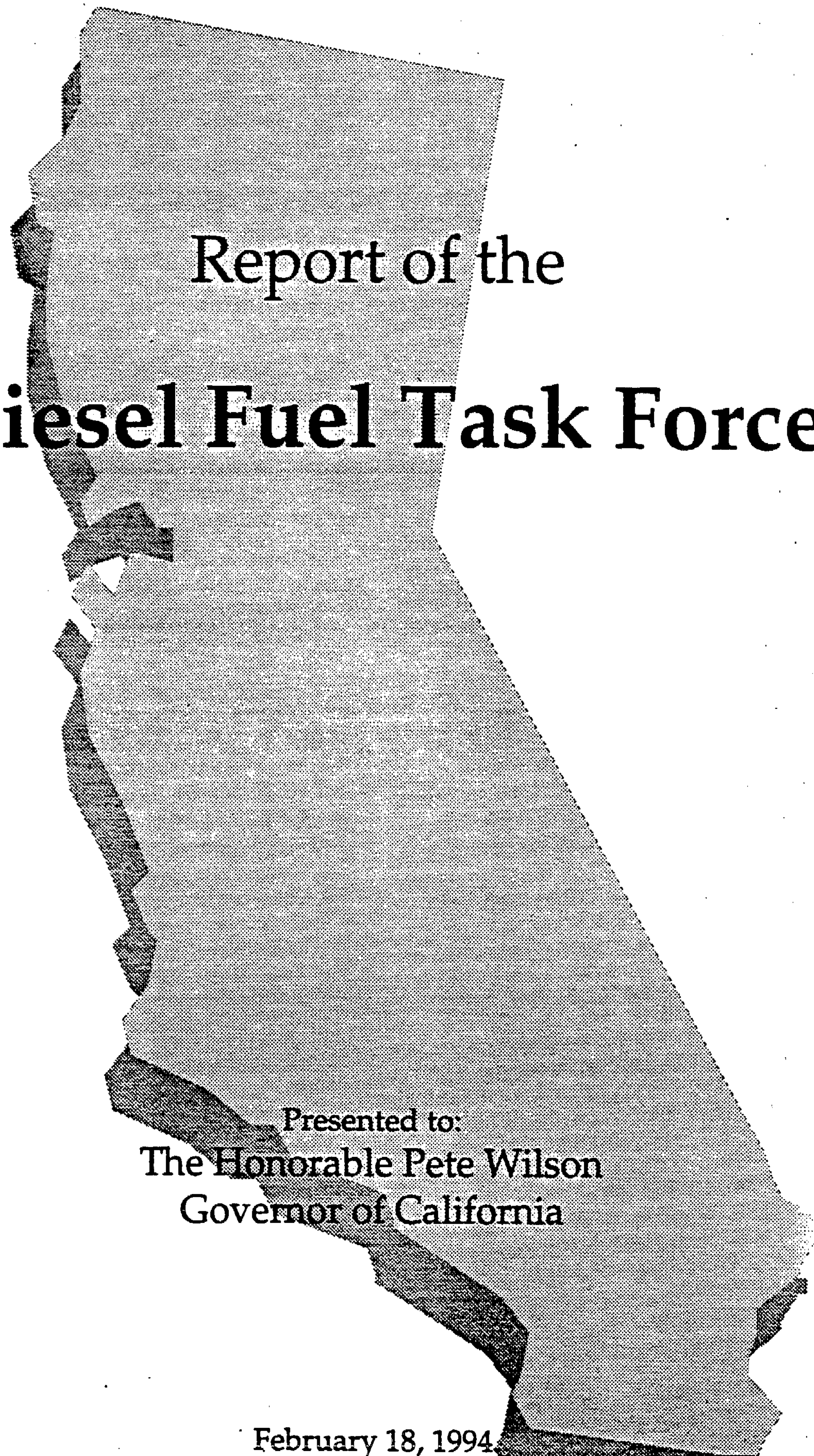


Report of the

Diesel Fuel Task Force

Presented to:
The Honorable Pete Wilson
Governor of California

February 18, 1994

DCN 93-674-062-01
RCN 674-062-04-00

REPORT OF THE DIESEL FUEL TASK FORCE

Prepared for:

The Honorable Pete Wilson
Governor of California

Prepared by:

The Diesel Fuel Task Force

February 18, 1994

Members of the Diesel Fuel Task Force

American Lung Association of California	Gladys Meade
American Petroleum Institute	Doug Morris Jim Williams
AMOCO	Chris McCarthy
Association of Diesel Specialists	David Fehling
Atlantic Richfield Company	Michael Payne Jack Segal Dave Smith
California Air Resources Board	Jacqueline Schafer Paul Jacobs Bill Loscutoff Mike Poore Dean Simeroth
California Bureau of Automotive Repair	James Schoning
California County Superintendents Education Service Association	Dale Holmes Elliot Duchon
California Department of Food and Agriculture	A.J. Yates Steven Shaffer
California Energy Commission	Charles Imbrecht
California Environmental Protection Agency	James Strock, Chair Bob Borzelleri
California Farm Bureau Federation	Merlin Fagan
California Independent Oil Marketers Association	Nick Bokides Evelyn Parker Gibson
California Public Utilities Commission	Daniel Fessler
California State Automobile Association	Amo Amerson
California State University Fresno	Ken Solomon David Zoldoske

Members of the Diesel Fuel Task Force (Continued)

California Trucking Association	Karen Rasmussen Richard Smith Mike Thomas
Caterpillar, Inc.	Don Dowdall Ron Palmer
Chevron	Randy Barber Al Jessel Manuch Nikanjam
Coast Fuel Injection	Rick Bumgardner
Cummins Engine Company	Steve Butler
Detroit Diesel	Patrick Butters
Diamond Diesel Service	Margaret Halford Terry Moore
DOE Energy Technology Engineering Center	Pat Green
DuPont Petroleum Laboratory	Ed Squire
Engine Manufacturers Association	Glen Keller Jed Mandel
Exxon Products Research Division	Bernie Kraus
Lubrizol	Glenn Blythe Fred Ruhland
Navistar	Frank Bondarowcz Warren Slodowske
Nisei Farmers League	Manuel Cunha
Natural Resources Defense Council	Janet Hathaway
Parker Hannifin Corporation	Robert Barbarin

Members of the Diesel Fuel Task Force (Continued)

Radian Corporation	Tim DeFries Ned Dickson Wyatt Dietrich Russ Henning Laura Markovich Bill Oliver Venus Sadeghi Melinda Thiessen Mike Thompson
Sandia National Laboratories	Bill Wilson
Stanadyne Automotive Corporation	Paul Henderson
Texaco	Roger Leisenring
UNOCAL	Denny Lamb Ross Iwamoto
U.S. Army/Southwest Research Institute	Paul Lacey
U.S. Environmental Protection Agency	Paul Machiele Sylvia Durgré
Western States Petroleum Association	Gina Grey

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION AND EXECUTIVE SUMMARY

On October 1, 1993, new diesel fuels were mandated for use throughout California in both on-road and off-road applications. The new California diesel fuels were designed to reduce emissions of nitrogen oxides and particulate matter from diesel-powered equipment. Also on October 1, 1993, the United States Environmental Protection Agency (U.S. EPA) required the use of a low sulfur diesel fuel for on-road applications throughout the remainder of the U.S.

Since the October 1, 1993 deadline, a number of fuels of varying characteristics have been present in the California market. The following definitions will be used in this report when referring to various fuels:

- High sulfur diesel fuel. This pre-regulation fuel was available for sale in California prior to the October 1, 1993 regulation. A large majority of these fuels typically have sulfur levels of approximately 0.30 percent by weight (wt%) and typical aromatics levels of 30%, with most fuels in the range of 20-40% aromatics. In October 1993, an emergency exemption was granted allowing the sale of high sulfur diesel fuel for off-road use in California for 45 days and its transfer into off-road vehicles for 120 days.

- Pre-regulation South Coast diesel fuel. As early as 1985, diesel fuel with a maximum limit of 0.05 wt% sulfur was sold in the greater Los Angeles area. This fuel was very similar in sulfur and aromatics levels to the current U.S. EPA low sulfur fuel.

- U.S. EPA low sulfur diesel fuel. This fuel was mandated for use in on-highway vehicles on October 1, 1993. The fuel must meet a maximum 0.05 wt% limit for sulfur content, and a minimum 40 cetane index or maximum 35% aromatics by volume (vol%). This fuel has the same characteristics as the "temporary California low sulfur" fuel defined below. However, the term "U.S. EPA fuel" will be used in the report when referring to on-road diesel fuel used outside of California.

- Low sulfur/reduced aromatics diesel fuel. These fuels are mandated by the October 1, 1993 Air Resources Board (ARB) regulation and fall into one of three classes, depending on aromatics content (as measured in volume % [vol%]). All three classes limit maximum sulfur levels to 0.05 wt%. The three classes are:

- Less than 10 vol% aromatics fuel. Note that aromatics levels can be averaged within a refinery's production. Therefore, some fuels in this class may exceed 10 vol% aromatics, while others may be well below 10 vol% aromatics.

- Alternative formulations that have been shown through testing to produce emissions equivalent to a 10 vol% aromatics fuel. Currently, aromatic levels of this class typically range from 15 vol% to mid-twenty percent.

- Small and independent refiner exempt fuel. These fuels must meet a 20 vol% aromatics limit. As with the less than 10 vol% aromatics fuels, this 20 vol% aromatics limit can be achieved by averaging of production.

• Temporary California low sulfur diesel fuel. To ensure adequate fuel supplies during the transition to the post-regulation diesel fuel, some temporary variances were granted by ARB for refineries to produce and distribute fuel meeting U.S. EPA low sulfur diesel fuel specifications for on-highway diesel fuels. In addition, small refiners were allowed one-year exemptions from the requirement to produce 20 vol% aromatics fuel. However, these fuels from small refiners must still meet U.S. EPA low sulfur diesel fuel specifications, including the 0.05 wt% sulfur limit. The aromatics level is not subject to the 10 vol% limit and typically ranges from 25 vol% to 35 vol%.

The fuels present in the on-road California diesel fuel market since October 1, 1993, have included low sulfur/reduced aromatics diesel fuel and temporary California low sulfur diesel fuel. Together these will be referred to as **post-regulation diesel fuels** in the remainder of this report. Since October 1, 1993, the rest of the diesel fuel market has included the post-regulation fuels, with some quantities of high sulfur fuel as well. Estimates of the relative distributions of low sulfur/reduced aromatics and temporary California diesel fuels are provided in Appendix A.

The introduction of the post-regulation diesel fuels in California was accompanied by significant price increases, reports of supply shortages, and reports of mechanical problems. The Governor created a Diesel Fuel Advisory Committee, which reported on these issues on November 15, 1993. The principal conclusions of the Committee were that market forces would resolve the price and supply issues. However, the Committee had insufficient technical information to report on the mechanical problems being reported, and advised the formation of an independent group to assess the extent of the mechanical problems and whether they may be attributable to the post-regulation diesel fuels and/or U.S. EPA low sulfur diesel fuel.

The Governor directed that the Diesel Fuel Task Force be created to investigate the mechanical problems that have been reported coincident with the introduction of post-regulation diesel fuels. In his charge to the Task Force on November 19, 1993, the Governor stated that:

> ...The Secretary of the California Environmental Protection Agency will convene a Task Force composed of private and public members to design immediately a test protocol for both CARB and federal EPA fuels, and implement a government funded, independently administered test of these fuels to be completed within 90 days.
>
> ...The Task Force protocol shall test four issues:
>
> - Whether mechanical damage is resulting from the introduction of a different fuel into diesel engines;
> - Whether mechanical damage is resulting from new, low sulfur levels contained in the clean fuel formulation;
> - Whether mechanical damage is resulting from new, low aromatic content in clean fuel formulations, and whether some minimum aromatic content standard should be adopted; and
> - Whether mechanical damage is resulting from some combination of the above factors.

This report is the product of the Governor's Diesel Fuel Task Force.

1.1 Summary of Task Force Activities

The initial meeting of the Task Force occurred on December 14, 1993. To address the questions in the Governor's letter, the Task Force formed three open-membership subcommittees: Subcommittee #1 focused on problem identification, Subcommittee #2 focused on fuel and component testing, and Subcommittee #3 studied lubricity and other diesel engine performance issues. The activities of each of these subcommittees are summarized below and described in detail in Sections 2.0, 3.0, and 4.0 of this report. References are provided in Appendix B. Fuel, engine, and component manufacturers and suppliers are identified in this report only by code (such as E1 for engine manufacturer 1 and C1 for component manufacturer 1).

1.1.1 Subcommittee #1 Activities

At the initial December 21, 1993 meeting of Subcommittee #1, six key questions were identified to guide investigation into the problem:

- What are the specific mechanical and performance problems being reported?
- What is the extent of the mechanical problems (i.e., which service categories/vehicles/components are being affected)?
- Which service categories/vehicles/engines/components are not being affected?
- What is the geographical nature of the reported problems?
- What is the temporal nature of the reported problems (i.e., how has the incidence of fuel system problems corresponded to the introduction of the new fuels)?
- Are there any apparent correlations between fuel formulation differences in samples and the reported mechanical problems? In particular, is there any correlation with the geographic or temporal nature of the reported problems?

In completing the problem identification effort, Subcommittee #1 gathered data and information, much of which was fragmented and anecdotal, from a wide variety of sources. These sources included:

- Passive surveys of reported failures of light and heavy duty diesel equipment owners. These surveys were conducted by the California Trucking Association (CTA), ARB, and the School Transportation Coalition.
- An active survey of light duty diesel vehicle owners conducted by ARB.
- Surveys and interviews with diesel trucking fleets, including national and California fleets.
- A survey and interviews with California pump repair facilities.
- Questionnaires completed by agricultural equipment owners and truck drivers at roadside inspection stations.
- Sales data of fuel system components supplied by engine manufacturers, industry groups, and governmental agencies.
- Follow-up interviews with individual vehicle owners, fleet operators, and repair facilities.
- Literature searches.
- Analysis of fuel samples collected from individual vehicles, retail stations, and refineries.

To help guide Subcommittees #2 and #3 in their investigation into the causes of the reported problems, Subcommittee #1 produced a Technical Memorandum with interim responses to these questions on January 22, 1994. Based on the information in the Technical Memorandum, Subcommittee #1 also recommended further investigation into a number of issues, including collection of data regarding the potential impact of the post-regulation diesel fuels on agricultural machinery. This included the collection of fuel samples for analysis and a questionnaire completed over the telephone by equipment owners to gather additional data. Subcommittee #1 also continued its investigation into the potential mechanisms of seal failures, including seal swell and fuel oxidation. Further examination of the available fuel analysis data and failure reports was conducted to isolate elements contributing to the mechanical problems. Included in Section 2.0 of this report are the updated findings from Subcommittee #1. Conclusions developed by Subcommittee #1 are provided in Section 1.2.

1.1.2 Subcommittee #2 Activities

Subcommittee #2 met on January 5, 1994 to discuss the potential causes of the seal leakage problems. In the absence of specific identified causes, Subcommittee #2 selected at least one potential seal failure mechanism for investigation.

This mechanism involves changes in the swelling of O-ring seals when exposed to fuels of differing characteristics. Many O-ring designs, particularly O-rings made of nitrile rubber, swell in the presence of diesel fuel. Considerable evidence shows that changes in fuel characteristics can lead to reduced swelling of nitrile O-ring seals. This reduced swelling, or shrinkage, of O-rings can lead to fuel leaks, particularly in O-rings that have reduced elasticity due to age, oxidation, or exposure to high temperatures.

Following the January 5, 1994 Subcommittee #2 meeting, another potential mechanism worthy of investigation by this subcommittee was identified. This mechanism, which has been addressed for several years by the petroleum industry, involves the potential for increased oxidation of the fuel to lead to deterioration of nitrile O-rings. Oxidation of the fuel forms peroxides, which can lead to hardening of nitrile O-rings. (Note that this potential oxidation mechanism usually occurs over a period of months.) This increased oxidation potential could arise from the fuel manufacturing process used to remove sulfur and aromatic species from diesel fuel. The manufacturing process is hydrotreating. Depending on its severity, hydrotreating can remove natural inhibitors such as sulfur, nitrogen, and oxygen components from the fuel. To compensate, supplemental additives may need to be added by the refiner to increase the oxidation resistance of the fuel. If insufficient oxidation resistance is present in the fuel, the potential exists for deterioration of nitrile O-rings. Fuel manufacturers are aware of this issue and many refineries have been adding oxidation inhibitors to diesel fuels.

To investigate these two mechanisms, three test programs were initiated by Subcommittee #2. The first two programs are examining the mechanism of reduced seal swell. The third program is examining existing fuel supplies to determine if some fuels are susceptible to increased oxidation.

The first program will test a variety of older high sulfur, U.S. EPA low sulfur, and post-regulation diesel fuels, and will examine their effects on O-ring seals. The second program will attempt to establish if switching from a fuel producing high seal swell to a fuel producing low seal swell could cause seal leakage. In the third program, a number of fuel samples will be collected from existing agricultural storage and retail outlets and tested for their oxidation stability. The detailed test protocols developed by Subcommittee #2 for each program are included in Appendix D.

As of February 15, 1994, the seal swell testing (Program #1) has begun. Fuel analyses are being conducted at Southwest Research Institute in San Antonio, Texas. Testing of O-rings will be conducted at Smithers Scientific Laboratories in Akron, Ohio. Experiment 1 of this seal swell program should require two to three weeks to complete. Experiments 2 and 3 of the seal swell program will begin immediately upon completion and analysis of the results from Experiment 1. Experiments 2 and 3 will require approximately three weeks to complete.

The testing of new and used fuel pumps (Program #2) will begin after the completion of the O-ring tests. The pump testing will be conducted at the U.S. Army Fuel and Lubricants Testing Laboratory in San Antonio, Texas. Assuming a start date of mid-March, the testing of all 24 pumps will require approximately 12 to 15 weeks to complete.

The fuel oxidation sampling and test program (Program #3) is currently underway. Fuel samples are being collected from agricultural and retail sources. Collection of the samples will be completed by early March. Completion of the full oxidation potential test requires six months.

1.1.3 Subcommittee #3 Activities

Subcommittee #3 met on January 5, 1994 to outline a course of investigation regarding concerns of reduced lubricity with the post-regulation diesel fuels. It was established that the concern over reduced lubricity extended beyond California to the rest of the U.S. and other countries. However, no adopted standards or test methods currently exist to evaluate fully the lubricity performance of diesel fuels. Furthermore, concern over the reformulated diesel fuel No. 2 has been the subject of a number of activities by technical groups and societies such as the Society of Automotive Engineers (SAE), the American Society for Testing and Materials (ASTM), and the International Organization of Standardization (ISO). The ISO group, in cooperation with the Coordinating European Council (CEC), is in the process of defining laboratory bench tests to evaluate the lubricity characteristics of fuels and solvents. The goal of the ISO program is to generate sufficient data from a number of candidate test methods and equipment performance tests to select a single test method as the universal method for determining diesel fuel lubricity. The results of this study should become available within the next 12 months. A minimum of two years will be required to develop and approve an ASTM lubricity standard.

Given these activities, the objectives of Subcommittee #3 were twofold:

1. To ensure equipment protection in the interim period before universal lubricity test methods and standards are established; and
2. To restore consumer confidence in the lubricity potential of the reformulated diesel fuel.

1.2 Conclusions and Recommendations

The investigation of the Diesel Fuel Task Force has resulted in the following conclusions based on data available to date:

- Coincident with the introduction of the post-regulation diesel fuels, fuel leaks and other failures have occurred to a small portion of the California diesel population. Analysis of failure reports, engine parts sales data, and interviews with equipment owners and repair facilities all show a marked increase in fuel leaks and other problems coinciding with the introduction of the post-regulation diesel fuels.

- Although fuel-related problems are apparently affecting a relatively small percentage of the overall vehicle population, these problems are serious for some of the owners of the vehicles involved. For example, data from the CTA for 74 trucking fleets experiencing apparent fuel-related problems showed that an average of 29% of the vehicles in each fleet were affected.

- Low sulfur and/or low aromatics levels in diesel fuels may not be directly causing the reported mechanical problems. Rather, it may be that the manufacturing process by which the lower sulfur and lower aromatics levels are achieved could be causing the problems. The manufacturing process is hydrotreating. Depending on its severity, hydrotreating can remove fuel constituents that are important to fuel lubricity. However, the specific fuel constituents involved in this process are not well understood at this time.

- The effect of hydrotreated fuels on swell/shrinkage characteristics of nitrile rubber components is being investigated by the Task Force.

- Fuel-related problems are not confined to the California post-regulation diesel fuels. Similar problems have been reported throughout the U.S. following introduction of the U.S. EPA low sulfur diesel fuel. However, the magnitude of the problem in California relative to the rest of the U.S. cannot be accurately determined at this time. Based on the problems experienced in the rest of the U.S., the use of the U.S. EPA low sulfur diesel fuel does not guarantee elimination of the mechanical problems seen in California.

- Sales and repair data through January 1994 suggest that the fuel system failure rate is not currently increasing. However, the present failure rate is still higher than normal. The available data are insufficient to show whether the failure rate will return to normal levels.

- Despite reported problems throughout the nation with U.S. EPA low sulfur diesel fuel, there apparently was no unusual increase in reported fuel system leaks after introduction in 1985 of pre-regulation South Coast diesel fuel in southern California.

- The reported problems include all types of light, medium, and heavy duty diesel engines. All types of vehicle service are included in the complaints.

- Fuel system leakage from aged O-rings and hoses have been the most common reported problems. (The age of a seal can be represented by a number of factors, including mileage, chronological age, and hours of use.) These problems have been affecting primarily O-rings and seals made of nitrile (or Buna N) rubber. This is a common seal material used in many automotive applications. Another common type of automotive seal material, fluorocarbon elastomer, is not experiencing seal failures.

- Two potential causes of fuel system leakage have been identified: reduced swelling or shrinkage of O-rings, and potential degradation of seals and hoses due to increased fuel oxidation. Testing programs have been initiated to investigate these mechanisms.

- Some incidences of repeated fuel system leakage failures have been reported. However, the Task Force investigation showed that most of the reports were repeat failures on the same engine, not repeat failures of the same component. Although some repeat leakage failures appear to have occurred, replacement of the failed component solved the leakage problem in most cases.

- Isolated reports of lubricity-related problems have been received. Because of insufficient data, the extent of this problem could not be determined. Most of the complaints involved poor operation due to sticking of injectors and fuel control valves. Only a few examples of accelerated wear and seizure of fuel pumps and injectors, as reported in Sweden[1] following introduction of a very low sulfur/low aromatics fuel, have been reported in California. Nonetheless, if an unadditized, severely hydrotreated fuel (with substantially reduced aromatic content) is used, the potential does exist for an increase in longer term lubrication-related problems for diesel fuel-injection systems.

- The impact of the post-regulation diesel fuels on agricultural diesel engines is not well understood. Initial questionnaire results show that some problems have occurred, but a specific level cannot be quantified at

---

[1]Whereas California post-regulation diesel fuels may contain sulfur at levels up to 500 parts per million (ppm), Sweden limits the allowable levels of sulfur at 10 ppm for "city diesel" and 50 ppm for other uses. California regulators permit aromatic hydrocarbons to range from 10 vol% for major refineries to 20 vol% for small refineries. In Sweden, city diesel is capped at 5 vol% aromatics, with 20 vol% being the maximum allowable for other uses (from the Diesel Fuel Advisory Committee report to the Governor, 11/15/93).

this time. Due to the limited exposure of the agricultural community to the post-regulation diesel fuels to date, the possibility for continued fuel system leaks and lubricity-related problems does exist. Initial review has indicated that a variety of different injection pump styles (fuel lubricated, oil lubricated, distributor type, and in-line) are used on agricultural equipment. The impacts of the change in fuel would likely depend on the distribution of different pump designs in the fleet. A more detailed investigation into the extent of possible problems in the agricultural community relating to the use of post-regulation diesel fuels is planned to coincide with increased farming activities in spring/summer of 1994.

- There is a significantly higher fuel system leakage failure rate in northern California than in southern California.

- Based on analysis of fuel sampling data, one potential contributor to the different leakage rates between northern and southern California could be overall differences in the fuel composition between the two regions. Multiple sampling studies show that, on average, southern California samples show a higher level of total aromatics than samples from northern California. Northern California also experienced a larger change in diesel fuel characteristics than southern California, as demonstrated by measurements of sulfur and total aromatic levels. Based on the Subcommittee #2 investigation, however, aromatics level should be treated only as a general indicator of seal swell and lubricity differences among fuels. Other factors that were not evaluated in the earlier sampling programs could impact the performance of individual fuels.

Recommendations regarding the fuel system leakage problem depend on the completion of the testing programs described in Section 3.1. In the interim, the Task Force encourages pump and engine manufacturers to continue their ongoing investigations into the compatibility of elastomer seals with post-regulation diesel fuels.

Regarding the lubricity of the post-regulation diesel fuel No. 2 in California, the Diesel Fuel Task Force recommends that:

- Interim steps be taken prior to establishment of an ISO test method/ASTM lubricity specification to ensure equipment protection and to restore consumer confidence in the lubricating potential of post-regulation diesel fuels.

- Petroleum manufacturers monitor diesel fuel lubricity using the U.S. Army modified BOCLE (Ball-on-Cylinder Lubricity Evaluator) test or other appropriate tests to determine the lubricity level of the fuel.

- Petroleum manufacturers maintain pre-regulation lubricity levels or add lubricity-enhancing additives to diesel fuel with a BOCLE scuffing load capacity of less than 3,000 grams, with due regard to recommendations of additive suppliers. This interim recommended action reflects the view of the Task Force and is not intended to be a lubricity guideline, standard, or specification.

- Equipment owners seek the advice of equipment manufacturers prior to adding any additives or oil to diesel fuel. Addition of used oil to diesel fuel in California is a violation of the California hazardous waste regulations.

2.0 PROBLEM IDENTIFICATION

This section presents the findings of Subcommittee #1. This subcommittee analyzed all available information to define the nature and extent of the reported mechanical problems and determine common characteristics of affected and unaffected engines. The results of Subcommittee #1 were communicated to the other two subcommittees in a Technical Memorandum (provided in Appendix F) to help guide their investigation into the cause of the mechanical problems.

At the initial meeting of Subcommittee #1 on December 21, 1993, a list of six key questions was identified. Questions 1 through 3 are interrelated and are, therefore, addressed together in Section 2.2. Questions 4, 5, and 6 address separate issues and are discussed individually in Sections 2.3, 2.4, and 2.5, respectively.

2.1 Conclusions

The investigation of Subcommittee #1 has resulted in the following conclusions:

- Coincident with the introduction of the post-regulation diesel fuels, fuel leaks and other failures have occurred to a small portion of the California diesel population. Analysis of failure reports, engine parts sales data, and interviews with equipment owners and repair facilities all show a marked increase in fuel leaks and other problems coinciding with the introduction of the post-regulation diesel fuels.

- Although fuel-related problems are apparently affecting a relatively small percentage of the overall vehicle population, these problems are serious for some of the owners of the vehicles involved. For example, data from the California Trucking Association (CTA) for 74 trucking fleets experiencing apparent fuel-related problems showed that an average of 29% of the vehicles in each fleet were affected.

- Low sulfur and/or low aromatics levels in diesel fuels may not be directly causing the reported mechanical problems. Rather, it may be that the manufacturing process by which the lower sulfur and lower aromatics levels are achieved could be causing the problems. The manufacturing process is hydrotreating. Depending on its severity, hydrotreating can remove fuel constituents that are important to fuel lubricity. However, the specific fuel constituents involved in these processes are not well understood at this time.

- The effect of hydrotreated fuels on swell/shrinkage characteristics of nitrile rubber components is being investigated by the Task Force.

- Fuel-related problems are not confined to the California post-regulation diesel fuels. Similar problems have been reported throughout the U.S. following introduction of the United States Environmental Protection Agency (U.S. EPA) low sulfur diesel fuel. However, the magnitude of the problem in California relative to the rest of the U.S. cannot be accurately determined at this time. Based on the problems experienced in the rest of the U.S., the use of the U.S. EPA low sulfur diesel fuel does not guarantee elimination of the mechanical problems seen in California.

- Sales and repair data through January 1994 suggest that the fuel system failure rate is not currently increasing. However, the present failure rate is still higher than normal. The available data are insufficient to show whether the failure rate will return to normal levels.

- Despite reported problems throughout the nation with U.S. EPA low sulfur diesel fuel, there apparently was no unusual increase in reported fuel system leaks after introduction in 1985 of pre-regulation South Coast diesel fuel in southern California.

- The reported problems include all types of light, medium, and heavy duty diesel engines. All types of vehicle service are included in the complaints.

- Fuel system leakage from aged O-rings and hoses have been the most common reported problems. (The age of a seal can be represented by a number of factors, including mileage, chronological age, and hours of use.) These problems have been affecting primarily O-rings and seals made of nitrile (or Buna N) rubber. This is a common seal material used in many automotive applications. Another common type of automotive seal material, fluorocarbon elastomer, is not experiencing seal failures.

- Two potential causes of fuel system leakage have been identified: reduced swelling or shrinkage of O-rings, and potential degradation of seals and hoses due to increased fuel oxidation. Testing programs have been initiated to investigate these mechanisms.

- Some incidences of repeated fuel system leakage failures have been reported. However, the Task Force investigation showed that most of the reports were repeat failures on the same engine, not repeat failures of the same component. Although some repeat leakage failures appear to have occurred, replacement of the failed component solved the leakage problem in most cases.

- Isolated reports of lubricity-related problems have been received. Because of insufficient data, the extent of this problem could not be determined. Most of the complaints involved poor operation due to sticking of injectors and fuel control valves. Only a few examples of accelerated wear and seizure of fuel pumps and injectors, as reported in Sweden[1] following introduction of a very low sulfur/low aromatics fuel, have been reported in California. Nonetheless, if an unadditized, severely hydrotreated fuel (with substantially reduced aromatic content) is used, the potential does exist for an increase in longer term lubrication-related problems for diesel fuel-injection systems.

- The impact of the post-regulation diesel fuels on agricultural diesel engines is not well understood. Initial questionnaire results show that some problems have occurred, but a specific level cannot be quantified at this time. Due to the limited exposure of the agricultural community to the post-regulation diesel fuels to date, the possibility for continued fuel system leaks and lubricity-related problems does exist. Initial review has indicated that a variety of different injection pump styles (fuel lubricated, oil lubricated, distributor type, and in-line) are used on agricultural equipment. The impacts of the change in fuel would likely depend on the distribution of different pump designs in the fleet. A more detailed investigation into the extent of possible problems in the agricultural community relating to the use of post-regulation diesel fuels is planned to coincide with increased farming activities in spring/summer of 1994.

- There is a significantly higher fuel system leakage failure rate in northern California than in southern California.

- Based on analysis of fuel sampling data, one potential contributor to the different leakage rates between northern and southern California could be overall differences in the fuel composition between the two regions. Mul-

---

[1]Whereas California post-regulation diesel fuels may contain sulfur at levels up to 500 parts per million (ppm), Sweden limits the allowable levels of sulfur at 10 ppm for "city diesel" and 50 ppm for other uses. California regulators permit aromatic hydrocarbons to range from 10 vol% for major refineries to 20 vol% for small refineries. In Sweden, city diesel is capped at 5 vol% aromatics, with 20 vol% being the maximum allowable for other uses (from the Diesel Fuel Advisory Committee report to the Governor, 11/15/93).

tiple sampling studies show that, on average, southern California samples show a higher level of total aromatics than samples from northern California. Northern California also experienced a larger change in diesel fuel characteristics than southern California, as demonstrated by measurements of sulfur and total aromatic levels. Based on the Subcommittee #2 investigation, however, aromatics level should be treated only as a general indicator of seal swell and lubricity differences among fuels. Other factors that were not evaluated in the earlier sampling programs could impact the performance of individual fuels.

2.2 Nature and Extent of Mechanical and Performance Problems

Questions 1, 2, and 3 are summarized below and discussed at length in the remainder of Section 2.2.

Question 1: What are the specific mechanical and performance problems being reported?

Question 2: What is the extent of the mechanical problem? Which service categories, makes, models, engines, and components are being affected?

Question 3: Which service categories/vehicles/engines/components are not experiencing mechanical problems?

Topics that have been evaluated relevant to these questions are:

- Types of mechanical problems reported by diesel vehicle owners (see Section 2.2.1);
- Types of passenger car and heavy duty diesel (HDD) vehicles that have experienced mechanical problems (see Section 2.2.2);
- Prevalence of reported problems among light duty diesel (LDD) and HDD populations (see Section 2.2.3);
- Trends seen in affected/unaffected vehicles (i.e. age/condition, mechanical configurations, elastomer materials used) (see Section 2.2.4); and
- Agricultural questionnaire (see Section 2.2.5).

2.2.1 Types of Mechanical Problems Reported by Diesel Vehicle Owners

The most common mechanical and performance complaints reported since the introduction of the post-regulation diesel fuels are discussed below.

Leaking fuel injection pumps. This complaint has been associated with a variety of different pump brands and models used on light, medium, and heavy duty diesel vehicles. Diesel vehicles of many makes, models, ages, and service types are represented in the reports. However, the common features among the majority of complaints are:

- Leaks occur most often at locations sealed by O-rings. Commonly cited leak locations include throttle shafts, bonnet covers, input shaft seals, and tachometer connections.
- Leaks occur in fuel injection pumps that use fuel (as opposed to motor oil) to lubricate moving pump parts. Pump designs that use engine oil to lubricate all internal moving parts are not subject to this type of leak.
- Failed O-rings are nearly always composed of nitrile rubber (as opposed to fluorocarbon elastomer).
- Failures are typically associated with "aged" components. The age of a seal can be represented by a number of factors, including mileage, chronological age, and hours of use. Other factors can also influence the aging of a seal, including maximum temperature, number of thermal cycles, and exposure to oxidants. In this analysis, mileage was the most widely available indicator of seal age.

The primary theory regarding why "aged" nitrile O-rings might be more susceptible to failure rests on the fact that nitrile O-rings swell when exposed to polar hydrocarbon molecules. When the chemical nature of the fuel suddenly changes, the volume (swell) of the seal may change by several percentage points. If the seal is pliable and elastic, it can change shape and still fill its cavity, maintaining seal. If the seal has hardened into a "set" in a flattened shape, it cannot change shape in response to the fuel change, and a leak may result.

Note that nearly all of the light duty diesel passenger vehicles in California are between 5 and 15 years old (no new light duty diesel-powered passenger cars have been sold in California from 1988 to 1993). Because of the age and type of pumps used, the bulk of the diesel passenger car fleet (with the exception of manufacturer E9) is described by most of the fuel injection pump leak candidate indicators listed above.

Leaking fuel injectors. Complaints have come mostly from owners of pickups and light duty trucks of a single make (E4). Injectors with fluorocarbon elastomer seals are apparently not experiencing fuel-related leaks.

Most reported leaks have been external (visible) leaks from fuel system components. Leaks of fuel into the engine oil from make C6 fuel injectors and from several fuel-lubricated injection pump designs have also been reported. These leaks are of greater concern because of the potential for severe engine damage if the leak is not detected. Truck fleets nationwide that use equipment of these designs have been alerted by engine manufacturers to the possibility of this type of leak.

Loss of power and reduced fuel economy. This complaint has been voiced nationwide from virtually all service groups. It should be noted that not all users have observed power and mileage reductions, and at least one manufacturer has stated that they are not yet convinced that there has been an across-the-board reduction in power and mileage with the new U.S. EPA low sulfur and California post-regulation diesel fuels.

Leaking fuel system hoses. Complaints have come mostly from owners of one make of passenger cars (E9). These hoses generally require periodic replacement, but the number of reports suggests that the change in fuel may have instigated failure in a number of older vehicles.

Lubricity. Various technical papers have pointed out that severe hydrotreating (for the removal of sulfur and aromatics) of crude oil can adversely impact the lubricating qualities of diesel fuel. These papers point to the Swedish experience with low sulfur/low aromatic fuel as evidence that fuel with poor lubricity can cause premature failure of distributor-type fuel injection pumps (Booth) (K. Krieger) (Volvo[1]) (C. Bovington).

Based on data from Sweden's experience with low sulfur/low aromatic fuels, Subcommittee #1 considered the possibility of premature failures of fuel pumps using post-regulation diesel fuels. A few isolated reports of seized fuel injectors and injection pumps have been received from California and various other states since the introduction of the post-regulation diesel fuels. However, with only four months of experience with the new fuels, it is not possible to draw definitive conclusions regarding long-term lubricity effects. However, many fuel suppliers are monitoring the lubricity of their fuels and adding lubricity additives.

Vehicle owners have attributed a variety of fuel system performance complaints to reduced lubricity of the post-regulation diesel fuels. The potential extent of problems and the mechanism for this effect are not well understood at this time. There are indications among the survey data from diesel vehicle owners, however, that the lubricity qualities of some of the new fuels may not be as good as the old fuels.

Two of the more commonly reported problems that have been attributed to fuel lubricity are the poor idling and underrunning stalls in vehicles equipped with distributor-type injection pumps from component manufacturer C2. Technicians who were interviewed reported that the fuel metering valve does not respond quickly enough after deceleration to sustain an idle speed, so the engine stalls. This complaint has been voiced nationwide since October 1993, and is widely associated with U.S. EPA low sulfur diesel fuel. Several diesel injection pump mechanics who were interviewed asserted that complaints of underrunning stalls are an indicator of low lubricity in the diesel fuel.

One major manufacturer of industrial and agricultural equipment undertook a study in September/October 1993 that contrasted low sulfur diesel fuel with higher sulfur diesel fuel. The survey examined records from the past five years. Records from California's South

Coast Air Basin (where low sulfur fuel has been used for more than five years) were compared to records from the eastern U.S. This survey found that complaints of underrunning stalls with distributor-type fuel pumps have been 2.9 times more common in the South Coast Air Basin over this five-year period than in the eastern U.S.

The above discussions suggest that low sulfur diesel fuels may have poorer lubricity than diesel fuels with higher sulfur levels. However, fuel lubricity is a complex issue and different mechanical systems are known to respond differently to various lubricating components in fuel. It is not clear if there is a correlation between the incidence of underrunning stalls and the potential for accelerated wear or other fuel system problems. To our knowledge, only one equipment manufacturer has suggested in writing that there may be lubricity concerns with low sulfur fuels. This statement was restricted to those models equipped with distributor-style injection pumps.

2.2.2 Types of Passenger Car and HDD Vehicles That Have Experienced Mechanical Problems

Most major engine manufacturers of LDD and HDD engines are represented among the failed equipment. Furthermore, virtually all types of vehicle service are represented in the vehicles reporting seal leakage or other problems, including long haul/interstate, local/delivery, agriculture, emergency vehicles, refrigerated units, and passenger vehicles. However, because of differences in design and materials used in different vehicles, the specific problems cited vary according to the type of vehicle.

Table 2-1 shows the failures reported to the CTA by engine make. Table 2-2 is a summary of the types of failures (by engine make) reported to California Air Resources Board (ARB) staff by California truck fleets surveyed.

While leaks have been seen in a variety of different vehicles and applications, the common component seen in many leak failures is nitrile (Buna-N) seals that have seen long

Table 2-1

CTA Diesel Fuel Failure Report (by Engine Make)

	Engine Manufacturer				
	E1	E3	E4	E5	Other[a]
Number of reports	113	436	241	384	360

[a] Includes passenger cars, refrigeration units on truck trailers, construction/farm equipment, forklifts, locomotives, and unidentified vehicles.

Reference: CTA[8]

Table 2-2

ARB Fleet Inspection Summary (Failures Noted By Engine Type)

	Engine Type		
Mechanical Problems	E3	E4	E5
Fuel Pump			
O-Ring	✓	✓	✓
Fuel Pump Failures (unspecified)	✓	✓	
Injector O-Rings		✓	
Return Hoses		✓	
Filters Plugging	Not Specific to Make		

Reference: ARB[25]

service at high temperatures. Manufacturer E3, who is prominently mentioned in the failure reports, indicates that it has had no warranty claims for fuel leaks as of February 1, 1994. The basic warranty covers the fuel system for 100,000 miles.

Fuel system designs that are not represented in the leak reports tend to be those that use fluoroelastomer or soft metal seals throughout the fuel system.

Virtually all major engine manufacturers of diesel passenger cars and pickups are represented among the failed equipment. The numbers of reported problems generally correspond to the populations of these makes within the overall vehicle population. The distribution of reported problems from the ARB light duty mail survey is shown in Tables 2-3 and 2-4. As with HDDs, differences in designs and materials result in differences in the specific complaints associated with different makes.

Vehicle makes E8 and E9 (a pickup and a car) are the major LDD vehicles represented in California, each making up approximately 25% of the population. These are followed by E11, which makes up approximately 8% of the light duty population. Tables 2-3 and 2-4 indicate that a large number of hose leaks were reported on E9 vehicles, but relatively few other problems (relative to the large population of these units in the state) have been reported. Reported failures among other makes are mostly confined to pump problems, with the relative numbers of reports roughly proportional to vehicle populations for European makes. In addition, few problems were reported for American-made diesel passenger cars and Japanese-made LDDs. However, the fraction of these vehicles in the overall LDD fleet is small.

2.2.3 Prevalence of Reported Problems Among the LDD and HDD Populations

Limited repair data and confounding variables make accurate estimates of the affected HDD population difficult. Estimates that less than 1% of the truck populations nationwide have suffered fuel leaks have appeared in a trade journal (*Fleet Owner*) and a technical bulletin from October 1993 (Chevron[2]). These estimates were generated soon after the

Table 2-3

ARB Light Duty Diesel Mail Survey — Leaks

	Vehicle Make																
	E21	E22	E8	E23	E26	E24	E14	E4	E16	E19	E9	E17	E25	E12	E18	E10	E11	Missing
Injector pump	9	10	43	1	8	1	9	1	2	2	36	1	5	38	7	23	87	8
Return lines	1	2	43	2	0	0	3	0	1	0	61	0	3	4	0	3	13	1
Injectors	0	1	45	0	2	0	3	1	0	1	22	1	1	4	1	2	9	2
Filter	0	0	15	0	1	0	2	0	1	0	14	0	2	6	1	0	2	1
Other/Unspecified	1	1	24	0	0	0	5	0	1	0	34	0	1	3	0	1	10	3

Source: ARB[35]

Table 2-4

ARB Light Duty Diesel Mail Survey — Performance Problems

	Vehicle Make																	
	E21	E22	E8	E23	E26	E24	E14	E4	E16	E19	E9	E17	E25	E12	E18	E10	E11	Missing
Power loss	1	1	20	1	5	0	3	1	1	0	26	0	3	16	1	7	21	5
Missing/irregular acceleration	0	0	3	0	2	0	1	0	1	0	7	1	0	2	0	1	2	0
Idle problems	1	0	6	0	1	0	3	1	0	0	4	0	0	5	0	3	0	1
Stalls[a]	0	0	7	0	1	0	0	0	0	0	6	0	1	3	0	1	0	0
Hard to start	1	4	34	0	3	0	7	0	2	1	31	1	3	10	2	5	23	5
Died[b]	0	1	2	0	1	0	0	0	0	0	5	0	1	0	0	0	1	1
Decrease in gas mileage	0	0	12	0	2	0	0	0	0	0	4	0	1	3	1	6	11	1
Noisy	0	0	3	0	0	1	0	0	0	0	6	0	0	0	0	0	0	1
Smokes	0	0	4	0	0	0	2	0	0	0	1	0	0	1	0	1	1	0

[a] Vehicle would start again
[b] Vehicle was towed to shop-dead

Source: ARB[35]

problem was identified and were based on limited data. No California-specific estimates for the HDD population can be generated from the data available.

Note that virtually all of the data on HDD vehicles presented in this section were gathered via passive surveys; that is, only vehicle owners who were aware of the ARB or CTA data-gathering efforts and were motivated to call or complete forms are represented in the data. The pattern of advertisement may, to some degree, affect the patterns of timing and geographic origin of reports and the vehicle types represented in the data.

To quantify the magnitude of fuel-related problems in California, the ARB surveyed truck drivers at California Highway Patrol (CHP) Commercial Vehicle Inspection Facilities, interstate rest stops, interstate border crossings, and random roadside locations throughout the state between October 25 and November 10, 1993. The ARB inspectors asked the vehicle operators if they had experienced mechanical problems with the post-regulation diesel fuels. Although a survey of this type does not produce statistically rigorous results, this survey was extensive and was a random sampling within the geographic areas where it was undertaken. A total of 7,695 truck operators were surveyed. The results from this survey were:

- 90% of truck drivers surveyed reported no mechanical problems with the post-regulation diesel fuels.
- 10% of the truck drivers surveyed cited mechanical/performance problems. One-fifth of these (2% of total) reported fuel leaks.

Although fuel-related problems are apparently affecting a relatively small percentage of the vehicle population, these problems are serious for some of the owners of the vehicles involved. Two examples of fleets that have been severely impacted are a San Francisco Bay Area transit bus and fire truck fleet, and a northern California trucking fleet. These fleet operators were visited by ARB staff and contacted by Subcommittee #1 researchers. In both cases, more than one-third of the fleet has required costly fuel system repairs since September 1993. Data from the CTA for 74 fleets experiencing apparent fuel-related problems showed that failures were reported on an average of 29% of the vehicles in each fleet. The percentage of reported failures in each fleet ranged from a low of 1% to a high of six fleets that reported failures in 100% of their vehicles. On the other hand, many comparable fleets using the same diesel fuels have not reported problems. This sporadic pattern of reported fuel-related problems has been seen nationwide since the introduction of U.S. EPA low sulfur and post-regulation diesel fuels.

The ARB conducted a study to determine the incidence of fuel injection system leaks in light and medium duty diesel vehicles since the introduction of U.S. EPA low sulfur and post-regulation diesel fuels (ARB[26]). This study included an extensive survey and statistical analysis of responses from diesel vehicle owners in northern and southern California.

Based on the results of their analysis and the statewide light and medium duty diesel populations, ARB estimated that the statewide incidence of leaks among light and medium duty diesel vehicles is approximately (ARB[26]):

Fuel injectors and injection pumps	2.4%
Other fuel system leaks	6.4%
Total	8.8%

Reports of fuel line leaks were prevalent among the LDD fuel-related failure reports. The results of ARB's telephone survey of light and medium duty vehicle owners indicated that 63% of all the reported leaks were in rubber hoses within the fuel system. Of these, 90% occurred in passenger cars of make E9. The complaints received by CTA also reflect a preponderance of rubber hose leaks in the E9 make passenger cars. Approximately 31% of passenger car leaks reported to CTA cited leaking fuel lines; of these 50% were E9 vehicles.

To investigate this problem, several repair shops specializing in repair of E9 vehicles were contacted to learn more about the "profile" of the damaged fuel lines. Several elastomer experts were also contacted. Anecdotal data from the repair shops were contradictory at times. For example, some repair shops stated that leaking fuel hoses are "normal" repair items and are replaced periodically; others said that this was not the case. Still other shops indicated that, whereas the hoses on the engine require routine replacement, the fuel tank return lines do not. However, in all cases there was agreement that fuel line leaks have been occurring more frequently since the introduction of the post-regulation diesel fuels.

There were also different descriptions of the failure profile. These can be generalized into four failure types: hoses that became brittle and "cracked," hoses that became loose and leaked at the connections, hoses that softened, and hoses that leaked along their full length.

Rubber fuel hoses are only used in low-pressure applications, such as in the fuel systems of light and medium duty vehicles. According to one source, fuel system return lines in heavy duty vehicles are reinforced with a steel mesh to provide durability.

Agricultural equipment effects. Data related to the possible impacts of the post-regulation diesel fuels on agricultural machinery are, as yet, very limited. The initial review of relevant information has indicated that a variety of different injection fuel pump styles (fuel-lubricated, oil-lubricated, distributor-type, and in-line) are used on agricultural equipment. The impacts of the change in fuel will likely depend on different pump styles in use, and are not yet known.

In winter, agricultural activities using diesel equipment are minimal compared with other seasons. Nevertheless, Subcommittee #1 investigated the potential effects of the post-regulation diesel fuels on agricultural equipment. The Subcommittee employed a questionnaire of agricultural equipment operators to identify the extent of any current mechanical problems and to identify plans for near-term agricultural activities. The results of this study are presented in Section 2.2.5.

2.2.4 Trends Seen in Affected/Unaffected Vehicles

The common theme seen throughout the interviews, research, and data analysis was that most fuel leaks involve nitrile seals that have seen long service at high temperatures. This suggests that the mechanism of failure is such that older seals may be less tolerant to a sudden change in fuel characteristics than less-aged seals. Rather than repeat those data, this discussion examines the exception to the trend (i.e., reports of repeat failures and low-mileage failures) to determine what can be learned from these reports. Specific topics discussed here are:

- Mileage of vehicles reporting failures;
- Repeat failure reports;
- Low-mileage failure reports;
- Fuel oxidation potential; and
- Significance of elastomer materials.

The age of a seal can be represented by a number of factors, including mileage, chronological age, and hours of use. Other factors can also influence the aging of a seal, including maximum temperature and number of thermal cycles. It should be noted that the mileage distribution of reported failures showed large variability, indicating that mileage alone is not an accurate gauge of seal condition.

Figures 2-1 through 2-4 are histograms illustrating the distribution of vehicle mileage as reported to ARB and CTA. The bars on the histograms represent the relative numbers of vehicles in each mileage range that have been reported to have fuel-related problems. Not all reports to ARB and CTA included vehicle mileage. Among the reports to ARB, approximately 90% of the passenger cars and 30% of the heavy duty trucks reported vehicle mileage. Among the reports to CTA, approximately 90% of the passenger cars and 12% of the heavy duty trucks reported vehicle mileage.

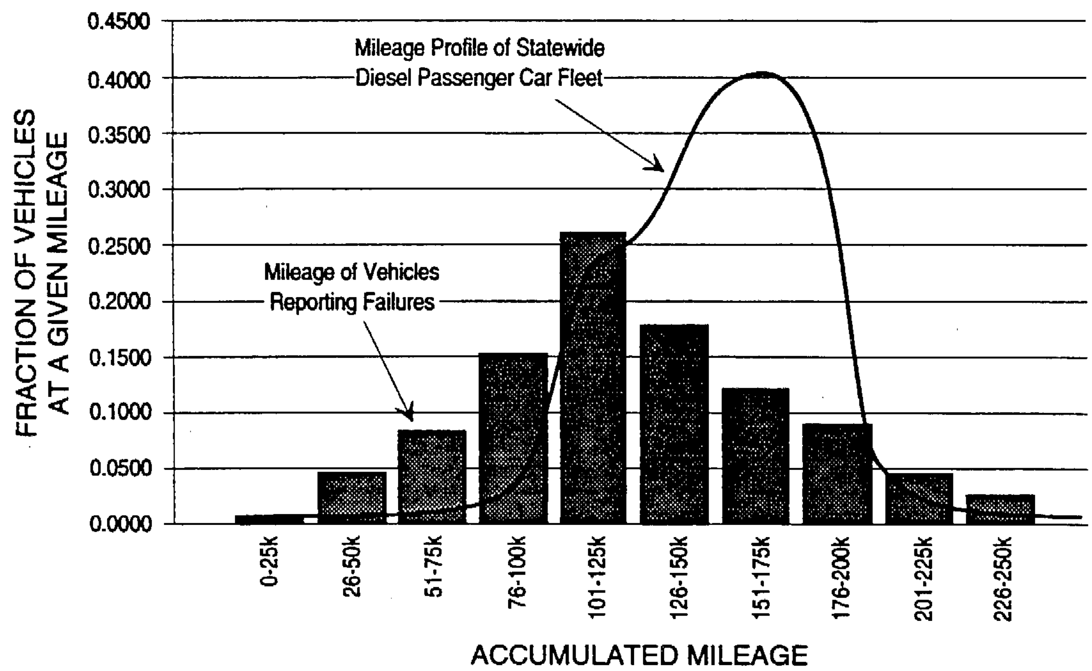


Figure 2-1. CTA Diesel Fuel Failure Reports (Diesel Passenger Cars)

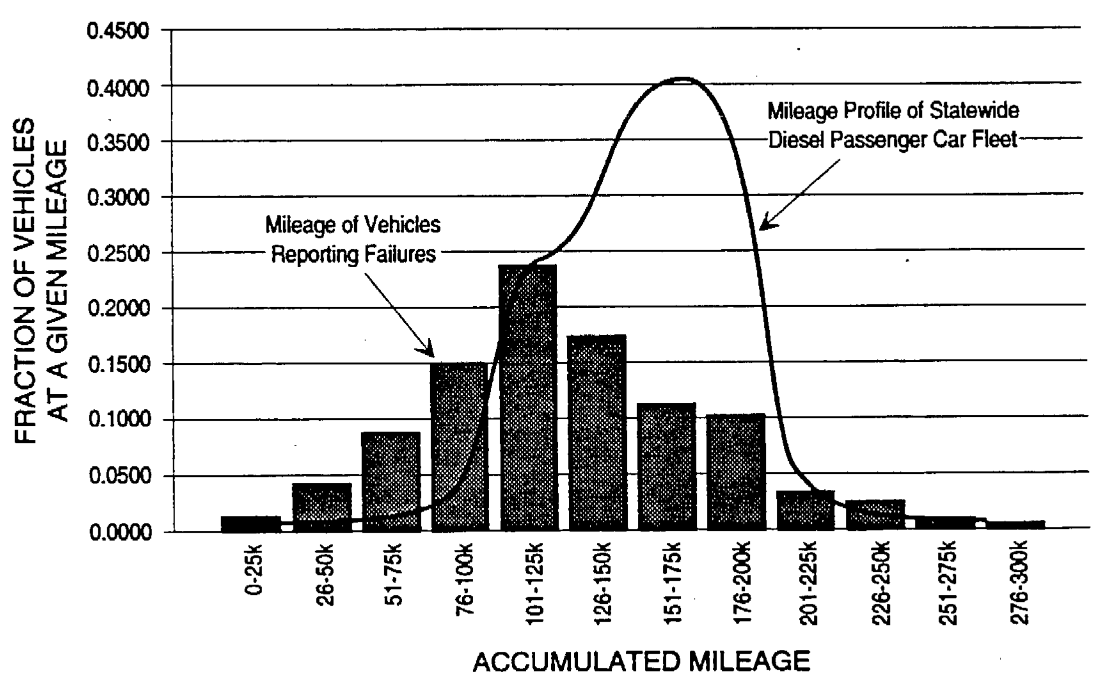


Figure 2-2. ARB Diesel Fuel Failure Reports (Diesel Passenger Cars)

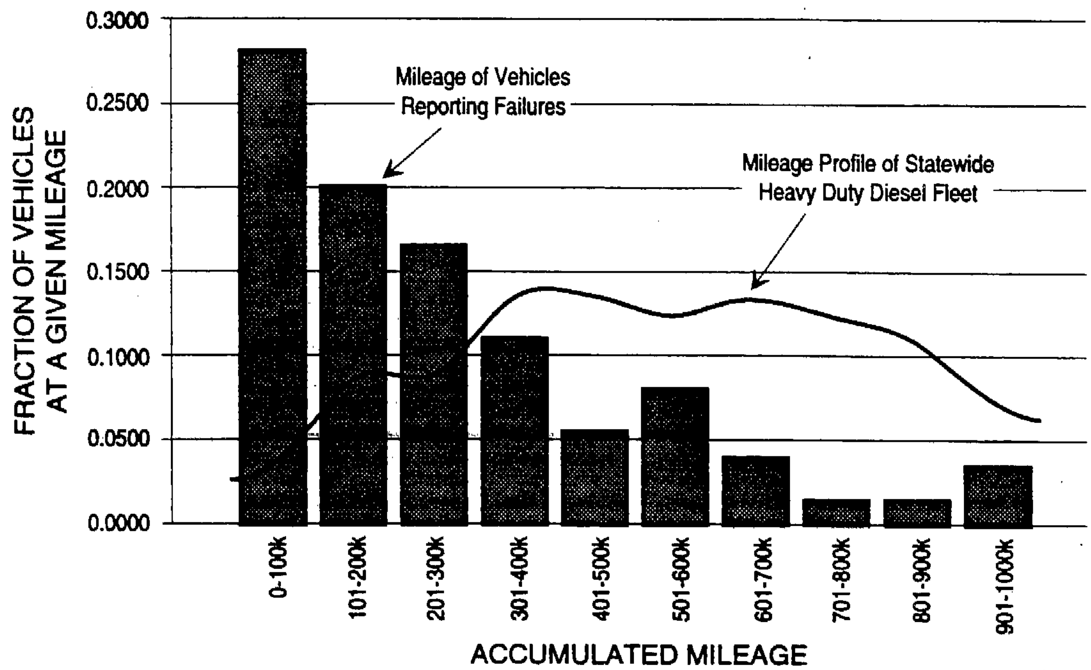


Figure 2-3. ARB Diesel Fuel Failure Reports (Heavy Duty Diesel Trucks)

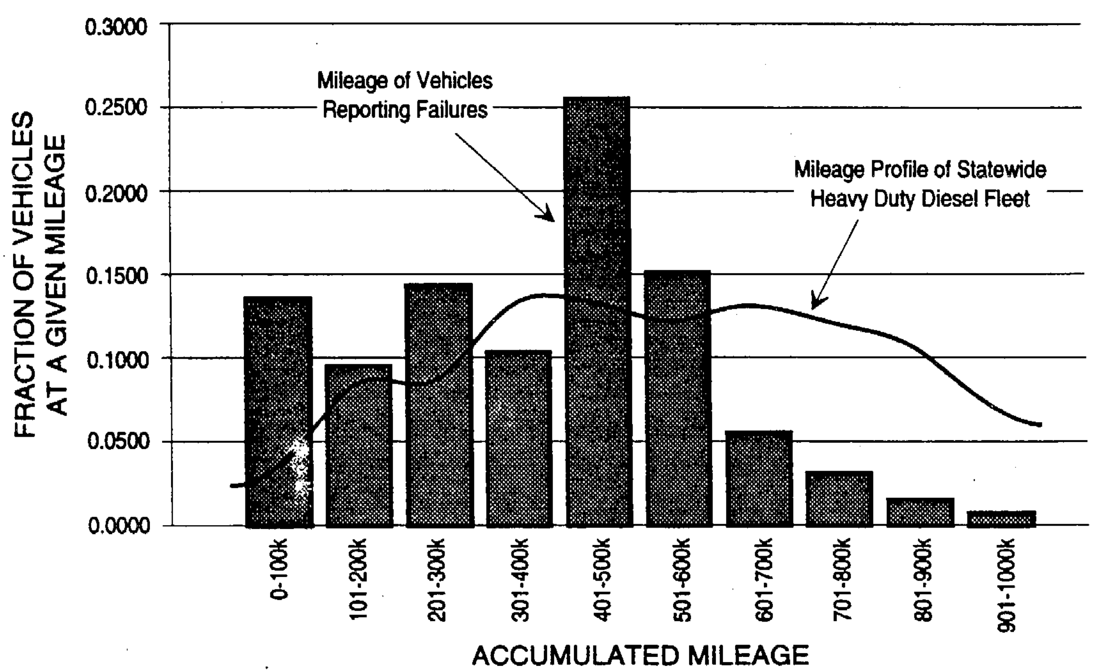


Figure 2-4. CTA Diesel Fuel Failure Reports (Heavy Duty Diesel Trucks)

The line drawn through each graph represents an approximation of the mileage distribution among all the diesel vehicles in the state. This statewide mileage distribution is based on the data and assumptions in the ARB computer model BURDEN7F. The BURDEN7F computer model is used to characterize vehicular use patterns to estimate on-road motor vehicle emissions.

Note that there is an inherent bias in the comparison of the lines and bars shown in Figures 2-1 through 2-4. The lines represent the total accumulated mileage of the vehicles in the statewide fleet. A truck with 1,000,000 miles that was overhauled at 650,000 miles will appear as a 1,000,000 mile vehicle on the line. Many owners, however, would have (correctly) reported this same vehicle as a failure at 350,000 miles. Because the statewide mileage distribution line counts total accumulated miles, and does not reset vehicles to zero miles after rebuilding, the line will tend to report a greater proportion of "high-mileage" vehicles than the owners have reported.

Several low-mileage failures and repeat failures reported to CTA and ARB appear to run contrary to the trend of higher mileage failures. These reports are significant because they contradict the verbal accounts from representatives of fleets, repair facilities, and manufacturers. They also raise the question of whether a failure mechanism other than reduced seal swell might be at work.

Subcommittee #1 carefully reviewed a number of the low-mileage and repeat failure reports (see Appendix C) to determine whether the reports were accurate and, if so, whether additional understanding of the mechanisms of seal failure might be gained from these case histories. In addition, research into fuel oxidation potential was undertaken.

Repeat failures. Reports of repeat failures were investigated through review of the hardcopy survey forms and follow-up telephone calls. Most of the repeat failures reported were "vehicle repeats" rather than "component repeats" (e.g., an injector O-ring and a fuel line failed in the same vehicle). However, there were a few, isolated reports of repeat component failures.

Conversations with O-ring manufacturers and repair shops indicated that a small number of repeat component failures do occur under normal conditions. Repeat failures may be caused by defective replacement parts or installation difficulties. "Notching" (e.g., the O-ring does not lie flat) or "shredding" (e.g., the O-ring tears when secured into place) are two complications that may arise while performing seal repairs.

It is important to keep in mind that the components that have been replaced since October 1993 are still quite new (as measured in terms of time, mileage, or usage). It may be too soon to adequately assess the frequency of repeat component failures at this time.

Low-mileage failures. To investigate the incidences of low-mileage failures, reports that were clearly very low mileage (i.e., less than 50,000 miles) were selected for follow-up telephone calls. Successful contacts with owners were made for thirteen reports of vehicle failures that occurred at less than 50,000 miles. Six reported failures were confirmed to be associated with low-mileage vehicles, although one was a street sweeper, classified as "high usage" by the fleet supervisor, despite its low-mileage status. Six of these low-mileage failures were erroneous due to misinterpreted data (e.g., 450 was reported to represent 450,000; 11,000 was reported from an odometer that actually had 111,000 miles; and mileage was reported for the new/rebuilt component rather than for the failed component). One low-mileage value reported was the mileage since major engine repair work. In this case, however, it was not possible to confirm that the subject fuel system component had been rebuilt or replaced at the time of the major engine rebuild. Therefore, some of the reported failures of low-mileage vehicles were confirmed to be accurate and some were found to be misleading.

A common trend noted among the reports of low-mileage failures and repeat failures for HDD and LDD vehicles was that they are generally privately owned vehicles that have been serviced by outside shops. Specific details on these cases, such as repair histories, types of parts previously used, or unusual operating conditions, are not available.

In summary, a review of the low-mileage and repeat failure reports indicates that some reports are erroneous, most are unclear, and some are genuine low-mileage failures. Because of the small number of reports and limited data, these reports do not support conclusive theories as to failure mechanisms. However, research into other failure mechanisms in addition to reduced seal swell, such as fuel oxidation potential (peroxide formation), is ongoing.

Fuel oxidation potential. The removal of sulfur and other antioxidants from the fuel during severe hydrotreating may result in a product with greater potential for peroxide formation during storage. Peroxide is a strong oxidant that is known to be destructive to nitrile elastomers. For this reason, Subcommittee #1 submitted a recommendation to Subcommittee #2 for additional study of this issue. Subcommittee #2 has initiated a program to test the oxidation potential of post-regulation diesel fuels. Note that many fuel suppliers are aware of this concern and are adding supplemental oxidation inhibitor(s).

Elastomer materials. Another common trend noted among the leak reports was the use of acrylonitrile (nitrile) seals as opposed to fluoroelastomer seals. Nitrile is selected for many fuel system O-rings because of its fuel tolerance, resistance to abrasion, and pliability at low temperatures.

Heavy duty engine manufacturer E2, who uses engine oil-lubricated fuel pumps and fluoroelastomer seals, is virtually absent from the reports of leaking vehicles. Likewise, several manufacturers who use fluoroelastomer in their fuel injectors have seen few reported injector failures.

There are exceptions to the fluoroelastomer versus nitrile trend in the reported failures. Manufacturer E1, who also uses fluoroelastomer seals in their fuel systems, is represented among the reported failures. However, when the manufacturer investigated two of the major fleets that reported failures, they identified confounding factors that were not directly related to the post-regulation diesel fuels. At this time it cannot be confirmed that these reports represent fluoroelastomer seals that failed solely because of contact with post-regulation diesel fuels.

Also, it should be noted that many different nitrile materials are used in O-rings, each of which has slightly different resistance to heat, oxidation, and other variables. These differences may contribute to different rates of failures among vehicles using nitrile elastomers.

The reader is cautioned against concluding from this discussion that, to avoid fuel system failure, only fluoroelastomer seals should be used in fuel systems, or that future fuel system leaks might be prevented if manufacturers simply changed their material specifications. The selection of O-ring materials must take into consideration a number of factors, including:

- The minimum and maximum temperatures that the O-ring will be exposed to, and the demands to be placed on the O-ring at these extreme temperatures.
- The materials that the O-ring will be exposed to, including fuels and fuel additives on one side, and hot motor oil, coolant, or air (which may carry oxidants and/or abrasive dirt) on the other side.
- The physical demands of the application (e.g., will the O-ring seal against a sliding or rotating shaft? Will the size or shape of the O-ring need to change with thermal expansion/contraction of the sealed parts?).
- Serviceability (can parts made from alternative materials be installed and removed easily without damaging the parts or other components?).
- Cost (will increased part cost be justified by increased value to the customer?).

Statements by equipment manufacturers and discussions with elastomer experts suggest that, where failed nitrile components are replaced with identical nitrile parts, there is, as yet, no evidence to indicate that the new components will suffer an increased incidence of early failures. A number of questions remain, such as how seals are affected when exposed to fuels with varying characteristics within California and nationwide. These factors are unknown because the complex chemical interactions between fuels and the elastomers are not well understood.

2.2.5 Agricultural Questionnaire

The objective of the agricultural questionnaire was to determine if there are problems (e.g., fuel leaks, reduced lubricity, or performance problems) related to the use of post-regulation diesel fuels in agricultural equipment. Where the respondent voiced a problem, as much information as possible regarding the scope and extent of the problem was obtained. To meet the schedule demands for completion of this report, determining the extent of the problem was given priority over collecting detailed information related to potential causes. A more detailed investigation into the extent of possible problems in the agricultural community relating to the use of post-regulation diesel fuels is planned to coincide with increased farming activities occurring in spring/summer 1994.

Two methods were used to determine the extent of the potential problem. First, a telephone questionnaire (not statistically valid) was developed to contact agricultural diesel fuel users regarding their experiences with post-regulation diesel fuels. Additionally, a number of equipment manufactures, dealers, and agricultural equipment repair facilities that work on diesel fuel injection systems were contacted to determine if they had observed an increase in fuel system problems that could be attributed to the post-regulation diesel fuels. Both methods focused on four counties, Fresno, Kern, Monterey, and Yolo, which are expected to provide a reasonable representation of the agricultural community in California.

The telephone questionnaire used to contact agricultural diesel fuel users was developed and implemented by the Center for Irrigation Technology (CIT) at California State University Fresno (CSUF). The questionnaire prepared by CIT was reviewed by representatives of the agricultural industry who are members of the Diesel Fuel Task Force, Subcommittee #1. The telephone discussions with the equipment dealers and repair shops were completed by

Subcommittee #1 researchers. Additional interviews with repair shop personnel provided by ARB staff were also reviewed. The report provided by CIT is included in Appendix E.

Results. Questionnaire respondents who could not confirm whether they were using "ARB low sulfur fuel," but who had purchased fuel after September 1, 1993, were assumed (for the purposes of this questionnaire) to be using post-regulation diesel fuels. Eighty percent (146 of 182) of the respondents were assumed to be using post-regulation diesel fuels. Of the respondents using post-regulation diesel fuels, 32% (47 of 146) indicated that they were having more fuel leaks than normal due to the post-regulation diesel fuels, and 47% indicated that they were experiencing more operating problems. The range of diesel-fueled equipment units per farm ranged from a low of zero to a high of 100. The average number of diesel-fueled equipment units was 12.4 per farm. Nearly 15% of all equipment assumed to be using post-regulation diesel fuels was reported to have leaks that respondents associated with the fuel use.

The results of the questionnaire are summarized in Table 2-5. The reader is reminded that the numbers and percentages in Table 2-5 correspond to individuals interviewed, not to equipment counts. Problems reported generally refer to only a subset of the equipment that the respondent owns. Even when this is kept in mind, however, the results from the questionnaire appear to contrast sharply with reports from shops and manufacturers. Of the more than 20 contacts made with staff at pump shops, dealers, and equipment manufacturers, only one indicated that they had seen an increase in fuel leaks that they felt were associated with use of the post-regulation diesel fuels. Many staff members at these shops did note a significant increase in problems in on-road and construction equipment, and it was generally recognized that there may be some performance problems, primarily in reduced power and fuel efficiency.

Limitations of the questionnaire methods. The telephone questionnaire is not considered statistically valid. There may be some bias in the population surveyed since the contact names came primarily from one source (the pesticide spray permits obtained from each county), and do not include all of the agricultural users in a given area. A total of 1,078 phone calls were made, resulting in a total response of 182 growers. Additionally, due to the need to

Table 2-5

CIT Agricultural Questionnaire Results

Question	Responses	Yes # %	No # %	Don't Know # %
Are you currently using ARB low sulfur diesel fuel?	182	132 (73%)	26 (14%)	24 (13%)
If "Don't Know," was fuel purchased after September 1, 1993?	24	14 (58%)	2 (8%)	8 (33%)
The 146 respondents who answered "yes" to either of the above two questions were asked the following additional questions:				
More than normal fuel leaks?	146	65 (44%)	81 (56%)	—
Believe leaks related to fuel?	65	47 (72%)	0 (0%)	18 (28%)
More operating/performance problems than normal?	146	69 (47%)	77 (53%)	—
Operating/Performance Problem (69 respondents)				
Hard Starting		35 (51%)		
Power loss		36 (52%)		
Reduced fuel economy		30 (43%)		
Injector or injector pump failure		20 (29%)		
Seizure or scoring		1 (1%)		
Other		10 (14%)		
Characterization of Fuel Leaks (65 respondents)				
Fuel pump		34 (52%)		
Injector(s)		29 (45%)		
Return lines		29 (45%)		
Fuel filter		15 (23%)		
Other		14 (22%)		

begin the telephone questionnaire immediately, the questions were not validated to avoid biasing the survey population due to the phrasing of the questions. In fact, potentially leading questions may have been included if they were thought to reduce the questionnaire completion time, thereby improving the questionnaire response rate.

Discussion of questionnaire and shop interviews. There has been extensive publicity and concern in the agricultural community over potential equipment damage resulting from the use of post-regulation diesel fuels. The publicity includes notices from a major manufacturer that fuel systems operating on the low sulfur fuels may not be covered by warranty, to advertisements from repair shops and notices in the media indicating that the post-regulation diesel fuels are damaging equipment. Many of the shop contacts felt that the increased awareness of the issue contributed to identification of leaks that might not otherwise have been identified at this time. Owners may have blamed post-regulation diesel fuels for damage to older systems or systems with known design problems, which the repair shop did not consider to be abnormal or to have resulted from use of the post-regulation diesel fuels.

Additionally, according to agricultural representatives on the Task Force, many agricultural users may have stockpiled the high sulfur or temporary California low sulfur fuel. Although many have purchased the post-regulation diesel fuels, it appears that much of the post-regulation diesel fuels used to date may have been mixed with high sulfur fuel. In most of the counties surveyed, there does not appear to be heavy usage yet of pure post-regulation diesel fuels. Monterey County, which is considered to have had the heaviest fuel use since introduction of post-regulation diesel fuels, experienced the highest percentage of performance problem reports (60%). Sixty percent of the Monterey County post-regulation diesel fuel users reported performance problems, compared to the 47% four-county total reported in Table 2-5.

The dealer, manufacturer, and shop contact information was used qualitatively, and no statistical evaluation of the data was conducted. There could also be bias in these contacts since they were weighted toward dealers and well-known pump repair shops. These sources may conduct proportionally more business with large, fleet-type farm operations than smaller shops. Dealers and equipment manufacturers may also be biased toward indicating that there are no problems associated with equipment that they are trying to sell.

2.3 Geographic Distribution of Reported Problems

Question 4: What is the geographical nature of reported problems?

The geographic distribution of the reported diesel fuel-related problems was investigated from two perspectives: the relative distribution of these problems within California, and the existence/extent of reported problems outside of California. The results of this analysis are discussed below.

2.3.1 Geographic Distribution of Problems Within California

In this analysis, areas north of Santa Barbara and Fresno were generally designated as "north." Areas inclusive of Fresno and Bakersfield were designated as "central," and the remaining areas were designated as "south." Without exception, the data reviewed indicated that the majority of reported failures were in the northern part of the state. Less than 20% of the reported leaks occurred in southern California. Interestingly, California vehicle population data for 1993 indicate that the majority (approximately 55%) of both LDD and HDD vehicles are registered in southern California. The geographic profile of reported leaks from ARB's LDD telephone survey, ARB's HDD mail survey, and CTA's database of complaints is summarized in Table 2-6. These data sets were selected because they adequately reflect the information from the other data sources that were analyzed. Note, however, that only the LDD telephone survey targeted a statistically representative population. The results of this survey are described in ARB[37].

An attempt was made to determine whether a noticeable increase in fuel equipment failures occurred in southern California in 1985, when the low sulfur fuel was first introduced. (By 1989, only low sulfur diesel fuel was produced in southern California.) The rationale for this inquiry was that an increase in failures may have resulted in replacement of "aged" fuel system components and consequent "adaptation" of these components to the low sulfur diesel fuel. Sources contacted included the staff of the Mobile Source Division of the South Coast Air

Table 2-6

Geographic Distribution of Reported Fuel-Related Problems in California

	Percent of Leaks in ARB's LDD Survey[d]	Percent of Leaks in ARB's HDD Survey	HDD Vehicles[a]	Percent of Reported Problems to CTA Cars and Pickups	Other[b]
North and Central	82	39	99	98	100
South	18	3	1	2	0
Missing or Outside of California	NA[c]	58	NA	NA	NA

[a] Includes ambulances.
[b] Includes refrigeration units on truck trailers, construction/farm equipment, forklifts, and locomotives.
[c] NA = not applicable.
[d] The ARB light duty diesel telephone survey did not include the central California region.

LDD = Light duty diesel
HDD = Heavy duty diesel
CTA = California Trucking Association

References: ARB[35]
ARB[13]

Quality Management District (SCAQMD), ARB staff, Automobile Club of Southern California (through CSAA contact), equipment manufacturers, fleet maintenance shops, and general diesel equipment repair shops in the south. With two exceptions, there were no recollections of mechanical problems caused by the low sulfur fuel prior to October 1993. In one case, performance problems were reported by staff at a fuel injection repair shop, who recalled a higher incidence of underrun, stalling, and low cranking efficiencies of diesel fuel vehicles.

The second case was reported by manufacturer E6, who surveyed fuel system warranty claims in the period 1989 through 1993. This survey indicated that claim rates (as a percentage of total equipment sold) were 2.9 times higher in southern California than in the eastern U.S. Most of these warranty claims reportedly involved stalling problems. (Note that stalling and underrun problems may be associated with inadequate lubricity of the fuel.) However, based on the overall outcome of this investigation, it was concluded that there was apparently no unusual increase in reported fuel system leaks after introduction in 1985 of low sulfur diesel fuel in southern California.

The investigation then established whether fuel composition differences existed between northern, central, and southern California after October 1993. The data used in this portion of the analysis consisted of the results from ARB's fuel testing program, in which over 200 diesel fuel samples from refineries, retail distributors, and truck fuel tanks at inspection stations statewide were collected in late October and November of 1993.

For the samples taken from retail distributors or vehicles, an analysis of variance (ANOVA) with the LSD (least significant difference) option was performed to evaluate the means by sample source (retail or vehicle) and California region (northern/central or southern). The means for total aromatic content were found to be statistically different with 95% confidence between the northern/central and southern regions for both retail and vehicle samples, as summarized in Figure 2-5. The regional difference between the vehicle means is smaller than for retail distributors. This may be influenced by the fact that some vehicles may have been fueled in one region but then sampled in the other.

Diesel fuel production estimates for California refineries were used in conjunction with the laboratory results for the refinery samples taken in late October and early November as part of the ARB Fuel Testing Program to calculate weighted averages by California region for various fuel characteristics. Figure 2-5 illustrates the average volume fraction of total aromatics in fuel collected from refineries in the northern, central, and southern parts of the state; the fuel samples were not selected in a statistical manner. Fuel analyses data obtained from the ARB laboratory and Caleb Brett (an independent testing laboratory), and refinery estimates of diesel fuel aromatic contents were weighted by refinery production estimates and the resulting average values were compared. Data were collected from 12 refineries and included estimates of quantities of fuel transferred between the two regions to more accurately reflect the geographic distribution of diesel fuels. Limited conclusions can be drawn from the magnitude of the differences between California regions due to confounding factors such as fuel

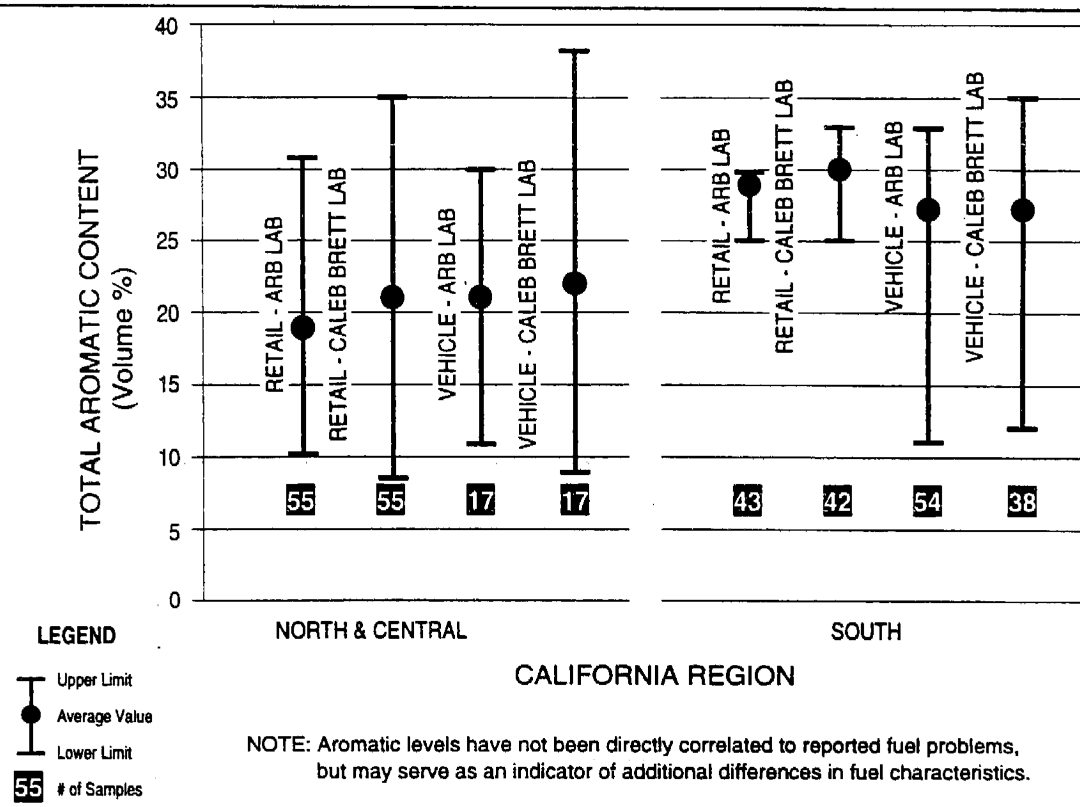
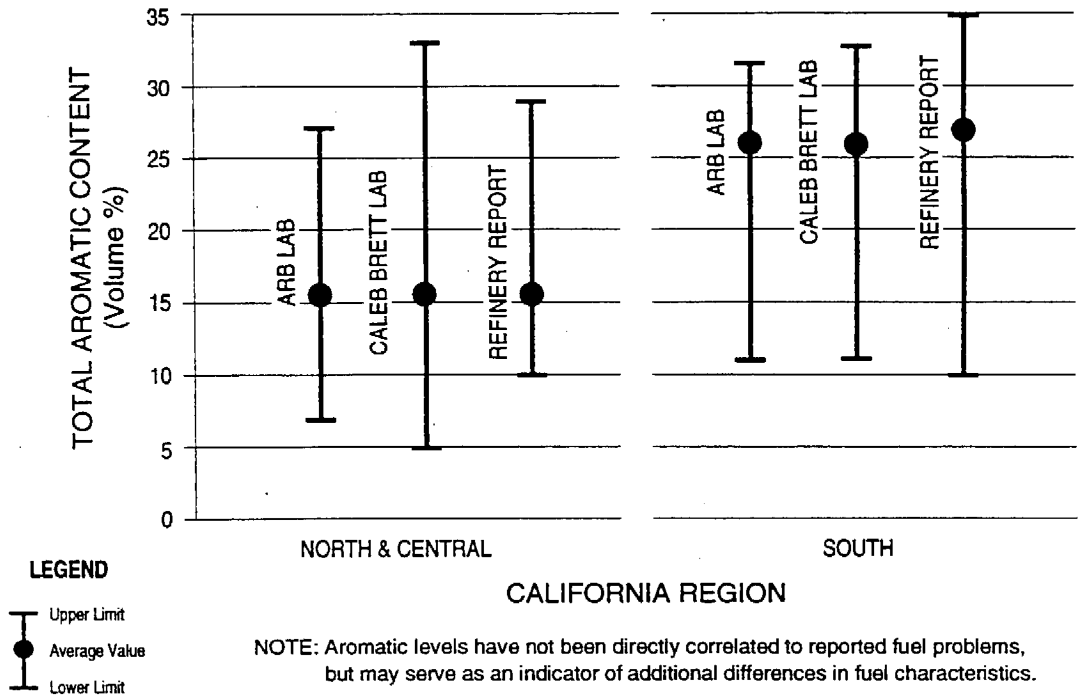


Figure 2-5. Diesel Fuel Samples - Total Aromatic Content for Retail and Vehicle Samples - Late October and November 1993

variability from batch to batch, potential bias in sampling, and fuel transfer and exchange agreements. However, the data sets presented in Figures 2-5 and 2-6 consistently indicate that by late October, the weighted average (total) aromatic content of diesel fuel was higher in southern California than in northern California. Total aromatic levels have not been directly correlated to reported fuel problems, but may serve as an indicator of additional differences in fuel characteristics.

2.3.2 National Extent of Problems

To investigate the occurrence of fuel-related problems outside of California, equipment maintenance directors of 10 national fleets were contacted. In addition, U.S. EPA contact reports of problems, original equipment manufacturer (OEM) fuel equipment sales data (from manufacturers E3, E4, E9, and C1), and sales data from independent fuel equipment



NOTE: Aromatic levels have not been directly correlated to reported fuel problems, but may serve as an indicator of additional differences in fuel characteristics.

Figure 2-6. Diesel Fuel Samples - Total Aromatic Content for Refinery Samples - Late October and Early November 1993 (Average Values Weighted by Refinery Production Estimates)

component suppliers were analyzed. Much of the information obtained from the trucking fleets was anecdotal. Only two of the fleet maintenance managers had no reports of fuel-related leaks or problems nationwide. The remaining anecdotal data from trucking fleets and U.S. EPA reflected reports of increased fuel equipment failures (for HDD and LDD vehicles) after introduction of U.S. EPA low sulfur diesel fuel nationwide, especially in the north central states of Ohio, Michigan, Iowa, Indiana, Minnesota, Wisconsin, and Illinois; the southern states of North Carolina, Texas, Georgia, Arkansas, and Tennessee; and the western states of California, Oregon, and Montana.

Of the numerical HDD failure data obtained, those from a national trucking fleet cover fuel-related failure reports from October 1993 to January 1994 and are, therefore, most current. These data are illustrated in Figure 2-7. Failures were reported across the country.

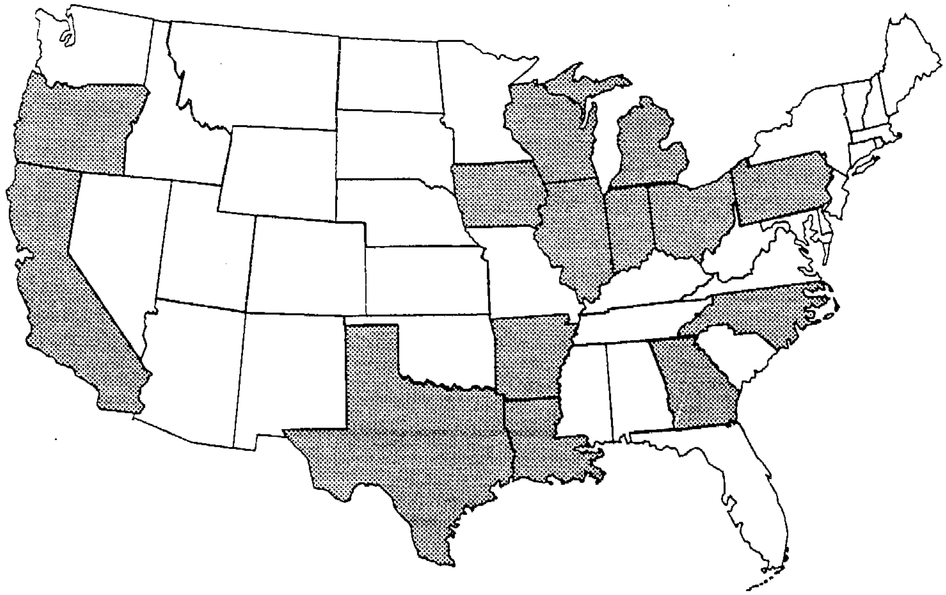


Figure 2-7. Fuel Pump Leaks Reported Nationwide by a National Trucking Fleet (Oct 14, 1993 - Jan 30, 1994)

To represent nationwide fuel-related problems of LDD vehicles, sales data of nitrile O-rings from passenger car manufacturer E9 were used. These data span the 12-month period between November 1992 and October 1993 for four geographic regions (south, west, northeast, and north central U.S.). Quarterly sales data, as a percentage of regional sales in the 12-month period mentioned above, are depicted in Figure 2-8. The data plotted in this figure indicate a dramatic increase for all regions in sales of O-rings during August to October 1993. Since the U.S. EPA low sulfur and California post-regulation diesel fuels were available as early as August 1993, the increase in O-ring sales seems to coincide with the introduction of the reformulated fuel nationwide.

Nationwide pump kit sales data from component manufacturer C1 are plotted in Figure 2-9. Analysis of these data indicates that pump kit sales increased nationwide by approximately 90% in 1993 as compared to 1992. By contrast, nationwide pump kit sales increased by 30% in 1992 as compared to 1991. The data plotted in Figure 2-9 indicate that the 1993 increase in pump kit sales was greater than 80% in most parts of the U.S., and that the smallest increase in sales (approximately 40%) occurred in the midwest. Again, the significant

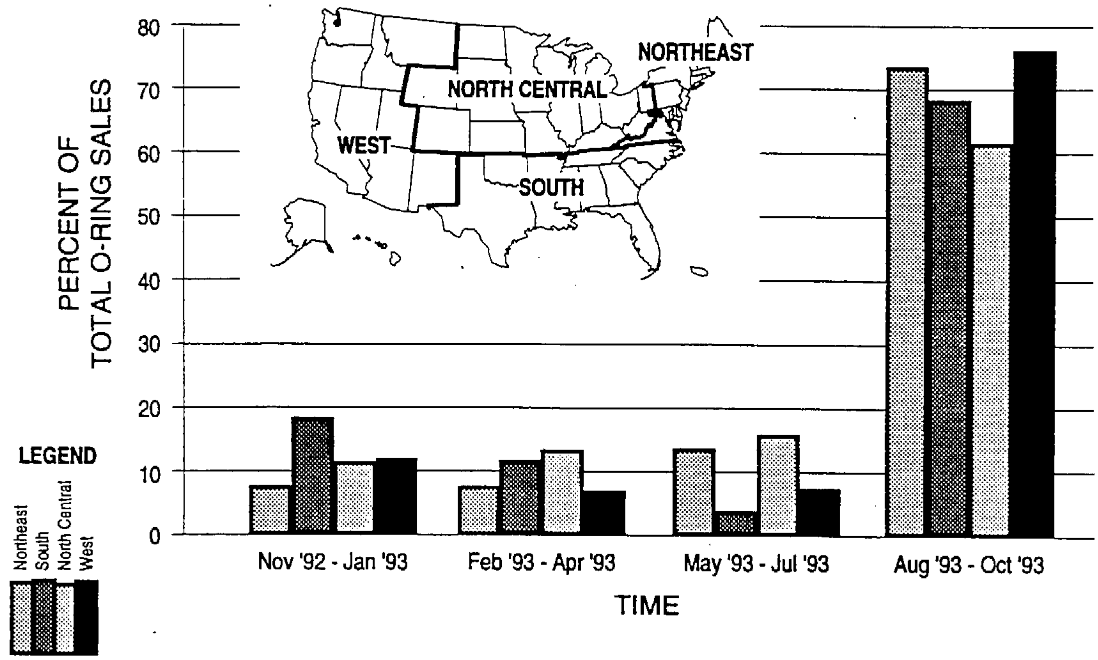


Figure 2-8. Sales of Nitrile O-Rings by Passenger Car Manufacturer E9 (November 1992 - October 1993)

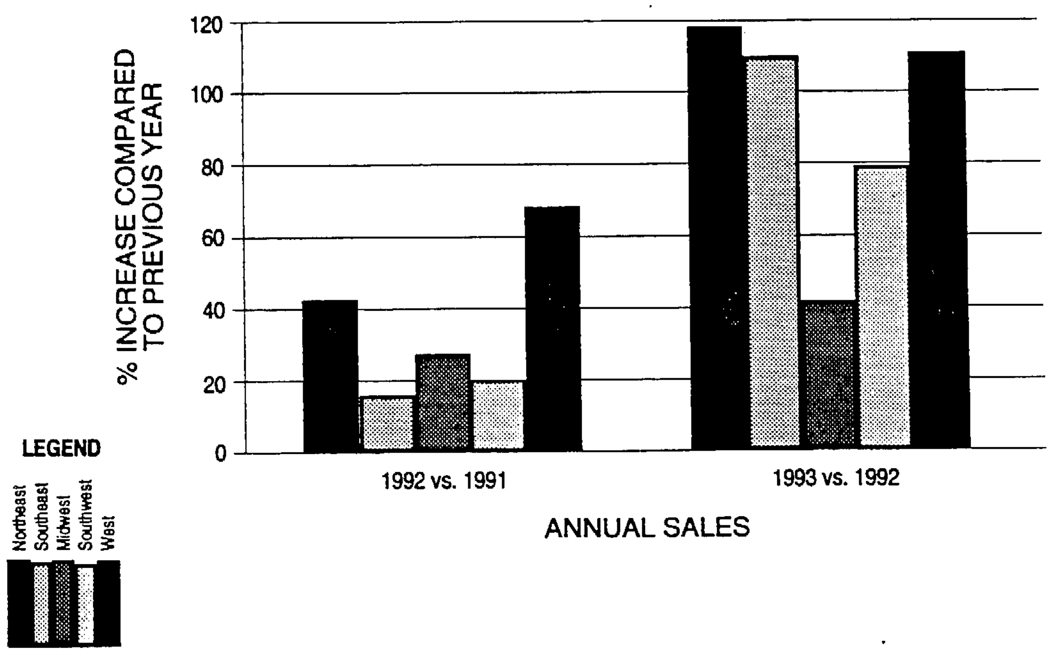


Figure 2-9. Pump Kit Sales by U.S. Region - Component Manufacturer C1

nationwide increase in C1 pump kit sales in 1993 as compared to 1992 coincides with the introduction of the California post-regulation diesel fuels and U.S. EPA low sulfur diesel fuel. (Note that C1 pumps are used in both LDD and HDD vehicles.)

The above data cumulatively point to the occurrence of fuel-related problems nationwide coinciding with the introduction of post-regulation and U.S. EPA low sulfur fuels. However, because of a shortage of numerical data from outside of California, the relative magnitude of these problems outside of California has not been determined. Note that some low sulfur fuel with reduced aromatics levels has been sold outside of California. Diesel fuel with aromatic levels as low as 10% was manufactured in Texas and reportedly shipped by pipeline to the midwestern and eastern U.S. While the distribution of this fuel correlates with reports of pump leaks, as shown in Figure 2-7, no additional evidence is available to directly connect this fuel with any fuel system problems.

2.4 Temporal Nature of Reported Problems

Question 5: What is the temporal nature of the reported mechanical problems? Are the problems potentially due to the new fuel? Currently, is the extent of the problems increasing, steady, or decreasing?

Based on historical data, an assessment was made to determine if a significant change occurred in the failure rate of diesel fuel injection system components after the introduction of the ARB and variance fuels. These data were collected through the end of January 1994 to evaluate whether the failure rate currently appears to be increasing, steady, or decreasing. Reports of leaks, repairs, and sales were provided by trucking fleets, repair shops, component manufacturers, and parts suppliers. The collected data sets covered California and the U.S. The most relevant data sets are discussed below.

2.4.1 National Trucking Fleet

A national trucking fleet that operates over 7,900 vehicles provided daily records of fuel pump leaks by shop location from October 18, 1993 through January 30, 1994. These leak data were summarized on a weekly basis, as illustrated in Figure 2-10. These data show that the number of component leaks that were reported peaked in late October-early November 1993. The failure rate currently appears to remain steady at approximately 20 component leaks per week. The national trucking fleet reports that, prior to the introduction of low sulfur fuel, they performed about 13 fuel pump repairs per month (about three per week).

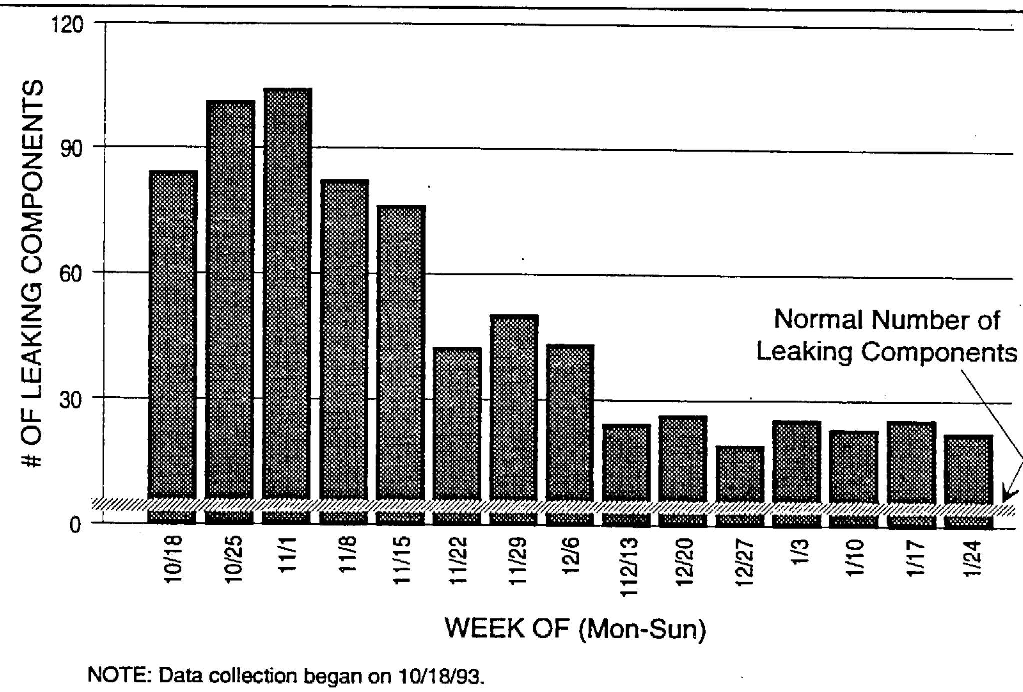


Figure 2-10. Fuel Pump Leaks Reported - National Trucking Fleet

2.4.2 California Parts Supplier

A major parts supplier for light duty trucks and automobiles provided popular pump seal and rebuild kit sales data for California. Annual totals were provided for 1992. For

1993, total figures were provided for January through September; monthly totals were provided for October, November, and December. Monthly sales data were also received for January 1994. Figure 2-11 presents all of these data on a monthly basis. The monthly sales totals began to increase dramatically in October 1993, and peaked in December 1993. Since then, the monthly sales rate decreased significantly for January 1994, but is still noticeably higher than the monthly average for 1992 and the first three quarters of 1993.

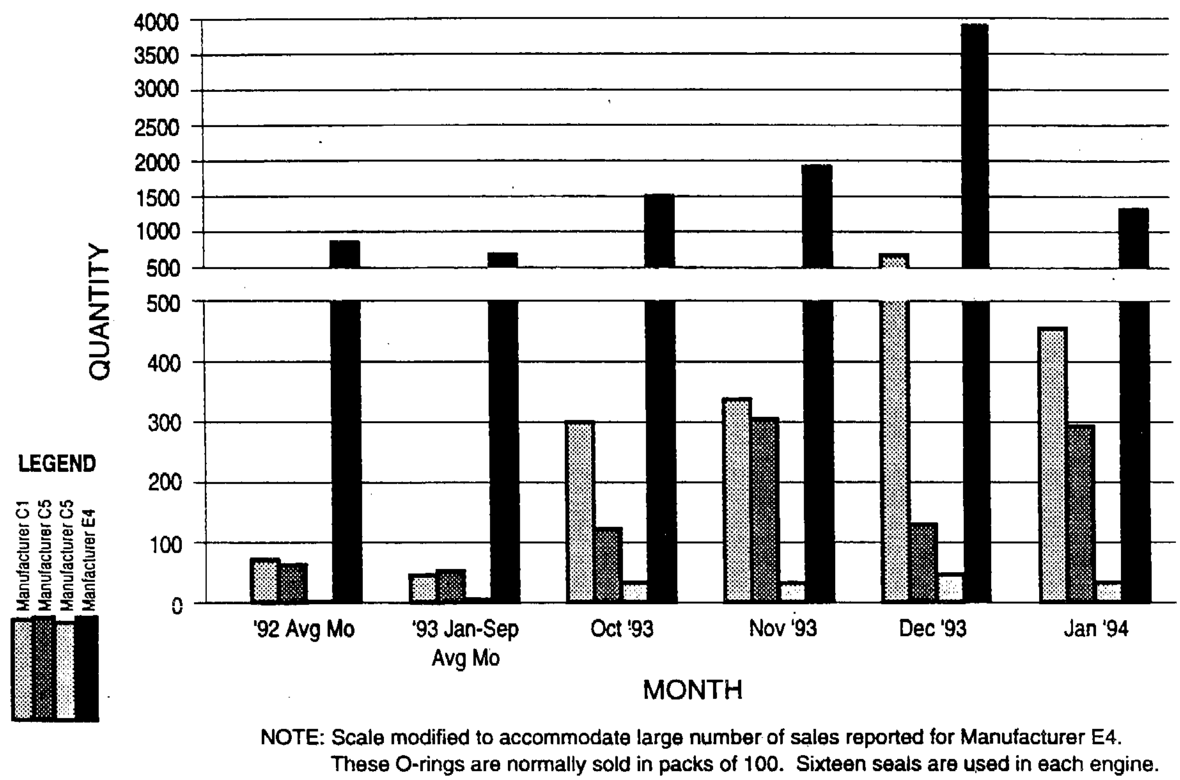


Figure 2-11. Popular Pump Seal and Rebuild Kit Sales - California Parts Supplier

2.4.3 National Component Manufacturer

Component manufacturer C1 gathered monthly pump kit sales data for 1993. These data were normalized based on January sales, as illustrated in Figure 2-12. Monthly sales totals were highest in October, November, and December, with monthly sales consistently increasing in this timeframe. January 1994 sales data were not available to further assess the continuing sales trend.

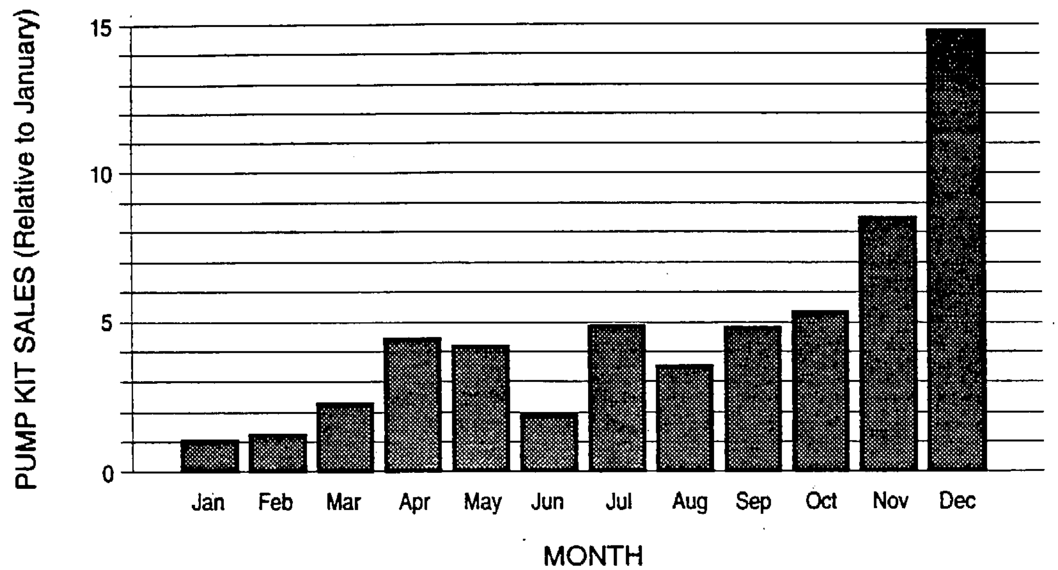


Figure 2-12. Monthly Pump Kit Sales for 1993 - National Component Manufacturer C1

2.4.4 National Engine Manufacturer

Monthly service sales for O-rings were gathered by component manufacturer E4 for January 1993 through January 1994, as shown in Figure 2-13. Nationwide sales totals began to increase dramatically in September, and in October and November reached levels more than four times the sales volume of the earlier months of 1993. The monthly sales rate has since decreased, but the January 1994 sales volume was still more than twice the level of January 1993.

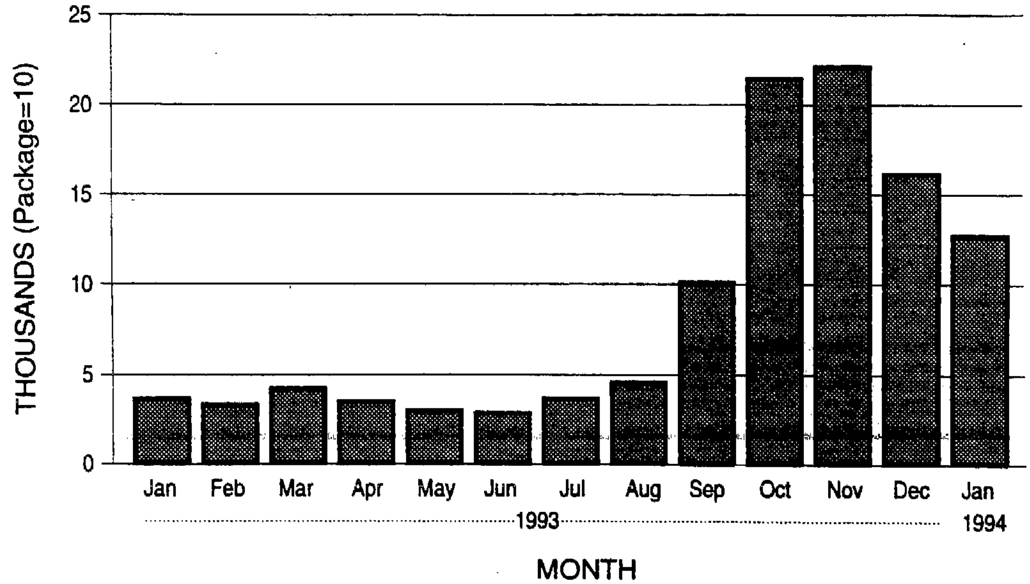


Figure 2-13. Monthly O-Ring Sales - National Engine Manufacturer

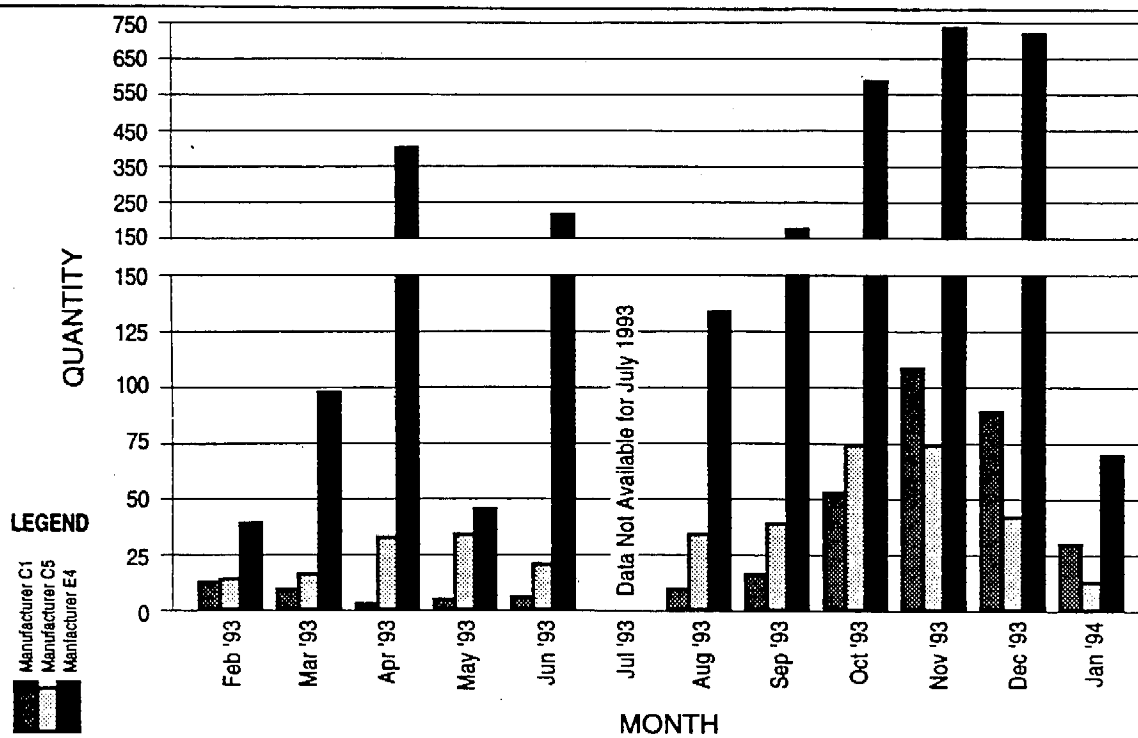
2.4.5 Northern California Repair Shop

A northern California repair shop supplied monthly parts sales totals for February 1993 through January 1994 for the same three branch locations. These monthly totals, illustrated in Figure 2-14, show that fourth quarter sales for 1993 were clearly higher than earlier in the year.

2.4.6 Additional Sales Data

Another repair shop supplied records of fuel injection pump kit sales from September 15, 1993 through January 31, 1994 for one of their northern California locations. Sales peaked in the November-early December timeframe and dropped off in January 1994. Historical data prior to the introduction of the new fuel were not available for comparison.

A parts supplier for fuel injection pump repair facilities throughout the country (with most of their customers clustered in the southeastern states) also provided sales data for monthly repair kit sales. From February 1993 through January 1994, the highest monthly sales



NOTE: Y-axis scale modified to accommodate large number of sales reported for Manufacturer E4. These O-rings are normally sold in packs of 100. Sixteen seals are used in each engine.

Figure 2-14. Northern California Repair Company Sales History (3 branches)

were reported for October and November. Since then, it appears that their overall sale rate has returned to normal.

The ARB repair facilities survey database included information to compare the number of pumps serviced in September-October 1992 and September-October 1993. Numerical and qualitative data were collected. Although approximately 40% of the responses indicated that more pumps were repaired in 1993 than in 1992, some repair shops reported fewer pump repairs in 1993.

2.4.7 Data Limitations

Sales and repair data are indirect indicators of failure rate, and should be interpreted with caution because of the conflicting factors of stockpiling and back orders. Stockpiling will tend to overestimate the failure rate, whereas back orders will underestimate the failure rate. In general, stockpiling and back orders were not significant issues for HDD vehicles. Most fleet repair shops had enough parts in stock to cover their repair needs until additional parts were received from suppliers. Some of the LDD vehicle repair shops experienced problems with back orders in early October when their business noticeably increased. Since no new LDD passenger cars have been sold in California from 1988 to 1993, some shops obtain parts from distant locations, resulting in a delay of one to two days.

More important than the back order of parts was the repair backlog due to a labor shortage. Most of the repairs required for the reported failures (e.g., seal replacement, fuel pump rebuild, etc.) take several hours. For economic reasons, many LDD vehicle owners choose to rebuild rather than replace major components. This option is more labor intensive. In addition, another confounding factor in the evaluation of sales and repair data is the influence of preventive maintenance. In general, the data do not allow the assessment of how many reported sales or repairs were preventive in nature.

2.5 Fuel Formulation and Relationship to Reported Problems

Question 6: Are there any apparent correlations between fuel formulation differences in samples analyzed thus far, and the reported mechanical problems? Is there any connection between fuel formulation and the geographic or temporal distribution of reported problems?

The results from the ARB Fuel Testing Program, the largest data set currently available on California diesel fuel properties, were analyzed to determine if there are any apparent correlations between fuel formulation and the reported mechanical problems. In this program, the ARB collected over 200 diesel samples throughout the state, starting in late October 1993 and continuing through November 1993. These samples were collected from refineries, retail distributors, and truck fuel tanks at inspection stations. The truck fuel tanks may have contained a mixture of post-regulation diesel fuels and U.S. EPA low sulfur diesel fuel.

Caleb Brett, an independent testing laboratory, analyzed the fuel samples for sulfur, total aromatics, polynuclear aromatics (PNA), moisture, peroxides, distillation properties, acid content, color, and density. The ARB laboratories analyzed the same samples for total aromatics and PNA. Data analysis performed for the 214 valid diesel samples indicated that the ranges of total aromatic content were 5.1 to 36.2 vol% as reported by ARB laboratories and 4.8 to 38 vol% as reported by Caleb Brett. (Caution must be used when comparing data from different laboratories because of the potential variability in test methodologies.) The PNA content values ranged from 0.1 to 12.4 wt%. Sulfur content in the fuel samples ranged from 0.001 to 0.435 wt% (i.e., 10-4350 ppm). Only eight samples had a sulfur content greater than the compliance limit of 0.05 wt% (i.e., 500 ppm). Of these eight, four samples were taken that were known to contain high sulfur (representing pre-regulation or agricultural fuels).

Diesel fuel production estimates from California refineries were used in conjunction with laboratory results to calculate weighted averages for the refinery samples in the ARB Fuel Testing Program. For the samples taken from retail distributors or vehicles, an analysis of variance (ANOVA) with the LSD (least significant difference) option was performed to evaluate data means. The LSD option performs t-tests for all of the specified parameter pairs one-by-one. The results of the t-tests indicate, with a 95% confidence level, which pairs are statistically different and which pairs are statistically the same.

The other relevant data set was provided by the CTA. Copies of fuel analyses prepared by W. Saybolt & Company, Inc. from October through December 1993 were analyzed. Most of the samples were submitted by companies in northern California. In all, 19 diesel samples were analyzed for total aromatics, olefins, and saturates. The total aromatic content ranged from 8.5 to 46.1 volume percent.

2.5.1 Correlations with Mechanical Problems

For the samples taken from vehicles in California, the ANOVA with the LSD option was performed to evaluate the means by vehicle seal failure (leak/no leak) and California region (north or south). The results of the t-tests did not indicate any significant differences in fuel analysis results between leaking and non-leaking vehicles for any of the fuel characteristics included in the laboratory results. The lack of direct correlation with mechanical problems may be influenced by other factors identified by Subcommittee #1, such as differences in elastomer seal material and "age" of seals. Further, there was no guarantee that the fuel sampled from vehicles with reported leaks was the same fuel that was in the vehicle when the leak occurred.

2.5.2 Connection with Geographic Distribution of Failures

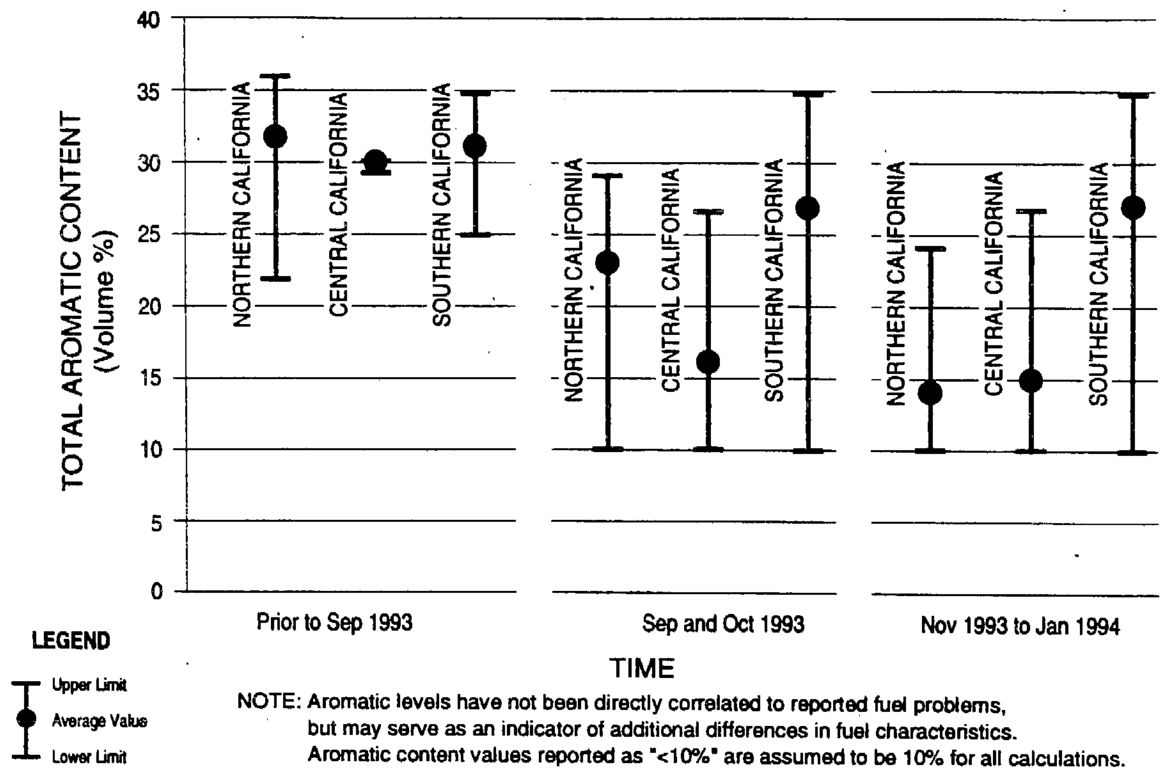
As previously presented in Section 2.3, the reported rate of seal failures in California has been greater for the northern part of the state. Estimated diesel fuel production volume data for 12 California refineries were used in conjunction with laboratory results to calculate weighted average aromatic content by north/south location for the refinery samples in the ARB Fuel Testing Program. These findings were previously shown in Figure 2-5.

2.5.3 Connection with Temporal Distribution of Failures

Unfortunately, fuel analyses data were not available for diesel fuels produced during the mid-September to late October time period. Performance problems including fuel system leaks began to appear in late September. Substantial documentation of performance problems was presented to the ARB at their mid-October 1993 public meeting. Therefore, the analyses of fuel sample data and how fuel composition may have caused performance problems is limited by lack of definitive analyses of fuels produced during the introduction of post-regulation diesel fuels in September and early October 1993.

To investigate the connection between fuel formulation and the temporal distribution of failures, diesel fuel production estimates and average fuel characteristics data were obtained for pre-regulation (prior to September 1993) and post-regulation (September-October 1993 and November 1993-January 1994) diesel fuels from 12 California refineries. These data, which included estimates of fuel quantities transferred between California regions, were used to calculate weighted averages of the total aromatic content for diesel fuel produced in northern, central, and southern California.

Figure 2-15 presents the results of this analysis and shows that, before the introduction of the post-regulation diesel fuels, the average total aromatic content (weighted by refinery production) was similar in all three regions. The data bounds indicate that the unweighted aromatic levels range from 22 to 36 vol% prior to September 1993 and from 10 to 35 vol% after the introduction of the post-regulation diesel fuels. In the September-October 1993 timeframe, the weighted average total aromatic content decreased by almost 10 percentage points in northern California, but decreased by only about 5 percentage points in southern California. The most dramatic change over this period was in central California, where the average total aromatic content of diesel fuels dropped by about 15 percentage points. Therefore, northern and central California experienced a greater change in average total aromatics content than southern California. This is also true for the change in average sulfur content since pre-regulation South Coast diesel fuel delivered in southern California already had a maximum limit of 0.05 wt% sulfur.



NOTE: Aromatic levels have not been directly correlated to reported fuel problems, but may serve as an indicator of additional differences in fuel characteristics. Aromatic content values reported as "<10%" are assumed to be 10% for all calculations.

Figure 2-15. Diesel Fuel Aromatic Content
(Average Values Weighted by Refinery Production Estimates)

3.0 FUEL SYSTEM LEAKAGE TESTING PROGRAMS

Subcommittee #2 of the Task Force met on January 5, 1994 to discuss the potential causes of seal leakage problems. In the absence of specific identified causes, Subcommittee #2 selected one potential seal failure mechanism for investigation.

This mechanism involves changes in the swelling of O-ring seals when exposed to fuels of differing characteristics. Many O-ring designs, particularly O-rings made of nitrile rubber, swell in the presence of diesel fuel. Considerable evidence shows that changes in fuel characteristics can lead to reduced swelling of O-ring seals. This reduced swelling, or shrinkage, of O-rings can lead to fuel leaks, particularly in O-rings that have reduced elasticity due to age, oxidation, or exposure to high temperatures.

Following the January 5, 1994 Subcommittee #2 meeting, another potential mechanism worthy of investigation by the subcommittee was identified. This mechanism, which has been addressed for several years by the petroleum industry, involves the potential for increased oxidation of the fuel to lead to deterioration of nitrile O-rings. Oxidation of the fuel forms peroxides, which can lead to hardening of nitrile O-rings. (Note that this potential oxidation mechanism usually occurs over a period of months.) This increased oxidation potential could arise from the fuel manufacturing process used to remove sulfur and aromatic species from diesel fuel. The manufacturing process of hydrotreating, depending on its severity, can remove natural inhibitors such as sulfur, nitrogen, and oxygen components from the fuel. To compensate, supplemental additives may need to be added by the refiner to increase the oxidation resistance of the fuel. If insufficient oxidation resistance is present in the fuel, the potential exists for deterioration of nitrile O-rings. Fuel manufacturers have been aware of this issue and many refineries have been adding oxidation inhibitors to diesel fuels.

Both of these mechanisms are discussed in greater detail in Appendix D. The testing programs established by Subcommittee #2 are designed to help determine if a change to a post-regulation diesel fuel could cause fuel system leaks to develop in some vehicles. These test programs are not designed to address the issue of reduced lubricity of the post-regulation diesel fuels; Section 4.0 contains the Subcommittee #3 report on lubricity issues.

3.1 Elements of Fuel System Leakage Testing Programs

To investigate these two mechanisms, three test programs were established by Subcommittee #2. The first two programs are examining the mechanism of reduced seal swell. The third program is examining existing fuel supplies to determine if some fuels are susceptible to increased oxidation.

The first program will test a variety of older high sulfur, U.S. EPA low sulfur, and post-regulation diesel fuels, and will examine their effects on O-ring seals. The second program will attempt to establish if switching from a fuel producing high seal swell to a fuel producing low seal swell could cause seal leakage. In the third program, a number of fuel samples will be collected from existing agricultural storage and retail outlets and tested for their oxidation stability. The detailed test protocols developed by Subcommittee #2 for each program are included in Appendix D.

3.1.1 Program #1: Seal Swell Testing of O-Rings

This program will examine the impact of different fuels on O-ring characteristics. Although the fact that various fuels have different effects on O-rings is well established, the specific fuel characteristics that cause these differences are not well known. This program actually includes three individual experiments. In the first experiment, differing types of nitrile O-rings will be immersed in a variety of diesel fuels, including post-regulation and U.S. EPA low sulfur diesel fuels. After the O-rings have equilibrated in the fuel (72 hours at 50°C), the O-rings will be removed and their characteristics measured. The measurements will include dimensional changes to gauge seal swell, changes in hardness, elasticity, and other characteristics.

While the test on O-rings is being performed, the fuels will be analyzed to determine their characteristics (including sulfur and aromatics levels, nitrogen content, and density, as described in Appendix D). The composition of the fuels will be measured using nuclear magnetic resonance (NMR) and Fourier Transform Infrared Spectroscopy (FTIR). Once the test results are complete, the data will be analyzed to determine if correlations exist between the O-ring test results and individual fuel characteristics.

The results of the first experiment will be used to identify four fuels for further testing in Experiments 2 and 3. The goal of these two experiments will be to measure the impact of switching from a fuel producing high seal swell to a fuel producing low seal swell. The four fuels chosen will include the two high sulfur fuels producing the highest and lowest seal swell changes and the two post-regulation or U.S. EPA low sulfur diesel fuels producing the highest and lowest seal swell changes. The O-rings will be immersed first in a high sulfur fuel, then in a post-regulation or U.S. EPA low sulfur diesel fuel. After immersion in each fuel, the characteristics of the O-rings (swelling and hardness) will be measured. All four possible combinations of high sulfur and post-regulation or U.S. EPA low sulfur diesel fuels will be tested.

Experiments 2 and 3 are identical, except that Experiment 2 will use new O-rings and Experiment 3 will use older O-rings taken from in-service vehicles. The older O-rings are being tested to determine if they have the same response to the high sulfur and post-regulation or U.S. EPA low sulfur diesel fuels as new O-rings.

3.1.2 Program #2: Leak Testing of In-Service Fuel Pumps

This program will attempt to establish in a controlled environment whether switching from a high seal swell diesel fuel to a low seal swell diesel fuel can cause fuel pumps to leak. New and used fuel pumps will be obtained and run first on a high seal swell diesel fuel, then switched to a low seal swell diesel fuel. The pumps will be run on the low seal swell diesel fuels to see if any leaks occur.

The specific pump type to be used in the test will be a type most commonly represented in the failure reports being examined by Subcommittee #1. Once the pump type is determined, 18 used pumps will be obtained from in-service vehicles. These pumps will be chosen from vehicles that have not suffered fuel leaks, but that are at or near the mileage where leaks have been reported. The type of vehicle service will also be taken into consideration, since higher engine temperatures tend to accelerate the deterioration of nitrile O-rings. Six new pumps will be obtained for use as a control group. The fuels will be chosen based on the results of Program #1. The two fuels will be the one that gives the highest seal swell results and the one that gives the lowest seal swell results.

All 24 pumps will be operated for 72 hours while pumping high seal swell diesel fuel. After 72 hours, 12 of the used pumps and all 6 of the new pumps will be switched to pumping the low seal swell diesel fuel for an additional 96 hours. The six remaining used pumps will continue to pump the high seal swell diesel fuel as a control group. The switch to the low seal swell diesel fuel is intended to determine if the change could directly cause a fuel pump leak due to seal shrinkage. Any pumps operating on low seal swell diesel fuel that develop leaks will be changed back to high seal swell diesel fuel after 96 hours to determine if the leaks can be reduced. The change back to pumping a high seal swell diesel fuel is only intended to establish further the potential interactions between fuel characteristics and seal leakage.

3.1.3 Program #3: Fuel Oxidation Potential Testing

The goal of this program will be to determine if increased oxidation potential is present in field samples of post-regulation diesel fuels. Fuel samples will be collected from existing agricultural storage tanks and from retail service stations. The fuels will be analyzed and tested to determine their ability to prevent oxidation. Note that this program is designed to determine if a potential oxidation problem exists, the program will not directly investigate the impact of fuel oxidation on O-ring performance. This impact of peroxides on nitrile seals appears to be well established, although the level of oxidation required to cause O-ring damage is not known. Complete investigation of the direct impact of diesel fuel peroxide content on nitrile seals requires a separate investigation. This could be pursued later based on the results of Program #3.

In the program, a total of 36 post-regulation and U.S. EPA low sulfur diesel fuel samples will be collected. They will include 24 samples collected from retail service stations and 12 samples collected from agricultural businesses. The characteristics of each fuel will be measured, including peroxide, water, sulfur, aromatics, nitrogen, carbon, and hydrogen levels; fuel density; aromatic species concentration; and distillation curve. While these analyses are being conducted, long-term tests at elevated temperatures (180 days at 43°C) will be run to measure the ability of the fuels to resist oxidation.

3.2 Status of the Testing Programs

As of February 15, 1994, the seal swell testing (Program #1) has begun. Fuel analyses are being conducted at Southwest Research Institute in San Antonio, Texas. Testing of O-rings will be conducted at Smithers Scientific Laboratories in Akron, Ohio. Experiment 1 of this seal swell program should require three weeks to complete. Experiments 2 and 3 of the seal swell program will begin immediately upon completion and analysis of the results from Experiment 1. Experiments 2 and 3 will require approximately three weeks to complete.

The testing of new and used fuel pumps (Program #2) will begin after the completion of the O-ring tests. The pump testing will be conducted at the U.S. Army Fuel and Lubricants Testing Laboratory in San Antonio, Texas. Assuming a start date of mid-March, the testing of all 24 pumps will require approximately 12 to 15 weeks to complete.

The fuel oxidation sampling and test program (Program #3) is currently underway. Fuel samples are being collected from agricultural and retail sources. Collection of the samples will be completed by early March. Completion of the full oxidation potential test requires six months.

3.3 Subcommittee #2 Recommendations on the Fuel System Leakage Problem

Recommendations from Subcommittee #2 depend on the completion of the testing programs described in Section 3.1. In the interim, Subcommittee #2 encourages pump and engine manufacturers to continue their ongoing investigations into the compatibility of elastomer materials with the post-regulation diesel fuels.

4.0 LUBRICITY AND OTHER PERFORMANCE CONCERNS

Diesel fuel functions as a lubricant to the moving components in many types of fuel injection equipment. The lubricating quality of diesel fuel is particularly important in rotary distributor injection pumps and unit injectors. Use of diesel fuels with inadequate lubricating capability can lead to premature wear, resulting in potential performance degradation, including fuel system seizures.

"Hydrotreating" (i.e., reaction of intermediate petroleum products with hydrogen) is used by refineries to reduce the sulfur and aromatic contents of diesel fuel. This process, which reduces trace components such as oxygen- and nitrogen-containing compounds and polycyclic aromatics, can result in reduced fuel lubricity. Therefore, if hydrotreating of diesel fuel is severe enough, it may result in a fuel with a low lubricity level, thus leading to excessive equipment wear and premature failure. Catastrophic failures associated with use of low sulfur/ low aromatic diesel fuel were first observed in Sweden in 1991, when diesel fuels with very low sulfur and very low aromatic levels were introduced. The problems were rectified by adding lubricity-enhancing additives to fuels exhibiting low lubricity characteristics. Addition of excessive quantities of certain lubricity additives can in itself lead to other problems, such as gum formation in lube oil and oil and fuel filter plugging.

Historically, there have been no perceived lubricity problems with high sulfur diesel fuels in the U.S. However, fuel injection equipment manufacturers, fuel users, and fuel suppliers have expressed concern regarding the reduced lubricity characteristics of some post-regulation diesel fuels. Numerous diesel equipment operators have also expressed concerns with increased fuel consumption.

Regarding lubricity concerns, the objectives of Subcommittee #3 were twofold:

1. To ensure equipment protection in the interim period before universal lubricity test methods and standards are established by technical societies; and

2. To restore consumer confidence in the lubricity potential of the reformulated diesel fuel.

4.1 Ongoing Lubricity-Related Activities

The concern over reformulated diesel fuel No. 2 has been the subject of a number of activities at technical groups and societies such as the Society of Automotive Engineers (SAE), the American Society for Testing and Materials (ASTM), and the International Organization of Standardization (ISO).

The ISO group, in cooperation with the Coordinating European Council (CEC), is in the process of defining laboratory bench tests to evaluate the lubricity characteristics of fuels and additives. A survey of proposed test methods was conducted. Four methods were selected as the most practical and relevant for use in a round-robin testing effort. These test methods and their respective sponsors are as follows:

- Modified Ball-on-Cylinder Lubricity Evaluator (BOCLE) test by the U.S. Army;
- A second modified BOCLE test by the Lubrizol Corporation;
- Ball on Three Seats (BOTS) test by the Falex Corporation; and
- High Frequency Reciprocating Rig (HFRR) test by the Paramins Technology Division of Exxon Chemical Ltd.

A test matrix including 12 fluids was designed. Effects of viscosity, sulfur content, processing severity, and additives were considered. All fuels were collected and shipped to test participants around the world. Test participants consisted of fuel suppliers, equipment manufacturers, additive suppliers, and independent test laboratories.

Several participants will use larger amounts of the same fuels and conduct in-house full-scale injection equipment tests. The goal of the ISO program is to generate sufficient data from these test methods and the equipment performance tests to select a single test method as the universal method for determining diesel fuel lubricity. The group also aims to produce sufficient information to define a minimum lubricity level to protect fuel delivery system components. The results of this study should become available within the next 12 months. A minimum of two years will be required to develop and approve an ASTM lubricity standard.

Discussions between the Engine Manufacturers Association (EMA) and the American Petroleum Institute (API) are in progress on various diesel fuel-related issues, including lubricity of highway diesel fuel No. 2, with the objective of developing suitable lubricity specifications. Recently, the EMA proposed a preliminary recommendation of a minimum BOCLE scuffing load capacity of 3,300 grams (g), below which there would be a concern for fuel lubricity. A diesel fuel task force at ASTM has also been addressing lubricity issues. ASTM will be in a position to consider a lubricity specification for inclusion in D 975, the *Standard Specification for Diesel Fuel Oils*, as soon as a test method has been identified.

4.2 Fuel Economy Issues

The hydrotreating process that reduces the diesel fuel sulfur and aromatic levels can also lead to reduced fuel density. The reduced density in turn may lead to reduced fuel economy. This issue was anticipated when the reformulation requirements were being considered and was discussed in public hearings held by ARB on the proposed regulations for diesel fuel.

Since the Diesel Fuel Task Force was directed by the Governor to address potential mechanical damage caused by the new diesel fuel, the issue of reduced fuel economy was not addressed further by Subcommittee #3.

4.3 Conclusions and Recommendations

Regarding the lubricity of the post-regulation diesel fuel No. 2 in California, Subcommittee #3 recommends that:

- Interim steps be taken prior to establishing an ISO test method/ASTM lubricity specification to ensure equipment protection and to restore consumer confidence in the lubricating potential of the post-regulation diesel fuels.

- Petroleum manufacturers monitor diesel fuel lubricity using the U.S. Army modified BOCLE test or other appropriate tests to determine the lubricity level of the fuel.

- Petroleum manufacturers maintain pre-regulation lubricity levels or add lubricity-enhancing additives to diesel fuel with a BOCLE scuffing load capacity of less than 3,000 g, with due regard to recommendations of additive suppliers. This interim recommended action reflects the view of Subcommittee #3 and is not intended to be a lubricity guideline, standard, or specification.

- Equipment owners seek the advice of equipment manufacturers prior to adding any additives or oil to diesel fuel. Addition of used oil to diesel fuel in California is a violation of the California hazardous waste regulations.

APPENDIX A

ESTIMATED PRODUCTION OF ON-ROAD MOTOR VEHICLE DIESEL FUEL BY TYPE

ESTIMATED PRODUCTION OF ON-ROAD DIESEL FUEL IN CALIFORNIA BY FUEL TYPE

Fuel Type	September 1993 - October 1993	November 1993 - January 1994
< 10 % aromatics	12%	36%
Equivalent alternative formulations	12%	13%
Temporary California low sulfur	40%	18%
Small and independent refiner	36%	33%

Since September 1993, a number of fuels of varying characteristics have been present in the California market. The following definitions are referred to in the above table:

- High sulfur diesel fuel. This pre-regulation fuel was available for sale in California prior to the October 1, 1993 regulation. A large majority of these fuels typically have sulfur levels of approximately 0.30 percent by weight (wt%) and typical aromatics levels of 30%, with most fuels in the range of 20–40% aromatics. In October 1993, an emergency exemption was granted allowing the sale of high sulfur diesel fuel for off-road use in California for 45 days and its transfer into off-road vehicles for 120 days.

- Pre-regulation South Coast diesel fuel. As early as 1985, diesel fuel with a maximum limit of 0.05 wt% sulfur was sold in the greater Los Angeles area. This fuel was very similar in sulfur and aromatics levels to the current U.S. EPA low sulfur fuel.

- U.S. EPA low sulfur diesel fuel. This fuel was mandated for use in on-highway vehicles on October 1, 1993. The fuel must meet a maximum 0.05 wt% limit for sulfur content, and a minimum 40 cetane index or maximum 35% aromatics by volume (vol%). This fuel has the same characteristics as the "temporary California low sulfur" fuel defined below. However, the term "U.S. EPA fuel" will be used in the report when referring to on-road diesel fuel used outside of California.

- Low sulfur/reduced aromatics diesel fuel. These fuels are mandated by the October 1, 1993 Air Resources Board (ARB) regulation and fall into one of three classes, depending on aromatics content (as measured in volume % [vol%]). All three classes limit maximum sulfur levels to 0.05 wt%. The three classes are:

- Less than 10 vol% aromatics fuel. Note that aromatics levels can be averaged within a refinery's production. Therefore, some fuels in this class may exceed 10 vol% aromatics, while others may be well below 10 vol% aromatics.

- Alternative formulations that have been shown through testing to produce emissions equivalent to a 10 vol% aromatics fuel. Currently, aromatic levels of this class typically range from 15 vol% to mid-twenty percent.

- Small and independent refiner exempt fuel. These fuels must meet a 20 vol% aromatics limit. As with the less than 10 vol% aromatics fuels, this 20 vol% aromatics limit can be achieved by averaging of production.

- Temporary California low sulfur diesel fuel. To ensure adequate fuel supplies during the transition to the post-regulation diesel fuel, some temporary variances were granted by ARB for refineries to produce and distribute fuel meeting U.S. EPA low sulfur diesel fuel specifications for on-highway diesel fuels. In addition, small refiners were allowed one-year exemptions from the requirement to produce 20 vol% aromatics fuel. However, these fuels from small refiners must still meet U.S. EPA low sulfur diesel fuel specifications, including the 0.05 wt% sulfur limit. The aromatics level is not subject to the 10 vol% limit and typically ranges from 25 vol% to 35 vol%.

The fuels present in the on-road California diesel fuel market since September 1993, have included low sulfur/reduced aromatics diesel fuel and temporary California low sulfur diesel fuel.

APPENDIX B

LIST OF REFERENCES — DIESEL FUEL TASK FORCE

List of References — Diesel Fuel Task Force

Author/Agency/Company	Date Generated	Title/Subject	Format (hardcopy, electronic)[1]
1991-92 International Directory of Members Products and Services	Not specified	ADS: Managing Change in the '90s. *Diesel Progress - Engines and Drives.*	HC
American Medical Response West (B. Sadler)	2/4/94	Master O-ring seal replacement data.	HC
American Trucking Association (A. Schaefer)	Not Specified	Table: *Diesel Fuel-Related Engine Problems.*	HC
Amoco	10/7/93	Low-sulfur distillate memo to commercial and industrial customers.	HC
ARB[1] (L. Haslett)	10/1-22/93	Fax to N. Dickson, Radian. Subject: project log — equipment problems associated with low sulfur diesel fuel.	HC
ARB[2] (P. Jacobs)	10/27/93	*Clean Diesel Fuel Performance Problems Investigation* - presented to the California Farm Bureau Board of Directors.	HC
ARB[3] (C. Ross)	10/31/93	Memo to D. Gaslan. Subject: Survey on low-sulfur diesel fuel usage throughout southern California.	HC
ARB[4]	11/1/93	Preliminary report: *Clean Diesel Fuel Performance Problems Investigation* (survey information and hotline complaint tallies attached).	HC
ARB[5]	11/8/93	*Clean Diesel Fuel Performance Problems Investigation* - presented to the Diesel Fuel Advisory Committee.	HC
ARB[6]	11/14/93	National incidence of fuel pump leaks (data from Schneider National Trucking Company).	HC
ARB[7]	11/16/93, 11/22/93	Diesel project results, sample log for diesel samples.	HC
ARB[8] (D. Chernich)	11/17/93	Memo to P. Jacobs, ARB. Subject: Kern Oil and Texaco diesel fuel investigation in Bakersfield, CA, 11/17/93.	HC
ARB[9] (D. Chernich)	11/17/93	Memo to P. Jacobs. Subject: Large California intra-state carriers' experience with ARB diesel.	HC
ARB[10]	12/6/93	U S EPA Diesel Fuel Injection System "O-Ring" Meeting summary	HC

List of References — Diesel Fuel Task Force (Continued)

Author/Agency/Company	Date Generated	Title/Subject	Format (hardcopy, electronic)[1]
ARB[11]	12/9/93	Summary of Diesel Fuel Analyses 10/29/93-12/7/93.	HC
ARB[12] (B. Loscutoff)	12/20/93	Memo to M. Scheible, ARB. Subject: Review of farm survey information.	HC
ARB[13]	12/27/93	Diesel Fuels Investigation - PC data files repository on SCOSYSV.ARB.CA.GOV.	HC (index) and E
ARB[14]	revised 12/27/93	Diesel Fuel Decoder Table - Northern California.	HC
ARB[15] (D. Chernich)	12/28/93	Fax to N. Dickson and B. Oliver, Radian. Subject: Diesel Fuel Investigation Database Dictionary, examples of source documents available to Radian from ARB.	HC
ARB[16]	12/30/93 revised 1/3/94	*Lubricity and Characteristic Determination of Diesel Fuels from California Refineries.*	HC
ARB[17] (P. Jacobs)	1/10/94	Fax to B. Oliver, Radian. Subject: List of county farm bureaus.	HC
ARB[18] (B. Loscutoff)	1/11/94	Fax to B. Oliver, Radian. Subject: Correspondence regarding agricultural equipment survey.	HC
ARB[19] (P. Jacobs)	1/12/94	Fax to N. Dickson. Subject: Bosch and Schneider data.	HC
ARB[20] (P. Jacobs)	1/14/94	Fax to N. Dickson and L. Markovich, Radian. Subject: Coast Fuel Injection monthly sales data.	HC
ARB[21] (P. Jacobs)	1/19/94	Fax to N. Dickson, Radian. Subject: DynoData Heavy Duty Diesel Fuel Pump Repair Comparison (1992-1993 Report).	HC
ARB[22] (M. Houghton)	1/20/94	Fax to R. Henning, Radian. Subject: Hotline survey form anomalies.	HC
ARB[23] (M. Houghton)	1/20/94	Fax to L. Markovich, Radian. Subject: Graphs of pump shop data from Coast Fuel Injection and Diamond Diesel (Oakland and West Sacramento).	HC
ARB[24] (C. Abdul-Karim)	1/26/94	Fax to L. Markovich, Radian. Subject: Sample log for diesel samples.	HC

List of References — Diesel Fuel Task Force (Continued)

Author/Agency/Company	Date Generated	Title/Subject	Format (hardcopy, electronic)[1]
ARB[25]	1/26/94	Computer database of information gathered during ARB staff visits to truck fleet headquarters statewide, INSPECT1.DB.	E
ARB[26]	2/94	"Assessment of Fuel Leaks in Light and Medium Duty Vehicles," Preliminary Draft.	HC
ARB[27]	Not specified	List of correspondence documenting nationwide diesel fuel leak problem.	HC
ARB[28]	Not specified	Cumulative roadside data statewide.	HC
ARB[29]	Not specified	Diesel field survey results - north and south.	HC
ARB[30]	Not specified	Composite October/November/December repair kit/O-ring replacement sales numbers.	HC
ARB[31] (M. Burnitzki)	Not Specified	List of Bosch service dealers.	HC
ARB[32]	Various	Miscellaneous news articles and manufacturers' position statements.	HC
ARB[33]	Various	Pump shop/dealership/fleet repair facility/independent repair facility data logs.	HC
ARB[34]	Various	Coast Fuel Injection pump shop data.	HC, E
ARB[35] (G. Klaas)	Various	Light duty diesel survey.	E
ARB[36] (P. Jacobs)	Various	File given to N. Dickson, Radian. Subject: Various materials related to the diesel fuel question copied from files of ARB employees.	HC
ARB[37]	Various	Light Duty Diesel Phone Survey.	E
ARCO[1] (M. Payne and M. Fraytet)	12/28/93	Fax to N. Dickson, Radian. Subject: Diesel O-ring failures.	HC
ARCO[2] (M. Payne)	1/3/94	Fax to N. Dickson, Radian. Subject: O-ring swelling with commercial diesel fuels.	HC
ASTM Designation: D 1414-78	Not specified	Standard methods of testing rubber O-rings.	HC

List of References — Diesel Fuel Task Force
(Continued)

Author/Agency/Company	Date Generated	Title/Subject	Format (hardcopy, electronic)[1]
Association of Diesel Specialists[1] (D. Fehling)	10/27/93	Fax to P. Jacobs. Subject: Articles in *Transport Topics*: "Fuel Pump Leaks Tied to Low Sulfur" (10/11/93); "Cause of O-Ring Failures Continues to be a Puzzle," (10/18/93).	HC
Association of Diesel Specialists[2] (D. Fehling)	11/10/93	Fax to P. Jacobs (ARB). Subject: Low-sulfur fuel.	HC
M. Booth and P.E. Wolveridge	8/16/93	"Severe Hydrotreating of Diesel Can Cause Fuel-Injector Pump Failure," *Oil and Gas Journal*.	HC
Robert Bosch Corporation[1] (T. Novak)	11/18/93 updated 1/12/94	Sales figures.	HC
Robert Bosch Corporation[2]	1986	*Automotive Handbook* (2nd Edition).	HC
BP Oil	10/6/93	In-house update on diesel fuel injection equipment leakage.	HC
C. Bovington and R. Caprotti (Exxon Chemical)	5/5-7/93	*Latest Diesel Fuel Additive Technology With Particular Reference to Lubricity* - paper given at the Fourth International Symposium on the Performance Evaluation of Automotive Fuels and Lubricants. Birmingham, U.K.	HC
California State Automobile Association (A. Amerson)	12/30/93	Fax to K. Rasmussen, CTA. Subject: California diesel fuel problems.	HC
B. Cassidy (Editor, *Transport Topics*)	Various	Fax to J. Corbett, Radian. Subject: Articles in *Transport Topics*: "Fuel Pump Leaks Tied to Low Sulfur," (10/11/93); "Cause of O-Ring Failures Continues to be a Puzzle," (10/18/93); "O-Ring Failures Point to Need for Testing of Alternative Fuels," (10/18/93); and "Leaking O-Rings," (*Fleet Owner*, 1/94).	HC
Chevron[1]	9/28/93	Summary of responses from questionnaire entitled *Questions Concerning Fuel System Problems Using Low Sulfur Diesel*.	HC
Chevron[2]	10/93	Technical bulletin: Fuel leaks from seals of vehicles using low-sulfur diesel.	HC
Chevron[3] (R. Barber)	12/30/93	Fax to N. Dickson, Radian. Subject: API input to the California Governor's Diesel Fuel Task Force - Subcommittee #1.	HC

List of References — Diesel Fuel Task Force
(Continued)

Author/Agency/Company	Date Generated	Title/Subject	Format (hardcopy, electronic)[1]
CIOMA[1] (E. Gibson)	1/3/94	Fax to M. Thomas, CTA. Subject: CEC reports showing the capacity of state refineries and data from ARB indicating volumes of diesel produced by various refineries.	HC
CIOMA[2] (E. Gibson)	Various	Fax to N. Bokides, CIOMA, and M. Thomas, CTA. Subject: Engine problem reports related to ARB diesel.	HC
CIOMA[3] (N. Bokides)	Various	Fax to N. Dickson, Radian. Subject: Engine problems related to ARB diesel.	HC
CIOMA[4] (E. Gibson)	1/9/94	Fax to N. Dickson, Radian. Subject: Engine Damage Report from Ramona Oil Company, Inc.	HC
Coast Fuel Injection	Not specified	Sales data of replacement parts - through 1/7/94	HC
CTA[1]	12/20/93	Diesel fuel investigation database.	HC (data dictionary) and E
CTA[2] (M. Thomas)	12/21/93	Interoffice memo to K. Rasmussen, CTA. Subject: Damage report information.	HC
CTA[3]	12/31/93	List of people who have received surveys, but not yet responded.	HC
CTA[4] (M. Thomas) - 3 copies	12/31/93	Memo to N. Dickson, Radian. Subject: Diesel fuel problem identification.	HC
CTA[5] (M. Thomas)	1/5/94	Memo to B. Borzelleri, Cal/EPA. Subject: Fuel/component testing.	HC
CTA[6]	2/2/94	CARB Form WK1 Database.	E
CTA[7]	Various	ARB Diesel Hotline complaints - assorted reports and inspection forms.	HC
CTA[8]	Various	Computer database of diesel fuel system failures reported CTA, CARBFORM.DBF.	HC and E
CTA[9]	Various	Diesel fuel failure report (computer printout).	HC
CTA[10]	Various	Fuel analysis data (lab report).	HC
Cummins Cal Pacific, Inc.	2/4/94	Fax to P. Jacobs (ARB). Subject: Sales data for throttle shaft O-rings.	HC

List of References — Diesel Fuel Task Force

(Continued)

Author/Agency/Company	Date Generated	Title/Subject	Format (hardcopy, electronic)[1]
Cummins Engine Company, Inc.[1]	10/1/93	Letter to L. Haslett, U.S. EPA. Subject: Response to customer complaints resulting from use of low-sulfur fuel.	HC
Cummins Engine Company, Inc.[2] (S. Butler)	12/21/93	Letter to K. Rasmussen, CTA. Subject: Engine information relevant to the Diesel Fuel Task Force.	HC
Cummins Engine Company, Inc.[3] (I. Kohen)	1/3/94	Fax to M. Thomas, CTA. Subject: Fuel pump maintenance procedures, and rebuilding and calibrating requirements.	HC
Cummins Engine Company, Inc.[4] (B. Jorgensen)	2/8/94	Cummins nationwide O-ring sales data.	HC
Deere	10/1/93	Product support bulletin. Subject: Fuel injection pump wear or internal failures caused by low-sulfur fuels.	HC
Detroit Diesel (J. Fisher)	2/1/94	Fax to N. Dickson, Radian. Subject: California Diesel Fuel Failure Report.	HC
Diamond Diesel Service, Inc.[1]	Not specified	Table summarizing fuel injection pump repairs in Oakland and Sacramento, CA stores, 10/20/92 - 12/20/92 and 10/20/93 - 12/30/93.	HC
Diamond Diesel Service, Inc.[2]	Various	Electronic data on repairs performed per month per engine type.	E
Diesel Fuel Advisory Committee	11/15/93	Report to Governor P. Wilson, *Report and Recommendations*.	HC
J.R. Dunn and R.G. Vara (Polysar Limited)	Not specified	Fax to N. Dickson, Radian. Subject: "Fuel Resistance and Fuel Permeability of NBR and NBR Blends."	HC
Engine Manufacturers Association[1] (G. Keller)	10/25/93	Letter to C. DiBona, API. Subject: Request that API provide EMA with information on current fuel composition, and that the API/EMA diesel fuel task force meet in 11/93.	HC
Engine Manufacturers Association[2] (G. Keller)	1/17/94	Fax to V. Sadeghi, Radian. Subject: Listing of engine manufacturers.	HC
J.W. Hadley and B. Mills (Liverpool John Moores University)	5/5-7/93	*The Influence of Composition on the Lubricity of Diesel Fuels* - paper given at the Fourth International Symposium on the Performance Evaluation of Automotive Fuels and Lubricants Birmingham, U.K.	HC

List of References — Diesel Fuel Task Force

(Continued)

Author/Agency/Company	Date Generated	Title/Subject	Format (hardcopy, electronic)[1]
J.W. Hadley (Liverpool Polytechnic)	Not specified	*BTC Status Report on Diesel Fuel Lubricity*	HC
E. Kates and W. Luck	1977	*Diesel and High Compression Gas Engines* (3rd Edition). Chicago: American Technical Society.	HC
K. Krieger (Robert Bosch GmbH Stuttgart)	11/19-20/92	*Environmentally Friendly Diesel Fuel -- Conclusions from Experience with Robert Bosch Diesel Injection Systems*, presented at the AGELFI 11th European Automotive Symposium, Sorrento.	HC
H.G. Makelim Company (G. Firchow)	12/21/93	Memo to P. Jacobs, ARB and M. Thomas, CTA. Subject: Updated sales numbers - through December 20, 1993.	HC
Mercedes-Benz Service Corporation	1/26/94	Letter to P.. Jacobs, ARB. Subject: Number of spare parts for the diesel injection system shipped to distribution centers.	HC
Miscellaneous Trucking Companies	Various	Responses to American Trucking Associations' request in the 10/8/93 Truck Line Letter No. 16 for information about fuel cost increases and mechanical/ performance problems.	HC
Navistar[1] (F. Bondarowicz)	11/10/93	Fax to R. Ianni, ARB. Subject: Tabulation of fuel analysis from the AMR ambulance fleet in California.	HC
Navistar[2]	12/14/93	Navistar O-Ring Report to California EPA Diesel Fuel Task Force.	HC
Navistar[3]	1/4/94	Fax to CTA. Subject: Service Manual - Injection Pump, Nozzles, Fuel Filter, Supply Pump, and Glow Plugs.	HC
Navistar[4] (F. Bondarowicz)	2/8/94	Updated information about monthly O-ring sales.	HC
Owner Operator Services	11/3/93	Power Service Technical Bulletin - Low-sulfur fuels lubrication update.	HC
Parker Seals (R. Barbarin)	12/22/93	Letter to B. Borzelleri. Subject: Suggestions to Subcommittee #1 on cause analysis.	HC
Peterson Cat	1/4/94	Fax to M. Thomas, CTA. Subject: Maintenance management schedule.	HC
T.L. Pugh	10/84	"Evaluation of Fluoroelastomers for Oil Field Service" (name of publishing journal not specified).	HC

List of References — Diesel Fuel Task Force

(Continued)

Author/Agency/Company	Date Generated	Title/Subject	Format (hardcopy, electronic)[1]
Radian Corporation[1]	1983-1993	Results of literature search using combination of "Diesel," "Seals," "Aromatics," and "Hydrotreating" as key words.	HC
Radian Corporation[2]	12/21/93	Notes from December 21, 1993 meeting of Cal/EPA Task Force -- Problem Identification Subcommittee.	HC
Riverside County Superintendent of Schools[1] (D.S. Holmes)	12/14/93	Memo to J. Stock, Secretary for Environmental Protection and Chair of the Diesel Fuel Task Force. Subject: Preliminary results of the school transportation coalition survey.	HC
Riverside County Superintendent of Schools[2] (D.S. Holmes)	1/2/94	Memo to J. Strock, Cal/EPA. Subject: Updated Results of the School Transportation Coalition Survey.	HC
Rodriguez, Ferdinand	1982	*Principles of Polymer Systems* (2nd Edition). New York: McGraw-Hill.	HC
SAE International Technical Paper Series	2/24-28/92	*Lubricity of Low Aromatics Diesel Fuel* by M. Nikanjam and P. Henderson; *Development of the First CARB-Certified California Alternative Diesel Fuel* by M. Nikanjam; and *Lubricity of Low Sulfur Diesel Fuels* by M. Nikanjam and P. Henderson.	HC
Santa Rosa, City of	1/31/94	City of Santa Rosa, California — List of diesel fuel failures from 9/21/93 to 1/31/94.	HC
Schneider National[1] (S. Duley)	11/4/93	Letter to P. Jacobs, ARB. Subject: Fuel leakage incidents related to low sulfur fuel.	HC
Schneider National[2] Fuels Department (H. Hoeft)	1/13/94	Fax to B. Oliver, Radian. Subject: Table on fuel pump leaks by shop location by day.	HC
Schneider National[3]	1/20/94	Fax to ARB. Subject: Fuel leak problems.	HC
Schneider National[4] (S. Duley)	1/31/94	Fax to L. Markovich, Radian. Subject: Fuel pump leak by shop location by day.	HC
E. Schulz and B. Evridge	1989	*Diesel Mechanics* (3rd Edition). New York: McGraw-Hill.	HC
Stanadyne Automotive[1] (P. Henderson)	9/23/93	Memo to various engine/component manufacturers. Subject: Low-sulfur/low-aromatics fuel - elastomer compatibility.	HC

List of References — Diesel Fuel Task Force
(Continued)

Author/Agency/Company	Date Generated	Title/Subject	Format (hardcopy, electronic)[1]
Stanadyne Automotive[2] (P. Henderson)	12/13/93	*Environmentally Friendly Diesel Fuel and Lubricity - Injection Equipment Concerns and Assessment Method Development.*	HC
Stanadyne Automotive[3] (P. Henderson)	12/23/93	Letter to members of Subcommittee #2. Subject: January 6 meeting.	HC
Stanadyne Automotive[4] (P. Henderson)	1/19/94	Fax to F. Cameron, ARB. Subject: Jan 17 memo from K. Rasmussen regarding draft interim Technical Memorandum - CTA comments.	HC
U.S. EPA (M. Smith)	10/28/93	Memo to Regional Air Directors. Subject: Diesel desulfurization regulations - complaints concerning leaking fuel pumps.	HC
J. Vardi and B.J. Kraus (Exxon Research and Engineering Company)	Not specified	Fax to N. Dickson, Radian. Subject: Abstract and introduction to SAE paper entitled "Peroxide Formation in Low Sulfur Automotive Diesel Fuels."	HC
Various	Various	Various newspaper articles of reported diesel fuel-related problems.	HC
Volvo[1] (A. Roj and L. Megas)	11/18/93	*Environmentally Friendly Diesel Fuels -- The Swedish Experience.*	HC
Volvo[2] (A. Roj)	12/17/93	Fax to T. Chang, ARB. Subject: Low-sulfur/low-aromatics fuel experience in Sweden.	HC
Volvo[3] (A. Roj)	1/5/94	Fax to M. Thomas, CTA. Subject: Seals and lubricity - low-sulfur fuels in Sweden.	HC
Volvo[4]	2/3/94, 2/9/94	Fax to P. Jacobs, ARB. Subject: Diesel fuel injection system warranty claims data/passenger cars.	HC
D. Wei and H.A. Spikes	1/29/86	*The Lubricity of Diesel Fuels* (publishing journal not specified).	HC
P. Wilson (Governor of California)	11/19/93	Letter to Daniel Wm. Fessler, President of the California Public Utilities Commission. Subject: Diesel Fuel Task Force responsibilities.	HC
Not Specified	Not specified	Composite October/November/December repair kits/O-ring replacement sales.	HC

[1] HC = hardcopy. E = electronic.

APPENDIX C

SPREADSHEET LISTING OF PEOPLE AND ORGANIZATIONS CONTACTED BY SUBCOMMITTEE #1

CONTACT LIST FOR DIESEL FUEL TASK FORCE

Business	Individual	Date Cont.	By	Comments
FLEETS				
Viking Freight Systems	Carroll Pinkley	1/31/94	LJM	re: repeat leaks, etc.
AMR (Amer. Med. Response)	Bill Sadler	1/26/94	LJM	re: repeat leaks, etc.
U-HAUL	Janet Cooper	1/26/94	VMS	nationwide leaks; no cooperation so far
Albertsons	Bob Yamamura	1/26/94	VMS	everything; RCH and LJM take note
Pepsi Cola	Gary Palmer	1/26/94	VMS	everything; RCH and LJM take note
Pepsi Cola	Bud Knoop	1/27/94	VMS	problems in Dayton Ohi Bud Knoop
Pepsi Cola	Rich Garrimone	1/27/94	VMS	no problems in Denver
Pepsi Cola	Ed Wakefield	1/27/94	VMS	no problems in Phoenix, AZ
Scrivner Inc.	Pat Murrey	1/27/94	RCH	Experience with EPA fuel & additives
Schneider National	Steve Duley	1/28/94	LJM	re: repeat leaks, etc./update FAX rec'd 1/31
Schneider National	Joe Schaffer	1/31/94	JJC	Nationwide exp. no contact yet
Ruan	Jerry Anderson	1/28/94	LJM	re: repeat leaks, etc./no further probs?
CFL(Certified Freight)	Ed Bill	1/28/94	LJM	re: repeat leaks, etc.
Bettendorf Trucking	Robert Phipps	1/27/94	RCH	Repeat & Viton Failures
City of Santa Rosa	Chuck Hammond	1/31/94	RCH	Repeat & Viton Failures
GI Trucking	Bud Bradley	1/31/94	JJC	Operational problems with new fuels
Giannini Trucking	Joe Giannini	2/1/94	LJM	Re: low mileage, etc.
LJ Transport	Arnold	2/1/94	LJM	Re: low mileage, etc.
Wholesale Cedar Products	Pat Faulkner	2/1/94	LJM	Re: low mileage, etc.
City of Fresno	Richard Mehelic	2/2/94	LJM	Re: low mileage, etc.
Case Construction Co.	Leroy	2/1/94	LJM	Re: low mileage, etc.
McGovern Trucking	Stacy McGovern	2/1/94	LJM	Re: low mileage, etc.
Ryder	Blaine Johnson	1/31/94	JJC	nationwide exp. left message
Penske Truck Leasing	Ron Linderman	1/31/94	JJC	Wrong contact for topic
Penske Truck Leasing	Dave Hahn	1/31/94	JJC	Nationwide exp.
Penske Truck Leasing	Ed Bochniak	2/03/94	JJC	Operational Problems with new fuels

CONTACT LIST FOR DIESEL FUEL TASK FORCE

Business	Individual	Date Cont.	By	Comments
FLEETS (continued)				
UPS	Don Parkinson	1/31/94	JJC	Nationwide exp.
J.B. Hunt	Dale Greathouse	1/31/94	JJC	Nationwide exp.
So Cal Rapid Transit	John Petres	1/31/94	JJC	left 2 messages
Panella Trucking	Leroy Ehlers	2/2/94	LJM	Re: low mileage, etc.
WHM Trucking	William Murray	2/2/94	LJM	Re: low mileage, etc.
Waste Mngmt,Fresno	Paul Stambaugh	2/2/94	LJM	Re: low mileage, etc.

PRIVATE INDIVIDUALS

22 private individuals were contacted regarding reports of repeat leaks and low mileage leaks. Names withheld.

CONTACT LIST FOR DIESEL FUEL TASK FORCE

Business	Individual	Date Cont.	By	Comments
REPAIR SHOPS				
Diesel Control Systems	Jim Griffith	1/17/94	RCH	Ag Pump Shop in SJV, very helpful
Diesel Control Systems	Jim Griffith	1/25/94	RCH	Ag Pump Shop in SJV, very helpful
Mosier Implement (SAC)	Derrel Mosier	1/19/94	RCH	John Deere experience
German Auto Service	John Dobson	1/25/94	VMS	Mercedes Benz, has parts
Dynodata Inc.	Gene Glanzer	1/27/94		re: repair rate, repeats, etc.
Garage Europa	Werner Zollenkopf	1/27/94	MSL	MB repairs
Stead Motors	Dennis Sheehan	1/27/94	MSL	MB repairs
Long Beach Transit Maint	Gene Sandovaul	1/27/94	VMS	South Coast; no problems for 5 years
Southwest Diesel	Mike Burt	1/27/94	VMS	repairs in AZ
Independent Repair	Dale France	1/13/94	RCH	experience with EPA fuel
Midwest Diesel	Lee	1/14/94	RCH	experience with EPA fuel
EuroCar Engineering	Oscar Crovetto	1/27/94	MSL	MB Repairs
Bob Lewis Volkswagon	Blaine McCurdy	1/28/94	MSL	VW, Peugot repairs
Autohaus Schuhmann	Mario Schuhmann	1/28/94	MSL	MB Repairs
Diesel Service Center	Chuck Garges	1/28/94	MSL	Misc LDV Repairs
Independent Diesel Repair	Bill French	1/28/94	MSL	Misc LDV Repairs
Marin Vehicle Repair	Deborah Nielson	1/31/94	LJM	re: repeat leaks, etc./Kathryn Taylor follow-up
Danville Auto Service	Ray?	2/1/94	LJM	re: repeat leaks, etc./Leo Steffen follow-up
Smythe European	Brian Nelson	1/31/94	MSL	O-ring tests;BN sent MB,Chevron pub.
Harper Motors	Keith, Svc Mgr	2/1/94	MSL	LDTrucks - Ford; Eureka
Steve's Pump and Inj. Serv.	Steve	2/2/94	LJM	Re: low mileage,etc./McGovern & LJ follow-up
Power Systems Assoc.	Kevin Campbell	1/31/94	JJC	Experience with new fuels
Berge's Sales and Service	Larry Berge	1/31/94	JJC	Experience with new fuels
Schaafsma Bros Diesel Service	Marty Melendrez	1/31/94	JJC	Experience with new fuels
Dumas Fuel Inj Repair	Terry McIlwaine	1/31/94	JJC	Experience with new fuels
Fuel Inj Sales & Service	Floyd Beadle	1/31/94	JJC	Experience with new fuels

CONTACT LIST FOR DIESEL FUEL TASK FORCE

Business	Individual	Date Cont.	By	Comments
REPAIR SHOPS (continued)				
Flying "J" Truck Service	Brenda Juckett	1/31/94	JJC	Experience with new fuels
Jim Fols Engineering	Jim Fols	1/31/94	JJC	Experience with new fuels
Stanadyne Diesel System	Marvin Imm	1/31/94	JJC	Experience with new fuels
Santa Rosa Diesel	Francis	2/01/94	RCH	Declined to discuss diesel fuel issues.
Santa Rosa Dodge	George Bernheim	2/3/93	MSL	Dodge has had few fuel-related problems
AutoWest Dodge	Carl Pierce	2/3/93	MSL	" "
Swift Dodge	Ron Moore	2/3/93	MSL	" "
Bug and Hare Repair	Pat	2/3/93	MSL	VW Repairs
Diesel Control Systems	Jim Griffith	1/25/94	RCH	Re: Ag Equipment - Effects of New Fuel
Coast Fuel Injection	George Otsuka	2/07/94	MJT	Re: Ag equipment problems associated with LSD fuel
Digs Repair	Audy Timp	2/04/94	MJT	Re: Ag equipment problems associated with LSD fuel
Advanced Diesel Systems	Paul Dean	2/03/94	MJT	Re: Ag equipment problems from LSD fuel
Diesel Power Systems	Kris Wolfenstein	2/01/94	MJT	Re: Low sulfur diesel ag equipment fuel and injector pump failures
Fuel Systems West	Allen Lane	2/04/94	MJT	Re: Ag equipment problems associated with LSD fuel
Top Cat Fuel Injection	Jim Favelo	2/02/94	MJT	Re: Ag equipment problems for LSD fuel
Garton Ford Tractor	Neil, Service Mgr	2/02/94	MJT	Re: LSD fuel problems
Farmers Mercantile	Lorne Tataryn	2/04/94	MJT	Re: Ag equipment problems associated with LSD fuel
Pioneer Equipment	Bob Lee	2/02/94	MJT	Re: Ag equip problems related to LSD fuel
Reed Equipment	Jim Beigley	2/03/94	MJT	Re: Ag equipment problems related to LSD fuel
Lougee-Michael	Bob Hennick	2/07/94	MJT	Re: Ag equipment problems associated with LSD fuel
Quine Company	Dale Ryan	2/04/94	MJT	Re: Ag equipment problems associated with LSD fuel

CONTACT LIST FOR DIESEL FUEL TASK FORCE

Business	Individual	Date Cont.	By	Comments
MANUFACTURERS				
Kubota Farm Tractor Div	Tom Caterina	1/20/94	RCH	Kubota position
Kubota Corp	Ken Raysin	1/19/94	RCH	Experiences and fuel pump apps.
Kubota Engine Division	Tech Service (Steve)	1/19/94	RCH	Experiences with ThermoKing units
Kubota Engine Division	Dennis Bourgoin	1/19/94	RCH	Experiences with ThermoKing units
Yanmar	Norm Weir	1/26/94	RCH	ThermoKing Units
Stanadyne	Paul Henderson	2/01/94	LJM	Re: elastomer matls/changes
Detroit Diesel	John Fisher	2/01/94	LJM	Re: elastomer matls/changes
Cummins	Steve Butler	2/01/94	LJM	Re: elastomer matls/changes
Cummins	Tom Gallant	2/02/94	LJM	Re: elastomer matls/changes
Navistar	Warren Slodowske	2/01/94	LJM	Re: elastomer matls/changes
Navistar	John Serio	2/01/94	LJM	Re: elastomer matls/changes
Caterpillar	Howard Jenkel	2/01/94	LJM	Re: elastomer matls/changes
Caterpillar	Richard Tennis	2/02/94	LJM	Re: elastomer matls/changes
Reliabuilt (DDC)	Pat Abbott	2/01/94	RCH	Re: elastomer matls/changes
Mercedes Benz	Bernd Herribich	1/28/94	VMS	Hose and seal material
Kubota Corporation	Ken Raysin	1/19/94	RCH	Re: experience with new fuel
J. Deere Industrial Eqpt.	Lynn Kurt	2/03/94	RCH	Re: fuel lubricity effects
Kubota Engine Division	Steve, Tech Service	1/19/94	RCH	Re: experience with new fuel
Ford Tractor	Phil Wright	2/04/94	MJT	Re: Ag equipment problems associated with LSD fuel
J. Deere, Ag Branch	Mike Inas	2/07/94	MJT	Re: Ag equipment problems associated with LSD fuel
John Deere	Bill Kilgore	2/04/94	MJT	Re: Ag equipment problems associated with LSD fuel
John Deere Dealer	John Mariano	2/04/94	MJT	Re: Ag equipment problems associated with LSD fuel
John Deere (Iowa Factory)	Mike McKinney	2/04/94	MJT	Re: Ag equipment problems associated with LSD fuel
Massey-Fergusen	Jim Woodward	2/04/94	MJT	Re: Ag equipment problems associated with LSD fuel
CIT/CSU Fresno	David Zoldoske	2/01/94	MJT	Re: Ag survey progress and reporting schedule

CONTACT LIST FOR DIESEL FUEL TASK FORCE

Business	Individual	Date Cont.	By	Comments
ORGANIZATIONS (AAA, Farm Bureau, etc.)				
Far West Dealers Assn.	Jerry Harder	1/20/94	RCH	Complaint data collection
Tennessee Farm Bureau	Rhedona Rose	1/20/94	RCH	Complaint data collection
Sandia National Labs	B.Wilson/C.Frost	1/25/94	ELD	re: elastomers/peroxide resistance
Parker Seals	Robert Barbarin	1/28/94	ELD	re: elastomers/peroxide resistance
Manual Cunha	Farmer's League	2/01/94	MSL	Fuel Sampling - Ag. Facilities
Transport Topics (publisher)	Bill Cassidy	1/31/94	JJC	Copies of relevant articles
CSAA	Amo Amerson	1/24/94	VMS	North vs South; nationwide
GOVERNMENTAL AGENCIES				
CARB Mobile Source Div.	Mark Burnitzki	1/26/94	RCH	Mobile life support fleet data
CARB Mobile Source Div.	Paul Jacobs	1/26/94	LJM	Repeat Leakers
SCAQMD	Dave Coel	1/26/94	VMS	historical trend of complaints
SCAQMD	Bruce Collins	1/27/94	VMS	SOCAL fuel experience
SCAQMD	Terry McCall	1/21/94	VMS	SOCAL fuel experience
SCAQMD	Mike Bogdanoff	1/21/94	VMS	SOCAL fuel experience
CARB Fuels Section	John Courtis	1/26/94	RCH	Fuel distribution volumes/types
CARB Mobile Source Div.	Chuck Owens	2/01/94	RCH	Fuel Sample numbers/sources
US EPA	Larry Haslett	2/2/94	VMS	Nationwide problems

APPENDIX D

TESTING PROTOCOLS AND POTENTIAL MECHANISMS FOR O-RING LEAKAGE

1.0 SWELL TESTING OF FREE O-RINGS

1.1 Hypothesis

Certain post-regulation diesel fuels cause O-rings accustomed to high sulfur fuel to shrink.

1.2 Goal

Determine the swelling behavior of O-rings as it is influenced by O-ring material, O-ring age, and fuel composition.

1.3 Testing Approach

Three experiments will be performed.

1) New O-rings will be immersed in a wide variety of diesel fuels, including high sulfur fuels, U.S. EPA low sulfur fuel, and post-regulation fuels. The changes in seal characteristics, including dimensional changes and hardness changes, produced by each diesel fuel will be measured.

2) New O-rings will be immersed in a high seal swell diesel fuel and then in a low seal swell diesel fuel. O-ring dimensions and characteristics will be determined before and after each immersion to define any differences caused by the fuel change.

3) Used O-rings, taken from in-service vehicles, will be immersed in high seal swell diesel fuels and then in low seal swell diesel fuels. O-ring dimensions and characteristics will be determined before and after each immersion to define any differences caused by the fuel change.

Experiment 1: The O-ring characteristics for five new O-rings immersed for 70 hours at a temperature of 50°C ± 2°C in each of the selected diesel fuels will be measured by the American Society of Testing and Material (ASTM) Designation D1414 –

Standard Methods of Testing — Rubber O-Rings. Characteristics to be evaluated include dimensions (inside diameter, outside diameter, and cross section), volume change, hardness, modulus, tensility, and elongation.

Experiment 2: The change in O-ring characteristics for new O-rings that are equilibrated for 70 hours at 50°C ± 2°C in a high sulfur diesel fuel and then immersed at the same temperature for 70 hours in a post-regulation or U.S. EPA low sulfur diesel fuel will be measured using procedures defined by ASTM D1414. Based on the results of Experiment 1, a subset of fuels will be used for this experiment. Four commercial No. 2 diesel fuels will be selected from Experiment 1 to reflect the extremes of seal swell performance:

- High sulfur fuel that results in the highest seal swell;
- High sulfur fuel that results in the lowest seal swell;
- Post-regulation or U.S. EPA low sulfur diesel fuel that results in the highest seal swell; and
- Post-regulation or U.S. EPA low sulfur diesel fuel that results in the lowest seal swell.

These fuels will be selected based upon dimensional changes rather than other characteristic measurements. The O-rings will be tested in a 2-by-2 matrix to evaluate their response to each high sulfur diesel fuel and each post-regulation or U.S. EPA low sulfur diesel fuel.

The same measurements as for Experiment 1 will be taken on three occasions: for each new O-ring, after immersion in a high sulfur diesel fuel, and after immersion in a post-regulation or U.S. EPA low sulfur diesel fuel. Each test will use five O-rings.

Experiment 3: The change in O-ring characteristics for used O-rings that are equilibrated at 50°C ± 2°C for 70 hours in a high sulfur diesel fuel and then immersed at the same temperature for 70 hours in a post-regulation or U.S. EPA low sulfur diesel fuel will be measured using procedures defined by ASTM D1414. The same fuels from Experiment 2 will be tested in the 2-by-2 matrix design. The same measurements as for Experiment 1 will be taken on three occasions: for each used O-ring as received, after immersion in a high sulfur diesel fuel, and after immersion in a post-regulation or U.S. EPA low sulfur diesel fuel.

O-Ring Types

New standard nitrile and high-acrylic acrylonitrile O-rings will be obtained from a single lot. Used O-rings will be obtained from diesel repair facilities in northern California. Only O-rings with known history (seal type, engine origin, engine mileage, engine model year, and type of engine use) will be selected.

Fuels

No. 2 diesel fuels will be obtained from four sources for Experiment 1 (listed below). Radian will provide a sample submittal form. This form will be filled out by each of the sample suppliers for each of the individual samples and submitted to Radian with the sample. All samples will be sent to Radian (at a location to be determined) for storage, analysis sample aliquotting, and sample number assignment.

- Major producers of California diesel fuels (ARCO, Chevron, Texaco, Unocal, Tosco, and Ultramar) will be requested to provide 2-liter samples of all No. 2 diesel fuels currently in production for sale in California. Samples of U.S. EPA low sulfur diesel fuel will also be requested. Two-liter samples of high sulfur diesel fuel will also be provided.

- California ARB will provide diesel samples from their current stock. Since each sample has a volume of 1 liter or less, the amount of sample available may dictate the amount of seal testing and fuel analyses that may be conducted.

- The California Trucking Association (CTA) will provide up to 10 samples of diesel fuel believed to be high sulfur formulations. These will be supplied in 2-liter quantities. Radian will supervise collection of the samples.

- Due to the apparent influence of the hydrotreating process on seal swell performance, an attempt will be made to obtain samples of low aromatics fuel that have similar total aromatics levels, but that reflect differing levels of hydrotreatment. The source of these fuels has not been identified.

Four commercially available hydrocarbon solvents (Exxsol D-110, Aromatic 200, Isopar M, and Norpar 15 from Exxon Chemical), which all boil in the middle of the diesel boiling range, will be used to examine changes in O-ring characteristics produced by varying organic liquid structure over a wide range, and to help establish outer bounds of seal swell performance.

Automatic transmission fluid (ATF) is being used by many diesel engine owners as a fuel additive to prevent perceived lubricity problems when using the post-regulation diesel fuels. However, the impact of ATF as a fuel additive on seal swell performance is not known. Four commercially available ATFs will be tested in Experiment 1 as 100% ATF (i.e., not blended into diesel fuel). The four fluids will reflect Dextron and Type F formulations from two national brands.

O-Ring Test Procedures

All testing will follow specifications as defined in ASTM D1414, which describes methods for determining the physical properties of O-rings and changes to the properties due to aging. ASTM D1414 references a number of other ASTM Designations, including D471 - Test Method for Rubber Property - Effect of Liquids; D1415 - Test Method for Rubber Property - International Hardness; D2240 - Test Method for Rubber Property - Durometer Hardness; and D395 - Test Methods for Rubber Property - Compression Set.

Reducing test variability is an important consideration in these procedures. To reduce the experimental error, each test combination of new O-ring and fuel will be tested using five O-rings. All tests will be conducted at the same laboratory, and each measurement (dimensional change, hardness, compression set, etc.) will be performed by the same individual.

Fuel Inspections for Characterization

The fuels that are being used for O-ring testing will be inspected to determine their general characteristics (listed below) at the same time that ASTM D1414 testing is underway.

- API gravity, by ASTM D287 to determine fuel density.
- Carbon (%), by combustion; hydrogen (%), by combustion; sulfur (ppm), by ASTM D2622 (X-ray fluorescence); and nitrogen (ppm) by Antek to measure elemental composition.
- Peroxide number, by ASTM D3703.
- Aniline point (°C), by ASTM D611; refractive index, by ASTM D1218; hydrocarbon type (%), by ASTM D5186 (supercritical fluid LC) to measure general aromaticity.
- Distillation curve, by ASTM D86 to measure the fuel boiling curve.

Many of these inspections have already been performed on the ARB fuel samples. To conserve the limited samples, these tests will not be repeated on the ARB-supplied fuels.

Fuel Analyses for Composition/Functionality

It is quite possible (even likely) that the fuel inspections listed above cannot be used to clearly predict the swelling behavior of O-rings. Since fuel inspections for characterization may not be able to establish a solid connection between the O-ring swell and the fuel inspections, two or more of the following more detailed measures of fuel chemical structure will be used:

- Gas chromatography/mass spectrometry (GC/MS) or similar type of analysis;
- ^{13}C Nuclear Magnetic Resonance (NMR);
- ^{1}H NMR; or
- Fourier Transform Infrared Spectroscopy (FTIR).

In particular, NMR and FTIR have been used successfully to predict bulk diesel fuel properties, such as cetane number. Both types of analyses give detailed chemical information about the aromatic and aliphatic constituents in fuel molecules.

Schedule for Testing

- January 18: Final Test Protocol distributed to Subcommittee #2 members.
- February 21: Experiment 1 begins.
- March 10: Experiment 1 complete. Data submitted to Radian for analysis.
- March 15: Experiments 2 and 3 begin.
- March 28: Experiments 2 and 3 complete. Data sent to Radian for analysis.

Fuel inspections and analyses will begin when the fuels are received by the laboratory.

2.0 SWELL TESTING OF IN-SERVICE O-RINGS IN PUMPS

2.1 Hypothesis

The majority of fuel pump O-ring failures are caused by a shrinkage of aged O-rings, which no longer have sufficient "reserve" resiliency to maintain contact with the sealing surface to prevent leaks.

2.2 Goal

Determine if a large fraction of fuel pumps, which have been in service long enough that their O-rings have a high degree of compression set, will leak when the fuel is switched from a high seal swell diesel fuel to a low seal swell diesel fuel. Specifically, we want to determine if the fuel switch is all that is needed to cause a non-leaking pump to begin leaking. In-service pumps will be run on the high seal swell diesel fuel and the low seal swell diesel fuel to see if O-ring failures occur.

2.3 Testing Approach

Older, but still in-service, fuel pumps will be operated on a high seal swell diesel fuel on the bench. After a test period of 72 hours, those pumps that do not exhibit leaks will be switched abruptly to a low seal swell diesel fuel. The number of pumps leaking after 96 hours of operation on the low seal swell diesel fuel will be recorded at the end of testing. All tests will be performed with fuels at a temperature characteristic of the operating temperature of individual fuel-injection pumps. Each 24-hour segment of pump testing will be made up of 8 hours of pump operation at operating temperature followed by 16 hours of no operation at room temperature. The leak rating (as defined by Attachment 1 - Cummins Engineering Standard 16312) will be determined at the beginning and end of each 8-hour pump operation period.

Any pump that develops a leak while operating (leakage class 2 or greater) after 96 hours on low seal swell diesel fuel will be switched back to the high seal swell diesel fuel for 72 hours to see if the use of high seal swell diesel fuel will reduce the leak. The change back to pumping a high seal swell diesel fuel is only intended to establish further the potential interactions between fuel characteristics and seal leakage.

Two control groups will be used. The first control group will be new pumps tested following the same procedure with the high seal swell and low seal swell diesel fuels. The second control group will be older, in-service pumps operated on high seal swell diesel fuel and not switched to low seal swell diesel fuel.

Pumps

The CTA will locate 18 pumps of the same make from in-service vehicles and 6 new pumps for testing. Six of the 18 in-service pumps will be used as a control group. The six new pumps will be used for the other control group. The results of the Subcommittee #1 findings will be used to select the pump type with usage histories that are most prone to seal leakage. Pumps that are already leaking will not be selected. Pumps that are known to have been re-built at any time also will not be selected. Radian will create a pump documentation form that will be completed before a pump is removed from the vehicle.

Fuels

Based on results of Experiment 1 of the Swell Testing of Free O-Rings, one high seal swell diesel fuel and one low seal swell diesel fuel will be selected, based on the swell exhibited by the different fuels and the availability of the fuels. Note that approximately 55 gallons of fuel for each pump are normally used for this type of test. While it may be possible to use less than 55 gallons of fuel for each pump without affecting the results, the selection of fuels may be influenced by fuel availability. Ideally, sufficient quantities of a high seal swell diesel fuel and a low seal swell diesel fuel with a large difference in percent swell between them can be obtained.

Schedule for Testing

The pump testing will be conducted by the U.S. Army Fuel and Lubricants Testing Laboratory in San Antonio, Texas. Some time must be allocated for configuration of the test facility to operate the pumps in a controlled manner. This will proceed while the bench testing of free O-rings is in progress. Selection of pumps can begin immediately. The two test fuels will be selected based on the results of the first phase of the free O-ring testing.

3.0 SAMPLING AND ANALYTICAL PROTOCOL TO INVESTIGATE OXIDATION RESISTANCE OF POST-REGULATION DIESEL FUELS

In processing diesel fuel to reduce the sulfur and aromatic content via hydrotreating, components of the fuel that inhibit oxidation may also be reduced, rendering the fuel less stable. This could lead to increased formation of sediments, gum deposits, and peroxide that may damage O-rings and other fuel system elastomeric components.

The objective of this testing program is to determine whether increased oxidation potential of the diesel fuels currently available in California exists. Diesel fuel samples will be collected and analyzed as follows:

- **Fuel Characteristics** - typical fuel characteristics (e.g., specific gravity, carbon content, sulfur content) will be measured and reported. These data will serve as indicators of fuel anomalies and facilitate comparison with other fuel analytical data.
- **Fuel Performance** - properties of the fuel (e.g., peroxide content, sediment quantities) will be monitored over time to evaluate long-term fuel stability characteristics.

Additional details of the test program are identified below.

3.1 <u>Technical Approach</u>

3.1.1 The Sampling Program

A total of 36 fuel samples will be collected from two primary sources: storage tanks at agricultural facilities (12 samples) and retail service stations (24 samples). The sampling matrix will be designed to include samples of diesel fuel that are from large and small refiners, are representative of most areas of California, and meet ARB specifications for sulfur and aromatic content. Samples of high sulfur fuels will be included for comparison purposes.

Fuel samples at each location will be collected in 1-gallon epoxy-lined steel cans and sealed for shipment. All of the fuel samples will be inerted using nitrogen sparging. The following data will be collected to document the identity and condition of the collected samples:

- Location of sample (business name, type of business (retail or agriculture operation), city, zip code);
- Name and location of fuel supplier;
- Type of fuel used to fill tank (post-regulation fuel, temporary California low sulfur fuel, U.S. EPA low sulfur fuel, or high sulfur fuel);
- Date tank was last filled;
- Amount of fuel added at last filling of tank;
- Use of any fuel additives (including automatic transmission fluid, used engine oil, or commercial additive);
- Storage conditions (fuel temperature, approximate quantity of fuel in the tank, aboveground or underground tank, size of tank, age of tank, general condition of tank, and existence of water trap or recirculation system);
- Results of previous analyses performed on this fuel (if available).

When possible, written documentation of the above information will be collected.

3.1.2 The Analytical Program

The following fuel characteristics will be determined for each of the samples:

- API specific gravity, by ASTM D287;
- Carbon (%), by combustion;
- Hydrogen (%), by combustion;
- Sulfur (ppm), by ASTM D2622 (X-ray fluorescence);

- Nitrogen (ppm), by Antek;
- Peroxide number, by ASTM D3703;
- Aniline point (°C), by ASTM D611;
- Refractive index, by ASTM D1218;
- Hydrocarbon type (%), by ASTM D5186 (supercritical fluid LC);
- Distillation curve, by ASTM D86; and
- Water content, by ASTM D1744.

Performance tests will also be conducted on the fuel samples to determine the stability of the fuel. Color (by ASTM Method D1500), sediment content, oxidation potential (by ASTM D4625) will be determined on the samples as received.

The samples will then be stored in a sealed container at a temperature of 43°C for approximately 180 days. Aliquots of the fuel samples will analyzed for the above parameters at intervals of 30, 60, 90, 120, 150, and 180 days to assess changes in fuel stability characteristics.

3.1.3 Reporting

Following the completion of the sample analyses, Radian will prepare and submit a draft report to the Diesel Fuel Task Force (Subcommittee #2). The report will summarize the results of the study and will contain relevant supporting documentation (e.g., sample collection records and chain-of-custody forms).

3.2 Schedule and Staff

The fuel oxidation sampling and test program is currently underway. Sample collection will be completed by early March. Fuel characterization tests will be completed approximately one to two weeks following sample submittal; the fuel performance tests will require six months to complete, depending upon fuel characteristics. Our draft report will be submitted approximately one to two weeks after the analyses are completed.

Sample collection will be performed by Radian; staff members from each of our California offices will be used to save time and costs. Fuel analyses and performance tests will be conducted at Southwest Research Institute, San Antonio, Texas. Radian will compile and review the results of the analyses and prepare a report summarizing the data.

4.0 POTENTIAL MECHANISMS FOR O-RING LEAKAGE

Nitrile rubber O-rings are used to create a seal between two metal surfaces in many diesel fuel-injection pumps. Leakage of diesel fuel from injection pumps can be caused by seal failure. Different mechanisms that can contribute to seal failure are discussed below. The discussion begins with a review of the mechanism by which O-rings seal two mating parts.

O-rings are toroid-shaped seals made of a resilient, elastomeric material and are available in many different sizes and compositions. O-rings are used to seal two parts that may be stationary or moving with respect to each other. Often, one of the parts has a smooth, flat surface for the O-ring to seal against. The other part typically has a machine-cut, rectangular, cross-sectional groove, known as a gland, designed to fit the chosen O-ring.

In diesel fuel-injection systems, the designed size of the groove takes into account expected changes in O-ring dimensions when the O-ring is put into service, since the dimensions of the in-service O-ring may change slightly upon exposure to diesel fuel. The depth of the groove is shallower than the natural thickness of the O-ring so that when the O-ring is sandwiched between the two parts, its cross-section is compressed.

This compression of the resilient O-ring material provides a constant force against the sealing surfaces, so liquids cannot escape through the joint between the two parts. Over time, however, O-rings may take on the form of the groove in which they are fit. This phenomenon, which is referred to as a "compression set," is accompanied by hardening and reduced resiliency of the O-ring material. Any mechanism that reduces the long-term resistance to compression or memory of the O-ring material can weaken the force against the sealing surfaces, potentially leading to a leak in the connecting joint.

O-ring memory and other physical properties depend on the physical and chemical properties of the O-ring material. In diesel fuel-injection systems, three O-ring materials are commonly used: standard nitrile (NBR), fuel-resistant nitrile, and fluorocarbon elastomers. Although O-rings made of these three materials are visually indistinguishable, they differ in properties and cost and are, therefore, used in different applications.

The standard nitrile O-rings are frequently used in diesel fuel-injection pumps. Nitrile is a polar rubber that is made by copolymerization of acrylonitrile with butadiene. Standard nitrile rubber, with an acrylonitrile content of about 30 weight percent (wt%), provides good compression set resistance, high resilience, and adequate resistance to swelling when in contact with nonpolar solvents. However, standard nitrile may actually swell more when in contact with polar fluids such as diesel fuel with a high aromatic content.

With increasing acrylonitrile (ACH) content (up to a maximum of 45 wt%), the cohesive energy and tensile strength of nitrile increases. The increased ACH content increases the resistance to swelling, especially in nonpolar, low-cohesive-energy-density solvents, but gives poorer low temperature properties. This high acrylonitrile content polymer is referred to as a "fuel-resistant" material and is more expensive than standard nitrile.

Highly saturated nitrile (HNBR) also has higher resistance to swelling, as well as significant in-heat resistance due to the elimination of most of the unsaturation present in conventional nitrile elastomers. The same is true of fluorocarbon elastomers, where the high thermal stability and oil/chemical resistance are due to the high ratio of fluorine to hydrogen, the strength of the carbon-fluorine bond, and the absence of unsaturation. The choice of fillers and additives also affect elastomer properties.

In summary, standard nitrile is lower priced, has high resilience, and good compression set resistance but swells more when in contact with some diesel fuels. Fuel-resistant nitrile and fluorocarbon elastomers are more resistant to swelling.

The failures experienced in diesel engines in California that have been attributed to the new diesel fuel have been confined to nitrile O-rings. The loss of resiliency in nitrile O-rings is governed primarily by exposure to high temperature and oxygen.

Normal aging of O-rings consists of slow, long-term oxidation of the polymer structure and is affected by the length of service time, operating temperatures, and exposure to oxygen. Higher temperatures or increased exposure to oxygen or oxygenated compounds can promote oxidation and hardening of the O-ring.

Work by Subcommittees #1 and #2 have identified two potential mechanisms leading to O-ring failures. The first mechanism may be caused by a change in the swell volume of the O-ring as a result of switching from diesel fuel with a higher polarity to diesel fuel with a lower polarity. Swelling of nitrile O-rings varies as the composition of aromatic species and other polar compounds vary in diesel fuel. The influence of individual fuel species on the swelling of nitrile O-rings is not well understood.

It is postulated that when standard nitrile O-rings are immersed in the low polarity fuel, they swell to a smaller degree than when they are immersed in a higher polarity fuel. Therefore, an in-service standard nitrile O-ring that has been exposed only to high aromatic (higher polarity) diesel fuel may shrink when a switch to the low aromatic (lower polarity) diesel fuel is made. If the O-ring has sufficient reserve memory, the seal strength will be maintained. However, if the O-ring has lost too much memory, the seal strength will weaken and the fuel will begin to leak. The "aging" of an O-ring, as well as exposure to low ambient temperatures, can lead to a loss of O-ring material resiliency.

The second mechanism for seal failure may be caused by accelerated oxidation of the O-ring material. Oxygen from any source can result in oxidation and accelerated aging of the O-ring. Regular diesel fuel contains a small amount of dissolved oxygen. However, experience with jet fuel development indicates that severe hydrotreating of fuel, which removes natural antioxidants such as amines, can produce a chemical environment in the fuel that is conducive to the formation of peroxides over time (usually over a period of months). These peroxides can be an additional source of fuel oxygen, which can accelerate the aging of elastomers used in the fuel equipment system. Accordingly, jet fuels use additives that prevent or delay the formation of peroxides. Depending on the level of processing used for a given fuel, some of the hydrotreated diesel fuels may be more prone to the formation of peroxides than traditional diesel fuels. Therefore, aged O-rings may undergo accelerated oxidation when in contact with some hydrotreated diesel fuel, if that fuel does not contain sufficient oxidation resistance. Seal failures caused by accelerated oxidation would typically be accompanied with hardening and cracking of the seal material since oxidation results in cross-linking and hardening of the nitrile rubber.

Long-Term Effects

It is difficult to predict how O-rings will be affected in the long term by the use of reformulated diesel fuel. The use of post-regulation diesel fuel may actually be beneficial for O-ring longevity. For example, the presence of sulfur in the fuel can promote cross-linking and hardening of nitrile rubber. Lower levels of sulfur in the new fuels reduce this process. Also, reduced levels of aromatics and other trace compounds reduces the swelling of the O-ring material. The reduction in seal swell will reduce the rate of compression set. Conversely, increased swelling enhances the sealing force afforded by the O-rings, and removal of natural antioxidants can result in accelerated oxidation of the O-ring material.

At this early stage, it is unclear which of these effects is more important in determining the service life of O-rings and seals. (Although sufficient data are not available to reach a definitive conclusion, anecdotal information from southern California, where low sulfur diesel fuel has been used since 1985, indicate that low sulfur/low aromatics diesel fuels may actually be beneficial for fuel-injection system longevity.)

Fuel Line Leaks

Reports of fuel line leaks were prevalent among the light duty fuel-related failure reports evaluated by Subcommittee #1. Various descriptions of the failure profile were given. These can be generalized into four failure types: hoses that became brittle and "cracked," hoses that became loose and leaked at the connections, hoses that softened, and hoses that leaked along their full length.

According to elastomer experts who were contacted, these fuel lines have inner tubes that are generally made out of the same material as the rubber seals and O-rings, but may contain more filler and plasticizer. In particular, standard nitrile and chlorinated polyethylene elastomers were mentioned.

California's diesel passenger cars are commonly between 9 to 16 years old, with an average age of 12 years. The older age of rubber components is indicative of more prolonged exposure to oxidizing agents and temperature variations. As mentioned above, such aged components are more susceptible to accelerated rates of oxidation when in contact with the post-regulation diesel fuel. Note that when in contact with certain elastomers other than nitrile, oxidants can break polymeric bonds, thus resulting in softening of the rubber. Conversely, oxidants can induce more cross-linking of polymeric chains in nitrile elastomers, resulting in hardening of the material. As mentioned above, both softening and hardening of failed fuel hoses have been reported. Reports of cracked and hardened/softened fuel hoses with full length fuel leakage may be indicative of accelerated oxidation of the hose material. However, a thorough examination may be required to distinguish a hose that failed due to accelerated oxidation from a hose that is at the end of its service life. Knowledge of the chronological age of the hose and its service conditions is important in this evaluation.

Note that such rubber fuel hoses are only used in low-pressure applications, such as in the fuel systems of light and medium duty vehicles. According to one source, fuel system return lines in heavy duty vehicles are reinforced with a steel mesh to provide durability in high-pressure applications.

Reference

Rodriguez, F., 1982. *Principles of Polymer Systems* (2nd Edition). McGraw-Hill, New York, NY.

APPENDIX E

AGRICULTURAL SURVEY REPORT

INITIAL AGRICULTURAL EXPERIENCES WITH POST-REGULATION DIESEL FUELS

Prepared for

The Diesel Fuel Task Force

Prepared by

David F. Zoldoske, Director
CENTER FOR IRRIGATION TECHNOLOGY
California State University • Fresno
February 15, 1994

EXECUTIVE SUMMARY

As part of an effort to evaluate the experiences of California growers who are using "post-regulation" (PR) diesel fuels, grower interviews were conducted by the Center for Irrigation Technology, CSU•Fresno. A total of 1078 phone calls were made to growers in four California counties. The selected counties of Fresno, Kern, Monterey, and Yolo represent broad geographical and agricultural activity in the state.

A total of 182 growers completed the questionnaires. Of these growers, 146 reported using PR diesel fuels based on personal knowledge or date of fuel purchase. These growers reported operating 1786 diesel-fueled equipment units, with a total of 269 diesel-fueled equipment units reported to be experiencing fuel leaks occurring since September 1st, 1993. Forty-seven of these growers indicated they believed these leaks were related to the use of PR diesel fuels.

Each grower was asked whether they were experiencing more operational problems than normal since using PR diesel fuels. Sixty-nine growers (47%) indicated they believed performance was affected by the use of PR diesel fuels with hard starting, power loss, and reduced fuel economy identified as the largest concerns.

Many growers who have not specifically experienced problems themselves knew of or had spoken to growers who were experiencing problems perceived to be caused by the use of PR diesel fuels. Almost 20% of the growers interviewed have "not" used PR diesel fuels in their equipment. Many of the other growers who are using the fuel have not accumulated high operating hours on their equipment to date. Growers are anxiously looking for an additive or solution to the perceived problems associated with PR diesel fuels.

Whether real or perceived, 47 growers (25%) of those growers currently using PR diesel fuels believe that fuel leaks they are experiencing with their equipment are directly related to the use of PR diesel fuels. It has become apparent from data collected during this investigation that more information will have to be obtained before conclusions can be safely drawn regarding the effects of PR diesel fuels used in agricultural equipment.

INTRODUCTION

The State of California mandated the use of specially formulated diesel fuels beginning October 1st, 1993. This was done in an effort to improve air quality throughout the state. The air quality in California is labeled as unhealthy in many locales because it exceeds state and federal limits for particulates, due largely to tailpipe emission from internal combustion engines. While the new fuel is proposed to improve air quality, some concerns about its use have been raised. The California Trucking Association and others noted that the post-regulation (PR) diesel fuels has less lubricity, and that increased mechanical failures (ranging from "O" ring failure to fuel pumps going bad in diesel-powered trucks) have been observed.

The agricultural community has also expressed concerns about the use of PR diesel fuels in farm equipment. In an effort to determine the range and scope of problems affecting diesel-powered equipment in the agricultural sector, input from various farming interests was collected.

METHODS

The Center for Irrigation Technology, part of the School of Agricultural Sciences and Technology at CSU • FRESNO, conducted phone interviews during the period of January 29th through February 5th, 1994. The questionnaire was developed with input from the Air Resources Board, California Department of Food and Agriculture, Nisei Farm League, the Farm Bureau, and the Center for Irrigation Technology. The final questionnaire consisted of eight questions pertaining to growers' experiences using PR diesel fuels in farm equipment.

A total of 1078 phone calls were placed to growers in four counties. These counties (Fresno, Kern, Monterey, and Yolo) were selected on the basis of geographic location and level of agricultural activity within the state. The contact list of growers was provided by the California Department of Food and Agriculture. The growers names were obtained from spray permit information for each county. An effort was made to contact growers with larger acreages where possible, those farms over 100 acres.

A total of 182 growers were interviewed: 20 in Yolo, 24 in Monterey, 26 in Kern, to 103 in Fresno county. Please note that 5 of Fresno counties responses were called in from growers alerted by a radio announcement and 10 responses were completed by Fresno County Farm Bureau members. All other responses were obtained via phone contact.

An attempt was made to contact the same percentage of growers in each county. In this case 489 calls were placed to growers in Fresno county, 291 calls to growers in Monterey county, 200 calls to growers in Kern county, and 98 calls to growers in Yolo county. The average phone interview lasted 6-8 minutes, with a common introduction to the purpose of the questionnaire (see Appendix A).

NOTE: Due to time limitations, we were not able to test and validate the survey instrument, nor develop a statistically rigorous sampling procedure for telephone surveys. Therefore, these results, while believed to be generally indicative, do not represent a scientifically valid inquiry into the situation.

SURVEY CHARACTERISTICS

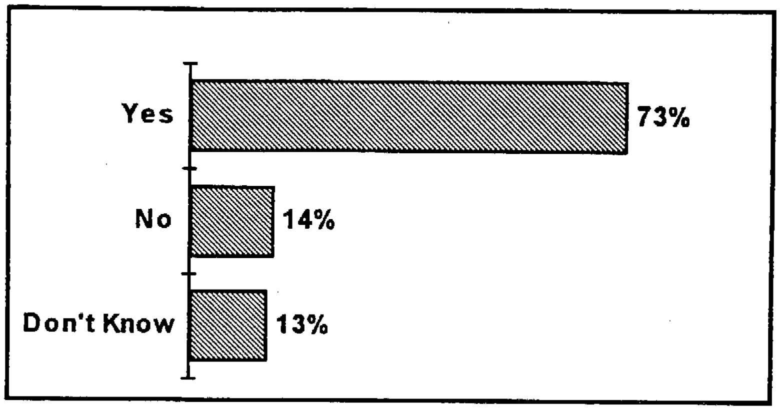
Users

Of the 182 growers interviewed, 73% (132 responses) indicated that they were currently using PR diesel fuels. Another 14% (26 responses) indicated that they were not using PR diesel fuels. The remaining 13% (24 responses) did not know or were not sure what type of fuel they were using. They were then asked if they were using fuel purchased after September 1st, 1993. Diesel fuel acquired after this date is presumed to be PR diesel fuels.

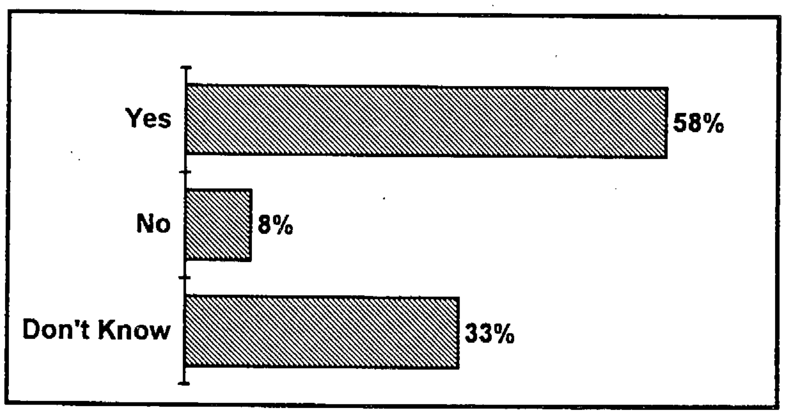
Of those respondents who did not know the type of fuel they were using, 58% (14 responses) indicated that they had bought fuel after September 1st. Only 8% (2 responses) had not purchased fuel after September 1st, and 33% (8 responses) were not sure when their fuel was purchased. For the purpose of this investigation, it is assumed that 146 of 182 persons (81%) interviewed are using PR diesel fuels. This is based on the 132 growers who responded yes to using PR diesel fuels and the additional 14 growers who indicated they purchased their fuel after September 1st.

RESULTS--ALL COUNTIES

Currently using PR diesel fuels (182 responses)



Fuel purchased after September 1, 1993 (24 responses)



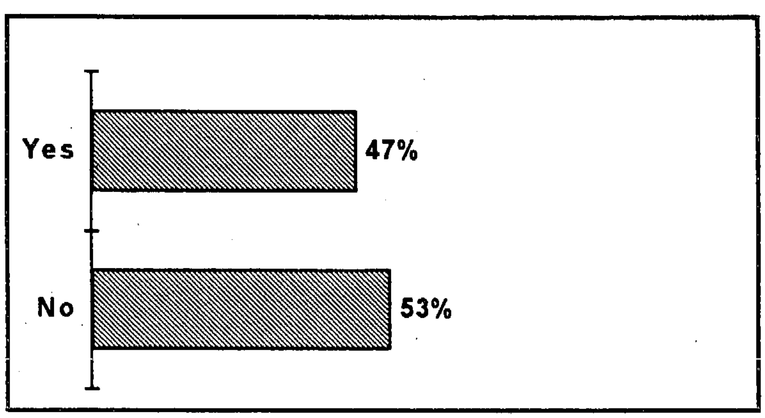
Equipment

The range of diesel-fueled equipment units operating per farm was from a low of 0 to a high of 100. The average number of diesel-fueled equipment units per farm was 12.4. The types of equipment used on these farms included John Deere, Massey Ferguson, Ford, International, Caterpillar, and Kubota tractors, diesel pickups and cars, and power plants from the above manufacturers used in other farm equipment. Over 15% of all equipment using PR diesel fuels was reported to have leaks thought to be associated with the fuel use.

Performance/Operating Problems

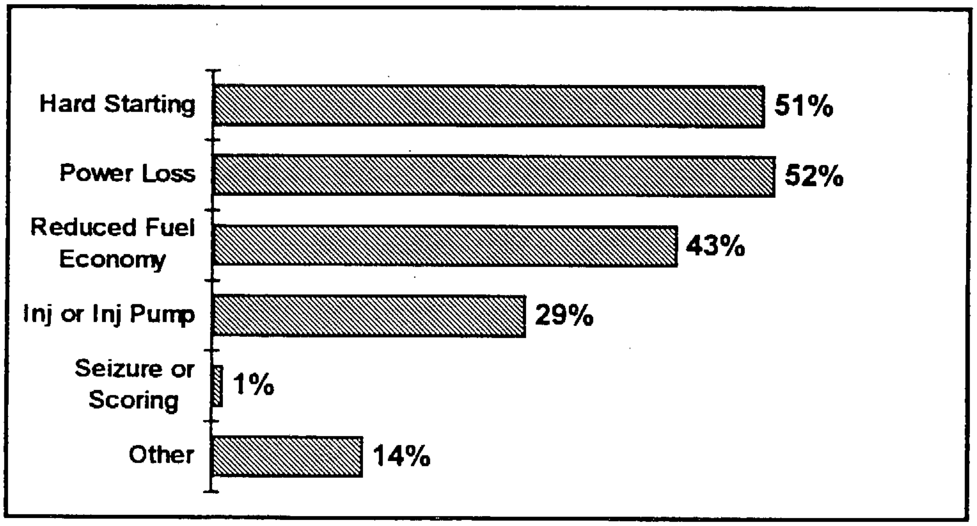
Each grower was asked whether they were experiencing more operating problems than normal using PR diesel fuels. Of the 146 growers interviewed who are currently using this fuel, 47% indicated they "were" experiencing more operating problems, and 53% indicated that they "were not" experiencing more operating problems.

Respondents experiencing more operating or performance problems than normal (146 responses)



Of the 69 respondents who indicated "yes" to having more operating problems than normal, power loss and hard starting was identified by over 50% as a major concern. Reduced fuel economy was also noted in 43% of the responses.

What kind of performance problems (69 responses)

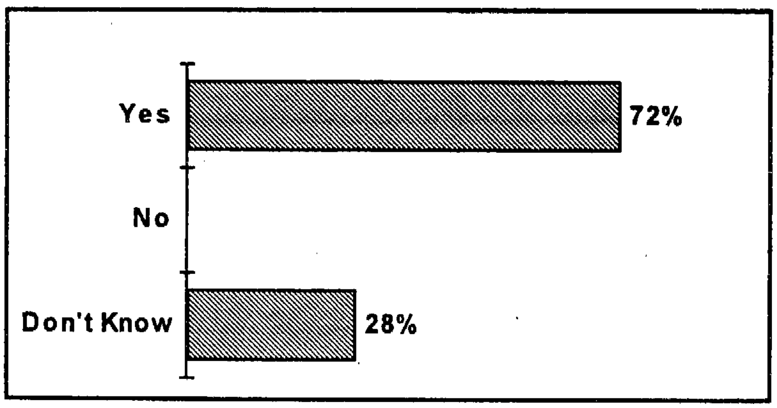


Another issue raised by several growers concerned equipment warranty claims. One equipment manufacturer has sent out a "Support Bulletin" which notes that "premature fuel injection system failures due to low lubricity diesel fuels are not covered under warranty by either the fuel injection pump manufacturer or John Deere" (see Appendix B). The Support Bulletin indicates that low-sulfur fuels may have low lubrication properties due to the hydro-processing used to remove sulfur and/or aromatic compounds during the refining process.

Fuel Leaks

Of the 65 growers who indicated that they are experiencing more leaks than normal using PR diesel fuels, 72% (47 responses) indicated that they believe these leaks are directly related to the fuel that was used at the time the leak occurred. While 28% (18 responses) of the growers did not know if the fuel was causing a problem.

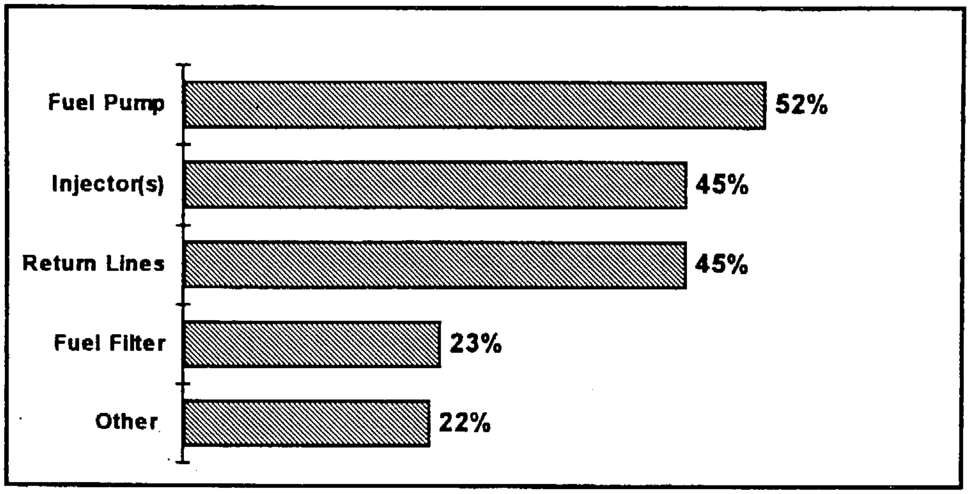
Believe leaks related to fuel (65 responses)



The major problem (52%) of those reporting fuel leaks occurred in the fuel pump; followed closely by leaks in the injectors (45%) and leaks in the return lines (45%). It is interesting to note that those growers who used fuel additives (42 responses) in their diesel fuel reported only a slightly different occurrence of fuel leaks (57% in the fuel pump, 43% in injectors and return lines, respectively). One grower commented that he "experienced 2 leaks early, and then started to use an additive and has not had any problems since."

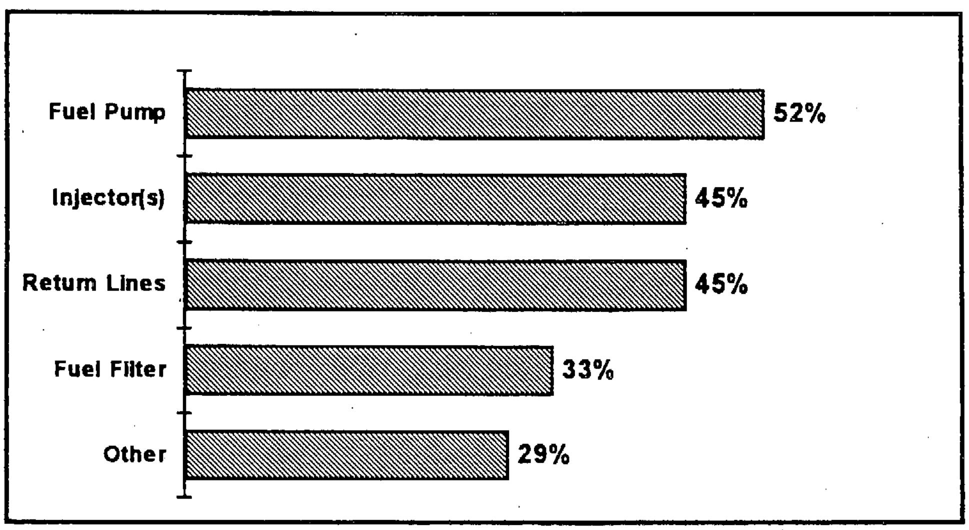
RESULTS OF THOSE REPORTING FUEL LEAKS--TOTAL RESPONSES

Characterization of fuel leaks (65 responses)



RESULTS OF THOSE REPORTING FUEL LEAKS--WITH ADDITIVES

Characterization of fuel leaks (42 responses)



Concerns raised by growers using PR diesel fuels and problems perceived to be associated with its use include:

1) Down time of equipment when premature failure occurs;
2) Cost of major repairs, with growers estimates ranging from $1,800 to $14,000.

On a county by county basis, it is interesting to note that Monterey county has the highest percentage (60%) of growers experiencing more operating problems than normal using the PR diesel fuels. Monterey county was selected in part due to the expectation of higher than average fuel consumption based on cropping pattern during winter months. Fresno county was a close second (54% yes), followed by Kern (33% yes), and Yolo (13% yes).

Remedial Actions

Growers who feel PR diesel fuels is contributing to performance or premature leakage/failure of the fuel system would like to identify an additive which will help alleviate this problem. One additive is suggested in the manufacturer's support bulletin mentioned earlier. The bulletin from John Deere also goes on to state that many additives do not provide the lubricating properties which they feel may be necessary for use in PR diesel fuels.

SUMMARY

The information gathered from growers during this study provides insight to several key areas and concerns. Some of these include:

1) Many growers who have not specifically experienced problems themselves knew of or had spoken to growers who were experiencing problems perceived to be caused by the use of PR diesel fuels.

2) Many growers filled up their farm tanks with the higher sulfur fuels just before the October 1st date which mandated the use of PR diesel fuels. Thus, some farm equipment has few hours of operation with the PR diesel fuels. Other growers have continued to top off diesel storage tanks, blending existing high sulfur fuels with the PR diesel fuels.

3) Because it is a quiet time of year, growers noted that they have not yet accumulated high operating hours on their equipment with the PR diesel fuels. They suggested a "call back" in several months for an update on equipment performance after they have experienced more hours of operation.

4) Growers are anxiously looking for an additive or other solution to the perceived problems associated with PR diesel fuels.

5) For those growers experiencing problems believed to be associated with PR diesel fuels, "O" rings and any rubber seals seem to be high problem areas.

CONCLUSIONS

Fuel leaks identified by growers as being caused through the use of PR diesel fuels, either real or perceived, are clearly reflected by 25% (47 responses) of growers contacted during this investigation. It has become apparent that more information will have to be obtained before conclusions can be safely drawn from the data regarding the effects of PR diesel fuels used in agricultural equipment.

APPENDIX A

Introduction
and
Questionnaire

Diesel Fuel Questionnaire for Farm Equipment

Hello my name is ________ and I am calling on behalf of the Farm Bureau, the Nisei Farm League & Fresno State University. We would like to take a few minutes of your time and ask you some questions concerning the performance of your Diesel powered equipment. We are trying to determine the effect of using Low-Sulfur Diesel fuel on farm equipment. Your response will be kept confidential. The summation of the survey results will be presented to the governor on February 18, 1994.

DIESEL FUEL QUESTIONNAIRE FOR FARM EQUIPMENT

DATE ______________________________

COMPANY NAME ______________________________

CONTACT ______________________________

ADDRESS ______________________________

CITY ______________________ STATE __________ ZIP __________

PHONE NUMBER (   ) ______________________________

1) Are you currently using ARB low-sulfur diesel fuel in your farm equipment?

☐ Yes ☐ No ☐ Don't Know

If you do not know, was your fuel purchased after September 1, 1993?

☐ Yes ☐ No ☐ Don't Know

Where do you buy your fuel? ______________________________

____

Are you using a fuel additive?

☐ Yes ☐ No ☐ Don't Know

IF YES, what brand/type of additive (biocide, stabilizer, etc.)

____

2) Approximately how many diesel-fueled equipment units do you currently operate? __________

3) Of these units, how many of them have experienced fuel leaks since September 1, 1993? ____________

4) Have you experienced more fuel leaks than normal since using the low-sulfur diesel fuel/fuel purchased since September 1, 1993?

☐ Yes ☐ No IF NO, GO ON TO QUESTION 6

IF YES, do you believe these leaks are related to the fuel you used at the time the leak occurred?

☐ Yes ☐ No ☐ Don't Know

5) If you are experiencing fuel leaks, how would you characterize them?

☐ Fuel pump leaking

☐ Injector(s) leaking

☐ Fuel return lines leaking

☐ Fuel filter leaking

☐ Other fuel system leaks IF YES, describe ____________________________

____

Do you know the type of equipment (i.e., tractor, pump, etc.) and the manufacturer of the equipment experiencing fuel leaks?

☐ Yes ☐ No ☐ Don't Know

IF YES, specify ____

____

____

6) Are you experiencing more operating or performance problems than normal using the low-sulfur fuel?

☐ Yes ☐ No IF NO, GO ON TO QUESTION 7

IF YES, what kind?

☐ Hard starting

☐ Power loss

☐ Reduced fuel economy

☐ Injector or injector pump failure

☐ Seizure or scoring

☐ Other, specify ____

____

7) Are there any other comments, observations, or other related information you would like to add? (Name and phone number if referenced to others)

____

____

____

____

8) May someone call you for a follow-up interview?

☐ Yes ☐ No

What day and time would be most convenient?

____

____

THANK YOU FOR YOUR TIME

APPENDIX B

SUPPORT BULLETIN

Support Bulletin

DEERE POWER SYSTEMS GROUP

NUMBER: PSB93-14

DATE: 01 OCT 93

FUNCTIONAL GROUP CODE: 0413

APPLIES TO: **ALL 300 AND 400 SERIES ENGINES WITH DISTRIBUTOR (ROTARY)-TYPE FUEL INJECTION PUMPS**

SUBJECT: **FUEL INJECTION PUMP WEAR OR INTERNAL FAILURES CAUSED BY LOW SULFUR FUELS**

DTAC SOLUTION: **K1034**

Complaint or Symptom:

- Premature rotary fuel injection pump wear or failures
- Engine speed instability
- Injector/injection nozzles plugging
- Hard starting
- Low power
- Engine smoke

Problem:

Diesel fuel lubrication properties could be reduced. This is caused by hydro-processing to remove sulfur and/or aromatic compounds during the refining process.

Solution:

When possible use existing fuel formulations for engines used off-highway. This fuel will not require any additives to provide good performance and engine reliability. However, many local fuel distributors will not carry both low and regular sulfur diesel fuels.

If the local fuel distributor will supply only low sulfur fuel, order and use John Deere Diesel Fuel Conditioner (TY22030). It provides lubricating properties along with other useful benefits, such as cetane improver, anti-oxidant, fuel stabilizer, corrosion inhibitor and others. TY22030 was added to the John Deere Merchandise product line specifically for use with low sulfur fuels. Nearly all other diesel fuel conditioners only improve cold weather flow and stabilize long-term fuel storage. They do not contain the lubrication additives needed by rotary fuel injection pumps.

Solution: (continued)

At this time, there is no lubrication test specification available to determine if the fuel requires the TY22030 additive. The additive will prevent the symptoms listed previously, but once they appear, only an injection pump overhaul will cure the problem. If the problems are prevalent in your area, request arctic (hardened) fuel parts be installed at the time of injection pump repair.

Additional Information:

Regulations by the EPA mandate that all diesel fuels for on-highway use after 01 October 1993 must have a low sulfur content. California regulations will require low sulfur fuel for all diesel engines. Current fuels have a sulfur level of about 0.29% while new fuels will have 0.05% sulfur maximum. Diesel fuel used off-highway (farm machinery, stationary engines, construction equipment, etc.) will still be able to use the current fuel formulations and will be easily identified by a blue dye. On-highway fuels with low sulfur will not change dye colors. All diesel-powered trucks are required to use the low sulfur fuel, even if they do not go on-highway.

Those fuels that have sulfur removed by a process that affects lubricity could cause internal fuel injection pump wear. The amount of sulfur that is removed from the fuel will be highly dependent upon the sulfur content in the base crude oil. This could be different for each oil refinery and could change as crude oil sources are changed.

Fuel quality could degrade faster during storage since sulfur is a natural anti-oxidant. This in turn can lead to gum and deposit formation which could contribute to restriction of the fuel through the filters, injectors, and in-line pumps. Field experience will determine if diesel fuel conditioners are also required to maintain typical fuel storage practices. TY22030 does contain the anti-oxidant and corrosion inhibitors and would work in this situation.

The California Air Resource Board (CARB) also has required fuel producers and marketers to meet the sulfur levels, and reduce the aromatic components from roughly 30% to 10%. Alternative levels of aromatic compounds can be used if equivalent emissions are demonstrated. In most cases, all California fuels will be much lower aromatic content. Reduced aromatics could likely further reduce the fuel lubricity, which could make adding a fuel lubricant like TY22030 even more important.

IMPORTANT: *Premature fuel injection system failures due to low lubricity diesel fuels are not covered by warranty by either the fuel injection pump manufacturer or John Deere.*

APPENDIX F

TECHNICAL MEMORANDUM FROM SUBCOMMITTEE #1

TO: Bob Borzelleri, Chair, Diesel Fuel Task Force Subcommittee #2
Paul Henderson, Co-Chair, Diesel Fuel Task Force Subcommittee #3
Manuch Nikanjam, Co-Chair, Diesel Fuel Task Force Subcommittee #3

FROM: Janet Hathaway, Co-Chair, Diesel Fuel Task Force Subcommittee #1
Karen Rasmussen, Co-Chair, Diesel Fuel Task Force Subcommittee #1

TECHNICAL MEMORANDUM FROM SUBCOMMITTEE #1: PROBLEM IDENTIFICATION

SUMMARY

On October 1, 1993, a new diesel fuel was mandated for use throughout California. Requirements for this fuel were designed to reduce emissions from diesel-powered equipment. This fuel is mandated for use in both on-road and off-road applications. To insure adequate fuel supplies during transition to the new fuel, some variances were granted to produce U.S. EPA low sulfur diesel fuel. Also on October 1, 1993, U.S. EPA required the use of a low sulfur fuel for on-road applications throughout the remainder of the United States.

This memorandum summarizes the interim status of analyses of the mechanical problems attributed to the new California diesel fuel. At the initial December 21, 1993 meeting of Subcommittee #1, a list of six key questions was identified. To meet the schedule demands of the overall Task Force, this memorandum presents preliminary answers to these questions based on data received by Radian Corporation as of January 12, 1994. This interim technical memorandum is presented to provide guidance from the investigations into the causes of the problems attributed to the new diesel fuel. Further analysis and data collection by Subcommittee #1 in the coming weeks will attempt to add additional detail for responding to these questions.

The preliminary conclusions to the six questions are summarized below, followed by recommendations for further analysis. Each question is addressed in more detail in the Technical Discussion section of the memorandum. (Questions 1, 2,and 3 are discussed in Section 1; Questions 4, 5, and 6 are discussed in Sections 2, 3, and 4, respectively.)

1. *What are the specific mechanical and performance problems being reported?*

- The majority of problems concern O-ring or other elastomeric component leaks/failures in the fuel system.
- Many major engine manufacturers of both light and heavy duty diesel engines are represented among the failed equipment.
- Isolated reports of lubricity-related problems have been received. Because of insufficient data, the extent of this problem has not been determined at this time.
- Other problems have been reported on an isolated basis, including hard starting and clogged fuel filters.

2. *What is the extent of the mechanical problem (i.e., which service categories/vehicles/engines/components are being affected)?*

- All types of vehicle service are represented in the vehicles reporting seal leakage problems, including long haul/interstate, local/delivery, agriculture, emergency vehicles, refrigerated units, and passenger vehicles.

- Failures were typically associated with "aged" seals, as represented by vehicle mileage. The age of a seal can be represented by a number of factors, including mileage, chronological age, and hours of use. Other factors can also influence the aging of a seal, including temperature and number of thermal cycles. It should be noted that the mileage distribution of reported failures indicated large variability.

- Data and other information received suggest that nitrile rubber seals are used in the vast majority of the failed O-ring seals.

3. *Which service categories/ vehicles/engines/components are <u>not</u> being affected?*

- Although additional data are yet to be analyzed, the data reviewed to date indicate that fluorocarbon elastomer seals are apparently not suffering failures.

- One major engine manufacturer has suffered no confirmed failures; this may be due to the differing mechanical design of their fuel system and use of fluorocarbon seals.

4. *What is the geographical nature of the reported problems?*

- O-ring leakage problems have occurred across the U.S., not just in California. However, because of insufficient data, the extent and severity of this problem outside California cannot be determined at this time.

- There is a clear distinction in failure rates between northern and southern California, with higher failure rates of diesel fuel systems reported in northern California.

5. *What is the temporal nature of the reported problems (i.e., how has the incidence of fuel system problems corresponded to the introduction of new fuels)?*

- While not amenable to rigorous statistical analyses, there is considerable evidence showing that the fuel system problems increased at the same time as the introduction of the new California diesel fuel (ARB and variance fuel).

6. *Are there any apparent correlations between fuel formulation differences in samples analyzed thus far, and the geographic or temporal nature of reported problems?*

- Initial examination of the ARB and CTA fuel analysis data does not show any clear trends between fuel properties and seal-related failures. Analysis of the fuel sampling data in connection with seal-related and other mechanical problems is continuing.

Recommendations for Further Analysis

This preliminary review has begun to answer some of the questions associated with the new diesel fuel. However, further data analyses are warranted to assist in determining the extent of the problems. We recommend that further analyses be conducted in time for the February 19 report to the Governor and under the guidance of Subcommittee #1:

- Pursue collection of data regarding the potential impact on agricultural machinery. This will include a survey of equipment owners to gather additional data and collection of fuel samples for analysis.

- Examine further the fuel analysis data to correlate with any documented diesel engine experiences.

- Evaluate the mechanical differences between engines and components to further isolate specific elements contributing to the problems.

- Continue investigation into potential mechanisms of seal failures including changes in seal swell, fuel oxidation, and other chemical effects.

- Assess why diesel fuel system failure rates are higher in northern California than in southern California.

- Update the repair, survey, and hotline databases to determine if the extent of the problems are increasing, steady, or decreasing.

- Investigate the cause of the numerous fuel line leaks reported in the ARB draft light duty/medium duty diesel vehicle survey data.

- Investigate the relative extent and nature of reported diesel fuel-related problems outside California.

- Investigate reports of repeat leak failures.

- Investigate reports of fluorocarbon seal failures.

TECHNICAL DISCUSSION

1.0 Extent of Mechanical Problems

Question 1: What are the specific mechanical and performance problems being reported?

Question 2: What is the extent of the mechanical problem?

Question 3: Which service categories/vehicles/engines/components are <u>not</u> experiencing mechanical problems?

References

California Air Resources Board (ARB) listing of diesel hotline complaints (database).

ARB heavy duty diesel field study.

ARB fleet inspections.

ARB light duty diesel mail survey.

ARB light duty diesel telephone survey.

ARB repair facility survey.

ARB roadside fuel survey.

California Trucking Association (CTA) diesel fuel failure reports from hotline calls, 1/5/94.

Memo from M. Payne and M. Fraytet, ARCO, to N. Dickson, Radian, 12/28/93.

Memo from engine manufacturer, 12/21/93.

Memo from D. Holmes, Chair, School Transportation Coalition, to J. Strock, 12/14/93.

ATA list of complaint phone calls.

Complaint reports to CIOMA.

Survey of the School Transportation Coalition.

Report of O-ring failures from ARCO.

1.1 ARB Listing of Diesel Hotline Complaints (database)

Radian has a copy of the ARB hotline log covering diesel fuel-related calls to ARB between October 13, 1993 and January 3, 1994. The log includes calls to the hotline and other ARB offices. As of January 3, a total of 1,064 individuals had made a total of 1,099 calls to ARB. Phone calls to ARB peaked during the week ending December 3, 1993, with 213 calls recorded that week. The geographic distribution of callers (based on telephone area code) has been:

- 86% from northern California;
- 11% from central California;
- 2% from southern California; and
- 1% from outside California.

The timing and geographic origin of these calls have likely been a function of publicity, as well as the location and frequency of fuel-related mechanical problems.

This is a passive survey; that is, only vehicle owners who heard about the hotline called. The content of the calls is recorded as narrative rather than being broken down into distinct data fields for vehicle type and specific problem.

The caller messages can be broadly classified into three categories:

- Callers describing severe leaks, plugged fuel filters, and/or performance problems with one or more vehicles;
- Callers requesting information regarding potential risks to their equipment, and mitigation measures that they might take; and
- Fleet operators who called to report that they have reported no unusual problems to date.

The vast majority of the 1,099 calls fell into the first of these three categories.

Agriculture: One focus of our review of the ARB hotline calls was calls from individuals identifying their business type as farming or agribusiness. Because agricultural machinery activity is low at this time of year, the new fuels have not yet penetrated much of the agricultural equipment fleet. Therefore, at this time we have very limited indications of the possible impacts of the new fuels on California agriculture. A total of 27 callers identified themselves as farmers/agribusiness. The 27 calls included reported problems with fuel leaks on farm tractors, irrigation pumps, heavy trucks, pickup trucks, and passenger cars.

1.2 ARB Heavy Duty Diesel Field Study

These questionnaires were sent to heavy duty diesel owners who called the Mobile Source Division or the ARB hotline. Questionnaires were also handed out to truck drivers during the roadside fuel survey. A total of 660 completed questionnaires were collected and logged.

Problems cited in the comment sections included: leaking fuel pumps and fuel injectors, poor gas mileage, power loss, hard starting, excessive smoke, rough idling, excessive noise, higher operating temperature, and problems attributed to reduced lubricity.

The total number of problem vehicles owned by the respondents cannot be determined from the database because many of the comments are associated with large fleets. In these records, there is no indication of the number or make of vehicles exhibiting problems.

No popular engine type was conspicuously absent from the list. However, the engine manufacturer identified as E2 was very sparsely represented. Only one reported leaking vehicle could be positively identified as E2.

Leaking was not restricted to high mileage vehicles. Leaks were reported for vehicles with less than 10,000 miles. Mileage distribution indicated large variability. These data are summarized in Table 1-1.

Only 20 respondents specified the type of O-ring associated with the leaks. Of these, 8 were nitrile seals and 12 were fluorocarbon elastomer. However, most of the respondents citing fluorocarbon elastomer seals operated vehicles known to use nitrile seals.

Several points should be taken into account before any conclusions are based on the above results. First, the survey audience was not targeted in a statistically selective manner (as the light duty survey was). Second, the survey did not ask the respondents to specify which components of their fleet makeup had experienced leaks.

1.3 ARB Fleet Inspections

The data set that Radian has is current as of October 27, 1993. As of that date, a total of 32 individuals and fleet contacts had answered this survey, providing information regarding fleet vehicle mechanical and performance problems. Table 1-2 presents a summary of the mechanical problems reported.

Performance problems reported in this survey include:

- Acceleration;
- Fuel mileage drop;
- Higher engine temperature;
- Starting problems;
- Idling problems; and
- Engine noises.

Information about the number of trucks (or components) is not complete. The data, as recorded, do not support comparisons between the current incidence of mechanical and performance problems and fleet history.

1.4 ARB Light Duty Diesel Mail Survey

These questionnaires were sent to light duty diesel owners who called the Mobile Source Division or the ARB hotline. A total of 170 questionnaires were logged into the database. Table 1-3 summarizes the results of these surveys.

1.5 ARB Light/Medium Duty Diesel Telephone Survey

This survey was statistically designed to determine the frequency of fuel leaks and background information from a representative sample of light and medium duty diesel vehicle owners in California. In the survey, ARB contacted 888 diesel vehicle owners throughout the state. (Note that the survey results are still in draft form and subject to change as the quality assurance process is completed.)

The draft results provide estimates of the frequency of fuel leaks experienced to date by light duty diesel vehicle owners since October 1, 1993. In the South Coast Air Basin, the estimated leak frequency ranges from 0.2 to 4 percent. Over the remainder of California, the estimated leak frequency is 5 to 12 percent. The ranges in estimated leak frequency are due to variations in the possible definition of what type of failure should be considered a leak. The lower value represents a strict definition of fuel injection system leaks; that is, verbally confirmed injection system fuel leaks. The high end of the estimated leak frequency range also includes verbally confirmed general fuel system leaks that did not involve the fuel pump.

Analysis of the data for leaking vehicles indicated the following:

- Most of the popular light duty diesel vehicles were represented. However, manufacturers E8, E13, E15, E19, and E22 were not represented. (All of these manufacturers were represented in the nonleaking vehicles, however.)
- Leaking was not restricted to high mileage vehicles. However, a majority (70%) of the leaking vehicles had in excess of 100,000 miles. These data are summarized in Table 1-1.

1.6 ARB Repair Facility Survey

The ARB surveyed diesel repair facilities via phone and field visits to document mechanical problems. Facilities surveyed included truck dealerships, passenger car dealerships, fuel injection pump rebuild shops, and fleet repair facilities. A total of 286 survey forms were logged into the database, and 43 facilities responded to questions regarding the total number of leak repairs by vehicle manufacturer. Table 1-4 presents a compilation of these reported repairs.

1.7 ARB Roadside Fuel Survey

This survey was essentially a random or "active" survey within the geographic areas where it was undertaken. These surveys took place between October 25 and November 10, 1993. A total of 7,695 truck operators were surveyed. The statewide results from this survey were:

- 90% of truckers surveyed reported no mechanical problems with the new fuel; and
- 10% of the truckers surveyed cited mechanical/performance problems. One-fifth of these reported fuel leaks.

These data are broken out by geographic region in response to Question 4.

1.8 CTA Diesel Fuel Failure Reports

Data were analyzed from a report dated January 5, 1994. A total of 251 individuals and fleet operators had called the California Trucking Association (CTA) hotline, reporting fuel-related problems with 1,423 vehicles. Table 1-5 presents a summary of the calls to the CTA hotline, broken down by vehicle category and geographic location of the caller.

Table 1-1 summarizes the mileage distribution of the reported failures.

It should be noted that this is a passive survey of reported problems; only vehicle owners who were aware of the hotline and were motivated to call are represented in the data. Our preliminary investigation has indicated that four heavy duty truck engine types, E1, E3, E4, and E5, were predominantly represented in the data set. The distribution of the various engine types is indicated in Table 1-6. It is noteworthy that no complaints were reported for engine type E2.

1.9 Memo from ARCO, 12/28/93

This memorandum documents the experience to date of four truck fleets:

- The ARCO truck fleet of 61 trucks operating on ARB-specification fuel and 22 trucks operating on U.S. EPA-specification low-sulfur fuel;
- The Certified Freight Lines (CFL) fleet of 50 trucks operating on ARB-specification fuel; and
- The Beneto Inc. fleet of 130 trucks which, ARCO understood, was operating on both ARB- and U.S. EPA-specification fuels through late 1993.

The ARCO fleets report one fuel system failure since the introduction of the new fuels. This is consistent with the normal maintenance history of these fleets. The CFL fleet has repaired the pumps on 35% of their fleet in less than one month, after being alerted to the potential for leaks through a manufacturer's bulletin. The Beneto truck fleet experienced no pump failures between the time of the introduction of the new fuels and the date of the memorandum (12/28/93).

1.10 Memo from Engine Manufacturer

Key points made in this memorandum are:

- Only one of the two pump styles manufactured by this firm is experiencing any problems.
- Reports of problems have been received from across the U.S, indicating that it is not a California-only problem.
- Failures have been reported in vehicles with mileage in the range of 300,000 to 700,000 miles.
- The exact number of failures or the percent of the fleet impacted is difficult to estimate because those seals that fail as a result of fuel composition changes mostly occur well after the warranty period has ended.

1.11 Memo from School Transportation Coalition to J. Strock, 12/14/93

This memorandum presents the results of a survey of all California school districts regarding diesel fuel-related problems. A total of 36 school districts have responded to the survey:

- 30% of the respondents have experienced an unusual increase in the failure of O-rings or leaking fuel pumps in their school buses within the month ending December 14.
- 33% of the respondents have experienced an increase in fuel consumption.
- 30% of the respondents reported poorer performance in the operation of their school buses.
- 50% of the respondents have additional concerns about the new fuel (e.g., costs, hard starting, lubricity questions).

It is noted that the percentages listed above represent the percent of responding fleet supervisors who have observed these problems, not the percent of vehicles within the fleets that are affected.

Conclusions

The most common mechanical and performance complaints reported since the introduction of the new ARB and variance fuels are:

Leaking fuel injection pumps. This complaint has been associated with an array of different pump brands and models used on light, medium, and heavy duty diesel vehicles. Diesel vehicles of many makes, models, ages, and service types are represented in the reports. However, the common features among the majority of complaints are:

- Leaks occur most often at throttle shaft O-rings, although certain pump models have additional O-rings on covers and tachometer connections that may also fail.
- Leaks nearly always occur on fuel-lubricated (as opposed to motor oil lubricated) fuel injection pumps.
- Failed O-rings are nearly always nitrile rubber (as opposed to fluorocarbon elastomer).
- Failures were typically associated with "aged" components. The age of a seal can be represented by a number of factors including mileage, chronological age, and hours of use. Other factors can also influence the aging of a seal, including temperature and number of thermal cycles. In this analysis, mileage was the most widely available indicator of seal age.

Note also that nearly all the light duty diesel passenger vehicles in California are between 5 and 15 years old (no new light duty diesel-powered passenger cars have been sold in California from 1988 to 1993). Because of the age and type of pumps used, the bulk of the passenger car fleet (with the exception of manufacturer E9) is described by most of the "leak candidate indicators" listed above.

A confounding factor in the evaluation of many vehicle repair data is the influence of preventive maintenance. In general, the data do not allow the assessment of how many reported repairs were preventive in nature.

Loss of power and reduced fuel economy. This complaint has been voiced nationwide from virtually all service groups.

Leaking fuel system hoses. These complaints come mostly from owners of one make of passenger cars (E9). Such hoses normally require periodic replacement, but the number of reports suggests that the change in fuel may have instigated failure in a number of older vehicles.

Leaking fuel injectors. These complaints come mostly from owners of pickups and light trucks with a single make of motor (E4). Pump systems using fluorocarbon elastomer seals are not experiencing failure. Manufacturer E2, which uses engine oil-lubricated fuel pumps and fluorocarbon elastomer seals, is absent from the reports of leaking vehicles.

Lubricity. A variety of fuel system problems have been attributed to reduced lubricity. The potential extent of problems and the mechanism for this effect are not well understood at this time.

Agricultural equipment effects. Data regarding the possible impacts of the new fuels on agricultural machinery are, as yet, very limited. Radian's initial review of relevant information has indicated that an array of different injection fuel pump styles (fuel lubricated, oil lubricated, distributor-type, and in-line) are used on agricultural equipment. The impacts of the change in fuel will likely depend on the distribution of different pump styles in the fleet. The impacts from diesel fuel changes are not yet known.

At this time of year, agricultural activities utilizing diesel equipment are minimal compared with other seasons of the year. Nevertheless, Subcommittee #1 is interested in investigating the potential effects of the new diesel fuel on agricultural equipment. For this reason, the Subcommittee has initiated a survey of agricultural equipment operators to identify the extent of any current mechanical problems and to identify plans for near-term agricultural activities.

Table 1-1
Mileage Distribution of Failure Reports
By Vehicle Type

Vehicle Type	Minimum Mileage Reported	Median Mileage Reported	Maximum Mileage Reported	# Vehicles Reporting Mileage
Heavy Duty Diesels[a]	8	197,236	1,000,000	176
Light Duty Diesels[b]	6,000[d]	121,000	400,000	77
Heavy Duty Diesels[c]	6,171	357,825	948,000	114
Light Duty Diesels[c]	8,573	117,800	250,000	235

[a] Source: ARB Heavy Duty Diesel Field Survey. This data set includes a few light duty vehicles.

[b] Source: ARB Light/Medium Duty Diesel Telephone Survey.

[c] Source: CTA Diesel Fuel Failure Reports. For the purposes of mileage pattern analysis, ambulances were included in the light duty diesel vehicle category.

[d] ARB has determined that the vehicle reporting failure at 6,000 miles had been recently rebuilt. It was not clear whether the fuel system had been rebuilt. If this data point is excluded from the calculations, the values for this row are: Minimum = 40,000 mi; Median = 125,500 mi.

Table 1-2
ARB Fleet Inspection Summary
(Failures Noted By Engine Type)

	Engine Type		
	E3	**E4**	**E5**
Mechanical Problems			
Fuel Pump			
O-Ring	✓	✓	✓
Fuel Pump Failures (unspecified)	✓	✓	
Injector O-Rings		✓	
Return Hoses		✓	
Filters Plugging	Not Identified		

Table 1-3
ARB Light Duty Diesel Mail Survey

Component	Vehicle Make														
	Missing	E21	E22	E23	E14	E24	E8	E14	E16	E9	E25	E12	E11	E10	E18	Total
Injector Pump	2	5	3	1	3	1	24	4	1	9	3	16	35	13	2	122
Return Line(s)		1		2			19	1		20	1		7	2		54
Injector(s)					1		21	3		9	1	1	3	1	1	41
Filter							8	1		5	2	2			1	19
Other/ Unspecified	1	1			1		16	2		8			7			36

Notes to assist in the interpretation of Table 1-3: Makes E8 and E9 (a pickup and a car) are the major light duty diesel vehicles in California, each making up approximately 25% of the population. These are followed by E11, which makes up approximately 8% of the light duty population. The trends indicate that a number of hose leaks were reported on E9, but relatively few other problems (relative to the large population of these units in the state). Reported failures among other makes are mostly confined to pump problems, with the relative numbers of reports roughly proportional to vehicle populations for European makes. Few problems were reported for American and Japanese-made light duty diesels.

Table 1-4
ARB Repair Facility Survey

Component Repaired[a]	Manufacturer						
	C1	C5	C2	C6	E1	Not Listed	Total
Pumps	137 10%	664 50%	452 34%	74 5%	NA	7 1%	1,334 100%
Injectors	32 2%	1,072 86%	NA	21 2%	124 10%	1 1%	1,250 100%

[a] Time frame of repairs was not specified.

Table 1-5
Summary of Calls to CTA Hotline

Region	Heavy Duty Trucks[a]	Cars & Pickups	Other[b]
Northern California	795	130	65
Central California	312	15	89
Southern California	14	3	0
Total	1121	148	154

[a] Includes ambulances
[b] Includes refrigeration units on truck trailers, construction/farm equipment, forklifts, and locomotives.

Table 1-6
CTA Diesel Fuel Failure Report (by engine type)

	Engine Type				
	E1	E3	E4	E5	Other[a]
Number of reports	108	410	238	387	280

[a] Includes refrigeration units on truck trailers, construction/farm equipment, forklifts, passenger cars, and locomotives.

2.0 Geographical Extent

Question 4: What is the geographical nature of reported problems?

To isolate the existence and causes of diesel fuel-related problems, it is important to determine the approximate geographical extent of the perceived problems, both within and outside of California. Early evidence indicated that the majority of reported problems occurred in northern California, with fewer reported problems in southern California. Other information indicated that this problem was not confined to California.

In analyzing the geographical question within California, areas generally north of Santa Barbara and Fresno were designated as "north." Areas inclusive of Fresno and Bakersfield were designated as "central," and the remaining areas were designated as "south."

The BURDEN7C California vehicle population estimates for 1993 were used to obtain the relative population of diesel-fueled light duty truck and passenger cars (LDD) and heavy duty trucks (HDD). The relative geographical distribution of these populations is listed in Table 2-1. These estimates should be updated with the latest version of BURDEN7F.

References

The following data were used in the geographical analysis:

ARB heavy duty diesel field study.

ARB roadside survey database.

ARB light duty diesel telephone survey.

ARB survey of repair facilities.

H. G. Makelim Co. data on O-ring sales.

CTA diesel fuel failure reports.

Complaint reports to CIOMA.

Data provided to ARB by Schneider National Trucking and Ruan Transportation Management.

ATA list of complaint phone calls.

2.1 ARB Heavy Duty Vehicle Diesel Field Study

The regional allocations were determined based on the area code, ZIP code, or the city of the reported fuel supplier. Table 2-2 contains the geographical distribution of both "leak" and "nonleak" problems as reported in this data set.

Since approximately half of the data had no location information for the fuel supplier, it is difficult to draw definite conclusions with regard to the geographical extent of the problems. However, when compared to the distribution of the HDDs in California (Table 2-1), it is evident that there is a preponderance of leak problems reported in the northern parts of the state.

2.2 ARB Roadside Survey Database

The roadside survey was carried out in various regions of the state (north, south, and central) and, thus, may provide insight into the geographical spread of reported problems. The results of this survey are summarized in Table 2-3. The results provide a clear indication of the predominance of HDD leak problems in northern California. Whereas 85% of the leakage reports were located in the north, only 13% were located in the south.

2.3 ARB Light Duty Diesel Telephone Survey

The regional allocations were determined based on the area code or ZIP code of the survey respondents. Table 2-4 contains the geographical distribution of both "leak" and "nonleak" responses in the data set.

As with the HDD data, there is a preponderance of leaks (78% of the total) reported in northern California. This result is important in view of the LDD population distribution indicated in Table 2-1. In other words, whereas over half the LDD population resides in southern California, roughly three quarters of the leak problems are reported in northern California.

2.4 ARB Repair Facilities Survey

Of the 286 records in this repair survey data set, 232 do not have the number of pumps serviced in 1992, and 226 do not contain the number of pumps serviced in 1993. Nevertheless, where the data were provided, geographical trends emerge.

The data are listed in Table 2-5 and indicate that, whereas there is a modest increase (15%) in the overall number of pumps serviced in 1993 versus 1992, there is a dramatic increase in reported services in the northern (107%) and central (1,183%) regions and a decrease (-7%) in the southern region. Caution should be taken not to attach too much importance to these data, however, because much data are missing from this data set.

2.5 Other Northern vs. Southern California Data

Additional data sets were examined that provide data supporting the distinction between northern California and southern California failure rates. These include:

- H.G. Makelim Co. data on O-ring sales;
- CTA diesel fuel failure reports; and
- Complaint reports to CIOMA.

2.6 Data Provided by Schneider National Trucking and Ruan Transportation Management

Several other data sources address the extent of the perceived mechanical problems nationwide. Reports of fuel pump leaks were provided by Ruan and Schneider from terminals across the U.S. A total of 141 such failures were reported by Ruan. By January 11, 1994, a total of 765 leaks (out of a fleet size of 4,900) were reported by Schneider, representing a leak percentage of 16.

2.7 ATA List of Complaint Phone Calls

Complaint phone calls reporting problems were received from the ATA. Data logged between October 4, 1993 and November 12, 1993 include complaints from across the U.S.

Conclusions

The data analyzed in this section support the following interim conclusions:

- The majority of leaks in California have been reported in the northern parts of the state; and
- The reported occurrences of leaks span the entire U.S. However, the extent and severity of this problem outside California cannot be determined at this time.

Table 2-1
Geographical Distribution Diesel Vehicles in California

	Percent of LDD	Percent of HDD
North	42	43
Central	3	4
South	55	53

LDD = Light duty diesel
HDD = Heavy duty diesel

Table 2-2
Geographical Distribution of HDD in ARB Heavy Duty Vehicle Diesel Field Study
(Based on fuel supplier location)

	Leak		Nonleak	
Region	**Frequency**	**Percent**	**Frequency**	**Percent**
North	138	37	47	15
Central	27	7	34	11
South	20	5	30	10
O[a]	16	4	16	5
M[b]	173	46	179	58

[a] Outside of California
[b] Missing

Table 2-3
Geographical Distribution of Roadside Survey Results

	Leak		No Problems	
Region	**Frequency**	**Percent**	**Frequency**	**Percent**
North	135	85	2,409	47
Central	3	2	339	7
South	21	13	2,390	46
Total	159	100	5,138	100

Table 2-4
Geographical Distribution of LDD Leaks from ARB Light Duty Diesel Telephone Survey

Region	Leak		No Problems	
	Frequency	Percent	Frequency	Percent
North	69	78	345	43
Central	4	4	80	10
South	16	18	370	47
Total	89	100	795	100

LDD = Light duty diesel

Table 2-5
Geographical Distribution of Pumps Serviced in 1992 and 1993

Region	Pumps Serviced in Sept/Oct 1992	Pumps Serviced in Sept/Oct 1993	Percent Increase
North	255	527	107
Central	6	77	1,183
South	1,355	1,261	-7
Total	1,616	1,865	15

3.0 Temporal Extent

Question 5: What is the temporal nature of the reported problems? Is the problem potentially due to the new fuel?

Based on historical data, we assessed whether a significant change occurred in failure rates after the introduction of the new ARB and variance fuels.

References

ARB Repair Facilities Survey database.

Diamond Diesel Service Inc. information on Oakland and Sacramento store fuel injection pump repair records.

Coast Fuel Injection Inc. information on parts sales records.

H. G. Makelim Co. information on popular pump seals and rebuild kit sales.

Fresno Truck Center information on O-ring and seal kit sales.

Component Manufacturer C5 (northern California, southern California) information on O-ring sales.

California State Automobile Association (CSAA) summary of California diesel fuel problems.

3.1 ARB Repair Facilities Survey

The data fields we reviewed were the number of pumps serviced in September/October 1992, the number of pumps serviced in September/October 1993, and the comparison of September/October 1992 with September/October 1993 (i.e., more/same/less). Table 3-1 summarizes these data.

For a majority of the repair facility records, these data fields were missing, so the findings are not conclusive. Another potential limitation is the wording of the comparison question on the survey form: "Has Sep.-Oct. 1992 business been (more, same, or less) than Sep.-Oct. 1993?" Based on a review of the data, it appears that the majority of the responses answered the converse of this question (i.e., "more" indicated 1993 > 1992).

3.2 Diamond Diesel Service Inc.

Diamond Diesel Service Inc. provided information on fuel injection pump repair records for October 20 through December 20, 1992 and October 20 through December 20, 1993 for their Sacramento and Oakland stores. Table 3-2 summarizes these data.

The key feature of these data is that, from an historical perspective, a consistent time frame is addressed both before and after the introduction of the new fuel. Hopefully, this would help to minimize any seasonal differences in repair rates. The major limitation to these data is that only a two-month period is addressed for each year, which may provide more of a "snapshot" evaluation rather than a clear trend.

3.3 Coast Fuel Injection Inc.

Coast Fuel Injection Inc. provided information on parts sales records for September 15 through December 31, 1992 and September 15 through December 31, 1993 for their San Jose, Salinas, and Stockton branches. Similar data were provided for the first week of January 1994. Table 3-3 summarizes these data.

Similar to the Diamond Diesel data, the key feature of these data is that, from an historical perspective, a consistent time frame is addressed both before and after the introduction of the new fuel.

3.4 H. G. Makelim Co.

H. G. Makelim Co. provided information on popular pump seals and rebuild kit sales in California. Annual totals were provided for 1992. For 1993, total figures were provided for January-September and monthly totals were provided for October, November, and December. These data are summarized in Table 3-4.

The key point of these data is that H. G. Makelim is a major parts supplier (for light duty trucks and automobiles). A key shortcoming of these data is that sales rates are only an indirect indicator of repair rates.

3.5 Fresno Truck Center

The Fresno Truck Center provided monthly information on O-ring and seal kit sales for December 1992 through November 9, 1993, and annual totals for the previous year (i.e., December 1991 through November 1992). These data are summarized in Table 3-5.

The key feature of these data is that monthly totals are provided for almost an entire year, including time both before and after the introduction of the new fuel. This continuum of data helps support trend analysis.

3.6 Component Manufacturer C5 (Northern California)

Component Manufacturer C5 provided information on O-ring sales in northern California for the fourth quarter of 1993. These data are summarized in Table 3-6.

The major shortcoming of these data is that only a three-month period is addressed. Therefore, these data may provide more of a "snapshot" evaluation rather than a directional trend.

3.7 Component Manufacturer C5 (Southern California)

Component Manufacturer C5 provided information on O-ring sales in southern California. Monthly totals were provided for July-November 1992 and July-November 12, 1993. These data are summarized in Table 3-7.

The key feature of these data is that a consistent time frame is addressed for both years. Hopefully, this would help to minimize any seasonal differences in repair rates. The major limitation to these data is that only a five-month period is addressed for each year, with only one month of complete data after the introduction of the new fuel. Therefore, these data may provide more of a "snapshot" evaluation rather than a directional trend.

3.8 California State Automobile Association (CSAA)

The CSAA submitted a summary of California diesel fuel problems reported by American Automobile Association (AAA) members. The CSAA and Automobile Club of Southern California have approximately 1,700 approved auto repair facilities under contract for guaranteed auto repairs for their roughly 6.8 million members. These facilities indicated that before the introduction of ARB and variance fuels in California, they were performing three or four repairs per month related to O-ring and seal failures. Since the introduction of ARB and variance fuels, they have been performing two or three repairs per week that are related to failure of rubber-based components. These repairs covered LDD passenger vehicles.

Conclusions

Overall, the available repair and parts sales data suggest that, in terms of a general trend, the failure rate of diesel vehicle components (e.g., O-rings, pumps, gaskets) has noticeably increased since the introduction of the new fuel. Additional data are needed to firmly establish recent trends in sales data indicating an increase or decrease in failure rates.

Sales and repair data should be interpreted with caution because of the conflicting factors of stockpiling and back orders. (Stockpiling will tend to inflate sales data, whereas back orders will deflate sales data; both have been reported.)

Table 3-1
ARB Repair Facilities Survey
Pumps Serviced Sep/Oct 1993 vs. Sep/Oct 1992

Facility Responses	Facilities Reporting Actual Numbers of Units Repaired	Facilities Responding "More" "Same" or "Less"
Pumps serviced 1993 > pumps serviced 1992 or "more"	23	47
Pumps serviced 1993 = pumps serviced 1992 or "same"	23	57
Pumps serviced 1993 < pumps serviced 1992 or "less"	8	16
Data missing	232	166

Table 3-2
Diamond Diesel Service Inc. Fuel Injection Pump Repairs
for October 20 - December 20 (1992 and 1993)

Component Manufacturer	Sacramento		Oakland		Total	
	1992	1993	1992	1993	1992	1993
C1	15	41	24	105	39	146
C2	7	13	28	41	35	54
C3	10	12	22	32	32	44
C5	9	19	31	75	40	94
C6	1	4	6	13	7	17
Total	42	89	111	266	153	355

Table 3-3
Coast Fuel Injection Inc. Equipment Sales[a]
(Total for San Jose, Salinas, and Stockton Branches)

Component Manufacturer	1992	1993					1994
	9/15-12/31	9/15-30	Oct	Nov	Dec	9/15 - 12/31	1/1-1/7
C1	23	23	80	100	57	260	19
C5	46	19	61	54	40	174	15
E4	78	42	111	81	77	311	34
Total	147	84	252	235	174	745	68

[a] Includes individual items (O-rings, pumps, etc.) and repair kits (return line, pumps, gasket, etc.).

Table 3-4
H.G. Makelim Co.
Popular Pump Seals and Rebuild Kits Sales

Component Manufacturer	1992	1993				
	Total	Jan - Sep	Oct	Nov	Dec	Total
C1	878	567	299	341	641	1,848
C5	760	646	122	304	130	1,202
C6	25	48	33	32	46	159
E4[a]	10,000	8,110	1,501	1,898	3,930	15,439
Total	11,663	9,371	1,955	2,575	4,747	18,648

[a] These O-rings are normally sold in packs of 100; 16 seals are used in each engine.

Table 3-5
Fresno Truck Center O-Ring and Seal Kit Sales

Component	1992	1992	1993											Dec '92-Nov '93
	Previous Year[a]	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov[b]	
O-Rings	30	3	1	0	3	3	4	4	1	10	6	65	7	107
Seal Kits	108	12	5	8	8	9	11	17	11	7	10	5	7	110
Total	138	15	6	8	11	12	15	21	12	17	16	70	14	217

[a] December 1991-November 1992
[b] November 1-9, 1993

Table 3-6
Component Manufacturer C5 (Northern California)
O-Ring Sales

1993			
Oct	**Nov**	**Dec**	**Oct - Dec**
179	587	578	1,344

Table 3-7
Component Manufacturer C5 (Southern California)
O-Ring Sales

Location	1992						1993					
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Jul - Nov**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Jul - Nov**
Montebello	16	22	28	32	18	116	28	48	42	33	5	156
Rialto	61	57	35	57	44	254	27	30	34	38	22	151
San Diego	6	4	2	4	4	20	1	1	1	4	2	9
Total	83	83	65	93	66	390	56	79	77	75	29	316

4.0 Fuel Formulation

Question 6: Are there any apparent correlations between fuel formulation differences in samples analyzed thus far, and the geographic or temporal nature of reported problems?

Variations in fuel formulations could be a contributor to the reported problems. Analysis of the data received to date is not complete. This memorandum presents interim findings from the two largest data sets (listed below). Initial examination of the data was focused on the impact of fuel on seal-related failures. Further analysis of the complete data set is continuing.

References

ARB fuel testing program.

CTA fuel analysis results (from Saybolt Laboratories).

4.1 ARB Fuel Testing Program

The ARB collected over 200 diesel samples throughout the state, starting in late October 1993 and continuing through November 1993. These fuel samples were collected from refineries, retail distributors, and truck fuel tanks at inspection stations. The truck fuel tanks may have contained a mixture of U.S. EPA- and ARB-specification fuels and ARB variance fuel. The fuel samples were analyzed for sulfur, total aromatics, polynuclear aromatics (PNA), moisture, peroxides, distillation properties, acid content, color, and density. Laboratory results were received for 216 samples. Due to funding limitations, 26 samples were tested only for total aromatics and PNA. In addition, the results for two samples were deemed invalid; one sample (i.e., N096) was determined to be gasoline and another sample (i.e., N109) was determined to be a mixture of gasoline and diesel.

Preliminary data analysis performed by ARB in mid-November (data had been received for 120 samples) indicated that the aromatic content of the diesel fuels sampled ranged from 10% to 36%. Subcommittee #1 does not currently have data to calculate averages weighted by sales or market share within a region. Radian is working to obtain this information. Pockets of fuels with 10% aromatic content were identified in Kern County and Oakland. Sulfur content in the fuel samples was uniformly less than 0.05% (i.e., <500 ppm), with the 10% aromatic fuels typically containing less than 0.01% (i.e., <100 ppm) sulfur. The remaining analyses found that all the other parameters fell within the specifications for diesel fuel. Unusual levels of peroxides or acid content were not found. The color analyses suggested that many of the fuel samples taken from trucks may have contained additives such as automatic transmission fluids.

Radian performed preliminary data analysis for the 214 valid diesel samples. The total aromatic content was 5.1-36.2 vol% as reported by ARB laboratories and 4.8-38 vol% as reported by Calab Brett, an independent testing laboratory. Caution must be used when comparing data from different laboratories because of variabilities in test methodologies. The PNA content values ranged from 0.1-12.4 wt%. Sulfur content in the fuel samples ranged from 0.001-0.435 wt% (i.e., 10-4350 ppm). Only ten samples had a sulfur content greater than the compliance limit of 0.05 wt% (i.e., 500 ppm).

Radian has been working with ARB staff to determine the point of origin for each fuel sample. Based on the available data, fuel samples have been identified by type (e.g., refinery, retail [service station/truck stop], or vehicle [truck/car]) and geographic location (e.g., north, central, or south). In addition, where possible, Radian has identified which fuel samples were taken from leaking versus non-leaking vehicles. This effort is ongoing and preliminary data analysis performed to date has been inconclusive.

4.2 CTA Fuel Analysis Results (from Saybolt Laboratories)

The CTA provided copies of fuel analyses prepared by W. Saybolt & Company, Inc. from October-December 1993. The majority of the samples were submitted by companies in northern California. In all, 19 diesel samples were analyzed for total aromatics, olefins, and saturates. The total aromatic content ranged from 8.5-46.1 vol%. The total olefin content reported ranged from 3.4-8.3 vol%. volume. Lastly, the total saturate content ranged from 49.2-88.0 vol%.

Conclusions

To date, the initial analyses of the ARB and CTA diesel fuel sampling data have not supported any clear correlations between fuel formulation and fuel system elastomer failures. Efforts to establish a connection between fuel formulation and the geographic nature of reported problems may be confounded by the movement of vehicles from one region of the state to another. In addition, attempts to establish a connection between fuel formulation and the temporal nature of reported problems may be restricted by the limited availability of historic fuel samples.

The available fuel analyses have focused on the regulated fuel characteristics (i.e., sulfur and aromatic content). Various parties have proposed hypotheses that the increased severity of hydrotreating necessary to produce compliance diesel fuel may have changed some other diesel fuel characteristic(s) (e.g., nitrogen content, amine content, partial saturation of multiple ring aromatics, susceptibility to oxidation). The fuel analysis data will be investigated to see if there is any correlation between fuel formulation and the geographic nature of the reported problems.

APPENDIX G

MINORITY VIEWS

• American Petroleum Institute •

• California Trucking Association •

• California Independent Oil Marketers Association •

TO: Radian Corporation
ATTENTION: Melinda Thiessen
10389 Old Placerville Road
Sacramento, CA 95827

REF: API Comments on the Diesel Fuel Task Force Report

API submits the following additional comments on the second draft of the Diesel Fuel Task Force Report:

- Although "reports" of pump failures have increased since October 1993, there is no clear evidence that the change to EPA or CARB fuel resulted in actual seal failures.

- All of the equipment manufacturers participating in the February 11, 1994 meeting stated that they did not "design for swell." This suggests that the focus on the change in the overall swell of the seals is misdirected.

- It appears that many operators are using or had been using various "additives" such as used oil in their diesel fuel. The relationship between the use of these additives and the reports of seal failures needs to be explored in greater detail.

  A statement should be added to the recommendations and conclusions which address the potential for increased o-ring failures resulting from discontinuing the practice of adding used motor oil to diesel fuel. Since the likelihood exists that the addition of used oil to diesel fuels had been a common practice for many diesel vehicle fleet operators before EPA and CARB regulations, it is not known what effect this has on seal swell characteristics of fuel pump o-rings.

  For future work, the Task Force should consider adding test fuels for the o-ring evaluation program to include a fuel containing used oil (at a concentration that can be defined as typical). This fuel should be included as one of the pre-regulation high sulfur diesel fuels, and used to age new seals.

- The report does not explore why there are variations in the failure rate between engine manufacturers.

- The variation between types of nitrile compounds needs to be examined in greater detail. In addition, batch to batch variation in the manufacturing of nitrile rubber seals needs to be examined.

- As noted earlier, API does not believe that the Task Force should develop or recommend specific lubricity levels for diesel fuels, as explained in Mr. Roger Leisenring's January 14, 1994 letter to Mr. Tim DeFries, Radian (attached), but should rely on technical organizations such as ASTM.

- The report should note that the majority of the Task Force believed that oxidation was probably not the cause of any seal failure.

Texaco Inc
Research & Development

P O Box 509
Beacon NY 12508
914 831 3400

January 14, 1994

Mr. Tim DeFries
Radian Corporation
P.O.Box 201088
Austin, TX 78720-1080
Fax: (512) 345-9684

Dear Mr. DeFries:

I am responding to your letter dated January 10, 1994 to parties interested in the proposed voluntary interim recommendation for a minimum scuffing load capacity of 3300 grams, based on a variation of the ASTM BOCLE test (D5001) now under development by US Army at Southwest Research Institute (SwRI) for California. As the representative for API on subcommittee #3, I would like to offer the following comments on the behalf of the API Diesel Fuel Task Force.

As is recognized in pending modifications in the ASTM D975 Diesel Fuel Specifications, fuel lubricity concerns can arise under certain specific circumstances. API supports and is participating in efforts with engine and hardware manufactures in which the minimum fuel lubricity requirements for No. 2 diesel fuel systems are established, a practical test method is developed, and appropriate fuel lubricity specifications are adopted for diesel fuels. The API membership are actively participating in the International Standard Organization (ISO), Society of Automotive Engineers (SAE), American Society for Testing and Materials (ASTM), and the Engine Manufacturing Association (EMA) technical committees on lubricity of diesel fuel. The ultimate goal of this participation is the establishment of a test method and a limit. We believe the test method established through these committees will be the most technically sound method for the evaluation of lubricity. By working through ISO and ASTM, a standard can be developed by representatives of all sectors that have an interest in the use of the standard. In ASTM these sectors include producers, users, and those having a general interest (representatives of government and academia), as well as ultimate consumers. ASTM standards are the most technically sound and credible of documents because the ASTM standard procedures requires technical scrutiny and peer review. Otherwise, there is a strong possibility that the proposed test method with a limit may fail to protect engines or result in unnecessary fuel restrictions, which may eliminate perfectly acceptable diesel fuel from the market place and potentially leading to supply disruptions or generate unforeseen fuel problems.The latter is a real possibility with excessive use of lubricity additive to comply with an overly restrictive specification. In either case, the user would incur unnecessary expense.

Making the future happen

The necessary knowledge about lubricity requirements of hardware in the field and the merits of any diesel fuel lubricity test used for a specification monitoring are actively being discussed and developed but have not been established. We believe, therefore, that it is premature to endorse any test method or set any scuffing load limit, even on an interim and 'voluntary' basis. The precision of the scuffing load test is as yet unknown, since round robin testing has not yet begun. The significance of the test results to fuel system performance, even as tested by the US Army, is highly questionable based on the comparison of subjective fuel pump rating by Stanadyne and scuffing load limits for California fuels as reported by CARB (Draft Report 093-095, January 3, 1994, Figure 1 and Table 3). Setting a scuffing limit, using a test of unknown precision and as yet questionable significance to fuel system performance, is inappropriate and potentially detrimental to the consumer.

The API Diesel Fuel Task Force believes that the efforts and the results from the activities that are currently underway in the various industry accepted technical committees are the most prudent course of action for developing a sound specification, which will ensure that the required fuel quality continues to be supplied by all without unneeded and costly restriction. API and its member companies are committed to working with the California Diesel Fuel Task Force to answer these fundamental questions. With great anticipation, we expect a test method and a limit will come forth from ISO and ASTM that all the industries can embrace and endorse.

Thank you for this opportunity to comment.

Sincerely,

Roger L. Leisenring, Jr.

RLL/ml

cc: Dr. Manuch Nikanjam (Fax: 510-242-3051)
Mr. Paul Henderson (Fax: 203-683-4501)
Mr. Chris McCarthy - API Diesel Fuel Task Force
Mr. Jim Williams - API
Mr. Chuck Krambuhl - API

CALIFORNIA
TRUCKING
ASSOCIATION

TO: Honorable Pete Wilson **DATE:** February 17, 1994

FROM: California Trucking Association

RE: Minority Report of California Trucking Association exceptions to the Diesel Fuel Task Force final Report to Governor Wilson

On October 1, 1993, new diesel fuels were mandated for use throughout California in both on-road and off-road applications. The new California fuels were designed to reduce emissions from diesel powered equipment.

The introduction of the California Air Resources Board (CARB) 10% low aromatic low-sulfur diesel fuels in California was accompanied by significant fuel price increases, supply shortages, and fuel system mechanical problems. The Governor directed that a Diesel Fuel Task Force be created to investigate the mechanical problems that have arisen with the introduction of CARB 10% aromatic diesel fuel.

California Trucking Association (CTA) has participated in the Diesel Fuel Task Force since its formation on December 14, 1993. CTA co-chaired Subcommittee #1 (problem identification) and was a active member of Subcommittee #2 (fuels/component testing) and Subcommittee #3 (lubrication).

CTA, representing one of the largest groups of diesel fuel users within California, takes exception to the Task Force Report prepared for Governor Wilson. Two observations concerning the report will put these exceptions into perspective:

1. There currently exists no test for diesel fuel lubricity that is generally accepted in the scientific community; and

2. The test recommended by sections three and four of the report are either redundant or too late.

In light of the known lubricity and seal failure problems caused by severely hydrotreated fuels (see appendix A), CTA cannot comprehend how CARB's low aromatic regulation was allowed to become effective without prior testing of fuels. Further, it is incomprehensible that the regulation has been allowed to remain in effect for nearly five months when the disastrous effect of the regulation was known (or could have been known with reasonable diligence) prior to implementation.

Testing the fuel now is disingenuous since its actual effect is already known from empiric data. Testing is an honest effort only (1) before the fuel is introduced, or (2) after it is removed from the market. Since the fuel was introduced without testing, government integrity is preserved by suspending the regulation while the fuel is being tested.

CTA specifically objects to the following sections of the report:

1.0 CTA requested specific information about the fuel formulations (U.S. EPA, CARB 10% aromatic, variance, etc.) distributed within California to assist task force analysis of damage patterns and the magnitude for potential damage. It was agreed that this information would be inserted into this section, however, the information was omitted in the draft received February 14, 1994.

This information would reveal to what degree CARB 10% aromatic diesel fuel was actually sold as of October 1, 1993. It would also show that if all refineries capable of producing CARB 10% aromatic diesel fuel actually did so, failures of catastrophic magnitude would have occurred throughout California.

1.1.2 Failed equipment is referred to as having "aged" O-rings throughout the entire report.

Mr. Tom Gallant, an expert on elastomer seals (O-rings) employed by one major engine manufacturer, informed the task force that O-rings are designed to last the life of the engine. He states that if nitrile O-rings are not immersed in diesel fuel, life expectancy is decreased by five to ten times. CARB fuel damages O-rings, causing the O-rings to fail prematurely long before the 1,000,000 mile expected service life.

1.2 Failure rates within California have been erroneously labeled as "small" (8.8%).

There are more than 1,000,000 diesel engines currently operating within California. If only 8.8% or 88,000 of these engines fail (ARB estimates), the results would be catastrophic to California's economy in terms of lost productivity, lost crops, and equipment repairs Based on the average repair cost per vehicle to date, CTA projects that the repair loss alone will reach $44,000,000.

The report claims similar fuel problems existed throughout the U.S. following introduction of the U.S. EPA low-sulfur diesel fuel. CTA introduced evidence of a 10% aromatic diesel fuel being refined and distributed by a Texas refinery. This CARB type fuel is shipped by pipeline to the midwestern and eastern U.S.

The nationwide fuel pump leaks reported in figure 2-7 correlates with the distribution patterns of the Texas low aromatic fuel. Only after CTA produced maps, production quantities, and other evidence was this vital information included in Section 2 of the report. However, it was not included within the Executive Summary.

2.3.2 The charts and graphs located within figures 2-7, 2-8, 2-9, and 2-13 lead one to conclude there is a nationwide fuel problem. The charts are based on percents of total O-ring sales, which includes California O-ring sales. If a region sold nine O-rings during the Nov 92 - Jan 93 period and fifteen O-rings during the Aug 93 - Oct 93 period, that chart would indicate a sixty-seven percent increase in sales. This type of reporting is not only extremely misleading to the reader, it is also not statistically sound.

CTA suggests that if a substantial increase in O-ring sales had occurred across the nation, actual sales figures would have been included within the report body.

2.4.7 This section leads the reader to conclude that total sales and repair data was inflated by repairs that were preventive in nature.

CTA maintains that companies repair and maintain their equipment as needed or go out of business. Businesses do not needlessly expend money on phantom repairs. The general public is just now recovering form this country's recession. Many light vehicle owners have been forced to park their failed vehicles because they cannot afford to have them repaired.

2.5.3 The report states that fuel analysis data was not available for diesel fuels produced during the September to late October time period. Therefore, definitive analyses of fuels produced during the introduction of CARB diesel in September and October were not available. During the first meeting of Subcommittee #3, January 6, 1994, CTA requested information concerning CARB 10% aromatic diesel fuels.

CTA was told by CARB that the report was classified. The Cal EPA representative instructed CARB to reproduce the report (attached as Appendix B) and distribute it to the subcommittee members. The report summarized testing of twenty-two different fuel samples taken between October 27 and November 6, 1993 and between November 16 and 19, 1993. Of the twenty-two samples taken, fifteen were of unacceptable quality and four of those had such low lubricity they would be certain to cause damage. Yet none of this critical information is included in this report.

3.1 To investigate fuel system leakage, Subcommittee #2 established three test programs. The first two programs examine the mechanism of reduced seal swell. The third program examines existing fuel supplies to determine if CARB 10% aromatic diesel fuel is susceptible to increased oxidation.

CTA collected numerous O-rings and fuel samples from its members and the general public. CTA has repeatedly offered them to the task force for use in the testing. To date, these critical O-rings and fuel samples gathered during the first months of CARB diesel fuel have been ignored by the task force.

CTA Research and studies:

Universities, test equipment manufacturers, testing laboratories and individual scientists have offered their advice and services to the California Trucking Association to study the impact of CARB low-aromatics diesel fuel. CTA has learned that the severe hydrotreating of petroleum required to achieve 10% or comparable aromatics (1) removes components from diesel necessary to lubricate fuel injection equipment; and (2) removes components from diesel necessary to prevent formation of hydroperoxides that damage nitrile elastomer seals in fuel injection systems. CTA has attached two appendices to these exceptions. Appendix A identifies published scientific reports on lubricity. Appendix C identifies tests and studies performed on CARB 10 percent aromatic diesel fuel samples and on O-rings exposed to these diesel fuels. From these scientific papers and from the tests and studies performed on the CARB 10% aromatic diesel fuel, CTA concludes that the 10% aromatic diesel fuel mandated by CARB has caused the failure of O-rings, hoses, injection pumps and injectors in California.

Conclusions and Recommendations:

California Trucking Association requests that the regulation that caused this unnecessary problem be publicly suspended.

California Trucking Association requests that fuel mandated by the regulation be tested for lubricity and for compatibility with elastomers before its use is required.

California Trucking Association requests that operators of diesel powered equipment (autos, trucks, farm and other off-road equipment, stationary equipment, vessels, trains, etc.) be compensated for damage caused by the low aromatic diesel fuel mandated by CARB.

cc: James Strock, Secretary, Cal/EPA
Bob Borzelleri, Cal/EPA
Radian Corporation

APPENDIX A

Lubricity:

1. SAE Paper 920825, February 1992 - Lubricity of Low Aromatic Diesel Fuel.
2. Dr. P. I. Lacey, September 1992 - Wear with Low Lubricity Fuels
3. ISO Paper TC22, February 1993 - Diesel Fuel Lubricity Evaluation.
4. SAE Paper 930728, March 1993 - Development of the First CARB Certified California Alternative Diesel Fuel.
5. Volvo Technological Development, August 1993 - Swedish debacle with low aromatic fuel.
6. SAE Paper 932740, October 1993 - Lubricity of Low Sulfur Diesel Fuels.

Hydroperoxides:

1. CRC report 559, April 1988 - Determination of the Hydroperoxide Potential of Jet Fuels.
2. SAE Paper 920826, February 1992 - Peroxide Formation in Low Sulfur Automotive Diesel Fuels.
3. Dr. Robert E. Kauffman and Debra A. Tiry, University of Dayton Research Institute - New Techniques to Predict and Evaluate the Effectiveness of Antioxidants in Jet Fuels.
4. Dr. Robert E. Kauffman, University of Dayton Research Institute - Development of a Rapid, Portable Hydroperoxide Test for Jet Fuels.

APPENDIX B

SIXTH DRAFT: LUBREP4.FLC (WordPerfect) - Lew/Cameron - 010394 - 14:39

State of California
California Environmental Protection Agency
Air Resources Board

Lubricity and Characteristic Determination of Diesel Fuels from California Refineries

Engineering Evaluation Branch
Monitoring and Laboratory Division

Surveillance Branch
Compliance Division

Project No. C93-095

January 3, 1994

This report has been reviewed by the staff of the California Air Resources Board and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Air Resources Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

I. INTRODUCTION

The Air Resources Board (ARB) established aromatic and sulfur content standards for diesel fuel. These standards, as well as the U.S. Environmental Protection Agency's (EPA) 500 parts per million by weight (ppmw) or 0.05 percent sulfur regulation, became effective on October 1, 1993. Hydrotreatment used by refiners to reduce the aromatic and sulfur content also removes other compounds which are important for the lubricity of diesel fuel. Several references have indicated that these impurities that enhance lubricity include nitrogen and polar (oxygenated) compounds and polyaromatics (three or more rings)[1]. There is concern that the new diesel fuels sold in California may not have adequate lubricity.

To address the lubricity issue, ARB staff collected diesel samples from California refineries. These diesel samples were sent to Stanadyne and Southwest Research Institute (SWRI) for lubricity determination. In addition, each diesel sample collected was also characterized according to American Society of Testing Material (ASTM) or ARB test methods.

II. BACKGROUND

An important function of diesel fuel is to provide lubrication for the fuel injection system of the engine. ASTM D5001-90a[2] defines lubricity as "a general term used to described the boundary lubrication properties of a fluid." Rotary/distribution injection pumps have a high number of moving contact components. These pump components, such as transfer pump and governor, depend on the diesel fuel to provide lubrication. Under mild wear conditions, the wear is due to the oxidation that occurs on the component surface. Fuels with low lubricity allow the formation of a thin oxide layer. Material removal results when the thin oxide layer is then repeatedly removed and formed during the sliding contact[3]. Under severe stress, the oxide layer fails and the more severe adhesive wear of metal against metal occurs. This adhesive wear or scuffing results in accelerated pump wear. The lubricity of the fuel is important to prevent premature pump failure by either the milder oxidation corrosion or the more severe scuffing.

Currently, there is no standard bench test for determining the lubricity of diesel fuel. There is general agreement that a long term pump wear test represents the reference procedure against which all bench tests should be compared. Several diesel pump manufacturers have developed pump wear tests. One such pump stand test developed by Stanadyne consists of operating a heavy duty diesel application pump for 500 hours. The fuel is pumped out of a 55 gallon drum and recycled back. After

---

[1] Manuch Nikanjam and Paul Henderson, Lubricity of Low Aromatics Diesel Fuel

[2] Standard Test Method for Measurement of Lubricity of Aviation Turbine Fuels by the Ball-on-Cylinder Lubricity Method (BOCLE)

[3] P.L. Lacey, Development of a Lubricity Test Based on the Transition From Boundary Lubrication to Severe Adhesive Wear in Fuel

completing the 500 hour test, the pump is disassembled and wear measurements are made on the fueling limiter component and transfer pump blade and roller contact points. In addition, information on the changes to the transfer pump pressure and fuel flow rate are collected. These four pieces of information are used to developed a subjective wear rating[4].

The subjective pump wear is on a scale from zero to ten. At ten, the pump is not operating and a zero means a new pump with little or no wear. Generally, fuels with a rating of four or less have an acceptable lubricity. According to SWRI, fuel with a wear rating of between four and seven is in the transition zone. Fuels rated between 4 and 5 are termed borderline. Fuels rated between 5 and 7 are determined to have low lubricity. A rating of seven or greater would mean catastrophic failure of the pump. The use of transition zone diesel fuels does not mean pump failure, but may lead to increased wear. This increased wear would degrade the pump performance and may result in poorer engine performance and increased smoking. Pump manufacturers prefer fuels which have wear ratings near two.

The obvious drawback of the pump stand test is the 500 hour run. A standard bench test that consists of shorter run time and correlates with the pump stand test results is needed. One such test developed by the Southwest Research Institute (SWRI) is known as the U.S. Army Scuffing Load Test (also called the scuffing ball-on-cylinder lubricity evaluator (BOCLE) test)[5]. The scuffing BOCLE test contains a number of modifications of the ASTM D5001-90a[6], the standard test method for measurement of jet fuel lubricity. In the test, a sequence of increasing test loads is applied until scuffing occurs, which is indicated by a marked increase in friction and wear of the test ball. Test results have been compared to rotary fuel injection pump wear. Previous SWRI testing has compared well with pump wear tests at Stanadyne.

III. TEST PROGRAM

Diesel fuel samples were collected at two intervals from California refineries during the months of October and November, 1993. The first group of samples was collected between October 27 and November 6, 1993 and the second group of samples was collected between November 16 and 19, 1993. Diesel fuels samples were submitted

---

4 Manuch Nikanjam and Paul Henderson, Lubricity of Low Sulfur Diesel Fuels

5 Suggested Test Procedures for Measurement of Scuffing Load Capacity Using the Ball-on-Cylinder Lubricity Evaluator (BOCLE) dated August 1, 1993.

6 ASTM Method D5001-90a consists of a rotating sphere partially submerged in the test fuel and in contact with a test ball. A load is applied to the ball and the size of the wear scar on the ball is the test result. Because the BOCLE test results have not compared well to full scale pump performance tests, the industry is currently evaluating four candidate test methods for lubricity of diesel fuels. The International Standards Organization (ISO), with members from the fuel industry, fuel injection equipment manufacturers, engine companies and other related companies, will complete evaluation of these four test methods in 1994.

to SWRI for lubricity determination by the U.S. Army Scuffing Load Test. Samples were also submitted to ARB laboratories and Caleb Brett, a contract laboratory, for fuel characteristic determinations. Tables 1 and 2 describes the test procedures used for characterizing each fuel.

Table 1
Diesel Fuel Characterization

Amount (liter)	Laboratory	Determination	Method
0.250	ARB	aromatic content	ASTM D5186
0.250	ARB	sulfur content	ASTM D2622 or ASTM D4294
1.0	Caleb Brett	water distillation temperature peroxide number acid/base number density heat of combustion	ASTM D1744 ASTM D86 ASTM D3703 ASTM D974 ASTM D1288 ASTM D240
1.0	ARCHIVE		

Table 2
Description of Methods Used to Characterize Diesel Fuel

Method	Description
ASTM D5186	supercritical fluid chromatography
ASTM D2622 or ASTM D4294	wavelength dispersive spectrometry or energy dispersive spectrometry
ASTM D1288	hydrometer
ASTM D1744 ASTM D86 ASTM D3703 ASTM D974 ASTM D240	Karl Fischer distillation iodine titration extraction/titration bomb calorimeter

At five of the sampling locations in Northern California, 55 gallon drum samples were also collected for long term pump wear tests at Stanadyne Automotive Corporation in Connecticut. Wear tests for Southern California refineries may possibly be conducted after December 1993.

Upon completion of the pump wear test, an aliquot of each fuel tested was analyzed to determine fuel characteristics and lubricity by the U.S. Army Scuffing Load test. The intent of these fuel analyses after the pump wear test is to determine whether changes to the fuel occurred during the pump wear test. These samples are denoted by a " - 1 " suffix in Tables 3 and 5.

IV. LUBRICITY and FUEL CHARACTERIZATION TEST RESULTS

The SWRI scuffing load test results and the Stanadyne pump wear results are presented in Table 3 for Northern California refineries. In addition to the scuffing BOCLE test results, given in grams, a wear rating for the scuffing BOCLE is also given, based on a correlation graph of previous data from these two tests. (See Figure 1.) Table 4 contains the SWRI scuffing load results for Southern California refineries. Samples with the same sample number followed by an a or b are taken from the same location at a different time.

As indicated in Table 4, the scuffing BOCLE test method was modified during this study, from 10% humidity for the earliest sets of lubricity data, to 50% humidity for the most recent set of lubricity data. Paul Lacey of SWRI indicated that 50% humidity was easier to maintain than 10% humidity, and the only effect that he has observed in the lubricity results is perhaps an enhancement of the effect of any additives present in a fuel sample.

Table 5 and Table 6 present the results of the characterization analyses of the diesel fuel samples collected from Northern and Southern California refineries, respectively. For comparison, the values in the last row of Tables 5 and 6 were obtained from ASTM D975-89a, Standard Specification for Diesel Fuel Oil.

It should also be noted that at the time of this draft, not all fuel characteristic or lubricity data have been received.

V. DISCUSSION OF RESULTS

A comparison of the results from the two lubricity methods in Table 3 shows a lack of correlation between the SWRI scuffing BOCLE bench test and the Stanadyne 500 hour pump wear test. Apparently, data from previous testing of very good, or lubricious, fuels and very poor fuels has shown better agreement. Most of the California fuels tested had lubricities somewhere between these two extremes. Paul Henderson of Stanadyne indicated that many midrange fuels have not been previously tested. Generally, the fuels were rated poorer with the pump wear test than with the SWRI test. One explanation for this difference may be that poor viscosity would increase pump wear, but, according to Paul Lacey of SWRI, should not affect the scuffing BOCLE results. Fuel viscosities for each sample would need to be determined to test this possible explanation for the differences in the results of the two test methods. As stated above, the scuffing BOCLE test was one of four lubricity bench tests being evaluated by the ISO. It may be worthwhile to obtain data from the other three tests and compare it with scuffing BOCLE and pump wear results.

The diesel fuel samples represent the entire range of sulfur and aromatic content currently produced in California. High sulfur content means a diesel fuel that exceeds the EPA/ARB standard of 0.0500 weight percent and high aromatic content fuel means a fuel that exceeds the ARB aromatic content standard of 10% by volume. Sample two is a diesel fuel with high sulfur and aromatic contents which is typical of the fuel produced prior to October 1, 1993. Samples 1, 5, 6, 7, 8, 9, 10, 11, 12, and 13 are fuels that are low in sulfur but exceed the aromatic content standard of 10%. Fuels that meet the ARB aromatic and sulfur standards are samples 3, 4, and 12. For comparison purposes, the ASTM D975-89a specifications for diesel fuel are included in Tables 5 and 6.

Based on the SWRI results, diesel samples 1, 2, 4, 6a, 7b, 10, 11 and 13 have acceptable lubricity. Diesel samples 5, 6b, 7a, 9, and 12 have a borderline lubricity. SWRI indicated that diesel sample three has a marginal lubricity and sample 8 has low lubricity. The fuels with acceptable lubricity have aromatics ranging from 7.9%, which is below the ARB 10% limit, to 32% aromatics. Sulfur content for these fuels ranges from 34 ppmw to 4300 ppmw. Fuels with borderline lubricity have aromatics from around 10 % (complying) to 28%, with sulfur varying from 99 to 433 ppmw. The marginal lubricity sample (sample 3) has an aromatic content of 8% and a sulfur content of 27 ppmw. The low lubricity fuel (sample 8) has an aromatic content of 19% and no reportable sulfur. As a whole, according to the scuffing BOCLE test, complying fuels, samples 3, 4, and 12 have lubricities ranging from borderline to marginal. As mentioned previously, diesel fuel in the transition zone (4-7) would be expected to degrade pump performance faster. Signs of degraded pump performance include reduction in ability to precisely meter the amount of fuel. One outcome may be smoking or reduced engine performance.

Lubricity results from the Stanadyne pump wear tests indicate that sample 4 is acceptable, in agreement with the scuffing BOCLE results, and sample 3 is borderline. Ironically, sample 2, the high sulfur and high aromatics fuel, was determined to have low lubricity by the pump wear test. Samples 1 and 5 were also determined to have low lubricity.

Two of the fuel samples were indicated to contain additives. One of these additive containing fuels was rated as having acceptable lubricity, another was rated as having borderline lubricity. The presence of impurities such as nitrogen and polar compounds, which are normally found in diesel fuel that is not severely hydrotreated is believed to give it its excellent lubricity. In addition, investigators have demonstrated that corrosion inhibitors added in the range of 10 to 100 ppmw can dramatically improve lubricity[7]. More investigation is needed to characterize the effects that additives or fuel blending may have on the lubricity of diesel fuels.

---

[7] Manuch Nikanjam and Paul Henderson, Lubricity of Low Sulfur Diesel Fuels

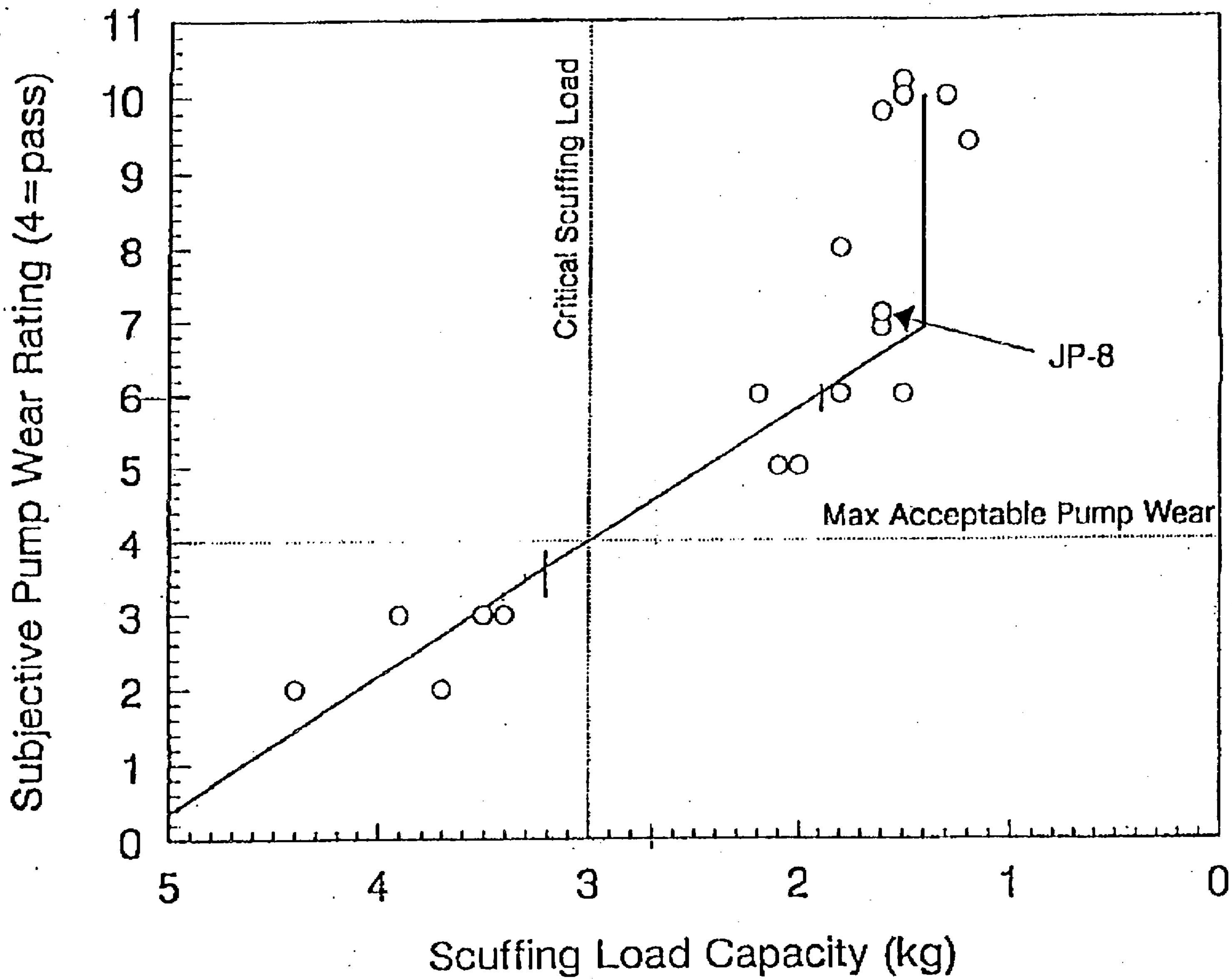


Figure 1. Correlation between U.S. Army Scuffing Load Wear Test and subjective measure of full-scale pump wear
Source: November 3, 1993 letter from Paul Lacey, SWRI, to George Lew, California Air Resources Board

SUBMITTED & TESTED ON 11-4-93

Revised December 27, 1993

A = 1 NOVEMBER
B = 1 DECEMBER

Table 3
Lubricity Test Results for Northern California Refinery Diesel Fuels

Sample Number	Average Scuffing Load Capacity (Scuffing BOCLE) (grams)	Wear Rating (Scuffing BOCLE)	Pump Wear Rating (500hrs)
1a	3800[1]	2.6	8
1a - 1 (after 500hr pump test)			
2a	4000[1]	2.2	6.5
3a	2400[1] ✓	5.0	4.4
3b	3200[2]	3.6	
4a	3300[1]	3.5	4
4a - 1 (after 500hr pump test)			
4b	2700[2] ✓	4.6	
5a	2800[1] ✓	4.3	7
5a - 1 (after 500hr pump test)			
5b	1900[2] ✓	6.0	

PRELIMINARY DRAFT

[1] Average of two results from two different scuffing BOCLE apparatus, performed at 10 % humidity.

[2] Average of two results from one scuffing BOCLE apparatus, tests performed at 50% humidity.

Table Revised January 4, 1994

Table 4

SWRI Scuffing Load Test Results for Southern California Refinery Diesel Fuels

Sample Number	Average Scuffing Load Capacity (grams)	Subjective Wear Rating
6a	3500[3]	3.1
6b	2900[4]	4.2
7a	2500[3]	4.8
7b	3300[4]	3.4
8a	1900[3]	6.0
8b	1900[4]	6.0
9a	2600[3]	4.9
9b	2600[4]	4.9
10a	3100[3]	3.9
10b	3400[4]	3.3
11b	3300[4]	3.4
12a	2850[3]	4.2
12b	2700[4]	4.6
13b	3200[4]	3.6

[3] Average of two results from two different scuffing BOCLE apparatuses, tests performed at 10% humidity.

[4] Average of two results from one scuffing BOCLE apparatus, tests performed at 50% humidity.

Table revised January 4, 1994

Table 5
Characteristics of Northern California Diesel Samples

Sample No.	Total Aromatic (vol %)	Total Sulfur (wt %)	Water Content (wt %)	Peroxide Content (ppm)	Distillation Temperature (°F)					Acid/ Base No.	Density (g/ml)	Heat of Combustion BTU/LB
					IBP ~~ISB~~	T_{10}	T_{50}	T_{90}	FBP ~~ESB~~			
1a	19.9	0.0114	0.005	<0.1	343	448	552	630	667	0.011	0.0484	19,356
1a-1[5]	19.7	0.0111	0.003	<0.1	331	439	550	628	664	0.012	0.8494	
2a	28.9	0.4264	0.009	<0.1	351	414	536	622	666	0.021	0.8556	19,176
2a-1[5]	29.2		0.006	<0.1	347	415	534	622	662	0.015	0.8561	
3a	7.8	0.0027	0.004	<0.1	347	383	439	568	657	0.011	0.8218	19,655
3a-1[5]	8.2	0.003	0.002	0.4	343	379	439	574	664	0.017	0.8228	
3b	8.6	0.0045	0.003	<0.1	352	363	450	604	682	0.020	0.8259	
4a	7.9	0.0034	0.005	<0.1	354	450	554	640	655	0.011	0.8413	19,560
4a - 1[5]	8.0	0.0028	0.002	<0.1	351	453	562	628	666	0.008	0.8423	
4b	7.0	0.0006	0.003	0.7	390	484	550	637	682	0.018	0.8388	
5a	23.5	0.0270	0.006	<0.1	363	424	489	622	671	0.012	0.8525	19,348
5a - 1[5]	23.5	0.0258	0.005	0.5	352	401	489	628	684	0.019	0.8535	
5b	20.7	0.0375	0.005	0.6	336	387	473	613	675	0.05	0.8447	
Spec[6]		0.50	0.05					540/ 640	~~125~~			

PRELIMINARY DRAFT

[5] Fuel sample after 500 hour pump wear test

[6] Diesel fuel conforming to ASTM D975-89a, Standard Specification for Diesel Fuel Oils

Table revised December 16, 1993

Table 6

Characteristics of Southern California Diesel Sample

Sample No.	Total Aromatic (vol %)	Total Sulfur (wt %)	Water Content (wt %)	Peroxide Content (ppm)	Distillation Temperature (°F)					Acid/ Base No.	Density (g/ml)	Heat of Combustion BTU/LB
					ISB	T_{10}	T_{50}	T_{90}	FSB			
6a	28.8	0.0254	0.005	<0.1	392	409	549	615	666	0.010	0.8629	19,280
6b	28.2	0.0275	0.005	<0.1	383	475	550	615	653	0.008	0.8534	19,367
7a	11.3	0.0099	0.003	0.2	352	388	453	583	671	0.060	0.8271	19,646
7b	32.1	0.0348	0.006	<0.1	397	433	485	558	601	0.008	0.8534	19,340
8a	18.9	0.0000	0.005	0.4	360	403	475	608	658	0.030	0.8334	19,573
8b	19.2	0.0000	0.006	<0.002	385	410	471	582	540	0.006	0.8284	19,668
9a	27.3	0.0433	0.004	0.2	338	338	689	631	666	0.020	0.8484	19,457
9b	28.3	0.0406	0.006	<0.1	329	396	522	639	693	0.008	0.8530	19,323
10a	30.4	0.0330	0.003	<0.1	414	457	545	626	680	0.020	0.8582	19,501
10b	26.0	0.0198	0.004	<0.1	376	428	513	621	675	0.011	0.8466	19,580
11b	23.1	0.0000	0.004	<0.1	414	450	523	610	657	0.012	0.8380	19,504
12a	9.8	0.0183	0.005	<0.1	374	392	475	612	667	0.110	0.8393	19,584
12b	11.4	0.0351	0.004	<0.1	354	392	473	587	658	0.065	0.8470	19,490
13b	27.4	0.0274	0.005	<0.1	381	426	509	622	666	0.024	0.8555	19,395
Spec[2]		0.50	0.05					540/ 640	125			

[2] Diesel fuel conforming to ASTM D975-89a, Standard Specification for Diesel Fuel Oils

APPENDIX C

Test and Studies Performed on CARB Diesel Fuels:

1. Dr. Robert E. Kauffman, University of Dayton Research Institute, January 1994 - O-ring failures occurring in California diesel fuels due to the poor oxidative stability of the hydrotreated diesel fuels.

2. Robert N. Anderson, Ph.D.,P.E, Consulting Materials Engineer, January 1994 - Effects of California low aromatic diesel fuels on O-rings.

3. Mr. Bob Voitik, Vice President Engineering, Falex Corporation, February 1994 - California Diesel Fuel Lubricity Tests.

CIOMA
California Independent Oil Marketers Association

February 17, 1994

Mr. Bill Oliver
Radian Corporation
10389 Old Placerville Road
Sacramento, CA 95827

Dear Mr. Oliver:

As you know, it has been my privilege to serve on the Diesel Fuel Task Force that supervised the work of Radian Corporation during its examination of engine damage caused by the low aromatic fuels mandated by the California Air Resources Board (CARB).

I believe that the report as it stands is probably the best document that could have been achieved considering the wide interests that were represented on the Task Force. During the process of compiling this final document, it became evident to me that various members, both public and private, did not intend to fix blame for the damage caused by this new product and to dilute all responsibility for the problems.

It is my belief that the correlation of the low aromatic levels in diesel fuel sold in Northern California and the high rates of seal failure in this same region present a very powerful argument that points directly to the new fuel as a culprit for such failures. Further, Figures 2-5 and 2-6 on page 2-31 in the final report do not clearly illustrate the correlation between aromatics levels and engine damage to the casual reader. In combining the separate charts showing the range and average aromatic levels on a single chart, the dramatic difference in aromatic levels between Southern California and Northern California is not clear.

It is clear that further work should be undertaken on this issue. It also is reprehensible that this work is being undertaken now after a great deal of damage has occurred to the economy of the State of California.

If anything is learned by this regrettable situation, it should be that good science should occur prior to major mandates by governmental agencies and not as an afterthought. CARB did not perform thorough testing before this product was mandated and did not properly supervise development of alternative formulations that were certified.

CARB did receive numerous warnings from our association and many other groups that problems would occur with supply, price, and product useability when these new fuels were introduced. However, our concerns were ignored, and all of our predictions occurred.

Four important issues should have been addressed in this report. They are as follows:

1. New products mandated for use in the State of California must be thoroughly tested for useability prior to introduction.

2. New fuel formulations should be phased in to prevent catastrophic market reactions like the one experienced in October 1993.

3. Restitution should be offered to all parties who experienced damage to equipment caused by the new diesel fuel. The funding for this restitution should come from a .05 to 1 cent per gallon assessment on all refiners in California's diesel market based on sales volumes from October through the present.

4. Supply monitoring must start now to avoid another diesel fuel crisis this summer.

Thank you for the opportunity to express this dissenting view. CIOMA feels very strongly that the economy of California should never again be put at risk by this kind of fiasco.

Finally, it must be said that a clean environment is a goal that all California should strive for, but one that must be attained by rational means.

Sincerely,

Nickolas Bokides

Nickolas Bokides
Chairman, Operations & Regulations Committee