UNEP Industry & Environment Guidelines Series

ENVIRONMENTAL GUIDELINES FOR THE DIESEL VEHICLE

UNITED NATIONS ENVIRONMENT PROGRAMME

Environmental Guidelines

for the Diesel Vehicle

Industry & Environment Office
UNITED NATIONS ENVIRONMENT PROGRAMME

UNEP - Industry & Environment Guidelines Series

Environmental Guidelines for the Diesel Vehicle

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Guidelines for Assessing Industrial Environmental Impact and Environmental Criteria for the Siting of Industry

Environmental Guidelines for the Motor Vehicle and its Use

Guidelines on Risk Management and Accident Prevention in the Chemical Industry

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FOREWORD

One of the specific objectives confirmed for the 1984 - 1989 medium term planning period by the UNEP Governing Council is the provision of guidance on environmental management of industrial activities, including use of goods and services.

Environmental Guidelines for the Motor Vehicle and its Use (1) were prepared by means of the consultative process developed by UNEP's Industry and Environment Office whereby expertise from Governments, industry and international institutions throughout the world is employed both in collecting the information used in the guidelines and in advising on the text as it progresses through the stages of drafting to approval and publication. With a view to improving awareness amongst countries concerning the environmentally related issues involved in the use of motor vehicles, particularly in urban areas, and consequently promoting environmental management in this field, two workshops were organized jointly with WHO, one principally for countries of the ESCAP region, the other principally for selected countries of Africa, West Asia, Southern and Eastern Europe. The UNEP Environmental Guidelines for the Motor Vehicle and its Use was a basic document at these workshops. During the discussions at the workshops the growing use of diesel vehicles in the transport sector emerged as an area of concern for many developing countries where further environmental management guidance would be valuable. Consequently the Secretariat has drafted these Environmental Guidelines for the Diesel Vehicle. They are intended to provide guidance for sound environmental management in relation to the diesel vehicle and its use and the basis on which measures appropriate to local circumstances and needs may be developed. They should be read in conjunction with UNEP's Environmental Guidelines for the Motor Vehicle and its Use which they supplement.

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(1) Environmental Guidelines for the Motor Vehicle and its Use, UNEP Industry & Environment Guidelines Series, Paris, 1981.

ACKNOWLEDGEMENTS

The Environmental Guidelines for the Diesel Vehicle were prepared by UNEP consultants Maurice Clavel, Paris, France, and Michael P. Walsh, Arlington, Virginia, U.S.A., and were circulated for comment and suggested amendment to sixty-one experts (1) from:

. the UNEP Environmental Consultative Committee for the Motor Vehicle and its Use;

. the UNEP/WHO Workshop on Planning for Control of Emissions from Motor Vehicles, Serdang, Selangor, Malaysia, 10-14 November 1980; and,

. the UNEP/WHO Interregional Workshop on Air Pollution from Motor Vehicles, Moscow, USSR, 5-9 October 1981.

Their assistance is gratefully acknowledged.

Special thanks are addressed to the Bureau permanent international des constructeurs d'automobiles and its members, for advice and comments received all along the preparation of the Guidelines.

The UNEP Officers responsible for this activity were Mr. John A. Haines, Senior Programme Officer, on inception, and Mr. Takao Hamada, Senior Industry Liaison Officer, on conclusion.

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(1) See Annex

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I INTRODUCTION

1. Greater use of diesel vehicles in the transportation sector creates opportunities to solve certain environmental problems associated with motor vehicles, such as those arising from emissions of carbon monoxide and to a lesser extent hydrocarbons, and offers the potential for reducing energy demand and possibly petroleum imports, but raises concern about public health and welfare owing to increased emissions of particulate matter, smoke and odours. As regards overall nitrogen oxides emissions, the diesel and the spark ignition engines are similar, although diesel vehicles emit a higher proportion of NO_2, which combines with the NO_2 resulting from NO emission conversion in the atmosphere. In order to take full advantage of the opportunities and to minimize the concerns, governmental action is required in the areas of:

- vehicle design
- vehicle servicing
- vehicle operation
- fuel characteristics and refinery patterns.

2. Effective action will require the co-operation of industry and the vehicle owner and operator. Furthermore, when considering various actions which can be taken in relation to diesel vehicles, it should be borne in mind that different approaches are possible for passenger cars, commercial and public transport vehicles since:

- commercial and public transport vehicles powered by diesel engines already exist in significant volumes whereas the diesel car, while numbers are rapidly expanding, will not reach its potential share of the vehicle pool for at least several years;
- owing to the larger engine size, as well as different engine design, the volume of emissions is greater from commercial and public transport vehicles than for diesel cars, although commercial and public transport vehicles provide greater load and passenger/mile capability. This is also true regarding noise.

3. Diesel technology is not confined to motor vehicles but can also be applied to stationary installations (e.g. for co-generation of energy) and to off-highway mobile vehicles (e.g. farm tractors, agricultural and construction equipment, etc.). Governmental actions required in relation to these latter applications of diesel technology may differ from those concerning motor vehicles and are not considered in these guidelines.

4. In developing a policy towards the use of diesel vehicles in the transportation sector, the environmental and resource aspects, as well as the economic and social conditions, should be carefully considered. As part of the overall strategy proposed by the UNEP Environmental Guidelines for the Motor Vehicle and its Use (1), the objectives of these guidelines, particularly addressed to those Governments and authorities wishing to familiarize themselves with the main environmentally and energy related diesel engine issues, are to:

a) provide information concerning certain key aspects relevant to an assessment of environmental protection requirements in relation to diesel vehicles;

b) review the technological considerations germane to diesel emissions and noise and their potential control as well as to fuel economy considerations;

c) identify potential governmental actions which could be adopted either to optimize the advantages or minimize the disadvantages of the diesel, as well as areas where United Nations and other international, governmental and non-governmental organizations could facilitate those actions.

5. Whilst diesel equipped vehicles are seen by most industrialized countries to offer certain advantages, a decision to favour the diesel for public and private road transport depends on such local circumstances as geography, climate and environmental conditions as well as energy supply and refinery patterns. It is in the light of those circumstances and conditions, as well as costs, that in those countries the advantages and disadvantages of the diesel engine compared to the spark ignition engine need to be seen, prior to assessing any strategy relating to diesel vehicles.

6. However, with regards to many developing countries a number of other additional factors are significant considerations in the decisions concerning the use of diesel vehicles in the transportation sector. On the one hand there are those factors that relate to road transportation as a whole and on the other those which are more specific to the diesel vehicle itself. First, developing countries in general lack a road infrastructure, there being questions concerning road quality and road signs, signals and regulations. Second, the lack of available public transport, particularly in rural areas, is often acute and results in overuse of vehicles, e.g. overloading and failure to respect periodic maintenance recommended by vehicle manufacturers. Third, that factor is compounded by local socio-economic factors where, on the one hand, capital is not available for investment in adequate transportation systems and the community cannot support the costs of operating such systems, and on the other hand, education and training among vehicle owners and operators is lacking concerning proper operation and maintenance of vehicles, both of which result in a poorer efficiency of resource use in the existing transportation systems than would be obtained in industrialized countries. Factors specifically related to the diesel vehicle include a lack of adequate inspection, maintenance and repair facilities, coupled with insufficient numbers and distribution in the country of trained vehicle mechanics, as well as a shortage of spare parts, and in addition inadequate fuel distribution and refining infrastructure to change present patterns. Other important factors relate to fuel quality, namely where local refining capacity cannot guarantee a supply of fuel with fixed specifications and where there is local tampering with fuel quality, the latter often being related to local socio-economic factors. Each of those additional factors militate against effective use of resources in relation to the diesel vehicle, as well as increase environmental degradation, reduce fuel economy and aggravate road safety.

7. Furthermore, a distinction has to be made between countries which are manufacturers of diesel vehicles and those which only import vehicles. With

regard to the former a series of policy options concerned with construction of new vehicles are available which are not in practice feasible for countries not manufacturing diesel vehicles. Finally, it must be borne in mind that when the diesel commercial vehicle was being introduced into the industrialized countries in the period immediately preceding the Second World War, a considerable amount of technical and research experience related to the development and use of spark ignition vehicles had already been in existence since the early part of the century. While that experience facilitated the introduction of the diesel vehicle in those countries, it was to a large extent absent in the developing countries.

II DIESEL VEHICLES WITHIN THE TRANSPORTATION SECTOR AND LIKELY TRENDS

8. Although petrol and diesel fueled vehicles are complementary and will probably continue to be so in the future, the greater use of diesel equipped vehicles for all categories of commercial vehicles, public transport and private cars is by far the major trend observed world-wide over the last decade in the motor vehicle field. Even prior to 1970, in the medium and heavy commercial vehicle category (greater than 4 tons) in Europe the diesel engine had progressively and almost entirely replaced the spark ignition engine over a period of less than ten years. In Japan the percentage of diesel powered medium and heavy trucks accounted for about 60% of total production by 1981. That significant evolution was mainly due to the greater efficiency of the diesel engine compared to the spark ignition engine, especially when the required output remained close to 3/4 of maximum power, a level very favourable to the operating conditions of the average heavy commercial vehicle and bus on the open road. With regard to light duty commercial vehicles and private cars, introduction of diesel engines came later in Europe but their use grew at a rapid pace during the 1970s as a direct consequence of the oil crisis and its impact on hydrocarbon availability and the rapidly increasing price of fuels. Moreover tax reductions in favour of diesel fuel rather than petrol were adopted by the European Governments, which accelerated diesel engine penetration and still remains an important factor encouraging diesel production and use for all categories of vehicles in Europe.

9. Such rapid development is highlighted in the Federal Republic of Germany where the percentage of light duty commercial vehicles equipped with diesel engines rose from about 70% in 1973 to about 90% in 1979. In France, the increase for light duty commercial vehicles was even more dramatic, rising from about 43% in 1973 to over 70% in 1979. For diesel equipped private cars, the percentage of total production grew from 2.7% in 1970 to 13.3% in 1979 in the Federal Republic of Germany, and from 1.7% to 8.5% in France. The trend is now observed in the United Kingdom, and, at a more rapid pace, in Italy and Japan, where the percentage of diesel equipped private cars accounted for 3% of total production in 1981. As far as sales of diesel equipped private cars are concerned, Table 1 illustrates the trends observed in diesel sales for the 1972 - 1980 period in the Federal Republic of Germany, France, Italy, Japan the United Kingdom and the United States of America, and associated fuel prices for 1979 and 1980.

TABLE 1

Trends in Diesel Sales and Fuel Prices in Selected Industrialized Countries

	United Kingdom	France	Fed. Rep. of Germany	Italy	Japan	United States
	Diesels as Per Cent of New Car Sales					
1972	0.09	2.4	3.4	0.8	-	-
1973	0.07	2.0	3.7	1.2	-	-
1974	0.08	3.3	4.6	1.6	-	-
1975	0.05	4.5	4.3	2.5	-	-
1976	0.5	4.3	3.8	2.5	0.4	-
1977	0.5	6.4	4.7	2.5	1.1	0.1
1978	0.2	6.5	5.9	4.5	1.5	0.4
1979	0.3	7.3	7.2	4.1	2.0	2.2
1980	0.4	8.9	7.4	6.8	-	4.6
1981	-	-	-	-	-	6.6
1982	-	-	-	-	-	4.5
	Gasoline (and Diesel) Prices in 1980 U.S. Dollars					
1979	2.44	2.84	2.31	3.18	3.14	1.20
1980	2.61 (2.73)	3.13 (2.21)	2.54 (2.44)	3.13 (1.46)	3.14 (3.14)	1.22 (1.13)

Source: Motor Vehicle Manufacturers Association of the United States

10. As can be seen, in 1979, 2.2% of all passenger car sales in the United States were diesel, climbing to 4.6% of 1980 sales. For 1981, diesel sales increased by an additional 30% and achieved 6.6% of total new car market for the entire year. It appears that the real growth period for diesel sales, however, will take place between 1982 and 1984, although diesel vehicles growing pace has declined significantly in North America with returning availability of oil fuel and changes in relative gas/diesel fuel prices. The motor vehicle manufacturer General Motors now expects approximately 3-5% of its vehicle production to be diesel equipped in the near term and 5-10% in the long term. Other manufacturers are following suit. After years of promoting the PROCO (a direct-injected stratified-charge gasoline engine), the Ford and Chrysler Motor Vehicle Companies now appear also to be moving towards dieselization. Chrysler is also expected to introduce a diesel vehicle. Daimler-Benz, Peugeot, Volkswagen, and Audi have traditionally sold diesel vehicles in the United States and they have been or will soon be joined by British Leyland, Citroën, Nissan, Fiat, Renault, Toyota and Volvo, and probably several other manufacturers.

11. While optimistic estimates indicated that diesels could comprise as much as 20% of all new car sales in the United States by 1985 and 30% by 1990, the outcome will depend largely on the policy adopted with respect to different fuel prices. More conservative estimates are 8% for passenger cars and 10% for light trucks in 1985. Diesel vehicles have historically dominated the "heavy-heavy" (greater than about 25 tons) inter-city freight truck class in the United States but have not been used extensively in the classes between 4 and 13 tons. Fuel economy considerations are changing the ratio, however, and several manufacturers are designing smaller heavy-duty diesel engines to be used in medium-sized trucks. By 1995 diesels are expected to comprise almost two-thirds of all heavy-duty vehicles, completely dominating the 10-ton and larger categories of trucks and powering approximately 30% of all 4 to 9-ton trucks in the United States. Because of the domination of diesels in the large, inter-city truck fleet, diesels will probably account for almost 80% of all truck miles driven by 1995.

12. Table 2 gives the proportion of diesel vehicles in the total vehicle population in certain developing countries (2) and indicates that in relation to rapid growth of motor vehicle sales in developing countries forecast for the period 1978 -1990, diesels may represent an even greater percentage of the existing vehicle population since commercial and public transport vehicles (which tend to be almost all diesel equipped) constitute, and will continue to constitute, a greater proportion of the fleet than in industrialized nations. This is illustrated further in Table 3. Moroever, since the passenger car market demand and population are growing at a much more rapid rate in developing countries than in industrialized countries (see Tables 4 and 5 respectively), at a time when an increasing number of new cars are diesel, it is likely that the proportion of diesels within the total vehicle population in future years will be greater in developing than in industrialized countries.

13. A recent analysis of future trends in the U.S.A. and Western Europe, conducted by International Business Reports, concluded that demand for diesel cars might be even greater than originally believed. As noted in Table 5, by 1985 diesels could account for 15.2% of new car sales in eight major European markets and about 5% in the United States. Fuel taxation policies may influence those trends.

TABLE 2

Proportion of Diesel Vehicles in Total Vehicle Population

in Selected Developing Countries

(1979 - 1980)

Countries	Total Vehicle Population	Diesel Vehicles %
Egypt	616,000	13
Greece	538,000	9
Hong Kong	218,000	21
Kuwait	496,000	10.5
Republic of Korea	513,000	40
Malaysia	2,190,000	7
Singapore	360,000	11
Sri Lanka	292,000	17
Thailand	1,470,000	26
Zimbabwe	220,000 passenger cars	5
	17,000 commercial vehicles	95

TABLE 3

Stock of Commercial Vehicles in Use

(1976 and 1977)

	Million of Vehicles		% of World Total		Commercial Vehicles as % of Total Number of Vehicles	
	1976	1977	1976	1977	1976	1977
North America	28.5	34.0	41	44	19	21
Western Europe	11.2	13.6	16	17	11	12
Japan	11.0	11.6	16	15	37	37
Africa	2.3	2.5	3.5	4	31	32
Latin America	4.9	3.6	7	5	27	25
Asia (a)	3.1	3.3	4.5	4	36	35
Others	8.7	7.8	12	11	30	
World	69.7	76.4	100	100	20	21

Note : (a) Does not include Japan and People's Republic of China

TABLE 4

Market Demand for Motor Vehicles (1)

(millions)

	1955	1960	1970	Peak(2) 1973-78	1979	Projection range 1985	Projection range 1990
CARS							
North America	8.3	7.0	9.0	12.3	11.6	11.0 - 12.0	8.0 - 13.5
Western Europe	1.8	3.5	7.9	10.4	10.0	10.0 - 12.0	9.0 - 13.5
Japan	0.03	0.1	2.4	2.9	3.0	2.3 - 3.5	2.0 - 3.8
TOTAL for mature markets	10.13	10.7	19.3	25.6	24.6	23.5 - 27.5	19.0 - 30.8
Rest of the world	0.8	1.3	2.6	5.9	5.9	9.0 - 16.0	15.0 - 27.0
TOTAL	10.93	12.0	21.9	31.5	30.5	32.5 - 43.5	34.5 - 57.8
Commercial Vehicles							
North America	1.3	1.0	1.9	4.4	3.9	2.0 - 3.0	1.5 - 3.0
Western Europe	0.5	0.7	1.0	1.2	1.3	1.0 - 1.3	0.9 - 1.35
Japan	0.1	0.3	1.7	2.0	2.1	1.6 - 2.1	1.0 - 2.0
TOTAL for mature markets	1.9	2.0	4.6	7.6	7.3	4.6 - 6.4	3.4 - 6.35
Rest of the world	0.8	0.9	1.5	3.1	3.2	4.2 - 8.0	7.0 - 15.0
TOTAL	2.7	2.9	6.1	10.7	10.5	8.8 - 14.4	10.4 - 21.35

Sources : Bhaskar, op.cit, p.350.
MVMA, World Motor Vehicle Data, 1981 Edition, pp. 45 and 88.

(1) Defined as new registrations

(2) Peak year for region between 1973 - 78

TABLE 5

Where Diesel Car Demand Will Grow in Western Industrialized Countries (1)

Country	New Registrations (x 000)			Market Share (%)		
	1980	1982	1985	1980	1982	1985
Belgium	49	67	107	12.4	16.0	24.0
France	186	247	425	9.9	13.0	20.0
Holland	27	66	127	6.0	12.5	23.0
Italy	105	124	262	6.9	9.5	16.0
Spain	19	29	61	3.3	4.5	8.5
Sweden	15	24	35	7.7	10.0	15.0
United Kingdom	11	38	121	0.7	2.5	7.0
Federal Republic of Germany	196	249	386	8.1	10.5	15.0
EUROPE	608	844	1,524	6.8	9.5	15.2
United States	387	1,493	2,795	4.3	4.5	5.0
TOTAL	995	2,337	4,319	5.5	12.4	21.3

(1) Main European markets only

(Source : International Business Reports)

(1) Defined as new registrations

III BASIC PRINCIPLES OF DIESEL ENGINE COMBUSTION

14. A diesel engine must be referred to as a compression ignition engine. Air is compressed and therefore heated in the combustion chamber before injection of the fuel which, in view of the temperature and pressure within the combustion chamber, ignites within about a millisecond after it is being injected. By comparison a petrol engine may be defined as a controlled ignition engine (spark ignition). Air and fuel are mixed and compressed in the combustion chamber, a spark being obtained electrically or electronically which ignites the air/fuel mixture.

15. As the diesel engine operates on the self ignition principles achieved by the high pressure and temperature of the air in the combustion chamber, the compression ratio is much higher than in a petrol engine where a spark provides the necessary energy to ignite the fuel mixture. The compression ratio is normally greater than 17 to 1 for naturally aspired engines, whereas for a petrol engine it is in most instances between 8 and 10 to 1. The diesel engine high compression ratio is one of the main reasons for its better efficiency. Furthermore, and in contrast to a petrol engine where the quantity of air/fuel mixture entering the engines varies depending on the throttle operation, the quantity of air compressed in a diesel engine is not limited by any control device; only the quantity of fuel injected is modified, according to the power required, through an injection pump feeding the injectors and depending on the position of the throttle.

16. As far as the combustion itself is concerned, the fuel injected in the form of fine mist must ignite easily since the combustion of the first vaporized particles of fuel must be almost instantaneous. This characteristic is measured by the fuel cetane rating. Through appropriate and precise fuel injection timing, vaporization and combustion continue for a short period as the piston descends, so that maximum pressure may be kept at a reasonable level. While most diesel light duty vehicles currently use a pre-chamber configuration providing smoother combustion and therefore less vibration, with concomitant reductions in combustion noise and mechanical noise, the use of direct injection may increase in the future because it achieves even better fuel economy (see Section IX below) at the expense of some increase in NO_x and particulate emissions.

17. As indicated above, combustion is a more protracted process in diesel engines since the injected fuel burns during its injection when the air-fuel ratio reaches the appropriate value as a part of a diffusion burning process. Normally, there will be no unburnt fuel in the "more remote parts" of the combustion chamber as may occur in classical petrol engines, where the flame propagation may be difficult and late in reaching remote parts of the air-fuel mixture. This means that there is a smaller proportion of unburnt or incompletely burnt gases (hydrocarbons and carbon monoxide) in all usage conditions of a diesel engine. All that is necessary is to provide a slight excess of air for all planned loadings in order to reduce unburned HC. However, the combustion leads to oxidization at high temperature of the nitrogen in the air, which forms toxic oxides of nitrogen, including nitrogen dioxide in greater quantities than are found in comparable petrol engines.

IV ENERGY AND FUEL USE IN RELATION TO THE DIESEL VEHICLE

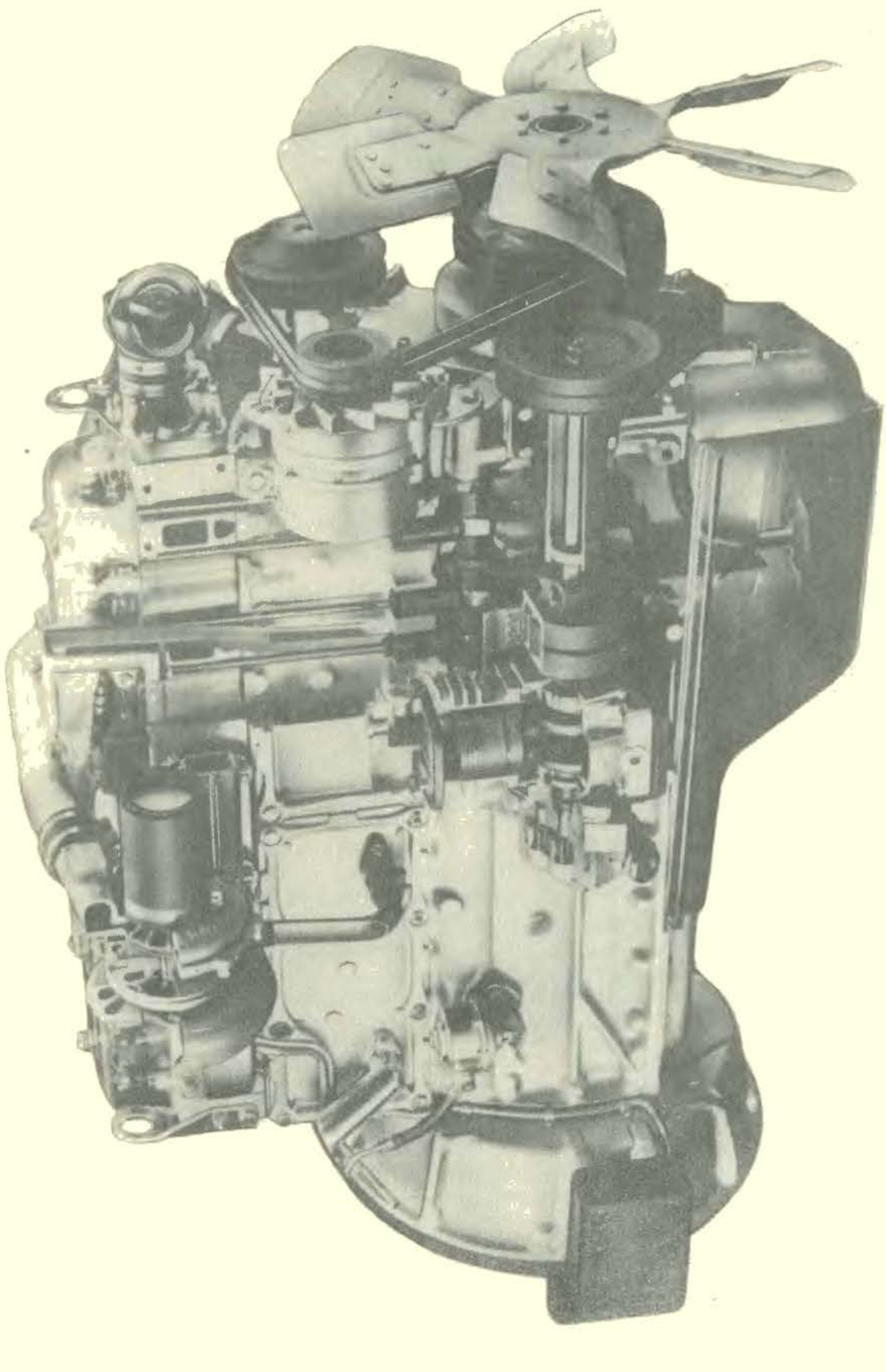
18. Diesel engines offer about a 15 to 30% increase in thermodynamic efficiency over spark ignition engines, and about the same percentage improvement in fuel economy over comparable sized vehicles powered by gasoline engines, while

sacrificing some acceleration and maxi-speed performances. Direct injection diesels offer even better thermodynamic efficiency, probably 30% to 40% over the conventional spark ignition engine efficiency, but are still plagued by rougher combustion, causing increased combustion and mechanical noise, and NO_x and particulate emissions. Diesel efficiency at medium and high speed can be significantly improved by the introduction of turbochargers and new combustion chambers combined with electronic air/fuel mixture monitoring which results in more complete combustion. Diesel engines are better adapted to the turbochargers than spark ignition engines because it is less of a problem to compress air in a diesel engine than the air-fuel mixture in a spark ignition engine. Moreover the highly reinforced diesel engine structure is better able to withstand the additional output and torque provided by turbocharging. Figure 1 gives a photograph of a typical diesel engine with turbocharging, employed in medium size commercial vehicles. That same structure carries an engine weight penalty of 20 to 25% and a manufacturing cost increase of about the same percentage. Since the engine accounts for only approximately 5 to 10% of total vehicle weight, depending on the vehicle type, the engine weight penalty increases vehicle weight by only 2 to 4%. Much if not all of this penalty could be eliminated in the future as light weight alloys become more predominant in diesel engine structure (see below, Section IX) as it is already for spark ignition engines. It should also be borne in mind that fuel utilization improves with gross vehicle weight, as indicated in Figures 2 and 3.

19. The potential for saving in crude oil consumption that might be attributed to increased use of the more efficient diesel engine depends not only on the reaction of both consumers and motor vehicle manufacturers to the advantages of the more fuel efficient diesel engine but also on local refinery and crude oil supply patterns. If motor vehicle manufacturers, while converting to diesel engines, still continue to produce vehicles of the same size and comfort as in the past, and consumers, regardless of the implicit fuel cost saving resulting from the more efficient engines, drive only the same number of vehicle-miles as before, every additional litre of diesel consumption would allow a decrease of up to 1.25 litres of petrol consumed. Alternatively, if consumers react to the lower fuel costs resulting from increased use of the diesel engine by driving more, and by purchasing heavier and larger vehicles, a higher level of consumer satisfaction may result, but little saving in fuel consumption. This latter situation may appear more likely in North America than in Europe, Japan and the developing countries. In that respect it has been estimated that in Europe, where currently only 20% of the overall diesel fuel consumption on road transport is used in passenger cars and taxis, the remainder in trucks and buses, a 10% average penetration of diesels into the passenger car and taxi market by 1985 (as against 2% in 1976) could save Europe as much as 4 million tons of crude oil per year (3).

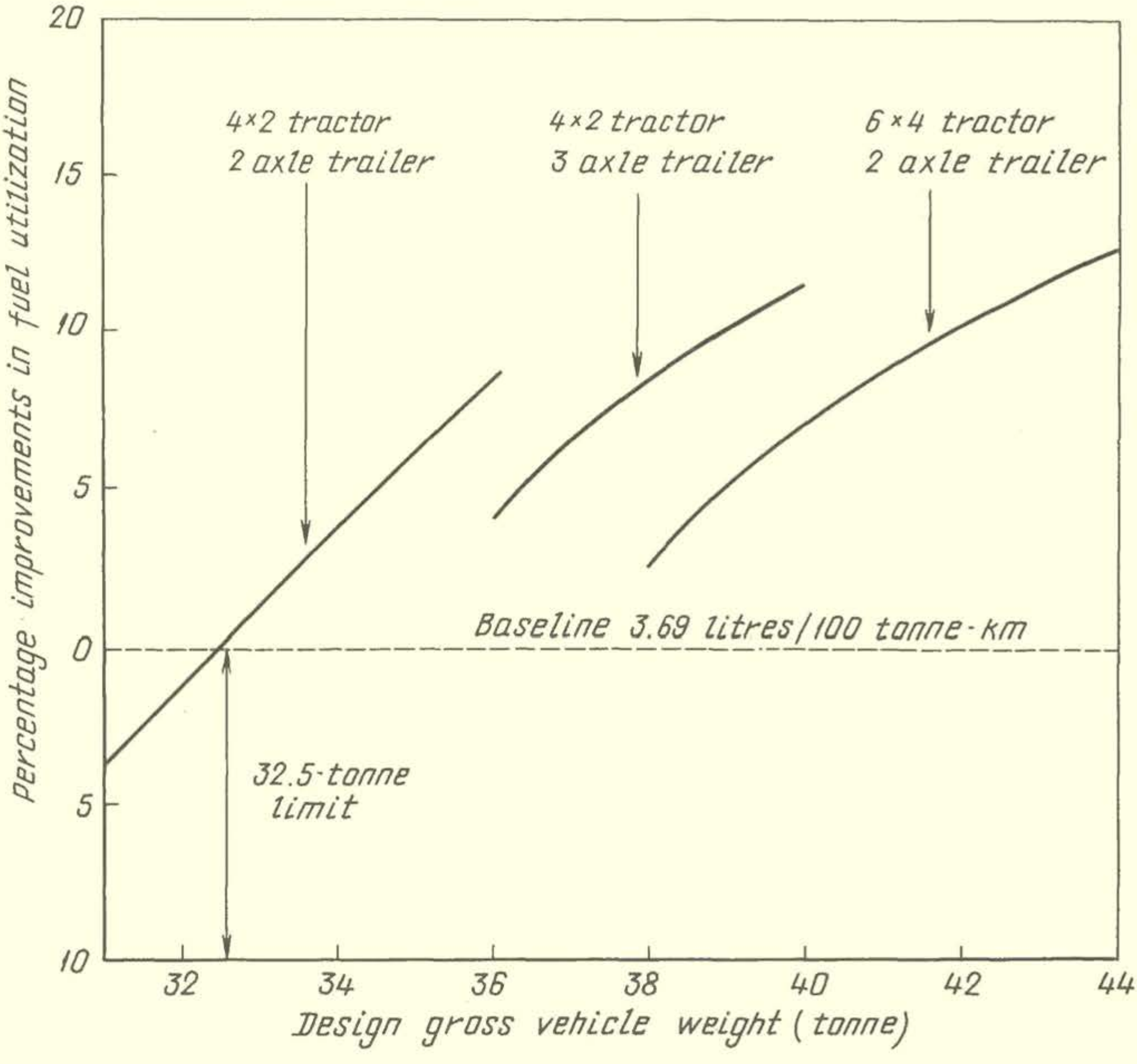
20. The amount of refinery energy consumed per unit of energy produced in converting crude oil to diesel fuel depends on the refinery configuration as well as on the crude quality and product demand. The impact on refinery configuration of changes in diesel demand is a complex question. While an increase in diesel demand would change the proportional market requirements for different refinery products, the necessary adjustment could be met in any of the following ways: changes in crude oil and feedstock inputs to the refinery; balancing product imports and modifications to the refinery, including inherent flexibility in various refinery processes. A saving in crude oil with increasing diesel fuel demand will come about if the balance of demand for all refinery products is adjusted to accommodate the

FIGURE I: **TYPICAL DIESEL ENGINE WITH TURBOCHARGING**



Source: RENAULT Véhicules Industriels MOTEUR 798

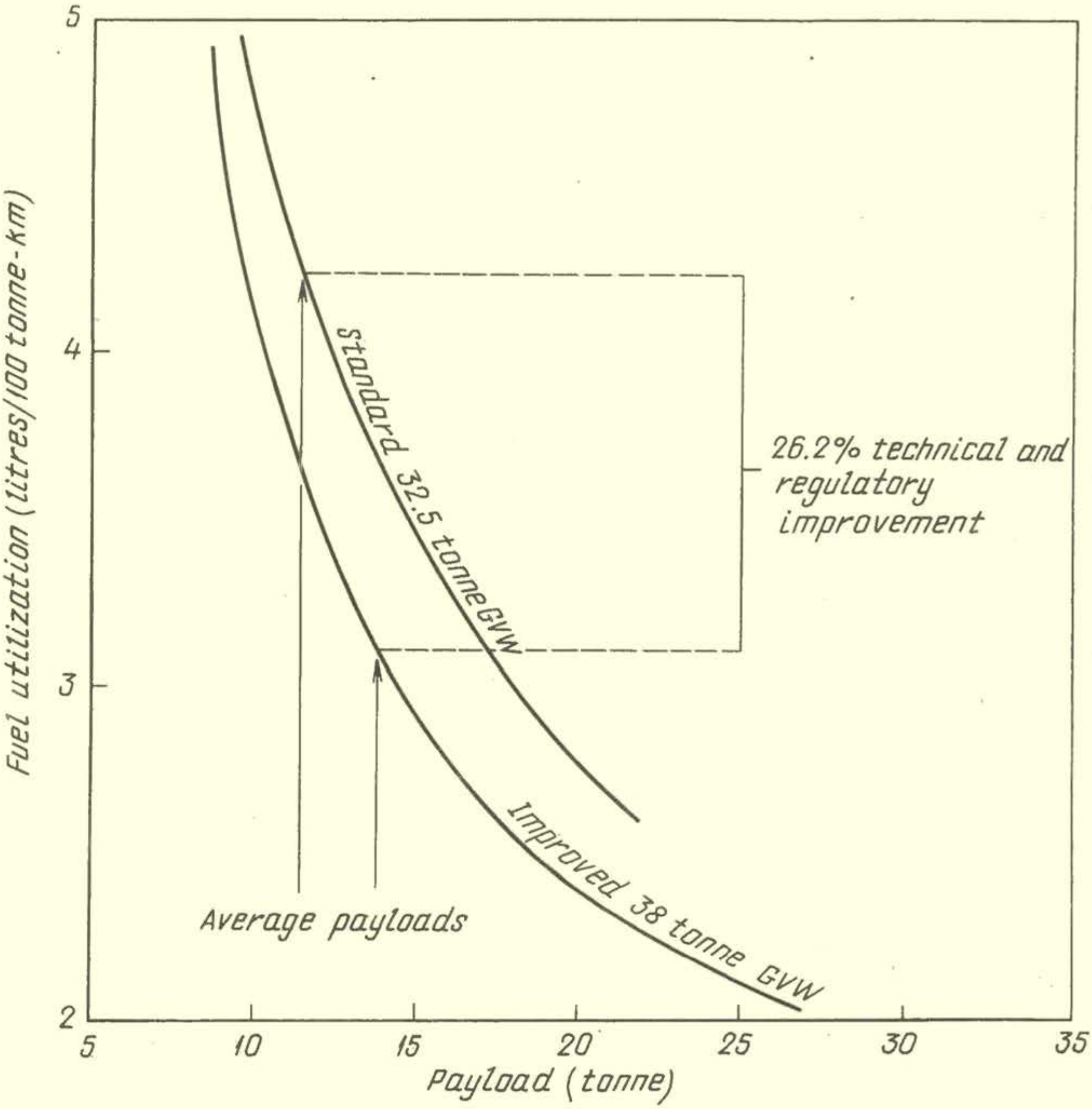
FIGURE 2



ESTIMATED IMPROVEMENTS IN FUEL UTILIZATION WITH DESIGN GROSS VEHICLE WEIGHT FOR PLATFORM ARTICULATED VEHICLES

Source: Transport and Road Research Laboratory Supplementary
Report 424 "Fuel utilization of articulated vehicles:
effect of gross vehicle weight", by L. Gyenes

FIGURE 3



ESTIMATED IMPROVEMENT IN FUEL UTILIZATION FOR A VAN ARTICULATED VEHICLE OPERATING OVER A REPRESENTATIVE DUTY CYCLE

Source: Transport and Road Research Laboratory Supplementary Report 424 "Fuel utilization of articulated vehicles: effect of gross vehicle weight", by L. Gyenes resulting reduction in residual fuel oil. Where the total demand for transport fuels (petrol and diesel) does not greatly change, an adjustment can be made amongst refinery products. When the finite flexibility amongst petrol, diesel and heating oils is exceeded, extra energy will be required to produce components of acceptable quality for diesel fuels from the heavier proportions of the refinery crude input. The energy required to make components necessary to maintain diesel quality is significantly higher than the energy required to make additional petrol components from comparable heavier fractions. Where the ratio of petrol to diesel is relatively low (less than 2:1 as in Europe) increased diesel demand beyond the natural capability of crude processing combinations could lead to increased refinery energy consumption and hence crude intake related to overall product demand. In the U.S.A. where petrol (gasoline) to diesel volume ratios are generally much higher (usually greater than 3:1) extra diesel demand could improve the energy optimization in a refinery situation and bring it closer to the optimum already achieved to a large extent in Europe. A recent study in the U.S.A., which assumed constant energy consumption in motor vehicle service, estimated that the national crude oil consumption could decrease by approximately 2% at about 50% diesel light duty vehicle penetration, while maintaining constant energy consumption in light duty vehicle service. Developing countries often have the added problem of less flexibility in refinery patterns and less practical market choice concerning types of crude and feedstocks. This makes it more difficult to guarantee acceptable quality for diesel fuel if there are significant changes in the pattern of fuel demand.

21. It must moreover be borne in mind that the operating conditions of the diesel equipped vehicles may to a large extent affect the above fuel estimate assumptions. This subject is considered in Section XI. Furthermore, the subject of alternative fuels and trends in relation to diesel fuels is considered in Section X.

V ENVIRONMENTAL AND HEALTH IMPACTS RELATED TO THE DIESEL VEHICLE

22. The most important recent report on this subject has been "Health Effects of Exposure to Diesel Exposure" by the National Research Council of the United States (15). In considering the environmental and health consequences of diesel vehicles it is necessary that the issues be looked at in the context of the country under consideration. As noted earlier, different countries have different physical, climatic, social and economic conditions as well as different vehicle characteristics, maintenance practices, and regulatory programmes, and in consequence the impact of the diesel relative to the existing circumstances can vary significantly. In addition, careful attention must be paid to the distinction between passenger cars and heavy commercial vehicles. For example, diesel trucks are inherently noisier and emit more exhaust gas in mass and volume than diesel light duty vehicles and cars, and any environmental protection programme should take that into consideration. This section reviews the air pollution and noise arising from use of diesel vehicles within the context of road transportation and in particular by comparison with the use of spark ignition vehicles. It should also be borne in mind that there may be sources of air pollution and noise other than road transport in any given area. The first part of this section deals with the specific air pollutants arising from diesel vehicles: carbon monoxide, hydrocarbons, nitrogen oxides. The second part considers pollutants for which, because of their complexity, their precise chemical and physical nature may not yet be fully known, e.g. particulate matter and certain complex hydrocarbons, but which are of environmental and health

concern as possible carcinogens, mutagens, etc. The third part deals with nuisance of reduced visibility and odour and the fourth part noise. Although lead is not an additive in diesel fuel, because of the concern with regard to the contribution from the motor vehicle transportation sector as a whole to ambient lead levels, a final part refers to fuel additives and in particular the lead issue, so as to provide the reader with the complementary aspects. Sulphur oxides are treated in this same section since they arise from the sulphur content of the fuel rather than from vehicle operation.

(i) Specific Air Pollutants

(a) Carbon Monoxide

23. Exposure to elevated levels of carbon monoxide produces serious adverse human health effects, especially for sensitive individuals such as those suffering from heart disease and pregnant women (4). Motor vehicles are usually the major source of ambient carbon monoxide levels in urban areas and almost the exclusive source of concentrations found at street level. During their operating life, diesel-powered light duty vehicles emit carbon monoxide at levels in the order of 2 g/mile (i), whereas uncontrolled spark ignition petrol powered cars emit at a rate of about 90 g/mile. Although further progress in the reduction of carbon monoxide emissions in the 1980s for petrol fueled vehicles (spark ignition engines) may be expected in Europe as a result of more stringent emission control limits applied to new vehicles, the very low level of carbon monoxide emissions from diesel-powered vehicles could contribute significantly to possible decreases in the ambient air concentrations of carbon monoxide around heavily travelled urban roadways. Therefore, diesels will likely provide a significant public health advantage over petrol-powered vehicles as far as this pollutant is concerned.

(b) Total Hydrocarbons (the non-carcinogenic/mutagenic components)

24. The main concern about the non-carcinogenic/mutagenic component of hydrocarbons is their contribution in the atmosphere to the formation of photochemical oxidants and ozone, which are both a public health concern and a nuisance from reduced visibility (5). Depending on the industrial and commercial activities of the region, road transport is usually a major source of hydrocarbons in an urban area. Refineries, incineration, dry cleaning, painting, etc. can be other important sources.

25. There are three sources of hydrocarbon emissions from vehicles:

- Exhaust: Diesel vehicles have normally similar or even lower emissions of total hydrocarbons than petrol vehicles. However diesel vehicles also emit aldehydes, a special type of reactive hydrocarbon, which can bring about atmospheric photochemical reactions and which may also be of health concern.

- Evaporative losses (ii): Diesel fuel has low volatility, resulting in near

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(i) Throughout this section units are based upon the United States Federal Test Procedure and given in grams per mile (g/mile); while different tests would yield different absolute values, it is anticipated that relative comparisons would be accurate.

(ii) See also the section below on carcinogens and potential carcinogens, particularly with regards to benzene.

zero evaporative emissions. Petrol is more volatile and contains reactive hydrocarbons that evaporate into the atmosphere where they may bring about the formation of photochemical oxidants and ozone. In urban areas, therefore, ozone ambient air levels should improve with increased conversion to diesel. The result should be an improvement in public health as regards oxidant exposure.

- Crankcase losses: Emissions of hydrocarbons from the crankcase of diesel vehicles are inherently low. However, some concern has been raised regarding possible emissions in some instances of small amounts of nitrosamines and multi-ring aromatic compounds, since certain of those substances may be human carcinogens.

(c) Nitrogen Oxides

26. Nitrogen oxides (NO_x) are of concern both because of their effects on health and their contribution in the atmosphere to photochemical oxidant and ozone formation (6). The nitrogen dioxide (NO_2) component of nitrogen oxides causes the most significant adverse impact; but it must be borne in mind that nitric oxide (NO) is readily transformed in the atmosphere to NO_2 and consequently appropriate control of NO should not be neglected. Nitrogen oxides are formed in all combustion processes involving air, and in typical urban areas the transportation sector contributes about half of the ambient concentrations of these substances.

27. In relation to the diesel vehicle as a source of oxides of nitrogen it is important to distinguish between total oxides and nitrogen dioxide:

- Total oxides: When uncontrolled, diesel and petrol vehicles emit approximately the same levels of nitrogen oxides (NO_x). However, the technology to control NO_x from petrol vehicles has advanced to a greater extent than that for diesels. Therefore, at present, tighter NO_x emission control of petrol engines is possible. Over time, that advantage of the petrol vehicle may be eliminated through technological development.

- Nitrogen dioxide: Diesel vehicles emit about one-fourth of their nitrogen oxides as nitrogen dioxide (NO_2), whereas petrol vehicles emit mostly nitric oxide (NO). Short-term increases in NO_2 concentrations near motorways and major highways can be expected as a result of increased use of diesel vehicles. Such increases may be of particular concern in some countries where meteorological conditions permit NO_2, hydrocarbons and aldehydes to react in the presence of sunlight to cause photochemical smog.

(ii) Pollutants of Complex Composition

(a) Total Particulate Matter

28. Two public health concerns are associated with emissions of diesel particulate matter into the ambient air. The first is their contribution to general levels of suspended particulate matter in the urban region which, particularly in the presence of sulphur oxides, are associated with respiratory ailments such as emphysema, bronchitis and asthma (7). Sulphur oxides are also associated with diesel emissions owing to the sulphur content of the fuel (see paragraph 35). Such particulate matter is considered non-carcinogenic. The other concern relates to the potential carcinogens and mutagens in the organic substances which are adsorbed onto the diesel particulate matter, as considered below.

29. Diesel vehicles emit substantially more particulate matter of a different composition than petrol-powered vehicles. Even when new, at the present time diesel vehicles emit between 0.2 and 1.0 g/mile of particulate matter (the average is about 0.6 g/mile), which is in the form of small particles, typically 0.3 microns in size. The particulates have organic substances adsorbed onto it. Even a properly tuned diesel engine emits between 30 to 100 times more particulate matter than present day comparable catalyst equipped spark ignition engines, depending on engine type and load.

(b) Potential Carcinogens

30. In order to determine cancer risks arising from substances emitted from diesel vehicles, it is necessary not only to identify actual carcinogens and public exposure to those carcinogens, but also their relative potencies. This is especially difficult when dealing with complex mixtures such as found in diesel exhaust because the results of the various available *in vitro* and *in vivo* screening tests preformed using extracts of diesel particulates are not very satisfactory and may be confounded by differences in human reactions. To give but one example of the difficulties in evaluating the results of animal (usually rodent) inhalation experiments, it is necessary to consider the following factors:

- Dose: It may be impossible to administer to the animal enough of the active material in the complex mixture in order to produce a statistically significant response, given the limited number of animals that can be exposed. That problem is particularly relevant when the active material may be a weak carcinogen and may be a small fraction of the total material.

- Cell turn-over rate: Cells in the respiratory tract of rodents reproduce slowly (about once per year). If the active material interferes with the cell's nucleus and causes damage, this may not be observable for several cell replications. Unless those cell replications are accelerated, the animal will die from old age before lung cancer can be observed.

- Anatomical differences: Rodents are nose breathers whereas humans are nose and mouth breathers. The diameter and length of the upper respiratory tract passages in rodents are different from those in man, causing the deposition, retention and clearance patterns to differ. For example, a larger percentage of fine particulate matter may be retained in man's lungs because more can penetrate to that depth.

Because of those problems, multiple experiments with various animal species using different test protocols are usually desirable. Further, care must be exercised in interpreting results of both a positive and negative nature.

31. With regard to their potential in bringing about a public health cancer problem the three sources of hydrocarbon emission from diesel vehicles are:

Exhaust: The organic substances emitted along with the particulate matter from diesel-powered vehicles are likely to contain known human carcinogens. However, the relative potency and therefore the significance of the materials is not well known at this time. The conclusion that carcinogens are present is supported by positive results from a wide variety of in vitro tests. Animal inhalation studies show that diesel particulate matter reaches the deep lung and remains there for a significant length of time. The organic substances associated with that particulate matter also penetrate to the deep lung. The opportunity for carcinogens to enter the deep lung of humans and remain there must be of public health concern. No carcinogenic effects in humans from diesel exhaust emission exposure, however, have yet been demonstrated.

Evaporative losses: Diesel fuel does not contain benzene while petrol contains a small amount (in North America about 2%, in Europe up to 5%), although very little benzene is present in the evaporative losses from petrol-powered vehicles. Exposure to benzene has been associated with leukaemia. Consequently a slight public health benefit, associated with reduction in benzene evaporative losses, would result from increase in conversion to diesel vehicles.

Crankcase losses: As indicated above, some concern has been raised with regard to the possible carcinogenic effects of small amounts of nitrosamines and multi-ring aromatic compounds arising from crankcase losses.

(c) Mutagens

32. The organic substances emitted along with the particulate matter from diesel-powered vehicles are likely to contain mutagens. This premise is supported by the in vitro test results noted above using the Ames bioassay tests for mutagenicity. Since the mechanisms that produce mammalian mutations are well understood, results from the in vitro tests are strong indications of the responses expected in human cells. If those mutagens are able to migrate to the germinal cells of the reproductive organs, then defective genetic information will be transmitted by the exposed parent to the offspring. When sufficient mutant, recessive genes are built up in the population gene pool, then mutations in offspring may be observed.

(iii) Reduced Visibility and Odour

33. Properly adjusted, petrol-powered vehicles emit very little smoke or odorous compounds. Diesel-powered vehicles can emit significant quantities of both. If there were public complaint from a large-scale conversion to diesel vehicles it is most likely that it would be due to unpleasant odours and smoke attributable to diesel vehicle operation in congested urban areas. The causes of the exhaust odours are incomplete combustion of fuel, thermal degradation of some fuel compounds, and partial oxidation of the unburned fuel components resulting in the formation of aldehydes, phenols and organic acids. The cause of visible emissions of black smoke is carbon particles, forming black smoke, from incomplete fuel combustion, sometimes associated with blue smoke from lubricating oil droplets. Apart from being a nuisance, black smoke reduces visibility and can be a safety risk. As will be seen below, while engine design technology is well in hand to control visible smoke emissions, some measures employed by manufacturers to meet future emission standards for nitrogen oxides, such as exhaust gas recirculation and retarded injection timing, may cause unacceptable increases in smoke levels.

(iv) Noise

34. Diesel equipped vehicles are noisy by nature of their engine combustion under very high pressure which gives rise to mechanical noise and vibration in frequencies

ranging from about 500 to 5,000 hertz. The effects of noise depend on the intensity of frequency range (8). Motor vehicle noise is a growing source of nuisance in many urban areas. A recent OECD Conference (9) pointed out that 15% of the population in OECD countries is currently exposed to an external daytime sound level greater than 65 dBA (Leq) and over half the population to levels exceeding 55 dBA (Leq). Road traffic constitutes by far the major source of such noise. Efforts being made to reduce engine noise are discussed in Section VI. In the United States, for instance, forecasts show that if nothing more is done to lower motor vehicle noise, the number of people exposed to "unacceptable" noise levels (65 dBA or greater on the Ldn scale) (10) would increase from 17.8 million in 1977 to 21.6 million in the year 2000. If noise limits on lorries were lowered by 10 dBA and those on light vehicles by 5 dBA, the population exposed to noise levels of Ldn 65 dBA or greater would be reduced to 6.5 million. Certain European estimates show that a general reduction at source of around 10 decibels for heavy vehicles and 5 decibels for light vehicles would reduce from 15% at the present time to approximately 3% to 5% the proportion of people exposed to noise levels greater than 65 dBA (Leq). However, it is understood that today presently known technologies do not permit to reduce noise level from lorries by 10 dBA, a reduction which cannot be obtained even by completely eliminating engine noise.

(v) Pollutants Arising from Diesel Fuels and Additives

35. Depending on the sulphur content of the original crude and its subsequent refinery treatment, diesel fuels usually contain sulphur. The proportion of sulphur in the lighter diesel fuels can be quite low and is usually below 0.5%, whereas in the heavier grades of fuel the sulphur content can well exceed 1%. Consequently, depending on the fuel quality and on the local ambient air situation, diesel vehicles can be an important local source of sulphur oxides and sulphuric acid aerosols at street level. As referred to in paragraph 28 sulphur oxides are of public health concern in the ambient air, especially when associated with particulate matter (7).

36. Section X reviews the trends in alternative fuels, and alcohols appear to be the most likely candidates with certain possible environmental benefits, e.g. reduced smoke and NO_x emissions. However, no comprehensive evaluation of the environmental impacts of alternative diesel fuels has yet been carried out. As regards diesel fuel additives, alkyl nitrates might be a source of possible health concern, but no evaluation has yet been made of these or other additives such as odour modifiers. Unlike many spark-ignition vehicle fuels, diesel fuels do not contain lead additives, ethylene dibromide or ethylene dichloride, each of which are of health concern in urban areas (1). Consequently the expanded use of diesel vehicles would tend to reduce public health risks from those substances.

VI POSSIBILITIES OF CONTROL TECHNOLOGY REMOVING ENVIRONMENTAL HEALTH AND WELFARE CONCERNS

37. Negative impacts on public health and welfare of the diesel vehicle use are being tackled in four primary areas :

- Nitrogen Oxides

- Particulate Matter

- Black Smoke and Odour

- Noise

Each of these will be discussed below.

NO_x Emission Control

38. Four main means are available for reducing the production of nitrogen oxides in vehicle engines:

- Partial exhaust gas recirculation (EGR), using vacuum or mechanically operated EGR valves already fully developed for spark ignition engines, may also be used for diesel engines thus providing a decrease of the combustion temperature and subsequently of NO_x emissions (the latter being exponentially related to combustion temperature). The use of EGR in diesel engines may result in a fuel economy penalty and increases in smoke, hydrocarbons and particulate emissions. It also can increase engine wear.

- Retarding injection timing and reducing the fuel injection rate, determined by the plunger diameter, the cam profile of the injection pump, the inner diameter and length of the injection pipe, and nozzle orifice can reduce NO_x emission by reduction of the combustion temperature at the expense of an increase in fuel consumption and smoke emission combined with some decrease in engine torque. In that respect Figure 4 shows how a slight change in injection timing adjustment may reflect on smoke emissions, fuel consumption and torque. In fact, the relationship between NO_x and smoke emissions, and fuel consumption is a very complex process where the fuel injection characteristics play the major role.

- A decrease of the air/fuel mixture ratio and a swirl reduction in the combustion chamber may provide a combustion temperature and NO_x emission decrease. Here again the NO_x reduction is obtained at the expense of some fuel economy and may also provide an increase in hydrocarbon emission from incomplete combustion and engine starting difficulties in cold weather.

- For turbocharged diesel engines, an intermediate cooler can bring down the compressed air temperature but may result in a slight fuel economy reduction.

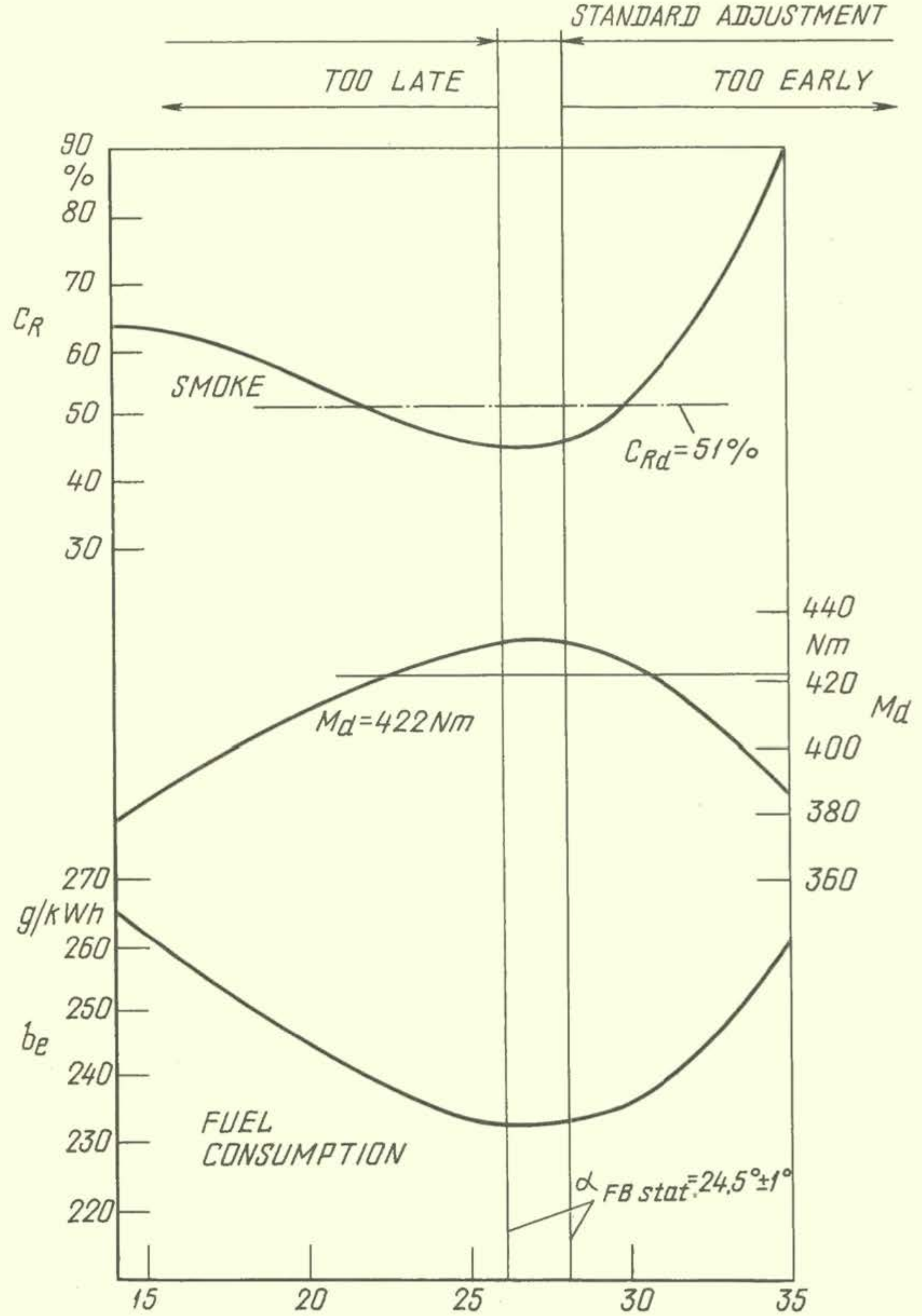
39. The above considerations highlight the potential conflicting situation arising from the efforts simultaneously to reduce NO_x , smoke and particulate emissions, while increasing fuel economy. The current stage of technological control for nitrogen oxides requires manufacturers to make trade-offs from the early stages of engine design. Improved solutions for simultaneous reduction of nitrogen oxides, particulate and smoke emissions as well as fuel economy may call for further complex study and evaluation of the alternatives, as well as new technological designs associated with extended experience in practical use.

Particulate Matter Emission Control

40. As noted above, some components in diesel exhaust may prove to be human carcinogens. One way of reducing this possible hazard is to reduce or remove those components from engine exhaust. Two questions should be considered when examin-

FIGURE 4

EFFECT OF WRONG INJECTION TIMING TO SMOKE, TORQUE AND FUEL CONSUMPTION



C_R = exhaust gas opacity in percent of absorption

b_e = specific fuel consumption in g/kWh

M_d = Torque in N. m.

$\alpha_{FB\,voT}$ (crankshaft angle)

Source: UN/ECE WP. 29 - GRPE/R. 36

INJECTION TIMING

ing the ability of candidate emission control technologies to reduce a health hazard :

- Will those components in diesel exhaust likely to cause adverse biological activity be removed by the candidate control technology, and

- When will effective control technology be available?

The current state of knowledge does not permit any firm identification of which components in diesel exhaust are the "bad actors" in terms of adverse effects. However, it is believed that reducing the total particulate emissions and their associated organic substances would contribute to a reduction of the carcinogenic health hazard. But, a substantial portion of the bad actors may still remain, even though most of the total particulate matter is removed. This concern is one that must be considered when candidate technical approaches are developed and evaluated.

41. The other question relates to the availability of effective control technology. Present estimates indicate that the commercialization of particulate trap systems and especially of the trap-oxidizers (either continuous or intermittent) remains hypothetical in the short term. Such devices appear able to remove a substantial percentage of the particulate matter and its associated organic substances. If these devices reduce those components in the diesel exhaust that may be the carcinogens to a level that does not pose any health hazard, then the possible carcinogenic health effects concerns will be largely removed. Preventive technologies are being evaluated that may reduce the formation of particulate matter and its associated organic substances such as: control of the complex combustion process, including optimization of the air/fuel mixture and flow, adequate flame propagation, optimization of the fuel composition, and reduction of the engine heat loss to the coolant. These various approaches for reducing particulate matter at source would enable trap devices for particulate filtration and reduction that might be combined with them, to function more efficiently and be more durable owing to lower initial concentration of particulates in the exhaust.

Control of Black Smoke and Odour

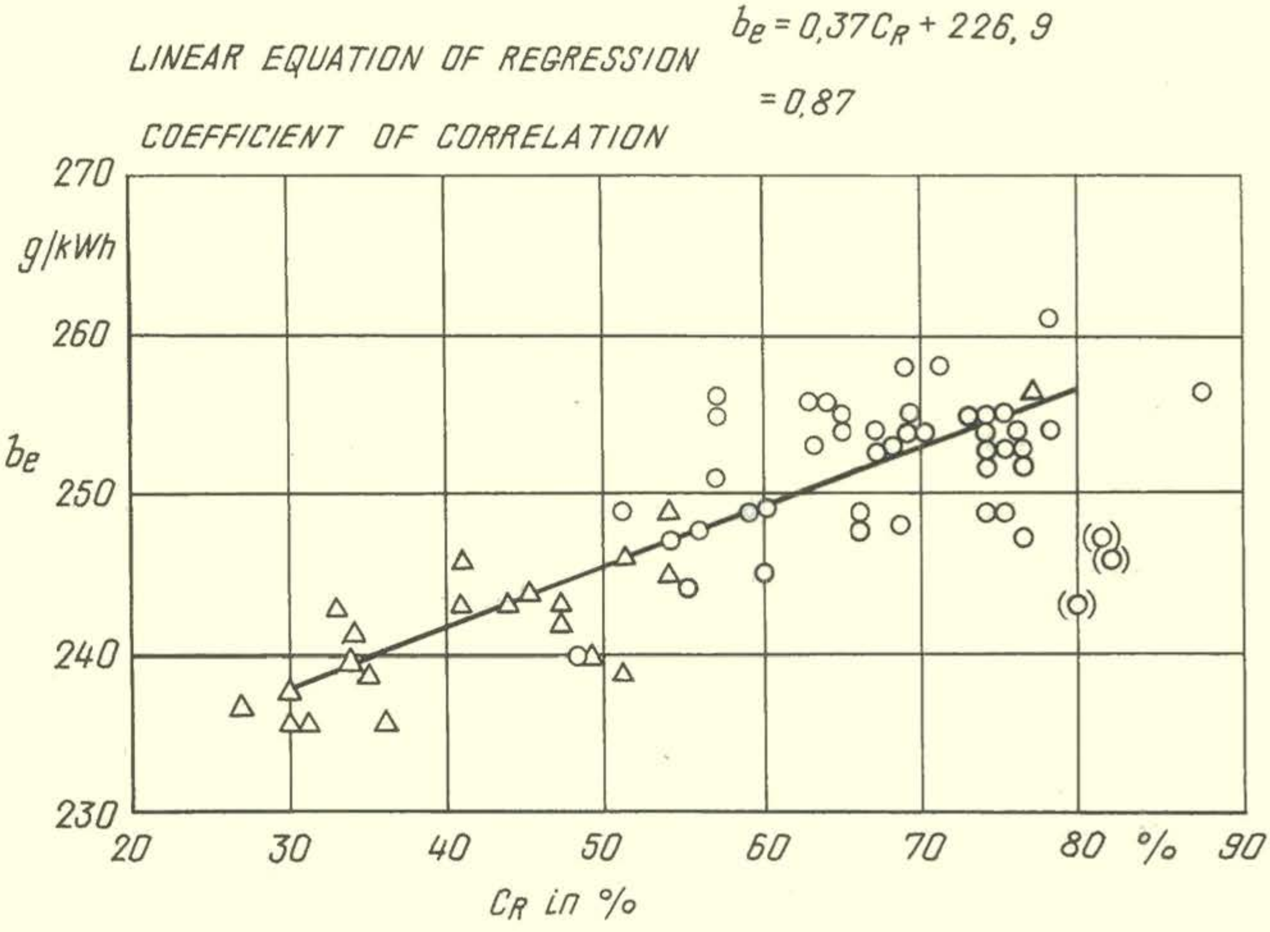
42. Visible smoke emissions of diesel equipped vehicles, especially from medium-sized and heavy trucks and public transport vehicles, require special attention. Thus over and above their unpleasant odour and potential road safety hazard of reduced visibility from black smoke, carbon particles are a vehicle for the more dangerous to health hydrocarbons. Furthermore, emission of black smoke implies a waste of fuel, just as blue smoke implies a waste of lubricating oil. Experiments have shown that the fuel economy penalty and smoke emissions are linearly related (see Figure 5). Engine design technology is well in hand to control visible smoke emissions, since smoke standards have been in effect in various countries since 1970. There are three necessary and vehicle operator related conditions for the control of diesel smoke emissions:

- correct operation of the fuel pump and especially adequate adjustment of the injection timing and maxi fuelling level setting at the time of manufacture and service,

- use of appropriate fuel,

FIGURE 5

CORRELATION BETWEEN FUEL CONSUMPTION AND EXHAUST GAS OPACITY FOR 68 ENGINES OF SAME TYPE (MEASUREMENTS 1968 – 1975)



○ ENGINES NOT RUN IN

△ ENGINES RUN IN

(○) FOR ANALYSIS OF REGRESSION NOT USED „RUNAWAYS"

b_e AND C_R ARE THE MEANS FROM 4 SPEEDS

Source: UN/ECE WP.29-GRPE/R 35

- correct vehicle loading during operations, with prohibition of vehicle overloading, and tampering with maximum fuelling device.

Those three conditions underline the importance of the adequate adjustment and operation conditions of the diesel equipped vehicle. In that respect, when the technical specifications provided to the user by the manufacturer are carefully followed, diesel equipped vehicles have shown a better resistance to the "degradation factors" affecting their reliability, durability and their emission performance than those of comparable spark ignition equipped vehicles.

43. Diesel engines, although more flexible than spark ignition engines, are designed to use fuel with a given range of specifications, which must be respected. Contamination of fuel, e.g. by water and sediment, may occur during transportation, handling or storage, particularly in developing countries. Adulteration of diesel fuel, for example with heavy fuel oil, would give rise to incomplete combustion and emission of black smoke and hydrocarbons, as well as to the need for more frequent maintenance. In many countries strict fuel quality specifications are maintained by the petroleum companies and fuel distributors and, moreover, checked periodically by the authorities. Unfortunately in some countries strict fuel quality control is neither ensured nor enforced and tampering of fuel by adulteration occurs. The temptation to tamper with the fuel often arises through significantly different prices for different fuel qualities owing to different tax levels, or alternatively because of a shortage of diesel fuel. The cause of this problem is mainly socio-economic and the solution lies not only with the fuel industry but also with Governments.

44. Diesel engines are designed to operate under a range of load conditions and if the engine is overloaded unburned fuel is emitted as black smoke. While many countries have regulations concerning the maximum loading of vehicles, e.g. number of passengers for cars and buses and weight limits for trucks, many other countries have no controls and overloaded, smoking vehicles are frequently seen on the roads. The problem is not merely one of regulation and enforcement, but rather a socio-economic question where the existing transportation system is inadequate to meet local needs and operators overload vehicles in order to make their transportation operations economically effective.

45. Concerning diesel-engine exhaust odour reduction, design changes, including modifications to the combustion chamber and fuel injector, in order to promote more complete combustion are among the most effective approaches. Furthermore, use of vertical exhaust stacks helps diffuse odours away from other road users. In addition, self priming injection equipment and foolproof filter replacement can help to combat unpleasant odour.

46. Changes in the composition of diesel fuel appear to have little effect on exhaust odour. Furthermore, chemical additives introduced into diesel fuel have had little effect on exhaust odour, with regard to the few additives which have been studied to date. Adding odour modifiers to change the odour character of diesel exhaust may result in temporary reduction of complaints about diesel-exhaust odour, but complaints may return as the public begins to associate the modified odour with diesel exhaust. The possible health effects of such an approach are uncertain; a portion of the odour modifiers will be emitted in their initial or altered chemical form.

47. Finally, it is worth noting that the use of alternative fuels may have a positive or negative impact on diesel odour characteristics. For example, the use of methanol fuel (which can be produced from vegetation, wood, coal, etc.) will increase aldehyde emissions if used in the future with modified diesel engines (spark-assisted diesel engines). As noted earlier, aldehyde emissions will increase odour. One potential remedy in the future may be to use catalytic converters to convert aldehydes to less odorous compounds.

Control of Sulphur Oxides Emissions

48. Sulphur oxides emissions are directly related to the sulphur content of the fuel and if an important contributor to undesirable ambient air conditions may be reduced by using lower sulphur distillate fuels. Such reduction presents no problems in the industrialized countries, where sulphur concentration rarely exceeds 0.3% in the diesel fuels in current use, since refiners usually have access either to low sulphur crudes or to desulphurization facilities. It is quite common in any case partially to desulphurize distillate fuels in those countries. In many industrialized countries the sulphur content of diesel fuel is regulated and rarely exceeds 0.3%. Some developing countries also regulate fuel sulphur content, e.g. in Singapore the maximum sulphur content is 0.5%. Developing countries without ready access to low sulphur fuels are often at a disadvantage. An examination of world crude oil distribution and consumption reflects this point - the poorer countries have tended to receive the poorer quality higher sulphur crudes since in the past they have not been able to afford the premium quality. It must also be borne in mind concerning sulphur emissions that where catalysts may be used to reduce other pollutant emissions such as CO and hydrocarbons, sulphur dioxide tends to be converted to sulphuric acid, a more noxious substance.

Control of Noise

49. Efforts are being made to reduce engine noise at the source in combination with noise radiation reduction. At the source, the use of indirect injection (pre-chamber) and retarding the fuel injection timing is one approach for smoothing the combustion process. However, as seen above, such methods may increase specific fuel consumption and smoke emissions.

50. Alternatively, lowering the injection rate, reducing the compression ratio in conjunction with turbocharging and reducing engine surface vibration by increasing rigidity, mass and damping, and by ribbing of the cylinder block, combined with suitable engine noise insulation (pump, valve cover, oil sump, etc.) also appear promising. Acoustic energy radiation is likely to be treated more and more (especially for heavy commercial and public transport vehicles) through transmission shielding and particularly engine encapsulation with the isolation of the vibrating engine surface - a complex technology related to engine efficiency and especially the engine cooling system and access for service maintenance, which requires careful design. It is expected that studies along such lines currently being conducted by Governments and industry in many of the diesel manufacturing countries will lead for the period 1985-1990 to a reduction of 5 to 8 dBA in the noise limits adopted in present regulations covering certification of new diesel equipped vehicles.

VII SAFETY ADVANTAGES OF DIESELS

51. Diesel fuel is less flammable than petrol under the same conditions. When diesel fuel tanks are punctured during collision, the probability of explosion and fire is substantially reduced. This advantage that diesel-fueled vehicles possess over petrol fueled vehicles may be eliminated as more stringent safety standards are imposed on the placement and construction of fuel tanks in vehicles.

52. From the point of view of occupant protection, in virtually all cases diesel engined passenger cars, although slightly heavier, are identical with the corresponding spark ignition engined models of a manufacturer's product range and comply with the same safety standards. However, diesel powered passenger cars may reduce fatal accidents since people will be able to get larger vehicles whilst not increasing their fuel expenses.

VIII REGULATORY ASPECTS

53. Countries which wish to familiarize themselves with vehicle pollutant and noise emission control should take note of the existing regulatory programmes such as those applied in most countries of Western and Eastern Europe, in Japan and in the U.S.A., where the legislation in question is published respectively by the United Nations Economic Commission for Europe (11), by the Japanese Ministry of Transport, Motor Vehicle Department (12), and in the U.S.A. Federal Register (13). The regulatory aspects concerning the case of new vehicle certification and that of vehicles in use should be considered separately.

New Vehicle Certification or Vehicle Type Approval

54. As far as pollutant emission control is concerned, CO, HC and NO_x restrictions are in common use in Europe, Japan, North America, Australia and a number of other countries for vehicle certification, including diesel equipped vehicles for which smoke emissions are also regulated. In that respect, European legislation (UN/ECE Regulation 15) for HC and NO_x is based on control of the sum of the concentrations rather than of individual concentrations. In the U.S.A. and in Japan, particulate matters from diesel engines are also regulated. Measurement methods, including gas sampling, analytical procedures and instrumentation in each country are becoming progressively similar as the result of efforts to harmonize. However, test procedures and especially the "driving cycles" differ significantly. Smoke emission control for diesel equipped vehicle certification is an exception for which similar test procedures and measurement methods, based on light absorption by smoke, using an instrument called an opacimeter with the measurement expressed as an absorption coefficient, are commonly used. UN/ECE Regulation 24 details the test procedures and the measurement methods in use as well as the instrument calibration for the control of diesel smoke emission (11). The "driving cycles", which define the way of exercising the vehicle engine on a dynamometer bench while the exhaust emissions are measured, were originally designed according to the various vehicle operations encountered under specific urban driving conditions found in the main cities of Europe, Japan and the United States of America. That is why the United States driving cycle, with higher and transient speed conditions,

corresponds to traffic conditions on urban and suburban motorways combined also with congested traffic conditions, while the European and Japanese cycles reflect driving operations in the main historical city centres with high density traffic and including a greater number of crossroads. Efforts have recently been made to reach some standardization as far as driving cycles are concerned. For example, the UN/ECE has adopted a 13-mode cycle similar to a U.S.A. federal driving cycle for emission control as a test procedure prescribed by Regulation 49 for diesel commercial vehicle certification, where exhaust emissions are analysed during a prescribed sequence of 13 specified steady-state operating conditions. Finally, it is essential to underline that new vehicle certification for pollutant emission control requires a complex and expensive laboratory infrastructure and calls for equipment to be strictly operated by trained technicians.

55. Concerning noise, emissions regulation and noise level limits cover all categories of vehicles, from private cars to heavy commercial and public transport vehicles in Europe and Japan. They are currently fixed at 80 to 81 dBA for motor cars, 86 to 88 dBA for heavy lorries and 82 to 91 dBA for heavy buses. In Japan, noise limits are maximum levels which may not be exceeded, while in the European communities a tolerance of 1 dBA is permitted at production level. In the U.S.A., noise regulations cover only commercial vehicles. Although in those three regions noise regulations use the same "full acceleration" test method based on the International Standardization Organization (ISO) and Society of Automobile Engineers (SAE) procedures, other aspects of test procedures and measurement methods differ for each region, for example as far as concerns vehicle speed when entering the measurement area, and the microphone position. Finally, it should be noted that the diesel equipped vehicle, noisier by the nature of its cylinder head high compression and the quieter gasoline engine vehicle are bound by the same noise limits as adopted in each region.

Vehicles in Use

56. Various technical inspection schemes are currently applied to vehicles in use in Europe, Japan and the U.S.A. These inspection schemes are considered an essential tool for assessing whether correct maintenance and repair of vehicles in use has been carried out. Amongst ways and means for preserving environmental, fuel economy and road safety performance of the vehicle population, the UNEP Environmental Guidelines for the Motor Vehicle and its Use (1) give measures to ensure correct maintenance and repair.

57. In Europe, for example, such inspection schemes take different forms and use different technical procedures depending on the country. These range from simple carburation/ignition diagnostic tests for vehicles, undertaken on a voluntary basis, and noise and smoke emission control undertaken at the roadside by the police, to more complete and mandatory periodic inspections. The latter, undertaken at authorized inspection centres or servicing garages, are based on well defined technical procedures, including specific tests of essential vehicle safety equipment, as well as CO and HC concentration measurement at idle for petrol fueled vehicles, and smoke measurement for diesel equipped vehicles. Experience with inspection schemes has shown that for spark ignition engines proper maintenance and repair may reduce emissions by 50% for ageing vehicles, i.e. more than 5 years old or having done more than 80,000 km. Concerning diesel vehicles, enforced regulations and inspection tend to minimize gross black smoke emissions. UN/ECE has under elaboration a technical inspection procedure for motor vehicles in use, based on the

various inspection operations applied in European countries. UN/ECE is also preparing its various existing regulations by appropriate guidelines for technical inspection.

58. In Japan, the Road Vehicle Act prescribes that vehicle owners submit their vehicles to the Ministry of Transport every two years to renew the period of validity of the Motor Vehicle Inspection Certificate.

59. In the U.S.A., a programme of emission inspection and maintenance (I/M programme) prepared by the EPA provides an inspection procedure to be applied to in-use petrol-fuelled vehicles only, based on a CO and HC measurement at idle. As already experienced in Europe, and in the light of results obtained in a number of States in North America (Arizona, New Jersey, Oregon, etc.) conducting such I/M programmes the "idle test" is considered to be highly efficient in identifying gross CO and HC emitters in need of remedial maintenance, adjustment or repair for carburation and ignition. To date, no similar short test has been established for diesel equipped vehicles in use. However, such a test, which would call for a simple measurement method for NO_x and particulate matter emission but is not yet available, may be instigated in the future owing to the increasing number of diesel vehicles in the North American market.

60. While a significant number of developing countries have technical inspection schemes of varying degrees of efficiency, covering vehicle road worthiness and safety, such as condition of brakes, steering, tyres, few have full-scale mandatory inspection for environmental aspects such as both emissions and noise. Among others, Hong Kong and Singapore have legislation allowing the police to prosecute owners of exceptionally noisy vehicles and those emitting black smoke. Regulations stipulate opacity limits for diesel black smoke emission at the time of inspection. Mexico City has developed a voluntary inspection scheme which also covers noise, visible emissions and emissions of carbon monoxide and hydrocarbons.

IX TECHNICAL DEVELOPMENT TRENDS IN DIESEL ENGINE EVOLUTION

61. At the outset, the diesel engine, generally heavy and normally suitable for use over a relatively limited range of engine speeds, was most naturally adapted to heavy installations and large vehicles. Progression in these applications has been and will continue to be marked by increased use of direct injection, of particular interest at the present time because of improved fuel economy. That solution is introduced progressively in the passenger car sphere. Current direct injection engines emit substantially more total NO_x and particulates than prechamber configurations. However, in view of the intrinsic qualities of the system regarding economy and lower emission of carbon monoxide, and of increasing interest in its application to light vehicles and passenger cars, efforts have been made to improve performance under load conditions, hence reduced response delay to the throttle operation; such research has led to rapid progress in supercharging technology. According to tests carried out in the Federal Republic of Germany, France and the U.S.A., improvements in fuel consumption and increase in average road speed for heavy diesel equipped commercial vehicles (38 t GTW) during the last 15 years have both been approximately 20%. During the last 8 years improvements have been 12% and 3.5% respectively for the 32 t GTW commercial vehicle category. Those improvements result from a combination of a lower specific fuel consumption on the engine side, down to approximately 200 g/Kw/h, associated with a noticeable trend

towards multi-gear transmission (12 to 16 gear transmission), the adoption of radial tyres and a significant improvement in vehicle aerodynamics (14). In the U.S.A. trend has been toward fewer transmission gears associated to higher engine torque and lower maxi speed.

62. Although it is difficult to foresee all spheres of development in relation to the diesel engine, mention should also be made of anticipated progress in the field of metallurgy and methods of forging which will allow increased use of light alloys for engine structure and components. This will provide savings in weight, improve the quality of heat exchange, and rapidity of warm-up. Furthermore, mention could be made of the standardization of auxiliary equipment, the generalization of shell bearings facilitating maintenance and simplifying lubrication. The fields of fuel combustion and supercharging will be considered in detail.

Improved Fuel Combustion

63. In the interest of flexible and silent operation under all loading conditions and with various fuels, etc., use of a precombustion chamber is very common in light duty diesel engines. This is constituted by a small and generally spherical volume formed in the cylinder head, or even in the piston: the vaporized fuel is injected into this small volume which communicates with the main chamber over the piston through a small channel.

64. Several patents have been taken out regarding the design of these precombustion chambers and their connection to the main combustion chamber. These different solutions are intended to provide the best conditions for the performance sought for the operation of the injectors, intake and exhaust manifold systems, etc. In general, the precombustion chamber, where piston movement causes strong air turbulence, facilitates rapid burning of the fuel even with a simplified injector. Moreover, as the pressure of combustion is transmitted to the piston through the intermediate channel, high loading on the piston is thus "filtered". This type of engine does not call for elaborate injectors, high injection pressures, or fuel with a high cetane rating. On the other hand the end of the combustion process is inefficiently used; thermal losses and friction in the small linking channel are a cause of losses in thermal efficiency.

65. Direct injection, which is a simpler concept, with a combustion chamber design almost similar to that of the petrol engine, does not present those disadvantages; nevertheless this technology presents more noise and emissions problems.

66. For improving fuel economy it may nevertheless be desirable to take advantage of the direct injection principle. A problem of delay in air-fuel mixture ignition arises. On the other hand, in a thermal engine, any "explosion" or more accurately any "detonation" must be avoided ; this can occur if the fuel injected is not ignited instantaneously since the fuel will accumulate to be followed by a sudden and untimely explosion, causing pressure waves subjecting the whole engine to high stress loadings. Although, in the extreme, such deterioration is tolerable in exceptional cases with large engines with low operating speeds, it is totally unacceptable with smaller and lighter engines. Progress in studies and developments of fuel stream air intake, shape of the combustion chamber including swirl chamber and the possible use of ceramic coating around the combustion area and other developments towards adiabatic conditions of the engine energy transformation cycle, as well as of higher compression ratios, spark assisted combustion and fuel

characteristics, could help to reduce this risk and therefore to promote the increased use of direct injection technology on all types of diesel engines, while improving their thermodynamic efficiency. Electronic control of the injection, monitoring the various parameters of engine running, will also enable the limit conditions of optimum engine functioning to be approached more closely.

Supercharging Devices

67. Air supercharging primarily provides extra power for an engine of given size. It also improves the engine thermal efficiency and therefore the fuel consumption. It can also reduce the engine response delay to the throttle operation, a driving characteristic very much appreciated in relation to road safety.

68. By controlling supercharging in different ways, this liveliness may be achieved at low as well as at high speed. Different systems are currently being developed to this end. One of them is the use of a volumetric compressor operated by the engine crankshaft which compresses air at inlet and provides extra power even at low engine speed, but does not recuperate the wasted energy at exhaust.

69. It is also possible to use several turbo-chargers. A turbo-charger operating at around maximum engine speed at which an increase in power is most desired will compress a large amount of air but in consequence, have a high inertia owing to its size. Its optimum efficiency will be at this high-flow rate. At low engine speeds it will be much less efficient. If to this "large" turbo-charger is added a second smaller turbo-charger, whose inertia is reduced to a minimum, engine "pick-up" may be obtained at low speed. It is nevertheless obvious that the problem is complicated by the existence of these two compressors whose control will have to be carefully studied. A number of valves automatically operated are necessary to direct the gases through the appropriate turbo-charger at the required flow-rate, without any delay so as to achieve an instantaneous response. Hydraulics, mechanics, but above all current developments in electronics could help in this field, bearing in mind that scientific progress will never be introduced in production vehicles unless the cost-effectiveness relationship is acceptable for large scale production. Certain experiments in the field of petrol engine supercharging on competition cars may provide new solutions suitable for adaptation to diesel engines, where turbocharging may be ultimately combined with adiabatic technology to use efficiently the present heat losses observed through conventional cooling systems.

Environmental Implications of New Diesel Technology

70. Although parallel progress will also be made in spark ignition engines, anticipated technological developments will make the diesel engine even more attractive for the propulsion of motor vehicles. It should not be forgotten, however, that at the present time regulatory prescriptions, concerning in particular safety and protection of the environment, strongly influence the design of road vehicles. Meeting certain constraints in one area may constitute in some cases an obstacle to progress in other areas. For example, and as noted above, direct injection generally results in higher noise levels than when using the precombustion chamber principle. A lightened engine or an engine where materials are used providing better heat dissipation will also generally be more noisy. Such an engine, where the operating conditions have been improved in order to provide more specific power, may also emit a greater quantity of certain pollutants.

71. In future progress in the motor vehicle field, manufacturers may therefore be obliged to choose solutions which are in fact compromises. Furthermore, the search for a compromise solution which is also economically acceptable may delay or even inhibit development of a technically attractive solution. This reinforces the necessity for encouraging new innovative technological developments which obviate the need for compromises.

X ALTERNATIVE FUELS AND TRENDS

72. During the last decade petroleum supply disruptions and cost increases have sent a shock wave through the world which has dramatically accelerated interest in alternative fuels for motor vehicles. Generally, which alternative fuel is the most promising depends upon geography. The need for these fuels, especially liquid fuels suitable for internal combustion engines, is of the highest priority for developing areas as well as for the industrial countries. Nearly 67% of total commercial energy consumption in developing countries consisted of petroleum and refined products in 1976 as compared with only 51% in the industrial countries. Demand for diesel fuels is rising faster than for petrol in developing countries and there is increasing competition for the middle distillates. While about half of the consumption might be replaceable with other non liquid sources for generating electricity or providing mechanical energy, there is at present no viable alternative to liquid and certain gaseous fuels in most of the transport sector. Such fuels can be produced from a number of sources, including coal, oil shale, natural gas, uranium and biomass. While synthetic petrol, synthetic diesel fuel and alcohol are all possible, most investigators have concluded that the alcohols, ethanol and methanol, appear the most promising alternative fuels during the next twenty years and probably beyond. Although market factors can influence the introduction of alternative fuels they are usually insufficient on their own and Government involvement has been necessary in encouraging the development and use of these fuels when they can be economically produced. Care has to be taken not to create an imbalance in fuel supply patterns when introducing alternative fuels, as has occurred in some countries using alcohol as a substitute for petrol.

Application of Alternative Fuels

73. Virtually all studies have concluded that present internal combustion engines, whether spark-ignition (Otto cycle) or diesel, will remain the dominant motor vehicle engines throughout the remainder of this century because they are well developed and highly adaptable. Alcohols can be used in those engines either by blending them with the primary fuel (petrol or diesel fuel) or by using 100% alcohol (i.e. "neat") which require specific engine modifications to prevent related corrosion.

74. Ethanol or methanol, the latter associated to an emulsifying agent, can be blended in with diesel fuel but the stability of the mixture is poor, particularly in the presence of water and even humidity. Blends containing 30% alcohol can be used to power an engine, but phase separation is likely, resulting in starting problems or failure of the fuel injectors. Furthermore alcohols have low cetane numbers reflecting poor ignition quality and work is in hand to find ignition improvers. A dual fuel injection system with diesel serving as the pilot that ignites first, appears promising. Its size, cost and complexity, however, may make it impractical for smaller engines but suitable for industrial engines and perhaps heavy transport engines.

75. With regard to diesel engine operation on neat alcohols, most current interest is focused on the so-called spark-assisted diesel. A spark assisted diesel bus engine developed by Maschinenfabrik Augsburg-Nurnberg (MAN) and operated on the streets of Berlin using neat methanol demonstrated very low energy consumption, reduced NO_x emissions, no smoke (presumably accompanied by low particulate emissions), adequate cold starting and excellent performance. Initial indications are that this may be the best overall energy - environment combination for many countries in the 1990's - a spark assisted diesel engine operating on pure methanol, provided that the fuel circuit, engine and exhaust system have been modified to eliminate the methanol corrosion factor.

76. In addition to alcohol some experience has been gained in using non-petroleum oils, as diesel fuels, e.g. vegetable oils such as coconut, palm, soya or sunflower oils. These oils have good cetane ratings and diesel vehicles run satisfactorily on them. Blends up to 30% would be acceptable. However, the power output may be reduced and more frequent maintenance may be required, since, having low volatility and being more viscous than normal diesel fuel, vegetable oils may give rise to filter blockages and engine fouling. In the Philippines blends of 5% coconut oil and 95% diesel fuel are being used and tests are in progress with blends up to 30%. In Brazil plans are in hand to use soya bean oil and possibly palm oil, replacing 1.5% of diesel fuel demand by 1986.

Fuel Additives

77. With the advent of cracked fuels and fuels of other than paraffinic base, additives are required to raise the cetane number of diesel fuels to desirable values (45-50) for high speed engines in order to improve the air-fuel ignition process and also to reduce smoke and noise emissions as illustrated in Figure 6. Almost all alkyl nitrates are ignition accelerators. Amyl nitrate, ethyl nitrate, cyclohexanol nitrates are typical examples. Aniline has also been used. To raise the ignition quality of alcohol to the diesel range, the quantity of additives required is found to be high, thus the focusing of work on the spark-assisted diesel.

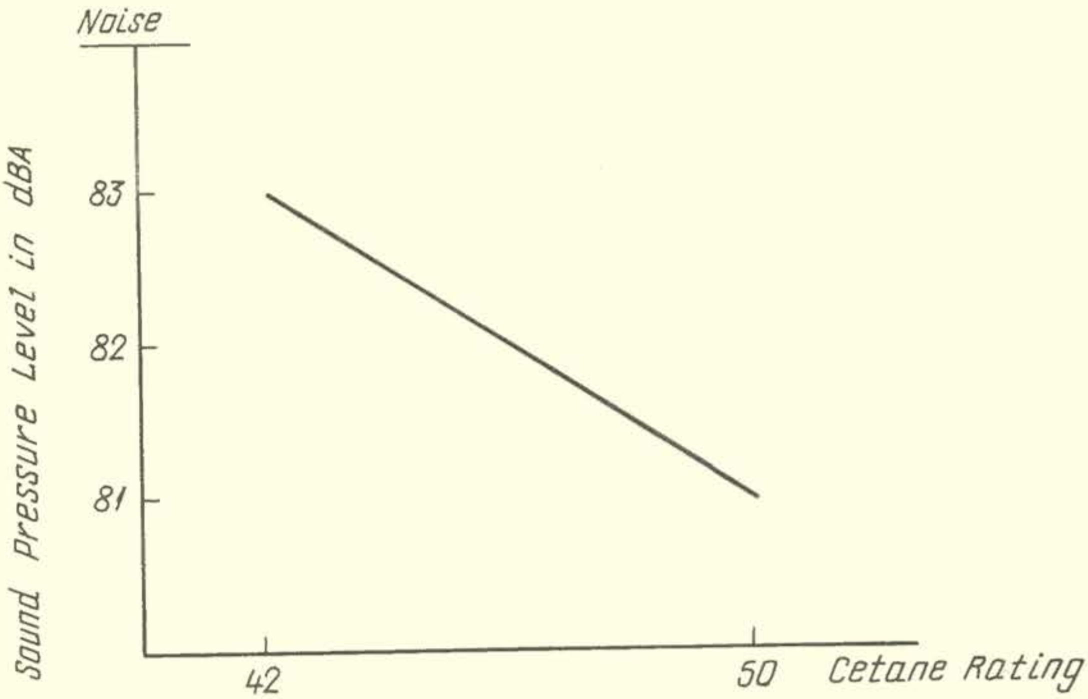
78. Anti-smoke additives are generally classified into two groups. The first group of additives work as detergents or anti-oxidants. These additives help in maintaining the injectors free of gums and varnish by their detergent action which would otherwise affect the injector atomizing efficiency. The second group of additives are mainly metal containing organic compounds (calcium and barium additives). These compounds are known to have significant effect on the mechanism of formation of smoke in a combustion process, although the latter gives rise to the formation of metallic particulates.

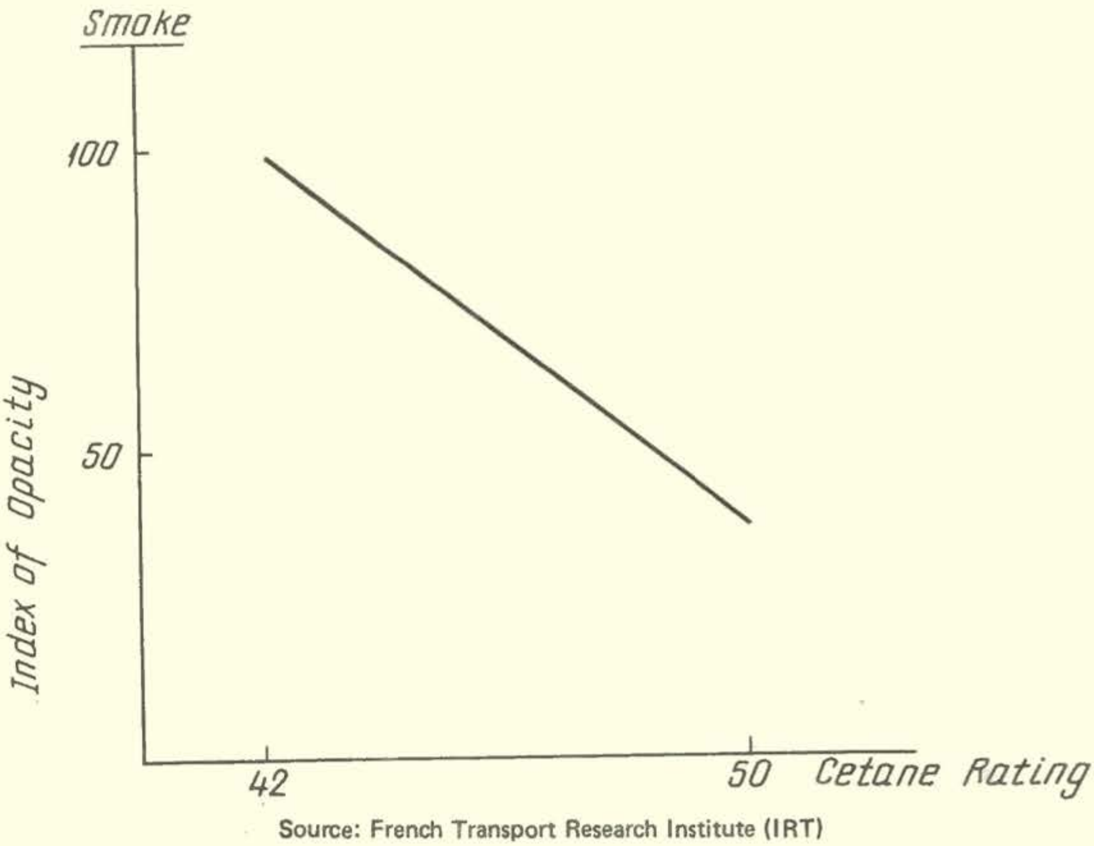
XI RECOMMENDATIONS CONCERNING DIESEL VEHICLE OPERATION

79. Compliance with the manufacturers' operating and maintenance instructions is essential in order to optimize vehicle performance and life, as well as to ensure that environmental and fuel economy design characteristics are met. While each vehicle type has its particular design and operating characteristics, the following recommendations highlight those essential issues relating to the operation of a diesel powered vehicle, that basically differ from those of the spark ignition engine powered vehicle.

FIGURE 6

CORRELATION OF CETANE RATING WITH NOISE AND EXHAUST EMISSION OPACITY





Source: French Transport Research Institute (IRT)

A. Specific Usage Conditions

(i) Warm Up Temperatures

80. Self ignition and complete combustion of the atomized fuel in the combustion chamber require the compressed air/fuel mixture to reach an appropriate temperature. The time required to obtain this temperature depends on the ambient temperature and particularly on the combustion chamber design and the injection process (direct and indirect injection). A "glow-plug", incorporating an electrical resistance, acts as a temporary air/fuel mixture ignition source. The glow-plug operation and the corresponding air heating time (a few seconds) are indicated by the manufacturer for each type of vehicle. The time may be less on certain engine designs.

(ii) Engine Speed and Vehicle Operating Conditions

81. Owing to their combustion principle, diesel engines give higher output and torque at relatively lower engine speed than equivalent spark ignition engines. Furthermore, as the compression ratio is fairly high, certain moving parts of the engine are reinforced. So, inertia and friction at high speed absorb a significant amount of power and therefore even with small diesel engines there is little advantage to be gained in reaching high engine revolutions per minute (RPM). Generally speaking, and especially for commercial and public transport vehicles, the range of efficient engine speeds under good road conditions is smaller than with the spark ignition engine, and therefore the gear-box must be used accordingly in order to obtain the best fuel economy performance. The manner of driving also differs from that of the spark ignition engine, since acceleration of a diesel powered vehicle is generally lower in response to the throttle position, although, when incorporated in the engine design, turbo-charging can overcome that disadvantage.

82. Since heavy commercial and public transport vehicles will represent for many years the main consumers of diesel fuel within the world diesel vehicle population, fuel economy and environmental considerations call for adequate attention to be paid to the operation of those vehicles. Consequently, heavy commercial and public transport vehicle operators should arrange their transportation schemes accordingly, whilst keeping in mind operating conditions essential for optimizing fuel economy and vehicle performance and life, such as:

- In hot climate conditions, prolonged idling should be avoided as it is in any case inefficient in terms of fuel usage, and may contribute to some cylinder wash, oil dilution, overheating and injection nozzle coking.

- Proper gear selection should be made according to load and road pattern, and tyres should be kept inflated according to manufacturers' specifications, these being the most important factors for reducing engine load to produce the required power and torque, and thus obtaining optimum fuel economy and minimum smoke emission.

- Diesel fuel specifications and grades for use during cold weather conditions should be strictly selected in accordance with manufacturers' recommendations, since diesel fuels tend to thicken and may no longer pass through the fuel filter. In some cases it may be necessary to add temporarily a small quantity of paraffin or appropriate additive to the diesel fuel to reduce increased viscosity. An electric heater for the fuel circuit may also be a solution.

- Naturally aspirated diesel engines normally operated above 1,500 metres should be derated to prevent over-fueling which reduces fuel economy, produces smoke and dilutes the engine oil. Derating turbocharged diesel engines may be required at altitudes above 2,500 metres. Here again manufacturers' recommendations should be carefully followed.

- Vehicle overloading resulting in increased fuel consumption, smoke emission, engine and vehicle fatigue and reduced road safety should be strictly avoided and even prohibited as far as possible by Governments.

(iii) Engine Idling Operations

83. In contrast to the spark-ignition engine, which does not operate at very lean air/fuel mixtures, the diesel engine functions correctly at idle with only a very small quantity of fuel being injected into the compressed air inside the combustion chamber. In addition and in order to obtain the lowest possible idling speed without risk of stalling the engine, almost all diesel engines equipping commercial and public transport vehicles are fitted with a centrifugal governor which increases fuel injection should the engine speed fall below a given limit. The resulting low fuel consumption at idle and low RPM operations requires the strict respect by the operator of the fuel injection adjustment adopted by the manufacturer, and highlights the significant advantage of using diesel equipped vehicles in congested traffic and "stop and go" driving conditions in urban areas, where they may save about 50% of the fuel consumed by a comparable petrol engine vehicle.

(iv) Specific Servicing by Operators

84. Owing to the high compression ratio of the diesel engine, the principal moving parts of the engine are subjected to high loads and necessitate an excellent seal between the piston and cylinder; a first class lubrication system must therefore be provided. Furthermore, if the engine is fitted with a turbo-charger whose operating speed is in the region of 100,000 RPM, this unit must also be perfectly lubricated. The vehicle operator must therefore regularly check oil levels.

85. The fuel system has to be strictly adjusted according to the geographical and climatic conditions, as prescribed by the manufacturer (see paragraph 82 above). It is protected by filters to eliminate any impurities and possible condensed water and also to allow any air to be expelled from the system. The filter in the air intake system also plays an important role. The vehicle operator must therefore check frequently the state of the filters, and rigorously respect the periods between changes of these filters as specified by the manufacturer in his documentation. At the time of those checks, any traces of fuel or oil on the outside of the engine or other mechanical components should be looked for as an indication of gasket or seal defects to be brought to the attention of the maintenance service.

B Maintenance and Technical Inspection of Diesel Engines

(i) Maintenance at Garage and Fleet Workshops

86. Each type of diesel engine strictly requires a certain number of specific maintenance operations, specified by the manufacturer. All service stations and

maintenance workshops must have a list of such information available associated with the appropriate equipment and spare parts, for the necessary checks, adjustments and repairs. These should be carried out in a well ventilated shop by well-trained personnel. In that respect the "Modules for Employable Skill" (MES) including "Learning Elements" published by the International Labour Office (ILO) provide the most appropriate learning material for ab initio training of garage and vehicle-fleet mechanics, including maintenance personnel for diesel equipped vehicles (15).

87. Oil and filter changes: Attention has already been called to the importance of perfect sealing between the piston and cylinder on a diesel engine (ensured by the oil). Owing to the higher temperature and pressure to which the oil is subjected the oil change period must be respected even more strictly than for petrol engines. Dirty or clogged oil, fuel and air filters restrict the free passage of oil, diesel-fuel or air and cannot provide satisfactory filtration. These filters should be replaced, or cleaned, strictly in accordance with the manufacturer's instructions. Apart from the risk of premature engine wear resulting from operation with filters in bad condition, fuel or air feed to the engine may also be affected and consequently the tuning conditions of the engine itself. Hence, the interval between these maintenance operations will be approximately one and a half times shorter than with a comparable petrol engine.

88. Injection pump and injectors: The injection pump or injectors can be calibrated only on test benches used in specialized garage or vehicle fleet workshops. However, it is normally a simple operation to check and adjust the timing of the injection pump. The manufacturer indicates in his documentation the procedure to be followed. This operation is normally carried out when a pump is changed because a service-station workshop is not generally able to overhaul a defective pump.

89. After any work has been done on a component in the high pressure circuit, bleeding of the circuit will be necessary. Any air in the circuit prevents the pressure for opening the injectors to be reached (in the case of "closed" injectors which are more usually used) and injection will not therefore occur in several cylinders. The correct tightening of the injectors on their seating and the procedure to be followed for bleeding the fuel circuit is specified by the manufacturer. Normally that operation does not necessitate any specialized equipment.

(ii) Inspection

90. As indicated in paragraphs 56 to 60, periodic technical inspection of vehicles in use has been officially established in many countries. Where no inspection exists it is recommended that Governments establish an inspection scheme adapted to local administrative and technical conditions. As far as diesel vehicles are concerned, inspection undertaken at a special centre or at the roadside permits the identification of those vehicles in need of immediate maintenance, adjustment or repair in relation to their smoke emission and noise.

Smoke emission: The opacity of the smoke emission from a stationary vehicle can easily be measured at various RPM and compared against values based on smoke opacity limits prescribed at certification. The test method which requires a minimum investment and checking time while ensuring the best guarantee for evaluating the exhaust smoke emission of diesel equipped vehicles in use consists in passing the whole exhaust volume through the opacimeter, the engine being operated at free acceleration under inertia loading a convenient procedure for inspection centers. This test method does not require dynamometer bench operations and the opacity value measured can be easily compared with the opacity limits obtained under the UN/ECE Regulation 24 corresponding test procedure at certification level, taking into consideration the type of vehicle considered and agreed deterioration factors relating to vehicle age.

Noise emission: As for noise, acoustic energy emitted by a stationary vehicle can be easily measured through microphonic equipment placed at a short distance (i.e. 0.5 m for light duty vehicles) from the tail pipe, in order to be independent of the acoustic environment. Results obtained should be associated with a visual inspection of the whole exhaust manifold and muffler and compared to a reference value based on the noise level measured for a stationary vehicle at type approval, taking again into consideration a precise tolerance related to agreed deterioration factor.

91. UNEP is co-operating with the United Nations Group of Experts on the Construction of Vehicles (Working Party 29 of the United Nations Economic Commission for Europe) and the International Motor Vehicle Inspection Committee (CITA) in the preparation of simple test procedures and measurement methods for emission and noise control which would be used in technical inspection programmes for vehicles in use, including diesel powered vehicles. It is intended that these test procedures and measurement methods would be applied internationally on a voluntary basis.

92. Needless to say, in order to verify the efficiency of the adjustments and repairs required for diesel-equipped vehicles when being tested at inspection centres, garage and vehicle fleet workshops, should as far as possible be equipped with the same smoke opacity and noise analyser equipment as used for official certification and subjected to the same calibration procedures. It must be emphasized that correct instrument and equipment calibration at garages and workshops is essential and calls for appropriate training of technical personnel.

XII INSTITUTIONAL AND ADMINISTRATIVE CONSIDERATIONS

93. In attempting to take full advantage of the opportunity for energy benefits and environmental gains from diesel technology or to minimize the public health and welfare concerns from diesel emissions, it is critical that countries look beyond the technical considerations alone, with which the preceding sections have primarily dealt, and consider also the institutional and administrative aspects. When the production or utilization of a consumer article creates certain side-effects or externalities, the costs of which are not internalized in the cost of the product, Government intervention may be needed to correct the situation. In that respect the social costs of motor vehicles (e.g. negative externalities such as air pollution, noise, road accidents, etc.) and their social benefits, (e.g. positive externalities such as increased mobility, fuel saving through increased use of diesel-equipped vehicles, etc.) are not generally taken into account in the consumer's private cost-benefit calculation. Moreover, and as far as fuel economy is concerned, for those crude oil importing countries, the social gains from saving a barrel of oil is greater than the

private gains from saving the same barrel since this saving results in a reduction in foreign currency expenditure, inflation rate and external dependence. The divergence between private and social costs and benefits is in theory, a justification for corrective Government action, but does not dictate the appropriate means of intervention. As pointed out in 1981 in the United States of America National Research Council report "Diesel Cars, Benefits, Risks and Public Policy" (16) before deciding on the optimal policies for diesels, a balanced social view requires that "related 'externalities' be considered and all important consequences weighed" in order to avoid Government interaction resulting in a cure more harmful than the disease.

94. As noted briefly in Section VIII, standard setting for new vehicles requires not just an evaluation regarding technological feasibility in the manufacture of new vehicles but a careful review of any fuel implications, serviceability problems, mechanic and operator training needs and administrative infrastructure and cost. In general, such a review of local conditions, problems and capabilities should precede the definition of a control strategy as well as fundamental modifications to an existing programme. Furthermore, any programme established should take account of available resources as well as other social and economic priorities of the country. For example, in considering the required degree of control to impose on diesel emissions, each country should review its existing problem, necessarily based on appropriate data, and attempt to estimate how that problem will increase or decrease over the following years as population changes occur, fuels are modified, energy costs increase and urban traffic patterns change. If a problem is judged so severe that stringent control is desirable, while related technical, economic and social problems involving both community and individual interest can be overcome, it is also important to consider what training of mechanics and vehicle operators will be needed to inspect, adjust, repair and replace sophisticated devices and to prevent their inadvertent destruction in actual use. Furthermore, where fuel modifications are considered necessary, attention must be paid to ensuring fuel quality, long-term availability and distribution. That will call for co-operation with the fuel industry. As a practical matter, careful consultation with a broad spectrum of interested parties within the country in order to build public support and identify previously unforeseen problems is desirable. Moreover, a review of steps taken by other countries and problems which were or were not overcome could be a useful early stage in programme development.

95. Costs must be carefully estimated, not only for the individual citizen but also for Government (i.e. appropriate institutional aspects, etc.) and the community as a whole. It may be necessary for Governments to apply economic and/or other means for encouraging specific actions. Furthermore, the authorities must consider the practical means to be applied for enforcement which will be successful without being too costly and that will receive the general support of the population. Administrative and institutional arrangements covering at least the following should be established:

- Certification of new vehicles in relation to emissions and noise where the country is a manufacturer of diesel vehicles and road network is in reasonable condition, especially in urban areas;

- Inspection of vehicles in service in relation to smoke emissions and noise, which may have a greater benefit than standards requiring complex and costly control devices;

- Ensuring correct quality of fuels, and especially correct octane rating and density;
- Avoiding overloading with particular attention to public transport and commercial vehicle overloading;
- Training of motor vehicle mechanics.

XIII CONCLUSIONS AND SUMMARY OF GUIDELINES

96. Evaluation and establishment of environmentally related policies with regard to diesel vehicles and their use must be made within the context of the overall transportation sector in a country. Transportation is a key activity in effective development but each country has its own needs in relation to both social and economic as well as physical constraints. Attention is drawn in these conclusions to UNEP's Environmental Guidelines for the Motor Vehicle and its Use, which provide guidance on the essential areas of land-use, urban, regional and transportation planning, traffic management and road user education as well as vehicle construction, operation and maintenance in applying environmental management to the motor vehicle and its use. The two documents complement each other and this one provides supplementary advice in considering environmental management policies for diesel vehicles.

97. It should be borne in mind that in the road transport field, the conventional spark ignition piston engine has been under continuous development for the last 80 years, whereas significant efforts to develop diesel engine technology for wide-scale transportation use did not take place before the 1950s and were accelerated from the 1970s as a consequence of the fuel crisis. Thus, the considerations summarized above assessing pros and cons of factors relating to the adoption of an "engine strategy" should not be seen in isolation. Consideration should be given to the wide range of technical improvements still remaining open for the development of diesel technology and its application to the whole range of the motor vehicle categories from the private car to the heavy commercial and public transport vehicle. In the light of recent developments relating to both the spark ignition and diesel engine, such as the introduction of electronics for fuel injection monitoring, combustion chambers involving specific swirl effect, turbo-charging and the possible introduction of ceramic coating of the combustion area, it is anticipated that the diesel engine will remain significantly more efficient and less polluting with regard to certain substances than its spark ignition counterpart but at the expense of a slightly extra manufacturing cost and the need for strict discipline in operation and maintenance. The technological advances of both types of engine remain the crucial factor concerning diesel vehicle use globally. Diesel smoke, noise and particulate emissions should be the main areas of attention for minimizing negative public health and welfare consequences of expanded diesel vehicle usage.

98. However, whilst it is only the motor vehicle manufacturing countries that will have any real influence on the future technological developments of the diesel engine, all countries should be concerned about ensuring environmentally-sound management and wise resource utilization in relation to the use of diesel vehicles in the overall transportation sector context. It should be clearly borne in mind that shortcomings in the road and transportation infrastructure as well as other factors, not the least socio-economic aspects, may be serious hindrances in achieving such sound environmental management.

99. National and local energy policies should be carefully integrated into any transport policies so that the balances of advantages and disadvantages are optimized. The energy and crude oil savings from increased diesel use in some cases appear significant but individual countries must consider refinery capabilities and feedstock availability before concluding that expanded diesel use is desirable in a particular case. It is essential that the fuel supply and distribution industry can provide diesel fuel of the correct quality for vehicles to be used, bearing in mind that diesel fuel quality may vary over a wider range than petrol. The necessary infrastructure should be available to ensure that fuel quality is guaranteed. Appropriate measures should be taken to check fuel quality and discourage adulteration. Each country needs to review which measures, whether economic or administrative, would be most effective under local conditions and the necessity under their own conditions of specifying certain fuel qualities such as sulphur content. Where substitution by alternative fuels is considered feasible and desirable, Government can play an important role both by direct funding of alternatives and providing incentives for their use.

100. In adopting a control policy for new vehicles, consideration should be given to existing regulatory programmes such as those in Europe, Japan and the United States of America. Adoption of Regulations established by the United Nations Economic Commission for Europe, which cover CO, HC and NO_x emissions for all vehicles and smoke emissions for the diesel, and which at present do not require sophisticated devices to meet them, would appear attractive to countries which have not yet regulated vehicle emissions but where a need and the resources to do so have been carefully established. Such a step would minimize problems of fuelling and servicing and allow those countries which seek to take action to control diesel vehicle emissions and improve fuel economy to take advantage to some degree of the experience from existing administrative and enforcement infrastructure established in industrialised countries. For example, countries could become better acquainted with the pollutant and noise emission performances as well as fuel economy aspects of the diesel vehicles which they import.

101. All countries should give priority to improvement of vehicle operation and maintenance in accordance with the manufacturers' specifications and good engineering practice, as well as paying attention to the education of garage mechanics and vehicle drivers and operators. Such education will be most effective when introduced in natural education programmes. Additionally, the strategy calls for investment in maintenance and inspection facilities and enforcement of emission and noise control, fuel quality and correct loading conditions, bearing in mind the hindrances to achieving sound environmental management in some countries, as referred to in paragraph 98.

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(11) See UN/ECE Regulation 15 for CO, HC, NO_x control which can be applied to diesel equipped private cars; Regulation 49, recently elaborated, for emission control of diesel commercial vehicles; Regulation 24 for smoke emission (both Regulations 49 and 24 applying to diesel equipped vehicles); and Regulation 51 for noise control - United Nations Economic Commission for Europe, Inland Transport Committee, Palais des Nations, Geneva.

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ANNEX

EXPERTS CONSULTED ON THE DRAFT GUIDELINES

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