terms of employment in the automotive sector - Germany's second largest branch of industry.

  About one third - i.e. one million - jobs in the German automotive industry are either directly or indirectly involved with commercial vehicle production.

- In 1989, the automotive industry was Germany's leading exporter. Commercial vehicles accounted for about one fifth of overall automotive exports which totalled some DM 120 billion.

Official traffic policy has gone over to call for intermodal concepts. Policy-makers are asking for the various modes of transport to be interlinked into transport systems that involve cooperation between road, rail, water and air transport. Their main concern is to reallocate the point of intersection centres or extend them accordingly.

One sensible modern approach, developed or re-developed towards the end of the sixties was intermodal transport in the form of containers, interchangeable bodies and rail trailer transport.

Growth rates witness to the intermodal concept:

- within ten years, rail trailer transport increased by over 100 % in terms of numbers of vehicles transported to a total of 663,000 units, while the volume of goods transported doubled to over 10 million tonnes.

- container traffic has not been able to match the rail trailer growth rate, rising in volume to 11.5 million tonnes.

- but even when these figures are added together, the volume of intermodal goods traffic still accounts for only a relatively low proportion of total domestic goods traffic in Germany.

Nevertheless, both in terms of organization and of the technology involved - notably with reference to trucks and truck bodies - intermodal transport has generated a surge of innovative engineering of proportions which, supported by modern transport logistics, is today without comparison anywhere in the field of goods transport.

But the demands of the legislators in traffic and environmental policy go still further. The strategy paper for the 90's, presented by the Federal Minister of Transport, states:

"The burden for man and the environment caused by traffic must be reduced even against a backdrop of rising mobility"

and

"Intermodal strategy calls for universal transport systems offering advantages for all modes of transport and having dimensions which will stand the test of time and be standardized worldwide."

The advantages of road haulage also emerge from the prognoses for its future development. Estimates already predict that goods transport by road will continue to increase. But driven by the advent of the single European market and now by the opening of the borders to the East and the liberalization of Eastern European markets too, the demand for goods transport will take on completely new dimensions, with particular impulses already being generated by the new German states. As in earlier times, the leading role here will fall to road transport.

Against this backdrop it is all the more important that the automotive industry should continue to concern itself with the impact of road traffic on the environment.

One major focus of our development activities therefore remains the aim of supplying commercial vehicles in future in which the sum of all the features - including primarily safety, economy and environmental compatibility - add up to the optimum vehicle.

CONCLUSIONS:

- **Goods transport by road, and thus the commercial vehicle, remains essential.**

- **Further optimization of safety, economic and environmental aspects has top priority.**

2. The proportion of total emissions attributable to commercial vehicles

In its 4th Report on Atmospheric Pollution, the German government provides the following figures for selected sources of pollution related to 1986:

Figure 1 - Atmospheric pollution table (see Annex)

The data for commercial vehicles are based on fuel consumption calculations and on Report No. 11/83 of the Federal German Environmental Agency [Umweltbundesamt (UBA)]. This report is by the technical inspectorate, T V Rhineland, commissioned by the UBA to study emissions behaviour of commercial vehicles in the Federal Republic of Germany for the year 1980.

Mercedes-Benz has on several occasions expressed public criticism of the results of this study. Criticism focused on:

- The way in which the handling of commercial vehicles was calculated using methods prescribed for passenger cars

- The way in which engine curves were generated for the entire commercial vehicle fleet on the basis of a measured characteristic curve.

2.1 Methods of calculating emissions

Calculating the emissions attributable to commercial vehicle traffic calls for data on the road-related emissions of each individual class of vehicle, the distances covered and the composition of the entire commercial vehicle fleet. A large number of factors have a direct bearing, all of which need to be taken into consideration. The required data are not yet or only partially available.

In order to overcome these problems temporarily, approaches are used involving models of typical handling characteristics and of what are considered typical emission factors and the results then extrapolated.

2.2 The Mercedes-Benz method

For its own emission calculations, Mercedes-Benz conducted road tests using a truck tractor combination on selected test routes in laden and unladen condition. The test routes were selected to correspond in terms of routing to as high a proportion of German roads as possible. Taking the load and speed spectrums resulting from these road tests, those partial emissions factors for NOx and particulates were determined from the exhaust curves which correspond closely to those deduced from typical handling models for a comparable vehicle.

Figure 2 - Nitrogen oxides and particulate emissions for the year 1986 (see Annex)

A counter check using the emission factors arrived and the data on distances covered for the year 1986 revealed a discrepancy of 30 % between Mercedes-Benz findings and those of the 4th Report on Atmospheric Pollution for nitrogen oxides and an even greater discrepancy of 87 % in the case of particulate emissions.

2.3 The Commercial Vehicle Emissions working group

In the meantime, the German government has convened a "Commercial Vehicle Emissions" working group in which experts from government, technical inspectorates, science and industry are developing improved calculation methods. Mercedes-Benz expects their work to produce important findings which will enable the real proportion of overall emissions attributable to commercial vehicles to be estimated reliably.

CONCLUSIONS:

- **The official government figures for the proportion of overall emissions attributable to commercial vehicles are based on inadequate data.**
- **The emission factors calculated for 1980 do not correspond to the realities of everyday driving.**
- **An improved method of calculating commercial vehicle emissions is currently being developed by a government working group.**

3. European exhaust emissions legislation for light commercial vehicles up to 3.5 tonnes gvw.

In the past, legislation on emissions from commercial vehicles has been developed on the basis of two classes of vehicle:

- vehicles of up to 3.5 tonnes gvw.
- vehicles of over 3.5 tonnes gvw.

The documentation is therefore drawn up along these lines.

3.1 Gaseous emissions

In the Federal Republic of Germany, light commercial vehicle emissions of carbon monoxide (CO) and hydrocarbons (HC) have been restricted by law since the early 70's. In 1977, restrictions on emissions of nitrogen oxides (NO_X) were added and the prescribed limits have since been tightened considerably.

Figure 3 shows the development of European exhaust legislation for light commercial vehicles with a maximum gvw. of 3.5 tonnes. Legislation was introduced in 1971 and has since been tightened in several stages throughout Europe.

Figure 3 - European exhaust emissions legislation - gaseous emissions from light commercial vehicles (see Annex)

The Geneva Directive ECE-R 15 was translated by the European Community into EC directives which are binding upon member states and which have also been subsequently tightened in stages. The fifth such stage, EC Directive 88/76, must be complied with in the Federal Republic of Germany by new models introduced since October 1, 1989 and by all light commercial vehicles which have come onto the road since October 1, 1990.

Unfortunately the introduction of uniform exhaust emissions regulations for light commercial vehicles throughout Europe has not proved possible. While the EC has stayed with the European cycle and the limits which were last tightened in 1990 for this class of vehicle, other countries such as Norway, Austria, Switzerland and Sweden have incorporated a modified form of the current US regulations into their national legislation.

As the US test cycles, limits and test conditions differ from their EC/ECE counterparts, the results of the two tests cannot be correlated.

3.2 Diesel smoke and particulate emissions

The diesel smoke of all diesel engines is restricted by ECE-R 24, translated by the EC into Directive 72/306/EEC and binding upon all member states. The ECE test procedures are described in chapter 4.

CONCLUSIONS:

- **European exhaust emissions regulations for light commercial vehicles have been tightened in five stages since their introduction in 1971.**
- **For light commercial vehicles with a maximum gvw. of 3.5 tonnes there is no sign of uniform exhaust emissions regulations being introduced either throughout Europe or worldwide in the foreseeable future.**

4. European exhaust emissions legislation for commercial vehicles of over 3.5 tonnes gvw

It has often been proposed that current US regulations be adopted for heavy commercial vehicles. In contrast to the passenger car sector where adopting US regulations makes sense, the current US test procedures for testing gaseous emissions from commercial vehicles, known as the Transient Test, do not on the whole reveal any findings not available from European test procedures in line with ECE-R 49. The ECE-R 49 assessment procedure corresponds to European conditions in that the test points at maximum torque and at rated output in particular are more heavily weighted than the remaining partial load points, reflecting more closely commercial vehicle operation in Europe (Figures 4 & 5).

Figure 4 - Operating frequency curves of a 40-tonne long-distance truck-trailer combination (see Annex)

Figure 5 - Operating frequency curves of a 10-tonne truck on urban and intercity runs (see Annex)

This explains why the EC and other European states have decided to base the further reduction of pollutants in commercial vehicle exhaust on a global concept, itself based on ECE-R 49 and derived from ECE-R 24 as far as smoke limits are concerned.

The individual regulations that form this concept are explained below.

4.1 Diesel smoke

ECE-R 24 limits visible smoke emissions. By comparison with other national regulations, ECE-R 24 is strict and its provisions, which have become part of EC Directive 72/306/EEC, are binding on EC member states.

Figure 6 - ECE smoke test (see Annex)

The test is conducted stationary and at full load at various engine speeds on an engine test bench.

4.2 Gaseous emissions, particulate emissions, the 13-point test

In the US, a 13-point test was devised in the 70's to determine levels of carbon monoxide (CO), nitrogen oxides (NOx) and hydrocarbons (HC) and permissible limits laid down. The Economic Commission for Europe (ECE) at the United Nations then commissioned Clausthal-Zellerfeld university to adapt this test to European motoring conditions and it's adoption as ECE-R 49 was then recommended to the member states in April 1982.

Figure 7 - Measuring points and weighting factors in the ECE 13-point emissions test (see Annex)

ECE-R 49 was in 1988 subsequently adopted by the EC as EC Directive 88/77/EEC. In the process, the limits recommended by the ECE were tightened by 20 % for NOx and CO and by 30 % for HC. Since October 1, 1990 all vehicles coming onto the road have been required to comply with this directive.

Transient Test

As of model year 1985, the stationary 13-point test was succeeded in the US by a non-stationary test procedure known as the Transient Test designed to simulate dynamic urban and highway driving conditions (Figure 8). It can however be more than adequately described by the stationary 8-point test developed by AVL (Figure 9).

Figure 8 - Torque and speed curves in the US Transient Test for commercial vehicle diesel engines (see Annex)

Figure 9 - Measuring points and weighting in the AVL 8-point Transient replacement test (see Annex)

Studies involving many different engines and using both ECE-R 49 and Transient Test measuring procedures have shown that good correlation exists in terms of gaseous emissions (Figures 10 & 11), and that for particulate emissions too, which it is planned to limit within the EC as of 1992, the two procedures lead to similar results (Figure 12). The logical conclusion is to base future European emissions legislation on the far more practical ECE procedure.

Figure 10, 11, 12 (see Annex)

Correlation of the test results using ECE-R 49 and US Transient Test procedures

4.3 Future developments in Europe

With Directive 88/77/EEC, based on ECE-R 49 but with more stringent limits, the EC imposed initial limits on commercial vehicle emissions. According to a resolution passed by the EC Council of Environment Ministers, these limits are to be further reduced in two stages, bringing them in line with developments in the US where pollutant emission levels are reduced in accordance with the current state of the technological art. Figure 13 provides an overview of the proposed concept.

Figure 13 - Steps towards reducing emissions (homologation levels ECE-R 49, 88/77/EEC, "Euro I", production engine limits "Euro II") (see Annex)

Implementation of the extremely demanding limits of stage 2, planned for 1995, presupposes the availability by then of high quality diesel fuel, low in both sulphur and aromatics. But very real problems will be encountered in view of the excessively short period allowed for the conversion of the complete engine range.

In the opinion of Mercedes-Benz, this international-scale concept will lead to effective reductions in commercial vehicle emissions in Europe. Solutions at national level, on the other hand, must be rejected in view of the international integration of road traffic. Only pan-European consensus can provide the key to an effective solution to supranational environmental problems.

CONCLUSIONS:

- **Supplemented by particulate measuring procedures, ECE-R 49 provides the best basis for European emissions legislation for commercial vehicle engines. There is no need to adopt the more complicated US Transient Test.**
- **In its commercial vehicle engine development and re-development efforts, Mercedes-Benz has voluntarily implemented ECE-R 49 for years now.**
- **Since early 1988, all newly certified Mercedes-Benz engines remain below the limits prescribed by ECE-R 49 by at least 20 % for NO_X and by at least 40 % for HC and CO.**
- **According to the proposal of the European Commission, future emissions legislation will see the introduction of a further considerable reduction in maximum emission levels, beginning in 1992. Even before the proposal is adopted, Mercedes-Benz is committed to complying with the envisaged limits as quickly as possible.**

5. Main development objectives for diesel engines in commercial vehicles

High economy, low pollutant emissions as well as low noise levels are the most important development objectives for commercial vehicle engines. However, these are requirements which contain a number of conflicting objectives.

Optimization work is therefore only worthwhile when the objectives and their priorities are specified long-term and not continually being changed.

The principle development objectives for commercial vehicle diesel engines in detail can be described as follows:

Economy (consumption):
Engine and drivetrain are developed to the highest level of economy. The engine characteristics, in other words the power and torque curve, are designed so that it is always possible to drive in the range of lowest fuel consumption. Combustion was previously designed for the most economical fuel consumption while keeping pollutant emissions as low as possible. However, the priorities have changed now.

Low emissions
Today and even more so in the future, the aim is to achieve the lowest pollutant emissions while keeping fuel consumption as low as possible (Figure 14).

Figure 14 - Fuel consumption characteristics of Mercedes-Benz commercial vehicle diesel engines (see Annex).

Hereby the emphasis must be on the reduction of NO_X and particulates. The HC and CO emissions of diesel engines are already so low that they are even lower than the values obtained with petrol engines fitted with a catalytic converter with lambda probe.

Low emission of smoke
Basically the emission of visible smoke should be avoided in all operating ranges. For naturally aspirated engines this means reducing performance as well as optimizing combustion. In particular, on engines with exhaust gas turbocharging, measures must be taken to optimize the transient range i.e. when starting off and accelerating. This affects both turbocharging as well as injection techniques.

Emissions of particulates
Measures within the engine to reduce smoke can be effectively supplemented by exhaust gas aftertreatment techniques. Particulate filters offer a particularly effective method of significantly reducing particulates, especially in heavy urban traffic. By using an oxidation catalyst, which of course requires the use of low-sulphur fuel if an increase in sulphur emissions is to be avoided, the odour of the exhaust gases is significantly reduced and a further reduction in CO and HC emissions achieved.

NO_X emissions

NO_X emissions from diesel engines cannot be reduced using the established three-way catalytic converter as in petrol engines due to the excess of air in the diesel combustion process. Thus measures within the engine are used which minimize formation of nitrogen oxides at low combustion temperatures by delaying the start of the combustion process for as long as possible. Appropriate technical measures are turbocharging with charge-air intercooling and suitably optimized injection systems.

Low emissions during cold starting and warm up

A considerable reduction of white smoke emission arising due to unburnt fuel during cold starting and during the warm up phase of the engine, is achieved by using a flame system, as well as increasing the compression ratio. This system is now available as a standard production fitment on all Mercedes-Benz commercial vehicles with direct injection diesel engines.

Low noise emissions

The stringent requirements in terms of noise can only be met by drastic primary measures aimed at optimizing the engine and drivetrain in connection with partial and full encapsulation measures on the vehicle. Further significant reductions in noise will only be made possible by low-noise tyres and road surfaces.

6. Internal engine measures for reducing pollutants in the exhaust gas of diesel engines in commercial vehicles

World-wide, heavy commercial vehicles are powered almost exclusively by diesel engines with direct injection. The reason for this - apart from the robustness of this form of propulsion, is the low fuel consumption which cannot be matched by any other type of propulsion. Moreover, emission of gaseous CO and HC pollutants is extremely low on the diesel engine . Of particular significance is the fact that the reduction of NO_X leads to an increase in particulate emissions and fuel consumption.

6.1 NO_X emissions

The formation of NO_X i.e. the combination of atmospheric nitrogen with atmospheric oxygen - is basically determined by the combustion temperature level. The higher the temperature level in the combustion chamber, the better the thermal efficiency of the engine generally is, although at the expense of increasing NO_X emissions.

A method frequently used to reduce these NO_X emissions - on which so much attention is being focused - is that of delaying the start of delivery of the injection pump. This does, however, have a negative affect on particulate emissions and on specific fuel consumption (Figure 15).

Figure 15 - Influence of NOx reduction induced by delayed delivery on fuel consumption (see Annex)

Starting from 100% as a basic value, the deterioration of the other components is still relatively low for a 10 % reduction of NO_X levels. With further reduction in NO_X, however, these deteriorations increase very quickly and disproportionately to completely unacceptable levels.

6.2 Optimizing combustion and new engines

The complete Mercedes-Benz engine range has been revised in view of the more stringent emission regulations effective in Switzerland from October 1991 and in anticipation of future EG regulations. Only turbocharged engines with charge-air intercooling are available in the medium and upper output classes. Two new engines have been developed, the 6 cylinder OM 401 LA and the 8 cylinder OM 402 LA, which together with the OM 441 LA ensure that the optimum engine is available for each output range (Figure 16).

Figure 16 - Relative fuel consumption of the 400 series charge-air intercooled engines on different types of haul (see Annex).

Comparison of fuel consumption of the 400 series engines shows that under heavy-operating conditions the biggest volume of engines are most favourable whilst under light-operating conditions the low displacement engines have the edge. The customer can thus select the optimum engine for each application from the extended range of engines.

6.3 New combustion process

The combustion process of engines in the 400 series has been completely revised. A high pressure injection pump ensures rapid injection with more than 1000 bar injection pressure. All components had to be adapted to the higher requirements.

The newly developed 5-hole nozzle significantly improves fuel distribution over the complete speed range. A piston recess indented towards the edge of the combustion chamber and a piston head which is raised in the centre favour the concentration of combustion in the direction of the piston center and reduces fuel flowing from the recess into colder zones (Figure 17).

Figure 17 - Shape of recess and jet position - old and new (see Annex)

Injection can occur very late due to the high injection velocity enabling low exhaust emissions to be achieved with good fuel consumption. The combustion process is further improved by increasing the compression, and exhaust emissions are also reduced, particularly white smoke characteristics during cold start. The more stringent exhaust gas limits in line with the EC Commission proposal (Euro 1) are met by this new environmentally friendly combustion process in the new turbocharged engines with charge-air intercooling.

The configuration of the cylinder head is matched to the high cylinder pressures in the area of the exhaust port, the valve seat and nozzle part. The cylinder heads have an exhaust port designed for good flow to reduce scavenging work. The turbulence of the intake air is adapted to the five-hole nozzle by means of specially shaped valve seat inserts.

In order to obtain a good air charge in the cylinder special cam profiles are used which are designed in line with the latest methods of calculating optimum scavenging and also for an adequate lubrication gap between cam and tappet.

The flow characteristics of the exhaust gas have been developed to ensure the least possible back pressure in the pipes to optimize the supply to the turbines.

The introduction of the new improved V6 and V8 engines has resulted in a completely new engine range.

Figure 18 - 400 series commercial vehicle engine range (see Annex)

This range now offers complete and evenly distributed coverage in terms of output and displacement for the individual classes of vehicle.

6.4 Cold start characteristics

Mercedes-Benz has introduced flame systems as standard equipment on all commercial vehicle engines with direct injection (Figure 19). The cold starting ability has been considerably increased with these systems so that even at outside temperatures below minus 35 °C starting does not present any problems.

Figure 19 - Influence of flame-start system on warm up (see Annex)

However, preventing engines from producing white smoke after starting is more important than cold start characteristics. The flame-start systems continue to burn until the coolant temperature has reached 20 °C. Thus the engine runs with little smoke, even at extremely low outside temperatures and even if it is not subjected to full load immediately after starting and is thus environmentally friendly.

Mercedes-Benz bus engines have as standard execution excess fuel limiting device which is dependent on temperature. This is a reliable method of preventing a puff of smoke being emitted when the engine is started.

6.5 Particulate emission and development of smoke

The potential measures described in Chapter 8 for exhaust gas aftertreatment by particulate filters are most suitable for frequent stop-and-go operation, i.e for buses and municipal vehicles.

Other solutions are being developed for normal truck usage. In trucks, excessive puffs of smoke are emitted primarily when starting off and changing gear.

Correctly allocating the quantity of fuel injected to the air drawn in by the engine does not present any problems during stationary operation. However, dynamic load changes, in which the mechanical governor cannot allocate the injected quantity of fuel to the quantity of air drawn accurate and fast enough, are a problem.

To combat this problem, Mercedes-Benz has developed an electronic full load control (lambda control) system to solve this problem. With the aid of sensors, intake manifold air pressure, air temperature and engine speed are measured and thus the mass of air drawn in thereby determined accurately. The information is processed by electronics and transmitted to an actuator which limits the respective full load quantity at the injection pump control rod. In addition (Figure 20), this equipment takes excess fuel, used at high altitude and other parameters also into consideration.

Figure 20 - Electronic lambda control (see Annex)

The lambda control is presently under fleet trial with selected customers. After analysing the results, an introduction as option is considered.

If the acceleration characteristics of turbocharged engines are to be further improved without causing increased emissions of smoke, then the transient air supply will have to be increased.

6.6 Outlook

Mercedes-Benz views a further development of boosting techniques as an important starting point for increasing the economy of commercial vehicles.

Turbochargers with electronically controlled adjustable guide blades provide means of adapting change air level pressure to engine requirements at the respective load.

Multi-stage turbocharging is another means of controlling the increase of air flow whereby two or more exhaust gas turbochargers in combination with electronically controlled valves ensure optimum boost.

"Turbo compound" is a system in which a superimposed turbine is fitted downstream of the engine. This superimposed turbine is connected to the engine crankshaft via a reduction transmission, allowing part of the exhaust gas energy to be used directly (Figure 21).

Figure 21 - Diagram of compound diesel engine with turbine fitted downstream in exhaust (Turbo compound); see Annex

All these systems have not yet reached the state of development where they offer economic advantages to our customers in practical everyday use. However, with their future potential they provide the opportunity to counteract the negative impact on fuel consumption brought about by stricter requirements in terms of exhaust emissions.

CONCLUSIONS:

- **The conflict arising when reductions in NO_X are accompanied by an increase in other pollutants cannot be solved in the short and medium term.**
- **Scope for improvement lies in further intensive, but laborious work in optimizing mixture formation and combustion (injection system, combustion chamber configuration, use of electronic control and regulating systems).**
- **Mercedes-Benz engines are equipped with a flame-start system to improve cold-start characteristics as a standard production fitment.**
- **An electronic full load control system soon to be available will ensure smoke-free driving under all operating conditions.**

7. Diesel fumes and particulate emissions

The term particulate emissions describes all soot as well as liquids, such as hydrocarbons, which collect these soots emitted in engine exhaust gases. Reducing particulate emissions from diesel engines therefore effectively means reducing the amount of soot.

The main constituent of soot is amorphous carbon which clusters together to form small particles which, although otherwise largely chemically inactive, attract other materials, and in a diesel engine in particular, attract hydrocarbons. Development engineers have been looking into ways of combating soot emissions for many years.

The possible health hazard posed by particulate emissions has been the subject of broad public discussion. However, research into diesel exhaust emissions has, to date, produced conflicting results with regard to this issue.

Tests have yet to provide conclusive results with regard to any risk posed to human health by these emissions. In fact, in the opinion of many experts, there is no hard evidence of a health hazard at the levels of concentration observed in normal road traffic. However, all concerned accept that it is better to err on the side of caution in this matter and to strive to reduce the concentration of particulate emissions wherever they occur - and not just at workplaces, where new regulations now limit emissions from diesel engines.

In cooperation with other vehicle manufacturers and the Federal German Government, Mercedes-Benz is currently involved in a research project which is making in-depth investigation of the possible link between lung cancer and diesel particulates. The most recent results would suggest that the potential hazard posed by diesel particulate emissions is the same as for all other so called "normal" particulate emissions.

Nevertheless, the effective reduction of particulate emissions remains the major challenge of current diesel engine research. Mercedes-Benz has risen to this challenge by employing the best available engine technology for its entire range of commercial vehicles. In addition, Mercedes-Benz offers a particulate filter for buses and other municipal vehicles. By treating exhaust gases in this way, it is possible to reduce particulate emissions by more than 80%. This form of emission control is particularly suited to buses and other municipal vehicles because they mainly operate in stop-and-go traffic as well as in areas with high population density where the quality of air can reach critical levels.

CONCLUSIONS:

- **Mercedes-Benz is working hard to further reduce particulate emissions. Although there is no conclusive proof of a health hazard from diesel exhaust emissions under normal road traffic conditions, Mercedes-Benz prefers to err on the side of caution.**

- **Current development work focuses on measures to improve the combustion process itself and on systems for the removal of soot.**

8. Particulate filter technology - The state of the art

Chapters 6 and 7 present the main objectives of Mercedes-Benz with regard to commercial vehicle engine development and points out possible ways of further reducing pollutant emissions. A key focus of this work is the effective reduction of particulate emissions (primarily soot, fuel ash, dust and rust particles and scale) from diesel engines.

However, no great steps forward can be expected with regard to cleaning up the engine itself, i.e. by further improvement of the fuel mixture control or combustion behaviour, since the potential for further advances in this area of commercial vehicle engineering has been largely exhausted. For this reason, Mercedes-Benz is concentrating its efforts on secondary systems in the form of particulate filters which can substantially reduce particulate emissions from diesel engines.

8.1 The removal of particulates by filtration

The soot particles which occur in diesel emissions are extremely small. The diagram below (Fig. 22) shows that the major proportion of particles is between 0.1 and 0.3 thousands of a millimetre in size. Ash and dust particles, for example, are considerably larger. For this reason, ultra-fine filters are required to remove diesel particulates.

Figure 22 - Distribution of diesel particulates in exhaust emissions and size in comparison to other materials (see Annex).

8.2 Filter regeneration

However, the filtration process itself is only the first step. To remain effective, the filter must also, from time to time, be regenerated, i.e. cleared of the accumulated filtrate. With particulate filters, this can be achieved by burning off the filtrate at high temperatures, causing the soot particles to be converted into gaseous CO_2.

Figure 23 gives the distribution of exhaust emissions temperatures of a municipal bus covering a typical urban route. Under normal conditions, exhaust emission temperatures rarely exceed 400 °C. In fact, temperature levels of 300 °C or more are only achieved during approximately 10% of total operating time. However, effective filter regeneration only commences at temperatures of around 600 °C. For this reason, additional equipment and technology are required to burn off soot particles.

Figure 23 - Pattern of exhaust emission temperatures for a municipal bus on a urban route (see Annex).

8.3 The Mercedes-Benz ceramic candle-type trap

After many years of intensive research into a variety of filter systems, for commercial vehicle diesel engines Mercedes-Benz decided to concentrate on the development of the ceramic candle-type trap. This filter system comprises of a large number of perforated stainless steel tubes which form a horizontal bundle within a stainless steel casing and which are wrapped in windings of coarsened ceramic threads (Figure 24). The exhaust gases flow from the exterior to the interior, passing through the ceramic thread windings and allowing the particulates to adhere to the coarse surface of the ceramic threads.

Figure 24 - Diagram of a ceramic candle-type trap (see Annex)

This type of particulate filter is extremely resistant to heat and can withstand the extremely high temperatures needed for regeneration. The filters can collect and retain a large amount of soot and are highly efficient at removing particulate emissions even in the transient state. In the US Transient Test, for example, which simulates commercial vehicle operation in mixed urban and intercity traffic, the ceramic candle-type trap was fitted to standard bus engines (OM 447 h/177 kW) and successfully removed up to 88% of particulate emissions.

Although filter efficiency declines as it becomes clogged up with soot, it can be expected to achieve an overall particulate emission removal rate of over 80% throughout its operational life because when the filter is regenerated, its efficiency rapidly returns to extremely high levels (Figure 25).

Figure 25 - Particulate emission removal rate during the US Transient Test (see Annex).

In addition, this type of filter is highly effective at absorbing sound, and in the majority of cases an additional silencer is unnecessary.

8.4 Particulate filter trials

The first trials on the ceramic candle-type filter under realistic conditions took place between 1986 and 1988 in a project which involved a large number of Mercedes-Benz buses and other municipal vehicles. This represented a particularly suitable test of the filter's feasibility since these vehicles are primarily used in stop-and-go traffic in inner-city areas where environmental policy assigns high priority to the reduction of particulate emissions.

These trials demonstrated that the ceramic candle-type filter offers a suitable means of filtering exhaust emissions from commercial vehicles. Furthermore, engineers were able to improve the design of the filter to increase its resistance to mechanical and thermal loads. However, the trials also brought disappointment with regard to the proposed regeneration method, with which it had been hoped to reduce the temperature at which the filter's particulate load combusts by injecting an oxidizing agent. As its contribution to the large-scale particulate filter project initiated in 1989 by the Federal German Government and involving many leading German companies, Mercedes-Benz was able to provide an improved version of the ceramic candle-type trap in conjunction with catalytic regeneration.

The main feature of this new regeneration method was the introduction of a coating of copper oxide catalyst on the filter windings. When the particulate filter is loaded with soot, this copper oxide catalyst can be activated by injecting a small amount of acetyl acetone. When the catalyst is activated and the exhaust gas temperature reaches 250 °C or more, the soot particles, hydrocarbons and acetyl acetone are oxidized to form water vapour and carbon dioxide. The copper oxide coating remains intact and is unaffected by this process.

Figure 26 - Ceramic candle-type filter with catalytic regeneration system (see Annex).

However, when the filter was fitted to a wide variety of vehicle types for a large-scale particulate filter project, Mercedes-Benz engineers realized that even this enhanced method of catalytic regeneration was not entirely suitable for mass production use.

Although the system can be adjusted to give reliable and efficient performance for almost any individual vehicle or operating conditions, Mercedes-Benz customers need many different kinds of commercial vehicle designs and the optimization of the filter to such a wide variety of requirements would be technically and logistically impracticable.

For this reason, this type of filter regeneration is likely to remain restricted to certain types of bus and other municipal vehicles with selected engines. In the future, the ceramic candle-type filter with catalytic regeneration may be offered as optional equipment for these vehicles, thereby providing our customers with the means of reducing particulate emissions to the lowest possible level in the critical operating conditions of inner-city areas.

8.5 Thermal regeneration

In order to offer particulate filters for other types of vehicle and for a wider range of engine designs, Mercedes-Benz is also pursuing a completely different regeneration concept. For many years, Mercedes-Benz has not only been developing the ceramic candle-type trap but also looking into thermal regeneration techniques, which use a burner to heat up exhaust emission gases to the temperature required to burn off the soot particles which have collected in the filter (Figure 27).

Figure 27 - Particulate filter regeneration based on a diesel burner (full flow); (see Annex).

Under the highly variable and dynamic operating conditions of normal traffic, this system needs extremely rapid and effective control of the heat output from the burner in order to achieve a sufficiently high regeneration temperature and, at the same time, to prevent damage to the particulate filter from thermal overload. Following in-depth development work in close cooperation with a supplier, Mercedes-Benz has now succeeded in designing an effective electronic control system for this thermal regeneration concept. The design has already been tried out on the test bench to confirm its feasibility and road tests are now being conducted to determine the suitability of the system under realistic traffic conditions. The results to date suggest that this completely innovative regeneration system will provide the basis, together with the already tried and tested ceramic candle-type trap, for a standardized particulate filter system which would be suitable for installation in a variety of

production vehicles and also for retrofitting to vehicles already on the road.
Since 1991, Mercedes-Benz has been trying out this new technology in a number of customers' vehicles in order to rapidly obtain results under a wide variety of realistic conditions. The results will then be incorporated into ongoing research work.

CONCLUSIONS:

- **Particulate filter technology is still extremely new and not yet ready for volume installation as a standard package in production vehicles.**
- **Mercedes-Benz already offers the ceramic candle-type trap with catalytic regeneration as optional equipment for selected types of buses and municipal vehicles.**
- **Mercedes-Benz is also continuing development of particulate filters with thermal regeneration with the aim of finding a standard solution which will be suitable for all new production vehicles and for retrofitting to certain models already on the road.**

9. Diesel engines and the 'cat'

The widespread discussion of the issue of emissions from petrol-engined passenger cars and pollution control by means of catalytic conversion has led to the call for the use of similar technology for diesel engines as well.

At the moment, petrol engines are only able to match the very low exhaust emission levels of diesel engines when fitted with a catalytic converter. These catalytic converters serve two very different purposes, the reduction of NO_X and the oxidation of hydrocarbons and carbon monoxide.

The reduction of nitrogen with a high degree of conversion (i.e. the parameter for the completeness of the reaction) can only be achieved with a rich fuel-to-air ratio, in other words a ratio slightly below the ideal stoichiometric value (Figure 28).

Figure 28 - Catalytic converter efficiency and fuel-to-air ratio (see Annex).

With the three-way catalytic converter, e.g. the type fitted to today's petrol engines, both these effects can be achieved with a single item of equipment. However this requires extremely precise control of the fuel/air mixture (by means of a lambda probe).

Since diesel engines require excess air for combustion (lambda of 1.3 or greater), it is not possible to combat oxides of nitrogen by catalytic reduction.

However, an oxidation catalyst can be used to oxidize the small amounts of gaseous carbon monoxide and hydrocarbons entrained in diesel engine exhaust gas and also to reduce the droplets of liquid hydrocarbons formed from unburnt diesel fuel and lubricant. This leads to a reduction in overall particulate emissions (Figure 29).

Figure 29 - Reduction of PM emissions diesels cat by means of catalytic conversion and low-sulphur fuel

However, such a reduction presupposes the availability of diesel fuel with a sulphur content of less than 0.05% (low-sulphur diesel fuel).

The level of sulphur dioxide emissions is directly proportional to the amount of sulphur contained in the fuel. However, in conventional diesels only a small fraction of the gaseous sulphur dioxide is converted via sulphuric acid to particulate sulphate within the exhaust system. Most of the sulphur is emitted in the form of gaseous sulphur dioxide which then reacts in the air to form sulphuric acid and sulphates. Installing an oxidation catalyst can cause this reaction to take place within the exhaust system and, as a consequence, substantially increase particulate emissions, depending on the sulphur content of the fuel (Figure 30).

Figure 30 - Sulphur content of fuel and total particulate emissions (US Transient Test); (see Annex).

However, the oxidation catalyst has practically no effect at all on pure carbon emissions (soot).

In order to ensure a good conversion rate, oxidation catalysts require high exhaust gas temperatures. These high temperatures are more common amongst trucks used for long-distance haulage than amongst buses and municipal vehicles used in urban areas.

Furthermore, oxidation catalysts can also considerably reduce the unpleasant odour associated with diesel fumes. However, this benefit too depends on the required exhaust gas temperature being reached.

Figure 31 - Pattern of exhaust gas temperatures for a bus/long-distance haulage truck and conversion of a conditioned oxidation catalyst (see Annex).

CONCLUSIONS:

- **In addition to cutting down carbon monoxide and hydrocarbon emissions, oxidation catalysts can also considerably reduce the typical "diesel smell".**
- **Achieving overall particulate reductions presupposes the availability of low-sulphur fuel and operating conditions which ensure sufficiently high exhaust gas temperatures.**

10. Diesel fuel and pollutant emissions

Sulphur content

In the public debate on air pollution. considerable importance has been attached to sulphur dioxide emissions. However, according to the Federal German Government's fourth report on atmospheric pollution, road traffic accounts for less than 3 % of total sulphur dioxide emissions.

The amount of sulphur dioxide emitted by road vehicles is directly proportional to the sulphur content of the fuel used and cannot be influenced by adjusting the combustion process itself. However, sulphur is not an essential constituent of engine fuel.

In the Federal Republic of Germany, the amount of sulphur in diesel fuel has gradually been reduced over the last 20 years. Furthermore, careful driving and fuel-efficient engines can also lower sulphur and all other emissions by reducing consumption.

A further cut in the sulphur content of diesel fuel would translate into a further cut in sulphur dioxide emissions and, as a by-product, would also lessen engine corrosion. The European Community has issued a directive limiting sulphur in fuel to 0.3% by weight, with an option for individual member states to reduce this to 0.2% by weight. The Federal Republic of Germany, along with other EC countries, has made use of this option.

However, future, even more stringent European exhaust emission limits will require a maximum sulphur content of 0.05% by weight or less.

A low sulphur content also helps the use of particulate filters and extends their useful operating life.

However, of significance with regard to pollutant emissions as a whole is not only the sulphur content but also the overall quality of diesel fuel.

Overall quality

Figure 32 shows the typical effects of poor-quality diesel fuel on emissions of hydrocarbons, NOx, carbon monoxide and particulates.

By the same token, high-quality diesel fuel has a positive effect on exhaust emissions and engine noise.

Figure 32 - Influence of diesel fuel quality on emission behaviour (see Annex).

In some overseas countries the quality of diesel fuel is relatively poor, with a negative effect on engine function and behaviour. Representatives of the European oil industry had once suggested that the changes to the structure of consumption of heavy and light heating oils as a result of the oil crises of the 1970s could lead to a deterioration in the quality of diesel fuel in the Federal Republic of Germany and in Europe as a whole. However, this has not proven to be the case.

As market research has shown, the quality of diesel fuel in the Federal Republic of Germany and in Europe as a whole remains satisfactory. However, spot checks on diesel fuel quality have shown up the occasional "bad apple" which will need to be eradicated if we are to meet environmental demands in full.

All European vehicle manufacturers have expressed their opposition to any changes which would allow the introduction of poorer quality diesel fuel and they have published the results of extensive research which demonstrate clearly that high-quality diesel fuel is essential to meeting environmental requirements. The quality of today's fuel needs to match the quality of today's automotive engineering.

Unfortunately, neither in the Federal Republic of Germany nor on a pan-European level has it been possible to reach a binding agreement between the automotive engineering industry and the oil industry anchoring the minimum future quality of diesel fuel at its present satisfactory level.

This situation prompted the European automotive industry to request the European Commission to define uniform quality characteristics for a single diesel fuel by means of an EC directive. The European Commission responded by calling upon the European Committee for Standardization (CEN) to draft corresponding proposals.

The experts of CEN have now completed their work for current diesel fuel, engines and exhaust emission laws and have created a definition of adequate diesel fuel quality.

A legally binding European standard can therefore be expected in the near future.

Experts estimate that good-quality diesel fuel translates into an overall reduction in particulate emissions from all diesel-engined vehicles of around 10%. Moreover, quality-oriented and environmentally-aware oil companies have now begun to accept the arguments in favour of higher quality diesel fuel.

Nevertheless, if future European exhaust emission limits are to be met, it will not only be necessary to further develop diesel engines but also be imperative that the quality of diesel fuel be improved to an even greater extent.

This applies in particular to sulphur content, ignition performance, and the tolerances for density, boiling behaviour, final boiling point and viscosity. Particular attention will also need to be paid to the type and volume of aromatics.

Experts are already working on defining the requirements for future diesel fuel quality.

CONCLUSIONS:

- **Improved diesel fuel quality leads to an immediate reduction in emissions from all commercial vehicles on the road.**
- **Key characteristics are low sulphur content, a high cetane number and limited density.**
- **There is a need for binding, uniform requirements for diesel fuel in Europe.**

11. Commercial vehicles now require less fuel

The extent to which the automotive industry has lived up to its responsibility with regard to fuel-efficiency above and beyond legal requirements is not only demonstrated by the figures for passenger cars. There has also been significant progress in reducing fuel consumption in commercial vehicles.

The further improvement of

- combustion
- the drivetrain (engine, transmission, final drive)
- air resistance
- rolling resistance

and the use of lightweight materials and construction techniques have led to a substantial reduction in fuel consumption despite a steady increase in average speeds. For a 40 t semi-trailer (Figure 33) there was an improvement in fuel consumption of more than 30% between 1976 and 1988, reducing the fuel requirement to less than 35 litres for every 100 km travelled. Over the same period, there was an increase in average speed of more than 30%. When applied to the volume of freight transported by a semi-trailer of this kind, the average amount of fuel required for transporting a tonne of freight a distance of 100 km fell during this period from 2.08 litres to 1.37 litres while the average speed increased from 49 to 68 km/h.

Figure 33 - Development of fuel consumption and speed for 40-tonne semi-trailers on a standard route over highways, overland routes and urban roads.

These figures are based on the results of tests carried out by a commercial vehicle trade journal based on a standard route using highways, overland routes and urban roads.

The progress made in fuel consumption is particularly impressive when viewed in the light of the considerable improvements made in other areas, e.g. in reducing gaseous emissions and noise, although - as stated above - these objectives often run contrary to the aim of fuel efficiency.

In this regard, it is worth taking a look at the figures for carbon dioxide (CO_2) emissions from diesel engines. The pre-chamber diesel engine used in passenger cars and light commercial vehicles produces around 15% less CO_2 than a petrol engine. The direct-injection diesel engines widely used in commercial vehicles are particularly outstanding, with an increase in efficiency from 38% to over 44% through improved combustion.

Figure 34 - Carbon dioxide emissions from commercial vehicle engines (see Annex).

For the same t/km performance, a modern truck diesel engine currently emits around 30% less CO_2 than a petrol engine.

Since CO_2 emissions are directly proportional to fuel consumption and it is in the nature of thermodynamics that a decrease in fuel consumption generally means an increase in NO_x emissions, the ever rising demands with regard to exhaust emission behaviour can only be met by extremely advanced engineering which reduces consumption and CO_2 emissions. One possible answer may lie in the use of alternative, renewable fuels which may slow down the rise in atmospheric CO_2.

CONCLUSIONS:

- **Since fuel consumption is an important factor in the overall assessment of an engine's performance, a further reduction remains one of the priorities of future development work.**
- **Due to their high efficiency, modern commercial vehicle diesel engines emit up to 30% less CO_2 than petrol engines.**

12. Alternative fuels

At Mercedes-Benz, researchers have been investigating the feasibility of alternative fuels for many years. Of the many possibilities, this chapter deals with only a few:

- methanol fuels based on natural gas or coal
- ethanol fuels based on fermentable biomass
- liquefied natural gas (LNG) or compressed natural gas (CNG)
- hydrogen, produced by harnessing natural gas, coal, nuclear power, water power, solar energy or wind energy and
- fuels based on vegetable oil.

It is highly unlikely that conventional fuels will be replaced to any substantial degree by alternative fuels in the short or medium term. Neither the present oil supply situation (i.e. price and availability) nor the state of development of alternative fuel systems (economic viability, availability, supply infrastructure) are yet ready for a change on the scale required. Nevertheless, there are many reasons to continue the development and testing of such systems up to a point where they become serious contenders. One of the reasons is that alternative fuels, despite economic drawbacks, can offer improved emission behaviour in comparison to diesel fuel in certain applications (Figure 35).

Figure 35 - Exhaust emissions, alternative fuels and diesel fuel (ECE 13-point test); (see Annex).

Some of these alternative-fuel systems have now reached a state of development where, depending upon the regional environment in which they would be used, they could be effectively employed in commercial vehicles today.

Compressed natural gas (CNG) can also be used in (spark-ignition) gas engines. With stoichiometric combustion, it is possible to treat emissions from natural gas engines by means of a three-way catalytic converter with lambda-probe control. However, a turbocharged, lean-burn natural gas engine with an intercooler and an oxidation catalyst offers far better fuel economy.

With only minor modifications it is also possible to operate direct-injection commercial vehicle diesel engines on alcohol doped with ignition agents (methanol or ethanol diesel). Here as well, it is possible to treat emissions with an oxidation catalyst.

Methyl esters of vegetable oil acids can even be used in completely unmodified diesel engines.

With regard to the environmental benefits, there is a need to differentiate between, on the one hand, the potential for reducing pollutant emissions (unburnt hydrocarbons, nitrogen oxides, carbon monoxide and particulates) and the potential for improving atmospheric CO_2 levels on the other (Figure 36).

Figure 36 - CO_2 cycle for fuel based on vegetable oil (see Annex).

A reduction in pollutant emissions may justify the use of more expensive alternative fuels if tangible improvements can be achieved in highly polluted areas, e.g. by using these fuels for buses and municipal vehicles or for underground vehicles. With regard to the individual pollutant components, it is possible to make the following general statements:

- **Particulate emissions:**
  Alcohol-based "diesel" fuels do not emit any soot and as a result, particulate emissions are drastically reduced. The same applies to natural gas.

  When using vegetable oil esters (rape seed oil ester is the most likely alternative in Europe) soot emissions are reduced by approximately half in comparison to diesel fuel.

- **Nitrogen oxide emissions:**
  Again, when alcohol-based diesel fuels are used, nitrogen oxide emissions are considerably lower than with conventional diesel fuel. Vegetable oil esters offer no advantages in this respect.
  It is also possible to achieve very low NO_x emissions with a natural gas engine in conjunction with stoichiometric combustion and a three-way catalytic converter. NO_x emissions are also very much improved with a lean-burn natural gas engine, which also offers the advantage of far lower fuel consumption.

- **Hydrocarbon emissions:**
  Hydrocarbon emissions from vegetable oil esters are considerably lower. In fact, emissions can even be halved in comparison to those of conventional diesel fuel. The other alternative systems described above actually lead to an increase in hydrocarbon emissions, but these can be significantly reduced by the use of a catalytic converter.

- **Carbon monoxide emissions:**
  Although conventional diesel engines emit relatively little carbon monoxide, the use of alternative fuels in conjunction with a catalytic converter can bring further improvement, bringing CO emissions to extremely low levels.

  In order to reduce the impact of the "greenhouse gas" carbon dioxide, it would be necessary to use fuels whose production and combustion emit less CO_2 than the most fuel-efficient of all existing systems, the direct-injection diesel engine.

  The use of hydrogen currently offers no solution to the problem of greenhouse gases. Although the combustion of hydrogen produces only nitrogen oxides and water, the employment of natural gas or coal to produce hydrogen fuel in the first place causes the emission of more carbon dioxide than is emitted from conventional diesel engines. Hydrogen fuel would only lead to an overall reduction in CO_2 emissions if the electric power used for its manufacture was obtained from hydroelectric, solar, wind or nuclear power plants.

By contrast, alternative fuels based on renewable resources offer a realistic way of reducing the increase in atmospheric CO_2 concentrations. This is particularly true of fuels based on ethanol and on vegetable oils which can, in some cases, be used in unmodified diesel engines.

CONCLUSIONS:

- **Currently, alternative fuels are not generally economically viable.**
- **Certain local requirements and conditions may make the use of alternative fuels a realistic proposition on a limited scale.**

13. Development and status of European legislation on noise pollution

A large proportion of the general public regards road traffic noise as a serious nuisance, particularly in residential areas and inner cities. For this reason, both the legislator and vehicle manufacturers are called upon to act. In fact, the first regulations on noise control came into force in Germany as far back as 1937, and have successively tightened up ever since.

Figure 37 shows the historical development of permissible noise levels for various vehicle types. This table shows that requirements in the European Community became considerably more stringent after 1980. Furthermore, by the mid-90s, the noise limit stipulated by Attachment XXI of the German Vehicle Type Approval Regulations (StVZO) for low-noise vehicles will be extended to all vehicle types.

Figure 37 - Simplified presentation of noise emission limits expressed in sound pressure levels in dB(A) for various vehicle types (see Annex).

In order to put these figures into perspective, the following should be considered:

- a reduction in the sound pressure level of 3 dB(A) is equivalent to reducing the amount of sound energy emitted by half.
- Twelve low-noise trucks in accordance with attachment XXI of the StVZO are no louder than a single truck complying with the 1974 requirements (given identical measurement methods).

Figure 38 - Reduction in noise emission levels for commercial vehicles since 1974; (see Annex).

In order to effectively reduce noise emissions from road vehicles it is necessary to assess each of the major noise sources individually. These sources include the engine, the exhaust system, the air intake system, the transmission, the propshaft, axles and tyre/rolling noise.

By a variety of measures designed to combat noise from each of these individual sources it has, in the past, consistently proved possible to meet and in some cases improve upon the noise limits applicable in the European Community.

However, the new limits which came into force in 1988/89 and, in particular the special national requirements with regard to low-noise vehicles, including the night ban on heavy truck traffic in Austria, have made necessary further primary and secondary measures (e.g. sound encapsulation), such as those already employed on municipal buses.

Considerable experience has been gained in engine compartment encapsulation in buses. In 1972, Mercedes-Benz was the first manufacturer in the Federal Republic of Germany to introduce a noise-encapsulated municipal bus (known as the "whispering bus") with a noise level of 80 dB(A). In comparison to conventional buses, there was a reduction in sound energy emissions of more than 70%.

However, there are limits to the action that can be taken to reduce noise and noise control often comes into conflict with other objectives such as fuel efficiency and this can only be resolved by compromise. This was demonstrated in particular by the "definition study for low-noise commercial vehicles", a project initiated under the aegis of the Federal German Ministry for the Interior and by the Federal German Environmental Agency and which included the participation of Mercedes-Benz. Mercedes-Benz contributed three commercial vehicle types: a local distribution truck, a municipal vehicle and a long-distance truck.

In view of the considerable achievements of recent years, primary measures to the engine, air intake system, drivetrain, exhaust system, etc. can only bring marginal further progress.

As a result, secondary measures such as encapsulation, by which it is possible to reduce noise by between 4 and 6 dB(A) depending upon the type of vehicle, will be essential to the fulfillment of future noise limits. However, encapsulation increases vehicle weight thereby reducing the effective payload.

Figure 39 - Low-noise vehicle (see Annex).

One example of active noise reduction is the new Mercedes-Benz engine brake with constantly open throttle valve system. The introduction of small-volume turbocharged engines for mid-range vehicles has led to a widening discrepancy between engine power and engine brake power. To overcome this, Mercedes-Benz developed an improved engine brake with considerably more power incorporating a constantly open throttle valve.

A throttle bore between the cylinder and the exhaust tract reduces cylinder pressure upon the expansion stroke and thereby increases the effective difference in pressure between compression and expansion. This results in an improvement in braking power of between 40 and 100%, depending upon engine type and engine speed range.

The constantly open throttle valve is actuated by compressed air in the same way as the setting cylinder of the engine brake butterfly valve.

Figure 40 - Constantly open throttle valve system in cylinder head (series 400); (see Annex).

Engine braking therefore occurs in two steps, first by activating the constantly open throttle valve and then the conventional engine brake. During the first stage, there is a considerable reduction in noise in comparison to the conventional engine brake.

The new Mercedes-Benz engine brake based on the constantly open throttle valve considerably increases engine brake power and contributes to greater road safety.

Despite great efforts on the part of Mercedes-Benz to reduce vehicle noise, it has become apparent that there are limitations which are beyond the influence of the vehicle manufacturer. Research into ways of fulfilling the latest EC noise control directive, 84/424/EEC, initially revealed inexplicable differences between the predicted effect of

particular measures and the actual results. Researchers traced the cause to tyre/rolling noise, which had not been adequately taken into account in the original calculations.
Using the coast-by measurement method, it was discovered that tyre/rolling noise was in fact more than 10 dB(A) under the required limit in the relevant speed range. Further investigation showed, however, that the influence of forward thrust is considerable, since increasing traction leads to increasing tyre/rolling noise.

Figure 41 shows results which clearly demonstrate the influence of traction on the noise emitted by a powerful 355 kW long-distance truck.

Figure 41 - Tyre/rolling noise and the influence of traction (see Annex).

This diagram compares the values recorded for tyre/rolling noise on a smooth asphalt surface for both driven and non-driven wheels. The lower set of values, with a spread of sound pressure levels between 4 and 6 dB(A), gives the results determined by the coast-by method for non-driven wheels of the standard arrangement. The upper set of values was determined by the accelerated pass-by test and gives the results for the driven wheels where the spread of values is considerably wider than for non-driven wheels, varying by 6 to 7 dB(A).

In the past, the introduction of more stringent noise limits for road vehicles required action on the part of vehicle manufacturers. However, the level of noise emitted by the main sources within the vehicle itself are now so low that noise is now dominated by tyre/rolling noise, particularly for heavy commercial vehicles. Consequently, the results of tests are highly dependent upon the choice of tyres.

For this reason, any further substantial reductions in noise levels will depend upon finding a satisfactory solution to the problem of tyre/rolling noise.

CONCLUSIONS:

- **European legislation now calls for extremely stringent noise control.**
- **Any further improvement in noise levels will depend to a decisive extent upon tyre/rolling noise.**

14. CFCs, hazardous materials and recycling

In recent times there has been much public discussion of the issue of chlorofluorocarbons (CFCs) due to the damage they cause to the ozone layer. For this reason, Mercedes-Benz is conducting in-depth investigations into suitable alternatives, in particular with regard to refrigerants for vehicle air conditioning systems.

Researchers at Mercedes-Benz have now succeeded in finding a an alternative to refrigerant R12 which offers similar thermodynamic properties but does not contain chlorine and therefore cannot endanger the ozone layer. However, it is not yet possible to immediately switch to this new material, known as R134a, since it must still undergo final testing, and the corresponding production facilities have still to be established. Nevertheless, Mercedes-Benz is able to offer the first CFC-free air-conditioning units already in 1991, and from 1993 onwards, all air-conditioning units in Mercedes-Benz vehicles will use R134a.

Recycling of CFCs

However, the problem of the safe disposal or recycling of CFCs encountered during vehicle maintenance work and scrapping remains. Since many Mercedes-Benz vehicles happily remain on the road for twenty years or more this is a problem which is likely to stay with us until well into the next century. To meet this requirement, all Mercedes-Benz branches have already been equipped with special extraction and regeneration units. These are used to extract the refrigerant by suction, preventing CFCs from escaping into the atmosphere. At the same time, the refrigerant is purified and it can either be re-used or returned to the manufacturer for further processing.

A similar system is being designed for the R134a fluorohydrocarbon refrigerant.

Hazardous materials

Mercedes-Benz has made the avoidance of hazardous or otherwise problematical materials in manufacturing processes one of its major development goals. Mercedes-Benz has for example discontinued use of cadmium, which was previously employed to surface-treat metals, as a pigment in plastics and paints and also as a stabilizing agent in plastics.

Intensive research and development work has also made it possible to convert all commercial vehicles to asbestos-free brake and clutch linings. However, considering the safety aspect of these linings, we wish to point out the following:

The use of brake linings which have not been approved by Mercedes-Benz can have a negative influence on correct brake pressure distribution which in turn can impair the braking behaviour of the vehicle to which they are fitted.

Recycling

At Mercedes-Benz we attempt to minimize the use of problematical materials in the manufacturing process. Moreover, from the design stage onwards we consider possible ways of re-using, recycling or, if this is not possible, cleanly disposing of old components and materials from commercial vehicles. Typical examples include the long-standing practice of reconditioning engines, transmissions and other major in-vehicle systems to serve as replacement parts or the use of recycled oils, known as secondary raffinates.

Currently, Mercedes-Benz is working on a comprehensive concept which will tie-in all of these individual measures for materials and components to ensure the best possible re-use or recycling of the entire vehicle or the environment-friendly disposal of residual waste. In particular, Mercedes-Benz is looking into the possibility of recycling plastics and the marking of plastic components in order to identify different material types for effective sorting and re-use.

CONCLUSIONS:

- **The avoidance of hazardous or problematical materials is an important aim in both the design and construction of commercial vehicles.**
- **The re-use and recycling of vehicle components and materials is to be expanded to create a comprehensive system encompassing the entire vehicle.**

Summary

Mercedes-Benz has consistently demonstrated that it regards environmental protection as an integral part of commercial vehicle development.

There follows a summary of the action which has already been taken in this respect or which is planned for the near future:

- Well in advance of EC legislation, Mercedes-Benz has effectively phased down pollutant emissions from all commercial vehicle engines.

- The latest proposals of the EC Commission foresee a further reduction in permissible exhaust emission levels from 1993 onwards. In comparison to the ECE-R 49 directive this would mean a further reduction of NOx emissions by 50%, of CO and HC emissions by 65% and the introduction of a limit for particulate emissions.

  Mercedes-Benz is committed to implementing this new exhaust gas concept as rapidly as possible.

- Mercedes-Benz began the development of particulate filter systems as far back as 1969. Particulate filter systems with catalytic regeneration can already be supplied as optional equipment for buses and for certain types of municipal vehicles. Once thermal regeneration systems have become available, we aim to extend this pollution control system to a wide range of other vehicles.

- All petrol-engined Mercedes-Benz vans are supplied with a three-way catalytic converter with lambda-probe control.

- By employing state-of-the-art passenger car engines with improved combustion behaviour in Mercedes-Benz vans, it has proved possible to reduce gaseous and particulate emissions in these vehicles to an extremely low level.

- Mercedes-Benz initially developed and offered a noise encapsulation concept for buses and coaches. Since then, the demand for low-noise vehicles in other fields of application has grown. Mercedes-Benz is now able to offer a selected range of low-noise commercial vehicles.

- By 1993, Mercedes-Benz will have replaced all chlorofluorocarbons for vehicle air-conditioning units and in other applications by alternative, environment-friendly materials.

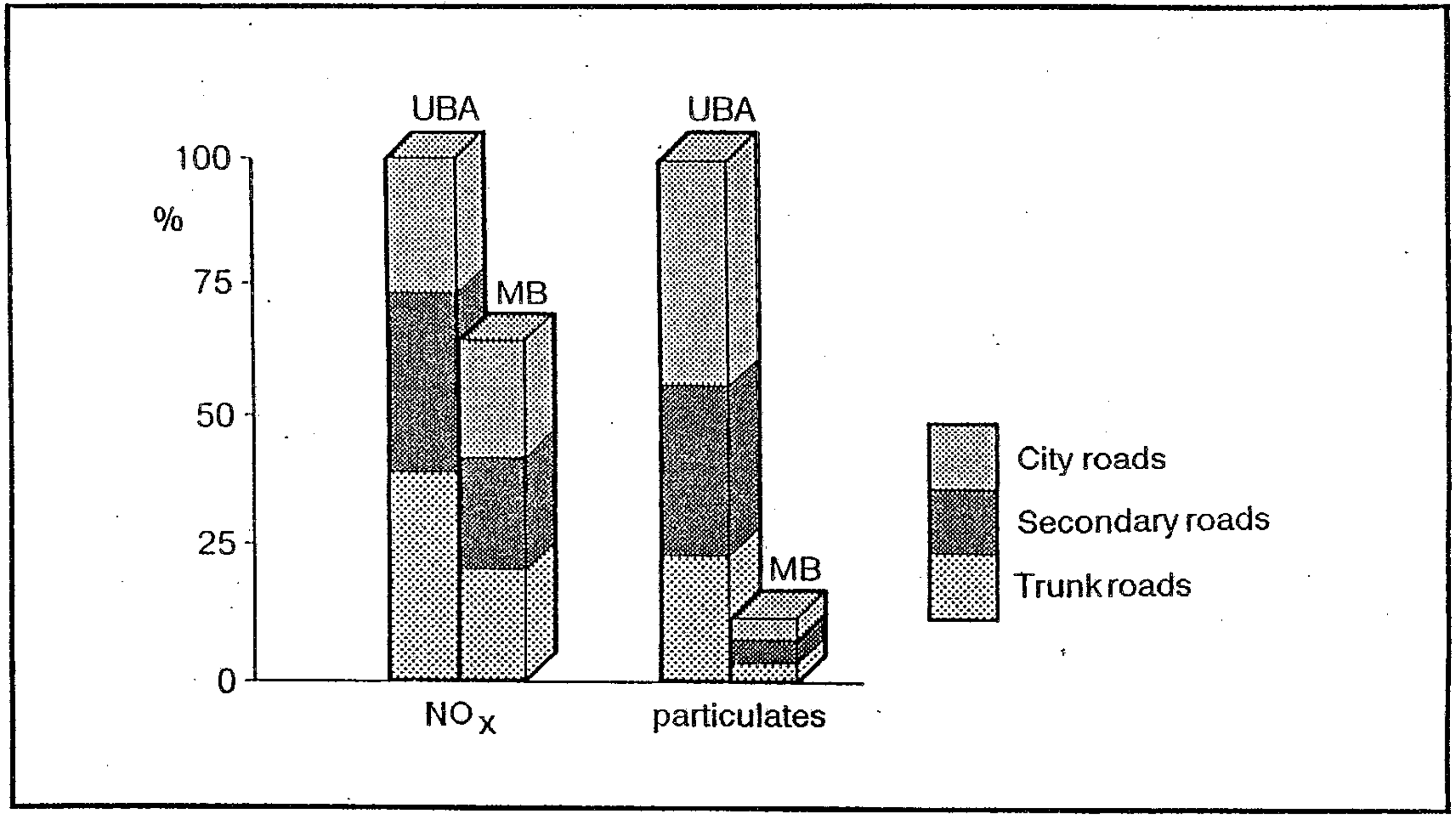
By means of all these individual measures and further improvements to its vehicles, Mercedes-Benz is pursuing a long-term strategy of developing efficient and environmentally compatible commercial vehicles which will promote public acceptance of their use.

Air pollution Group of emissions	1986	
	kt	%
Nitrogenoxide NO_x as NO_2		
Altogether	3000	100,0
Traffic	1800	60,0
Road Traffic	1550	51,6
Commercial Vehicles	495	16,5
Organic Compounds		
Altogether	2400	100,0
Traffic	1260	52,5
Road Traffic	1200	50,0
Commercial Vehicles	146	6,1
Sulphur Dioxide SO_2		
Altogether	2200	100,0
Traffic	110	5,0
Road Traffic	65	2,9
Commercial Vehicles	no details	
Carbon Monoxide CO		
Altogether	8900	100,0
Traffic	6570	73,8
Road Traffic	6300	70,8
Commercial Vehicles	126	1,5
Staub		
Altogether	550	100,0
Traffic [1]	72	13,1
Road Traffic	55	10,0
Commercial Vehicles	33	6,0

kt = Kilotonnen = 1000 Tonnen

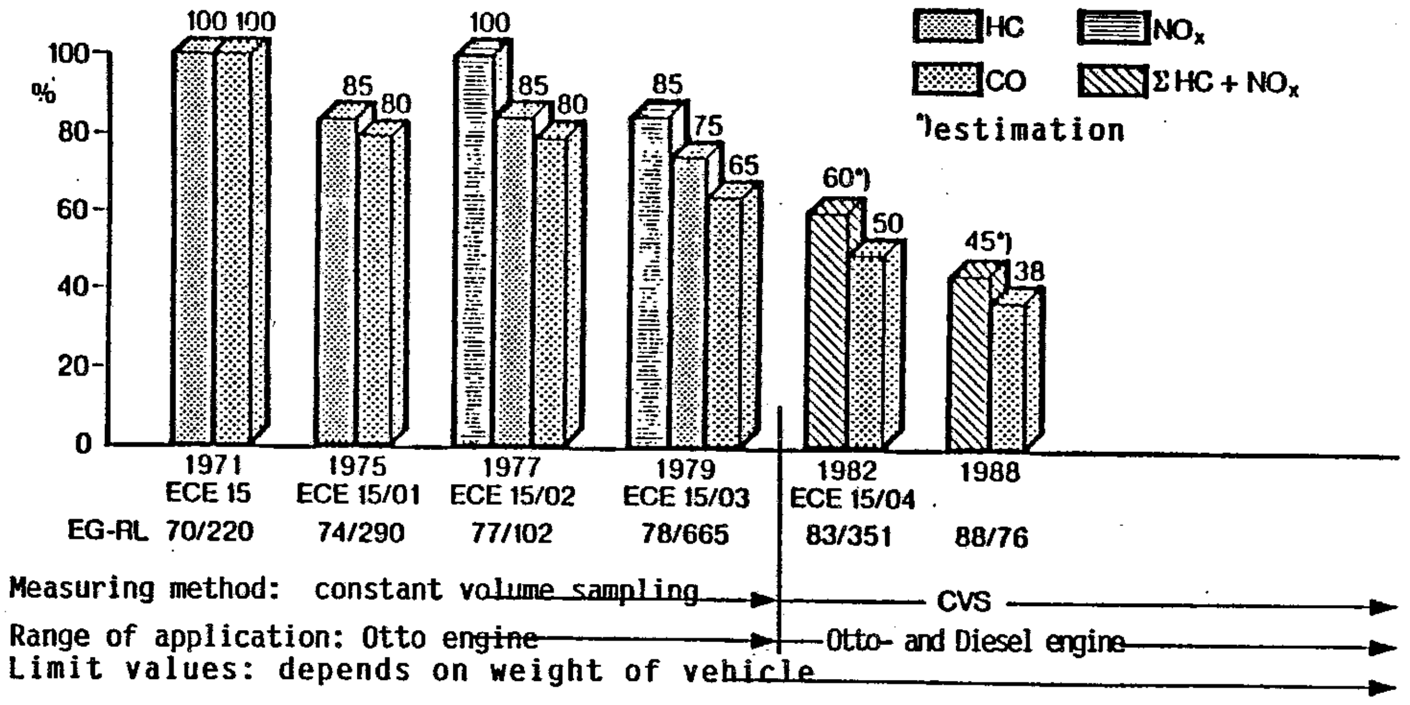
[1] only exhaust gas emissions

Emission of nitrogen oxides and particulates reference year 1986



Legislation of exhaust gas in Europe, gaseous emissions of passenger cars and light vehicles

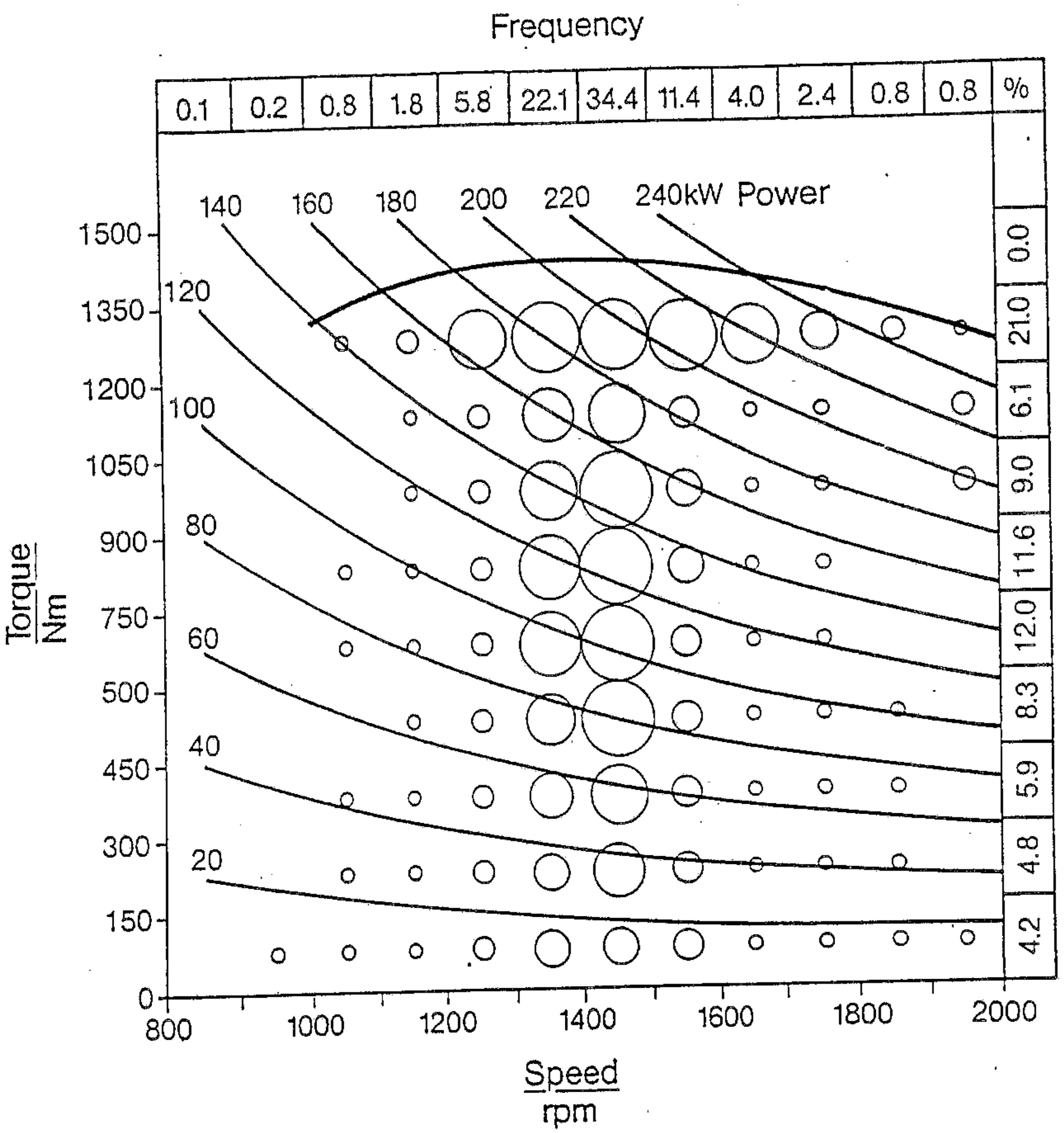
Limit values of emission



Measuring method: constant volume sampling

Range of application: Otto engine

Limit values: depends on weight of vehicle



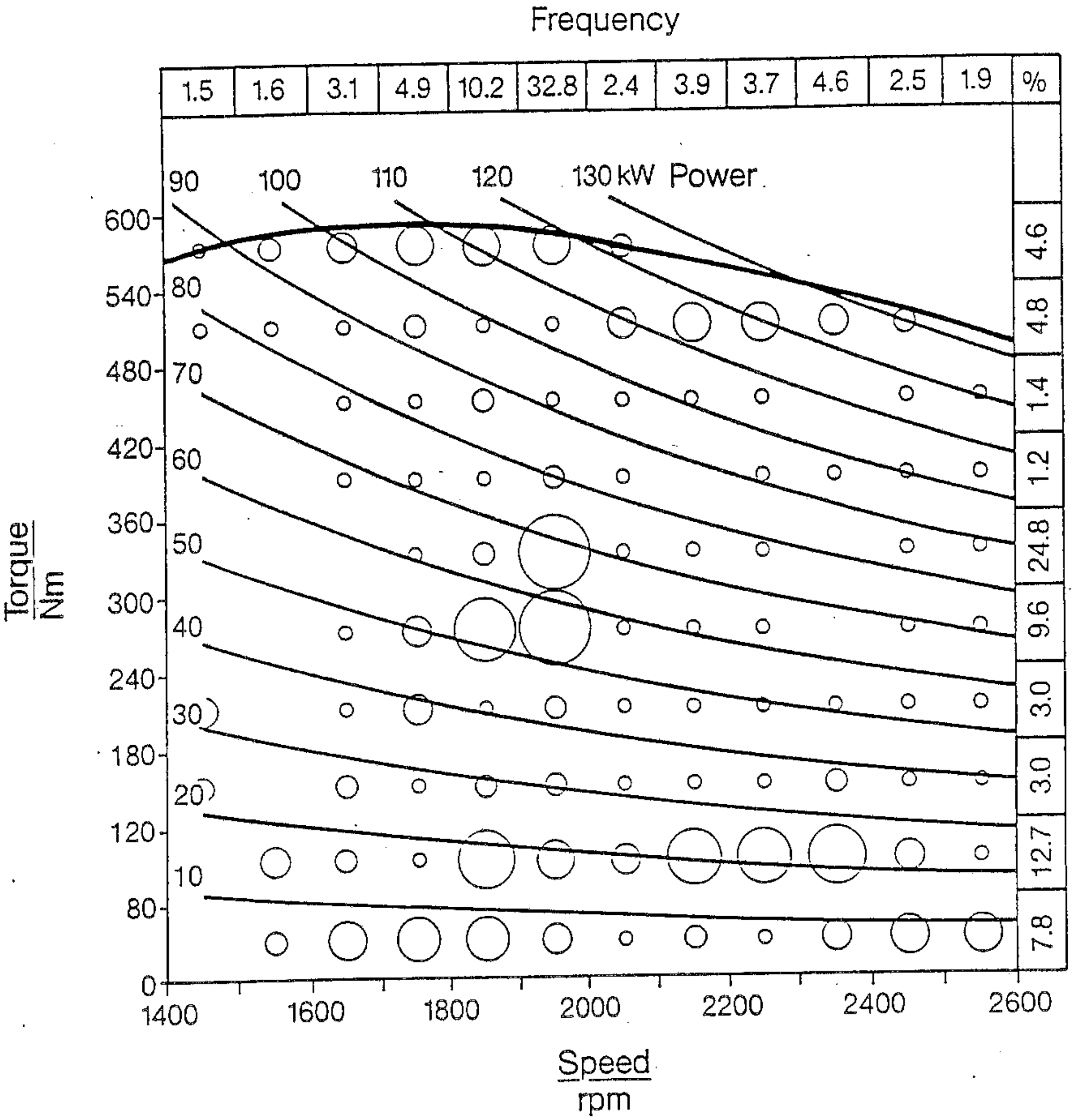
B 4

Lit.: Netherlands Delegation to MVEG

Mercedes Benz
Nutzfahrzeug
Entwicklung

Engine map frequencies of a 40 t long haul truck

EN/MVT 9102-02



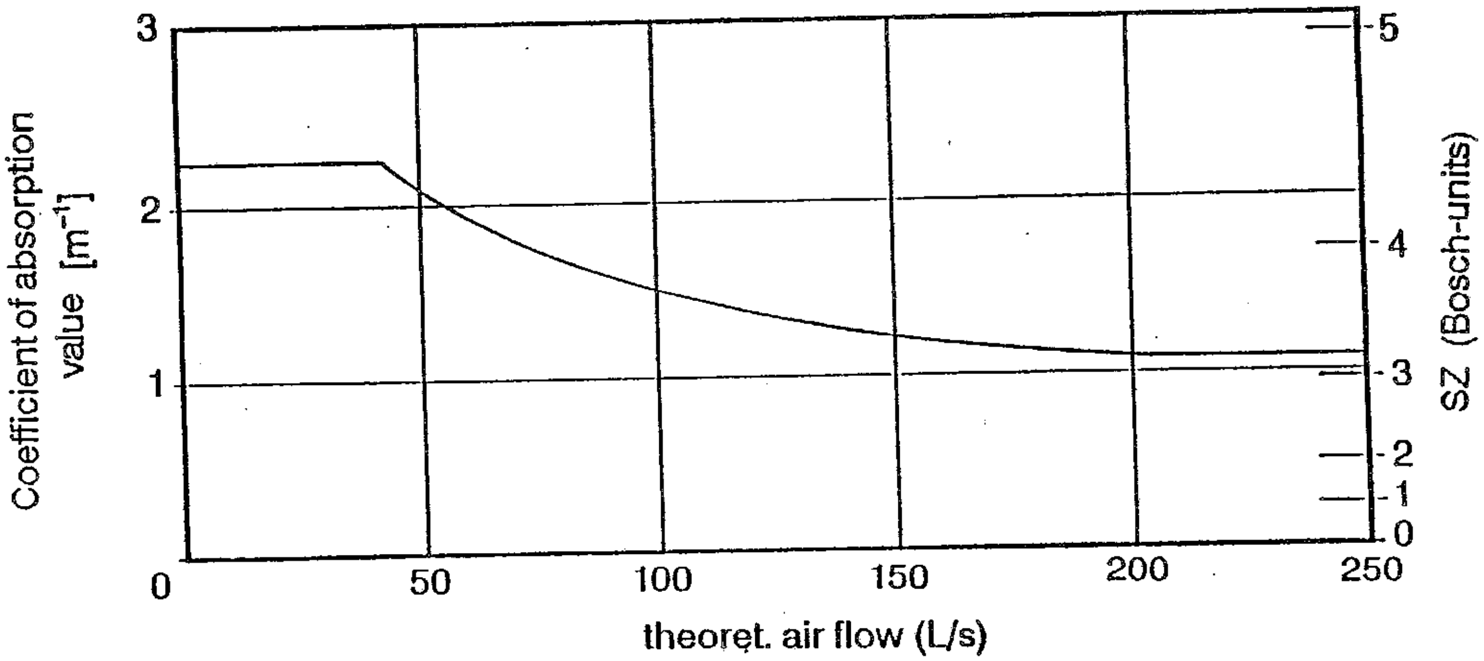
B 5

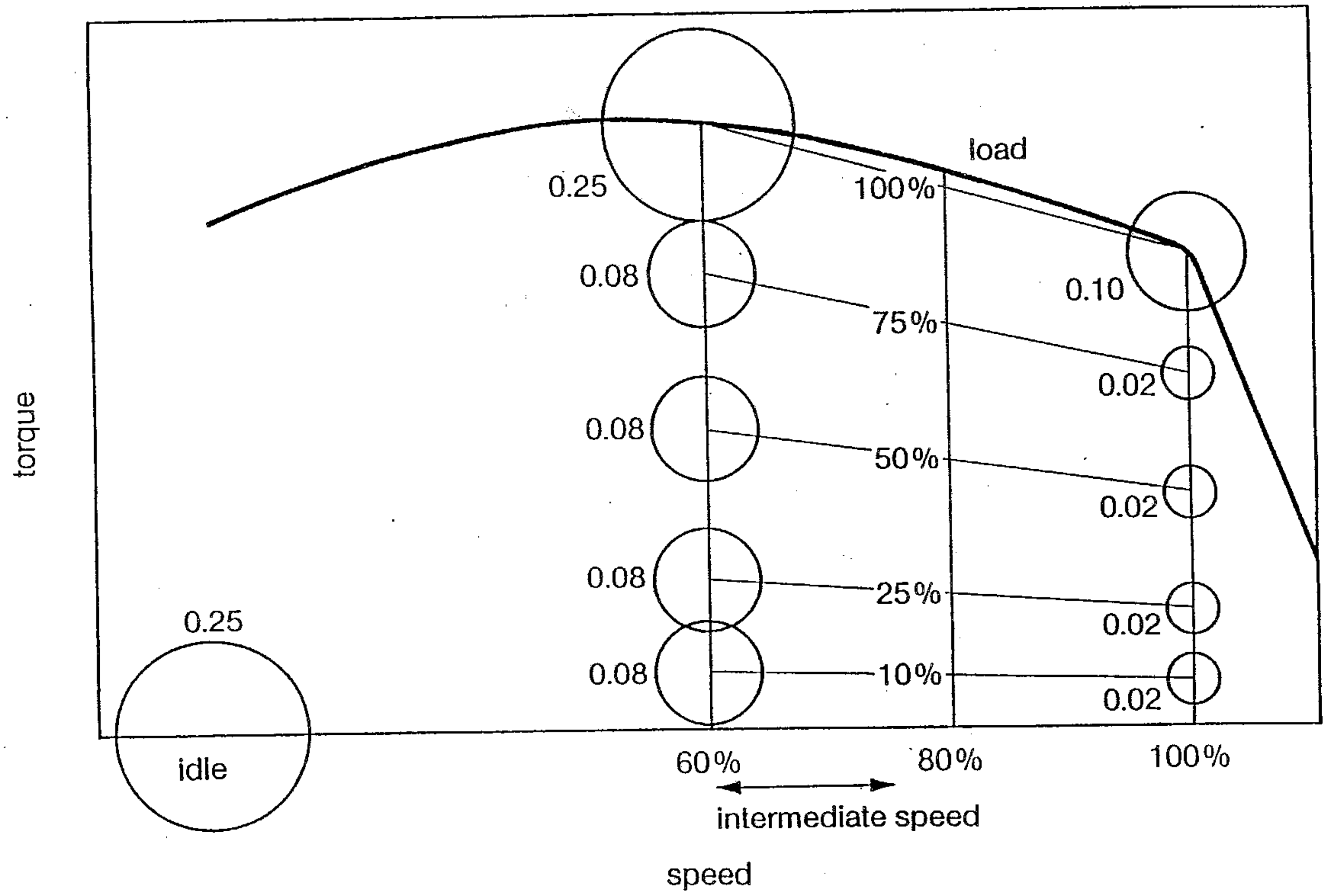
Lit.: Netherlands Delegation to MVEG

Mercedes-Benz
Nutzfahrzeuge
Entwicklung

Engine map frequencies of a 10 t truck for urban traffic

EN/MVT 9102-01

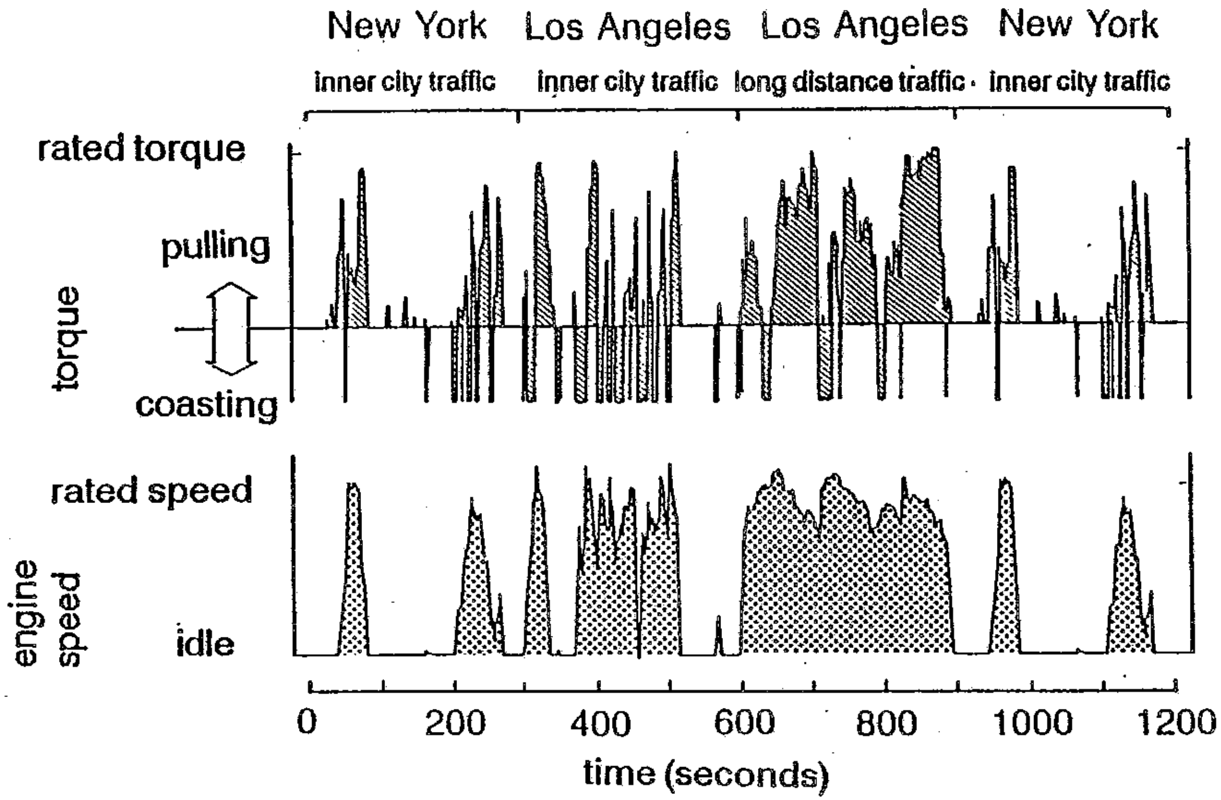

Coefficient of absorption value [m⁻¹]
3
2
1
0
50
100
150
200
250
theoret. air flow (L/s)
SZ (Bosch-units)
5
4
3
2
1
0



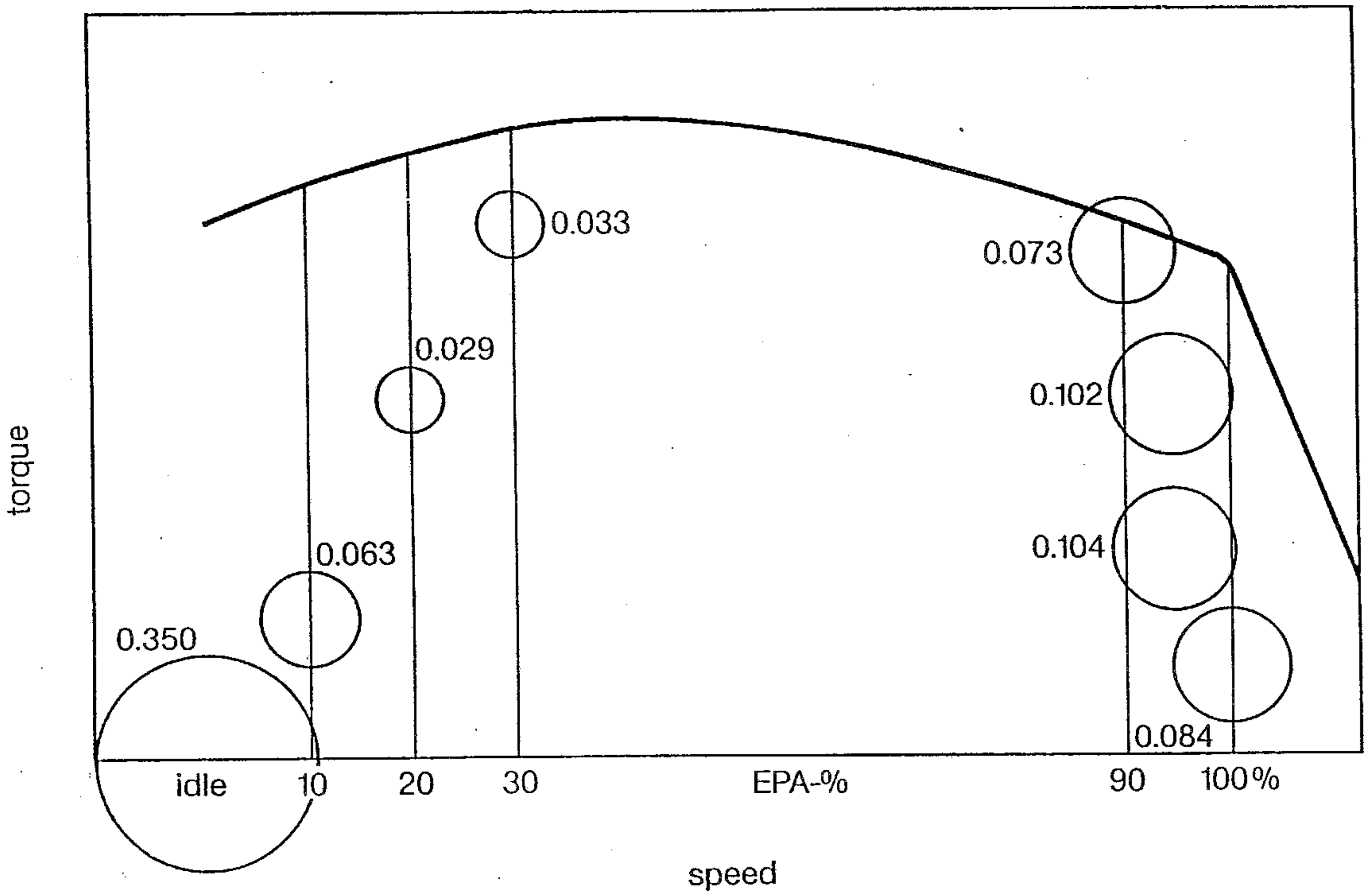
B 7

Mercedes Benz
Nutzfahrzeuge ·
Entwicklung

Measuring points and weighting factors of ECE R49 13-mode test



Torque- and speed graphs in the US-transient test cycle for commercial vehicle diesel engines



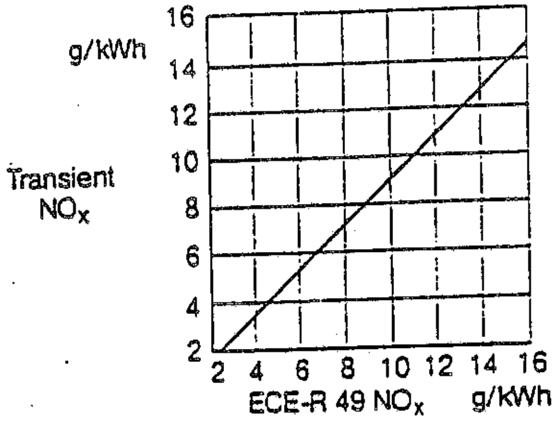
B 9

Mercedes Benz
Nutzfahrzeuge
Entwicklung

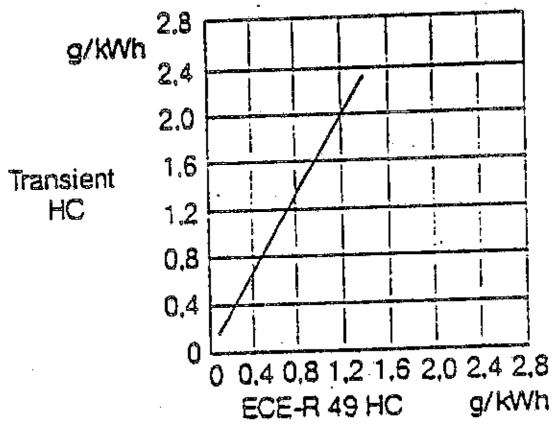
Measuring points and weighting factors of AVL 8-mode-Transienttestsimulation

Correlation of US-Transient Test and ECE R49-13-modes-Test

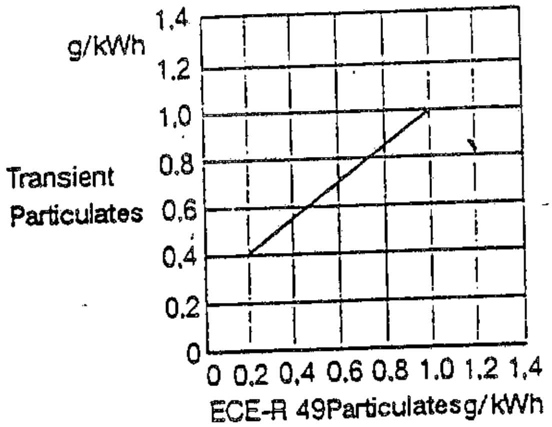
B 10

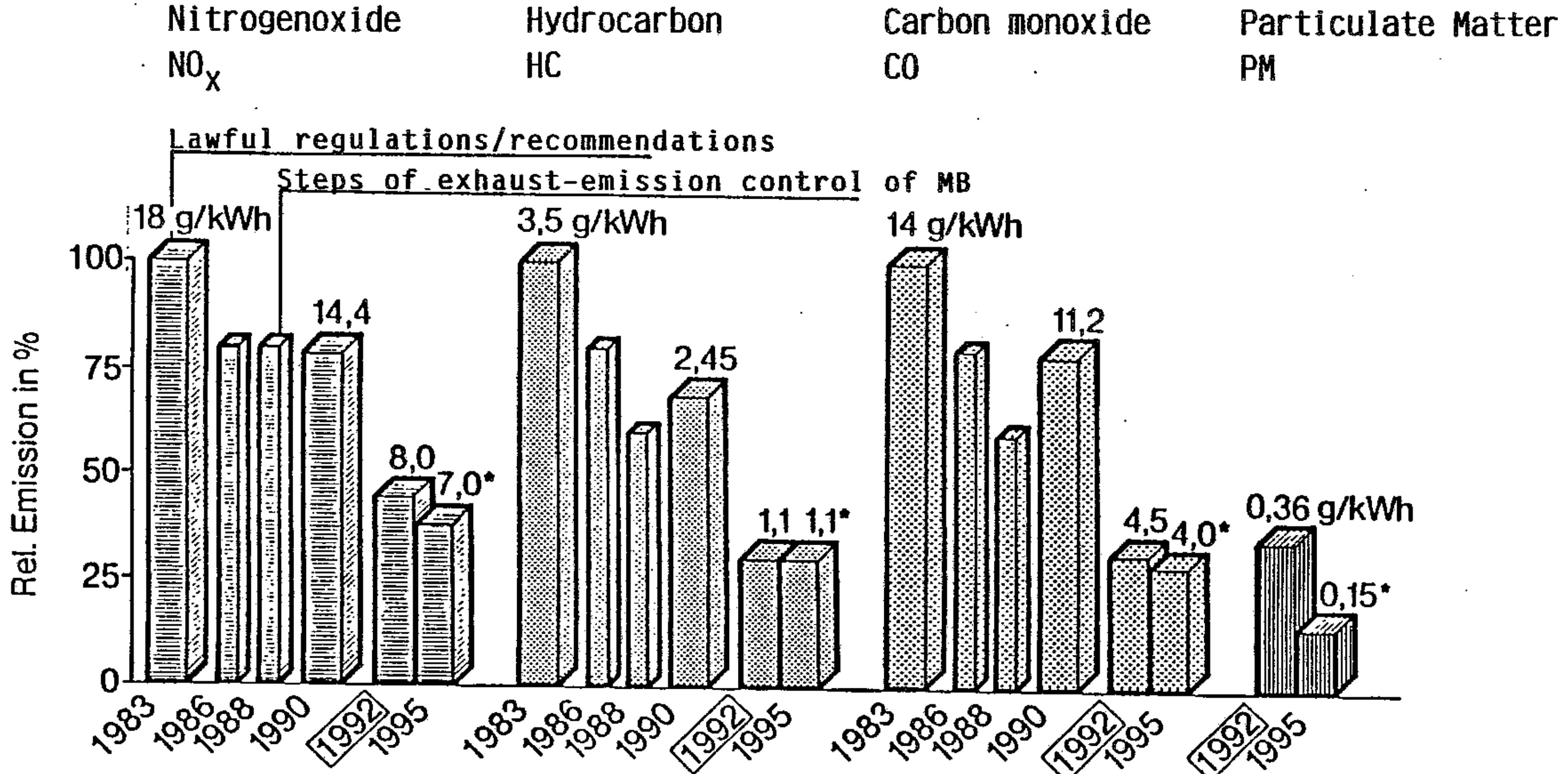


B 11

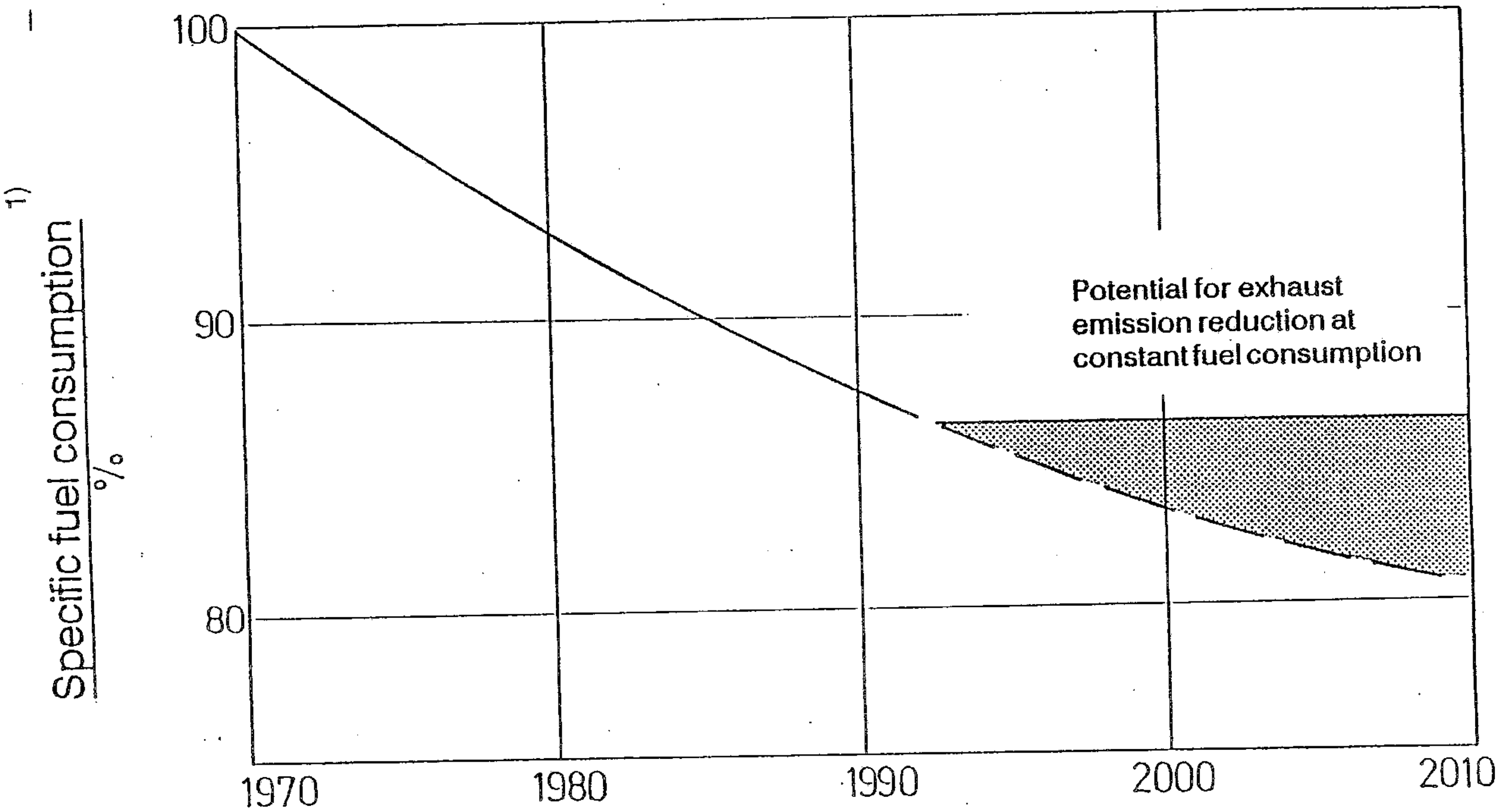


B 12



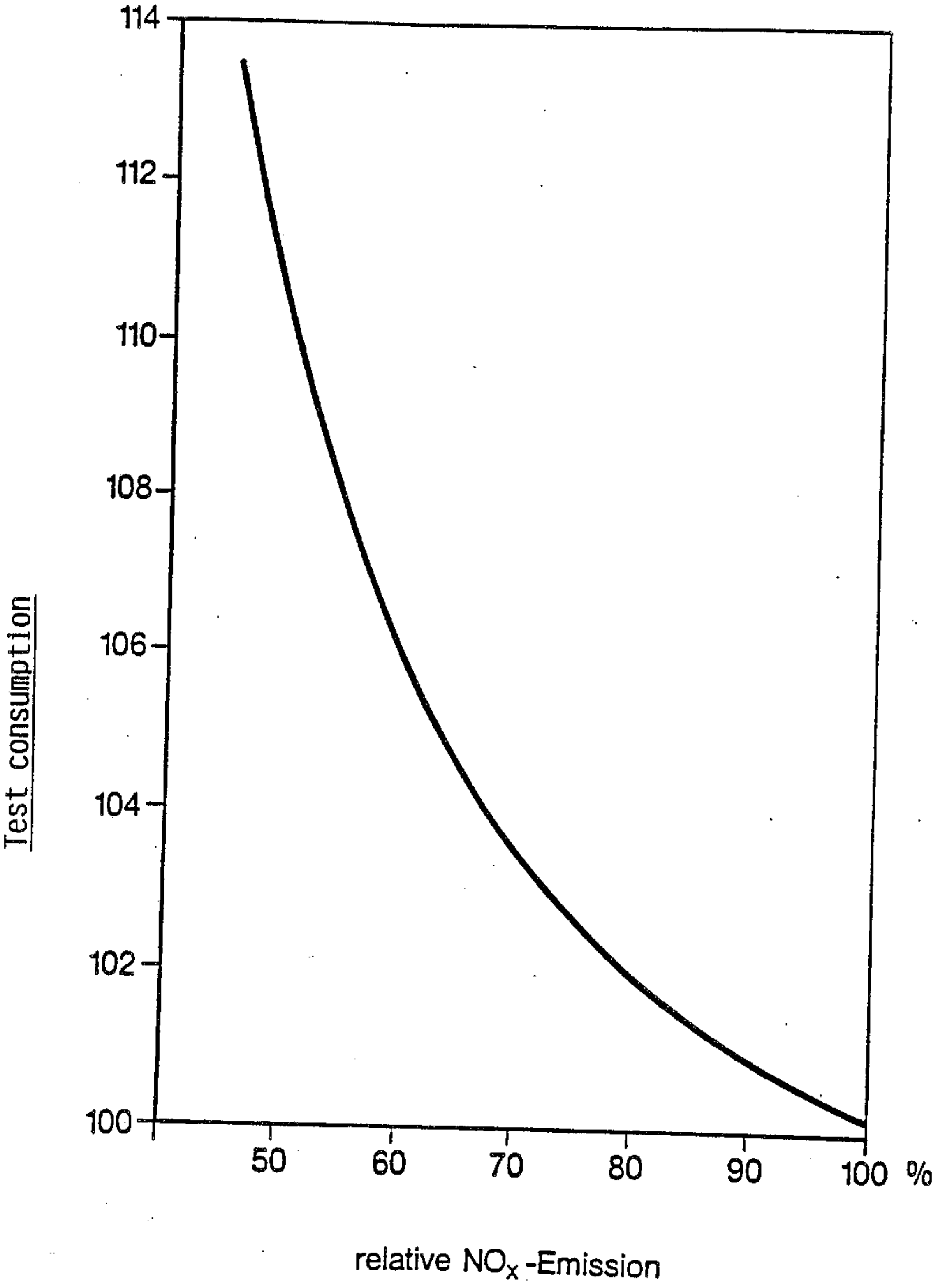


Steps for reducing emission in Europe
(* Standard limit values)



1) in acc. with ECE-R49

Development of specific fuel consumption of Mercedes-Benz commercial vehicle diesel engines

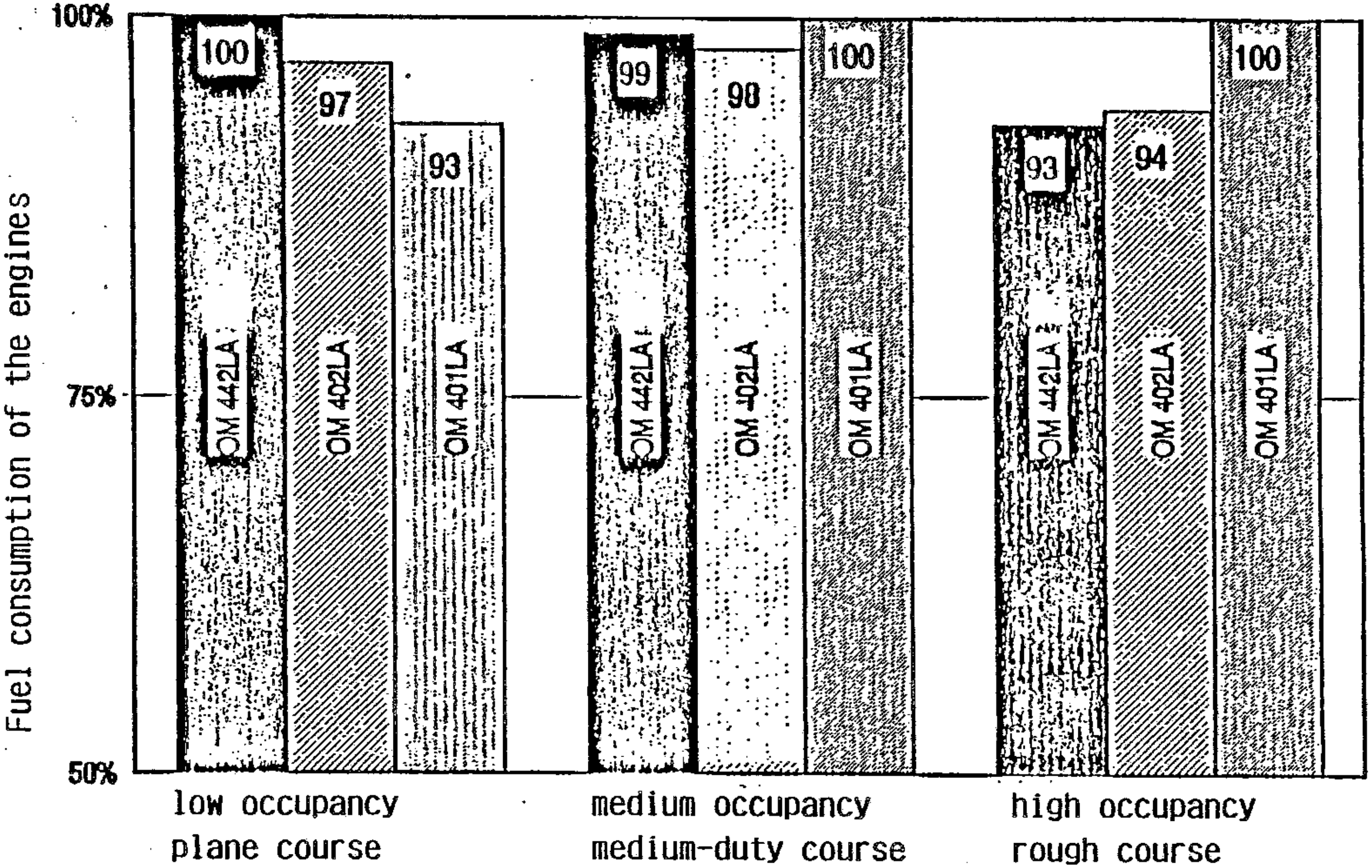


B 15

Mercedes-Benz
Nutzfahrzeuge
Entwicklung

BR400

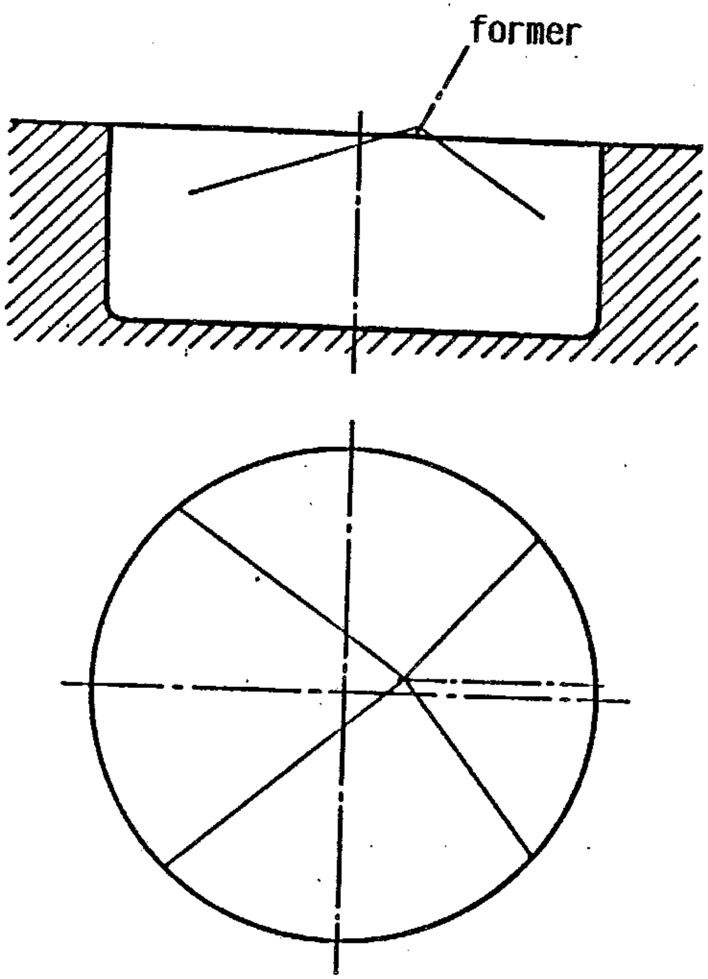
Results of test according to ECE-R49

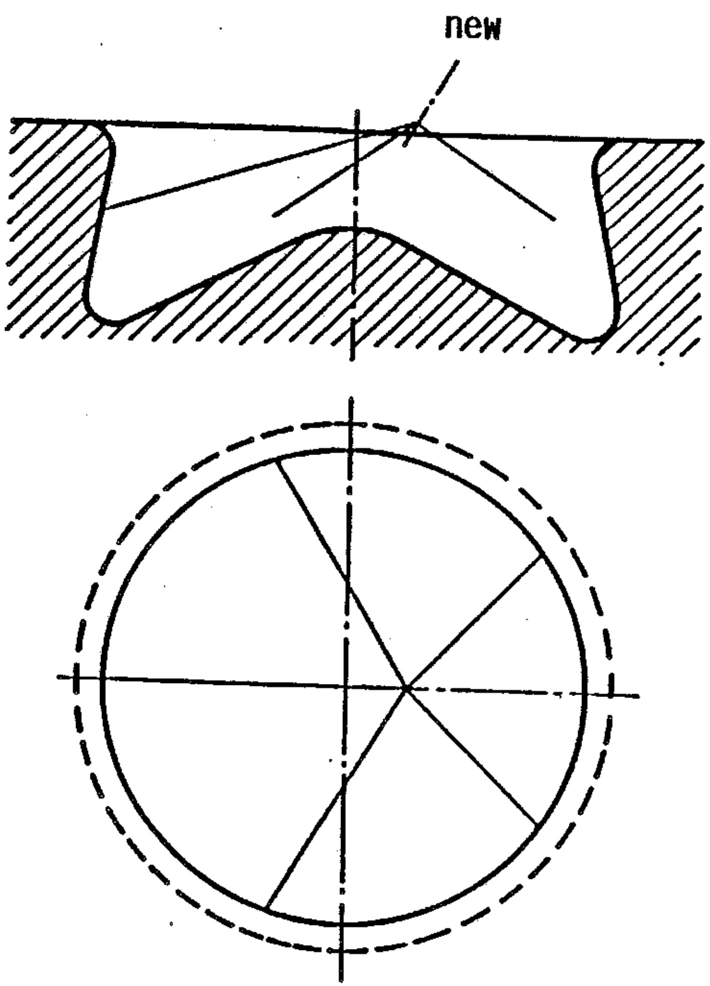


B 16

Fuel consumption of different engines
in dependance on the performance of the vehicle

Geschäftsbereich NFZ
Entwicklung
GBN/ES 0391 F
ENZ/TI 31 963.GRF

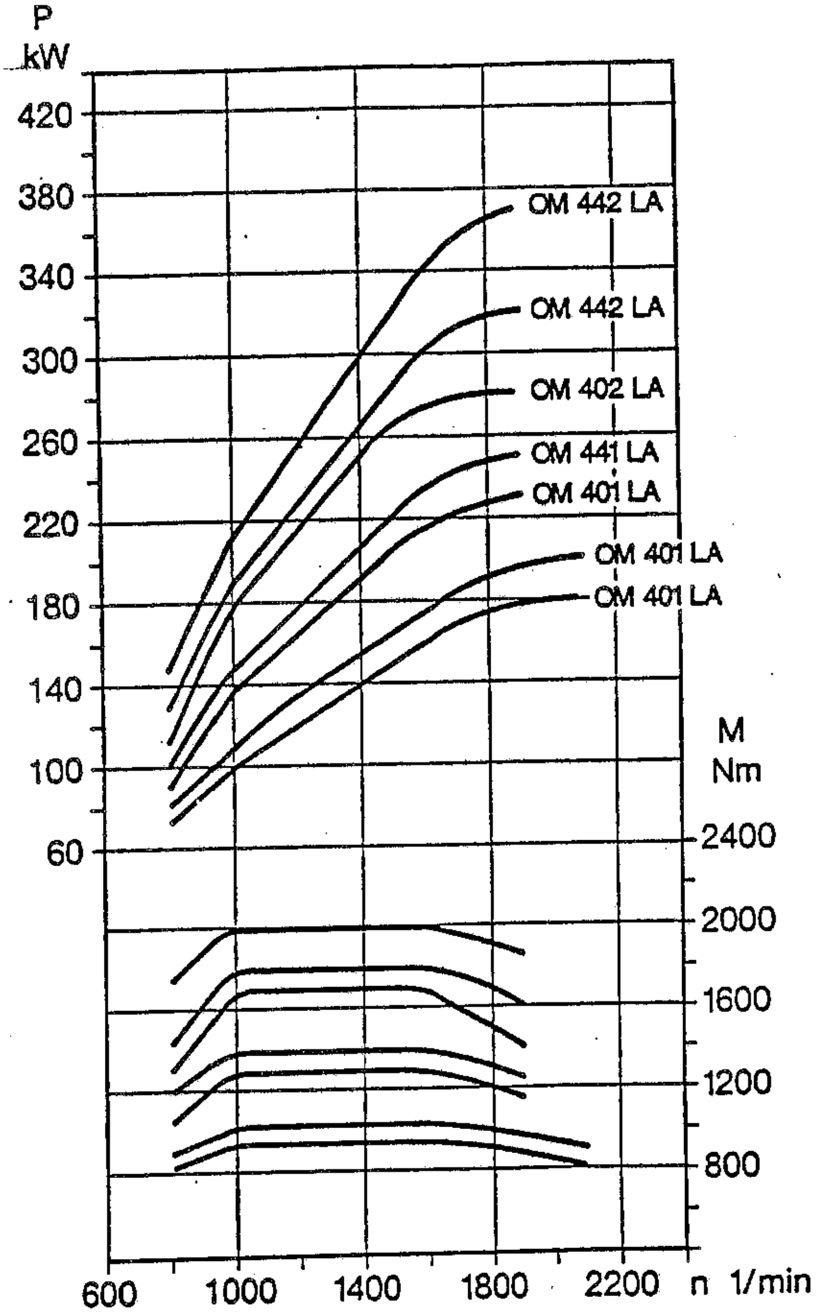




B 17

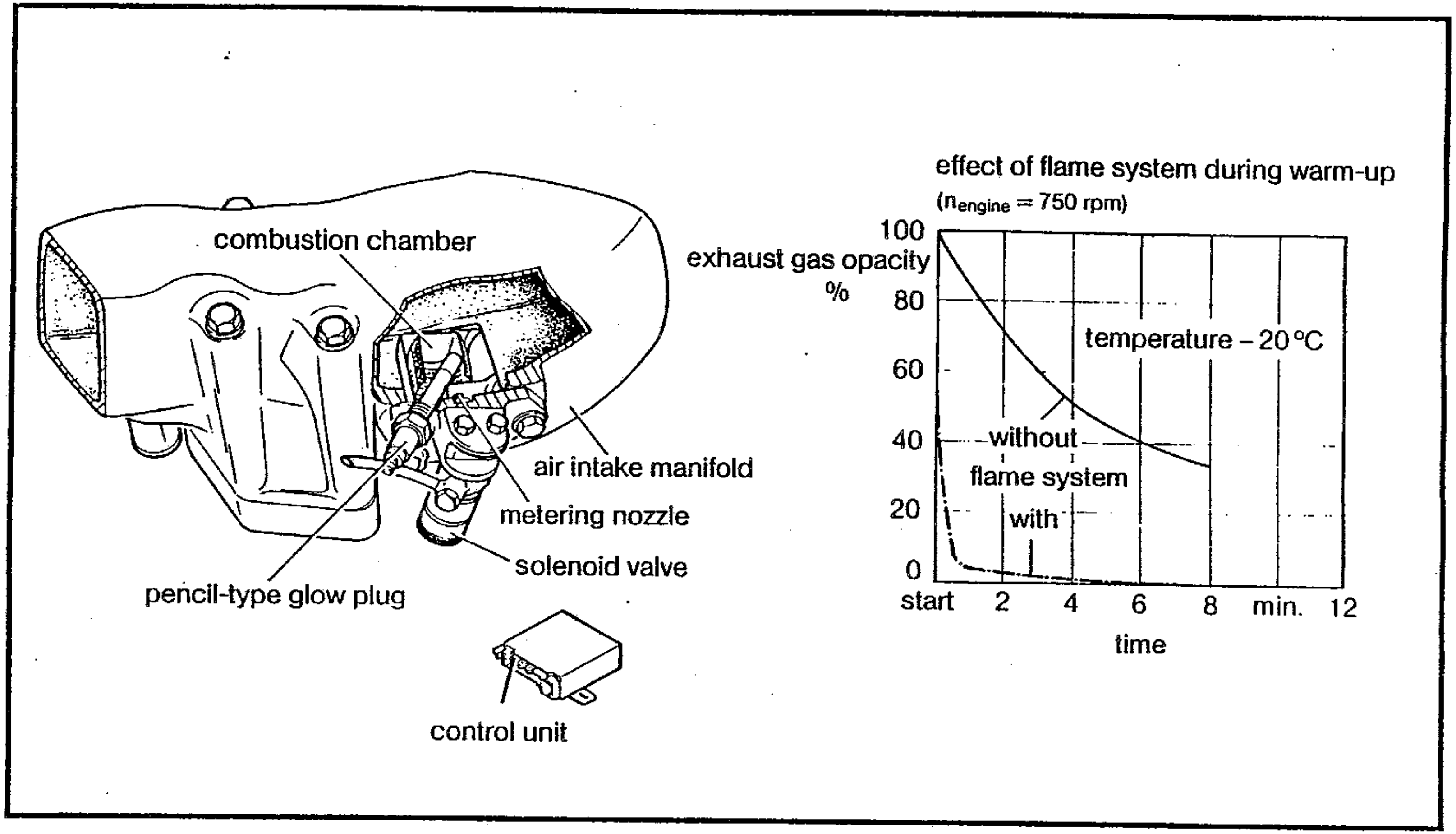
Mercedes-Benz
Nutzfahrzeuge
Entwicklung

Shape of recess and jet position

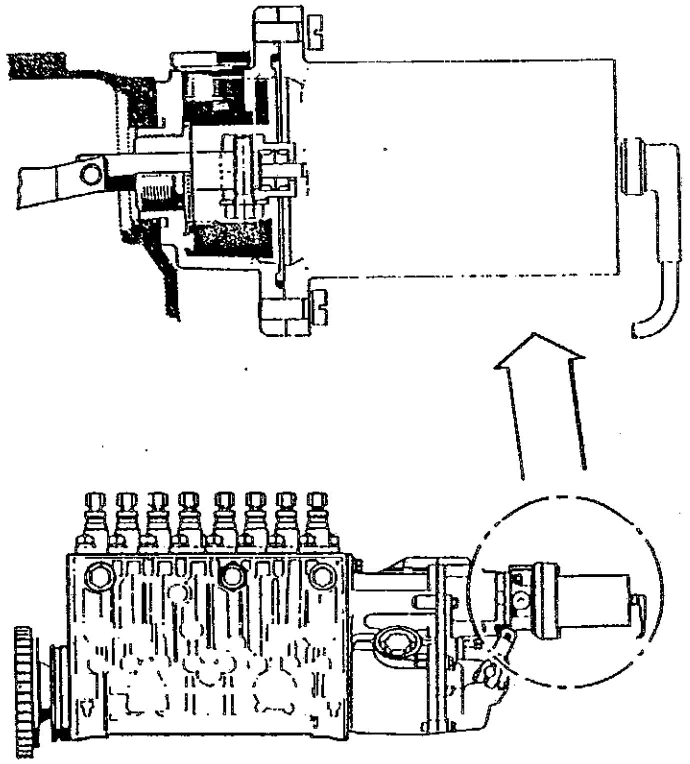


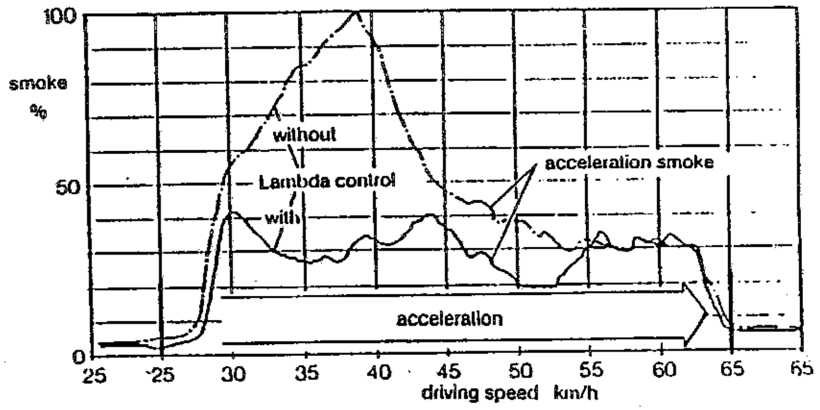
400 series commercial vehicles
engine range

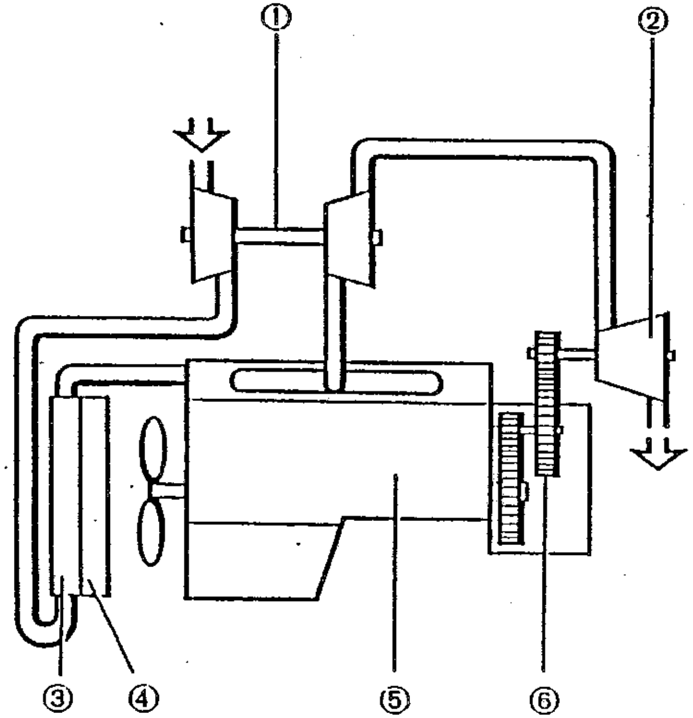
Flame system



Electronic
Lambda (λ) control





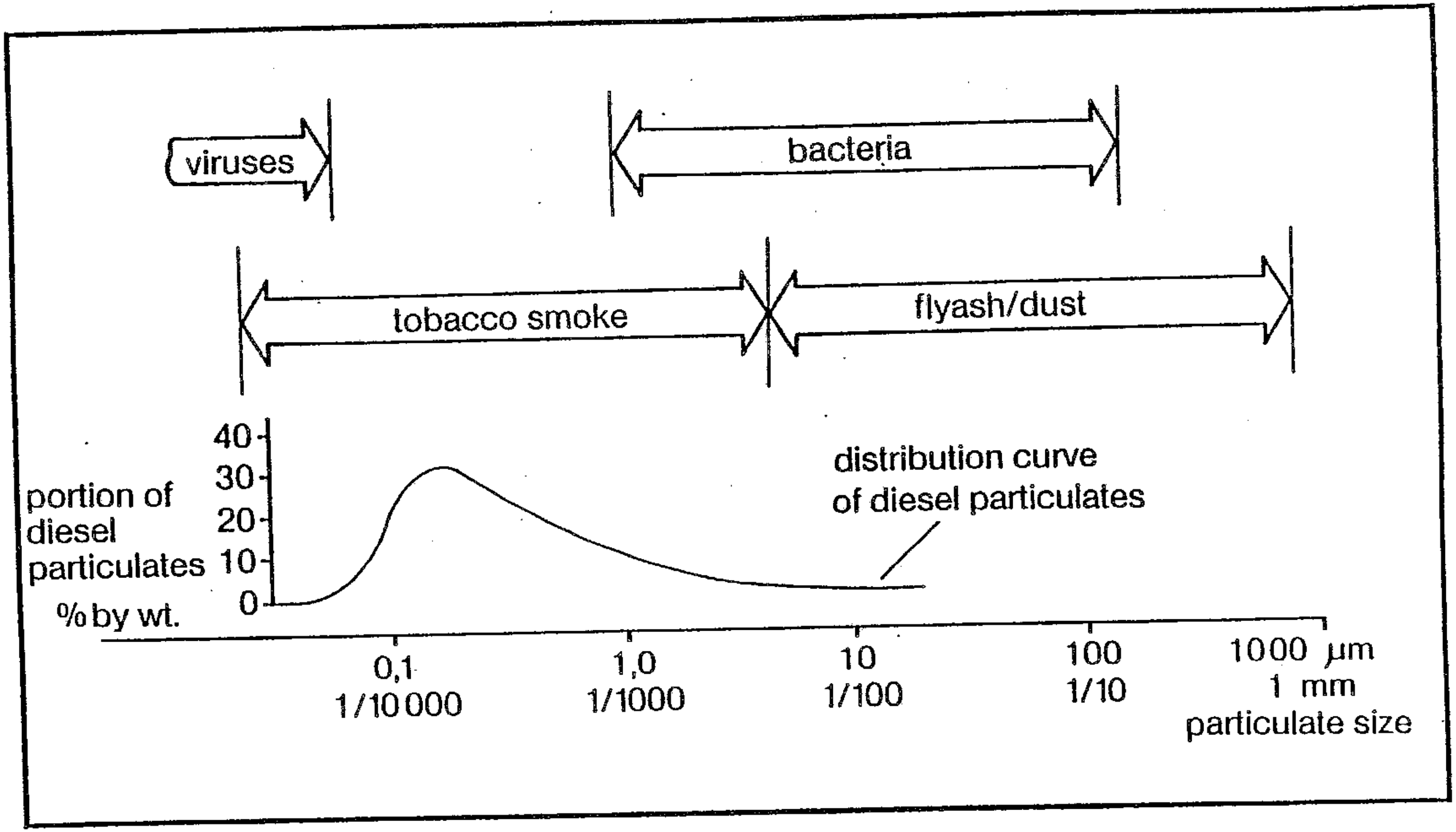


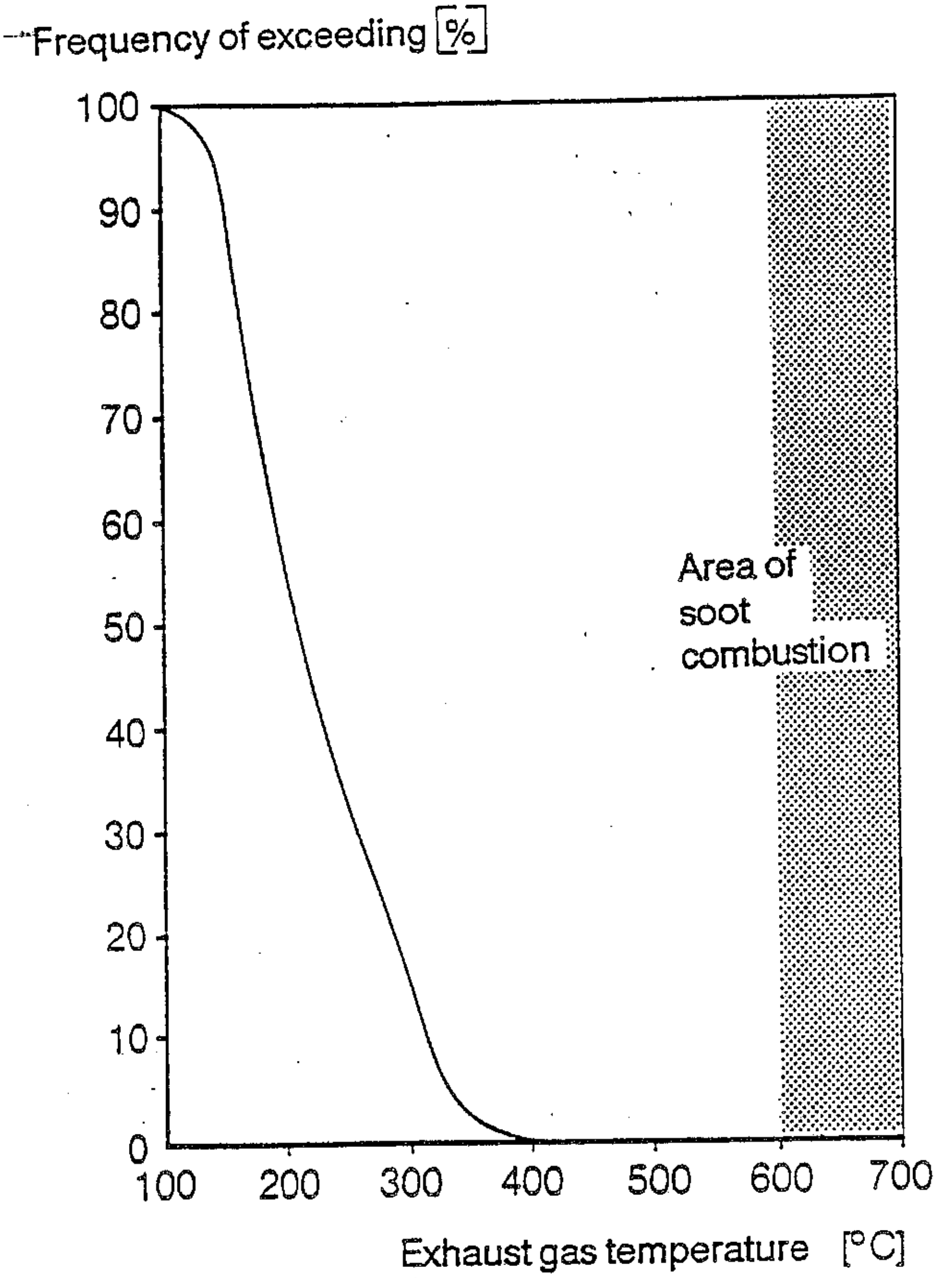
1. Turbocharger
2. Recovery power turbine
3. Intercooler
4. Engine cooling
5. Diesel engine
6. Reduction gear with
   overrunning clutch and
   torsional-vibration damper

Scheme Diesel compound engine with exhaust recovery power turbine

Geschäftsbereich Nfz.
Entwicklung
EN/MMVK

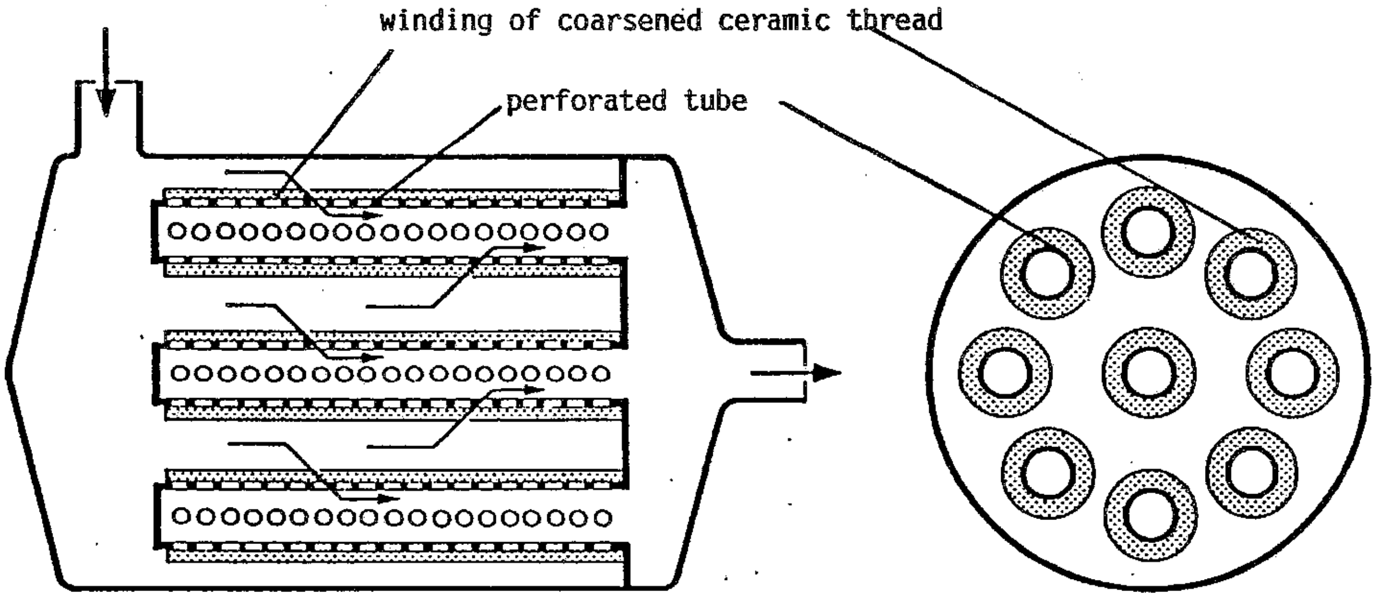
Distribution curve of diesel particulates in the exhaust gas and assignment to other substances





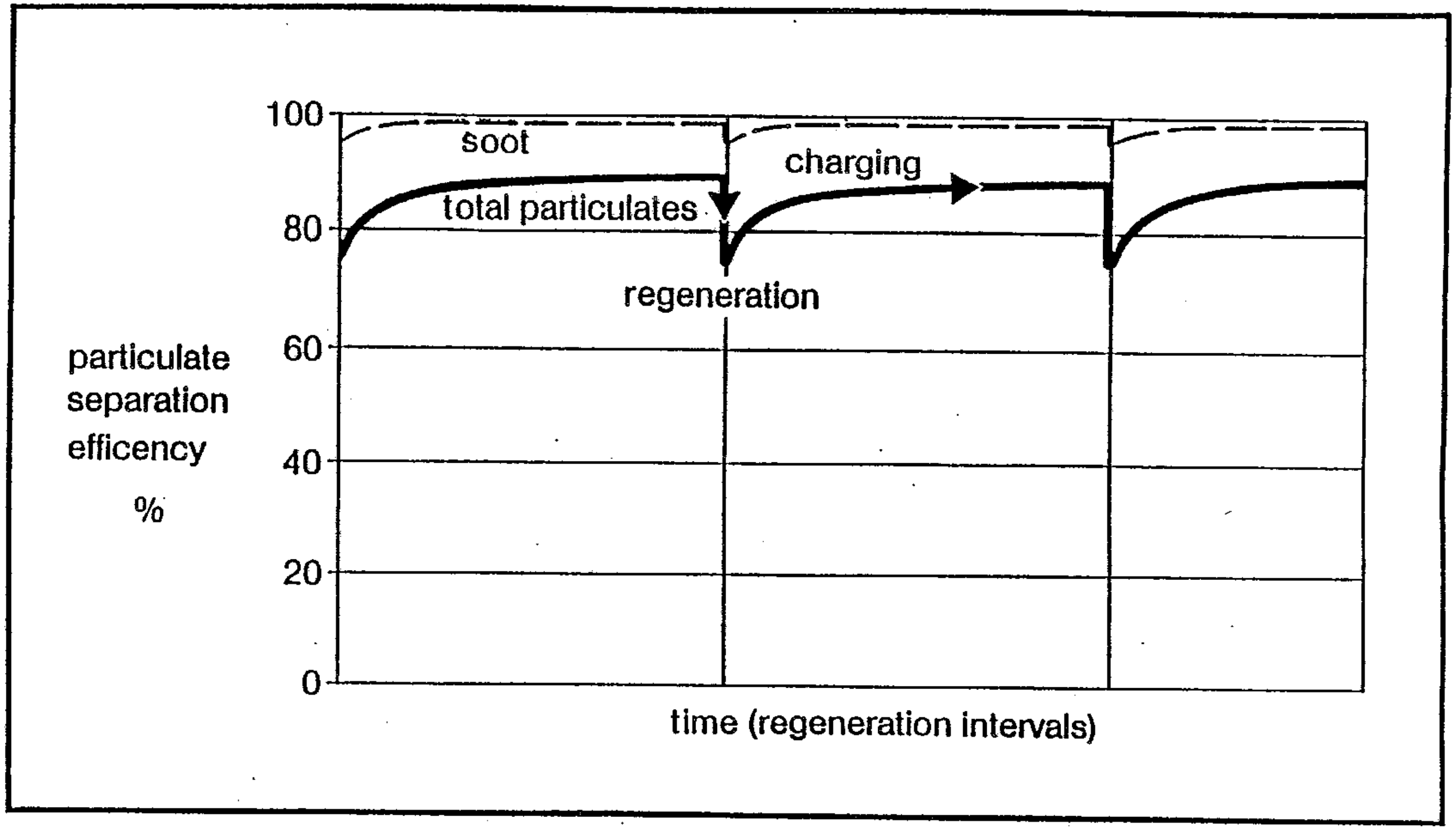
GB Nutzfahrzeuge
Entwicklung

Distribution of exhaust gas temperature of a city bus during regular traffic

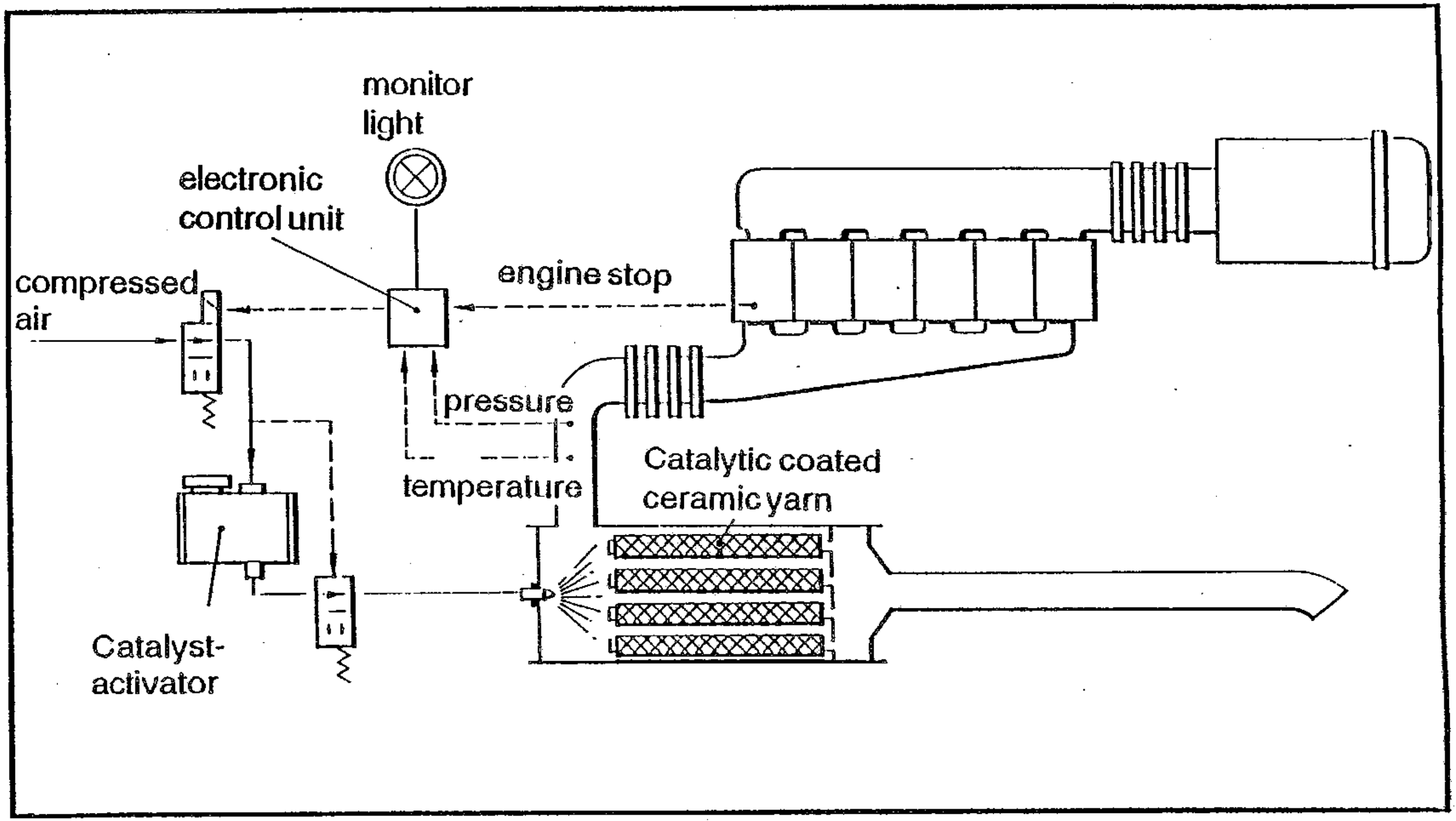


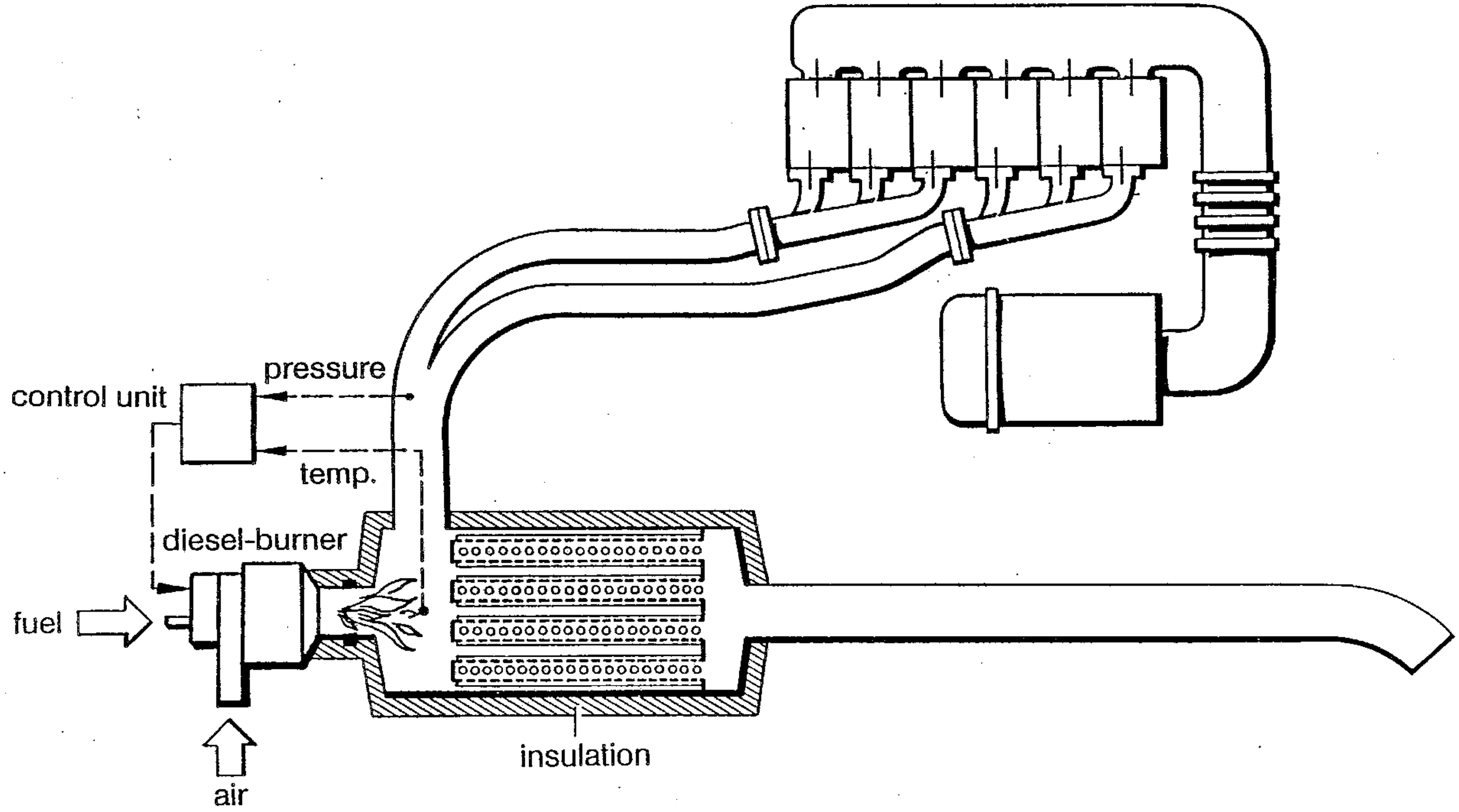
Candle-Type Filter (schematic)

Particulate and soot separation efficiency of ceramic fiber coil particulate trap (US Transient Test)



Ceramic coil-type filter with catalytic regeneration





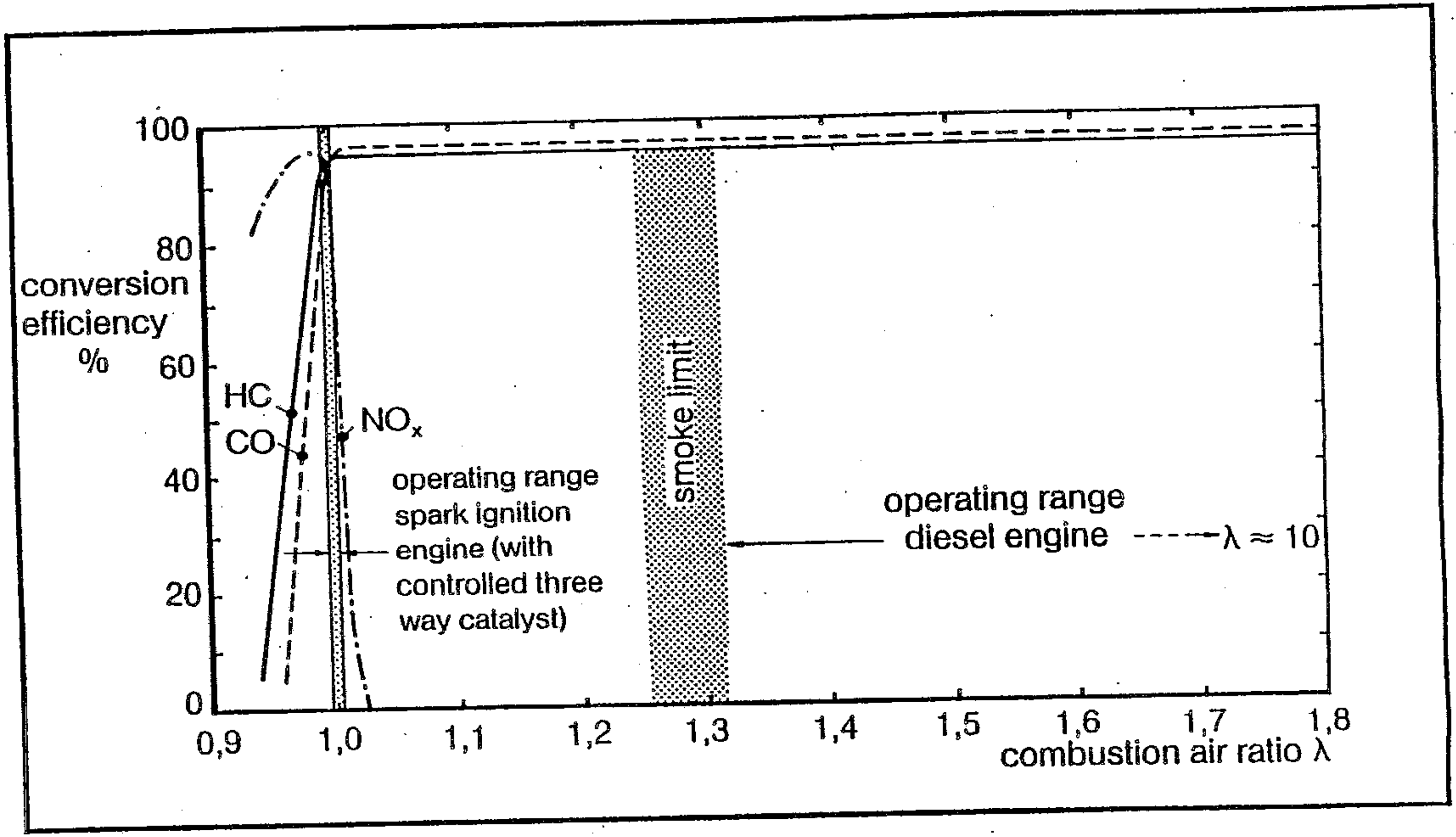
B 27

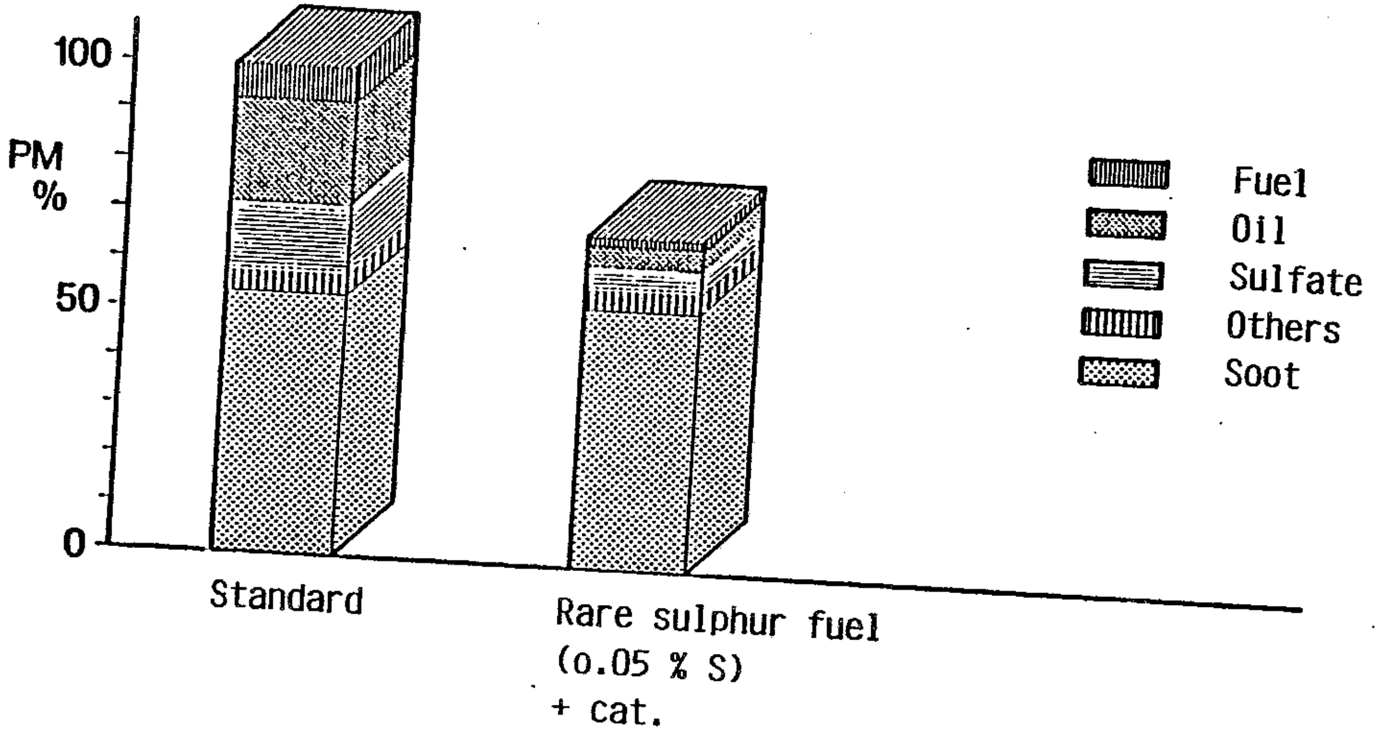
Particulate trap system with full-flow burner regeneration

90 012 050

Mercedes-Benz
Nutzfahrzeuge
Entwicklung

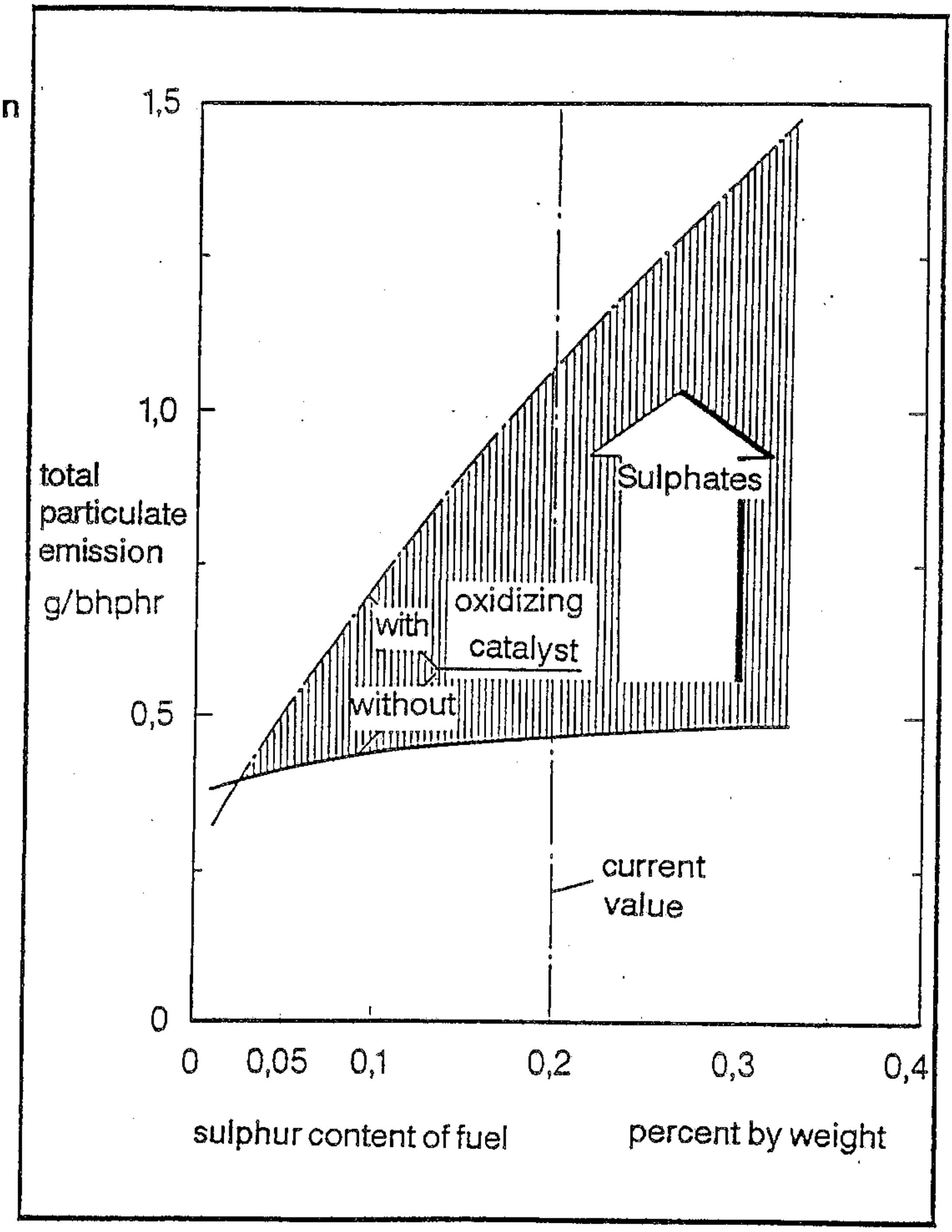
Conversion efficiency of catalytic converter and engine operating range



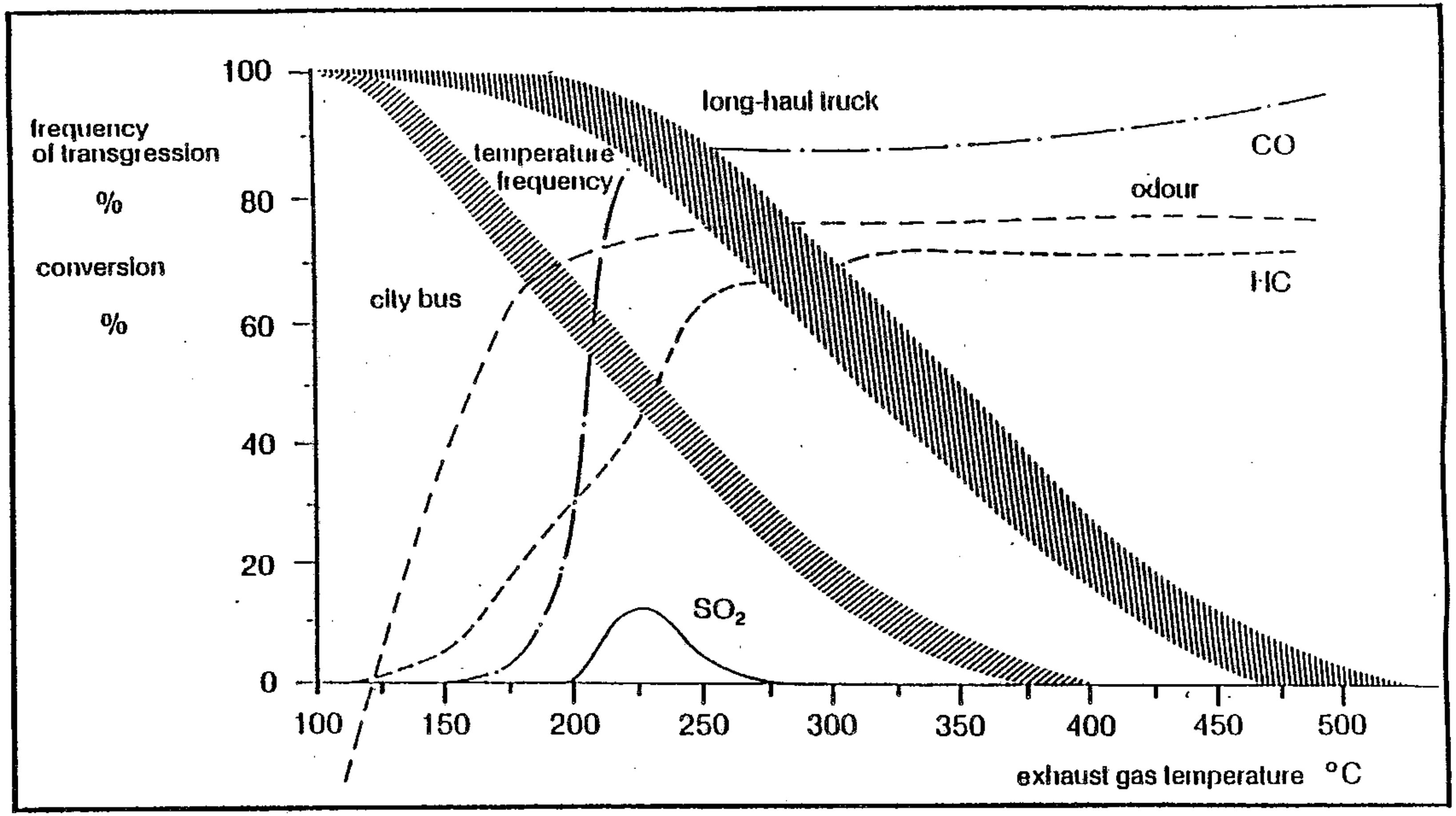


Reduce of Pm-emission
Diesel-cat. and rare sulphur fuel

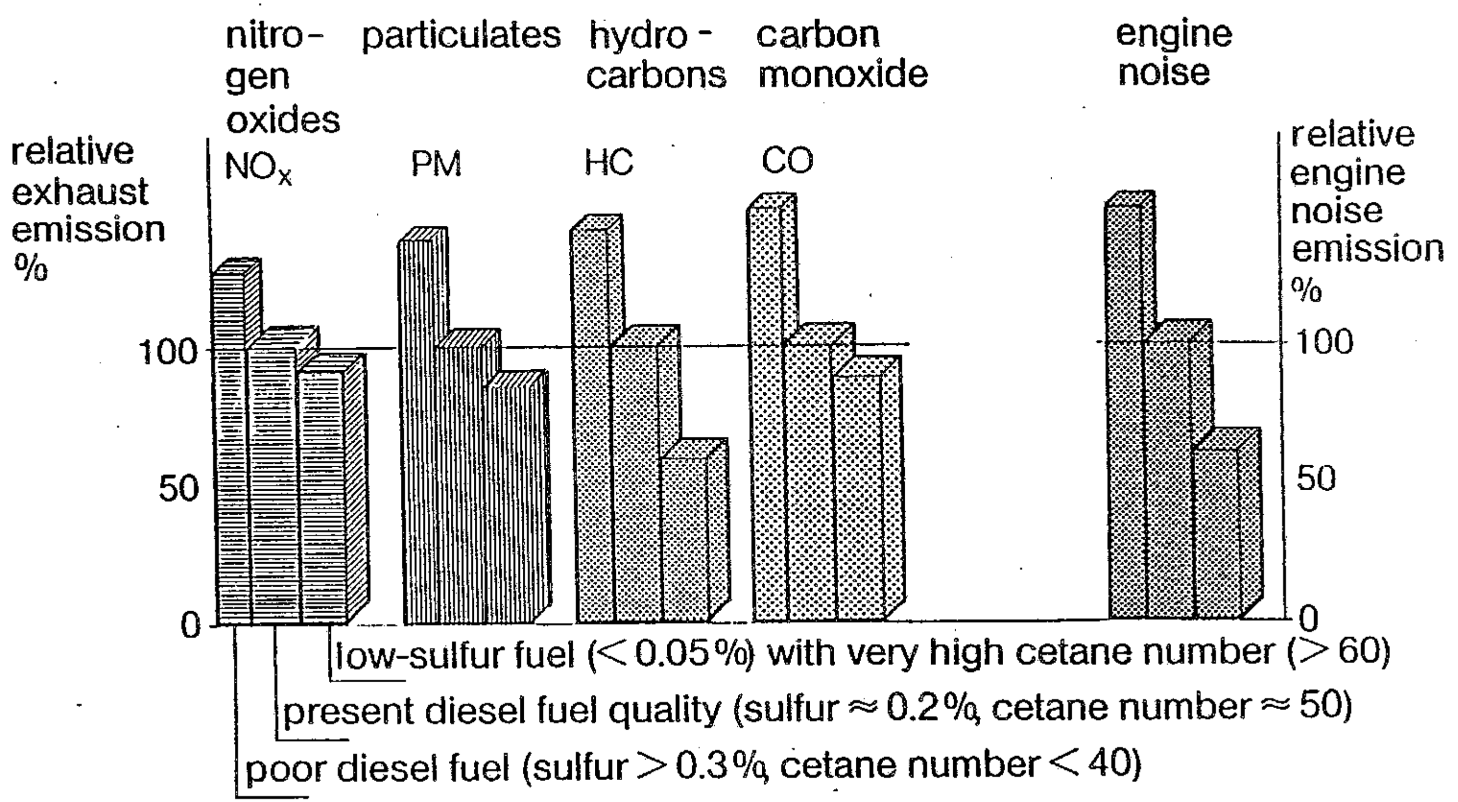
sulphur content of fuel and total particulate emission (US transient test)



Exhaust gas temperature distribution of a city bus/long-haul truck and conversion of a conditioned diesel catalytic converter

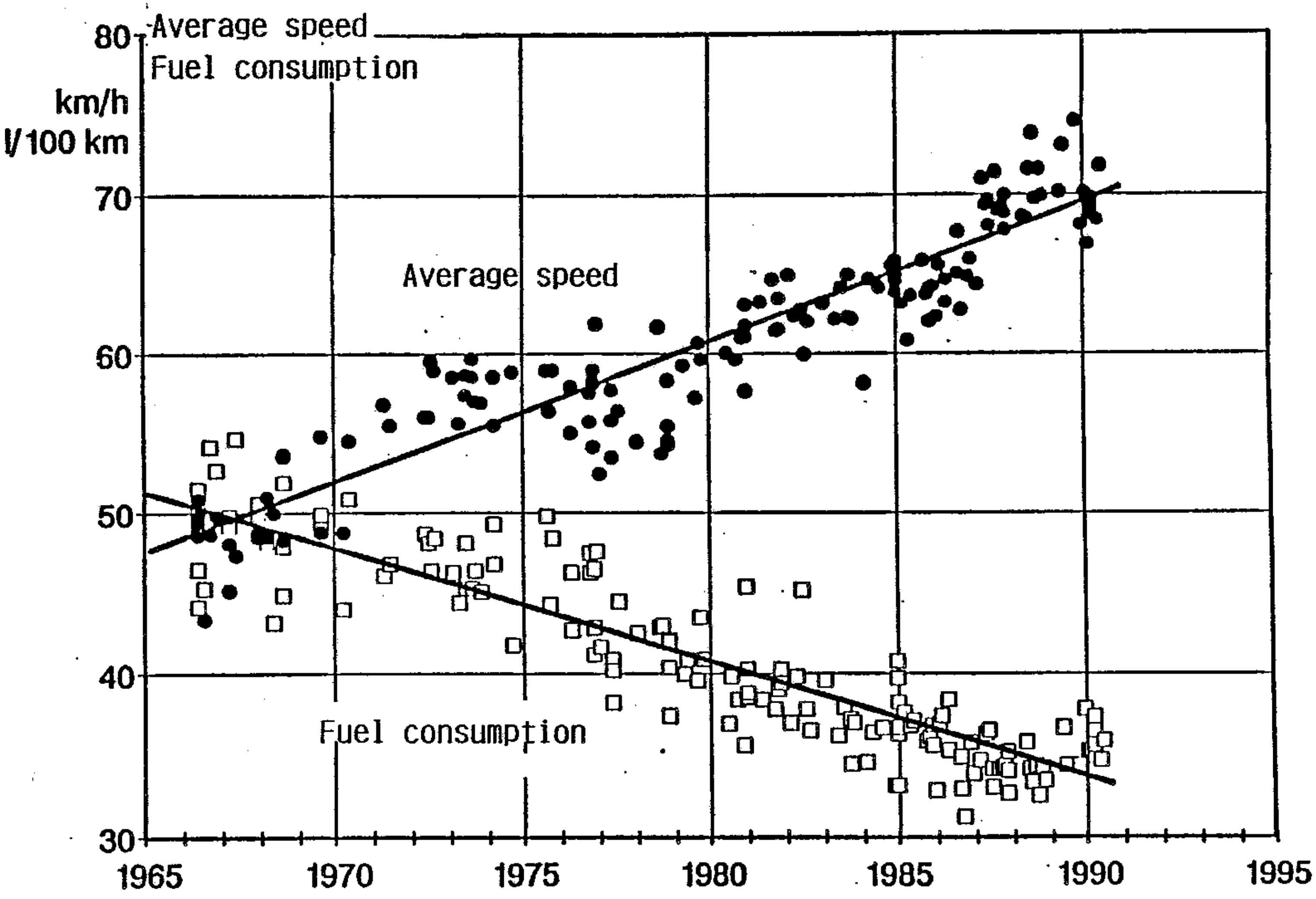


Diesel fuel quality and emissions



Fuel consumption
and
average speed

Results of test of 38- resp. 40-t-semitrailer
(Data "lastauto omnibus")



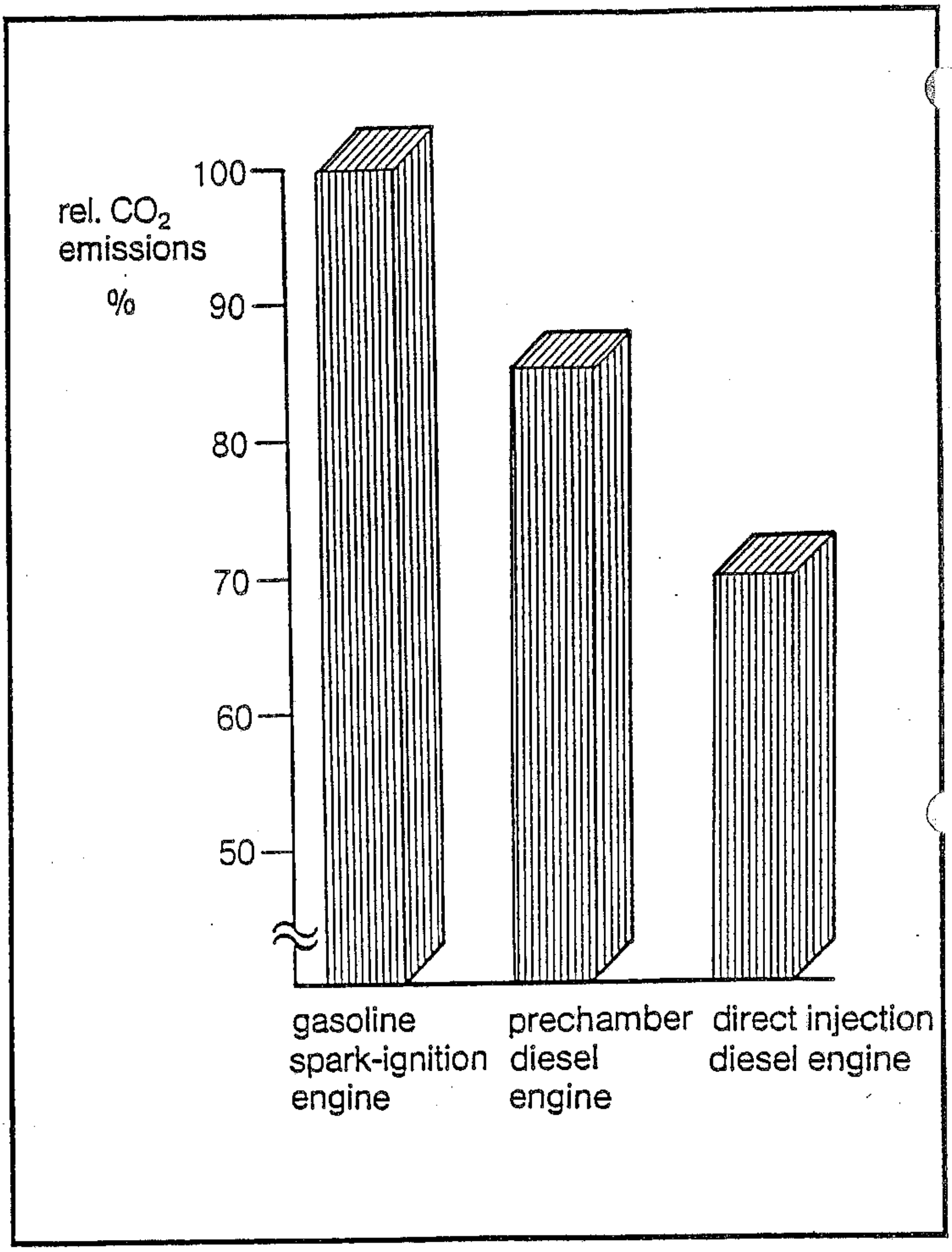
B 33

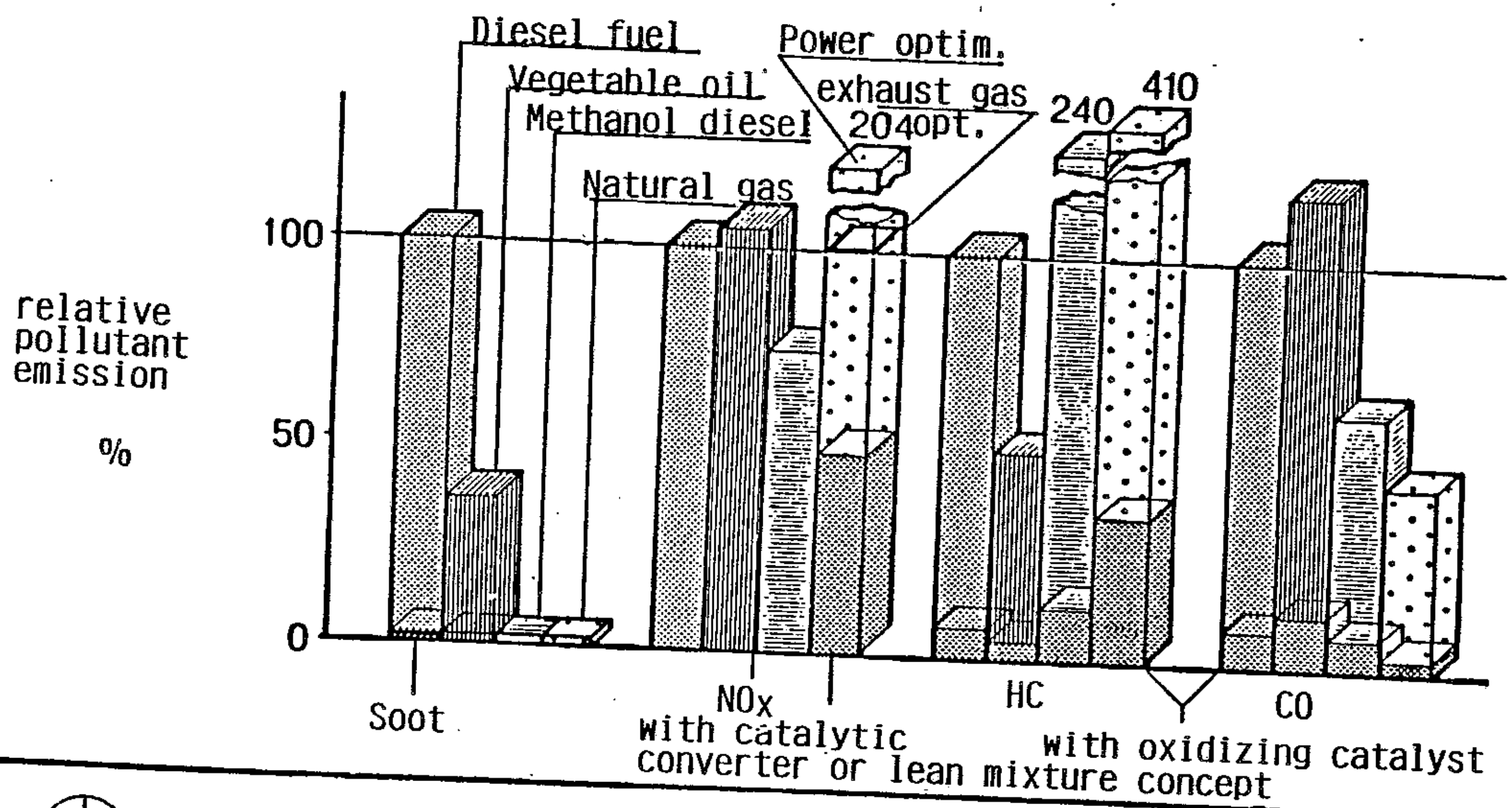
Mercedes-Benz

Geschäftsbereich NFZ
Entwicklung
GBN/ES 1190

GBN/ES 61.050 FRN

Carbon dioxide (CO_2) emissions of truck engines

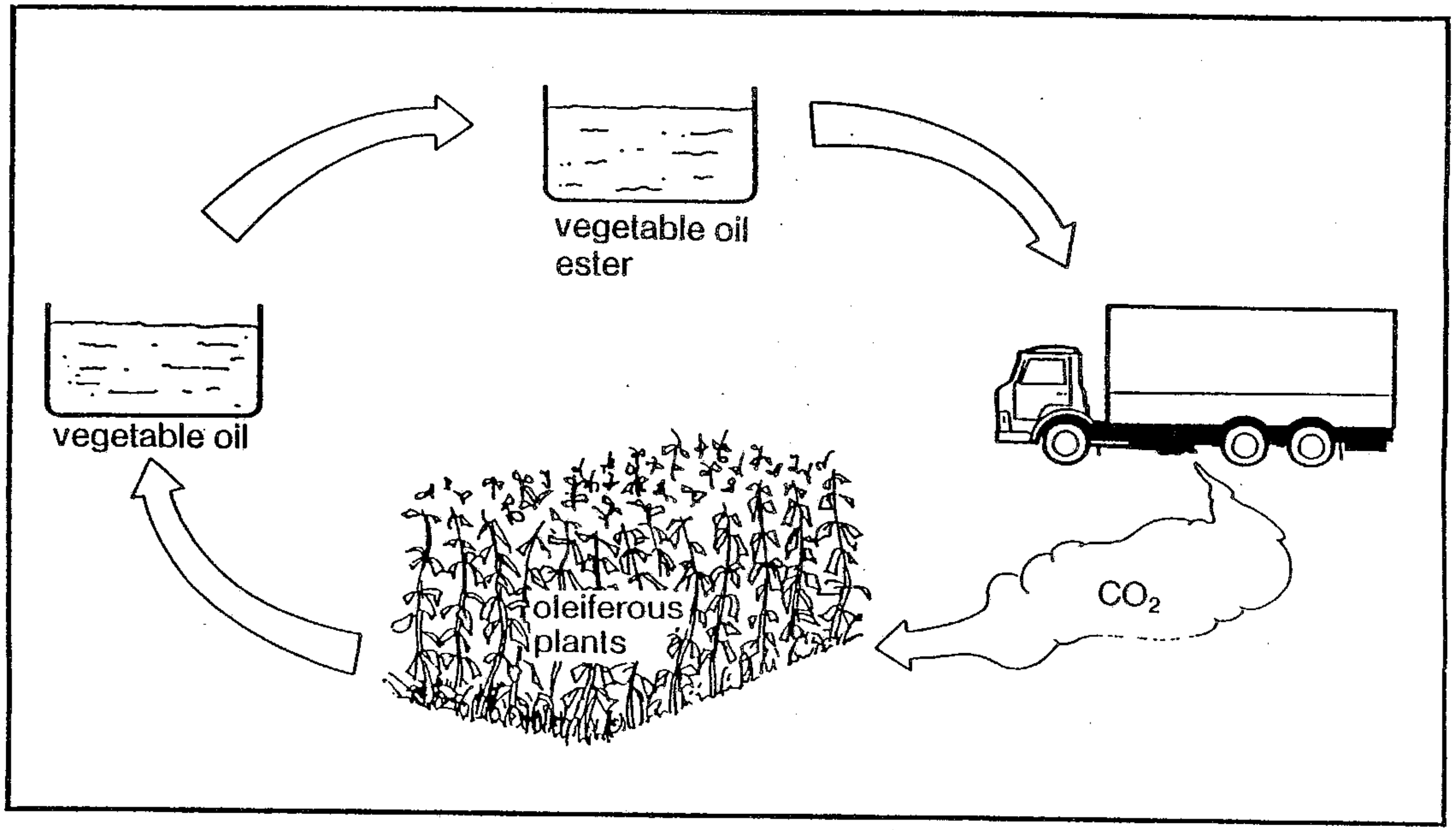




B 35

Exhaust emission alternative fuels and diesel fuel (ECE-Test)

CO_2 cycle using fuels from regenerative energy sources



Fahrzeug-art	Richtlinie 70/157/EWG vom 6. 2. 1970	Richtlinie 77/212/EWG vom 8. 3. 1977	Richtlinie 81/334/EWG vom 13. 4. 1981	Richtlinie 84/424/EWG vom 3. 9. 1984	Geräuscharme Kfz nach Anlage XXI zur StVZO
Pkw	82	80	neues Meßverfahren. Dadurch indirekte Verschärfung der Anforderungen um bis zu 5 dB (A), je nach Fahrzeug-Typ. Grenzwerte nicht mehr direkt vergleichbar.	77-78**	-
Lkw < 3,5 t > 3,5 t > 12 t und > 147/150 kW	 84 89 91	 81 88 88		 78 - 80* 81 - 83* 84	 77 - 78* 77 - 80*** 80
Kraft-omnibusse < 3,5 t > 3,5 t > 147/150 kW	 84 89 91	 81 82 85		 78 - 80* 80 83	-
Tritt in Kraft für Fahrzeug-Typen	ab 1. 10. 1974	ab 1. 04. 1980	ab 1. 10. 1984	ab 1. 10. 1988/89	fakultativ

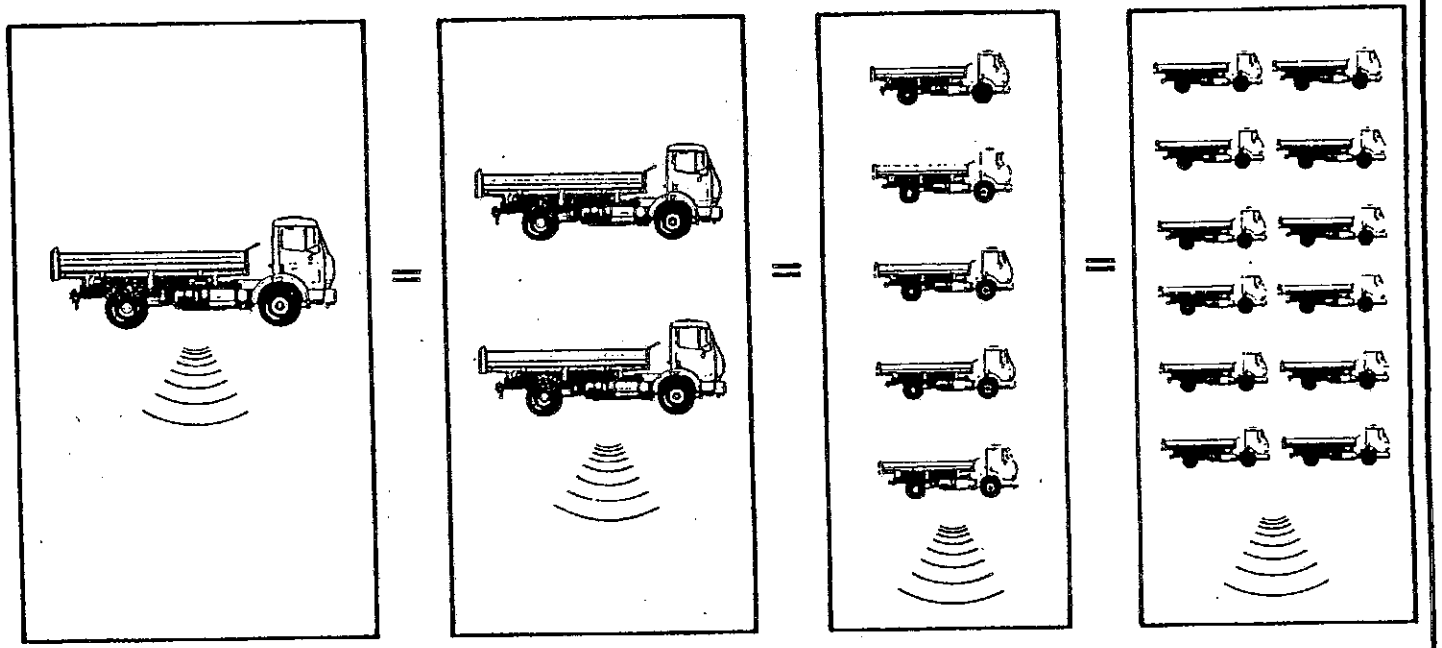
* konkreter Wert abhängig von Motorleistung, Gewicht, Gemischaufbereitung
** Direkteinspritzer
*** Es gibt LKW < 12 t mit mehr als 147 kW

B 37

Simplified representation of noise-emission values -
Sound-pressure level in dB(A) for different vehicle types

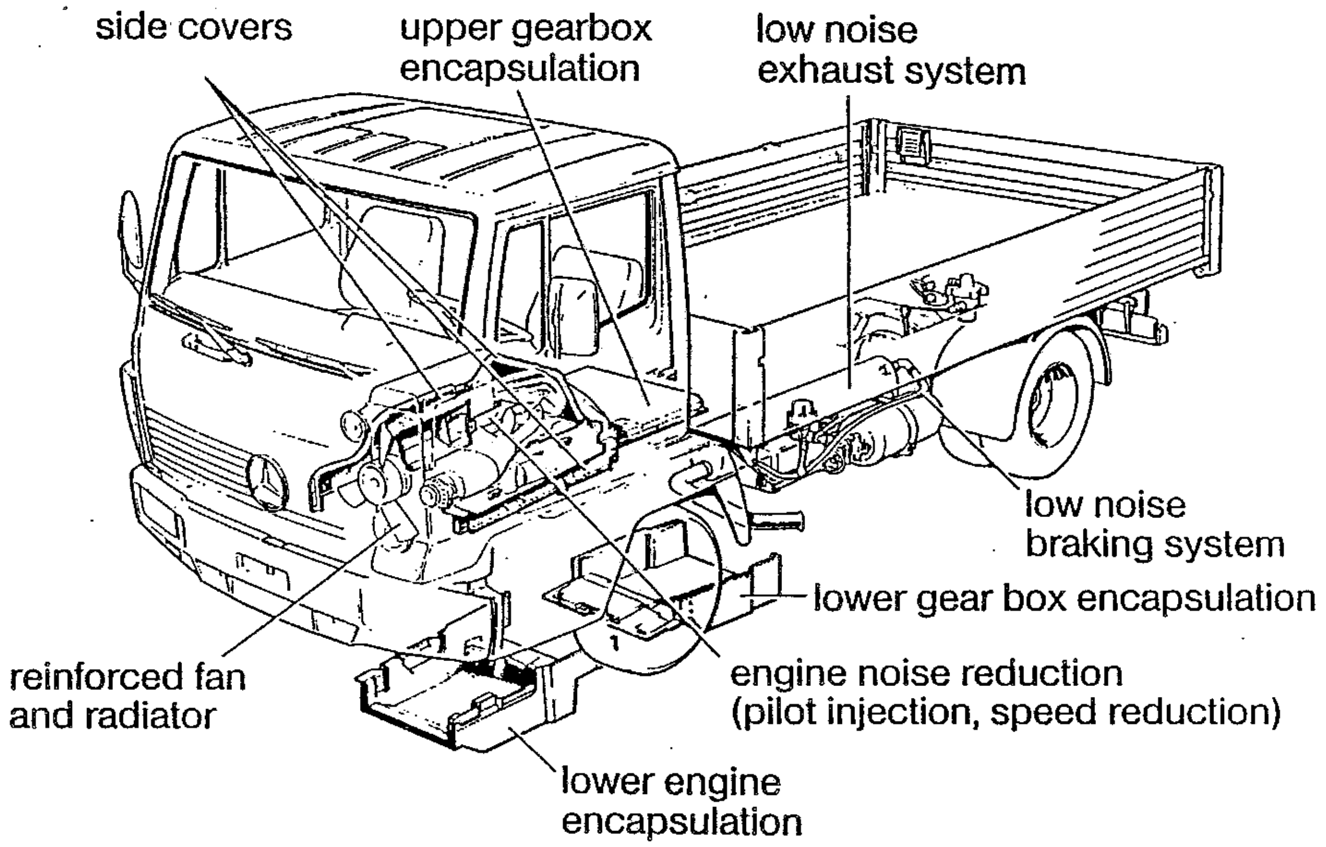
f

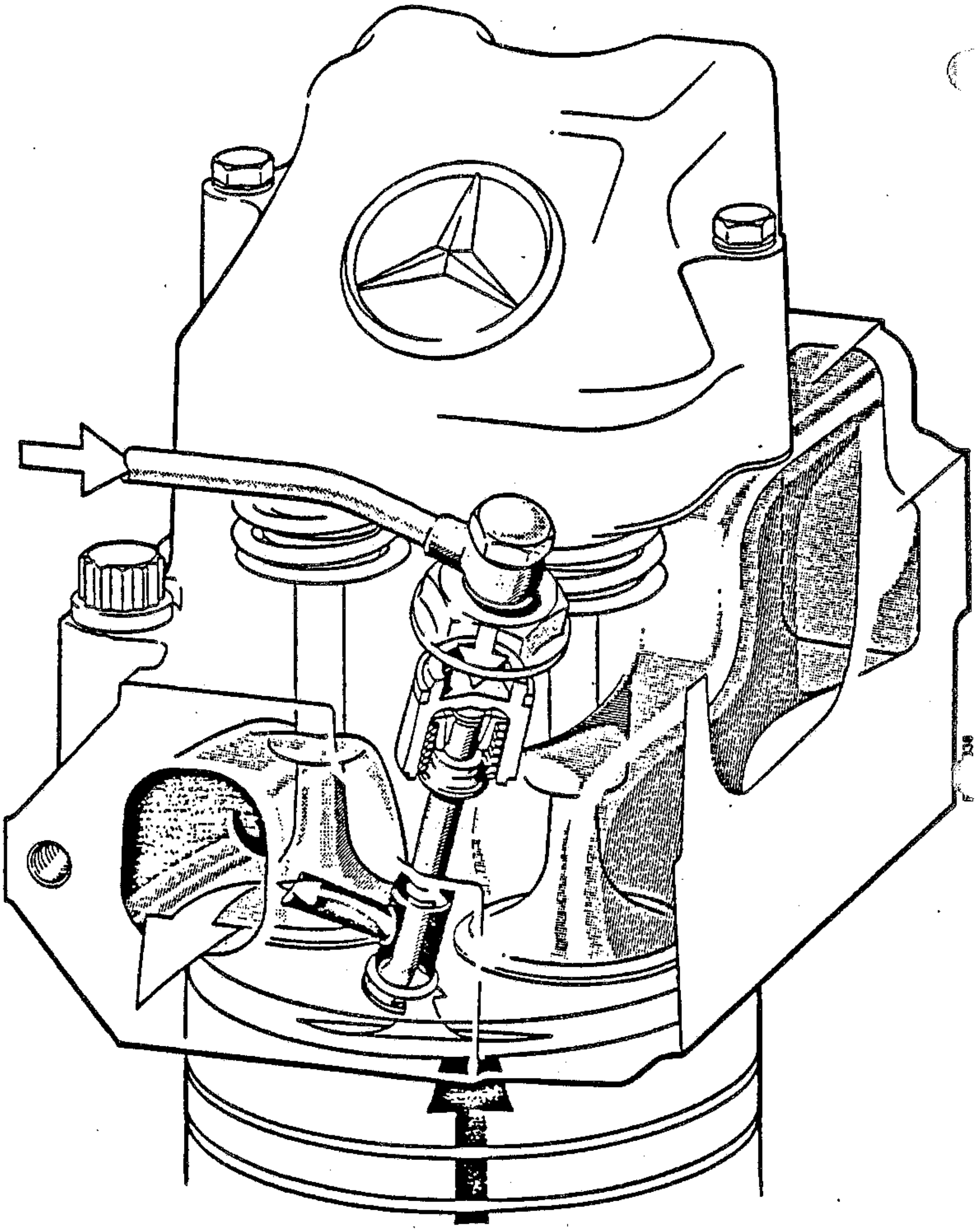
Truck noise reduction since 1974



noise-standard:	91 dB (A)	88 dB (A)	84 dB (A)	80 dB (A)
legislation:	70/157 EWG	77/212 EWG	84/424 EWG	§ 49/3 StVZO
mandatory since:	1974	1980	1990	(low noise)

Noise reduction devices





Engine brake with constantl
open throttle
Valve cylinder head
(Model range 400)

Tire effect on accelerated drive-by noise emission