ELIMINATING LEAD FROM GASOLINE:

REPORT ON VALVE SEAT RECESSION

Report by the Valve Seat Recession Working Group

to the

Partnership for Clean Fuels and Vehicles

ACKNOWLEDGEMENTS

This document was compiled by the Valve Seat Recession Working Group of the Partnership for Clean Fuels and Vehicles.

Jane Armstrong (Independent)
Lucia Bartocci (UN DESA)
Loren Beard (DaimlerChrysler/Alliance of Automobile Manufacturers)
Bruce Bertelsen (Environmental and Energy Technology and Policy Institute)
John Cabaniss (Association of International Automobile Manufacturers)
John Courtis (Daedalus, LLC)
Larry Cunningham (Ethyl)
Rob de Jong (United Nations Environment Programme)
Maureen Delaney (US Environmental Protection Agency)
Atanu Ganguli (Society of Indian Automobile Manufacturers)
Frank Gerry (BP)
Wendy Jackson (Partnership for Clean Fuels and Vehicles)
Tsuneo Kamitamari (Japan Automobile Manufacturers Association)
Joe Kubsh (Manufacturers of Emission Control Association)
Robert Leidich (BP Products North America)
Jane Metcalfe (US Environmental Protection Agency)
Ellen Shapiro (Alliance of Automobile Manufacturers)

Special thanks go out to Working Group Chair John Mooney (Environmental and Energy Technology and Policy Institute) for his indefatigable enthusiasm for clean fuels/vehicles issues and his tireless dedication to ensuring the Working Group concluded its deliberations in a timely fashion.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Background of Partnership for Clean Fuels and Vehicles

The Partnership for Clean Fuels and Vehicles (PCFV) was launched at the World Summit on Sustainable Development (WSSD) in Johannesburg in September 2002 by a group of committed partners from governments, international organisations, industry, and non-governmental organisations (NGOs). This global partnership will help developing countries reduce vehicular air pollution through the promotion of clean fuels and vehicles, specifically through the elimination of lead in gasoline and the phase down of sulphur in diesel and gasoline fuels, concurrent with the adoption of cleaner vehicle technologies.

For more information on the PCFV, please visit the website: www.unep.org/pcfv

1.2 Mission Statement of PCFV

Partners agreed on the following Mission Statement for the Partnership:

- Help developing countries to develop action plans to complete the global elimination of leaded gasoline and start to phase down sulphur in diesel and gasoline fuels, concurrent with adopting cleaner vehicle requirements;
- Support the development and adoption of cleaner fuel standards and cleaner vehicle requirements by providing a platform for exchange of experiences and successful practices in developed and developing countries as well as technical assistance;
- Develop public outreach materials, educational programmes, and awareness campaigns; adapt economic and planning tools for clean fuels and vehicles analyses in local settings; and support the development of enforcement and compliance programmes, with an initial focus on fuel adulteration; and
- Foster key partnerships between government, industry, NGOs, and other interested parties within a country and between countries to facilitate the implementation of cleaner fuel and vehicle commitments.

1.3 Establishment of Global Working Groups

The PCFV has established Working Groups to implement its mission. These Working Groups consist of various Partners, and are generally representative of the Partnership's membership.

1.4 Valve Seat Recession Working Group

When a country plans to replace leaded with unleaded gasoline, two issues tend to arise: replacement of octane, and whether valve seat recession will occur in older vehicles. The Valve Seat Recession Working Group was established to address the latter issue. This report is the result of the deliberations of the Working Group on the issue of valve seat recession. The Working Group consists of representatives from various governments, the fuels industry, the vehicle industry, and international organisations.

2.0 ELIMINATION OF LEADED GASOLINE

2.1 Why was leaded gasoline used?

Gasoline does not naturally contain lead. The additive tetra-ethyl lead (TEL) is a metal-organic compound that improves the octane rating or octane number of gasoline. The octane rating is a measure of the anti-knock performance of a gasoline, that is, its resistance to abnormal combustion events such as pre-ignition that cause a knocking or pinging sound in an engine. The higher the octane rating, the greater the resistance to engine knock.[1] Knock reduces engine power output, and severe or prolonged knock will likely result in damage to the pistons and/or overheating of the engine. The tendency for a fuel to knock increases with increasing engine compression ratio. Higher-octane fuels are more resistant to knocking, and are typically recommended in engines with higher compression ratios.

Lead additives typically improve the octane rating about six to twelve octane numbers, depending on the amount of lead added and the octane response of the base fuel. Leaded gasoline was used from the early 1920s until recently because it was more cost-effective to add lead additives to raise octane. However, a number of options are available to achieve increased octane levels.[2]

2.2 Benefits of unleaded gasoline and negative effects of leaded gasoline

The movement to remove lead in gasoline began in earnest in 1969, when the US auto industry – after several years of research – announced that emissions from passenger cars could be substantially reduced with an emission control technology called a catalytic converter. However, this technology is only useful if unleaded gasoline is used in cars that have that device. As a result, the US

[1] *Bosch Automotive Handbook – 5th Edition*. 2000. R. Bosch GmbH, Stuttgart, Germany.
[2] For more detail on octane issues, please see the PCFV Octane Working Group document, which should be available on the PCFV website in mid-2004. Contact Wendy Jackson (wendy.jackson@unep.org) for more information.

government decided to require oil companies to phase-down the use of leaded gasoline and introduce unleaded gasoline to the market.

Catalytic converter technology was introduced on new vehicles in the US beginning in 1974 (concurrent with the introduction of unleaded gasoline) and has been very successful at reducing tailpipe emissions for over 30 years. Catalytic converter technology has now been introduced around the world – over 90% of the new cars and small trucks sold today use this technology. Many countries have adopted unleaded gasoline and modern emissions control systems for their newer fleets.

With modern emissions control technology, emissions of carbon monoxide, hydrocarbons, and nitrogen oxides can be reduced by more than 90 percent compared to the levels for vehicles without catalytic converter emission controls. Using leaded gasoline permanently disables catalyst emissions control technology. Even a minute amount of lead in gasoline irreversibly poisons catalytic converters and renders them inoperative.

Lead in gasoline also has other negative effects on a modern vehicle's engine and exhaust system. These negative effects include: the corrosion of exhaust valve materials, the contamination of engine oil with corrosive acids, the fouling of spark plugs, and the corrosion of exhaust systems. Using unleaded gasoline can extend engine life by 1.5 to 2 times, and spark plug and exhaust system life is considerably extended as well. Lower maintenance costs, improved engine durability, less frequent oil changes, fewer visits to the repair shop, and less time out of service due to repair, are all likely benefits of using unleaded gasoline. Automakers around the world recommend that lead should not be intentionally added to gasoline in any market, including where vehicles have no, or the first level of, emissions control.[3]

Lead enters the environment from numerous anthropogenic sources, including combustion of leaded gasoline. Other sources of lead include lead-based paint, waste incineration, secondary smelting (battery recycling), mining, primary smelting, and other industrial activities specific to the area. Removal of lead from gasoline can significantly reduce lead emissions from one of those sources, the transportation sector. Many studies have linked elevated blood lead levels in children to negative effects on mental health development, IQ and behavior. According to the US Agency for Toxic Substances and Disease Registry blood lead levels of 10-30 ug/dl, or lower, may damage the brain and nerves in young children, resulting in learning deficits and lowered IQ.[4] In addition, exposure to

[3] For more detail, please check the World-Wide Fuel Charter – www.autoalliance.org/environment/cleanfuel.php. December 2002.
[4] ATSDR. *Case Studies in Environmental Medicine, Lead Toxicity.* Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA, 1992 – http://www.atsdr.cdc.gov/HEC/CSEM/lead/ or http://www.epa.gov/ttn/atw/hlthef/lead.html.

lead causes high blood pressure, increases heart disease, especially in men, and damages specific organs.[5]

In 1989, researchers estimated that the health benefits of reducing the US populations' blood lead level by 1 ug/dl amounted to $17.2 billion annually.[6] According to estimates from EPA, the benefits of phasing out leaded gasoline exceeded the costs more than ten times in the US.[7] This magnitude of benefits suggests that phasing out lead from gasoline is likely to produce substantial benefits in other countries, as well.

A cost/benefit estimation of the reduction in airborne lead levels and improvement in health was made for Mexico City in 1993, where the total cost of lead content reduction and the use of unleaded gasoline was $717 million. The benefits for health and vehicle maintenance improvement were calculated at $1,740 million with net benefit of $1,022 million.[8]

For more information on the impacts of leaded and unleaded gasoline on health, air quality and engines, please see the List of References. For a discussion of refinery considerations, please go to Appendix A.

2.3 Status of leaded gasoline phase-out

Worldwide, 90% of the gasoline produced is unleaded. Australia, Canada, South Africa, many European countries and the United States took a slow phase-out approach to eliminating leaded gasoline. However, it is possible, and may be preferable, to completely replace leaded with unleaded gasoline in a very short period of time.[9] This approach has been taken in the last ten years by an increasing number of countries and is considered the most cost effective approach and the quickest way to bring airborne lead levels from the transport sector to near zero. This approach was taken by, *inter alia*, China, Egypt, Ethiopia, Ghana, India, Mauritania, Mauritius, Vietnam, and the Central American countries. Thus, experience has shown that governments of all sizes and capabilities can successfully develop and execute a programme to eliminate lead in gasoline and achieve significant health and environmental benefits.[10]

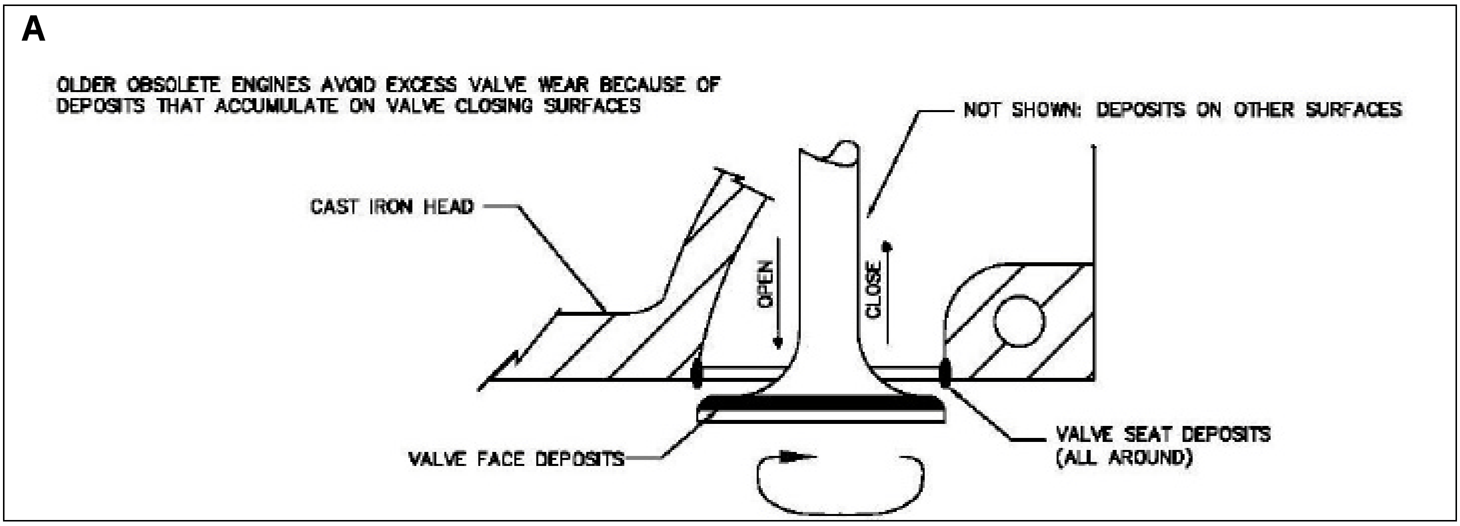
[5] http://www.epa.gov/air/urbanair/lead/hlth.html.
[6] Schwartz. "Societal Benefits of Reducing Lead Exposure", *Environmental Research*, No. 66, pp. 105-124. 1994a.
[7] US EPA. *Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis*. EPA-230-05-85-006. Office of Policy Analysis, U.S. Environmental Protection Agency, Washington, DC. 1985.
[8] US EPA, Implementer's Guide to Phasing Out Lead in Gasoline, 1999)
[9] The benefits of a quick changeover include eliminating the need for multiple fuel distribution networks, which may be costly, and the risk of misfueling, which may be exacerbated by differential pricing.
[10] For more information on the status of leaded gasoline phase-out, visit the PCFV website at www.unep.org/pcfv. Also please see Table 2 in Section 3.6.

3.0 VALVE SEAT RECESSION

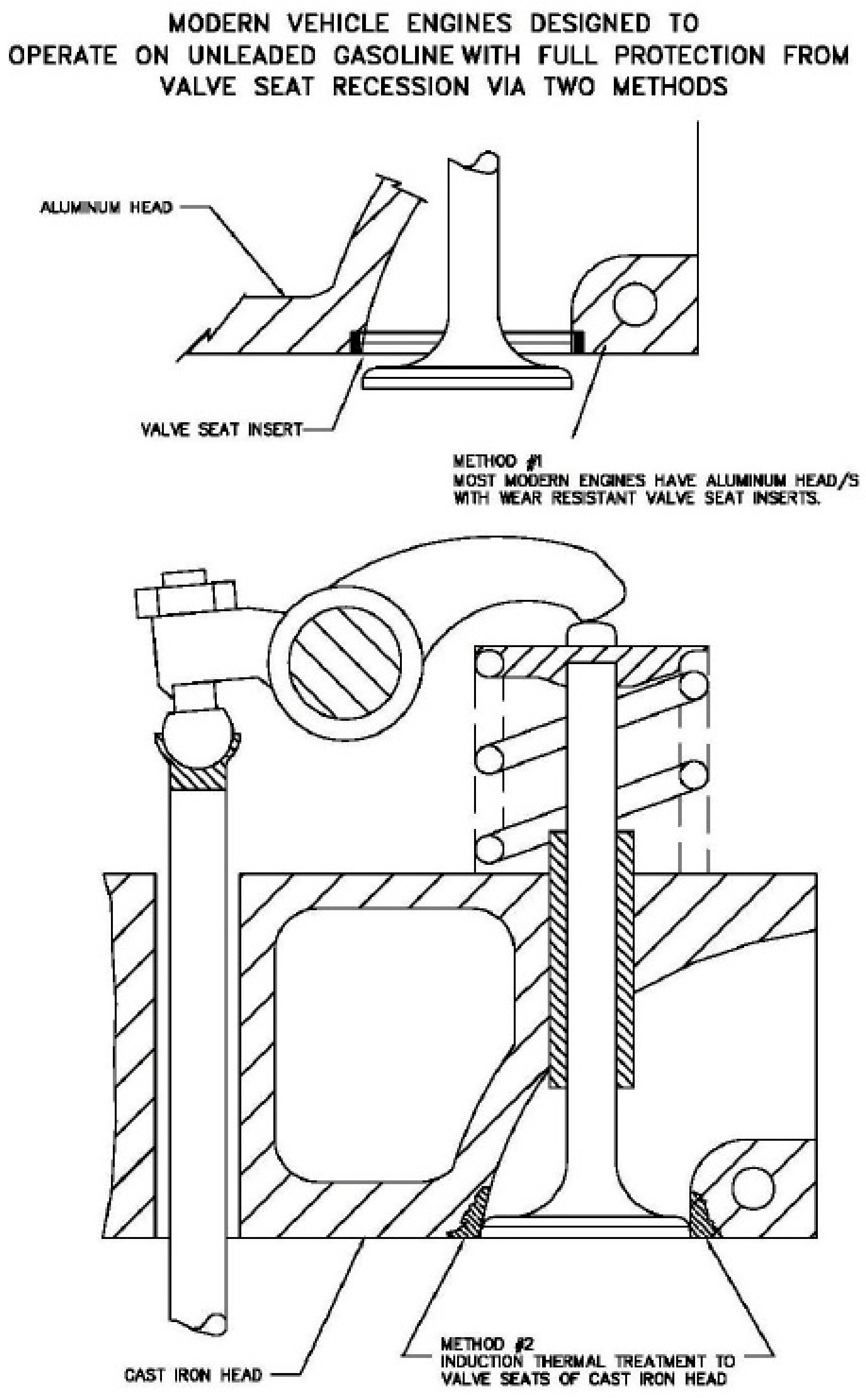
3.1 Statement of issue

Valve seat recession became an issue related to the phase-out of leaded gasoline when it was theorised that the removal of lead – which was thought to act as a 'cushion' between the valve and the cylinder head – might increase the wear or recession of the valve seats in older vehicles. Figure 1 below illustrates this concern. Box A explains the valve function and role of deposits in preventing valve seat wear in older engines; Box B illustrates two versions of redesigned valve seats; and Box C illustrates the theoretical condition of an obsolete valve seat that has receded.

Figure 1: Exhaust valve/valve seat recession

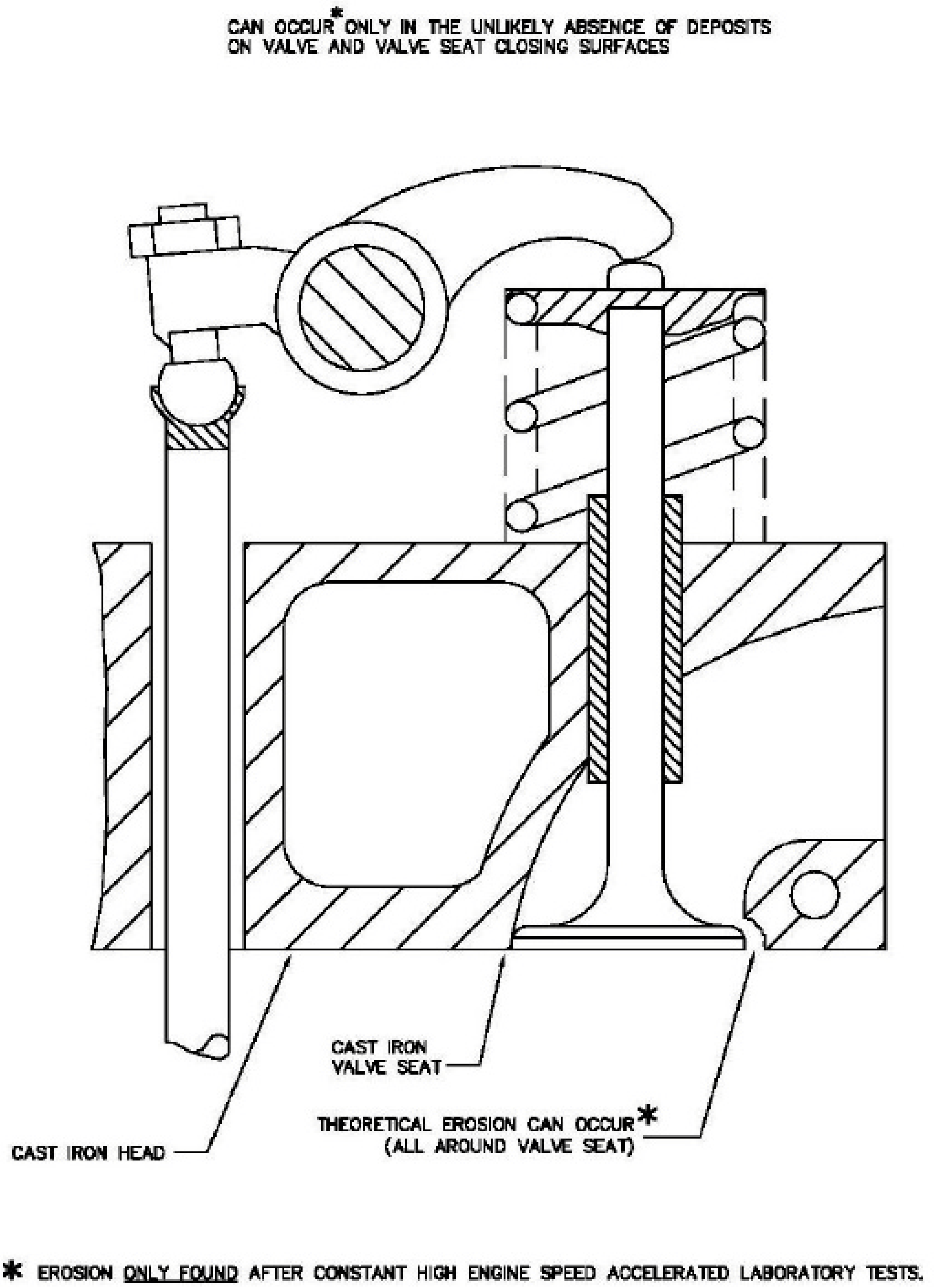


B


MODERN VEHICLE ENGINES DESIGNED TO
OPERATE ON UNLEADED GASOLINE WITH FULL PROTECTION FROM
VALVE SEAT RECESSION VIA TWO METHODS
ALUMINUM HEAD
VALVE SEAT INSERT
METHOD #1
MOST MODERN ENGINES HAVE ALUMINUM HEAD/S
WITH WEAR RESISTANT VALVE SEAT INSERTS.
CAST IRON HEAD
METHOD #2
INDUCTION THERMAL TREATMENT TO
VALVE SEATS OF CAST IRON HEAD

C

THEORETICAL VALVE SEAT RECESSION IN OLDER OBSOLETE ENGINES



* EROSION ONLY FOUND AFTER CONSTANT HIGH ENGINE SPEED ACCELERATED LABORATORY TESTS.
EROSION VIRTUALLY NOT FOUND WHEN VEHICLES ARE USED FOR EVERYDAY NORMAL OPERATION.

3.2 Why are older vehicles thought to be more at risk?

Valve seat recession was theorised to occur on some older vehicles because the valve seat systems of these vehicles were made from materials that are thought to be more susceptible to excessive valve wear. Automakers changed the engine design long ago in most locations, so that redesigned valve seats, which are found on new vehicles everywhere and all but a small percentage of the motor vehicles in use worldwide, are completely resistant to excessive valve seat wear.

Today, the percentage of vehicles with obsolete valve system designs will vary from country to country, but is believed to be less than 10% and will decline year after year with normal fleet turnover. South Africa was the last manufacturing country to changeover to redesigned valve seat systems. Even so, in percentage terms, those pre-change vehicles will decline to 7.2% of vehicle population by 2006 and 3.2% by 2010 due to normal fleet turnover.[11] The table below indicates when car manufacturers from various countries completed the process of equipping all their new vehicles with redesigned valve systems.

Table 1: Date when virtually all vehicles were equipped with redesigned valve systems, by country/region [12]

Country/Region	Year
US	1971
Japan	1975
Europe	mid-1980s
South Africa	1997-1998

3.3 What are the chances that valve seat recession might occur?

The Theory

Excessive valve seat recession is defined as the wearing down of the exhaust valve closing surfaces by abrasion, corrosion and erosion processes, but mostly by abrasion (see Figure 1). Wear is excessive when the valve system no longer has the ability to seal the combustion chamber resulting in loss of compression, power, fuel efficiency and engine performance. Excessive valve seat recession

[11] South Africa will switch to 100% unleaded petrol in 2006. *Investigation (Desk Top Study) Into the Optimum Future Octane Grade Structure For South Africa*. Prepared for Director: Petroleum Policy, Hydrocarbons, Department of Minerals and Energy, Pretoria, South Africa. 27 July 2003.

[12] Many vehicle manufacturers converted to making engines with redesigned valve seats well before – sometimes decades before – the last sales of vehicles with vulnerable engine designs. Some vehicle manufacturers further state that none of their vehicles, including older vehicles without catalysts, are at risk of valve seat recession.

could occur due to valve rotation when abrasive material is caught between the surfaces of the valve face and the valve seat. Researchers have concluded that abrasive particles are formed by a welding mechanism; the welding occurs between the valve metal and the valve seat metal when the valve strikes the valve seat with force upon closure and then pulls the welded particle with it upon opening. The welded base metal from the valve seat then oxidises due to the much higher temperature of the valve seat. The resulting oxide is abrasive and excessive valve wear could proceed by abrasion.

The Experience

The debate as to whether valve seat recession actually occurs in real world conditions has narrowed with experience. Valve seat recession has been virtually absent in actual vehicle or engine operation in normal everyday use. Incidents of valve seat recession have been demonstrated in laboratory-based accelerated tests of vehicles running at constant high engine speeds. Such accelerated engine and vehicle tests usually are designed to stress vehicle and engine components to their limit to observe component failure. In some accelerated laboratory tests of engines or vehicles, the testing-induced excessive valve wear ultimately led to engine failure. This laboratory-based experience has led most people to conclude that excessive valve seat recession would occur only when the engine experienced this type of extreme operation.

In real world conditions, virtually no evidence of excessive valve wear has been found in vehicle or engine operation in normal everyday use, and several studies that monitored vehicles in actual daily service in countries that eliminated lead found no excessive valve wear.[13] Experience in a number of countries that switched to unleaded gasoline demonstrates that virtually all types of fleets can operate successfully on unleaded gasoline without experiencing more valve wear than occurs with leaded gasoline.[14] As mentioned, redesigned valve seats are found on all but a small and shrinking number of vehicles worldwide. For all vehicles, accelerated tests are *not* representative of actual driving modes of vehicles, because most vehicles operate in mixed driving modes of idle, urban, suburban, country driving and infrequent high speeds. Studies and actual experience have shown that excessive valve wear does not occur with mixed-mode driving. Moreover, few gasoline vehicles, especially older ones, are likely to experience long periods of uninterrupted operation at high engine speeds where the potential for excessive valve seat wear would be most likely to occur.

[13] J. Ghojel and H. Watson, Department of Mechanical and Manufacturing Engineering, the University of Melbourne. For Lead Abatement Task Force, Standards and Chemicals Branch, Commonwealth Environment Protection Agency. Valve Seal Lubrication – Desk Study. August 1994; and Implementer's Guide to Phasing Out Lead in Gasoline. United States Environmental Protection Agency, Office of International Activities. 160-B-99-001. Mail Code 2760A. Document 160-B-99-101. http://www.epa.gov/oia/itc.htm March 1999.
[14] Ibid.

Compared to newer vehicles, older ones generally are used for shorter trips, use less gasoline per trip and under conditions that would not induce excessive valve seat wear.[15]

Also, the prior accumulation of lead and oil ash deposits on the valve face and/or valve seat in older engines minimises metal-to-metal contact and the welding mechanism is avoided. The protective nature of lubricating oil ash deposits is one reason that excessive valve wear has not been experienced in older vehicles in any country that replaced leaded with unleaded gasoline. It is also possible that some suppliers in some of these countries may have voluntarily added an anti-valve wear additive (AVWA) to their unleaded fuel supply.

Mitigating factors offsetting the potential for excessive valve seat wear:

1. Older light-duty vehicles with obsolete valve systems are declining in number due to fleet turnover or have been rebuilt (with valve seat inserts).
2. Older vehicles are typically used less and for shorter trips.
3. Older vehicles do not typically engage in continuous high speed driving or other driving modes that would result in continuous periods of operation at high engine speeds.
4. In normal everyday use, virtually all light-duty vehicles operate in mixed-mode driving, which has been shown not to cause high valve wear problems.
5. Older vehicles typically have an established layer of lead deposits on valve closing surfaces when they switch to unleaded gasoline.
6. Older vehicles have relatively high lubricating oil consumption and thus lubricating oil ash deposits (similar to lead deposits and AVWAs) provide a cushion between valve closing surfaces, preventing the first step of the generally accepted excessive valve wear process.
7. Some refiners voluntarily use AVWAs.

3.4 What about vehicles other than passenger/light duty vehicles?

Gasoline fueled truck engines and engines of vehicles that operate at high engine speed have historically been equipped with valve seat inserts designed to prevent the welding mechanism and abrasive valve wear. Therefore, truck engines have not been expected to experience excessive valve seat wear, and no problems have been reported by any country. Other engine applications, such as motor boats or stationary engines that run at high engine speeds, have also been routinely equipped with valve seat inserts.[16] Furthermore, trucks and other

[15] Keith Reading and Steve McArragher. Shell. *Phasing out leaded gasoline – the way forward*. July 1998; and J. Ghojel and H. Watson, Department of Mechanical and Manufacturing Engineering, the University of Melbourne. For Lead Abatement Task Force, Standards and Chemicals Branch, Commonwealth Environment Protection Agency. Valve Seal Lubrication – Desk Study. August 1994.
[16] William Giles, Valve Division, TRW, Inc. SAE 710368. Influence of Low Lead fuels on Exhaust Valve Performance. 1971; and J. Ghojel and H. Watson, Department of Mechanical and Manufacturing

high-speed engines generally undergo routine overhaul and rebuild operations, making it easy to upgrade them if necessary to the latest alloy valve seat technology.

Other gasoline engines include 2-stroke engines, used for motorcycles and other two-wheel vehicles and hand-held engines such as chainsaws and lawn and garden equipment, have exhaust ports rather than exhaust valves and therefore cannot be subject to valve wear problems.

Another category of gasoline engine includes small engines in the 3 to 25 horsepower [2.24 to 18.66 kW] range. These are used for a variety of industry, agriculture, and lawn and garden applications such as lawn mowers, generators, pumps, tillers and tractors. Briggs and Stratton, a large manufacturer of these small engines, has stated that unleaded gasoline will not cause engine or excessive valve wear problems.[17]

Some auto enthusiasts own vintage or antique vehicles. These vehicles are unlikely to be operated under conditions that would induce excessive valve seat wear, so operating them with unleaded gasoline is generally not a problem if the octane rating is sufficient. In the event that someone has a concern, several options are available: (1) Operate the vehicle only at speeds lower than 60 miles/hour (96 kilometres/hour); (2) Install redesigned valve seats when the engine is rebuilt; (3) Use fuel designed to replace leaded gasoline, if available; and (4) Use one of several anti-valve wear additives that are commercially available at filling stations or automobile parts and supply stores (note discussion in Section 3.5 below).

3.5 What are anti-valve wear additives? Are they needed?

Anti-valve wear additives (AVWA) are metal-organic in nature and are formulated to be soluble in gasoline. Upon combustion, such additives form debris that deposits on the engine's internal surfaces. These deposits help prevent valve seat wear in cars with valves that may be prone to valve seat recession when using unleaded gasoline. AVWA have been made available as a pre-mixed additive sold in single-use cans or added to special grades of unleaded gasoline, known as lead replacement gasoline, in some countries.

Many studies and the record of countries that have switched to unleaded gasoline without requiring AVWA in the unleaded fuel supply have shown no

Engineering, the University of Melbourne. For Lead Abatement Task Force, Standards and Chemicals Branch, Commonwealth Environment Protection Agency. Valve Seal Lubrication – Desk Study. August 1994.

[17] See www.briggsandstratton.com; search: FAQs ID 1414 Fuels and FAQs ID 1415 Fuels.

reported problems with valve seat recession or excessive valve wear.[18] Collectively, these countries have vehicle fleets consisting of a full complement of make, model and vintage of vehicles used in the full range of service and operation modes in all types of environments including at sea level and high elevations, and in tropic, arctic, wet and arid climates.

Some countries in Europe and other regions have chosen to introduce lead replacement gasoline containing AVWA. It had been thought that European high-speed roads presented a different vehicle operating environment than other countries that had previously switched to unleaded gasoline.[19] While the European countries that have used lead replacement gasoline have not observed excessive valve wear problems, they have reported other engine problems – such as destructive corrosion of turbo-chargers, valve sticking and valve burnout – when using lead replacement gasoline with some additive systems.

Countries that choose to allow the use of AVWA in lead replacement gasoline or allow AVWA to be sold in individual containers should take special measures to ensure the proper use of AVWA and to avoid misfueling, excessive use or other improper applications of these products. Use of certain AVWA in vehicles for which they were not intended may in some cases have adverse impacts.[20]

Considerations for countries considering replacing leaded with unleaded gasoline, and using AVWAs:

1. Lead replacement gasoline can only be used for non-catalyst equipped vehicles. Catalyst-equipped vehicles have to use unleaded fuel.[21]
2. Separate distribution, storage and fueling pumps for lead replacement gasoline are necessary, which may involve a large capital and operating expense for a declining market, unless the current system can accommodate multiple grades.
3. The number of older vehicles that utilise lead replacement gasoline will decline to a very low number in a few years or these older engines will be rebuilt with redesigned valve seats and do not require lead replacement gasoline.

[18] See section 3.6 and correspondences a, b and c. Also see J. Ghojel and H. Watson, Department of Mechanical and Manufacturing Engineering, the University of Melbourne. For Lead Abatement Task Force, Standards and Chemicals Branch, Commonwealth Environment Protection Agency. Valve Seal Lubrication – Desk Study. August 1994; and Implementer's Guide to Phasing Out Lead in Gasoline. United States Environmental Protection Agency, Office of International Activities. 160-B-99-001. Mail Code 2760A. Document 160-B-99-101. http://www.epa.gov/oia/itc.htm March 1999.

[19] Note: It is not known how long lead replacement gasoline will continue to be used in Europe.

[20] Most vehicle manufacturers believe catalysts and oxygen sensors are at risk of adverse impact from AVWA.

[21] Some vehicle manufacturers state that none of their vehicles of any vintage need AVWA, including vehicles without catalysts.

4. Not all AVWA systems were found acceptable. Some cases of engine problems have occurred with lead replacement gasoline in some countries – valve burnout, turbocharger melting and valve sticking. Developing countries and industry should be selective in the use of AVWA systems.
5. Lead replacement gasoline mixed with leaded or unleaded gasoline can cause problems because additive packages can cause problems.
6. High speed highways are not common in developing countries.

3.6 What is the experience of countries that have eliminated lead in gasoline?

A review of the literature on valve seat recession shows that no country has reported excessive valve seat recession or engine problems when replacing leaded gasoline with unleaded gasoline. See the following table for details.

Table 2: Experience of countries that have eliminated lead in gasoline[22]

COUNTRY / REGION	PROCESS	YEAR	COMMENTS	VSR EXPERIENCE
United States	Gradual phase-out	Start of unleaded in 1974; phase out virtually completed by 1986; total ban of leaded in 1996	High octane premium unleaded was widely available during the 1950s-1975 by at least one oil refiner (Amoco).	No excessive valve recession has been reported at any stage in the US phase-out programme. Tests done on 7600 US Army vehicles (some from 1940s) revealed no problems. Tests on US Public Utility vehicles revealed no problems. Tests on 1500 US Postal Service vehicles revealed a valve failure rate comparable to that expected with leaded gasoline, while the valve seat failure was significantly lower.
Canada	Gradual phase-out	Similar to that of United States		There were no reported incidences of excessive valve wear in older vehicles with older valve systems when leaded gasoline was replaced by unleaded gasoline in Canada. However, in Canada, some oil companies add a manganese (Mn) additive to unleaded gasoline as an octane enhancer. Mn is one of several metal complexes used in AVWA.

[22] These are only those countries where literature on the introduction of unleaded gasoline is available.

Japan	Gradual phase-out	Unleaded introduced in 1975; total ban of leaded in 1987	Unleaded gasoline became popular for all cars. By 1975, the volume of leaded gasoline in the marketplace was already down to 20.6%; by 1978, it was down to 7.5%.[23]	Japan's changeover was smooth with only one reported problem. A car manufacturer encountered excessive valve wear in one or two mid-1970s model year engines in actual on-road service, but determined that the problem was due to the introduction of a more vulnerable valve rotation system design. The manufacturer quickly discontinued that design.
Brazil	Gradual phase-out	Phase-out started in 1979; lead banned in 1991	Brazil introduced two grades of ethanol fuel in 1975. One was 100% ethanol and the other contained approximately 22% ethanol.	In 1991, Brazil still had a large older vehicle fleet with older valve systems, but no significant or widespread VSR problems were experienced.
France	Gradual phase-out	Unleaded introduced in 1989; leaded banned since 1 Jan 2000		Since 1 Jan 2000, one of three octane grades (97 RON) contains AVWA while the other two grades (95 and 98 RON) do not. Potassium (K) is the only AVWA authorised. No problems have been reported. France intends to discontinue AVWA use when its market is deemed too small, but it may end it sooner (in 2005) to make room for new low sulphur gasoline grades.
Central America	Immediate introduction of unleaded	Switch to unleaded: Panama – 2000; other Central American countries: early 1990s	These were the first countries in the world to immediately switch to unleaded gasoline rather than phase out lead. They determined this approach was the most cost effective for them.	No one reported excessive valve wear despite a large population of older vehicles, many originating in the United States or Europe.

[23] J. Ghojel and H. Watson, Department of Mechanical and Manufacturing Engineering, the University of Melbourne. For Lead Abatement Task Force, Standards and Chemicals Branch, Commonwealth Environment Protection Agency. Valve Seal Lubrication – Desk Study. August 1994.

Thailand	Six-year rapid phase-out	Phase-out and ban mandated in 1996. Lead concentrations first were reduced, then unleaded grades were introduced and, finally, the lead ban was implemented. .	Thailand has a wide range of older model light-, medium-duty and two-wheeled vehicles– many equipped with older valve systems. These vehicles operated in a wide variety of urban and rural on- and off-road conditions in a broad range of equatorial environments.	Careful studies of on-road vehicles accompanied the steady progress. Anti-valve recession additives were planned but found unnecessary.
China	Immediate introduction of unleaded	Immediate switch started in Beijing in 1996 and continued sequentially city by city and province by province until completely unleaded in 2000.		Government officials report "no such excessive valve wear has been reported in China after the leaded gasoline was eliminated a couple of years ago."
India	Immediate introduction of unleaded	Started in Delhi in 1999 and proceeded city by city throughout the country.	The Indian vehicle population, even today, consists of a large fraction of older vehicles.	Authorities have stated that no engine problems or excessive valve wear problems have been reported. The Indian Oil Company reported that after unleaded gasoline replaced leaded gasoline in India, retail outlets have reported no complaints of valve seat recession. (letter dated 18 October 2003)
Vietnam	Immediate introduction of unleaded	Started in July 2001	Some petrol in Vietnam contains AVWA.[24]	No reports published of engine problems or excessive valve wear after the switch to unleaded gasoline

[24] ***REFERENCE REQUESTED***

The Philippines	Started gradual phase-out but then changed to total ban.	Introduction started in 1994; ban of leaded gasoline in 2000. Voluntary use of an AVWA additive grade of gasoline is permitted but must be dyed red.		Government reports say they have not received any report of excessive valve recession (letter dated 8 August 2003)
Egypt	Immediate introduction of unleaded	Implemented in less than six months		There have been no reports that excessive valve wear has occurred after the switch to unleaded gasoline.
South Africa	Gradual phase-out with dual fuel system.	Leaded petrol to be prohibited by January 2006, lead replacement petrol to be allowed until December 2008	Some South African automakers began equipping engines with newer valve systems only in the last decade, so a significant number of older valve systems remain in the vehicle population. Still, by 2006, they will represent less than 7.2% of the total population and will decline to 3.2% by 2010.	No incidents of excessive valve seat recession have been reported. In 2002, leaded gasoline still dominated the market at 67% of gasoline sales.
Australia	Gradual phase out.	Started 1985. Final lead ban effective on 1 January 2002.	Voluntary program for Lead Replacement Petrol started 2003 (earlier in some Australian States). LRP is estimated to cease in 2005. Existence of under-utilised distribution system once LP was banned allowed for temporary use of LRP on voluntary basis by oil companies and fuel distributors to serve the declining market of older light-duty vehicles. In 2005, when Euro III emission regulations take effect, LRP will be replaced with higher octane ULP grade needed by new cars.	No reports of excessive valve seat recession during phase-out program.

3.7 What is the conclusion?

Valve seat recession has been virtually absent in actual vehicle or engine operation, including the normal everyday operation of older vehicles. Conversely, lead in gasoline has multiple negative effects on the engine and exhaust systems of vehicles – both new and old.

3.8 Who can I contact for more information?

For more information, please contact:

United Nations Environmental Program (UNEP)
Partnership for Clean Fuels and Vehicles
Partnership Clearing-House
P.O. Box 30552, Nairobi - KENYA.
Telephone: +254-20-624184
Fax: +254-20-624324
Email: wendy.jackson@unep.org or rob.jong@unep.org

GLOSSARY

Anti-valve wear additives (AVWA) – Gasoline additives designed to reduce valve seat wear.

Excessive Valve Wear – valve wear rates that are higher than normally seen, especially with the use of leaded gasoline

Lead replacement gasoline – Designed for older obsolete engines, LRG is an unleaded gasoline containing one or more of several metal organic compounds that upon combustion produce ash. The ash adds to the deposit layer on the valve closing surfaces, providing additional cushion and protection from potential valve wear.

Mixed-type driving – Driving that includes different types, as normally seen in actual vehicle use. It can include any combination of periods of idle, urban type driving in a variety of traffic conditions, periodic engine stop and start, country road driving, and little high speed driving.

Valve problems – Valve seating or other problems, such as 'guttering' of seat or valve, valve burnout, physical valve failure or excessive valve wear.

Valve rotation –Valve rotation is used to scrape off or scrub deposits from valve closing surfaces. A large lead deposit layer can cause valve burnout or guttering [channels] which allows gases to escape and also leads to valve burnout. A variety of designs have been used, such as: (1) positive rotor caps, and (2) natural rotation in response to engine vibration. Valve rotation designs remain in redesigned engines.

Valve seat recession – Excessive wear of exhaust valve seat closing surfaces by abrasion, corrosion, and erosion processes with abrasion being the main cause. Found when accelerated high-speed engine tests of long duration are used. However, virtually not found in everyday normal vehicle use.

Vehicles or engines with redesigned valve systems – Designed for unleaded gasoline. In the case of cast iron cylinder heads, where the valve seats are machined into the head, an induction thermal treatment process is used to prepare the valve seat closing surface. Most redesigned engines have aluminum heads where a valve seat insert is used to form the valve seat. Inserts contain alloy metals designed for unleaded gasoline. Anti-wear coatings may be applied to valve closing surfaces. All engines were equipped with redesigned valve seat systems in the United States since the 1971 model year, in Japan since 1975, in Europe since the 1980s and some other countries since the 1990s.

Vehicles or engines with obsolete valve systems – Primarily used leaded gasoline in the past but most now use unleaded gasoline. Engines made prior to dates indicated in Section 2. Valve seats machined into cast iron heads without induction thermal treatment process. Used for passenger car engines. Truck engines, because of high engine speeds, have valve seat inserts.

APPENDIX A – Unleaded gasoline and refinery considerations

A finished gasoline without TEL has a lower octane number than if lead were added (because lead was very effective in increasing octane number). Certain octane levels are required to prevent engine knock and potential engine damage. The process of blending replacement octane levels is influenced by:

- the availability, costs and volume of other octane blending components or additives
- the impact of other gasoline specifications
- blending component marginal energy value
- the impact of imports
- the availability of capital

Unleaded gasoline can be more expensive to produce. Some governments have been able to provide tax incentives to offset the increased cost to the refiner or to lower the price for the consumer.

With modern refining technology, lead additives are no longer needed to meet gasoline octane specifications. Although unleaded gasoline can cost about 1 to 2 cents (US) more per gallon to manufacture, the cost is offset by benefits to the refiner as well as to society. Some studies and financial analyses show positive paybacks of refinery investments and improved plant efficiency.[25] When the benefits of reduced vehicle maintenance and more durable vehicles are considered, it is estimated that using unleaded gasoline can save up to 18 cents/gallon for the vehicle owner.

[25] J. Schwartz, et al. For the Economic Analysis Division, Office of Policy, Planning and Evaluation, US EPA. *Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis*. 1985.

APPENDIX B – List of Correspondence

Responses from countries that have banned leaded gasoline documenting the incidence of or lack of excessive valve recession after replacing leaded with unleaded gasoline:

a) China. Letter from Peng Jinxin, Department of Policy & Law, State Environmental Protection Administration, China. September 8, 2003.

b) The Philippines. Letter from Fernandino Y. Concepcion, Assistant Director, Department of Environment and Natural Resources, Environmental Management Bureau, Republic of Philippines. August 8, 2003.

c) India. Letter from B. Bhanot, Director, ARAI, of October 18, 2003 enclosing letter From N. R. Raje, Director R&D, Indian Oil Corporation of October 13, 2003.

LIST OF REFERENCES

(Note: Publications listed below are not necessarily endorsed by all Partners and/or members of the Working Group.)

Akarapanjavit, N. and B. Pipon., Thailand. SAE 962029. *Valve Seat Recession and Protection Due to Lead Phase Out in Thailand*. 1996.

Alliance To End Childhood Lead Poisoning. *Myths and Realities of Phasing Out Leaded Gasoline.* www.globalleadnet.org. 1997.

Bosch Automotive Handbook – 5th Edition. R. Bosch GmbH, Stuttgart, Germany. 2000.

British Standard Specification for High Octane Unleaded Petrol (Gasoline) Containing Valve Seat Protection Additive. Document: 99/120286. January 1999.

Clean Fuels for Asia: Technical Options for Moving Toward Unleaded Gasoline and Low-Sulfur Fuel. http://publications.worldbank.org/ecommerce/catalog/product?item_id=206324. September, 1997

Cleaner Transport Fuels for Cleaner Air in Central Asia and the Caucasus. http://publications.worldbank.org/ecommerce/catalog/product?item_id=213971. September 2000.

Gandhi, H.S., et al. "Affinity of Lead for Noble Metals on Different Supports," *Surface and Interface Analysis*. Vol. 6, No. 4, pp 149-161. 1984.

Ghojel, J. and H. Watson, Department of Mechanical and Manufacturing Engineering, the University of Melbourne. For Lead Abatement Task Force, Standards and Chemicals Branch, Commonwealth Environment Protection Agency. *Valve Seal Lubrication – Desk Study*. August 1994.

Giles, W. and S. H. Updike, Valve Division, TRW. SAE 710674. *Influence of Low Lead fuels on Exhaust Valve Performance*. 1971.

Giles, W., Valve Division, TRW, Inc. SAE 710368. *Influence of Low Lead fuels on Exhaust Valve Performance*. 1971.

Godfrey, D. and Richard Courtney, Chevron. SAE 710356. *Investigation of Mechanisms of Exhaust Valve Seat Wear in Engines Run on Unleaded Gasoline*. 1971.

Graboski, M. *An Analysis of Unleaded Petrol Additives for South Africa*. (Presentation for CERF/IIEC Conference South Africa). January 2003.

Guibet, J. *Fuels and Engines: Technology, Energy, Environment*. Vol 1 and 2., Insitutut Francais du Petrole Publications. Paris, France. 1999.

Hansel, J. and Mooney, J.J. *Auto Exhaust Catalyst and Unleaded Fuel – Partners in Clean Air*. Seminar of University of New South Wales, Australia. 10 December 1980.

Hutcheson, R. C., Cameron Associates. SAE 2000-01-2015. *Valve Seat Recession – An Independent Review of Existing Data*. 2000.

International Fuel Quality Center. *Current Status of Leaded Gasoline Phase Out Worldwide*. www.ifqc.com. 17 December 2002.

Investigation (Desk Top Study) Into the Optimum Future Octane Grade Structure For South Africa. Prepared for Director: Petroleum Policy, Hydrocarbons, Department of Minerals and Energy, Pretoria, South Africa. 27 July 2003.

International Petroleum Industry Environment Conservation Association. *Getting the lead out: Downstream strategies and resources for phasing out leaded gasoline*. 2003. See www.ipieca.org/working_groups/fuels/fuels_home.html.

Kent, W. and F. Finnegan, Union Oil. SAE 710673. *The Effect of Some Fuel and Operating Parameters on Exhaust Valve Seat Wear*. 1971.

Lead Replacement Petrol with Valve Seat Recession (VSR) Additive. (Presentation) EA98_20.11. 22 January 1998.

Major Nationwide Transfusion for Motor Vehicles. Dispatch of Office of State Council, China. [PWRW&G translation 9/21/98].

Mathee, A. and Y. von Schirnding, *The Risk of Environmental Lead Exposure Amongst South African Children*. South Africa Medical Research Council and World Health Organization. amathee@mrc.ac.za. August 2002.

Manufacturers of Emission Controls Association. *The Case for Banning Lead in Gasoline*. www.meca.org. January 2003.

McArragher, J.S., L.J. Clarke and H. Paisler, Prevention of Valve-Seat Recession in European Markets, SAE-CEC EF19, May 1993.

Merck Index 13th Edition. 9277; RTECS # TP450000.

Needleman, H.L., et al. “Deficits in Psychologic and Classroom Performance of Children with Elevated Dentine Lead Levels,” *New England Journal of Medicine*. 300:689-695. 29 March 1979.

Pan-European Strategy to Phase-Out Leaded Petrol. (Presentation at Fourth Ministerial Conference, Environment For Europe, Arhus, Denmark). 23-25 June 1998.

Phasing Out Lead in Gasoline in Central and Eastern Europe: Health Issues, Feasibility, and Policies. http://publications.worldbank.org/ecommerce/catalog/product?item_id=205001. June 1997

Reading, K. and S. McArragher. Shell. *Phasing out leaded gasoline – the way forward*. July 1998.

Rogan, W. and J. Ware, “Exposure to Lead in Children – How Low is Low Enough?
New England Journal of Medicine. 348:16. 17 April 2003.

Schoonveld, G., R. Riley, S. P. Thomas, and S. Schill, Phillips Petroleum Co. SAE 861550. *Exhaust Valve Recession with Low-Lead Gasolines*. 1986.

Schwartz, J. et al. For the Economic Analysis Division, Office of Policy, Planning and Evaluation, US EPA. *Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis*. 1985.

Schwartz, J. “Low-level Lead Exposure and Children's IQ: A Meta-Analysis and Search for a Threshold,” *Enviromental Research*, Vol. 65, pp. 42-55. 1994.

Schwartz, J. “The Societal Benefits of Reducing Lead Exposure,” *Environmental Research*. Vol. 66, pp. 105-124. 1994.

Steiner, D., H. Burtscher and H. Gross, “Structure and Disposition of Particles from a Spark-Ignition Engine,” *Atmospheric Environment*. Vol. 26A, No. 6, pp 997-1003. 1992.

Stott, Howard, Corrosion and Protection Center, Manchester, UK. *Potential High-Temperature Corrosion in Automobiles Running on Lead-Replacement Gasoline*. Undated.

Successful Conversion to Unleaded Gasoline in Thailand. http://publications.worldbank.org/ecommerce/catalog/product?item_id=208122. June 1998.

US Department of Health and Human Services, Public Health Service. *Case Studies in Environmental Medicine - Lead Toxicity*. Atlanta, GA. 1992.

US EPA Office of International Activities. *Implementer's Guide to Phasing Out Lead in Gasoline*. 160-B-99-001. Mail Code 2760A. Document 160-B-99-101. http://www.epa.gov/oia/itc.htm. March 1999.

US EPA, Office of Policy Analysis. *Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis*. EPA-230-05-85-006. Washington, DC. 1985.

US EPA. *Air Quality Criteria for Lead*.
http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=32647. 1986.

Vintage Sports Car Club, Newbury, Berks, England. *Valve Seat Recession: Use of Unleaded Gasoline in Older Vehicles*. 1990.

Wall, S. W. *The Reduction of Lead in Gasoline and Its Effect on Exhaust Valve Seat Recession: The Problem and Its Solution*. (Presentation given in Warsaw). 8 December 1995.

Wangwongwatana, S. Pollution Control Department, Ministry of Science, Technology and Environment, Thailand. *Unleaded Air in Bangkok: A Story of Success*. 1998.

Weaver, C. S. SAE 860090. *The Effects of Low-Lead and Unleaded Fuels on Gasoline Engines*. 1986.

World-Wide Fuel Charter. www.autoalliance.org/environment/cleanfuel.php. December 2002.

Yates, A. D. B. Sasol Ltd. R&D. For South African Institute of Tribology – Liquid Fuels. *An Investigation into the Mechanism of Valve Seat Recession*. 2001.