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Summary and Analysis of Comments Regarding the Potential Safety Implications of Onboard Vapor Recovery Systems

U.S. Environmental Protection Agency
Office of Mobile Sources

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Table of Contents

Page

Chapter 1 - Introduction
- A. Background 1-3
- B. Nature of the Comments 1-4
- C. Overview of the Current Analysis 1-13

Chapter 2 - The Safety of Current Fuel/Evaporative Systems
- A. Introduction 2-1
- B. Vehicle Fires 2-2
- C. In-Use Performance of Fuel/Evaporative Emission Control Systems 2-18
- D. Summary 2-31

Chapter 3 - Onboard System Design and Safety Comments
- A. Summary of Technology & Safety Comments 3-1
- B. Trends in Fuel/Evaporative System Design 3-12
- C. Onboard System Design and Safety 3-40
- D. Other Safety Concerns 3-75

Chapter 4 - Potential Safety Benefits
- A. Effects on Service Station Safety 4-1
- B. Potential Vehicle Safety Benefits Due to Onboard System Design 4-13
- C. Summary and Conclusions 4-16

Chapter 5 - Summary and Net Assessment
- A. Introduction 5-1
- B. Defining the Relationship Between Complexity and Risk 5-2
- C. EPA's Onboard System Design 5-5
- D. Safety Benefits of Onboard Controls 5-7
- E. Net Safety Impact 5-8

Appendix I - Onboard System Designs Submitted by Manufacturers

Appendix II - Safety Implications of Onboard Refueling Vapor Recovery Systems

Appendix III - Service Station Fire Data

CHAPTER 1

Introduction

A. Background

Section 202(a)(6) of the Clean Air Act (as amended 1977) requires EPA to determine the feasibility and desirability of requiring onboard control of refueling emissions as an alternative to implementing Stage II controls. If onboard controls are found to be feasible and desirable, and after consultation with the Department of Transportation (DOT) regarding the safety implications of such controls, appropriate standards and regulations are to be prescribed. In response to this requirement, as early as 1981, EPA undertook studies related to refueling control. More recently, EPA's decision to propose an onboard refueling control requirement arose from the results of an August 1984 analysis, the draft Gasoline Marketing Study (GMS).[1] The GMS assessed the technical feasibility, effectiveness and efficiency, costs and cost effectiveness of both onboard and Stage II control of refueling emissions. Reanalysis done in response to comments received on the GMS led the Agency to the conclusion that onboard controls represented the preferred approach, in terms of the criteria set forth in the Clean Air Act, to controlling VOC emissions from refueling operations. The Act requires EPA to consider the administrative burden of enforcement, equitable distribution of costs, and effects on fuel economy in addition to the cost of the technology involved. This process culminated in the August, 1987 proposal to require onboard control of refueling emissions for gasoline-fueled LDVs, LDTs and HDGVs.

In accordance with the provisions of the Act, EPA began consultation with DOT's National Highway Traffic Safety Administration (NHTSA) in March of 1986. Several months later, automotive interests and the Insurance Institute for Highway Safety (IIHS) raised a number of safety concerns regarding onboard controls. In response to these concerns, and similar concerns subsequently raised by others, EPA conducted an evaluation of the safety implications of onboard vapor recovery systems. This report, released in June, 1987, is found in Appendix II. The report presented EPA's initial evaluation of the onboard safety issues and was the basis of the Agency's conclusions that safe designs are available and that onboard-equipped vehicles can achieve the same level of in-use fuel system safety as present vehicles. Nevertheless, some safety concerns were not resolved to the satisfaction of other parties involved prior to issuing the NPRM. EPA therefore agreed to a supplemental proposal of onboard controls, limited to safety issues and other significant changed circumstances, to allow the fullest possible discussion and consideration of all relevant safety concerns and to allow additional opportunity for public comment on EPA's reanalysis of the safety issues.

The purpose of this document is to provide a summary and analysis of the safety comments received in response to the NPRM. It also provides EPA's expanded and updated analyses of the safety issues related to onboard controls.

B. Nature of the Comments

A listing of the commenters is contained in Tables 1-1 and 1-2. EPA received well over 1000 sets of comments on the NPRM. Of course, not all made mention of safety issues, and many who did reiterated positions taken by others. The comments that specifically addressed safety concerns can be subdivided into a number of general areas, based largely on the source of the comments.

The primary concern expressed by auto industry-related commenters was that onboard systems would be more complex than current evaporative systems, and this would lead to an unquantifiable increase in the risk of crash- and non-crash-related vehicle fires. More specifically, these commenters pointed to an increase in the size and number of components, an increased number of vapor line connections, and a general concern that the location of some of these components could degrade vehicle safety. The IIHS expressed concerns similar to those raised by the auto industry-related commenters. Auto industry commenters also offered a number of safety comments on specific hardware components of onboard control systems.

Petroleum industry commenters, on the other hand, stated that adding onboard controls represented a smaller change than the initial requirement for evaporative controls or the recent switch to fuel injection systems. They pointed out that larger canisters and vapor lines were the main differences between onboard systems and current evaporative systems. They also stated that those systems have had almost no history of safety problems, and pointed to studies showing that the risk of refueling vapor ignition in either a crash or non-crash situation was very small. In their view, onboard systems offered the opportunity for a safety benefit over current evaporative systems because they could be designed to decrease the risk of fuel tank overpressurization, reduce excess evaporative emissions and running losses, and reduce the number of external fuel tank connections.

A number of comments were received from other Federal agencies, and state government agencies. The National Transportation Safety Board and the Department of Commerce, as well as a number of state governmental commenters supported the concerns raised by the auto industry commenters. The California Air Resources Board did not make a detailed assessment of onboard safety, but nevertheless felt that onboard systems were similar to current evaporative control systems. They also stated that they were unaware of any serious safety problems with evaporative systems.

TABLE 1-1

LIST OF COMMENTERS ON THE ONBOARD NPRM

ORGANIZATIONAL COMMENTERS

ACTIVATED CARBON, INC.
ALLIANCE OF AMERICAN INSURERS
AMERICAN AUTOMOBILE ASSOCIATION
AMERICAN INDEPENDENT REFINERS ASSOCIATION
AMERICAN NORIT CORPORATION
AMERICAN PETROLEUM INSTITUTE
AMERICAN TRUCKING ASSOCIATIONS
AMOCO
ANDERSON DEVELOPMENT COMPANY
AREA AGENCY ON AGING FOR NORTH FLORIDA, INC.
ARIZONA AUTO ASSOCIATION
ARIZONA AUTOMOBILE DEALERS ASSOCIATION
ARKANSAS FEDERATION OF WATER AND AIR USERS
ASSOCIATED EMPLOYERS OF ILLINOIS
ASSOCIATED GENERAL CONTRACTORS OF IOWA
ASSOCIATED GENERAL CONTRACTORS OF MAINE
ASSOCIATED MOTOR CARRIERS OF OKLAHOMA
ASSOCIATION PETROLEUM INDUSTRIES OF PENNSYLVANIA
AUDI AG
AUTOMOBILE IMPORTERS OF AMERICA, INC.
AUTOMOTIVE DEALERSHIPS OPPOSING ONBOARD CONTROLS (6 LETTERS)
AVIS RENT-A-CAR COMPANY
BAY STATE GASOLINE DEALERS ASSOCIATION
BMW OF NORTH AMERICA
BREGMAN, ABELL, AND KAY FOR AMERICAN CAR RENTAL ASSOC.
BUSINESS COUNCIL OF GEORGIA
CALGON CARBON CORP.
CALIFORNIA AIR RESOURCES BOARD
CAPPOZZOLI/BRAUN PATENTS
CARBON DEVELOPMENT CORP.
CAROLINA PETROLEUM DISTRIBUTORS
CATALER INDUSTRIAL CO., LTD.
CENTER FOR AUTO SAFETY
CHEVRON USA, INC.
CHRYSLER MOTORS
CONSERVATION LAW FOUNDATION OF NEW ENGLAND
CONTEL SERVICE CORPORATION
COOPER OIL COMPANY
DEPARTMENT OF ENERGY
DETROIT EDISON
DOVER CORPORATION
ENTERPRISE LEASING COMPANY
EXXON CO.
FARMERS UNION CENTRAL EXCHANGE

FIAT R & D
FLORIDA DEPARTMENT OF TRANSPORTATION
FLORIDA PETROLEUM COUNCIL
FLORIDA PETROLEUM MARKETERS ASSOCIATION
FORD MOTOR COMPANY
FRESHWAY FOOD STORES
FRIENDS OF LYNCHBURG STREAM VALLEYS
GABEL. RUDOLPH C., INC
GAS PROCESSORS ASSOCIATION
GASOLINE DISTRIBUTORS & STATION OWNERS IN
  FAVOR OF ONBOARD CONTROLS (665 LETTERS)
GENERAL MOTORS COMPANY
GEORGIA ASSOCIATION OF CONVENIENCE STORES
GEORGIA OILMEN'S ASSOCIATION
GIANT INDUSTRIES
GOODWIN AND GOODWIN LAW OFFICES
GOODYEAR TIRE AND RUBBER COMPANY
GRACO
HEALTH EFFECTS INSTITUTE
HOGEN AND HARTSEN FOR DAIMLER-BENZ AG
HONDA
HOOSIER MOTOR CLUB
HUSKY CORPORATION
ILLINOIS COALITION FOR SAFET BELT USE
ILLINOIS PETROLEUM COUNCIL
INDEPENDENT GASOLINE MARKETERS OF AMERICA
INDIANA AUTO SERVICE ASSOCIATION
INDIANA FARM BUREAU CO-OP ASSOCIATION
INDIANA MANUFACTURED HOUSING ASSOCIATION
INDIANA PETROLEUM COUNCIL
INDIANA RETAIL COUNCIL
INSURANCE INSTITUTE FOR HIGHWAY SAFETY
IOWA DEPARTMENT OF PUBLIC SAFETY/TRANSPORTATION
IOWA PETROLEUM COUNCIL
IOWA TIRE DEALERS ASSOCIATION
JAGUAR CARS LIMITED
JEFFERSON COUNTY, KENTUCKY PUBLIC SAFETY CABINET POLICY DEPT.
JOE BASIL CHEVROLET
KANSAS PETROLEUM COUNCIL
KELLER CRESCENT COMPANY
KEMP SERVICE CENTER
KENTUCKY AUTOMOBILE DEALERS ASSOCIATION
KENTUCKY CHAMBER OF COMMERCE
KENTUCKY PETROLEUM MARKETERS ASSOCIATION
KURARAY CHEMICAL CO.
LAKES REGION ASSOCIATION
LAMBERT CHEVROLET OLDSMOBILE
LIFE/JOBS
MAINE BETTER TRANSPORTATION ASSOCIATION
MAINE FARM BUREAU ASSOCIATION
MAINE FOREST PRODUCTS COUNCIL
MAINE MOTOR TRANSPORT ASSOCIATION

MAINE PETROLEUM ASSOCIATION
MARATHON PETROLEUM COMPANY
MARSH VILLAGE PANTRIES
McCORMICK AND COMPANY, INC.
MICHIGAN ASSOCIATION OF CONVENIENCE STORES
MICHIGAN MANUFACTURERS ASSOCIATION
MICHIGAN PETROLEUM ASSOCIATION
MIDWEST PETROLEUM MARKETERS ASSOCIATION
MIDWEST SERVICE STATION ASSOCIATION
MILGRIM, THOMAJAN AND LEE FOR LANGHAM-HILL PETROLEUM & CLARENDON LTD.
MINNESOTA AUTO DEALERS ASSOCIATION
MINNESOTA FARM BUREAU FEDERATION
MINNESOTA GROCERS ASSOCIATION
MINNESOTA HIGHWAY USERS FEDERATION
MINNESOTA PETROLEUM COUNCIL
MINNESOTA RETAIL MERCHANTS ASSOCIATION
MISSISSIPPI ECONOMIC COUNCIL
MISSISSIPPI FARM BUREAU FEDERATION
MISSOURI AIR POLLUTION CONTROL PROGRAM
MISSOURI OIL JOBBERS ASSOCIATION
MITSUBUSHI MOTOR COMPANY
MOBIL OIL COMPANY
MORRISON IMPLEMENT, INC.
MOTOR VEHICLE MANAGEMENT BUREAU
MOTOR VEHICLES MANUFACTURERS ASSOCIATION
MULTINATIONAL BUSINESS SERVICES, INC.
MUTURN CORPORATION
NATIONAL AIR CONSERVATION COMMISSION/AMERICAN LUNG ASSOCIATION
NATIONAL ALLIANCE OF SENIOR CITIZENS, INC.
NATIONAL ASSOCIATION OF CONVENIENCE STORES
NATIONAL ASSOCIATION OF FLEET ADMINISTRATORS, INC.
NATIONAL AUTOMOBILE DEALERS ASSOCIATION
NATIONAL HIGHWAY TRANSPORTATION SAFETY ADMINISTRATION
NATIONAL PETROLEUM REFINERS ASSOCIATION
NATIONAL SAFETY COUNCIL
NATIONAL TRANSPORTATION SAFETY BOARD
NATIONAL TRUCK EQUIPMENT ASSOCIATION
NATIONAL VEHICLE LESING ASSOCIATION
NATURAL RESOURCES DEFENSE COUNCIL
NEBRASKA PETROLEUM COUNCIL
NEW HAMPSHIRE PETROLEUM COUNCIL
NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION
NEW JERSEY GAS STATION OWNERS IN FAVOR OF ONBOARD CONTROLS (472 LETTERS)
NEWHALL REFINING CO.
NISSAN MOTOR COMPANY, LTD.
NORTH AMERICAN CARBON, INC.
NORTH CAROLINA ASSOCIATION OF CONVENIENCE STORES
NORTH CAROLINA AUTOMOBILE DEALERS ASSOCIATION
NORTH CAROLINA PETROLEUM MARKETERS ASSOCIATION
NORTH CAROLINA TRUCKING ASSOCIATION
NORTH DAKOTA PETROLEUM COUNCIL
NORTHEAST STATES FOR COORDINATED AIR USE MANAGEMENT

NORTHWEST FLORIDA AREA AGENCY ON AGING, INC.
NORTHWESTERN OIL
OCEAN AUTOMOBILES TECHNOLOGIES, INC.
OFFICE OF MANAGEMENT & BUDGET
OHIO ASSOCIATION OF CONVENIENCE STORES
OHIO BELL TELEPHONE COMPANY
OHIO DEPARTMENT OF HIGHWAY SAFETY
OKLAHOMA CITY CHAMBER OF COMMERCE
OKLAHOMA HIGHWAY SAFETY OFFICE
OKLAHOMA STATE CHAMBER OF COMMERCE AND INDUSTRY
PALMETTO SAFETY COUNCIL
PAPER INDUSTRY INFORMATION OFFICE
PASCO MOTORS, INC.
PENNSYLVANIA CHAMBER OF COMMERCE AND INDUSTRY
PENNSYLVANIA MANUFACTURED HOUSING ASSOCIATION
PENNSYLVANIA MANUFACTURERS ASSOCIATION
PENNZOIL
PETROLEUM MARKETERS ASSOCIATION OF AMERICA
PEUGEOT
PHH GROUP INC.
POLK OIL COMPANY
PUGMIRE LINCOLN-MERCURY-MERKUR
QUIK STOP MARKETS
QUIK-CHEK, INC.
R & H MAXXON, INC.
RECREATIONAL VEHICLE INDUSTRY ASSOCIATION
REGIONAL AIR POLLUTION CONTROL AGENCY
RENEWABLE FUELS ASSOCIATION
RETAIL GROCERS ASSOCIATION OF FLORIDA
ROLLS ROYCE MOTOR CARS
RYDER SYSTEM
SAAB-SCANIA
SENATE COMMITTEE ON AGRICULTURE, NUTRITION AND FORESTRY
SERVICE STATION AND AUTOMOTIVE REPAIR ASSOCIATION
SERVICE STATION DEALERS OF AMERICA
SOCIETY BANK, DAYTON OHIO
SOCIETY OF AUTOMOTIVE ENGINEERS
SOCIETY OF INDEPENDENT GASOLINE MARKETERS OF AMERICA
SOHIO OIL COMPANY
SOUTH CAROLINA DEPARTMENT OF HEALTH AND ENVIRONMENTAL CONTROL
SOUTH CAROLINA HIGHWAY USERS CONFERENCE
SOUTH CAROLINA TRUCKING ASSOCIATION
SOUTHWESTERN BELL
STATE FARM INSURANCE
SUBARU OF AMERICA
SUN REFINING & MARKETING
SUNOCO RETAIL MARKETING
TENNESSEE OIL MARKETERS ASSOCIATION
TEXACO
TEXAS AIR CONTROL BOARD
TEXAS AUTOMOBILE DEALERS ASSOCIATION
TEXAS DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

TIME SAVER STORES
TOM BOLAND FORD
TOYOTA MOTOR COMPANY
TRAFFIC SAFETY ASSOCIATION OF MICHIGAN
TRI-STATE GASOLINE AND AUTOMOTIVE DEALERS ASSOCIATION, INC.
UNION OIL COMPANY
UNITED PARCEL SERVICE
UNITED STATES DEPARTMENT OF COMMERCE
UNITED STATES DEPARTMENT OF TRANSPORTATION
UNITED STATES SMALL BUSINESS ADMINISTRATION
UNOCAL REFINING AND MARKETING DIVISION
U.S. FLEET LEASING, INC.
VAN WATERS AND ROGERS, INC.
VERMONT RETAIL GROCERS' ASSOCIATION
VIRGINIA AGRIBUSINESS COUNCIL
VIRGINIA CHAMBER OF COMMERCE
VIRGINIA FARM BUREAU FEDERATION
VIRGINIA GASOLINE AND AUTOMOTIVE REPAIR ASSOCIATION
VIRGINIA PETROLEUM JOBBERS ASSOCIATION
VOLKSWAGEN OF AMERICA, INC.
VOLVO CARS OF NORTH AMERICA
WEST VIRGINIA GASOLINE DEALERS AND AUTOMOTIVE REPAIR ASSOCIATION
WEST VIRGINIA PETROLEUM MARKETERS ASSOCIATION
WESTVACO, CARBON DEPT.
WISCONSIN MANUFACTURERS AND COMMERCE

TABLE 1-2

LIST OF COMMENTERS ON THE ONBOARD NPRM

MEMBERS OF CONGRESS, STATE LEGISLATORS & OTHER OFFICIALS	PRIVATE CITIZENS
ADAMS, BROCK	ABEL, CYNTHIA C.
AFFLERBACH, RAY C.	ABEL, JODY
BALLENGER, CASS	ABEL, MICHAEL
BARNARD, DOUG JR.	ANDERSON, BEVERLEE F.
BOULTER, BEAU	ARLOGAST, DAVID
BRANSTETTER, OLIN R.	BAINES, LAVERN AND JAMES
BROOMFIELD, WILLIAM S.	BATHE, JOHN G.
BUSTAMANTE, ALBERT G.	BERRY, ANNE K.
BYRD, ROBERT C.	BERRY, ROBERT C.
CESSAR, RICHARD J.	BIEBER, C.F.
CHENEY, DICK	BLOUGH, MARY HELEN
CHILES, LAWTON	BREGOLI, KENNETH
CLARK, WILLIAM A.	BREGOLI, MARYBETH
COURTER, JIM	BROWN, CYNTHIA
COY, JEFFERY W.	BRYANT, CHARLENE
DARDEN, GEORGE	BRYANT, STEVEN
DAWSON, W.T.	BUGG, DOROTHY S.
DEWINE, MIKE	CADWELL, BRUCE
DINGELL, JOHN P.	CAMPBELL, KAREN R.
DIXON, ALAN J.	CARROL, DIANE
DOLE, BOB	COLEMAN, PAUL
DONNELLY, BRIAN	COSTEILLO, JOSEPH A.
EDWARDS, T.W. JR.	COULSON, M. FRANCIS
EXXON, J. JAMES	CROWN, JOHN J.
FASCELL, DANTE B.	DAVIS, EARL W.
FAWELL, HARRIS W.	DEARLES, HAROLD D.
FEIGHAN, EDWARD F.	DEIBEL, WILLIAM T.
FESSLER, RICHARD D.	DEMOS, RUSSEL
FIELDS, JACK	DiGIACOMO, JAN
FISHER, D. MICHAEL	DUMAS, S.J.
FOLEY, THOMAS S.	DUNHAM, CHRIS
GRADISON, BILL	ERNST, R.G.
GRANT, BILL	GABEL, RUDOLPH C.
GREGG, JUDD	GIESCHEN, ALICE M.
GUARINI, FRANK J.	GIRARD, MIKE
GUNDERSON, STEVE	GREENHAUS, DOUGLAS I.
HARRISON, DUDLEY	GREGGS, NORMAN P.
HASENOHRL, DONALD	GRENON, LEO E.
HATCH, ORIN G.	GRIGSBY, EVERETT M.
HAYES, SAMUEL E. JR.	GUGLIATAN, RALPH
HECHT, CHIC	HANIFY, DONALD F.
HEFLEY, JOEL	HARRISON, DR. KEVIN
HEFNER, BILL	HOLLATZ, MR. & MRS. KENNETH
HERTEL, CURTIS	KELLY, MILDRED

HESS, RALPH W.
HOFFMAN, PHILLIP E.
HUBBARD. CARROL
HYDE. HENRY J.
JONES. WALTER B.
KAFOGLIS. NICK
KASSER, MATTHEW
KOSTMAYER, PETER H.
KRUELL, RICHARD T.
KOSTEVA, JAMES A.
KUBIER, JULIUS E.
LENTOL,JOSEPH R.
LEWIS, H. CRAIG
LIVINGSTON, ROBERT L.
McCAIN, JOHN
McCLURE. JAMES A.
McCONNELL. MITCH
McDADE, JOSEPH M.
McDONALD, NANCY H.
McEWEN, BOB
McMILLAN,ALEX
McNALLY, RANDY
MELCHER, JOHN
MIKULSKI, BARBARA A.
NELSON, BETTY JO
NOLEN, FRANK W.
ORR, KAY A.
OUWINGA. SIDNEY
OXLEY, MICHEL G.
PASSERELL, WILLIAM J.
PETERSON. WILLIAM E.
PETRI. THOMAS E.
POLINSKY, JANET
PORREA, VINCENT
RAHALL. NICK J.
REGOLI, JOHN W.
RHODES, JAMES J.
RICHARDSON, BILL
ROCKEFELLER, JOHN D. IV
ROMANELLI, JAMES A.
ROSE, CHARLIE
ROSHELL, MARVIN J.
ROTH, TOBY
ROWLAND, JOHN G.
SARBANES. PAUL S.
SAVATORE, FRANK A.
SCRUGGS, PAUL C.
SECREST, JOE
SEVERENCE, CHARLES M.
SLAUGHTER, D. FRENCH JR.
SMITH, BILLY RAY
SMITH, LAMAR
KING. FRANCIS W.
KNOTT, C. ROBERT
LAPHAM. DELPHINA
LUCIANO, ANTHONY J.
LUNDBERG. JAN C.
MACK, JULIE S.
MAGNANO. DAVID A.
MARKOWITZ, ROBIN
MATTIOLI, DIANE
McBEE, HOLLY E.
MEDLEY, J.H.
MILLER, ROBERT
MITCHELL, DAVID B.
NEUFELD, SUSAN
NEWPORT. HAROLD A.
NOYES. WALTER O.
NUSSBAUM, MRS. BRESSEL
O'CONNELL, DANIEL K.
PAGE, ED
PHILLIPS, HOWARD E.,JR.
RAPP, PATRICIA M.
RAPP, PETER J.
RICHMOND, ARLENE
ROBISCONE, RALPH A.
ROMBERGER, WINIFRED
RUTES, IRIS
SEAY, CYNTHIA
SEAY, JEFFREY
SHATTUCK, JAY DEE
SHEETS, RONALD L.
SHELTON, HENRY Z.
SHEPARD. JOAN
SIEGMAN. JOSEPH
SPERLING. SHARON LEA
STAUCH, ALBERT
STROME, IRENE
TABLER, KAREN
TOAL, CHRISTINE A.
TOAL, KATHLEEN F.
TODD, J. RICHARD
TUCKER, BARBARA
TUCKER, LISA
TUCKER, WILLIAM Q.
VOEKS, JOHN F.
WALL, CATHERINE E.
WARNER, KIMBERLY
WHYTE, BRIDGET J.
WHYTE, DANIEL T.
WHYTE, MARY LOUISE
WHYTE, MICHAEL
WHYTE, THOMAS P.
WILLIAMS, WILL F.

SMITH, ROBERT C.
SORRENTO, L.J.
SPECTER, ARLEN
STAPLETON, PATRICK J.
STECZO, TERRY A.
STRANGE, JAMES R.
STRANGELAND, ARLAND
SULLIVAN, MIKE
SUNDQUIST, DON
THURMOND, STROM
VANDER JAGT, GUY
VARNED. DOUG JR.
WILKINS, S. VANCE
WILT, ROY W.
ZEMPRELLI, EDWARD P.
WISLOCKI, JENNIFER
WISLOCKI, THEODORE M.
WRIGHT, SAMUEL H.
YERGES, JAMES J.
YOUNG, E. LEE & CO.

Several public interest groups commented on the onboard safety issue. The most extensive comments were submitted by the Center for Auto Safety (CAS). In a detailed study of NHTSA safety complaint reports and recall files, CAS found the risk of fires from onboard systems to be minimal and easily handled by improved technology. This was because onboard systems were, in their view, only marginally more complex than current evaporative systems, which their study indicated are an almost insignificant source of current vehicle fires. CAS expressed the view that onboard controls combined with volatility controls would enhance vehicle safety. The Natural Resources Defense Council supported the conclusions of the CAS report that vehicle safety would be improved by onboard and volatility controls. They stated that onboard systems were "evolutionary," rather than "revolutionary," and urged EPA to proceed with the rulemaking. The National Safety Council took no official position, but indicated that it also had some reservations regarding possible additional fire risk.

In addition to the above general groups, EPA received many comments from members of Congress, state legislators, various special interest groups such as oil marketing or auto service groups, and a large number of private citizens expressing their views on the onboard proposal. Many of these commented on safety issues, generally supporting the views of one or another of the groups mentioned above. Since these comments tend to fall into the abovementioned categories, they will not be specifically identified, but are implicitly considered and addressed along with the other comments dealing with the general issues outlined above.

EPA's initial study of the potential safety implications of onboard vapor recovery systems, released in June 1987, was designed to identify and evaluate both general and specific onboard safety concerns which were raised prior to the NPRM. The study discussed the design of safe onboard systems and evaluated in-use safety issues such as crashworthiness, tampering, defects, misrepair and refueling operation safety. In general, there were few comments directly addressing technical aspects of EPA's report. The comments received were general in nature or amounted to a suggestion that additional analysis was needed to support EPA's conclusions.

C. Overview of the Current Analysis

The purpose of this report is to consider and evaluate new issues that have been raised by the commenters and to provide supplemental analysis for past concerns where necessary in response to the comments received. For areas where the previous analyses is sufficient, the comments will be summarized but referred to the initial study for response. This Summary and Analysis of Comments consists of five chapters, plus this Introduction. Each of these chapters is discussed below.

Chapter 2 deals with the safety of current fuel/evaporative systems. Many auto industry commenters, and some others as well, have suggested that onboard controls would be more complex than current evaporative systems and thus would lead to an unquantifiable increase in the risk of crash- and non-crash- related vehicle fires. Some have stated that there was an increase in vehicle fires following the initial requirement for evaporative systems. The purpose of this chapter is to establish a baseline for vehicle fire risk and to assess the safety performance of fuel evaporative emission control systems since their inception.

The next section, Chapter 3, focuses on the analysis of comments received regarding onboard control system design considerations and how these affect safety. It begins with a summary of the technology and safety comments received in response to the NPRM. This is followed by a review of trends in fuel/evaporative control system design which helps provide a baseline for comparison. The remaining two sections of the chapter provide EPA's analysis of the comments in this area. The third section also includes a discussion of recent onboard prototype system development work completed by EPA.

Chapter 4 addresses some potential safety benefits of onboard controls. These include a reduction in service station fires related to refueling, and a discussion of how incorporating various onboard system design features provides an opportunity for improvements in the operating safety of in-use fuel systems in both crash and non-crash situations.

Chapter 5 presents a summary of EPA's findings in the previous chapters and a current net assessment of the expected safety impact of onboard controls.

Section 202(a)(6) of the Clean Air Act also provides that if onboard controls are required, EPA shall provide the manufacturers adequate leadtime for implementation. A substantial number of comments were also received regarding the necessary initial leadtime or the desirability of a phase-in period for safe and effective implementation of onboard controls. EPA recognizes that leadtime is a critical component of the manufacturers' overall ability to implement onboard controls safely and effectively. However, this report is designed to deal only with the technology and safety aspects of onboard implementation. It is not designed to deal with the leadtime issue. EPA intends to completely resolve the leadtime issue before the Final Rulemaking, and intends to consider and account for all factors raised by the commenters relevant to the leadtime issue. The Agency remains fully committed to providing the industry with adequate leadtime for the safe and effective implementation of onboard controls, if such controls are imposed.

0365X

References for Chapter 1

1. "Evaluation of Air Pollution Regulatory Strategies for Gasoline Marketing Industry," U.S. EPA, Office of Air and Radiation, EPA-450/3-84-012a, July 1984.

CHAPTER 2

The Safety of Current Fuel/Evaporative Control Systems

A. Introduction

One of the key arguments against the promulgation of an onboard refueling emission standard is the assertion that the implementation of onboard refueling control systems will lead to an unquantifiable increase in the risk of crash and non-crash fires. Generally speaking, the increased risk that is claimed to accompany onboard systems refers to a potential increase in fuel and/or vapor leaks which in turn could lead to an increase in the number of vehicle fires and associated consequences.

Those in support of the increased risk argument have further claimed that while the number of increased fires cannot be quantified, any potential increase in vehicle fires warrants the withdrawal of the onboard proposal. However, it should be noted that independent of the potential effect of onboard controls, this all or nothing philosophy seems inconsistent with the acceptance of fire risk associated with the implementation and continued use of other vehicles systems where the added risk is determined to be finite yet sufficiently small to be acceptable.

Any consideration of incremental risk must start with the determination of the baseline for that risk. When considering vehicle fires, the number of incidents and the consequences of those fires must be assessed, with special attention given to the baseline risk for those portions of the vehicle fuel system most likely to be impacted by onboard controls (i.e., the evaporative control system). The purpose of this section is to characterize the current level of fire risk that now occurs in vehicles, and to thus provide an adequate basis to put the alleged incremental fire risk of onboard into the proper perspective. This section will examine estimates of total annual vehicle fire rates and evaluate the extent to which the fuel tank was a factor in these fires. Consequences of current vehicle fires such as deaths, injuries, and property damage will also be assessed. In addition, trends in the historical fire rates will be analyzed to evaluate the extent to which (if any) evaporative control systems have affected fire rates.

In addition to vehicle fires, this section will focus directly on the in-use performance of current evaporative control systems to evaluate the impact these systems have had on overall vehicle safety. A good indicator of the safety of evaporative systems can be obtained by examining the failure frequency and severity of associated consequences relative to other types of system failures. Failure characteristics can be assessed through the following three mechanisms: recall campaigns, manufacturer service bulletins, and owner complaints, all three of which are maintained in computer files by NHTSA. All of these records will be examined in the last part of this section to assess the relative safety performance of evaporative control systems.

B. Vehicle Fires

The examination of past fire occurrences in motor vehicle accidents serves two useful functions. First, it provides a good baseline for consideration of the "unquantifiable risk" claims of onboard and allows one to place these risks into context. Second, historical fire rates give a good perspective on how significantly other fuel system changes such as evaporative control systems (which EPA believes are very similar to onboard controls) have affected fire rates. By analyzing the impact evaporative control systems have had on fire rates, a more definitive estimate of the impact of onboard control systems can be made.

1. Total Annual Collision Fires

When one considers the number of vehicles in use, the number of miles driven, and even the number of accidents which occur each year, motor vehicle fires are rare events. According to the NASS data base discussed below, vehicle fires occur in only 0.25 percent of all accidents. It is more difficult to determine with precision the exact number of vehicle fires that occur each year. Not all fires get reported, and not all reports are gathered and processed through a single uniform collection system. Most of the available information arises initially from police and fire marshall reports from different states, but the nature and extent of the fire data vary in different state reports. Nevertheless, several computer data bases have been established in recent years which gather sufficient quantities of accident data from the states to make possible a reasonable extrapolation of national projections.

Three such data bases were examined recently by EPA and NHTSA in attempts to characterize current and historical vehicle collision fire rates. EPA's findings are summarized in its "Analysis of Fuel Tank-Related Fires,"[1] and NHTSA's analysis is contained in the draft contract report, "Study of Motor Vehicle Fires."[2] The three data bases that were examined are the National Accident Sampling System (NASS), the Fatal Accident Reporting System (FARS), and the National Fire Incident Reporting System (NFIRS). Both NASS and FARS are operated and maintained by NHTSA whereas NFIRS is the responsibility of the Federal Emergency Management Agency (FEMA).

NASS, a statistically based data sampling and analysis system gathers information on all types of accidents and was used in NHTSA's fire report[2] to project that about 16,700 car fires occur annually in police reported accidents nationwide. This estimate is consistent with the 19,500 annual post-collision fires estimated in an earlier NHTSA report, "Evaluation of Motor Vehicle Safety Standard 301-75, Fuel System Integrity: Passenger Cars,"[3] and the 15,313 annual post-collision fires estimated in a report by the Highway Safety Research Institute (HSRI, now the University of Michigan Transportation Research Institute or UMTRI) entitled, "Fires in Motor Vehicle Accidents."[4] Therefore, it appears that between 15,000 and 20,000 vehicle fires occur annually in this nation. Based on data obtained from FARS, EPA's fire report[1] estimated that up to nearly 1,700 people are killed in accidents involving fire each year. In addition, about 3,700 serious injuries and 3,600 moderate injuries occur in post-collision motor vehicle fire accidents each year.[1]

2. <u>Non-Collision Vehicle Fires</u>

In addition to vehicle fires resulting from crashes, it is also worthwhile to characterize the number of vehicle fires that result from some defect or failure in the vehicle which did not involve a crash. One data base, NFIRS, does contain information on non-collision vehicle fires. However, this data base contains information on all non-collision vehicle fires regardless of whether the cause of the fire originated in the vehicle. For example, NFIRS contains data on fires where a building caught fire and then spread to a vehicle. Because of the wide range of causes of vehicle fires, and the level of detail reported by NFIRS, it is not always possible to identify which fires originated as a result of a problem in the vehicle.

Therefore, it is not possible to identify the exact number of true non-collision vehicle fires from NFIRS. Nevertheless, NFIRS can provide some interesting summary statistics. For example, in 1986, over 350,000 vehicles were involved in fires not related to crashes. This figure is nearly 20 times higher than the number of vehicle collision fires. About 100,000 of these 350,000 fires involved electrical equipment, and approximately 150,000 involved gasoline.

3. Fuel Tank-Related Fires

The total number of annual vehicle fires helps give an overall view of the fire safety performance of current vehicles and the current level of fire risk now accepted for the entire vehicle. More specific to onboard refueling control systems however, is the number of collision fires related to the fuel tank since many commenters have stated that onboard will affect the number of connections to and from the fuel tank, and this in turn will affect the fuel system integrity during a crash. Thus, one area to consider in the assessment of the potential change in risk brought about by onboard control systems is the number of collision fires related to the fuel tank.

EPA has already performed a comprehensive analysis of the number of fuel tank related collision fires.[1] NHTSA has reviewed and commented on EPA's analysis which estimated that between 10-30 percent of all vehicle collision fires affected the fuel tank. This translates to approximately 1,900-6,000 annual fuel tank-related collision fires. EPA's analysis also contains ranges of the consequences that accompany fuel tank related fires. These consequences are summarized in Table 2-1. It should be noted that the number of fires quoted here as being related to the fuel tank are only estimates. Some uncertainty exits in these estimates because it is not always possible to distinguish between such things as fuel tank fires and trunk fires. Also, there is some uncertainty with regard to how well reported fires represent all fires. Therefore, these figures are simply approximations.

Some commenters have also stated that onboard controls have the potential to affect non-collision fires. EPA's analysis indicates that about 4,750-10,700 collision and non-collision fuel tank fires occur each year, which suggests that non-collision fires are at least as frequent as collision fires.* The non-collision fires can also be associated with serious consequences as indicated in Table 2-1. A complete baseline for onboard vapor recovery is therefore contained in Table 2-1, and the change in fire risk associated with onboard controls (for collision and non-collision) can therefore be viewed relative to the information in this table in addition to the overall fire risk data discussed above.

4. Evaporative Control Systems' Effect on Fire Rates

In addition to estimates of overall and fuel tank related fires, in assessing potential onboard risks it is also useful

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* Because these estimates were developed using different data sets, it is not valid to subtract collision fires from the total to get a direct estimate of non-collision fuel tank related fuels.

Table 2-1

Fuel Tank Related Fires and Associated Consequences*
(Annual Basis)

	Collision	Collision and Non-Collision
Fuel Tank Fires	2,000 - 6,000	4750 - 10,700
Fatalities	125 - 840	235 - 840
Serious Injuries	335 - 1,140	625 - 1,140
Moderate Injuries	1,130	1,130
Property Damage	$14 million	$32 million

* Data from reference [1].

to examine how fire rates were affected by the implementation of evaporative control systems since these systems are very similar in nature to onboard refueling control systems. Evaporative control systems' effect on fire rates forms a useful perspective on the likely impact of onboard control systems on safety.

Federal regulations requiring evaporative control systems were first implemented beginning with model year (MY) 1971 vehicles (passenger cars and light trucks to 6000 lbs GVW). It has been suggested that by comparing fire rates of model year vehicles a few years prior to the implementation of evaporative controls with model year vehicles a few years subsequent to evaporative controls, it may be possible to identify whether or not this supposed increased complexity to the fuel system led to a significant change in fire rates. One of the commenters (General Motors) submitted an analysis of this type using FARS data and accident data obtained from a variety of states. (The results of this analysis are discussed later in this section).

EPA performed its own analysis of this type using FARS data because FARS was one of the data bases utilized in the analysis submitted by General Motors. However, before presenting this analysis, it should be noted that EPA is not confident that FARS is a suitable data base for this type of analysis for the following reasons. First, FARS only gathers data on all police-reported accidents (for all types of vehicles) in which a fatality occurs. Since only 6 in 1000 accidents involves a fatality, a large number of accidents would not be considered in an analysis of FARS data. In addition, FARS covers all vehicle fires whether they are related to the fuel system or otherwise, and does not specify the origin of the fire. Since evaporative control systems would only affect fuel system fires, use of a data base which contains data on a variety of vehicle fires could mask the true effect of a change to the fuel system. Further, since FARS data represent only accidents with fatalities, the accidents contained in this data base are generally more severe, and are also somewhat limited in their coverage of the complete range of vehicle fires. Therefore, use of these data alone could misrepresent or overestimate the overall fire hazard for these vehicles. Nevertheless, the results of EPA's analysis are presented here for comparison with the results of the analysis submitted by General Motors.

Table 2-2 shows FARS data for MY 1966-86 vehicles taken from the previously mentioned draft NHTSA contract study.[2] As shown in this table, FARS data indicate a small generally increasing trend in fire rates for fatal accidents between 1966 to 1975 model years. However, a similar trend can also be observed in the data for model years 1981 to 1986. An important question to ask is whether the change in fire rates that occurred with the implementation of evaporative controls is significantly different from normal year to year variations.

Table 2-2

Car Fire Rates Per 100 Fatal Accident Involved Cars and Their Standard Errors*

Model Year	Fire Rate	Standard Error**
1966	1.72	0.23
1967	1.94	0.20
1968	1.96	0.16
1969	2.08	0.14
1970	2.13	0.13
1971	2.34	0.13
1972	2.38	0.11
1973	2.26	0.10
1974	2.37	0.10
1975	2.90	0.12
1976	2.53	0.10
1977	2.50	0.10
1978	2.29	0.10
1979	2.62	0.11
1980	2.19	0.11
1981	2.02	0.12
1982	2.06	0.14
1983	2.28	0.17
1984	2.28	0.17
1985	2.50	0.22
1986	2.53	0.34

* Data from FARS (1975-1986).

** Standard error based on statistics for various model year cars in different calendar years.

Using a multivariate linear regression technique, the following best-fit curve was obtained from the FARS data for model years 1966 to 1975:

$$\text{Fire Rate} = -201.7 + 0.1035(MY) - 0.0335(EVAP) \qquad r^2 = .84$$

where:

MY = model year
EVAP = 0 if MY $<$ 1971, or
EVAP = 1 if MY $>$ 1970.

The "EVAP" parameter was determined to have a confidence level of only 14% (i.e., there is an 86% probability that "EVAP" has no effect on fire rates), whereas the constant term (-201.7) and model year parameter were calculated to be statistically significant at a confidence of 98%. Hence, it is highly unlikely that evaporative controls had any effect on fire rates. Further, even though the coefficient of the EVAP term is negative, EPA does not view this result as an indication that evaporative controls may have decreased fires. Our overall conclusion is that the changes observed in fire rates from one model year to another are due to factors other than evaporative control systems.

For example, over the two year period of 1968-1970, fire rates increased 8.7 percent without any influence from evaporative control systems (in other words, other factors were responsible for this increase). Similarly, from 1981-1983 and 1984-1986, fire rates increased 12.9 and 11.0 percent, respectively. From 1970 to 1972 (during which time evaporative control systems were implemented), fire rates increased 11.7 percent. This figure is not substantially different from normal year to year variation or the increase that occurred when evaporative control systems were not even a factor. Therefore, the change in fire rates from 1970 to 1972 cannot be attributed to the implementation of evaporative control systems since changes similar in magnitude occurred in fire rates due to other factors even without the presence of evaporative controls. The increase in fire rates from 1968 to 1972 could be partially related to the fact that newer model year vehicles were on average exposed to higher levels of fuel volatility over their lifetime as compared to older model year vehicles. At any rate, it is not possible to conclude from FARS data whether evaporative control systems had any significant effect on fire rates.

It should be noted that vehicle fires are rare events especially when considered relative to other vehicle risks. No clear trends are obvious in rate changes between any model years. Overall, fire rates have fluctuated somewhat but have continued to remain low. Other changes more significant than evaporative control systems have occurred to fuel systems, such as fuel injection, but even the effects of these changes would be difficult to detect in rates that are so low.

Further, data from the states of Michigan and Maryland also taken from the previously mentioned NHTSA report[2] (Table 2-3) suggest that post-evaporative fire rates were even somewhat lower than pre-evaporative fire rates. For example, Michigan data show an average pre-evaporative (1968-70) fire rate of 3.0 fires per 1000 accident involved cars, and an average post-evaporative (1971-73) fire rate of 2.87. Similarly, Maryland data show an average pre-evaporative fire rate of 3.8, and an average post-evaporative fire rate of 3.23. The average pre-evaporative Ohio data shown in this same table indicate essentially no difference between the average pre- and post-evaporative fire rates.

The Michigan data also included information on fuel leak rates. It is interesting to note that fuel leak rates continued to decrease from MYs 1968-73 even though evaporative control systems added additional components and connections to the fuel system. For example, the average pre-evaporative fuel leak rate was 19.7 per 1000 accident involved cars, and the average post-evaporative rate was 14.1. This indicates that fuel system vulnerability in the form of additional disconnections with subsequent possible leakages does not have to increase with the implementation of new components and complexity. The Michigan and Maryland data suggest that evaporative control systems did not degrade safety, although one commenter did provide analysis to the contrary.

Failure Analysis Associates (FaAA) prepared an analysis for General Motors using FARS data, which stated that post-evaporative fire rates were significantly higher than pre-evaporative fire rates. In EPA's view, however, there are several problems with their analysis. To begin with, FaAA developed a technique to neutralize vehicle age as a possible confounding factor in their comparison, but by doing so, may have inappropriately biased the data.*

FaAA used 1968 through 1973 model year vehicles and separated the vehicles into pre- (1968-70) versus post-evaporative (1971-73) groups. Next since they wanted data on vehicles of the same age and were working with a data base

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* The following paragraphs discuss FaAA's age neutralizing technique as it applied specifically to FARS data. FaAA also applied this technique to the data from several states, and in general the discussion that follows also applies to FaAA's analysis of the state data with specific differences noted where applicable.

Table 2-3

Car Fire Rates Per 1000 Accident Involved Cars in the States of Michigan, Maryland, and Ohio

	MICHIGAN (1978-84)		MARYLAND (1978-84)	OHIO (1982-1984)
Model Year	Fuel Leak No Fire	Fire Rate*	Fire Rate**	Fire Rate***
1968	20.8	3.0	3.5	2.5
1969	19.7	3.2	4.4	3.2
1970	18.6	2.8	3.5	2.4
1971	16.2	2.8	3.5	3.0
1972	14.1	2.9	3.1	2.7
1973	11.9	2.9	3.1	2.5

* Irrespective of fuel leak.
** All fire involved accidents.
*** Due to crash.

(FARS) which was started in 1975 (the first year of data collected from the various states ranged from 1970 to 1982), several analytical decisions were made on how the data should be used. Different model years were paired ('71 & '70, '72 & '69, and '73 & '68), and then FARS data for the different calendar years were used for vehicles of the same age. For example, as FaAA stated in their report, "for a collision of a 1971 model-year vehicle to be counted in a given accident year, the previous accident year must be available for 1970 vehicles of the same age. Similarly, in order to count 1972 and 1973 model-year vehicles, accident data for three and five years earlier had to be available to provide the balancing data for 1969 and 1968 model-year vehicles, respectively."

The first problem with this technique is that the desire to use matched model years as described above led to several situations where apparently valid data were excluded because there were not corresponding data for the matching model year, even though there were data for vehicles of the same age and contrasting type (evap or pre-evap.) in non-matching model years.

This is illustrated in Table 2-4, which shows the approach used by FaAA applied to FARS data. Across the top and bottom of the table are the evaporative and pre-evaporative model years as matched by FaAA; listed down the sides are the calendar years of FARS data available. The entries within each column are the age/vehicle type for each matching model year set. FaAA used only data where there was corresponding age data within the same model year set. Thus as can be seen in the table there were six calendar years of pre-evaporative or evaporative data excluded under this approach, even though there were data for the contrasting vehicles of the same age in non matching model years. The effects of this apparent omission are uncertain. It appears, however, that 3 MY/CY of pre-evaporative and 3 MY/CY of post-evaporative data was excluded. This represents about 11 percent of the data used.

Second, since this approach used only FARS data, it forced consideration only of data for vehicles five years of age or older. (For the state analyses, vehicle ages considered range from zero years and older up to twelve years of age and older for the various states.) This alone could introduce an age bias. Clearly, any safety assessment should be based on the full life and history of the fleets involved.

Third, as discussed earlier, any analysis based on FARS data may be inherently unrepresentative of the true performance of the systems since a fatal accident had to be involved. Vehicle fires are rare, and deaths involving accidents and fire are only a small percentage of that total (<5 percent).[2] Furthermore, only about 6 in 1,000 accidents involves a fatality, so a large number of accidents were not even

Table 2-4

Illustration of FaAA Matching Scheme for FARS Data

Evaporative MYs - "E"

CY FARS Data		71 (E)	70 (P)	72 (E)	69 (P)	73 (E)	68 (P)
	75	4E	5P	3E	6P	2E	7P
	76	5E	6P	4E	7P	3E	8P
	77	6E	7P	5E	8P	4E	9P
	78	7E	8P	6E	9P	5E	10P
	79	8E	9P	7E	10P	6E	11P
	80	9E	10P	8E	11P	7E	12P
	81	10E	11P	9E	12P	8E	13P
	82	11E	12P	10E	13P	9E	14P
	83	12E	13P	11E	14P	10E	15P
	84	13E	14P	12E	15P	11E	16P
	85	14E	15P	13E	16P	12E	17P
	86	15E	16P	14E	17P	13E	18P

Pre-Evaporative MYs - "P"

- A total of six data points were excluded under MY matching scheme, even though each point could be matched with a contrasting vehicle type in another MY.

- A total of 18 data points were excluded but usable if vehicle age is not a factor.

considered in the analysis of FARS data. A valid analysis must consider all accident and fire experience not just fatal accidents.

Fourth, the fact that different calendar year data were used for pre- and post-evaporative vehicles introduces a number of potential confounders which cannot be easily eliminated. Table 2-5 shows which calendar year information remained for the comparison of pre-evaporative and post-evaporative model years in FaAA's analysis of FARS data.

This table shows that for each matched set of model years there was some difference in the calendar years from which the data were collected. The most pronounced effect is for the comparison of the 1968 MY pre-evaporative vehicles and 1973 model year evaporative vehicles. For example, information collected between 1975-81 was used for 1968 MY vehicles in comparison to data collected between 1980-86 for 1973 MY vehicles. In other words, for vehicles of like age, 1968 MY data was obtained a full five years earlier than data for 1973 MY vehicles. The offset, while less pronounced, is three years for 1972 MY vehicles and one year for 1971 vehicles. Any possible trends observed in this comparison of pre- and post-evaporative vehicles could be more due to changes in other influential factors that occurred between these very different time periods.

For example, any number of factors could contribute to the observed trends in FaAA's results including driving pattern changes, weather differences, vehicle population/concentration, and especially the noticeable increase in volatility as shown in Figure 2-1. This figure shows that summer fuel volatilities were roughly 3/4 psi RVP higher in 1981-86 than they were in 1975-80. In addition, winter fuel volatilities also averaged about 1 psi RVP higher in 1981-86 compared to 1975-80. Factors such as these make comparisons of pre- and post-evaporative vehicle fire performance over long time periods quite difficult.

Further, the data shown in Table 2-6 from the states of Michigan and Maryland do not show any conclusive evidence regarding the effect of age on fire rates.* The Michigan data tend to indicate no appreciable effect, whereas the Maryland data do indicate a possible relationship between vehicle age and fire rates. Therefore, given the uncertainty of the true effect of vehicle age on fire rates, and the potential for FaAA's technique to introduce additional confounding factors

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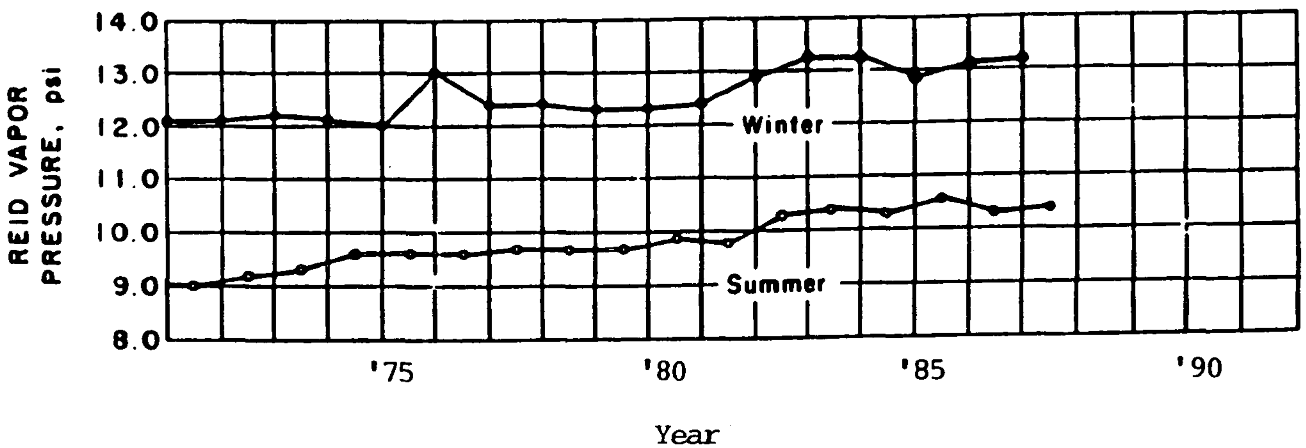
* Ohio data were not included in Table 2-6 because the Ohio data only date back to 1982, and therefore, not enough information existed to separate model year information into three distinct age groups.

Table 2-5

Calendar Year Data Used in FaAA's Analysis of FARS Data for Model Years 1968-73

Model Year	Calendar Year Data Used
1968	1975-81
1969	1975-83
1970	1975-85
1971	1976-86
1972	1978-86
1973	1980-86

Figure 2-1: Gasoline Volatility Trends*



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* From "Motor Gasolines, Summer 1987," Cheryl L. Dickson and Paul W. Woodward, NIPER, Report 153, March 1988.

Table 2-6

Car Fires per 1000 Accident Involved Vehicles in the States of Michigan and Maryland (1978-84) as a Function of Model Year and Car Age

	MICHIGAN			MARYLAND		
Model Year*	All Ages	< 6 Years	< 4 Years	All Ages	< 6 Years	< 4 Years
1975	2.4	2.4	2.4	3.4	2.6	2.2
1976	2.0	1.8	1.8	2.1	1.5	1.2
1977	1.8	1.7	1.6	1.5	1.2	0.8
1978	1.9	1.8	1.7	1.3	1.2	0.8

* Only these 4 model years are shown because data for all three age classes were only available for vehicles in these 4 model years.

such as significant RVP differences, the technique used to correct for vehicle age effects appears to have been unwarranted.

FaAA's conclusion that evaporative control systems have increased fire rates is also based on a comparison of fire rates for eight specific vehicle models in immediately adjacent model years of 1970 and 1971. However, such a small sample of models in comparison to the entire fleet of models available at that time cannot yield any significant results regarding the typical characteristics of the entire range of models. In addition, no mention was made of an adjustment to account for the fact that California evaporative control systems were implemented on 1970 model year vehicles.

In summary, FaAA's conclusion that evaporative control systems increased fire rates is not supported by the analysis presented in their comments. Even if the analysis were reaccomplished to address the apparent analytical bias introduced by the matching scheme, and the same results were found, it would still be necessary to satisfactorily address the concerns that 1) in their analysis of FARS data (and most of the states) all vehicles were at least more than four years old, and 2) the data were gathered over a number of calendar years that did not overlap, so that other factors such as volatility could be responsible for the trends observed.

As a matter of fact, EPA's analysis of the data shown in Table 2-2 was done without consideration of age factors (i.e., it included all data). This analysis supports the conclusion that no difference is apparent between the fire rate changes that occurred as a result of implementing evaporative controls and those changes which occur normally from one model year to the next. EPA believes that FaAA's analysis would have reached the same conclusion if all the available data had been used. All other information available to EPA does not indicate that evaporative control systems have had a noticeable effect on vehicle fire rates. Some additional information which supports EPA's view is presented below.

In addition to trying to identify trends in fire rate data that have resulted from implementing evaporative controls, it would be useful in the evaluation of the safety of these systems to know the extent to which evaporative control systems have been involved in vehicle fires. However, no such hard data exist. Indeed, one of the reasons why this information does not exist is because evaporative control system fires are extremely rare events. For example, the Center for Auto Safety's (CAS) recent review of over 20,000 fuel system related owner complaints maintained in NHTSA's files revealed 1,501 fires.[5] Only six of these were even tangentially related to the evaporative system. This is only 0.4 percent of the reports involving fire. A similar review by a NHTSA contractor revealed 23 or less such incidents out of a total of 2850 vehicle fires involving fuel related components.[2] Even if taken at its maximum, this represents only 0.8 percent of owner complaints involving fire. The difference in the number of evaporative involved fires between CAS and NHTSA (6 versus $\leq$ 23) is because the NHTSA report presented only summary information on fuel emission control related fires (code 612X000) where evaporative problems are recorded. However, this category of complaints includes many other problem areas as well (e.g., crankcase ventilation). An EPA review of these 23 owner complaints related to fire in category 0612X indicated that 10 or less involved the evaporative system, which represents only 0.4 percent of the owner complaints involving fire. The rare occurrence of fire problems with evaporative systems is one reason why the fire risk of onboard control systems is often characterized as unquantifiable.

In addition, other sources of information are available related to the performance characteristics of evaporative control systems which can be used to provide a further assessment of the relative safety of these systems. The next section discusses the level of safety that has been demonstrated in-use by evaporative control systems as indicated by available performance information.

C. In-Use Performance of Fuel/Evaporative Emission Control Systems

The effect of evaporative control systems on vehicle fire rates is just one of several useful indicators of the relative safety of such systems. Another good measure of the safety of a particular system is the reliability or in-use performance exhibited by the system. A system which fails infrequently or results in minor consequences when it does fail can be considered a relatively safe system.

It is useful to study the in-use performance of evaporative control systems because these systems are very similar to the proposed onboard refueling control systems, and therefore evaporative systems provide a useful perspective on the safety concerns related to onboard controls. As a matter of fact, onboard control systems are more of a modification to the current evaporative system rather than the addition of a whole entire new system. Onboard systems use components similar to those found on current systems such as vapor lines, clamps, charcoal canisters, and valves. By studying how these components have performed in-use in the past, it is possible to predict how similar components for onboard control systems are likely to perform in the future.

The in-use performance of a particular system is often measured in terms of the past failure characteristics of such a system. Three bodies of information contain data regarding historical failures/problems with vehicle systems/components. These are NHTSA recall campaigns, manufacturers technical service bulletins, and owner complaints. Information in all three of these areas is maintained in computer files by NHTSA. Manufacturers also maintain their own records of recalls and service bulletins related to vehicles they have produced. This section examines information gathered from NHTSA, motor vehicle manufacturers, and other interested parties on the recalls, service bulletins, and owner complaints related to evaporative control systems as part of an overall assessment of the in-use performance of these systems.

1. <u>NHTSA Recall Campaigns</u>

NHTSA recall campaigns are one of the most important sources of performance information since they are the most directly related to the safety of a system. EPA first began to examine the available safety recall information in the fall of 1986 as part of an assessment of the safety of evaporative control systems that appeared in the EPA's June 1987 onboard safety technical report (Appendix II). The analysis in that report was based on file summaries provided by NHTSA that were classified under their "Fuel Emission Control" category. This category covers recalls for all vehicle types (passenger vehicles, light-duty trucks, and heavy-duty vehicles), and includes recalls dating back to 1967.

As of November 1986, only 22 recall campaigns (out of a total of more than 4200) appeared in NHTSA's "Fuel Emission Control" category. A closer examination of these 22 files for the onboard safety technical report revealed only 12 cases that could even be remotely linked to the evaporative emission system. Examples of the 10 unrelated recalls range from defective PCV systems to defective valves on diesel trucks to cracked breather tubes on 1967 vehicles.

NHTSA reviewed and commented on the onboard safety technical report prior to its finalization, but provided no feedback regarding the correctness of EPA's finding that only 12 recalls were found to be relevant to evaporative emission controls. Since the time of the report, however, we have received additional input from NHTSA, the manufacturers, and the Center for Auto Safety (CAS) regarding the appropriate number of relevant recalls. This section summarizes this new information, and updates our assessment of the number of recall campaigns pertinent to evaporative emission control systems.

a. <u>Additional NHTSA Input</u>

In October 1987, NHTSA, as part of testimony given in a hearing before the House Subcommittee on Oversight and Investigations, presented the results of a supplemental review of their recall files. In this review, NHTSA examined all fuel system recall campaigns, not just those classified under the "Fuel Emission Control" category. Thus, by definition, this review resulted in the identification of additional recalls which had not been previously classified under the fuel emission control category.

In their testimony, NHTSA characterized the additional recalls they had discovered as ones "that might involve evaporative-related fuel systems or fuel systems," and as such, not all additional recalls mentioned in their testimony were relevant to evaporative control systems. NHTSA's purpose in conducting this subsequent review was to identify recalls which might be related to future onboard control systems, not necessarily to better characterize past evaporative system performance.* Nevertheless, EPA's review of these additional recalls resulted in the addition of eight more recalls to the list related to evaporative control systems. Combining these additional recalls with the original 12 in the EPA safety report resulted in a total of 20 recalls which pertain to evaporative control systems. Table 2-7 contains the 20 recalls that appear to be relevant to evaporative controls.

In response to a recent letter from EPA on the recall issue,[6] NHTSA suggested that determining a recall's relevance to evaporative control systems is not always clearly defined, and that several types of recalls (e.g., those involving fires, exhaust temperatures, manifold vacuum, or stalling/ driveability) may indirectly also involve the evaporative control system.[7] To help illustrate their point, NHTSA included as part of their letter the computer file summaries of 300 recalls involving fire, 30 related to stalling, and 20 involving exhaust emissions/temperatures.

EPA has reviewed this information very carefully and the following points represent EPA's views on the relevance of these other types of recalls to evaporative controls. First, no new recalls <u>directly</u> relevant to evaporative emission systems were uncovered. In addition, no new recalls were discovered in which evaporative controls have had any adverse effects (direct or indirect) on stalling or exhaust emissions/temperatures. In their letter NHTSA noted their belief that five recalls in particular concerned adverse effects of evaporative emission controls on exhaust temperatures and indicated that EPA should take these five recalls into consideration as evidence of the types of tangential problems that can arise from a vapor recovery system.[7] However, three of these recalls simply involved the addition of a heat shield, with no indication of the problem being a result of the evaporative control system. The other

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* The issue of the effect of onboard controls on recalls is addressed in Chapter 3, Section D.

Table 2-7

Evaporative System Recalls

NHTSA Campaign Number	Model Year(s)	Vehicle Type	Number of Affected Vehicles	Description of Problem
70V137	1970	Pass. Veh.	12,550	Emission control hose may interfere with bracket.
71V051	1971	Lt. Truck	25,500	Fuel/vapor separator (part of evap system) may leak.
72V014	1971	Pass. Veh.	110,614	Malfunction in evap system causes stalling.
73V019	1973	Lt. Truck	1,600	Vent line from tank to canister may contact exhaust pipe.
75V011	1974-75	Motor Home	197	Saturated canister can discharge vapor over exhaust pipe.
75V164	1975	Motor Home	496	Fuel tank spillage may result in evap system failure.
76V037	1976	Pass. Veh.	2,400	Misrouted vapor return line which runs from the fuel filter/vapor separator assembly back to the fuel tank.
76V126	1976	Pass. Veh.	9,137	Erroneously installed piping for the "check and cut valve".
78V036	1977-78	Lt. Truck	20,000	Blockage of tank vent system can lead to pressure buildup and force fuel or vapor leakage through cracks in tank.
78V106	1977-78	Pass. Veh.	10,500	Defective fuel tank vent valve.
78V145	1973-77	Med. Truck	2,500	Liquid gasoline may discharge from bottom of canister because evap system may lack adequate capacity under certain fuel expansion conditions.
78V181	1978-79	Lt. Truck	23,000	Obstructed evap line causes pressure build up in tank.
79V019	1976-78	Pass. Veh.	17,800	Possibility of kinked evaporative system hose.

Table 2-7 (cont.)

Evaporative System Recalls

NHTSA Campaign Number	Model Year(s)	Vehicle Type	Number of Affected Vehicles	Description of Problem
79V032	1977-79	Pass. Veh.	83,000	Obstructed evap line causes pressure build up in tank.
79V045	1979	Pass. Veh.	3,700	Misrouted vapor line to canister.
79V048	1975-76	Pass. Veh.	61,000	Defective pressure control valve.
79V212	1973-78	School Bus	2,950	Defective liquid/vapor separators.
84V116	1985	Pass. Veh.	2,385	Improper functioning of vacuum line valve.
87V111	1984-87	Van (Ambulance)	250	Defective vapor valve grommet on fuel tank. (This component was installed as part of a preliminary attempt at correcting the fuel expulsion problem of Recall No. 87V113).
87V157	1984-88	Pass. Veh.	25,000	Overfilling of the fuel tank can increase fuel system pressure to the point where fuel vapors escape from the charcoal filter and cause an engine compartment fire.

two recalls concerned problems with exhaust emission controls. None of these recalls involved the evaporative control system in any way. EPA sees no direct connection between evaporative control systems and exhaust system temperature problems.

An examination of the fire recalls revealed a few recalls involving pressurized fuel systems (tanks). Depending on one's viewpoint these could be viewed as tangentially related to evaporative controls. However, an assessment as to whether a recall of this type is truly related to the evaporative system requires an assessment as to why the fuel tank was essentially sealed (which by design causes the tank to operate in-use at pressures above atmospheric) and what caused the problem which led to the recall. This assessment would expose what actually led to the unsafe conditions that caused the recalls to occur. First, it should be noted that fuel systems are normally vented through a small orifice to assist in control of evaporative emissions and to assist in meeting the rollover requirements of FMVSS 301. As to the cause of the pressurization related recalls, it appears to EPA that fuel volatility increases and high tank temperatures were the most likely the cause. While evaporative control systems and other system components are sometimes modified as the recall fix to deal with pressurization problems resulting from high volatility fuel, this is not due to a problem with the original system design but is necessary to deal with higher fuel volatilities that are beyond the manufacturer's control. In conclusion, EPA believes that A careful have evaporative controls have not adversely affected the number of fire, stalling, or exhaust emission related recalls.

b. Manufacturers Comments

In addition to information supplied by NHTSA, EPA also received views from manufacturers on recalls as part of their comments on the NPRM. Much of the information received from manufacturers was simply a replication of the data received from NHTSA. For example, some manufacturers claimed not to have had any evaporative emission system recalls. Others pointed out that NHTSA would be in the best position to determine the number of recalls relevant to evaporative emission controls. Several manufacturers provided recalls which they believed were relevant to onboard refueling controls, but did not distinguish between which files related strictly to onboard controls and which files were also relevant to evaporative control systems.

One manufacturer (Chrysler) did supply information on recalls directly concerning the evaporative control system. Two of the three recalls they provided had already been included in EPA's earlier review of NHTSA's files. However, the third recall involved a blocked vent on 1973 Dodge trucks and had not been identified prior to Chrysler's comments. This recall was not found in NHTSA's computer files, nor was it identified by the Center for Auto Safety in their review of NHTSA's recall files.[5] There existed some doubt regarding whether or not this third item was an official recall. Information received in response to a June 9, 1988 phone conversation with Chrysler indicated that this recall had been sent to NHTSA, but that it had been classified as a non-safety related defect.[8] Thus, it may have simply ended up as a technical service bulletin in NHTSA's Files. Based on this information this action was not classified as a recall.

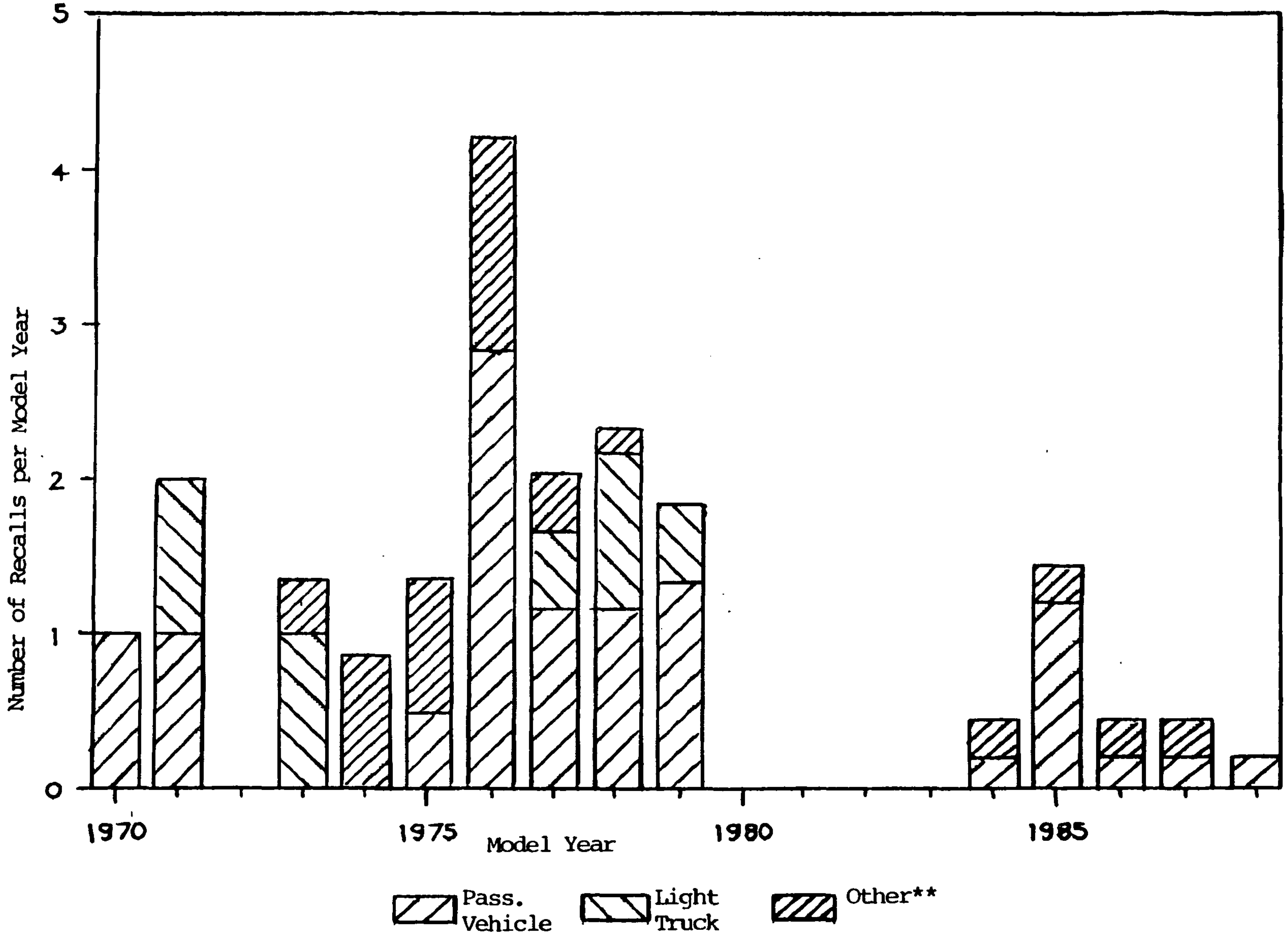
c. Center for Auto Safety Report[5]

The Center for Auto Safety (CAS) recently completed a study of the safety of evaporative control systems and the effects of recent increases in gasoline volatility. This study was based on a comprehensive review of two NHTSA computer data bases: recall campaigns and owner complaint records. CAS concluded that 21 recalls over the past eighteen years have involved the evaporative control system. Of these 21 recalls, no new additional recalls were presented which had not been identified previously by EPA or others. Of the 21 recalls identified by CAS, only two were associated with the potential for post-crash fires. Further, no fires, injuries, or deaths were linked to either of these two recalls. CAS's overall conclusion is that "evaporative emission controls have not resulted in any significant incidence of vehicle fires or recalls."

d. Summary of Evaporative System Recalls

After careful review of all available information regarding evaporative emission control system recalls, EPA has determined that a total of 20 evaporative system related recalls (shown in Table 2-7) have occurred since evaporative control systems were first implemented eighteen years ago (an average of about one recall per year). The distribution by model year is shown in Figure 2-2. These 20 recalls cover all vehicle types including passenger vehicles (11), light truck (4), motor homes (2), buses (1), and other heavy-duty gasoline vehicles (2). These 20 recalls which involved about 470,000 vehicles represent about 1/2 percent of the more than 4,200 recalls that have occurred since 1966. They have affected less than 0.5 percent of the vehicles certified with evaporative systems since 1971. In other words, problems with evaporative control systems account for less than 1/2 percent of all safety-related problems. While one might argue that a few more or a few less recalls should be included, this would not change the conclusion that they represent only a very small proportion of safety recalls.

Figure 2-2: Evaporative System Recalls*



* Fractional numbers of recalls involve vehicles from more than one model year. For example, a recall covering 3 model years was represented as 1/3 recall per model year.

** Includes school buses, motor homes, vans, and heavy trucks.

2. Manufacturer's Service Bulletins

Another important source of information regarding the performance characteristics of a system is the number of technical service bulletins issued to correct problems/ defects. Technical service bulletins are less directly linked to safety than recalls because the problems addressed through service bulletins are typically minor performance adjustments with either minor or no safety ramifications. Indeed, the technical service bulletin file includes a wide assortment of other categories of information such as product improvement notices, warranty information, service newsletters, and emission recalls. Nevertheless, the study of service bulletins does provide some useful perspective on the failure characteristics of vehicle systems.

As with recalls, EPA first began to examine service bulletins back in late 1986 as part of an assessment of the reliability of evaporative control systems. After examining NHTSA's "Fuel Emission Control" category for the onboard safety technical report (Appendix II), EPA found only 21 cases, out of more than 800, that involved the evaporative emission control system. Since the time of that report, we have received some additional information from NHTSA to help refine our initial estimate of the number of evaporative control service bulletins. (Note: the CAS study [5] did not cover service bulletins, and manufacturers did not provide comments which specifically address the number of bulletins relevant to evaporative controls.)

a. NHTSA's Input

It should first be stated that as with recalls NHTSA reviewed and commented on the onboard safety technical report but did not address the accuracy of the number of service bulletins EPA found to be relevant to evaporative control systems. Since that time, however, EPA has received two additional inputs from NHTSA relevant to evaporative control service bulletins. These are NHTSA's April 12, 1988 letter to EPA,[7] and NHTSA's draft contract report "Study of Motor Vehicle Fires."[2]

In their April 12, 1988 letter, NHTSA made the same point about service bulletins as they did about recalls; that is, the role of evaporative control systems in contributing to the need for a service bulletin is not always clearly defined. NHTSA believes that it is possible for the evaporative control system to indirectly lead to service bulletins for problems involving fuel systems, carburetors, exhaust systems, and other emission systems. To help illustrate their point, NHTSA included all service bulletins related to fuel, exhaust, and emission systems as part of an attachment their letter[7] (over 6800 bulletins in total).

As far as any connection with evaporative emission control systems, NHTSA mentioned a total of 17 bulletins out of the more than 6800 provided as being relevant. Ten of these bulletins concerned purge interaction with exhaust temperatures, and seven involved canister overloading effects on stalling/driveability. To get a better idea of how evaporative control systems have affected other systems, EPA examined the 5,900 bulletins out of the total 6,800 which were classified under categories other than "Fuel Emission Control." (We concentrated on these bulletins first, since we had previously already examined the bulletins in the "Fuel Emission Control" category.) EPA found approximately 35 to 45 bulletins somewhat relevant to the evaporative control system which had been classified under categories other than "Fuel Emission Control"(ten of the bulletins are duplicates of the same problem on a different model of the same manufacturers vehicles). EPA does not know the extent to which these bulletins overlap the 17 identified by NHTSA since NHTSA did not provide bulletin numbers for each of the 17 items they discussed. These 35 to 45 bulletins were not included as part of the bulletins discussed in the safety report since the 5,900 bulletins in categories other than "Fuel Emission Control" were not available at the time of that report.

As far as service bulletins related to evaporative emission control systems that fall under NHTSA's "Fuel Emission Control" category, EPA decided to reexamine this issue after receiving NHTSA's draft contract report, "Study of Motor Vehicle Fires."[2] This report identified 882 "Fuel Emission Control" bulletins in NHTSA's computer files and implied by the title of this category that all 882 bulletins involved the evaporative control system. Since this number was substantially different from the 21 files identified previously, EPA decided to review this category once again.

A careful review of this category reveals that "Fuel Emission Control" includes many bulletins other than evaporative emission control including exhaust emissions, spark knock, driveability, high altitude emission standards, glow plugs, oil consumption, oxygen sensors, EGR valves, PCV systems, and many others. In addition, many entries in this category contain no summary information and often are missing model year information making it essentially impossible to determine whether the entry is applicable to evaporative emission controls. These two types of bulletins ("other," and "no information") comprise over 90 percent of the 882 entries in the "Fuel Emission Control" category.

As was mentioned before, it should also be noted that not all entries in this category are really technical service bulletins. Some are service newsletters, warranty information, product improvement notices, parts notices, service manual corrections, and even "recalls." Further, some of the entries are for the same problem but on different model vehicles or are updates to prior bulletins. Needless to say, it was difficult to identify with certainty the actual number of bulletins truly related to evaporative control systems and perhaps more importantly the actual number of separate problems which were really identified in the bulletins.

From the service bulletins that did provide enough information, it appears as though 35 to 75 could be relevant to the evaporative emission control system. This estimate is higher than EPA's original estimate. It includes problems such as broken or incorrect canisters, poor purge characteristics, vapor line problems, and tank vent/overpressurization problems. This is primarily because our most recent review was quite liberal in the acceptance of a relevant bulletin. The range of 35 to 75 was used because there are some bulletins which are possibly related, but could not be identified as such absolutely because of the quality of the description of the problem. Even with this being the case, adding the 35 to 45 evaporative system bulletins revealed in other NHTSA categories brings the total to 70 to 120. It thus appears that evaporative control systems account for only about 0.1 percent of the 88,000 service bulletins issued. Because these problems have been so infrequent, identifying the exact number of service bulletins related to evaporative control systems is not critical.

3. Owner Complaints

The third data set which contains information on the performance characteristics of vehicle systems is NHTSA's files of owner complaints. When this information was analyzed for the 1987 onboard safety report, only about 100 complaints were found which related to the evaporative control system. Since the time of that report, we have received two additional sources of information regarding owner complaints, neither of which altered our original findings.

The first piece of additional information appeared in NHTSA's draft contract report, "Study of Motor Vehicle Fires."[2] This report showed 447 cases of owner complaints filed under the "Fuel Emission Control" category, 23 of which mentioned fire. However, as was true of NHTSA's "Fuel Emission Control" category for service bulletins, our review of the detailed information concluded that not all owner complaints filed under this category are relevant to evaporative control systems. For example, many of the complaints in this category related to PCV systems, air pumps, exhaust emissions, EGR, etc.

This category was originally searched as part of the 1987 safety report. A second, more recent, review revealed roughly the same findings as discussed in that report. In total, only about 100 complaints out of the 447 listed in this category could be even remotely linked to evaporative control systems. Relevant complaints included canister problems, tank venting/overpressurization, vapor line, and purge problems. These 100 complaints represent less than 0.05 percent of all complaints (210,000) in NHTSA's computer files. Out of these 100, less than 10 made mention of fire.

This complaint level is similar to that determined by the recent work completed by the Center for Auto Safety (CAS). In their study,[5] CAS searched through owner complaints filed since 1977, and found only 27 cases involving the evaporative control system. Again, as was true of service bulletins, because there have been so few complaints, it is not essential to focus on the exact number of relevant complaints. Of these 27 cases, only 6 were found which involved fire.

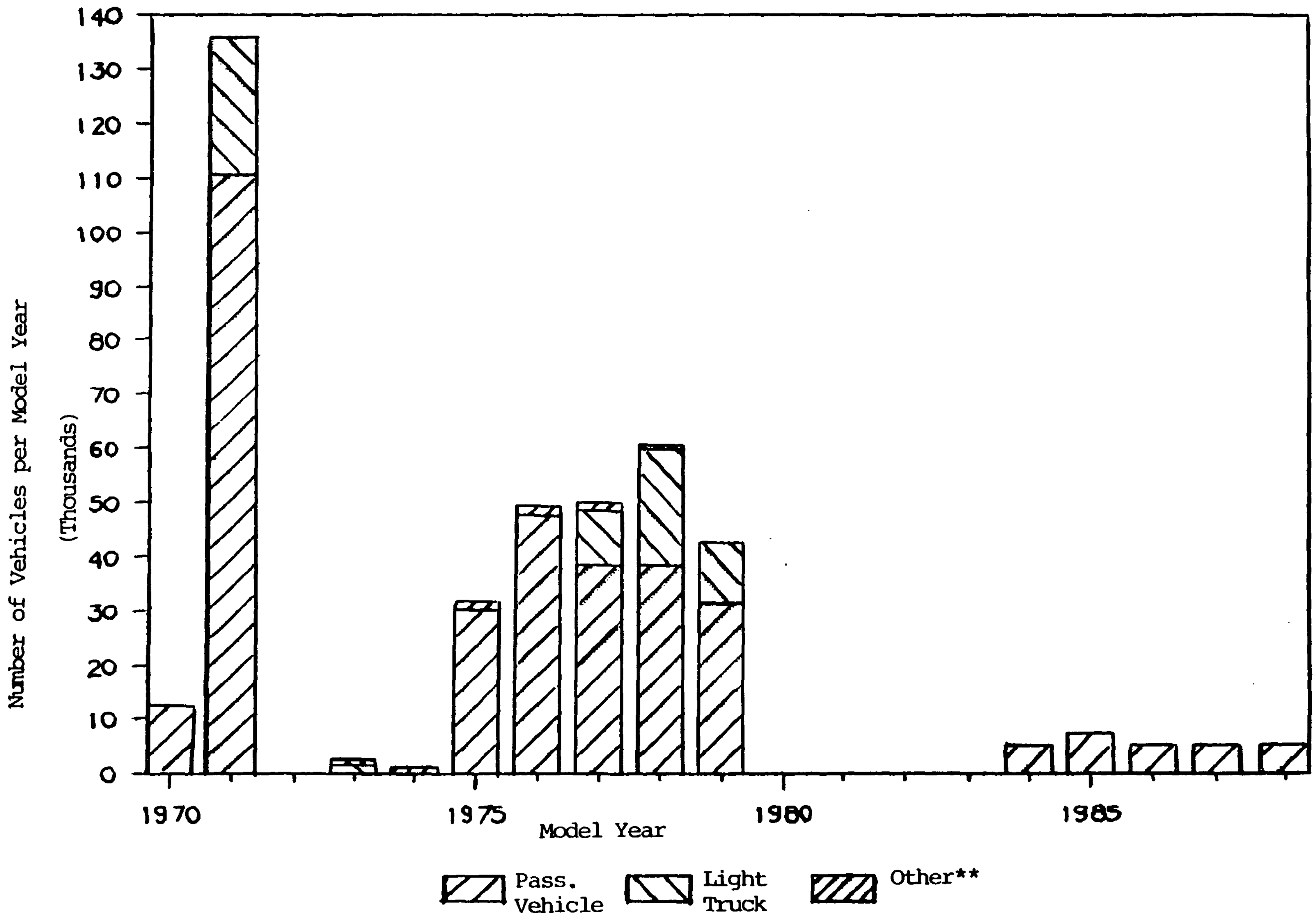
In summary, of the hundreds of thousands of owner complaints filed with NHTSA, only a minute percentage (<0.05%) have involved the evaporative control system. Further, only a handful of these involved fire. When these complaints are considered relative to the 130 million plus vehicles sold with evaporative control systems, it appears that evaporative control systems have not created a significant number of safety problems for vehicle owners.

4. Conclusions

The basic conclusion that can be drawn from an examination of the recall files, service bulletins, and owner complaints provided by NHTSA and others is that evaporative control systems have worked safely. Evaporative control systems account for only a tiny fraction of the total problems appearing in NHTSA's computer files. Therefore, while problems have occurred, they have been infrequent. Further, when problems have occurred, the consequences have been minimal. NHTSA's records indicate that no deaths or serious injuries have resulted from an evaporative control system failure. Owner complaints taken at face value would indicate less than 10 fires since NHTSA began keeping records in 1977; this is at a rate of less than one per year. This information demonstrates the effectiveness of NHTSA's programs to not only prevent system failures, but to correct any infrequent mistakes that do occur before they lead to any significant consequences.

Another important result of this examination of NHTSA's files is that most of the evaporative system recalls involved pre-1980 vehicles. This can be seen in Figure 2-3. This indicates that as manufacturer's experience with evaporative

Figure 2-3: Evaporative System Recalls*



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* When a recall involved more than one model year vehicle, the total number of vehicles involved in the recall were distributed equally among the number of model year involved.

** Includes school buses, motor homes, vans, and heavy trucks.

systems has increased, so has their ability to design and produce problem free systems. Further, because of the similarity between onboard and evaporative control systems, this experience should be directly applicable in the design and development of safe, effective, reliable refueling control systems.

Finally, it is quite possible that evaporative controls may have resulted in safer fuel systems then would have occurred without such requirements. The basic requirement for a closed fuel system may have contributed to the avoidance of numerous fuel leaks. The requirement that carburetors vent their fuel vapors to a canister instead of allowing the continued direct venting of such vapors in the engine compartment may have avoided numerous engine fires. Unfortunately, it is impossible to quantify such potential benefits.

D. <u>Summary</u>

As was stated at the beginning of this chapter, auto manufacturers and others have asserted that onboard control systems would lead to an unquantifiable increase in fire risk. To address this concern, we first attempted to put the current fuel/evaporative system risk in perspective. An examination of fire rates in accidents revealed that evaporative control systems have had no discernible effect on vehicle fires. Further, an examination of past recall campaigns, service bulletins, and owner complaints reveals that evaporative control systems have created very few problems, and of the rare problems that did occur, no serious consequences resulted. The basic conclusion that can be drawn from this information is that evaporative control systems have worked safely and well. The past safety performance of evaporative systems strongly suggests that an onboard system which incorporates evaporative system design concepts can be made to be safe, effective and reliable.

References for Chapter 2

1. "Analysis of Motor Vehicle Fuel Tank-Related Fires," K. Steilen, U.S. EPA, AA-SDSB-88-05, February 1988.

2. "Study of Motor Vehicle Fires - DRAFT," prepared for NHTSA by Data Link, Inc., Washington, D.C., February 1988.

3. "Evaluation of Federal Motor Vehicle Safety Standard 301-75, Fuel System Integrity: Passenger Cars," DOT HS-806-335, January 1983.

4. "Fires in Motor Vehicle Accidents," UM-HSRI-SA-74-3, Peter Cooley, April 1974.

5. "Stopping Vehicle Fires and Reducing Evaporative Emissions: The Need to Control Gasoline and Alcohol Blend Volatiltiy," Center for Auto Safety, March 1988.

6. Letter to George Parker, NHTSA, from Chester J. France, U.S. EPA, January 22, 1988.

7. Letter to Chester J. France, U.S. EPA, from George L. Parker, NHTSA, April 12, 1988.

8. Conversation with Jim Furlong, Chrysler, June 9, 1988.

CHAPTER 3

Onboard System Design and Safety

A. Summary of Technology and Safety Comments

1. Introduction

As was discussed in Chapter 1, many parties submitted comments concerning the technology and safety aspects of onboard vapor recovery systems. Most of the comments in these two areas were provided by either auto or petroleum interests, but as was mentioned in Chapter 1, important comments and information were provided by others as well.

With a few exceptions, the technology and safety comments tend to fall into four general areas: 1) general views and concerns regarding onboard system technology and safety, 2) specific onboard control designs proposed by the commenters, 3) specific technology and safety concerns regarding onboard system designs and hardware, and 4) specific concerns about the in-use safety implications of requiring onboard controls. The comments received in each of these areas are summarized below. Since there is an inherent relationship between the technology/design and the safety of onboard systems, the related comments and concerns will be summarized together when appropriate. Other comments which fall outside this approach are summarized and addressed in Section D (below).

2. General Views on Onboard Technology and Safety

A common assertion made by automotive industry commenters is that onboard systems are not a simple extension of current evaporative control systems and that it may not be technically feasible to meet EPA's proposed refueling emission standard. They argue that EPA cannot base the feasibility of onboard on a few prototype systems because the complexity of these systems will naturally develop and increase as the testing and progress towards a complete vehicle-based system continues. The petroleum industry and the California Air Resources Board relayed the opposite opinion in their comments, stating that onboard is a simple extension of current evaporative systems. API has built several vehicle based prototype systems (described later in Section C) and provided documented refueling test data from refueling tests run on these systems which they feel demonstrates the feasibility of onboard controls.

One reason the automotive industry commenters do not consider onboard to be a simple extension of current evaporative systems is because they maintain that onboard designs must have separate canisters for controlling evaporative and refueling emissions. In the commenters' view, these "separate" systems are much less an extension of current evaporative systems than the "integrated" systems which use one large canister to capture both evaporative and refueling emissions. Unlike integrated systems, separate systems would have a greater number of components than most evaporative systems. Both EPA's and API's prototype designs are of integrated systems.

Those commenters who chose separate instead of integrated system designs gave several reasons for their choice. Even though integrated systems are less complex, and therefore considered more safe by many of the manufacturers who chose separate systems, they cited perceived drawbacks of integrated systems which drove them to focus on separate systems. Many said that the test procedure favors a separate system. Most said that they expect only a short amount of leadtime to be allotted before onboard systems would be required which would force them to design "retrofitted" separate systems. Some said that they could use a "clean sheet" approach for later designs and then may consider integrated systems. Almost all commenters said that packaging and purging the single large canister of an integrated system would be difficult, if not impossible, especially on smaller cars and carbureted vehicles. On the other hand one commenter chose an integrated system, saying that it would be advantageous from both a safety and a purge design viewpoint (IV-D-340).*

Therefore, presumably based on this view of system design, a widespread opinion of automotive industry commenters is that onboard vapor recovery systems would be more complex than current evaporative control systems, and that adding this complexity to a vehicle fuel system would cause an unquantifiable increase in the risk of both crash and non-crash fires. Several complexity and risk factors were cited such as larger components, more components, more connections, the locations and materials chosen for these components and possible effects on other systems. For example, complexity is said to be added by increasing the size of components such as the vapor line diameter and carbon canister. Larger components were thought to increase crash risks because they are more vulnerable to damage and could damage the fuel tank in an accident if located nearby. Along the same lines, commenters said that since onboard refueling control systems handle a larger amount of vapor than evaporative systems there must be an increased degree of both crash and non-crash risks. Also, commenters said that onboard systems would require more components and more connections than an evaporative system, such as a pressure relief valve and a liquid/vapor separator.

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* References such as this indicate the entry in public docket A-87-11 wherein the document/comment can be found.

These were thought to increase risk by providing more targets in accidents and a greater chance of disconnections. Non-crash risks were said to be greater because a greater number of components increases the chances of manufacturing missassembly, leaks, and other failure modes. Commenters said that some onboard components are likely to be put in risky locations such as a crash zone, near the fuel tank or under the hood. Canisters and fillneck mounted vent valves were common examples of such components. The location of onboard components is also said to be a non-crash concern since some likely locations are susceptible to tampering and other failure modes. The possibility that some components would be plastic was mentioned as a safety concern because they might have questionable strength. Also, according to NTSB, a static charge could build up if metal components isolated by plastic components are not properly grounded. Finally, one commenter suggested that the complexity issue also included concerns regarding indirect effects of onboard controls on other vehicle systems through impacts in areas such as manifold vacuum, exhaust system temperature, and driveability.

3. Specific Onboard System Designs

A total of 26 different onboard system designs were submitted by commenters. Diagrams of the designs that were provided in the comments are shown in Appendix I. As can be seen in the appendix, a mechanically sealed fillneck was a common control system feature found in the onboard designs submitted by auto industry commenters. Separate activated carbon canisters for storing the evaporative and refueling vapors were also frequently incorporated into manufacuturers' designs. At least two commenters indicated that they would use liquid seals (IV-D-08,IV-D-363). There was no general agreement on the choice of rollover/vent valves. Some designs used a fillneck mounted rollover/vent valve while others suggested either a mechanical or solenoid-actuated tank mounted valve. Most designs involved a rear-mounted canister for reasons discussed later in Section D regarding canister safety. Also, most designs submitted incorporate a component that would act as a liquid/vapor separator which separates entrained liquid fuel droplets from refueling vapors enroute to the canister.

A few commenters discussed methods other than a carbon canister based system for controlling refueling emissions onboard a vehicle. Installing a vapor condenser or a vapor combustor onboard the vehicle are two examples of alternative control methods. Generally, commenters concluded that these alternative systems are more expensive than canister based systems and that the level of control possible is not superior to a canister system. Nevertheless, a few manufacturers stated that they are continuing to investigate these alternative systems. Several commenters have also investigated collapsible fuel bladders as a control strategy. Some problems cited are that no potential bladder material has been proven to be durable and compatible with all possible in-use conditions. Commenters think that air entrainment and fuel permeation through the bladder material may be significant problems. It was generally thought that current bladder technology can not presently provide control independently from a canister system. However, several companies are continuing research with the hope that bladders will be a viable long-term solution to refueling controls.

4. Specific Technology and Safety Concerns-Design/ Hardware

In addition to the general views on onboard technology and safety and the onboard system designs received in the comments, a number of comments were received regarding specific onboard system design options and hardware. These comments will be summarized by grouping them together according to the specific component of the onboard system to which they apply. The components will be discussed in order, starting at the fillneck and working through the entire onboard system to the purge valve.

a. Fillneck Vapor Seals

Despite EPA's view that liquid seals would be preferable, a number of commenter's designs used mechanical seals. Only a few automotive manufacturers used liquid seals in their designs. BMW and Toyota said they were still considering liquid seals (IV-D-342, IV-D-363). Many commenters simply assumed liquid seals, whether J-tube or flowing type, would not perform adequately to pass the proposed refueling emissions standard. From the comments, this appears to be an assumption since essentially no actual liquid seal testing data was provided. On the other hand, Exxon, Mobil, and EPA all have developed onboard systems using liquid seals and performed tests which showed that liquid seals functioned effectively and could reduce refueling emissions to levels below the proposed refueling emission standard (IV-D-360 (a), IV-D-320).

Commenters gave several reasons why liquid seals would be problematic and may not be a viable option. For example, they said that evaporation at the fuel/air interface, vapor diffusion out of the open fillneck, or a plugged drain hole could cause a liquid seal onboard system to fail the proposed refueling emissions test. They were also concerned about the ability to form a complete seal at low flow rates. One manufacturer said that tests on their flowing seal system indicated a need for dispensing rate limits of 6-10 gallons per minute (IV-D-363). Conversely, the testing results reported by Exxon showed that liquid seals functioned adequately at low flow rates and another commenter stated that flowing liquid seals can prevent vapors from escaping, since the inflow of fuel being dispensed forms a vacuum in the fillneck (IV-D-01).

Commenters predicted that the backpressure in liquid seal systems would increase spitback spills and premature nozzle shut off. They said this would be a safety hazard unless an anti-spitback or anti-surge feature is incorporated in liquid seal systems. Very little test data were provided to support this belief but one manufacturer reported spitback on a liquid seal system while dispensing at 8.5 gallons per minute (IV-D-08). On the other hand, Mobil was able to fill their prototype onboard equipped vehicle to automatic shutoff with no spitback (IV-D-320). Chrysler and GM recognized that spitback and anti-spitback valves are not a new problem or a new solution, since they currently use caged-ball valves in the fillnecks of some of their vehicles. General Motors did limited testing on sleeve seals and accumulators and concluded that neither device demonstrated acceptable performance at this point but both provided fuel splashback control.

Commenters mentioned that liquid seal systems would be harder to package than mechanical seal systems. Fitting the J shaped end of a J-tube seal into a shallow tank (which was pointed to as the shape of most future tanks) is a packaging concern as is attaching the J insert to plastic tanks. The possibility that this J-shaped end could puncture the tank in a crash was raised up as a safety concern. Commenters also said that the refueling canister on a J-tube system would be larger, and therefore harder to package, than a canister sized for a mechanical seal system. They said that a J-tube system canister would need to be larger due to greater entrainment, turbulence and splashing which generates more vapors. General Motors provided data which show that liquid seals caused the generation of up to 50 percent more vapor then mechanical seal systems (IV-D-360).

Another packaging drawback raised is that liquid seals require a certain fill height in order to contain a standing column of fuel backed up in the fillneck due to system backpressure. No actual test data relating the necessary fillpipe height during dispensing to the system backpressure were provided, although some simple theoretical calculations of standing liquid height were performed. Some commenters said that the elimination of the external vent line on liquid seal designs contributes to increased backpressure. Providing the necessary fill height would necessitate redesigning the fillneck and side body panels on some vehicles, according to commenters.

Even though most manufacturers prefer mechanical seal systems to liquid seal systems, they also raised concerns about the technology and safety of mechanical seals. Many said that no material exists with the required durability and cold temperature performance for this application. Most commenters also said that nozzle standards (diameter, length) would be necessary in order to ensure nozzle and mechanical seal compatibility. One commenter noted significant damage to a prototype mechanical seal after 50 refuelings due to burred and nicked nozzles (IV-D-362). For this reason, many commenters feel that nozzle inspection and enforcement would be necessary if mechanical seal systems are used. They said that any difficulty in inserting the nozzle would lead to increased tampering rates.

Many commenters expressed concern about the safety of mechanical seal systems. They said that an overpressure relief device would be necessary in case of nozzle shutoff failure. Some said that if the pressure relief device fails, tank overpressurization could lead to canister flooding. One commenter even said that fuel tanks may need to be strengthened in order to remain sealed during this potential excessive pressure buildup (IV-D-342).

b. Refueling Vent Valves

All commenters recognized the need for a multifunctional refueling vent valve. Most said that this valve would need to: 1) provide rollover protection, 2) vent adequately during both refueling and normal operation, and 3) act as a fill limiter. Commenters cited several optional designs and locations for this valve, including a fillneck mounted, mechanically actuated valve and a tank mounted, solenoid valve. Several commenters said they were concerned about the safety of a fillneck mounted valve, stating that body panel modifications would be required since it is in a crash zone. Nissan and other commenters expressed concern over fillneck mounted valves since they could be located in a crash zone (IV-D-452). There is added concern if the valve is plastic, since it could be more susceptible to damage in a crash. Plastic parts also necessitate careful grounding of adjacent metal components to prevent static charge buildup. Some commenters said that having an electrically actuated solenoid valve near the fuel tank could be a potential safety hazard due to the proximity of electrical relays to ignitable liquid or vapor fuel.

c. Vapor Lines

A larger vapor line diameter is required on an onboard system than on an evaporative system in order to route the higher flow rate of vapors from the tank to the canister during refueling. Several commenters made estimates and/or calculated the necessary size of the refueling vapor line leading from the fuel tank to the canister. One manufacturer stated that their vehicles would require a line with 0.55 - 0.71 inches inner diameter compared to their current 0.47 - 0.55 inches inner diameter evaporative lines (IV-D-377). Others estimated 0.625 - 0.75 inches and 0.98 inches inner diameter (IV-D-01, IV-D-367). Many noted that a rear-mounted canister helps to minimize the required diameter and length of the refueling vent line since less system backpressure is generated. Various vapor line materials were suggested such as terne plated steel, nylon and Buna-N rubber.

Several concerns were expressed about the safety of refueling vent lines. Many commenters said that the larger diameter of refueling system vent lines make them a larger target in an accident than evaporative system vent lines. They are more prone to punctures since more surface area is exposed. Commenters also claimed that these lines could get pinched, increasing pressure during both normal operation and refueling and leading to more frequent spitback. Condensation in these lines could also increase back pressure and lead to spitback.

d. Liquid/Vapor Separator

Most commenters suggested that some component on an onboard vapor recovery system must act to separate liquid fuel droplets from the refueling vapors before they reach the canister so that the adsorptive capacity of the carbon is not decreased. Most commenters' designs show the liquid/vapor separator as a separate component which forces liquid out of the vapor by gravity, filtering, or inertial impaction.

Commenters gave several reasons as to why there is an increased chance of liquid fuel reaching the canister (and hence a greater need for separator) with an onboard refueling vapor recovery system than with current evaporative control systems. One reason is increased tank splash due to turbulent fuel flow in a sealed system. Several commenters thought J-tube seals could have the effect of aiming liquid fuel directly at the vapor line during the filling process. A second reason given is that vapor condensation is more likely in a larger diameter vapor line. One commenter also said that a liquid/vapor separator is necessary if the canister is mounted below the fuel tank level, or if the vapor lines are sloped (IV-D-342). Another commenter stated that a liquid/vapor separator could be a safety hazard since it is virtually a miniature fuel tank with all of the same associated safety problems, yet no evidence was given of problems with fuel expansion tanks and liquid/vapor separators found on current vehicles (IV-D-356).

e. Canister

Several commenters estimated the canister volume necessary to control refueling emissions. The estimates ranged from two to eight times larger than the current evaporative canister, assuming that the same quality of carbon is used. Many commenters specifically stated that their estimates account for deterioration of the carbon's working capacity over the life of the vehicle. EPA has estimated that integrated evaporative and refueling canisters will be approximately three to four times larger than current evaporative canisters.

Many commenters expressed concern about the location of the larger refueling canister. A frequently chosen location for the canister was the rear of the vehicle. Some reasons given for the rear-mount preference are that there is not enough room in the engine compartment for the canister and that locating it near the fuel tank allows for a smaller vent line diameter and reduces the total backpressure in the system. Obviously, lack of space in the engine compartment is a greater concern for small vehicles than for large vehicles. BMW is an example of one commenter who said that they would locate the canister in the engine compartment on their larger vehicles (IV-D-342).

However, several commenters stated that all feasible rear-mount locations have unavoidable negative affects on other important vehicle designs parameters. For example, one choice is to mount the canister next to the fuel tank. This is described as feasible but undesirable since it could decrease fuel tank size and, therefore, vehicle driving range. Some commenters were also concerned that this location could limit, or even eliminate the option of dual fuel tanks or dual exhaust systems on some vehicles. A second possible rear-mount location is below the floor pan, underneath the rear seat. Commenters described this as inconvenient since it must either reduce the head space over the rear seat, or reduce the thickness of the seat cushion. The third feasible rear-mount location is in the trunk compartment. This would require sheet metal changes and would reduce the total volume of the trunk and the total flat floor area. One commenter pictorially demonstrated that the lost trunk volume cuts the cargo capacity from three to two suitcases (IV-D-363). Some commenters thought that this location could eliminate the possibility of carrying a spare tire.

Manufacturers raised many concerns about the safety of canisters. As was discussed previously, some manufacturers said that a refueling canister is a greater safety concern than an evaporative canister simply because of its larger size. Other canister safety issues that were raised are the implications of canister location on the crash performance of canisters and the potential danger of the release of vapors from the canister. One manufacturer said that there are no safety concerns unique to a canister (IV-F-101). Many manufacturers said that space constraints might force them to place the canister in "crush zones." These are designed empty spaces which help absorb crash forces and prevent damage and puncture of components. Commenters said both front or rear locations could affect crush zones. For instance, a rear-mounted canister might be placed in the crush zone near the fuel tank and could puncture the tank in a crash. However several commenters thought a rear-mounted canister location was preferable (IV-D-339, IV-D-342, IV-D-376). Some commenters thought that the canister and the activated carbon may be explosive and/or flammable. Some feared that the carbon itself (not vapors released from the carbon) might be a fire hazard. This concern is addressed in Section D of Chapter 3.

Most commenters felt that there is a potential fire hazard if vapors are accidentally released from the canister. Damage to the canister in a crash, loss of purge, tampering and other malfunctions which cause canister breakthrough were mentioned as possible situations which would lead to a dangerous presence of hydrocarbon vapors. Commenters said that this problem should be taken into account when placing the canister on the vehicle since some locations are more dangerous than others. According to commenters, front-mounted canisters might be affected by the many potential ignition sources in the engine compartment. The hot exhaust system could potentially ignite vapors from a rear-mounted canister. A canister located in the trunk was also raised as a safety hazard because vapors could potentially penetrate the passenger compartment.

Two commenters did test work to help define the hazard associated with vapors released from on onboard system. The commenters reached different conclusions about the probability that these vapors would cause any fire hazards. General Motors submitted a videotape of a tampered onboard system which caused an engine compartment fire (IV-D-360(c)). In their test the purge hose was disconnected and aimed at some spark plug wires which were in poor condition. The tape shows a fire starting when vapors pushed through the disconnected hose are ignited by sparks from the wires. General Motors later provided information which showed that an evaporative system under the same conditions could also cause a similar fire (IV-D-524).

However, API also studied the hazards of released vapors (IV-D-358) and found no significant difference in the flammability or ignitability of refueling and evaporative systems. In both systems, flammable fuel/air mixtures were found only at the exit points of the disconnected vapor line in the engine compartment. API also found that surface temperatures in excess of 1350°F are necessary to ignite a flammable fuel/air mixture. API did not find surface temperatures greater than 580°F under normal operating conditions. API mentioned that they did not investigate any turbo-charged vehicles which would have higher surface temperatures.

f. Purge System Components

Most commenters felt that the purge system on a vehicle with onboard refueling controls will be very complex and that the purge process will be difficult to perform. Although there were other comments concerning the technology and function of purge system components the only safety concern raised related to these component was the potential occurrence of purge valve failure and the problems that this would cause. The commenters stated that a purge valve which fails in the open position would lead to driveability problems. Valve failure in the closed position could lead to canister breakthrough and the perceived safety problems of the released vapors.

5. Crash Concerns

As was mentioned earlier, many commenters expressed concern about the crash resistance of onboard refueling control systems. Specific concerns mentioned include the questionable strength of plastic parts and the interference of components with designed crush spaces. Such components would interfere because they could puncture parts protected by crash zones, such as the fuel tank. They also may require added body panel reinforcement. A fillneck mounted vent valve was pointed to by several commenters as an example of a component in a highly vulnerable crash zone which would require added body panel reinforcement.

General Motors submitted a videotaped demonstration of crash testing done on an onboard equipped vehicle and also provided written documentation of the results (IV-D-360(c)). The testing performed by a contractor (Failure Analysis Associates) was designed to demonstrate that onboard system components are not crashworthy. The test method was to subject the vehicle to a thirty miles per hour side impact crash and then to measure the leak rate of fuel escaping through damaged components. This is similar to part of FMVSS 301, except that the crash impact point on the test vehicle was centered directly at the fuel fillneck instead of at the centerpoint of the side of the vehicle, and another vehicle was used in the collision instead of a barrier. The test vehicle was equipped by FaAA with a copy of an onboard system originally designed by Mobil which was not intended to be production quality (IV-D-329). The fuel fillneck was chosen as the crash impact point because, the rollover valve was mounted on the fillneck, and is supposedly one of the most vulnerable components. Even though it was not an official FMVSS 301 test or a production quality onboard system the 5.3 ounces per 5 minute leak rate of the system was compared unfavorably against the 5.0 ounces per 5 minute standard of FMVSS 301. No other commenter submitted crash test results or challenged EPA's finding in the safety report that onboard systems could be designed to pass FMVSS 301 crash tests.

6. FMEAs

Finally, to support various viewpoints regarding onboard safety, three commenters submitted Failure Modes and Effects Analyses (FMEAs) for onboard and evaporative systems. As part of the critique of the Mobil System, GM submitted the FMEA which they originally prepared for the stock system selected by Mobil. Also, for comparison sake, GM submitted a contractor prepared FMEA of the Mobil prototype onboard system (IV-D-360, IV-D-360(c)). In addition, Ford submitted an FMEA type analysis which compared the potential failure modes and effects of a current evaporative system to those of three different onboard control approaches (IV-D-362). API also submitted an FMEA type analysis which compared the relative risks of a simple current evaporative system against those for several different onboard configurations (IV-D-358(e)). These FMEAs will be discussed in Section D of this chapter.

B. Trends in Fuel/Evaporative System Design

1. Introduction

As can be seen from the comments summarized above, the "complexity" issue is one of the key safety concerns raised in association with EPA's proposal to implement onboard controls. However, in EPA's view (which is shared by several other commenters), onboard systems are primarily a modification or extension of the current evaporative emission control system. Because of the "overlap" of these two systems, the evaluation of the onboard system complexity issue must be made in light of the complexity and safety of current evaporative systems. Therefore, in order to provide a baseline for analyzing the "complexity" issue comments, EPA conducted a review of current fuel/evaporative system complexity and design features by examining shop manuals, comments on the onboard proposal and other pertinent literature. While this review was not totally comprehensive, a wide variety of vehicle sizes, system designs and manufacturers were studied.

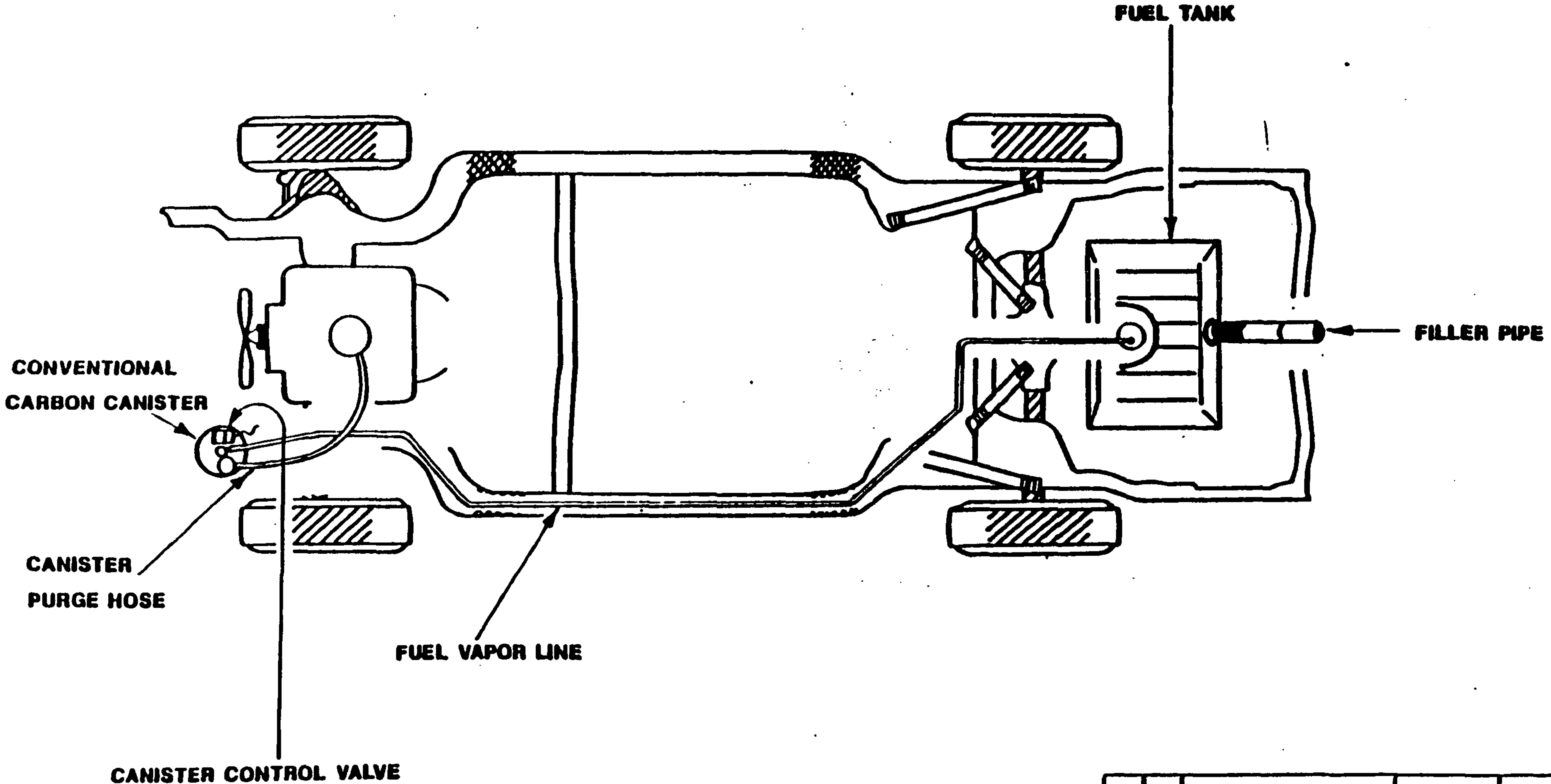
This section will present the results of this review. It will show that the trend in fuel and evaporative system design has been one of increasing complexity and yet as was shown in Chapter 2, there apparently has been no compromise in vehicle safety as a result of this increase in complexity. It will further show that many of the design features criticized as potentially unsafe for possible onboard system designs are in fact incorporated on present fuel/evaporative systems.

The remainder of this section is broken into three parts. The next part (2) discusses trends in fuel/evaporative system design with respect to specific design features and demonstrates the wide range of complexities among current systems which result from these design features being implemented. The implications these current system designs have for onboard systems, both in terms of overall complexity and specific design features is discussed in part 3. A short summary of this section is then presented in part 4.

2. Trends in Fuel/Evaporative System Design

a. Introduction

As was discussed in Chapter 2, fuel/evaporative systems have not been a safety concern historically and are not currently considered to be a problem. Yet over time these systems have generally become more complex and currently there is a wide range of system complexities in-use. To generally illustrate this point, Figure 3-1 shows the general fuel/evaporative system layout for a Chevrolet Caprice which is probably one of the more "simple" systems on current vehicles.[1] In contrast to this is the Volkswagon Golf



ITEM NO	QTY REQD	DESCRIPTION	MATERIAL	SPECIF.

EXISTING VAPOR RECOVERY SYSTEM
CHEVROLET CAPRICE

MUELLER ASSOCIATES, INC Baltimore, MD

DATE 12-29-86	SCALE: NONE	SKETCH	PAGE 1 OF 1.

Figure 3-1

Chevrolet Caprice

pictured in Figure 3-2. This system incorporates a number of design features not included on the Caprice including two fillneck-mounted valves, multiple vapor lines exiting the fuel tank, a liquid-vapor separator tank mounted on the fillneck, and the use of plastic for the entire fuel tank/fillneck assembly. Despite the differences in design and complexity between these systems, both comply with Federal safety standards (FMVSS 301) and are currently operating safely in-use.

As will be discussed below, there are a number of factors governing fuel/evaporative system design. While these factors have tended to cause evolutionary changes in fuel/evaporative systems designs over the past 10 to 15 years, not every vehicle model was affected the same by these factors and thus not all of the design features discussed below appear on every vehicle. For the purposes of this discussion these design trends will be broken down into the general categories of fuel metering changes, system sealing and venting, component location, fillpipe designs, the number of connections between components, and the use of alternative materials for system components. Each of these is discussed below.

b. Fuel Metering

Of all of the changes to fuel and evaporative systems over the past several years, the change in the fuel metering system from carbureted to fuel injection is probably the most revolutionary. In 1980 there were very few fuel-injected vehicles available, but by 1990 almost all vehicles are projected to be fuel injected. This change resulted in the use of high pressure in-tank fuel pumps and high pressure fuel lines. An additional line and its associated connections were also added to return the excess fuel and vapor from the engine compartment to the fuel tank. Because this excess fuel is heated in the engine compartment, its return to the fuel tank meant that higher fuel tank temperatures and pressures also had to be accommodated. The resultant designs have clearly added complexity to fuel/evaporative systems. Yet, there is no evidence to suggest that this fundamental change in the fuel metering system has compromised vehicle safety.

c. Tank Sealing and Venting

The area of fuel/evaporative system sealing and venting has seen a number of evolutionary changes over time. Initially, a limiting orifice was placed at the fuel tank/vapor line outlet to meter evaporative emissions, to act as a liquid/vapor separator and to minimize fuel leakage in the event of a vehicle rollover. Later, a rollover valve, such as those shown in Figure 3-3, was added at this location to improve system integrity. Some of these rollover valves also included float mechanisms which allowed them to also act as an overfill limiter. Finally, high-flow rollover valves with

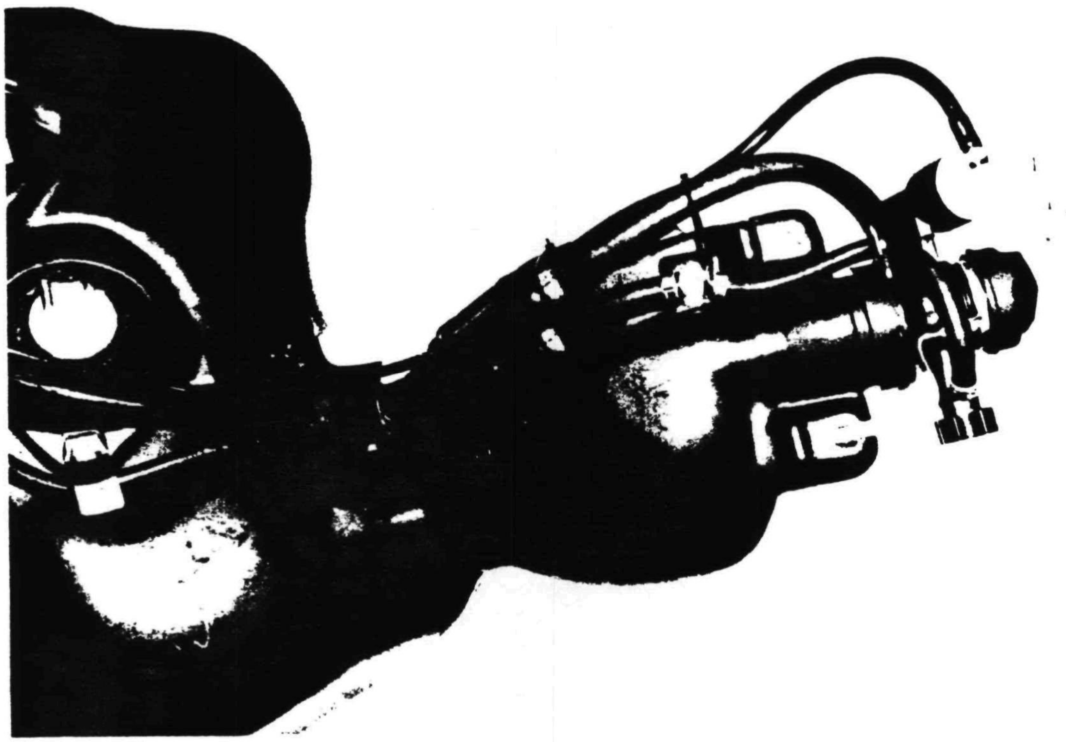


Figure 3-2

Volkswagon Golf

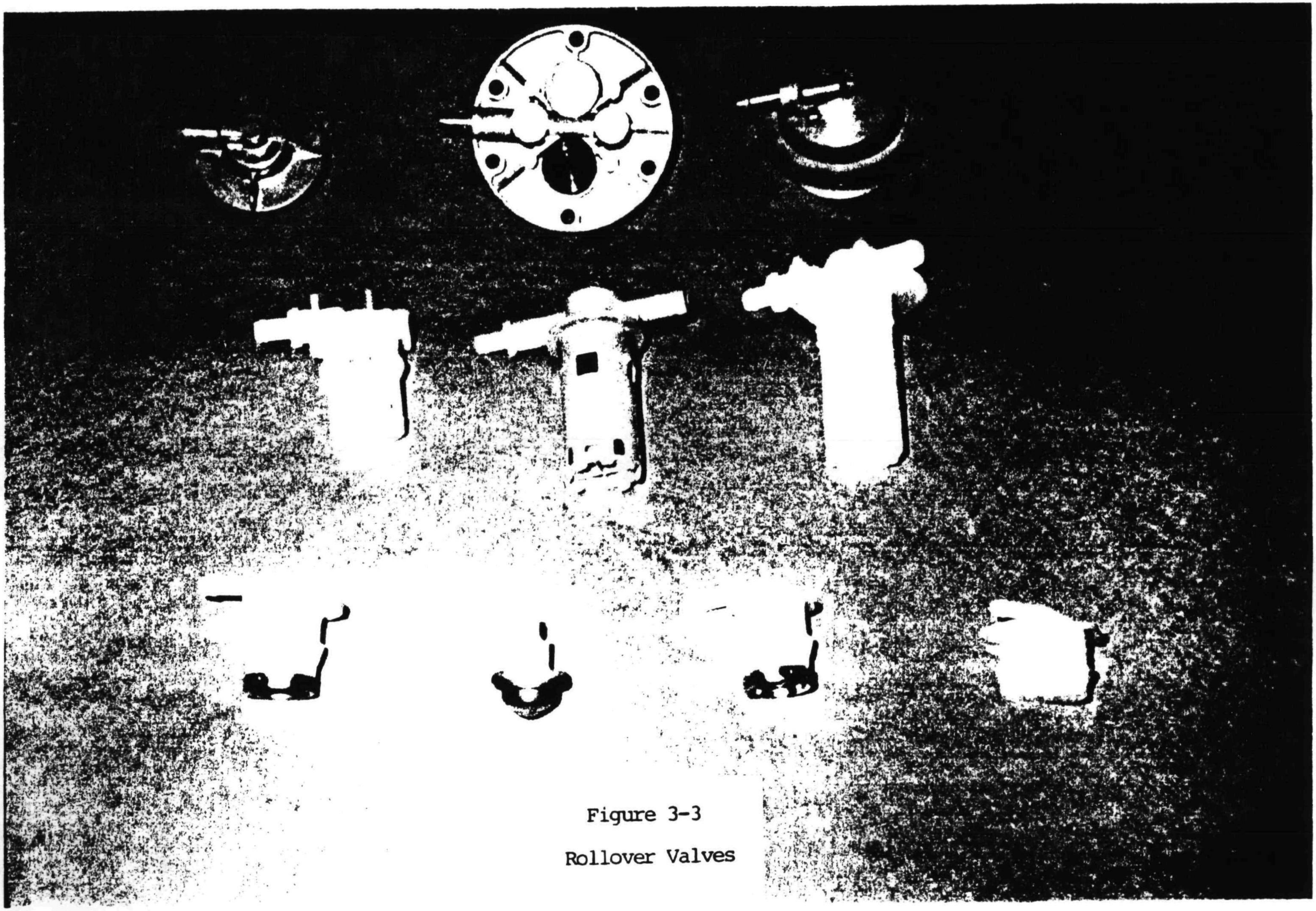


Figure 3-3

Rollover Valves

built-in pressure relief mechanisms were introduced to handle increased tank pressures brought on by higher volatility fuels and the use of fuel injection. However, these relief valves sometimes operate at very low pressures and consequently vent vapors directly to the atmosphere under many in-use conditions. Fillcap designs have also changed in response to the need for a better sealed system. Tighter sealing fillcaps with pressure/vacuum relief valves were introduced and more recently two-stage fillcaps have been implemented in response to increased tank pressures. These two-stage fillcaps are removed in two steps which allow for safe tank depressurization and thus should help to prevent spurting upon fillcap removal.

d. Component Location

Fuel and evaporative system component location is another area in which there have been a number of changes over time. Since the mid-1970s there has been a trend toward moving the fuel tank forward of the rear axle. This change has resulted in a number of other system changes. First, the fillpipe was moved from the rear to the side of the vehicle. Second, in many cases the packaging considerations of the new fillpipe location dictated that the fillpipe diameter be reduced by approximately 25 to 50 percent necessitating the addition of an external vent line to vent refueling vapors. This change was also influenced by a desire to reduce vehicle weight to improve fuel economy. It should be noted that these external vent lines are not generally protected by a rollover valve.

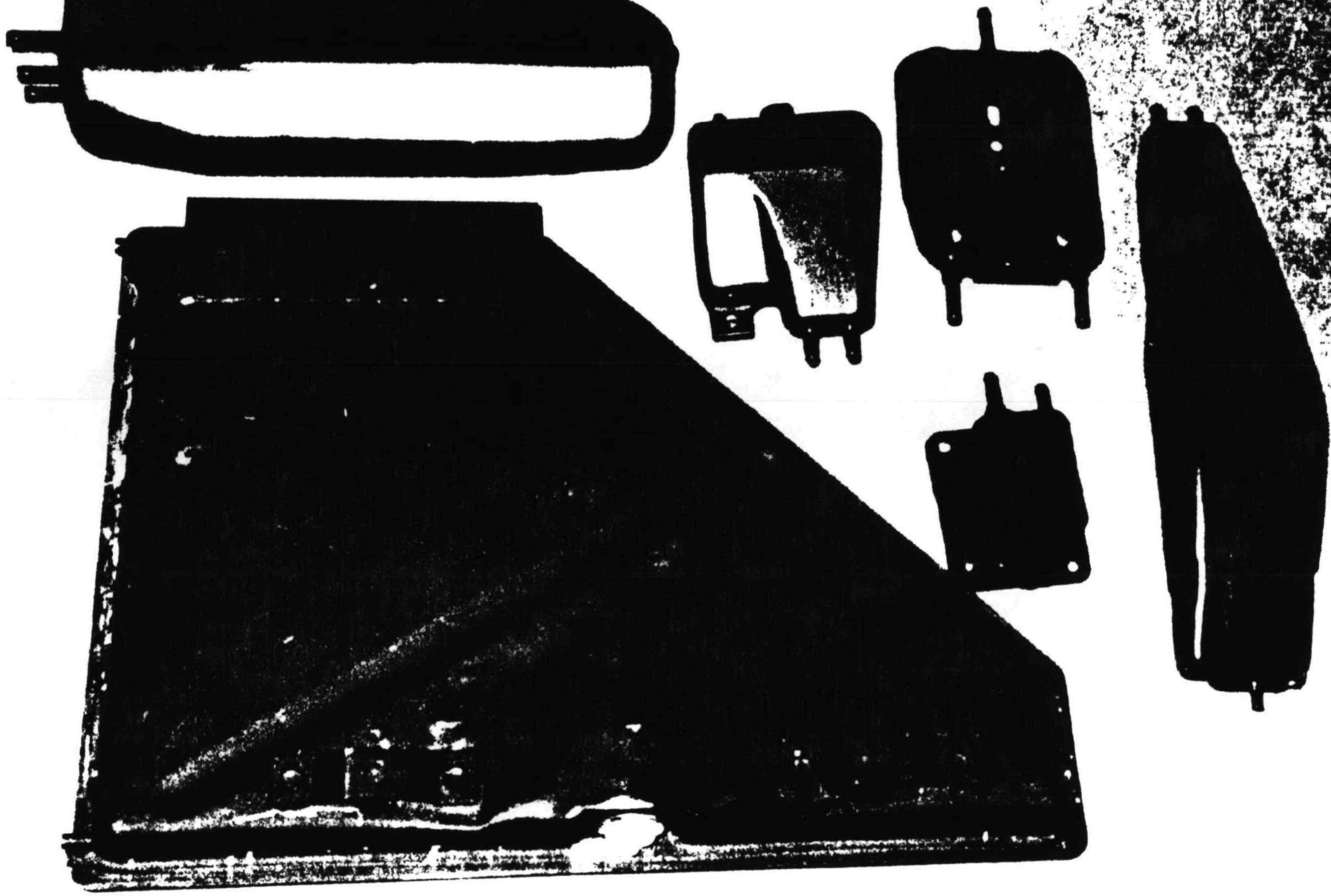
Finally, in some cases the new tank location left no room for the tank vapor dome, which led to the external packaging of the vapor dome and other components normally found on the fuel tank itself. Examples of these external components include fuel expansion or separator tanks (which are sometimes placed in the crash zone due to space considerations) as shown in Figure 3-4, external rollover and check valves like those in Figure 3-5 which are placed between the fuel tank and the evaporative canister, and external fill limiters. Associated with this increase in the use of external components was a corresponding increase in the number of hoses and connections used in fuel and evaporative systems. Yet, despite the increased complexity brought about by these changes the design trade-offs do not appear to have compromised safety.

e. Fillpipe Related Changes

There have been a number of changes to the fillpipe and related components over time. As was discussed previously, there has been a general move from rear-to side-fill tank designs and the trend toward external vent lines which accompanied it. Because both of these components are located in the crash zone, the insertion of flexible rubber sections in the fillpipe and vent line was instituted to improve

Figure 3-4

Liquid/Vapor Separator
and
Fuel Expansion Tanks



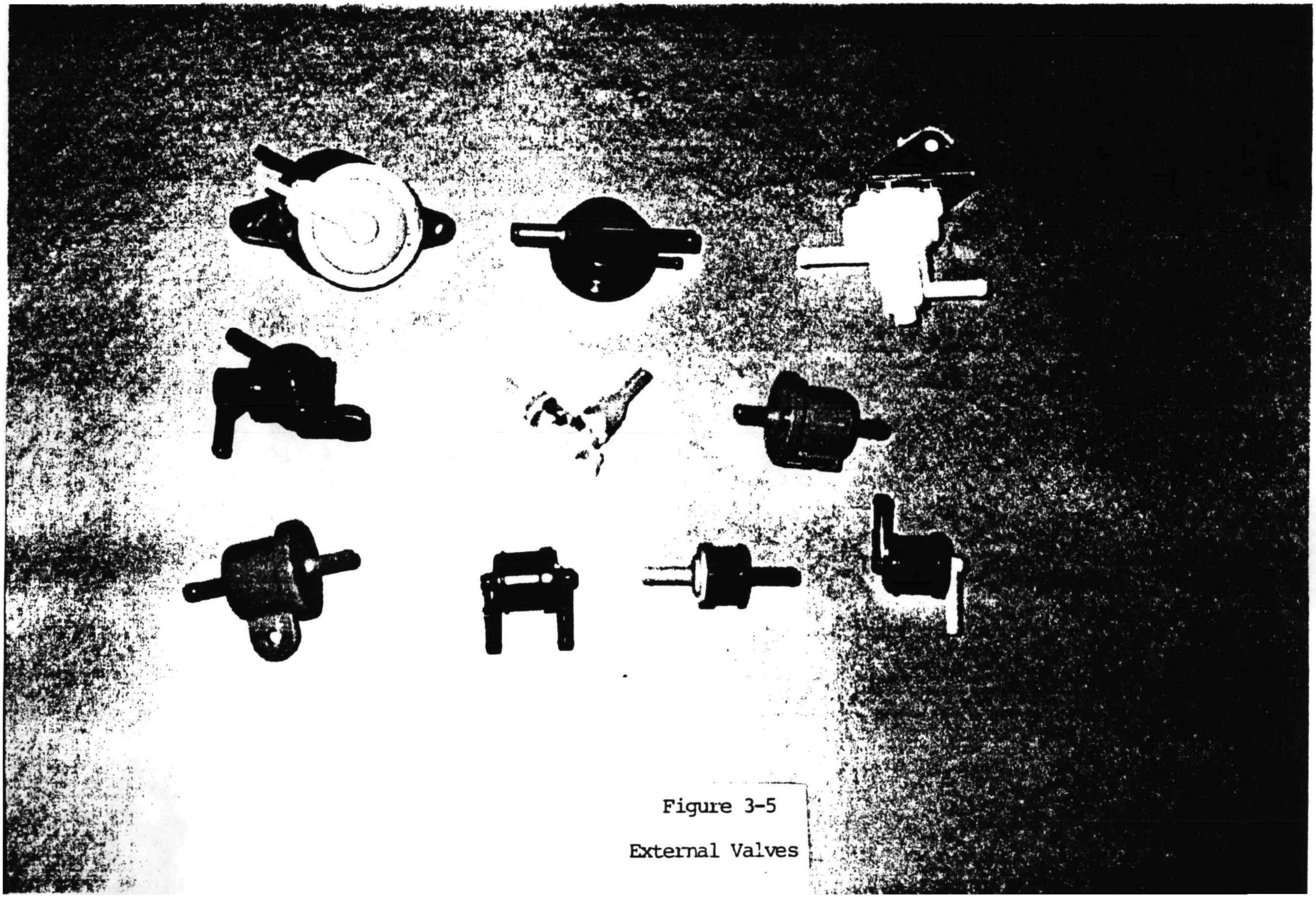


Figure 3-5

External Valves

crashworthiness. In order to improve fill quality or "fillability" (i.e., the quality or acceptability of the vehicle refueling process in the areas of consumer reaction and safety) a number of features have been added to the fillpipe including anti-spitback valves like those in Figure 3-6. These components reduce the number of premature nozzle shut-offs and fuel spitback onto the refueler. Another interesting development in this area is that some manufacturers have designed the fillpipe/fuel tank interface such that the end of the fillpipe is submerged in the fuel during at least part of the refueling event. An example is shown in Figure 3-7.[2] This creates a "liquid seal" that helps to modulate pressure during refueling but also introduces the potential for spurting if the tank is overpressurized and the fillpipe is submerged when the fuel cap is removed.

In addition to the fillpipe modifications discussed previously, the fillpipe has seen increasing use as a mounting point for other components. Mounting components in the fillpipe area was raised as a safety concern by several commenters, but the mounting of components in this area on present vehicles is not uncommon. Examples of this include the fillneck-mounted valves shown in Figure 3-2 and the fillpipe-mounted liquid/vapor separators shown in Figures 3-2, 3-8, and 3-9. While mounting components in the fillpipe places them in the crash zone, there is no evidence to suggest that this trend has compromised vehicle safety.

f. <u>Connections</u>

As fuel/evaporative systems have become more complex and the number of external components has increased there has been a corresponding increase in the number of connections between components. An example of the extra connections associated with liquid/vapor separators is shown in Figure 3-10. The introduction of rubber sections added two new connections to both the fillneck and external vent line. Also, the use of external rollover and check valves has increased the number of connections in the vapor line to the canister. An important point to note here is that some of the added connections, such as those associated with fuel expansion or separator tanks, are direct connections to the fuel tank and often not protected with a rollover valve. It is also worth noting that increased connections often involve areas which often contain liquid gasoline such as the fillpipe, external vent lines and liquid/vapor separators.

g. <u>Alternative Materials</u>

The last trend to be discussed is that of increasing use of alternative materials, such as plastic and rubber, to fabricate fuel and evaporative system components. The use of these materials in onboard system components was characterized

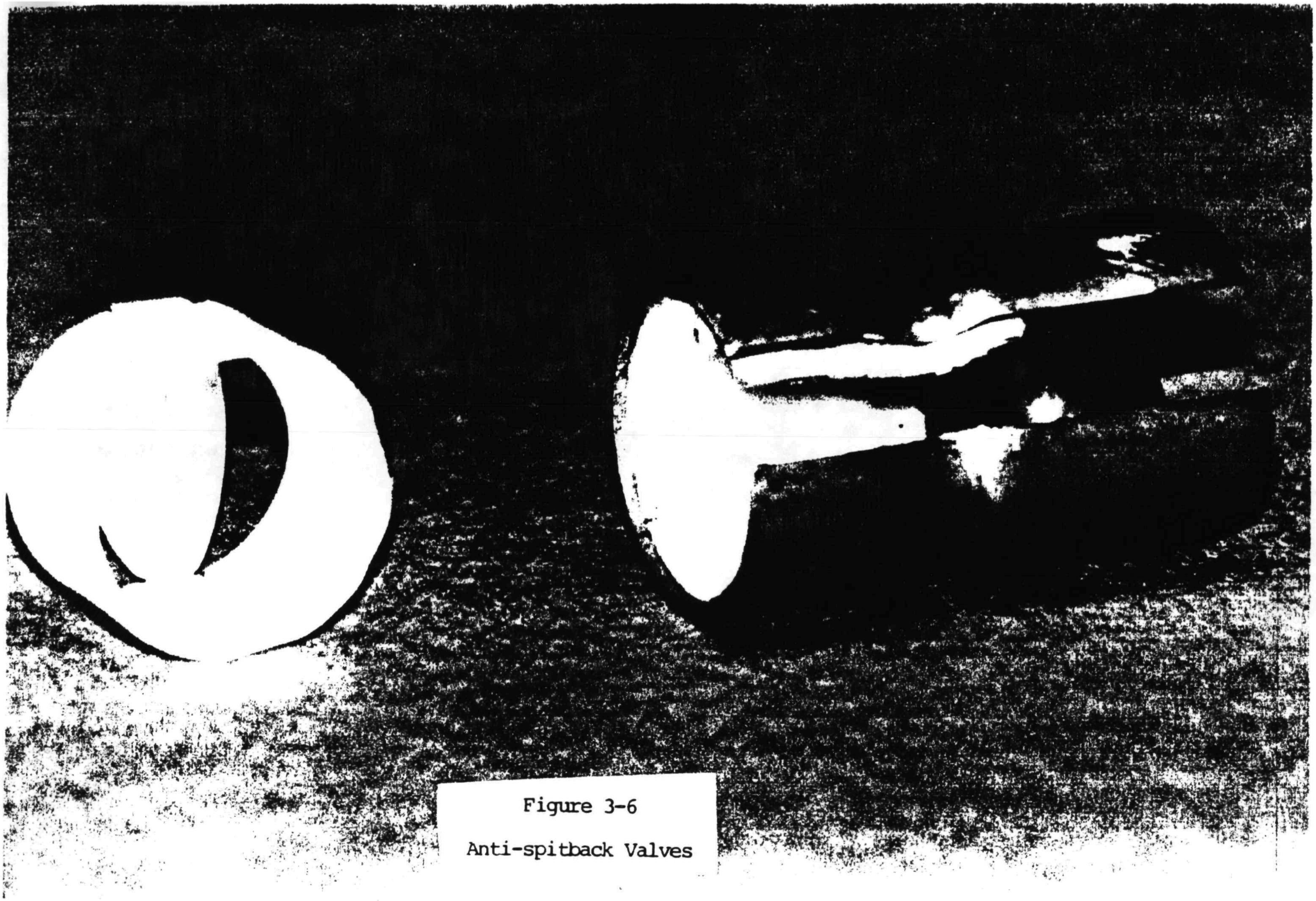


Figure 3-6

Anti-spitback Valves

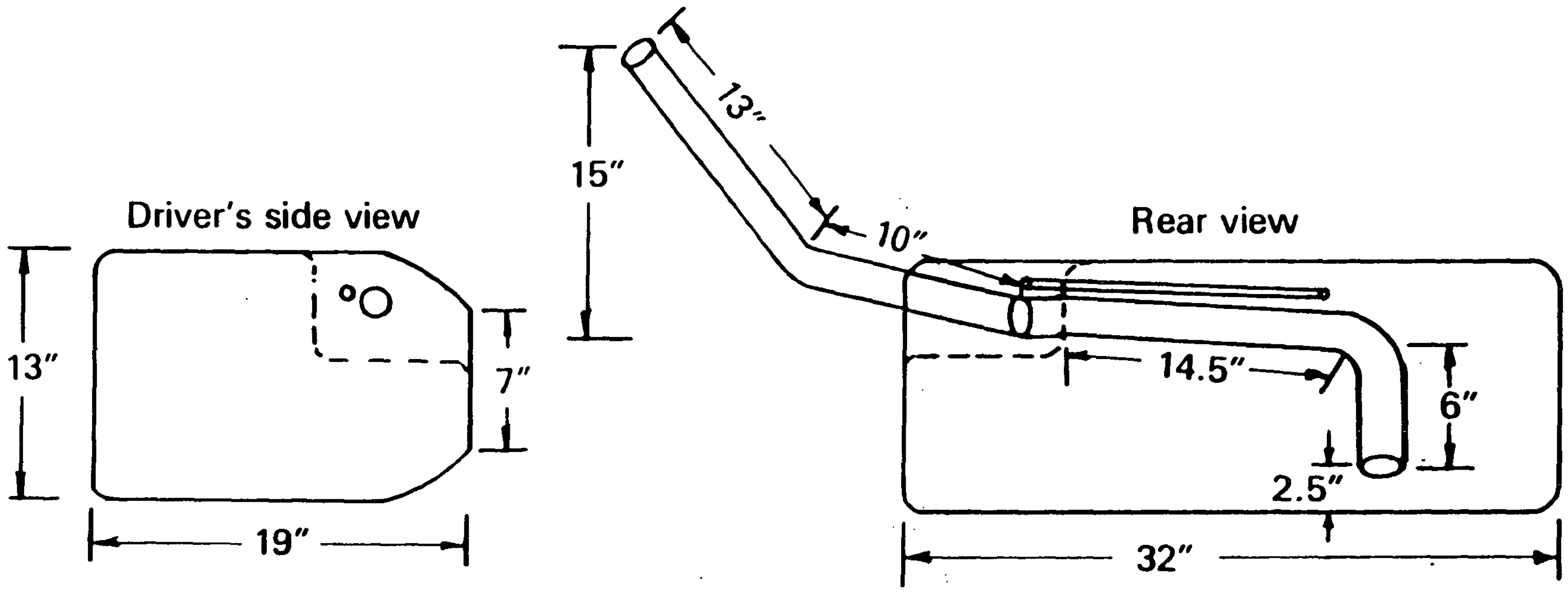


Figure 3-7

AMC Jeep Cherokee

Figure 3-8

Honda Accord
Fillpipe Assembly

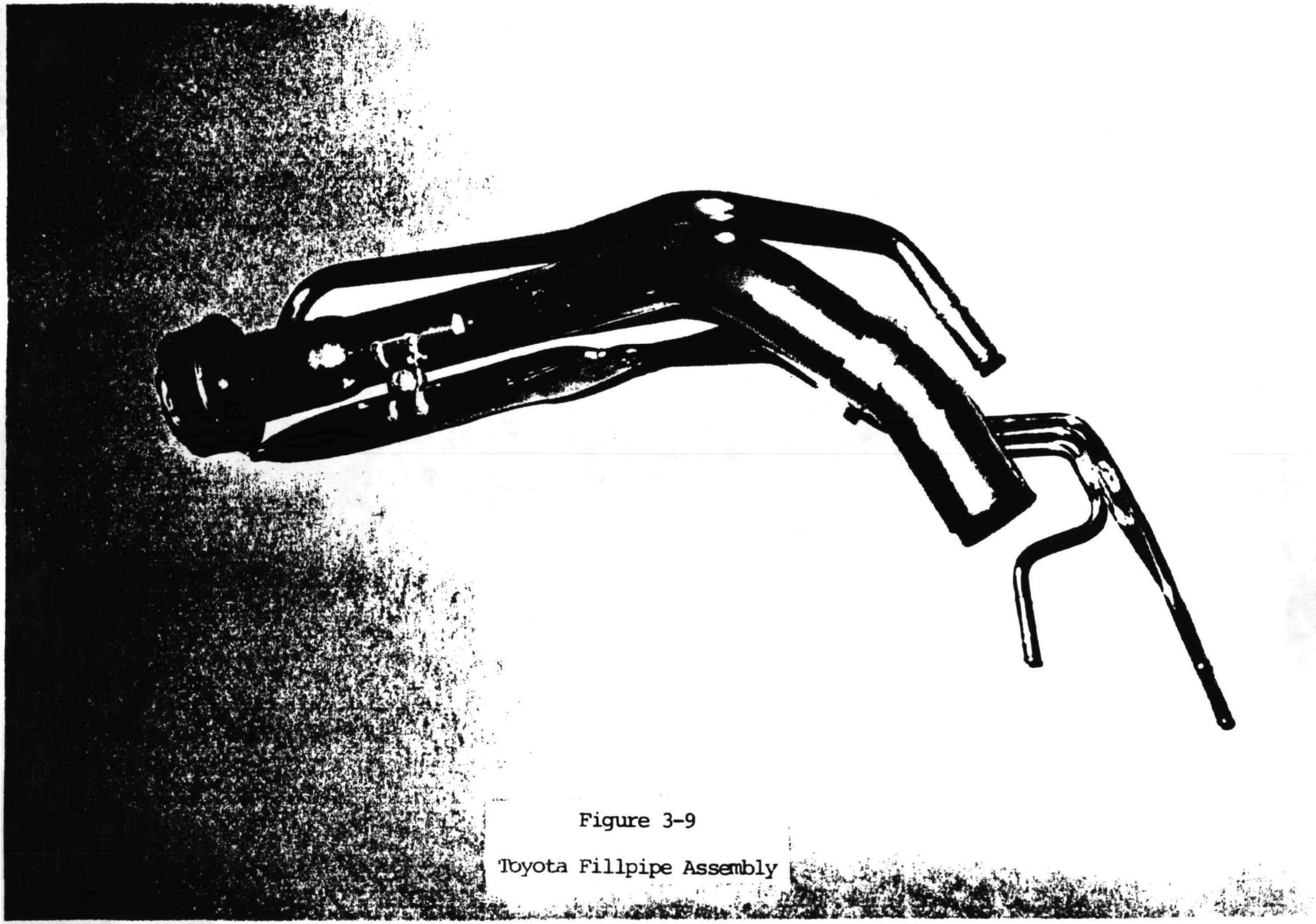


Figure 3-9

Toyota Fillpipe Assembly

FUEL TANK

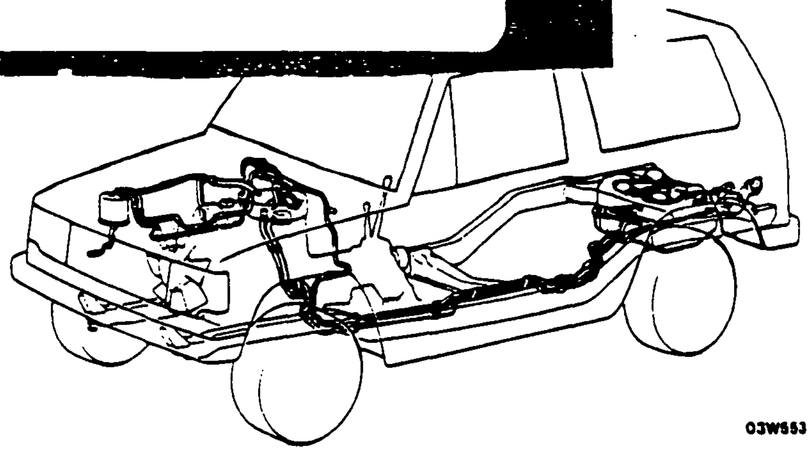
REMOVAL AND I[redacted]

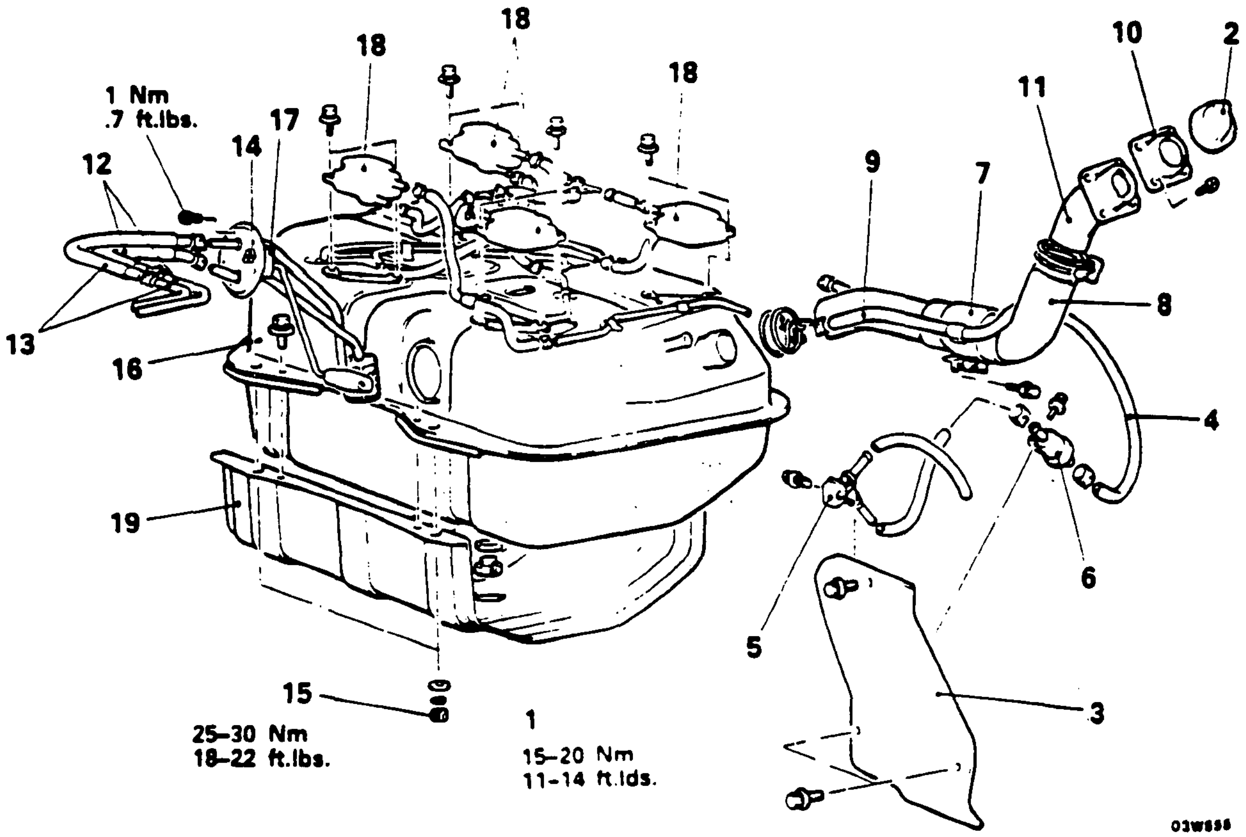
Figure 3-10

Mitsubishi Montero

Pre-removal Operation
- Draining of the Fuel.

Post-installation Operation
- Supplying of the Fuel.





Removal steps

1. Drain plug
2. Fuel filler cap
3. Fuel filler hose protector
4. ◆◆ Vapor hose
5. ◆◆ Check valve
6. Overfill limiter (Two-way valve
7. Clamp assembly
8. ◆◆ Fuel filler hose
9. ◆◆ Breather hose
10. Packing
11. Fuel filler neck
12. ◆◆ Main hose
13. ◆◆ Return hose
14. Fuel gauge unit connector connection
15. Fuel tank assembly mounting nuts
16. Fuel tank
17. Pipe assembly
18. Separator tanks
19. Fuel tank protector

NOTE
1) Reverse the removal procedures to reinstall.
2) ◆◆ Refer to "Service Points of Installation".

as potentially unsafe by one commenter, yet the use of plastics and rubbers in vehicle fuel and evaporative systems is common on most of today's vehicles. While plastic fuel lines have been used intermittently on domestic vehicles since the mid-1960's,[3] recent years have seen the more widespread use of plastic fuel tanks and the increased use of plastic fuel lines. In fact, one source estimates that as much as 50 percent of all domestic fuel line business will be plastics within the next five or six years.[4] In addition to fuel lines and fuel tanks, plastics are presently being used for fillnecks, filler caps, evaporative canisters, liquid/vapor separators and other external hardware such as rollover valves. The use of rubber components has also increased over time with the addition of the flexible sections in the fillneck and external vent line and the use of rubber for fuel and vapor lines. It appears that this trend of increased use of plastic components and other alternative materials in current fuel and evaporative system design has not compromised vehicle safety.

h. Summary/Conclusion

This brief discussion, and the examples provided above, show that there is indeed a wide range of fuel and evaporative system complexity on current vehicles. These differences in complexity are reflected by a number of factors. Fuel and evaporative systems vary in their general designs, the number and function of the components used, and the number of connections needed to integrate these components into a working system. Component dimensions vary as does the material of which they are made and their location on the vehicle. Indeed, many components are commonly located in potential crash zones on the vehicle.

Given the number of comments received regarding the purported relationship between safety and complexity and the importance of that concern to the commenters opposing onboard controls, one might ask whether the fuel/evaporative system experience with complexity led to an increase in safety problems. While detailed information on the safety performance of specific systems is generally not available in public records, several conclusions are possible. First, the recall information in Figures 2-1 and 2-2 shows that evaporative system recalls have historically been rare. The trend, if any, does not show an increase in recalls with later model years as systems have become more complex. Also, the information in Table 3-1, taken from Tables 64 and 68 of the draft NHTSA study mentioned previously, shows that the number of owner complaints and service bulletins for fuel emission control (category 0612) does not seem to have any relationship to model year, and thus indirectly to increasing system complexity.[5] Furthermore, it should be noted that EPA's review of evaporative system recalls, service bulletins and owner complaints discussed in

Table 3-1

References to Technical
Service Bulletins, and Owner Complaints
for Fuel Emission Control Components

Complaints

MY	%
78	12.3
77	12.1
75	11.2
79	10.7
76	8.3
74	6.9
84	5.8
83	5.6
80	5.6
81	4.9
82	4.3
pre-60	3.6
73	2.9
86	2.2
85	1.3
71	0.9
72	0.4
87	0.4
70	0.2

Service Bulletins

MY	%
Unknown	24.0
82	10.2
81	8.4
83	7.8
79	6.8
77	6.2
78	5.9
80	4.8
84	4.8
73	3.9
75	3.9
85	3.1
74	2.4
76	1.9
68	1.6
70	1.0
86	1.0
71	0.9
72	0.6
87	0.6
67	0.2
69	0.1

Chapter 2 provided no evidence to indicate that any one design, design approach, or manufacturer's systems were safer or less safe than any other. EPA presumes that the manufacturers have concluded that the complexity added to fuel and evaporative systems over the recent years was warranted and the data available indicates that safety was not compromised in the process.

As is evidenced by the previous discussion, many changes to fuel and evaporative systems which have increased system complexity have been implemented over time and a wide range in design complexity currently exists. Yet, the discussion in Chapter 2 indicates that these "evolutionary" changes have been implemented safely and there appears to be no direct relationship between complexity and safety. Since, in the opinion of EPA and others, onboard systems are merely an extension of current evaporative systems, their implementation is an evolutionary rather than a revolutionary change. As such, the manufacturers could reasonably be expected to implement onboard controls using the same approaches used to safely implement the fuel and evaporative system modifications previously discussed.

Furthermore, the analysis provided above indicates that evaporative system safety is generally independent of design variation and complexity. Since the hardware and technology used to control refueling emissions would essentially be the same as that used in evaporative systems, this experience suggests that variations in system designs or complexity with onboard controls would also not lead to safety problems. Thus systems labeled as "complex" by some would not necessarily be any less safe than those labeled as "simple." Manufacturers have accommodated a wide variety of fuel/evaporative system designs safely, and this experience indicates that the same could be done for refueling controls.

3. Implications of Specific Design Features

As was discussed in Section A of this chapter, EPA has received numerous comments voicing concerns about the safety implications of specific anticipated onboard system design features. EPA does not necessarily agree that onboard systems will require these design changes. However, the following paragraphs will briefly review some of these concerns and demonstrate that a number of these features, which have been labeled potentially unsafe by the commenters, are already in production on current systems and, as was discussed above, are operating safely. These include the increased use of external components and associated connections, placement of components in crash zones and the use of plastic components.

First, the argument has been made that some onboard system designs will increase the number of components external to the fuel tank. This would increase the number of connections between components and the fuel tank and therefore increase the number of possible failure points in crash and non-crash situations. The widespread use of external components and extra connections on current designs shows this not to be problem. A specific comment in this area came from the National Truck Equipment Association which stated that liquid/vapor separators could be a safety hazard.[6] There are numerous examples of the use external fuel and evaporative system components including liquid/vapor separators on current vehicles. Figures 3-11, -12, and -13 show examples of liquid/vapor separator tanks and important valves which are located away from the fuel tank area. Each external component adds at least two additional connections in the fuel/vapor handling system and, depending on the design used, the fuel/vapor separator tanks add between four and ten connections per fuel tank. As was previously discussed there is a wide disparity among current systems with respect to the number of connections. Some current systems, such as the system in Figures 3-14,[1] and -15, have relatively few connections while others have many, such as the system shown in Figure 3-10. In addition, components such as the fuel/vapor separator tanks have added significantly to the amount of vapor hose used and the complexity of the layout of the hose. A good example of the increased use of vapor tubing and external valves is the 1988 Honda Accord fillpipe assembly shown in Figure 3-8. In this case the extra vapor tubing is routed to act as a liquid/vapor separator and this is then connected to a two way (pressure/vacuum) valve to the tank.

It can be seen from these selected examples, that a number of current fuel and evaporative systems use external components which handle fuel and/or vapor. These external components involve an increase in the number of connections and the amount of vapor line used over some simple systems. However, there is no evidence to indicate that these designs have degraded vehicle safety. Once again, EPA presumes that the manufacturers have concluded that the use of external components and the corresponding increase in connections was warranted and the evidence indicates that the design trade-offs involved were managed successfully.

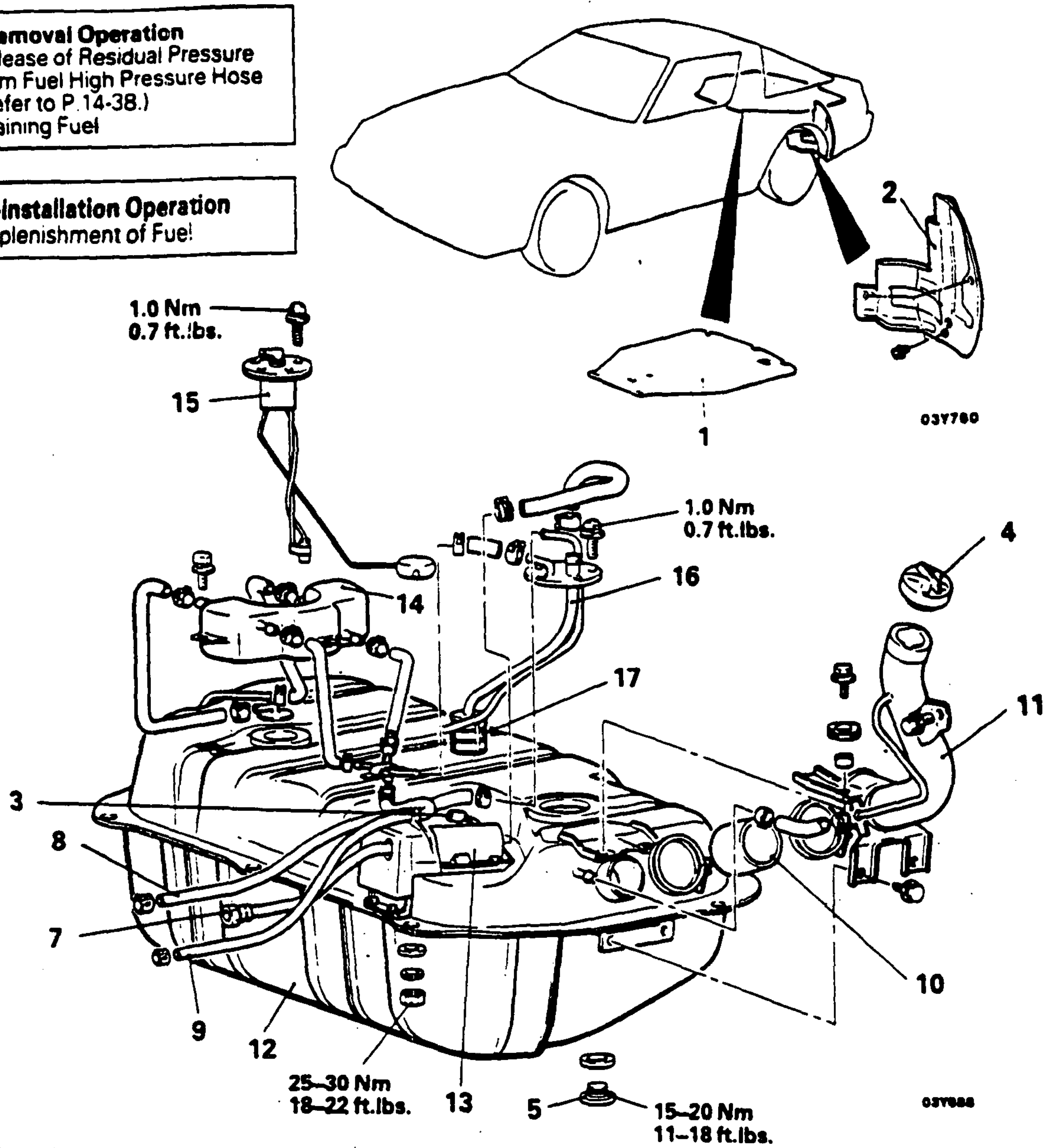
The use of plastics in onboard systems is another concern that has been expressed by MVMA and others. The concern is that while metal parts may bend or crush, but still maintain integrity in a crash situation, plastic parts may crack or break on impact. A related concern is the buildup of static charge on isolated plastic components if not properly grounded. However, as was mentioned in the previous section, the use of plastics for both fuel lines and fuel tanks is becoming more widespread and apparently has not degraded safety. An example of a plastic fuel tank is the Volkswagon Golf shown in Figure 3-2. In this system, not only is the entire fuel tank plastic but also the filler neck assembly

FUEL TANK

REMOVAL AND INST/

Pre-removal Operation
- Release of Residual Pressure from Fuel High Pressure Hose (Refer to P. 14-38.)
- Draining Fuel

Post-installation Operation
- Replenishment of Fuel



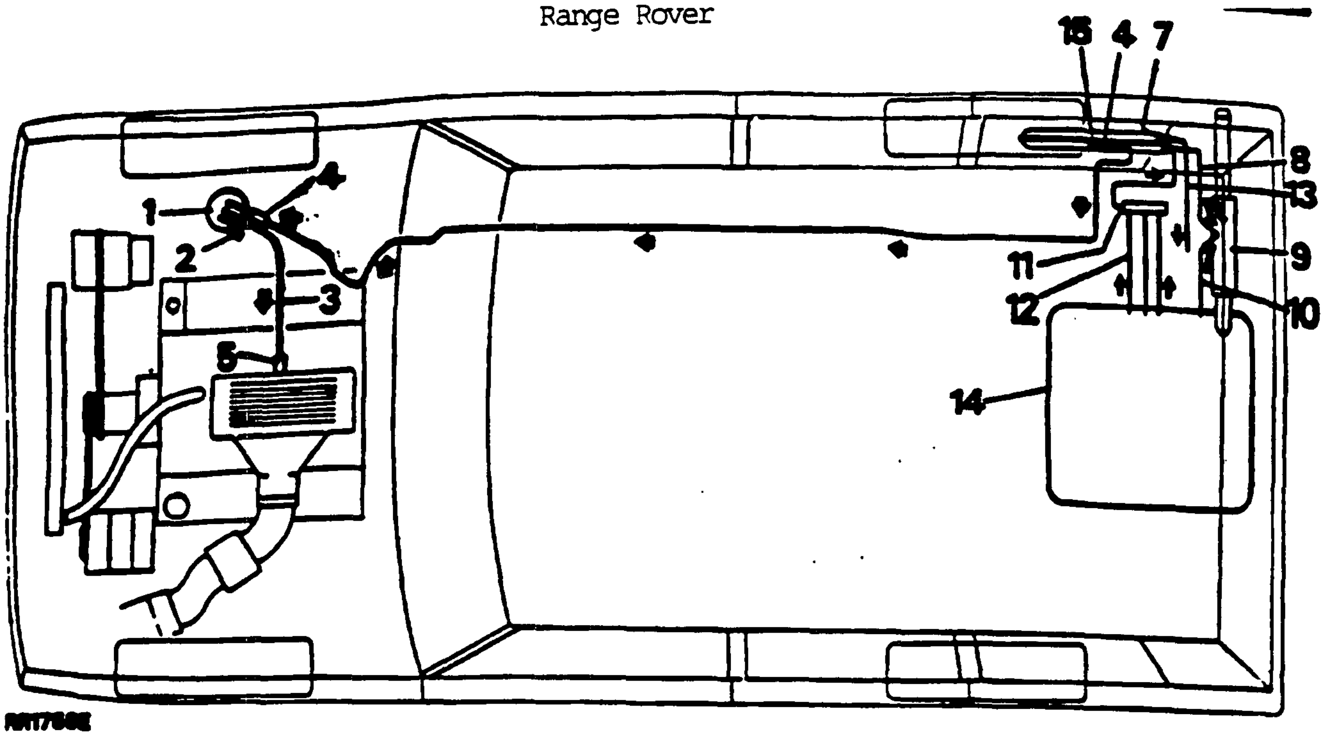
Removal steps

1. High floor side panel
2. Fuel pipe cover
3. Fuel pump connector connection
4. Fuel tank cap
5. Drain plug
6. Fuel gauge unit connector connection
7. ◆◆ Fuel high pressure hose connection
8. ◆◆ Return hose
9. ◆◆ Vapor hose
10. Fuel filler hose
11. Fuel filler neck
12. Fuel tank
13. Electrical fuel pump
14. Separator tank
15. Fuel gauge unit
16. Pipe assembly
17. In-tank fuel filter

NOTE
(1) Reverse the removal procedures to reinstall.
(2) ◆◆: Refer to "Service Points of Installation".

Figure 3-12

Range Rover



RR1766E

KEY TO DIAGRAM

1. Charcoal canister
2. Air inlet to canister
3. Purge line to plenum chamber
4. Connector hoses with restrictors
5. Restrictor in purge line
6. Fuel expansion tank
7. Fuel vapour pipe from manifold
8. Breather hose with anti-surge valve
9. Fuel tank filler neck
10. Filler neck breather hose
11. Manifold
12. Fuel vapour pipes from fuel tank (3 off)
13. Pressure relief valve and hose
14. Fuel tank
15. Float/rollover valve
16. Grommet

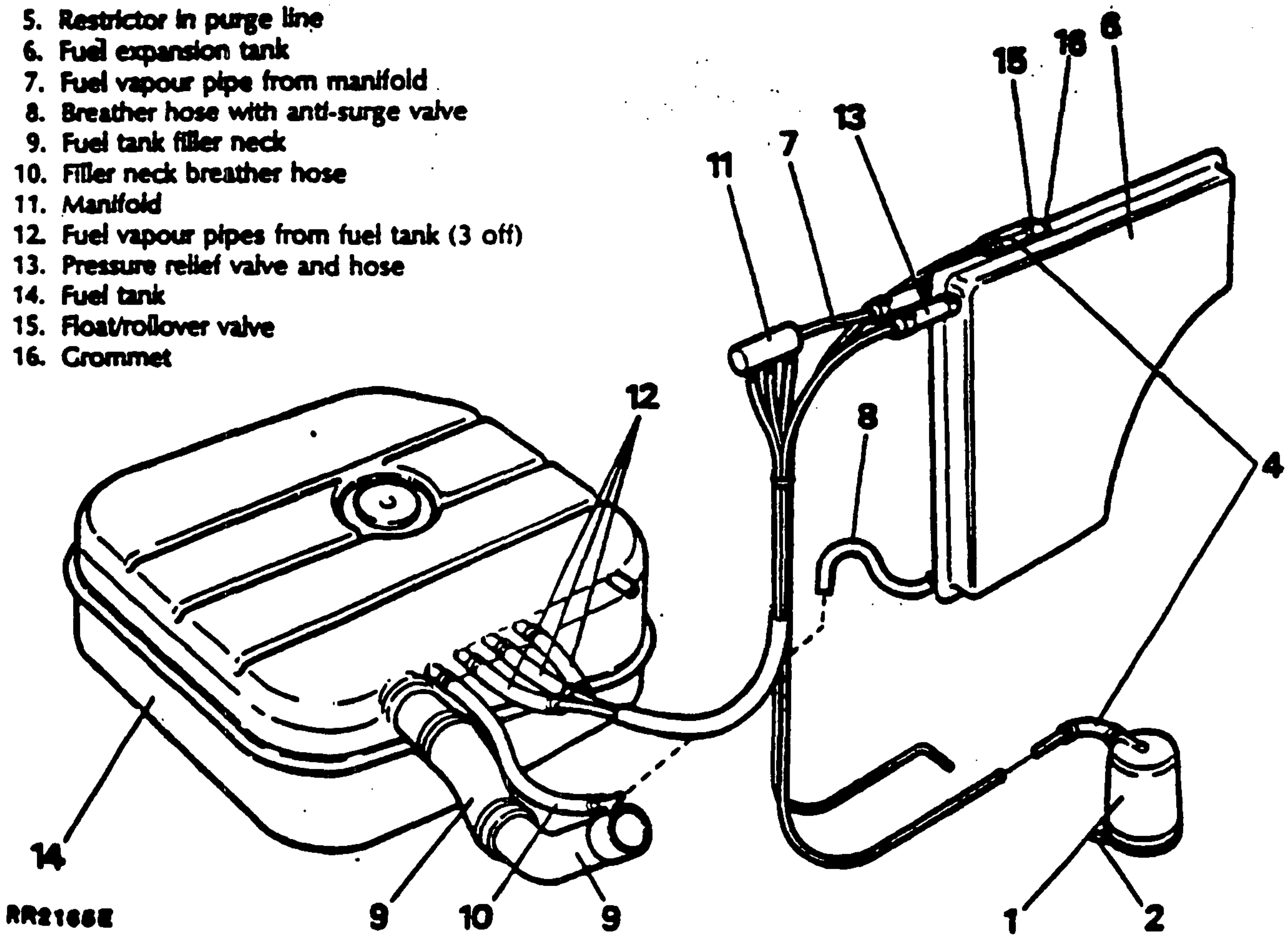


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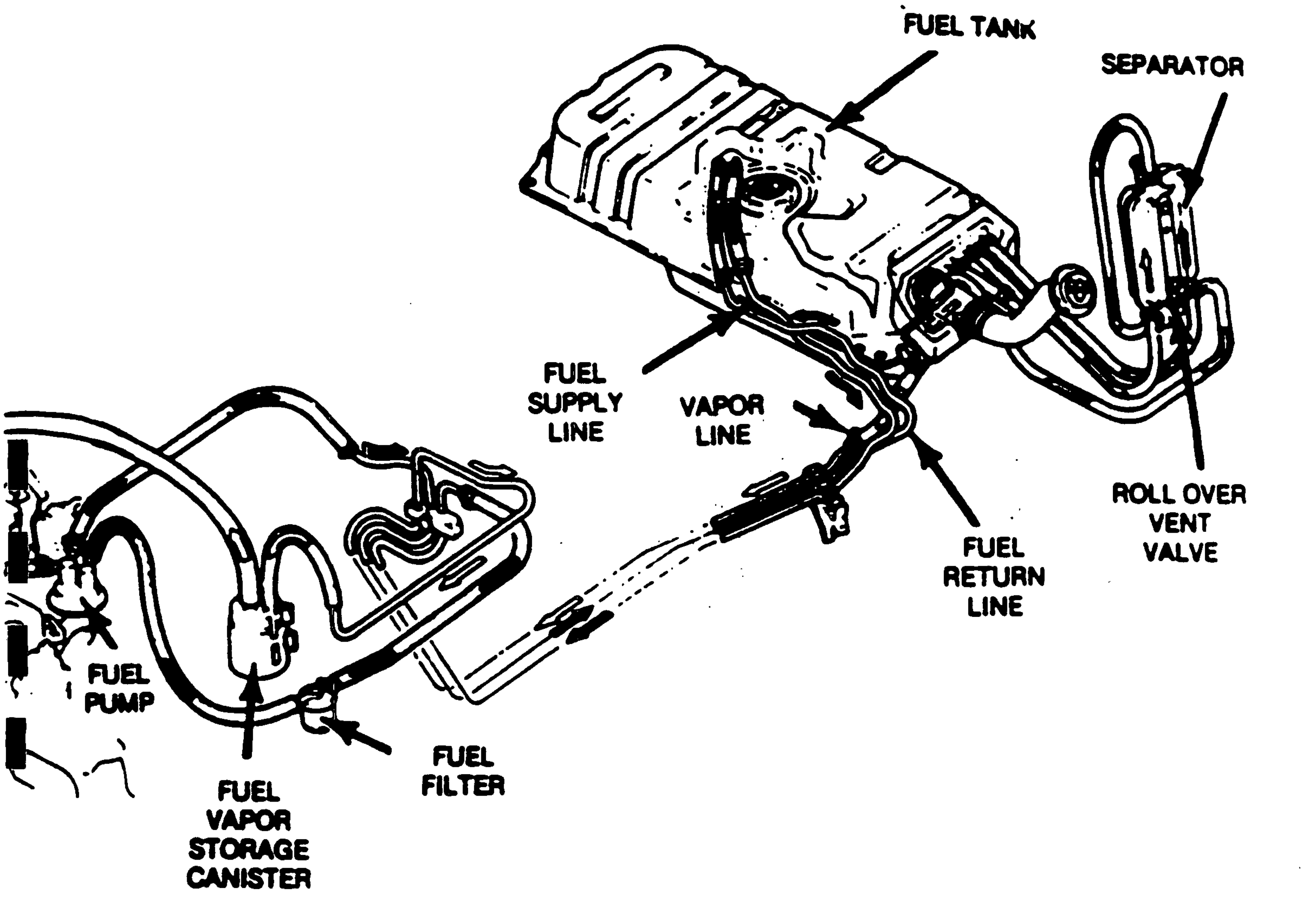
Figure 3-13

Ford Festiva



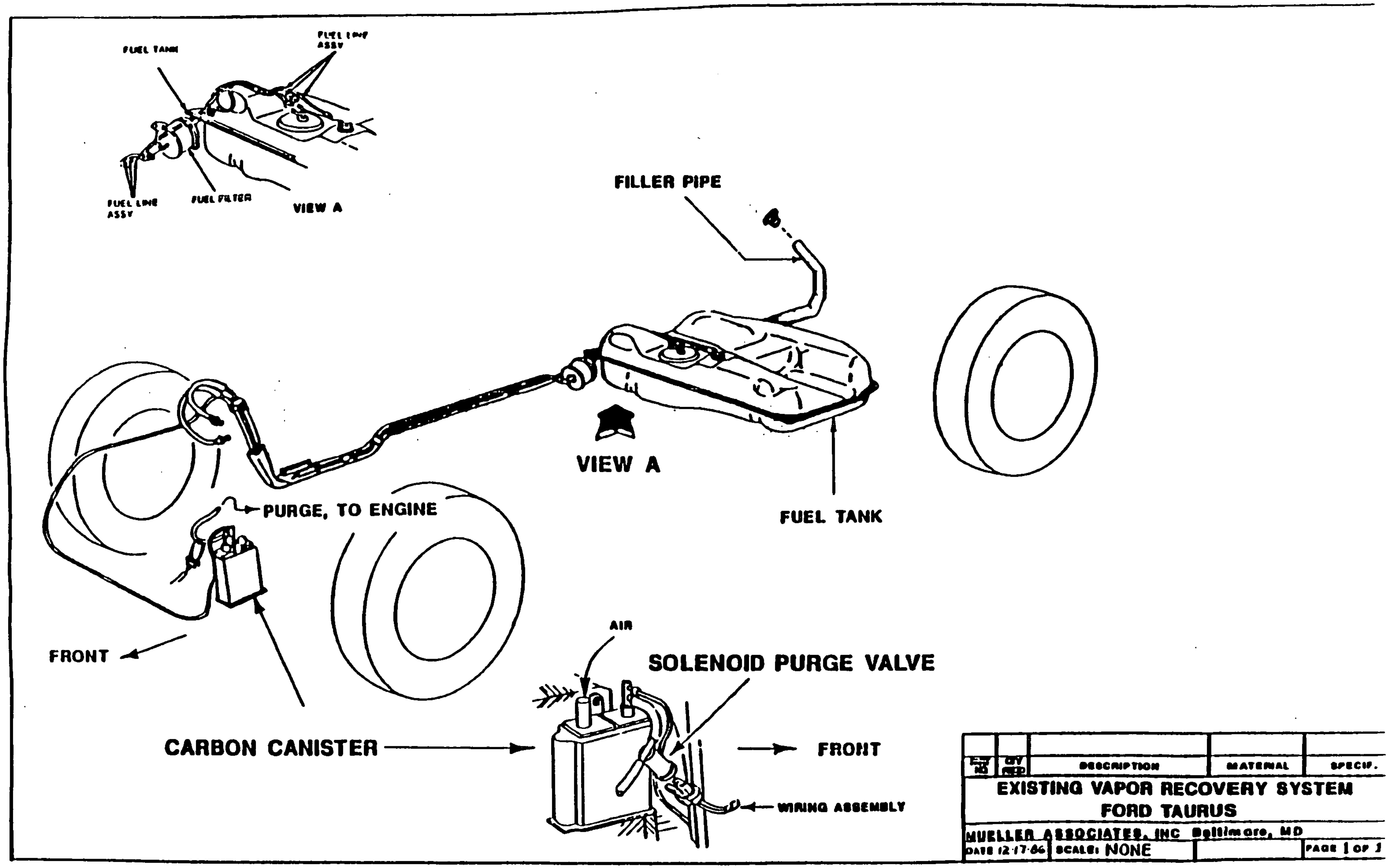
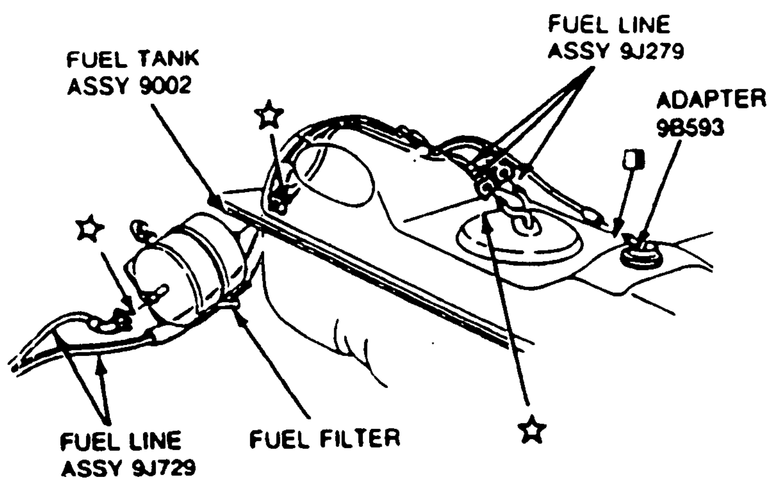


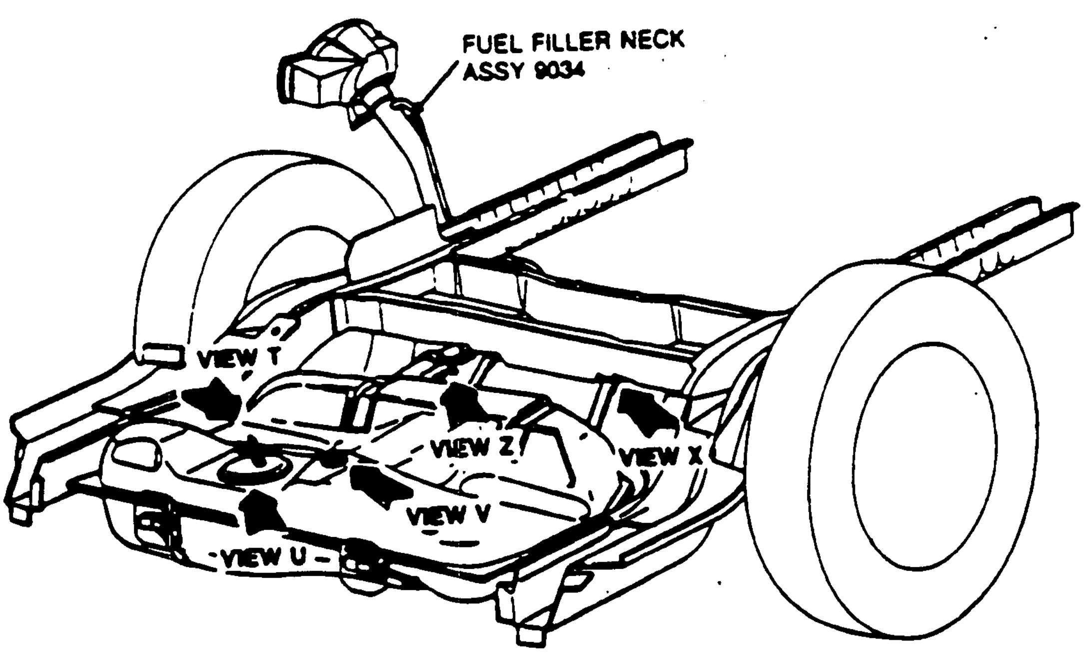
Figure 3-14

Ford Taurus

Figure 3-15

Ford Taurus





including the fillneck-mounted valves and liquid/vapor separator. Indeed there are many more examples of plastic tanks now in use. Furthermore, many other components in the fuel/vapor handling system on today's vehicles are plastics. Examples include the fillneck assembly on the SAAB 9000 (Figure 3-16), the liquid/vapor separator tanks in Figure 3-13, and essentially all of the external valves used in the fuel/vapor handling system. These examples provide good evidence that the use of plastics does not adversely impact safety. Concerns expressed about the use of plastics by MVMA are not supported by in-use experience on current vehicles.

Another concern voiced by several commenters is that onboard systems will require the placement of some components in the crash zone, such as the fillpipe area, and that this may create a hazard in accident situations. While EPA believes this design approach is not necessary, there are numerous examples of rollover valves and other components in current systems that are mounted on the fillpipe or in other crash zones. Again there is no evidence to suggest that the placement of those components has degraded vehicle safety. Examples include the fillneck-mounted rollover valve of the Volkswagon Golf shown in Figure 3-2 or the rollover valve of the SAAB 9000 shown in Figure 3-16. Another example, the 1988 Mitsubishi Cordia/Tredia in Figure 3-17, has a fillpipe mounted separator assembly with five separate vapor hoses in the vicinity. The Mazada 626 fuel system (Figure 3-18) has three vapor hoses in or on the fillneck plus the necessary connections to the fillpipe. And both the Range Rover (Figure 3-12) and the Ford Festiva (Figure 3-13) have the fuel/vapor separator tanks mounted in the crash zone. Thus, while it is certainly legitimate to be concerned about placing components in the crash zone, the examples demonstrate that even critical components have been placed in the crash zone on current vehicles.

4. <u>Summary</u>

Fuel and evaporative systems have gone through a number of revolutionary and evolutionary changes over time, and today's vehicles show a wide range in design complexity. Perhaps the most significant change, the adoption of fuel injection systems, has complicated fuel system design significantly and raised fuel tank temperatures and pressures. Many of the other changes discussed above which have contributed to the wide range of design complexity in current fuel/evaporative systems are more evolutionary in nature. Whether evolutionary or revolutionary, it is assumed that the manufacturers included these design features for good cause, and the available evidence suggests that vehicle safety was not compromised. This experience strongly suggests that onboard systems of various design complexities could also be implemented safely.

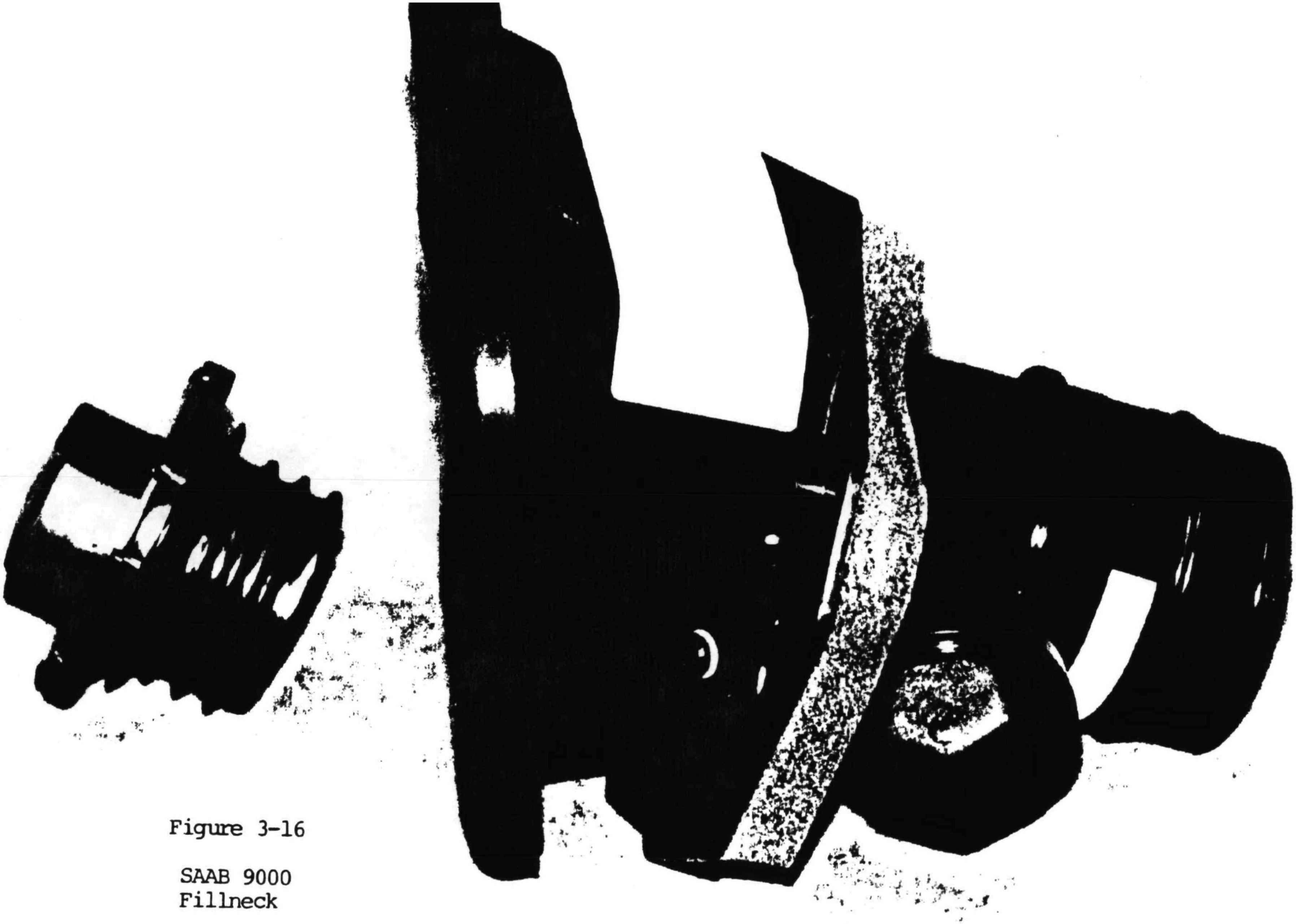


Figure 3-16

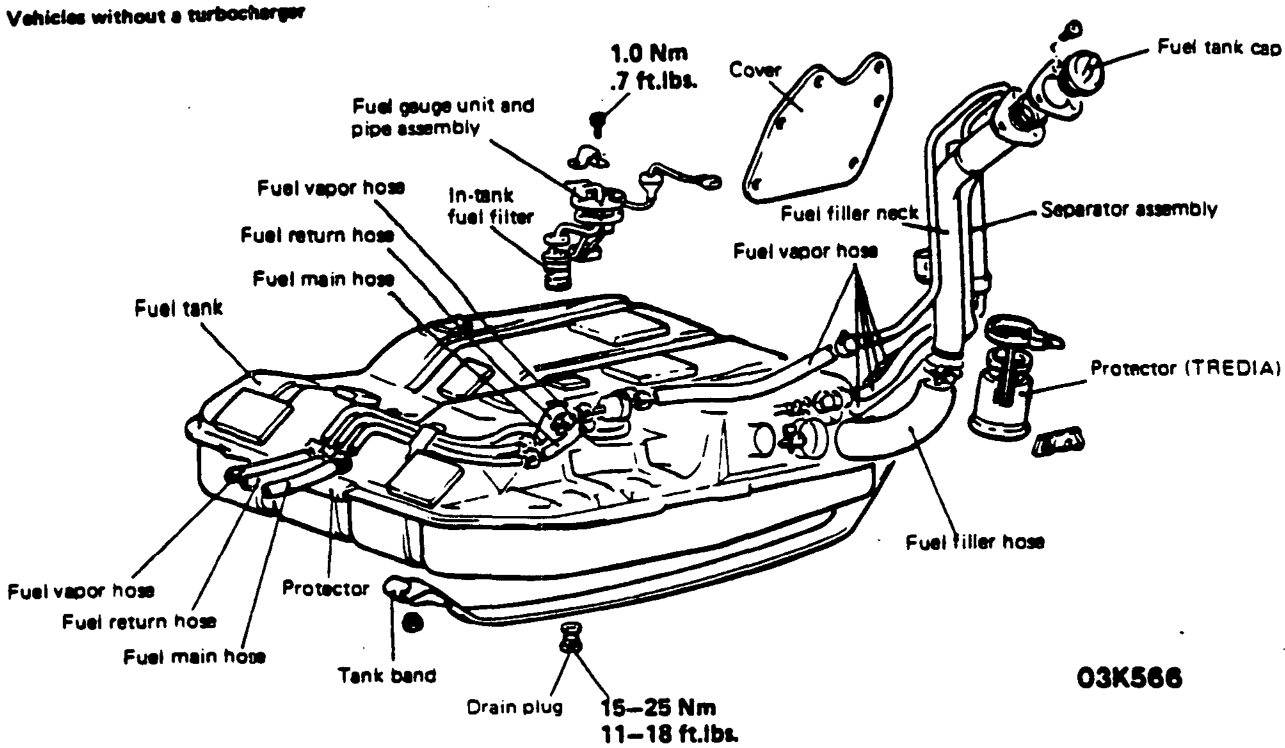
SAAB 9000
Fillneck

Figure 3-17

Mitsubishi Cordia/Tredia

COMPONENTS

Vehicles without a turbocharger



Vehicles with a turbocharger

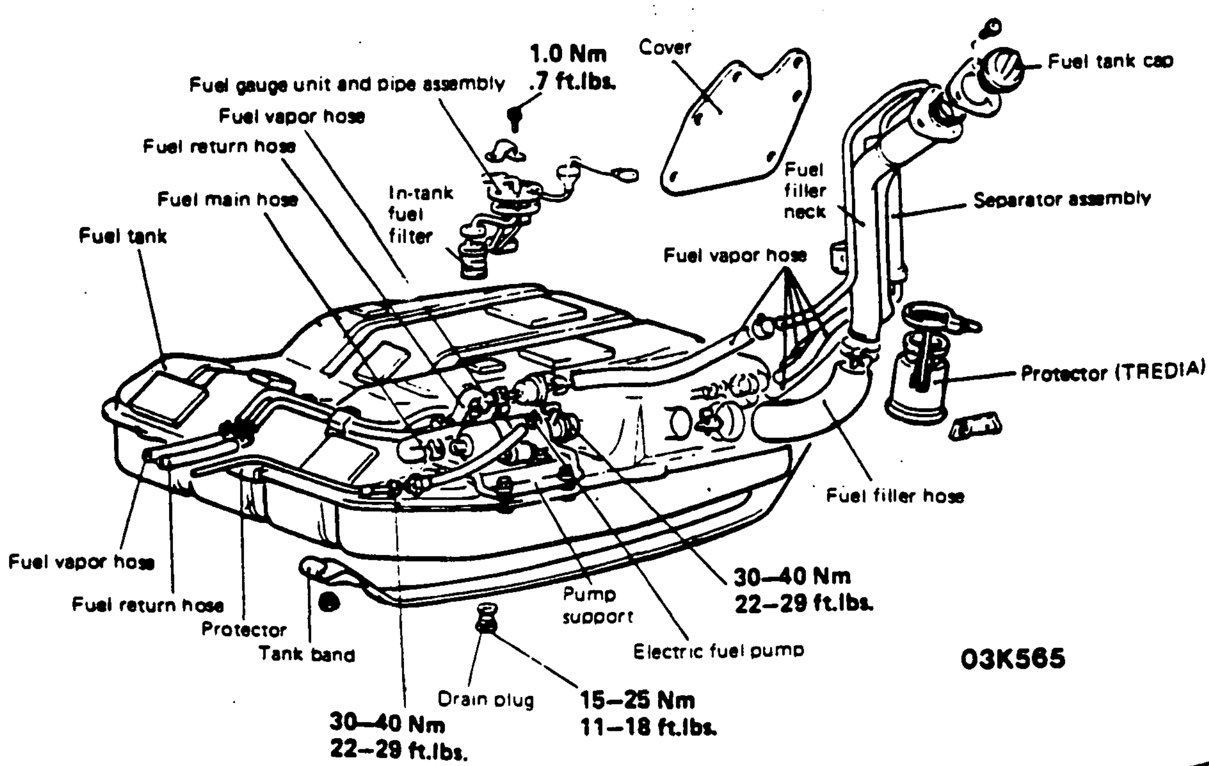
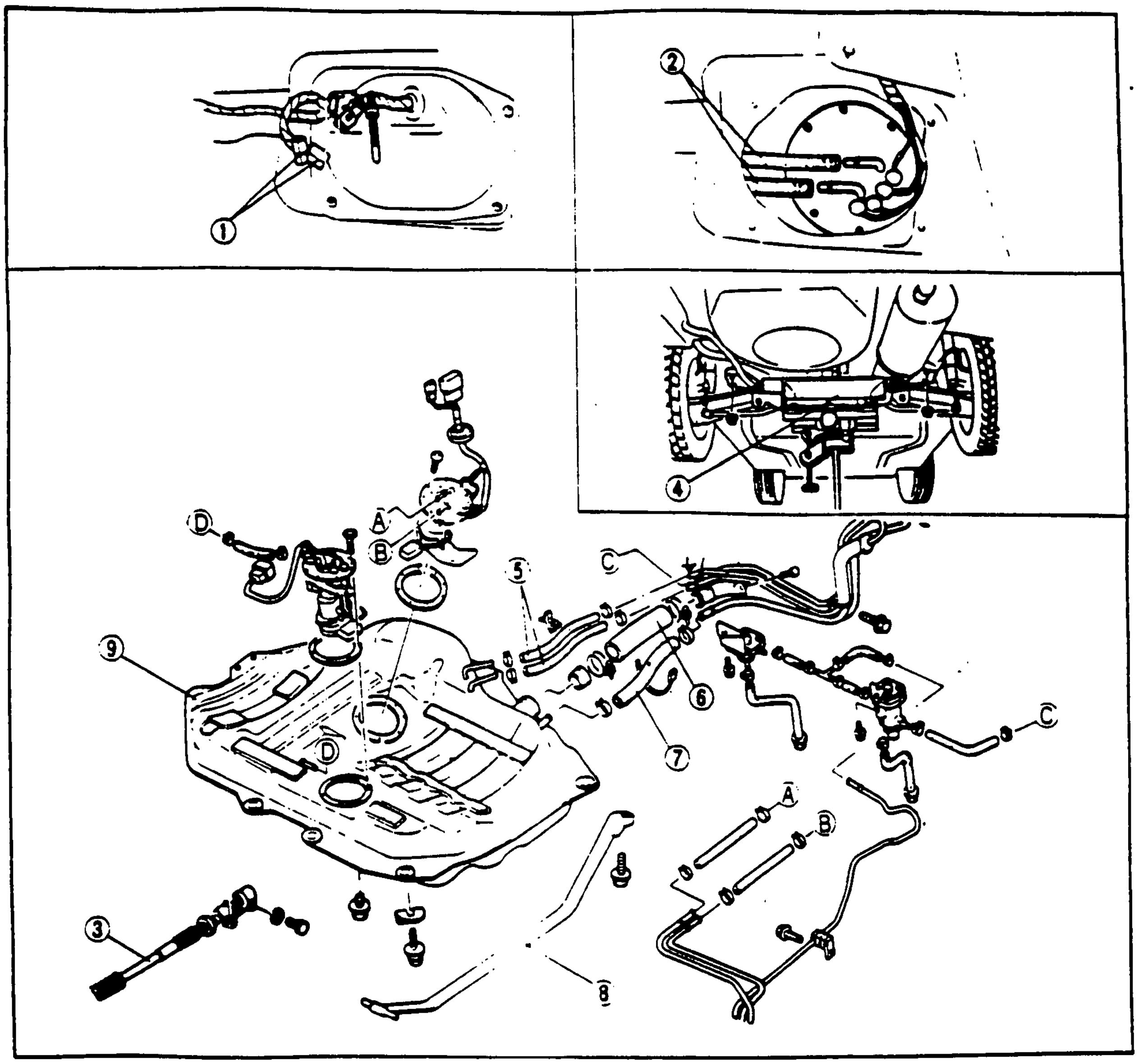


Figure 3-18

Mazda 626/MX-6



Note
Drain the fuel from the fuel tank before removing the tank.

1. Fuel pump connectors
2. Fuel hoses
3. Steering angle transfer shaft (4-wheel steering)
   (Refer to section 10)
4. Cross member (4-wheel steering)
5. Evaporative hoses
6. Fuel filler hose
7. Breather hose
8. Fuel tank strap
9. Fuel tank

Furthermore, this review of current fuel/evaporative system design has revealed that a number of design features such as component locations, alternative materials, and extra connections which were characterized as potentially unsafe for onboard systems are not specific or unique to onboard systems at all. In fact, the very components or design features cited as onboard concerns are present on current vehicles. Once again, it is reasonable to believe that the manufacturers concluded that these design features were needed and that they would not compromise safety . Clearly, if such design features are used safely on current vehicles they can be incorporated safely into onboard systems as well.

C. Onboard System Design and Safety

1. Introduction

The issue of system complexity and safety was raised by several parties prior to the NPRM and in the comments received subsequently. The focus of the issue was that onboard vapor recovery systems would be more complex than current evaporative systems, and that adding this complexity would cause an unquantifiable increase in the risk of both crash and non-crash fires. Complexity factors cited by the commenters included larger components, more components, more connections, the location and materials chosen for these components, and possible effect on other vehicle systems.

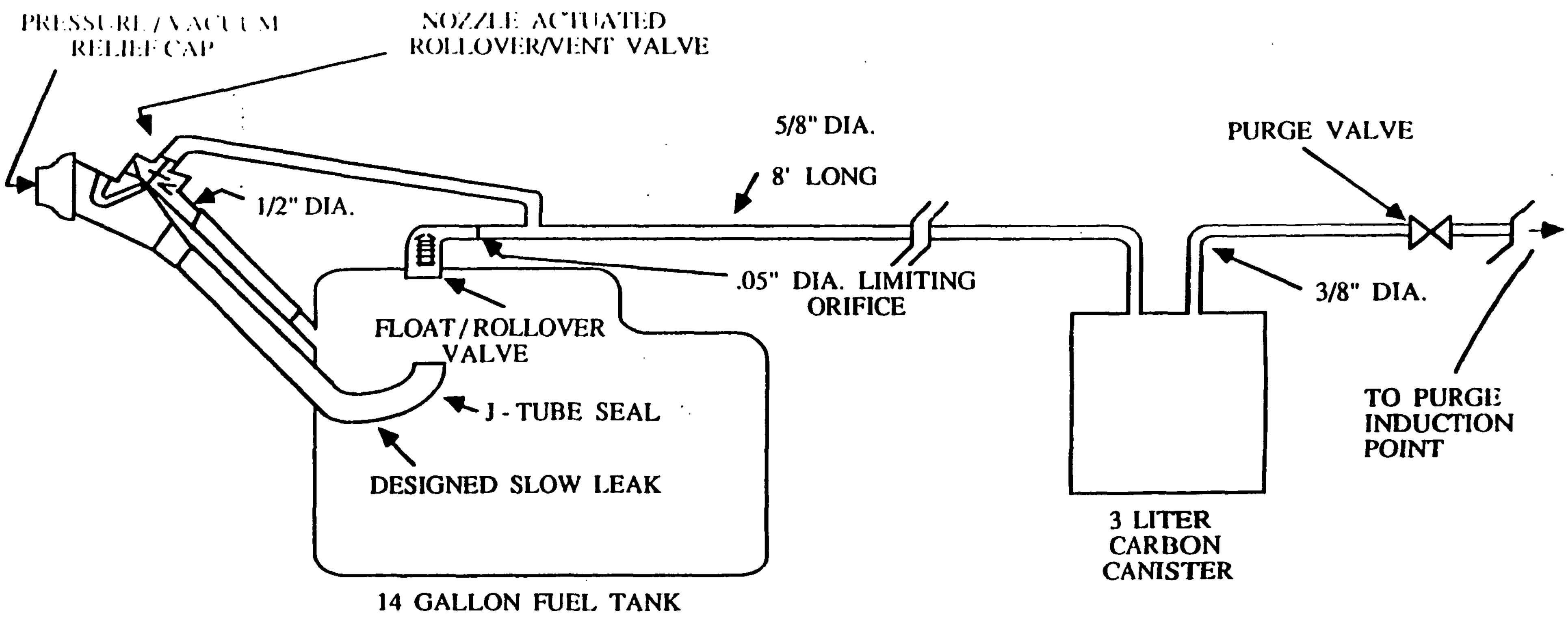
In EPA's view, the integrated onboard/evaporative system described in the NPRM was not considered complex, especially in light of the range of complexities in present evaporative systems. As is shown in Figure 3-19, it involved modifying the fillneck to provide a liquid seal, adding a fillneck mounted, nozzle actuated vapor control valve, and enlarging the vapor line diameter and charcoal canister. EPA's initial study of the safety implications of onboard vapor recovery systems found that systems such as that presented in the NPRM are simple extension/modifications of current evaporative systems and the "straightforward, reliable, and relatively inexpensive engineering solutions exist for each of the potential problems identified." The study went on to conclude that "no increase in risk need occur or be accepted as a result of an onboard system" and that vehicles equipped with onboard systems can "provide a level of in-use fuel system integrity equal to or better than achieved on present vehicles which incorporate evaporative emission control systems," (see Appendix II).

Nevertheless, as was described above, concerns were raised in the comments regarding the complexity issue in general and more specifically with regard to features of the NPRM design. Specific comments addressed areas such as fillneck valves, use of plastics, increased connections, increased vapor line length and diameter, canister location, and crash/crush zone concerns. The potential onboard system designs submitted by the commenters varied greatly. As is shown in Appendix I, some commenters submitted design approaches with features similar to that shown in the NPRM system such as liquid seals and integrated canisters. Other systems employed mechanical seals with separate canisters for refueling and evaporative emissions control and with a variety of different vapor control valve approaches.

EPA's follow-up on these comments took two different approaches. The first involved a review of evaporative system designs found on present vehicles. This review divulged a great deal of information regarding evaporative systems design

Figure 3-19

Integrated Evaporative/Refueling System
J - Tube Seal



approaches and complexity, and the hardware used in the systems. As was discussed in Section B, essentially every specific hardware concern for the onboard system was found to have a counterpart already being used on current evaporative systems. Furthermore, the review found that there was a wide range of complexity in current evaporative systems and that some of the design concepts used in evaporative systems are similar to that expected for onboard controls. Even with this wide range in design approaches and concepts, no evidence was found to indicate that increased complexity has decreased evaporative system safety. Furthermore, the wide variety in design complexities in current evaporative systems without an impact on safety suggested that a variety of design complexities in onboard systems could also be implemented safely.

Nevertheless, even though the premise was debatable, EPA decided to confront the complexity issue directly by developing a system even simpler than that presented in the NPRM and which doesn't add complexity to the current evaporative system. The basic design approach used was similar to that shown in Figure 18 of the initial safety study (Appendix II) with even further simplifications and improvements. The intent of this program was to show even further the simple designs available for onboard controls, and that the more complex design approaches suggested by some commenters are not necessary to achieve safe and effective control of refueling emissions.

As an overview, the remainder of this section of Chapter 3 is broken into five parts. Part 2 which follows this introduction explains EPA's goals in the onboard system design and development program. Part 3 describes the baseline fuel system evaluated and the modifications/additions needed to incorporate onboard controls. Part 4 presents the results of the emission testing conducted and part 5 draws conclusions and discusses why simple systems such as that developed here by EPA should and would be preferred by most manufacturers. Finally, part 6 discusses how the use of simple systems such as that developed by EPA addresses many of the general and specific safety concerns raised by the commenters.

2. Program Goal and Constraints

The main goal of the EPA program was to address the complexity issue by developing a simple integrated refueling/evaporative control system which incorporated the fewest features possible to perform the necessary functions. It was also EPA's intent to utilize system components that were based on current production hardware.

In terms of testing, several constraints were established. First, it was decided that the complete fuel system should be tested using the RVP, temperature and dispensing conditions in the proposed test procedure and that this testing should be conducted with the system in the geometry and configuration which exists when mounted on the vehicle. Second, other issues not directly relevant to onboard safety such as canister purge were not to be evaluated in this program since for the most part they were viewed to be more evaporative control issues. With these goals and constraints established, the first step of the process was to select a baseline vehicle fuel/evaporative system to modify. This plus the necessary modifications are described next.

3. Development of the Onboard System

a. Baseline Vehicle Fuel/Evaporative System

The fuel/evaporative system selected for modification was that found on fuel injected 1986 General Motors (GM) A-body cars. This particular system was selected for several reasons. First, it is typical of mid-size passenger cars in today's fleet in terms of fuel tank size, fill location, fuel metering, and has a relatively simple evaporative system. The use of the relatively simple evaporative system over some more complex designs presented a bigger challenge in terms of demonstrating the same level of simplicity as compared to the evaporative system. Second, this general fuel system configuration was presented by GM at the public hearing as having an outstanding record of crash integrity in the field, and thus appeared to be a good base case vehicle in that regard.[7] Third, this fuel system was selected for modification over others since it was already being used as the base case in an ongoing failure modes and effects analysis being conducted by EPA (see Section D of this chapter). It should be noted that the concept to be demonstrated here was viewed to be equally applicable to most other fuel systems, but it is not EPA's role to design and demonstrate control systems for every vehicle model.

The base fuel/evaporative system is shown in the photo in Figure 3-20 and is illustrated in Figure 3-21. As can be seen in the figures, the fuel system is configured for side fill. Both the fillpipe (1.25" I.D.) and the external vent line (0.5" I.D.) have rubber connector pieces. The fuel tank is about 59 liters in capacity and has a vapor dome of about twelve liters. The fillneck enters the tank on the driver's side and continues into the tank for about four inches. It thus provides a submerged fill after about 95 percent of capacity has been dispensed.

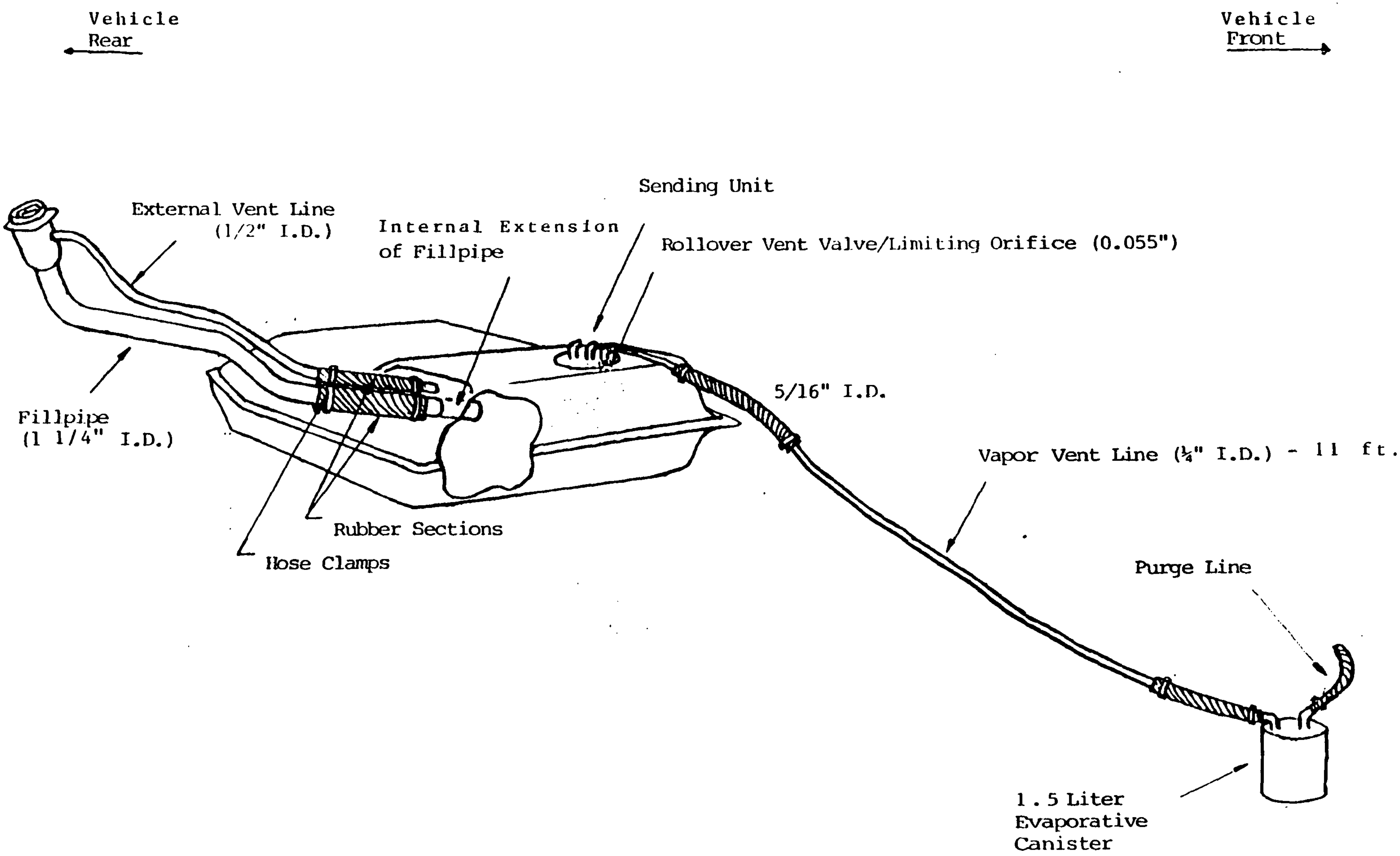
As is the case with most fuel/evaporative systems, the vapor line to the canister is protected by a rollover valve which is fitted on the underneath of the fuel sending unit.

Figure 3-20

Stock Fuel/Evap System

Figure 3-21

Stock Fuel Tank/Evaporative Control System



The outlet into the vapor line also incorporates a 0.055" limiting orifice. The vapor line to the canister is both steel (1/4" I.D.) and fuel resistant rubber (5/16" I.D.). The 1.5 liter open bottom canister is located under the vehicle hood, even though no vapor line is used from the engine to the canister. It is worth noting that this particular fuel system did not incorporate an anti-spitback valve even though this is becoming an increasingly common feature in many other fuel systems. The fillneck cap had a warning to loosen the cap slowly to allow the tank to depressurize before fully removing the cap in order to prevent fuel spurting.

b. Modifications to Make on Onboard System

1) Introduction

Keeping in mind the goals of this program as described above, only minor modifications of the stock system were needed to incorporate refueling controls. A picture of the modified system and a labeled sketch showing key components are shown in Figures 3-22 and 3-23. The changes needed to make an integrated onboard refueling/evaporative control system are listed below and described in more detail in the discussion which follows. The changes/modifications to the stock system included:

- Fillpipe
  - Remove the external vent line
  - Slightly reduce the minimum diameter in the fillpipe
  - Add a current production anti-spitback valve to the end of the fillpipe in the tank
- Vapor Control Valve
  - Replace the current rollover valve and limiting orifice with a multi-function valve with a larger orifice
- Vapor Line
  - Shorten and slightly enlarge the vapor vent line.
- Canister
  - Move to the rear of the vehicle and enlarge canister from 1.5 to 2.5 liters

2. Description of Modifications

a) Fillpipe Related

Three modifications were needed for the fillpipe. First, since the design used envisioned a liquid seal and tank mounted vapor control valve, the external vent line was no longer needed. This piece was removed, and the ports in the tank and

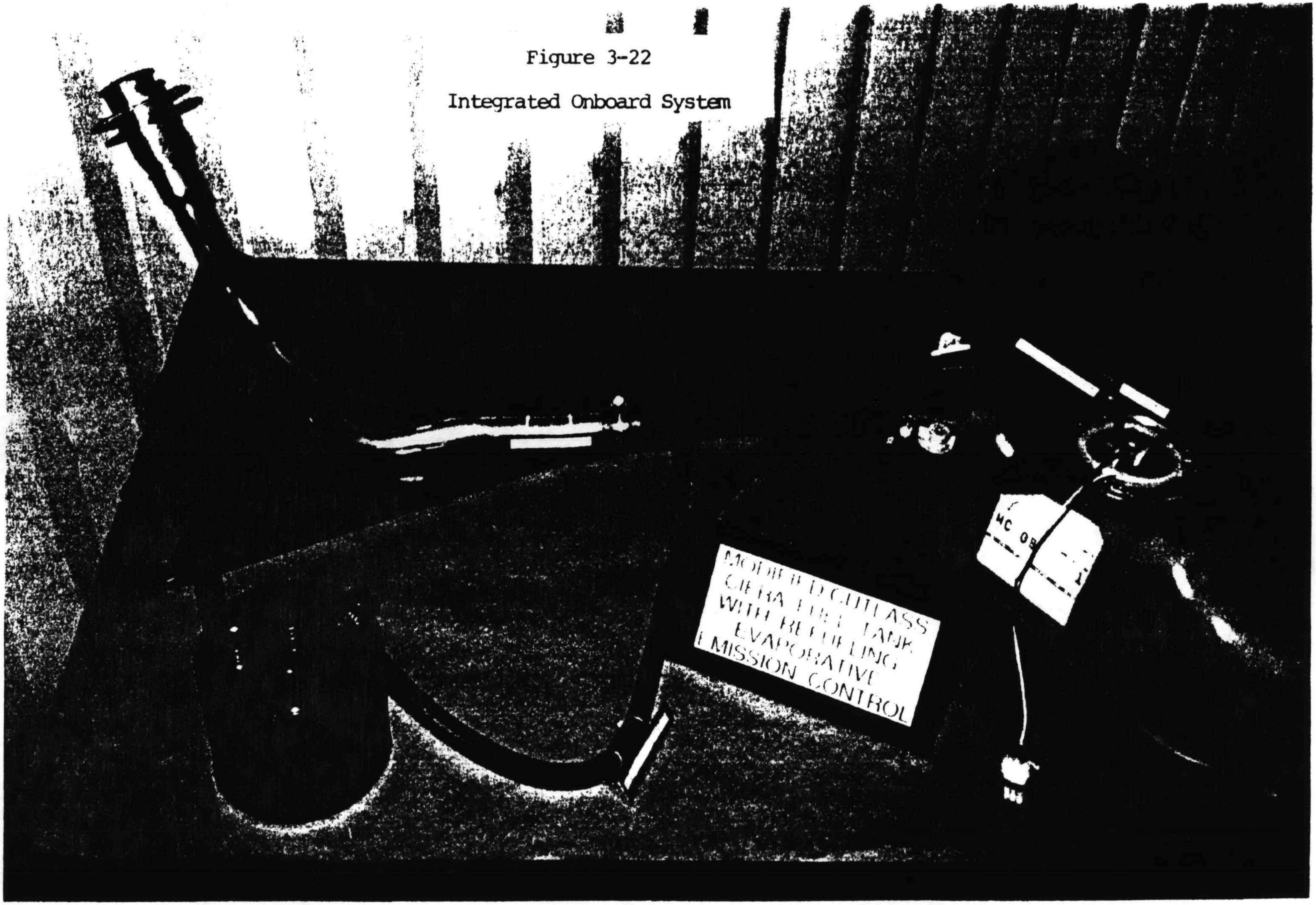
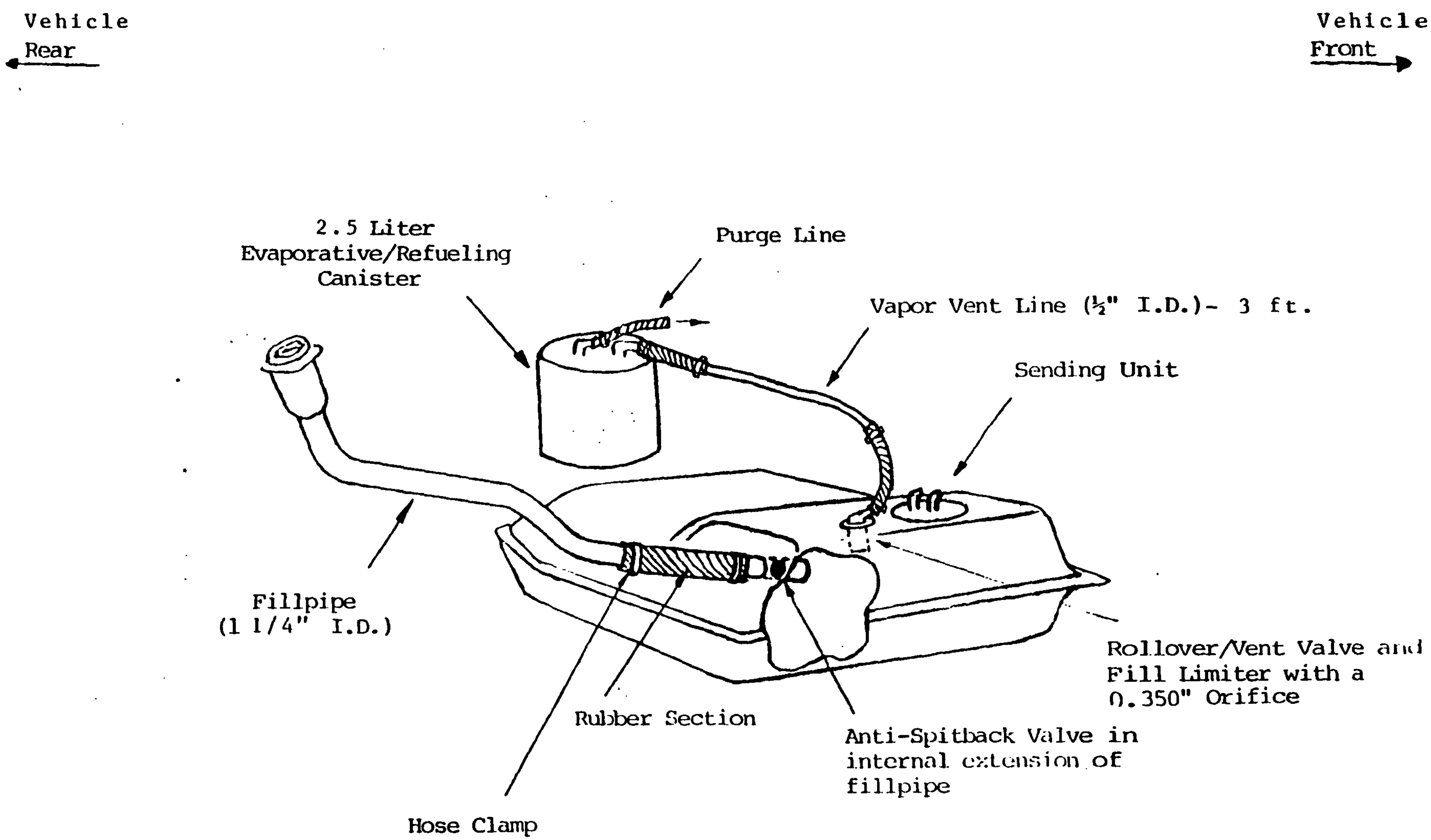


Figure 3-22

Integrated Onboard System

Figure 3-23

Integrated Refueling/Evaporative Control System



fillneck were sealed. Consequently an exposed steel/rubber vapor line in the crash zone was removed and four connections were eliminated.

Second, very minor modifications were necessary to ensure vapor would not escape the fillneck during refueling under any reasonably expected in-use dispensing conditions. The fillneck seal system developed by EPA employed a liquid seal. That is, vapors were prevented from escaping to the atmosphere due to the consistent flow of fuel being dispensed and the formation of a liquid seal within the fillneck itself by the dispensed fuel slightly backing up in the fillneck during refueling. This is precisely the situation which exists in many current systems during refueling, and is the reason why an external vent line is needed to vent refueling vapors.

EPA's initial testing found that the unmodified stock system provided a liquid seal over the initial flow rates tested - 6 to 10 gpm. The system was later tested at dispensing rates as low as 3 gpm and it was found that a slight restriction was needed in order to ensure a liquid seal over the full range of reasonably expected in-use flow rates (3-10 gpm). A restrictor which reduced the diameter of the stock fillpipe by 0.2 inches (from 1.25" to 1.05") was installed in the rubber section of the filltube adjacent to the tank. With this restriction, the system filled satisfactorily, and controlled refueling vapors, at dispensing rates of 3-10 gpm. Flow rates below 3 gpm were not tested because they are very uncommon in-use and most nozzle manufacturers recommend flow rates be above this value so that the nozzle automatic shut-off function works properly. The 10 gpm value is near the high end of the current in-use range and represents EPA's proposed in-use maximum.

As part of EPA's proposed test procedure, essentially all fuel spitback during refueling must be eliminated in order to comply with the proposed emission standard. The unmodified stock tank was subject to premature shut-offs and spitback during refueling under some conditions, and this problem had to be solved. This is a common problem in many fuel systems today. A similar problem, fuel spurting, occurs upon cap removal when fuel in the fillpipe is subject to high fuel tank pressures. As was discussed in Section B of this chapter a number of devices are available to address this spitback/spurting problem. EPA simply chose one such device, a Chrysler anti-spurting valve which has been in production since 1984,[8] made some minor modifications, and attached it to the stock fillpipe. The ball-in-cage type device shown in Figure 3-24, was modified by increasing the specific gravity of the ball to be the same as liquid gasoline, and it was attached by removing a three inch piece from the end of the stock fillpipe and replacing it with a three inch piece which included the valve. This valve effectively stopped fuel spitback during refueling, both with premature shut offs and at the end of the refueling event. Thus fill characteristics were improved as compared to the stock fuel system.

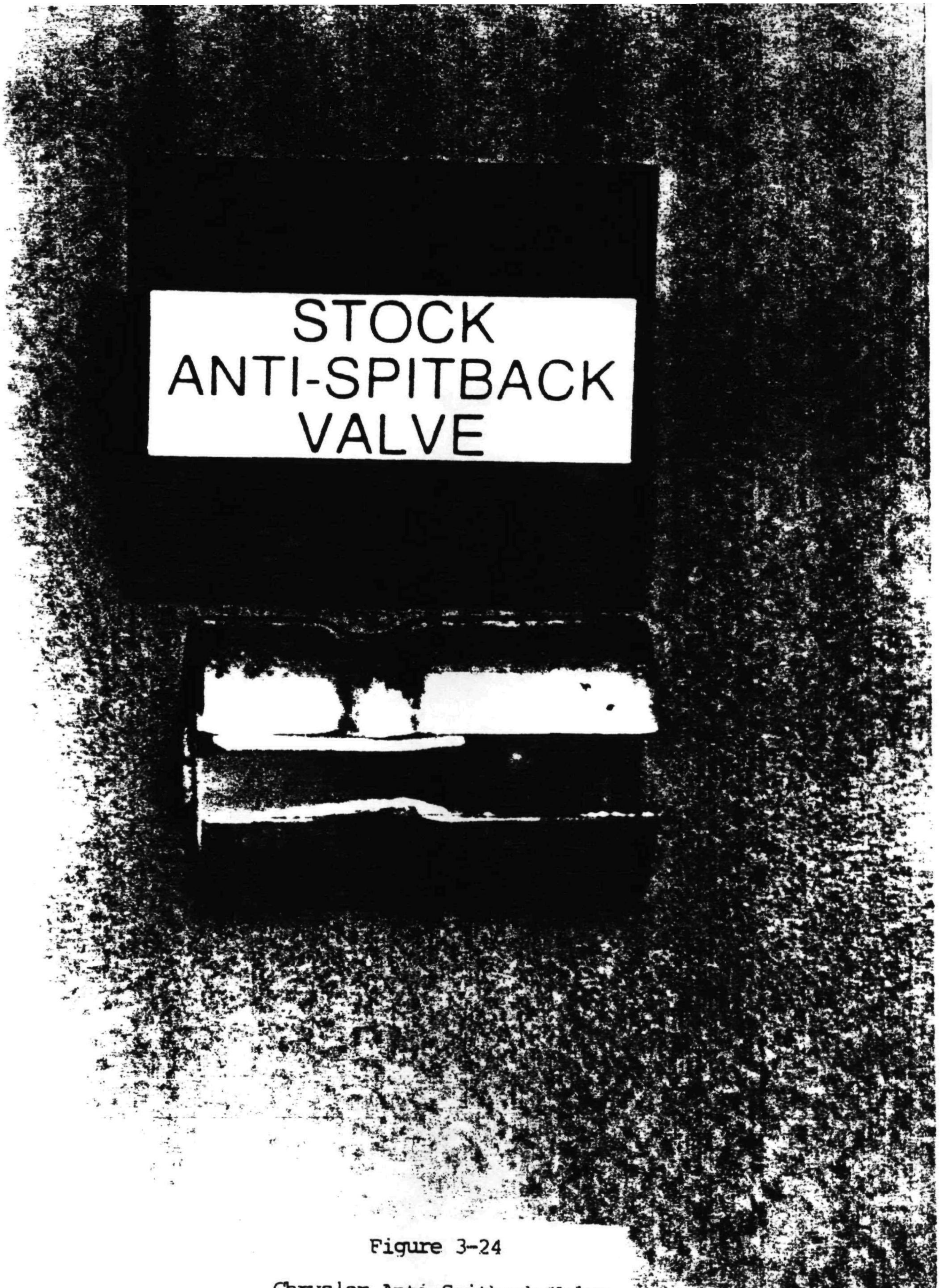


Figure 3-24

Chrysler Anti-Spitback Valve

b) Vapor Control Valve

The next modification involved the rollover/vent valve. The stock system employed a ball and plunger type approach built beneath a 0.055" limiting orifice. This design would not provide adequate venting for an integrated onboard/evaporative system and would probably not be sufficient for enhanced evaporative control. Thus, some changes would be needed in either case. A tank mounted vapor control valve for an integrated system would ideally need to perform four functions: 1) venting of refueling vapors, 2) fill limiting, 3) rollover protection, and 4) venting of evaporative vapors. The last three of these functions are performed by most current production valves now in use. Each of these is discussed below.

First, since the external vent line was removed and a liquid seal existed in the fillpipe, all refueling vapors had to be vented through the valve. Thus, it was important that the valve be sized to allow full venting of refueling vapors, at a tank pressure which would avoid premature shut-offs. After conducting testing on the system, it was determined that at a 10 gpm dispensing rate the valve would need to be able to flow 2 scfm of vapor at a backpressure of 4" H_2O. This requires an orifice of about 0.35".

Second, the valve design used needed to incorporate a fill limiting capability. With the removal of the external vent line and the need to enlarge the fuel tank outlet orifice to accommodate higher vapor flow rates during refueling, the fill limiting design of the stock tank was no longer effective. Thus a fill limiter was needed which would close off the vapor vent outlet when the tank was full thus increasing tank backpressure and allowing automatic nozzle shut-off to occur as in the present vehicle.

Third, to provide in-use fuel system integrity, the valve would need to incorporate rollover protection functions such as those provided by the stock rollover valve. Ideally, the valve would provide protection for partial and total rollovers.

Finally, since this was an integrated system, the valve would also have to be to vent evaporative vapors to the canister under a variety of fuel temperature and volatility conditions. Since the preferred design incorporated a fill limiter it would have to be able to vent even when the tank is full.

As was discussed in Section B of this chapter, rollover valves of various sizes and designs are in common use today. They vary in size, design and functional approach. The valve selected for this project is that used on current Ford 350 pickups, vans and ambulance chassis (see Figure 3-25). This particular valve was selected because the orifice was larger than on most other valves (0.17") and the rollover mechanism

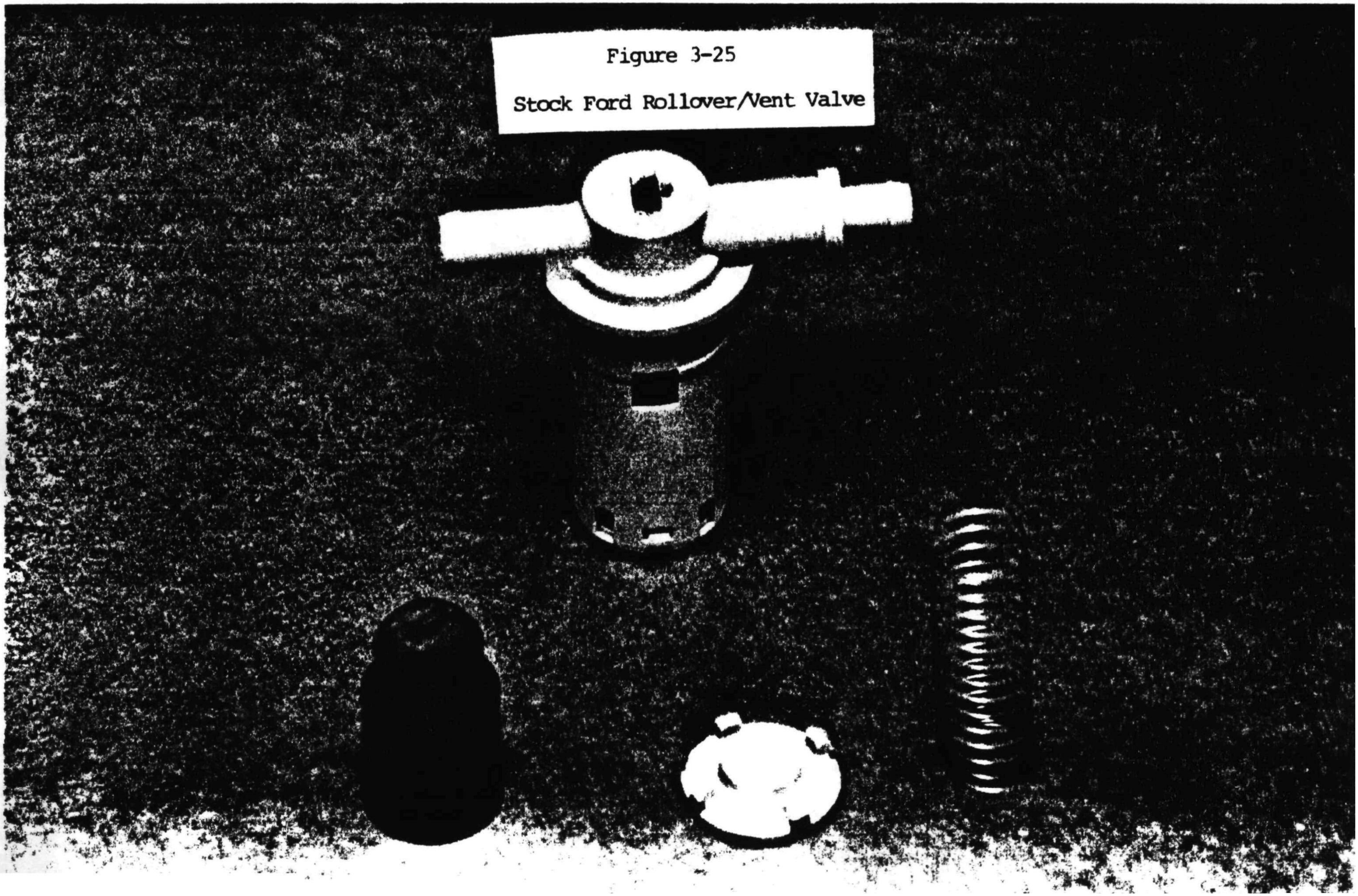


Figure 3-25

Stock Ford Rollover/Vent Valve

was float actuated. In fact, the valve used was originally produced as a recall fix which would provide more tank venting and reduce tank pressures.

Several modifications to the valve were necessary to allow it to serve the functions described above. These modifications included.

- enlarging the vent orifice from 0.17" to 0.35"
- plugging one of the two vent ports on the valve since only one was needed*
- enlarging the vapor flow passages within in the valve

Using the stock grommet designed for the valve, the modified valve was then mounted on the fuel tank at a point and height such that the original tank capacity was retained. The valve was positioned on the tank near the position of the previous external vent line to as closely as possible simulate the refueling characteristics of the stock system.

Finally, since this is an integrated approach, the system would ideally need to be able to vent evaporative emissions under all conditions. The modified valve, as described above, would serve this function under all conditions except perhaps when the fuel tank is full. While the need for full tank venting is a relatively rare occurrence, two approaches can be used,to accommodate fuel tank venting under these conditions. The first involves further modification of the existing valve to incorporate a .055" bypass within the valve body itself. To do this, a two stage valve could be used. The main .350" vent shuts off upon tank filling, while the smaller .055" vent remains open under all conditions as it does on the stock tank. This .055" vent is also rollover protected. A schematic of this type of valve is shown in Figure 3-26. Since this two stage valve vents fuel tank emissions under all scenarios, it is not necessary to have the vent in the fuel sending unit which vents evaporative emissions on the stock system. For this reason, the present fuel vent line could be removed. Alternatively, the second approach involves retaining the current rollover/vent approach and teeing the vapor line from this outlet into the vapor line from the refueling port. A sketch of this approach is shown in Figure 3-27. Either

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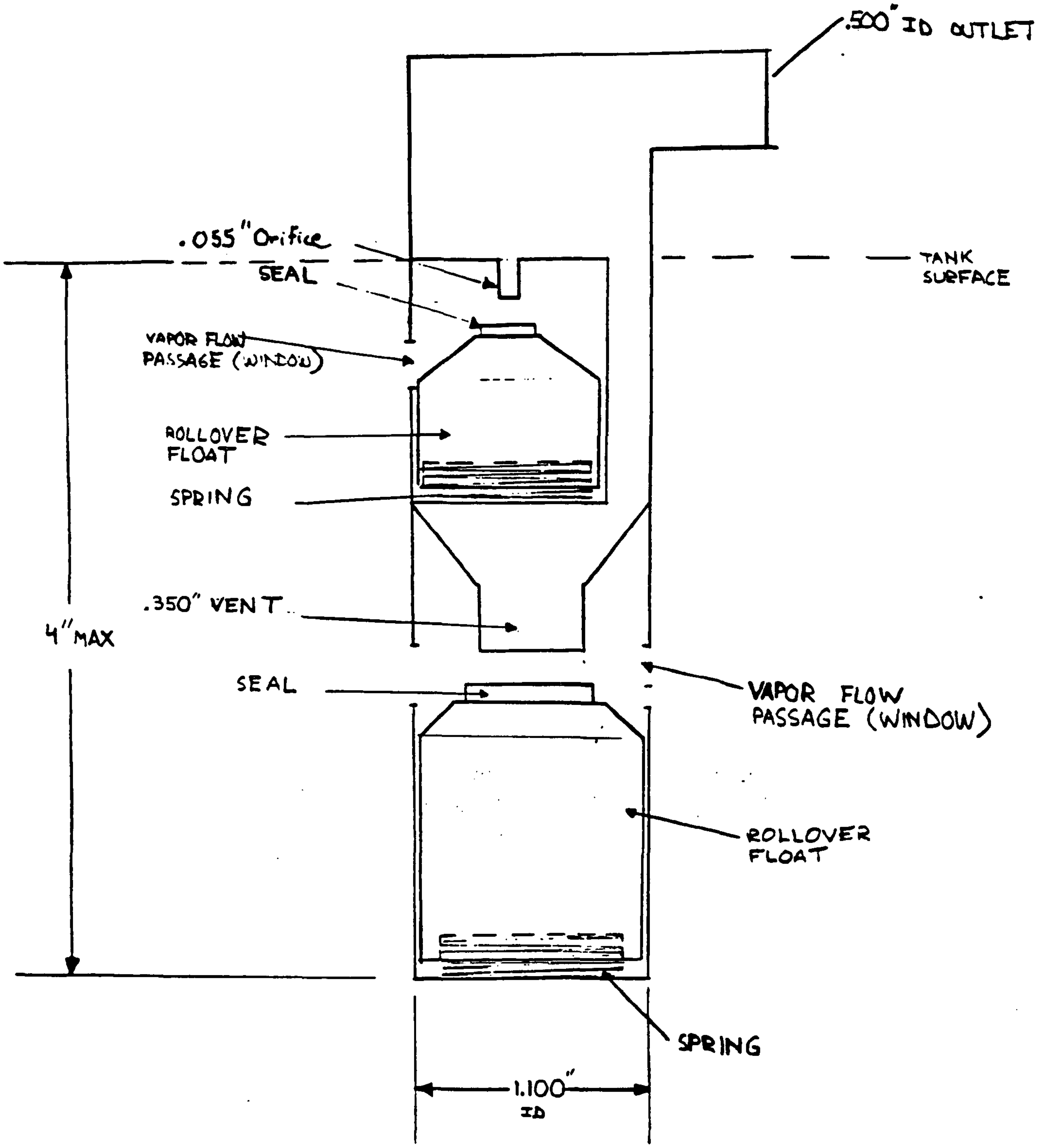
* The stock valve incorporated a pressure relief function which allowed uncontrolled vapors to vent at fairly low tank pressures. This was deleted since a larger vent diameter in the main orifice would prevent significant tank pressurization. Deletion of this pressure relief valve would provide some improvement in emissions control performance as well, since all evaporative emissions would be routed to the canister.

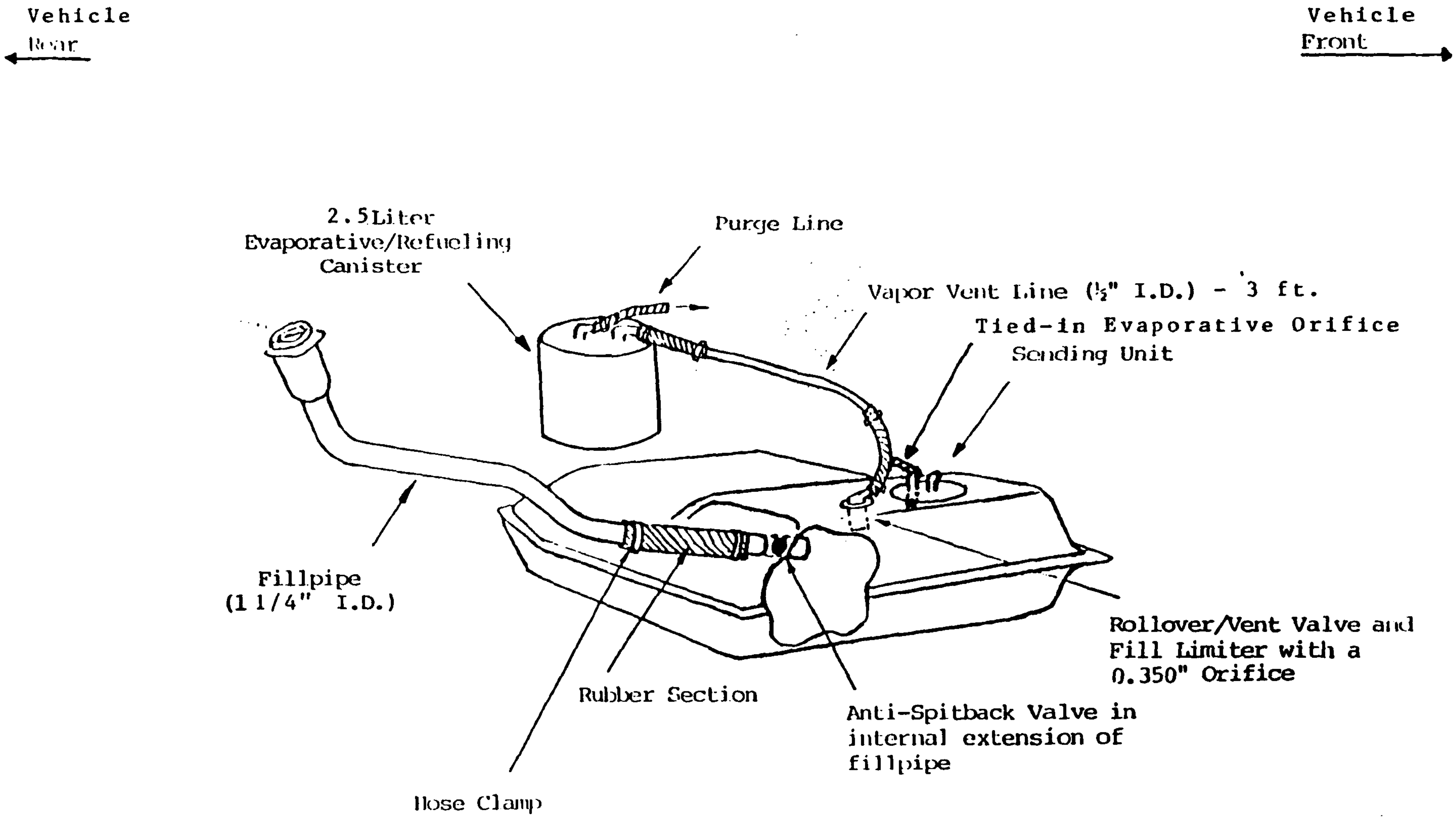


Two Stage Vapor Control Valve

Figure 3-26

Figure 3-27

Integrated Refueling/Evaporative Control System
With Separate Evaporative Orifice



approach would provide tank venting under all conditions and could have been implemented easily into EPA's prototype design evaluation program.

Thus, with a few simple modifications, an existing rollover/vent valve was modified to perform all of the functions needed for a refueling vapor control valve. The valve is designed and sized to vent refueling emissions, and the float will provide fill limiting capability. In fact, the larger diameter vent orifice will provide greater flow capacity for evaporative vapors and will thus provide the means to significantly reduce in-use fuel tank pressures and thus the possibility of fuel spurting as compared to the stock system. The benefits associated with lower tank pressures are discussed in Chapter 4.

And finally, since the basic geometry of the valve and mechanism used to provide rollover protection in the stock valve are unchanged, the valve would provide both partial and full rollover protection, just as it did in its original configuration. Discussions with the supplier of the stock valve indicated that they saw no problem in closing off the 0.35" orifice in a rollover situation. Overall, the tank mounted float activated vapor control valve is fully functional in handling all fuel tank vapors. Given the similarity in design and functional operation to current valves, it should provide at least the same level of safety in-use as is now seen in present systems. In fact, the greater vapor flow capacity for evaporative vapors provides protection against fuel spurting as compared to the stock valve.

c) <u>Vapor Line and Canister</u>

Because of the increased vapor flow rate during refueling relative to evaporative flow rates, there was a need to slightly increase the vapor line diameter. However, for a given tank backpressure, during refueling, the actual diameter needed depends upon the length of the vapor line used. A shorter vapor line would allow a smaller diameter. The vapor line length, in turn, depends almost entirely on canister location. There are basically two options for canister location; the front of the vehicle under the hood or the rear of the vehicle in an underbody location or in a rear quarter panel area.

Most vehicles today locate the evaporative canister under the hood. This design originated with the need to collect hot soak emissions from carbureted vehicles and to purge evaporative emissions from the canister into the engine. It also required less total vapor and purge line than would any other location. However, since the majority of engines today are fuel injected and require no direct venting, vapor line lengths are now governed by fuel tank emissions, and there is no compelling reason why canisters have to be front mounted. By locating the canister in the rear of the vehicle the vapor line length would be less. As is discussed below, one of GM's current vehicle models uses this approach.

Given this design option, EPA selected a rear-mounted location for its canister. This led to vapor line length for the integrated refueling/evaporative system of about three feet, only about one third of that used for the stock system. This also allowed a vapor line of only 1/2" I.D. versus 5/16" for the stock system. An even smaller diameter vapor line could have been used, but 1/2" I.D. was selected to optimize backpressure within the total system (vapor control valve, vapor line, canister). Testing by other commenters suggested that a 1/2"-5/8" I.D. vapor line would be needed for an under hood canister location.[9]

Finally, the canister itself, shown in Figure 3-28, was a GM 2.5 liter closed bottom canister, the size and design currently used on large light-duty trucks and heavy-duty gasoline vehicles for evaporative emissions control. Some modifications were needed to improve vapor flow into the canister and charcoal bed, but basically the canister was used as produced. No efforts were made to optimize canister size relative to the expected refueling emissions load or to accommodate the expected formation of a heel. Finally, depending on the canister design used and the location on the vehicle some type of dust cap may be needed to clean the purge air. However, this would be a minor design modification to the basic canister, as is shown in the discussion later in this section.

d) <u>Design Applicability to Other Vehicles</u>

As was stated in the beginning of this discussion, the goal of this program was to demonstrate the concept that it is possible to construct a simple integrated onboard refueling/evaporative control system which does not increase the complexity of current systems, using components based on current production hardware. As can be seen in the discussion above, a system was constructed which required essentially only minor modifications of currently available hardware, and complexity was not increased.

While this concept was demonstrated for only one fuel system, EPA sees no technical reason why it cannot be applied to essentially all current fuel systems. There is no apparent reason why some form of liquid seal cannot be used. Most of today's vehicles essentially have liquid seals now based on the widespread use of external or internal lines to vent refueling vapors. Vent valves serving the same or similar functions as

Figure 3-28

Stock 2.51
GM Canister

that required for this system are used on current vehicles and the relocation of the canister is a straightforward design change. Thus while the system would need to be engineered and optimized for each vehicle model, the design concepts and approach demonstrated have wide if not universal applicability.

With this discussion of the overall refueling/evaporative control system developed by EPA and description of the components used in the system the next section describes the results attained in tests to control refueling emissions.

4. Emission Test Results

After constructing the initial prototype system, tests were conducted to see how well the system controlled refueling emissions. Tests were conducted on the entire fuel system using the procedures and conditions prescribed in the test procedure portion of the NPRM. All tests were conducted at a nominal 9 psi RVP, and the canister was bench purged between tests. The results of the testing are shown in Table 3-2, and while self explanatory, several points are noteworthy.

The first important point is that all tests yielded emission results lower than EPA's proposed standard of 0.10 g/gal. Average emissions for the thirteen tests were 0.04 g/gal, less than half the level of the proposed emission standard. Second, it should be noted that the liquid seal worked effectively at a wide range of dispensing rates. A dispensing rate of 10 gpm was selected as the high end based on current in-use practice and EPA's proposal to limit dispensing rates to this level in-use. On the low end dispensing rates of 3,4, and 5 gpm were evaluated to assess the effectiveness of liquid seals at lower flow rates. The 3 gpm value was also evaluated to see if the fill limiting function and nozzle automatic shut off mechanism would work at low flow rates or if the tank would overfill. In all cases the system worked as designed. Finally, a third key point is that the relatively simple anti-spitback valve incorporated into the system was very effective. There was no fuel spitback either during premature shut-offs or at final shut-off for any of the above tests.

Subsequent to the completion of this testing EPA presented a series of briefings to interested parties on the details of the system development described above and the results of the emission testing. While EPA has not as of yet received any significant comments on the program, its results, or implications, it was suggested that additional testing be conducted. Further testing has been conducted with the use of higher RVP fuels, higher fuel tank temperatures, different fuel nozzles, different tank angles (slopes), and with the evaporative orifice teed into the refueling vapor line. In all

Table 3-2

Test Data Results for Onboard Control System

Test No.	Fill Rate (gpm)	Emissions (g/Gal)	Average Tank Backpressure (in Hg)	Premature Shut-offs	Shut-Off Mechanism	Gallons Dispensed (c)	Comments (d)
1	10	.01	.38	N/A	N/A	12.8	
2	10	.02	.38	None	Manual (e)	13.2	
3	10	.03	N/A	N/A	N/A	12.8	
4	5	.05	.30	2(a)	Automatic	13.5	Filltube restricted with clamp
5	5	.06	.12	None	Automatic	13.6	3/8" Vapor Line Filltube restricted with clamp
6	5	.06	.13	None	Automatic	12.8	3/8" Vapor Line Filltube restricted with clamp
7	5	.04	.12	None	Automatic	12.8	3/8" Vapor Line Filltube restricted with clamp
8	5	.05	.06	3(a)	Manual (b)	12.8	1.025" restriction in filltube
9	10	.08	.20	3(a)	Manual (b)	12.7	1.025" restriction in filltube
10	10	.04	.30	None	Manual (b)	13.0	1.050" restriction in filltube
11	5	.04	.09	None	Manual (b)	12.8	1.050" restriction in filltube
12	4	.01	.05	None	Manual (b)	12.8	1.050" restriction in filltube
13	3	.02	.03	None	Manual (b)	12.9	1.050" restriction in filltube

(a) Shut-off occurred at the start of the refueling event.
(b) Nozzle shut off automatically upon topping off.
(c) This does not include the 1.5 gallon initial (10%) fill. Nominal tank capacity is 15 gallons.
(d) All tests were performed using a 1/2" vapor line and 1 1/4" minimum fillpipe diameter unless noted.
N/A Data not taken.

cases the system has performed as expected. The only real finding, although not surprising, is that higher RVP fuels require a larger canister.

5. Conclusions

The goal of EPA's program was to demonstrate the concept that it is possible to construct a simple, yet fully functional integrated onboard refueling/evaporative system using components based on current production hardware. As can be seen from the discussion above, a system very much like the present evaporative control system was constructed using currently available production hardware, which for the most part required only minor modifications. No complexity was added to the system and in fact the system was simplified as compared to the stock system; the external vent line was removed, connections were eliminated and the vapor line to the canister was shortened significantly. In addition, fill performance was improved by the elimination of the spitback which occurred in the stock system, and it is reasonable to expect that improved venting and the anti-spitback valve would reduce fuel spurting problems related to high in-use tank pressures. The emission test results shown in Table 3-2, clearly indicate the ability of the system to meet EPA's proposed refueling emission standard with a comfortable margin of safety. These results were accomplished with minimal time and resources and improvements to the system are clearly possible. EPA made no real attempt to improve component design or in any way to optimize system performance.

EPA expects that because of cost and design considerations manufacturers will be motivated to adopt the simple approach presented here and apply its concepts to their different fuel systems, with modifications and improvements engineered into these components and systems just as they are for other systems/components used on the vehicle. For example, just as manufacturers use different rollover/vent valve design approaches on their current vehicles, some manufacturers could choose a valve approach which is a variation on, but not identical to, that used by EPA. However, with or without onboard controls, in order to address the proposed test procedure modifications, EPA expects that manufacturers will have to incorporate a valve that provides adequate tank venting, thereby resulting in low tank pressures. Similarly, just as vapor line diameter and canister locations vary on present vehicles EPA also expects some variation in these design features for an onboard control system. However, upon full evaluation, for simplicity and cost considerations, EPA expects that manufacturers will likely select an integrated approach over separate control systems . Thus while systems identical to EPA's may not be used by all manufacturers, EPA's development work suggests that integrated systems with tank mounted valves and liquid seals are the preferred approach.

As is shown in Appendix I, it should be noted that many manufacturers presented non-integrated systems in their comments. A dominant reason for this choice was the proposed refueling test procedure, which manufacturers believed favored non-integrated over integrated systems. As proposed, they believed the test procedure requirements imposed a less difficult vapor purge requirement on non-integrated systems compared to integrated systems. However, as was discussed in the NPRM, from an environmental perspective, integrated systems have definite advantages in terms of controlling excess evaporative emissions. In the notice that announces the availability of this report, EPA will propose test procedure modifications that will insure that either approach results in systems that deliver equivalent in-use performance. If non-integrated systems are to be used, the proposed test procedure changes will insure that they provide the same in use performance as integrated systems. These test procedure changes are likely to eliminate any perceived purge advantage of non-integrated versus integrated systems in terms of test procedure requirements and thus lead manufacturers to further consider the advantages of an integrated approach discussed below.

Given that many of the system designs presented in the comments did not incorporate the concepts used by EPA, one might ask what elements of the approach would ultimately make it preferable. In general, these can be broken into four areas: design improvements, cost, packaging, and systems engineering.

First, as will be discussed further in Chapter 4, the EPA concept is no more complex than current evaporative systems and provides improvements by removal of the external vent line, a reduction in fuel spitback and spurting, a shortened vapor line, lower fuel tank pressures, and control of excess evaporative emissions which are often now vented in engine compartments. Depending on one's view of the complexity issue, these design improvements may also have some positive safety implications. Second, in terms of cost, an integrated system is less expensive than a separate system. It requires only one canister, one vapor line and one purge line, versus two of each for a separate system. The use of a liquid seal avoids all cost associated with mechanical seal designs. Also, avoiding the use of these components reduces weight and improves fuel economy relative to the separate system. Closely related to cost are advantages related to packaging and engineering. Use of an approach similar to that shown by EPA will require that only one canister, purge line, and vapor line be packaged on the vehicle instead of two as would be required on a separate system. Finally, in terms of engineering, developing and implementing this type of system into the vehicle is likely to be a simpler task than with other approaches. There are fewer components, fewer connections, and integrating one vapor control system into the vehicle should be an easier task than is two.

In summary, an objective evaluation of the pros and cons suggests that the use of the concepts shown by EPA have a number of advantages. They could be implemented on most vehicles and would likely require no more time and other resources than systems suggested by the commenters.

6. Analysis of Comments

a. Introduction

Chapter 2 and Section B of this chapter provided key background information on the design and safety of current fuel/evaporative control systems. Taken together these discussions show that despite the wide range of complexity in current fuel/evaporative control systems there is no evidence that there is a safety problem with evaporative control systems in general or that the increased complexity of some systems designs has affected their in-use safety. Furthermore, the analysis in Section B of this chapter showed that most safety concerns regarding various onboard system components were essentially rendered moot by the fact that very similar components were now in-use, presumably safely, on current evaporative systems. Given the important perspective provided by this information on evaporative system design and safety plus the description of the design, development and testing of EPA's onboard control system concept, presented above, we turn now to an analysis of the technology and safety comments regarding onboard control systems. These comments were summarized previously in Section A of this chapter.

The analysis of comments is generally broken into two sections. The first portion addresses general comments received regarding onboard technology and safety while the second addresses specific technology and safety concerns related to design and hardware.

b. Analysis of General Comments

The general concerns regarding onboard system technology and safety can be summarized by the statement in Section A of this chapter that "onboard vapor recovery systems would be more complex than current evaporative control systems and that adding this complexity would cause an unquantifiable increase in the risk of both crash and non-crash fires." The discussion then goes on to cite complexity and risk factors such as larger components, more components, more connections, component materials, component locations, and indirect effects on other systems. The commenters then provided various potential systems designs to demonstrate the possible complexity involved (see Appendix I).

Two key points need to be made in response to this general concern. First, one must question the premise. What evidence is there of a relationship between safety and complexity?

Since evaporative control systems are presently the best analog for onboard vapor recovery systems, it is valuable to consider what can be learned from the experience with safety and complexity for current evaporative system designs. First, as was discussed in Section B of this chapter, there is a wide range of complexity in current fuel/evaporative systems. The size of the individual components, the overall number of components, and the number of connections required varies greatly among the designs. Also, a variety of different materials were used to make these components and the locations of the components on the vehicles varies with essentially every model. Yet despite the wide range of diversity and complexity in these evaporative system designs, Chapter 2 found very few evaporative system safety problems and there was no relationship evident to suggest that any one design or design approach was any more or less safe than any other. Thus, the available evidence suggests that the current in-use systems most analogous to onboard vapor recovery systems incorporate a wide range of design complexity with no evident effect on safety.

Second, if there is still a concern about complexity, perhaps the most important point demonstrated by the EPA onboard system development program discussed above is that onboard vapor recovery systems need not be any more complex than even the more simple current evaporative systems and that onboard could indeed be viewed as an extension of evaporative systems. A visual comparison between Figures 3-21 and 3-23 clearly demonstrates this point. Very few changes were needed to incorporate onboard refueling controls into the stock fuel evaporative system. The concepts of operation are essentially the same and essentially every change necessary to incorporate refueling controls brings with it a design improvement as compared to the stock system. Depending on one's view of the complexity issue, these design improvements could bring safety benefits as well. The addition of an anti-spitback valve protects against fuel spurting upon cap removal and reduces spitback during refueling. Use of an enlarged vapor control valve allows fuel tanks to vent more freely at lower tank pressures and this also reduces possible fuel spurting problems. Eliminating the external vent line closes off a 1/2" passage from the tank now unprotected in the event of a disconnection. Locating the canister in the rear of the vehicle allows a much shorter vapor line, and allows uncontrolled emissions to be vented in a safer place than under the vehicle hood. Finally, increasing canister size improves the ability to capture excess evaporative emissions thus preventing their escape to the atmosphere.

Overall, an onboard vapor recovery system need be no more complex and in many cases could be less complex than current evaporative systems. Furthermore, the results of the EPA onboard design and development program demonstrate that onboard systems need not be as complex as suggested by many of the commenters design concepts. Much simpler approaches are possible. EPA recognizes that our emission standards are performance standards and that we cannot dictate design. However, simplicity concerns and cost considerations will clearly encourage manufacturers to evaluate and apply design concepts and approaches similar to those put forth and developed by EPA. More complex systems are not inherently driven by an onboard requirement. If more complex designs are chosen, we expect manufacturers to safely incorporate them into their vehicles just as they have done with the wide range of complexity in evaporative system design.

In addition to the more general concerns expressed regarding onboard technology and safety, EPA received a number of safety comments related to specific designs and hardware. The comments in these areas are addressed next in essentially the same order as present in Section A of this chapter.

c. <u>Analyses of Specific Technology and Safety Comments</u>

1) <u>Fillneck Seals</u>

The onboard system presented by EPA in the NPRM included a liquid seal approach to controlling refueling emissions. Despite EPA's view that this system would be preferable from both a cost, performance and safety perspective a number of commenters cited reasons why a liquid seal could not be used, but essentially no data were provided to support their views. The concerns cited by the commenters included: 1) ability to pass the proposed standard, 2) ability to form a seal at low flow rates, 3) increased refueling emissions, 4) an increase in spitback spills, 5) difficulty in packaging, and 6) fill height limitations. Each of these is addressed below.

First, the results of the EPA test program presented above plus information developed in test programs conducted by two different commenters all clearly demonstrate that liquid seal systems are capable of providing the control needed at the liquid fillneck interface. Several different fuel systems have been fitted with a number of different liquid seal systems (J-tube, flowing liquid seal, submerged fill) and all have been capable of reducing emissions to a level well below the proposed standard.[9,10,11] Concerns raised by the commenters regarding fuel evaporation or vapor diffusion at the fuel/air interface did not manifest themselves in the test results. The liquid seal approach has been demonstrated to provide the sealing protection needed in the fillpipe.

Second, test results from EPA's recent program and that of one of the commenters showed that liquid seals could be effective over a wide range of dispensing rates. EPA's program was capable of controlling emissions at dispensing rates ranging from 3 to 10 gpm while the other commenters program was effective in a range of 4 to 11 gpm.[12] These results demonstrate that with proper design liquid seals can be effective at any reasonable lower dispensing rate.

Third, the concern that the use of a liquid seal would increase refueling emissions and lead to the need for a significantly larger canister appears largely to be an assertion not based on test data. As was discussed, most of today's vehicle fuel systems use either internal or external vent lines to route refueling emissions, so essentially by definition these vehicles now fill with a liquid seal in the fillneck. Thus, there should be no major impact on the refueling emissions load to the canister by using a liquid seal. The only extremely small incremental affect might be related to the nozzle aspiration and entrainment of all air in a liquid seal system versus air and vapor in a current system which uses a vent line. The only real exception would be in cases where the fillpipe diameter is relatively large (>2") and refueling vapors are routed out the fillpipe as fuel is dispensed. Designs of this type are uncommon on today's vehicles and will be rare in the future as the trend toward side fill continues.

EPA acknowledges that vapor generation could be reduced with a mechanical seal approach and that this could allow a small decrease in canister size. While a mechanical seal approach may be desirable from this point of view, as is discussed in the initial safety report (Appendix II), there are cost and other performance trade-offs involved with this approach and it is expected that their use will not be as common as now depicted in the comments.

Fourth, since most fuel systems now encounter a liquid seal during refueling, the concern that an onboard system using a liquid seal would inherently increase spitback spills is unfounded. In fact, the degree to which spitback spills are a problem on current vehicles would be addressed with onboard equipped vehicles by the use of an anti-spitback valve or similar piece of hardware. As discussed above, the use of this hardware essentially eliminated all spitback spillage for EPA's onboard prototype system and would be expected to be equally effective for other fuel systems. It is interesting to note that several manufacturers now use anti-spitback type valves in their fuel systems to address problems related to fuel spurting upon cap removal under high tank pressure. An anti-spitback valve design such as that presented above would help to address this problem as well.

Fifth, manufacturers expressing concerns about packaging a J-tube must realize that the NPRM presented the J-tube as one method of forming a liquid seal. Subsequent work has demonstrated that it is not needed in many fuel systems. Nevertheless, other options such as the submerged fill, flow restricting gate, etc., could also be used.

Finally, several commenters stated that fill height limitations would prevent the use of liquid seals on some vehicles. EPA agrees that simple fluid dynamics suggests that some minimum fill height is needed to make liquid seals work without premature shut-offs. However, when considering the fill height concern, one must once again realize that most vehicles today encounter liquid seals during refueling, so current fill heights must be sufficient by definition. Also, as the trend toward side fill designs continues, rear fill vehicles with inadequate fill heights will be even more uncommon. Furthermore, the required fill heights can be reduced through measures aimed at reducing turbulence, entrainment, and backpressure, and all of the liquid seal approaches mentioned previously can be evaluated.

EPA has carefully considered the concerns expressed by the commenters regarding the use of liquid seals. The data and information available still support EPA's view that liquid seal approaches could be used on most if not all vehicles and the cost, durability, tampering and other benefits of this approach suggest that liquid seals will likely be the design of preference. However, as is discussed in the attached initial safety report (Appendix II), mechanical seal approaches can be used effectively and safely if a manufacturer elects this approach after considering the trade-offs associated with this design option.

2) Vapor Control Valves

Three basic valve designs were presented and discussed by the various commenters. These included a fillneck mounted valve, a tank mounted mechanical valve, and a solenoid activated tank mounted valve. Each of these basic design concepts was also addressed in the previous EPA safety report provided in Appendix II. Comments regarding these valves are addressed below.

Several commenters expressed concern regarding the crashworthiness of fillneck mounted valves, and one commenter suggested that crash shields would be needed to protect these valves since they would be mounted in a crash zone. As was discussed in Section B of this chapter, fillneck mounted valves are used on several current fuel systems with no known safety problems. This evidence suggests that any manufacturer electing to use a fillneck mounted valve could do so safely. Furthermore, a review of the shop manuals for the two fuel systems discussed in Section B indicates that neither uses fillneck crash shields. Nevertheless, if a manufacturer elects use of these shields it certainly does not create a safety concern. Valve location is a manufacturer's design choice; there is no inherent reason why valves have to be placed on the fillneck or in other crash zones.

A tank mounted mechanical valve similar to those used on most vehicles today (see Figure 3-3) was discussed by several commenters. This is the basic approach used by EPA in the onboard prototype system discussed above, and since it could essentially replace the current valve, there is incrementally no real change in risk. Discussions with several manufacturers of these valves indicate no concern about being able to design a valve to serve the functions needed effectively and safely, and since manufacturers perform quality control checks on 100 percent of their production of these valves, high in-use reliability would be expected just as is experienced with current valves.[13]

With regard to both fillneck and tank mounted valves, concern was expressed that the use of plastics in these components reduced their crashworthiness. The issue of the use of plastics was addressed in Section B of this chapter, but it is clear from even a cursory review of current fuel and evaporative system designs that fuel tanks, fillneck pieces, and valves are made of plastic. This clearly suggests that there is no inherent safety risk in their use.

Finally, with regard to plastic valves and solenoid activated valves, concerns were expressed regarding static charge and electrical relays. Quite simply, these concerns are not new to onboard controls. Isolated plastic components must be grounded just as they are in present fuel systems. Furthermore, while EPA understands the concern regarding electrical relays in and around fuel tanks, one must consider that incremental to the widespread use of electric fuel pumps, potentiometers, etc., within current fuel systems this concern is not new or unique to onboard systems.

Thus, in summary, EPA's review of the comments regarding vapor control valves leads to the conclusion that they introduce no new or unique safety concerns. Any potential problems with these valves exist on current vehicles and presumably have been addressed satisfactorily.

3) <u>Vapor Lines</u>

A number of commenters indicated concern that a refueling vent line requires a somewhat larger diameter than an evaporative line and this would make it more prone to puncture or rupture in an accident or problems during assembly and repair. Several points should be made in response. First, it should be noted that based on EPA's latest work the refueling vapor line approximates the size of the current evaporative line it would replace. Thus, this is not a new or significantly changed component. Second, current evaporative lines vary in diameter by about a factor of 2 to 3 (5/32" to 3/8") and there is no indication of more problems with larger diameter lines. Third, as is discussed in SAE Standard J30, rubber vapor line wall thickness increases with inside diameter, so in contrast to the comments received, puncture and rupture resistance should increase. And of course, manufacturers have the option to use rubber, steel, nylon, or some combination of the three materials within their vapor line design configuration. Finally, as was discussed above, in conjunction with the development of the EPA onboard prototype program, a rear mounted canister leads to a substantially shorter vapor line, and thus can address any perceived vapor line safety concerns as compared to the current system.

4) <u>Liquid/Vapor Separator</u>

Many commenters suggested that a liquid/vapor separator would be needed in an onboard system, especially if the vapor lines slope downward or the canister is mounted below the fuel tank outlet point for the vapor line. However, the only safety concerns raised were with regard to the extra connections required with some approaches and an unsubstantiated assertion that due to its function such a component could potentially have all the same safety problems as a miniature fuel tank.

As was discussed in Section B of this chapter, fuel and liquid/vapor separators of various designs are in widespread use on today's vehicles. In addition to functional design variations, they also vary in size, material, number of connections, and location on the vehicle. Despite these differences, EPA is not aware of safety problems with any of these present components. The use of liquid/vapor separators will remain a design option with onboard system just as they are on current systems. Neither the stock system nor the EPA onboard prototype system discussed above incorporated this function other than indirectly through separation caused by the the path taken by the vapor enroute to the canister and the location of the canister itself. Either way, the common use of these components on current vehicles without safety problems indicates that, if desired, these components can also be incorporated safely into onboard systems.

5) <u>Canisters</u>

This discussion addresses comments received with regard to safety concerns about canister size, location, and other packaging impacts. More specific concerns regarding the safety of the canister itself and vapor ignitability are addressed in Section D of this chapter.

First, with regard to canister size, there are a number of factors which affect the size actually needed for any given set of fuel tank size and test conditions. These include factors such as purge rate and schedule, canister shape, and charcoal working capacity. Nevertheless, canister size itself is not really a safety issue. Current evaporative canisters vary in size by about a factor of 4, but there is no evidence of any relationship between size and safety. None is expected for refueling canisters either, since the design, materials and technology would be essentially identical. Other canister safety issues are addressed in Section D of this chapter.

Second, with regard to canister location, as was discussed above, there are good design reasons to place the canister in a rear location, but this is a design option since an underhood location is also possible and has been the location of choice for many manufacturers. While a number of commenters stated that a rear location for the canister would be preferable, several also stated that a rear location would have other drawbacks with regard to fuel tank size, cargo capacity, or head space in the passenger compartment. EPA's onboard prototype programs envisioned a rear mounted canister location, notably in the left rear quarter panel of the vehicle, similar in location to that of a current vehicle. General Motors packages the evaporative canister in the left rear quarter panel on its 1988 "W" body vehicles (e.g., Pontiac Grand Prix, Oldsmobile Cutlass Supreme, Buick Regal, etc.). The canister, shown is essentially a slightly modified version of one of GM's present canisters. The only modification is the dust cap added to the bottom of the current open bottom canister of the same size. Figure 3-29 shows the stock canister, modified canister, and dust cap.

A picture of the canister location on the vehicle is shown in Figure 3-30. It is interesting to note that the vehicle photographed in Figure 3-30 was a dual-exhaust vehicle (as shown in Figure 3-31). There was adequate space to package the canister, still accommodate the tailpipe and muffler assembly nearby, and not affect the crush zone on the vehicle. Given the relatively small size of this vehicle model, adequate packaging space without affecting crush zones would be available on most if not all other vehicle models. Similarly, EPA would expect that dual tank vehicles (only on larger light trucks) could rear mount canisters if desired since rear quarter panel space is even greater on these larger vehicles. While this is in the "crash zone," the analysis presented in Section D indicates that damage to the canister in an accident presents no unique safety concerns. In fact, a review of most manufacturers evaporative canister locations indicates that they must be considered expendable in accidents, since many are located in crash zones in underhood areas. This evidence indicates rear mounted canisters are clearly feasible from a safety view point and that manufacturers need not sacrifice

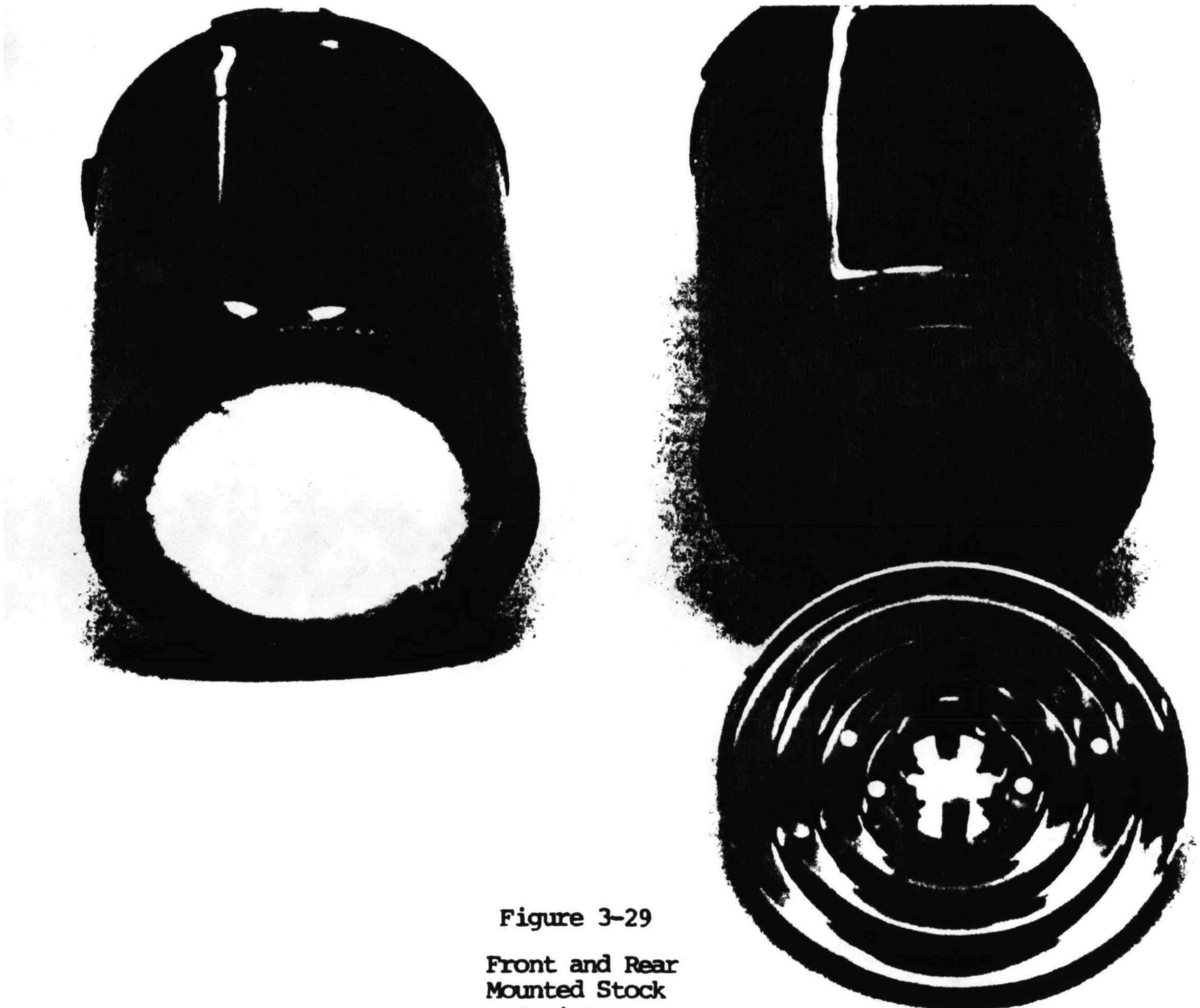


Figure 3-29

Front and Rear Mounted Stock Canisters

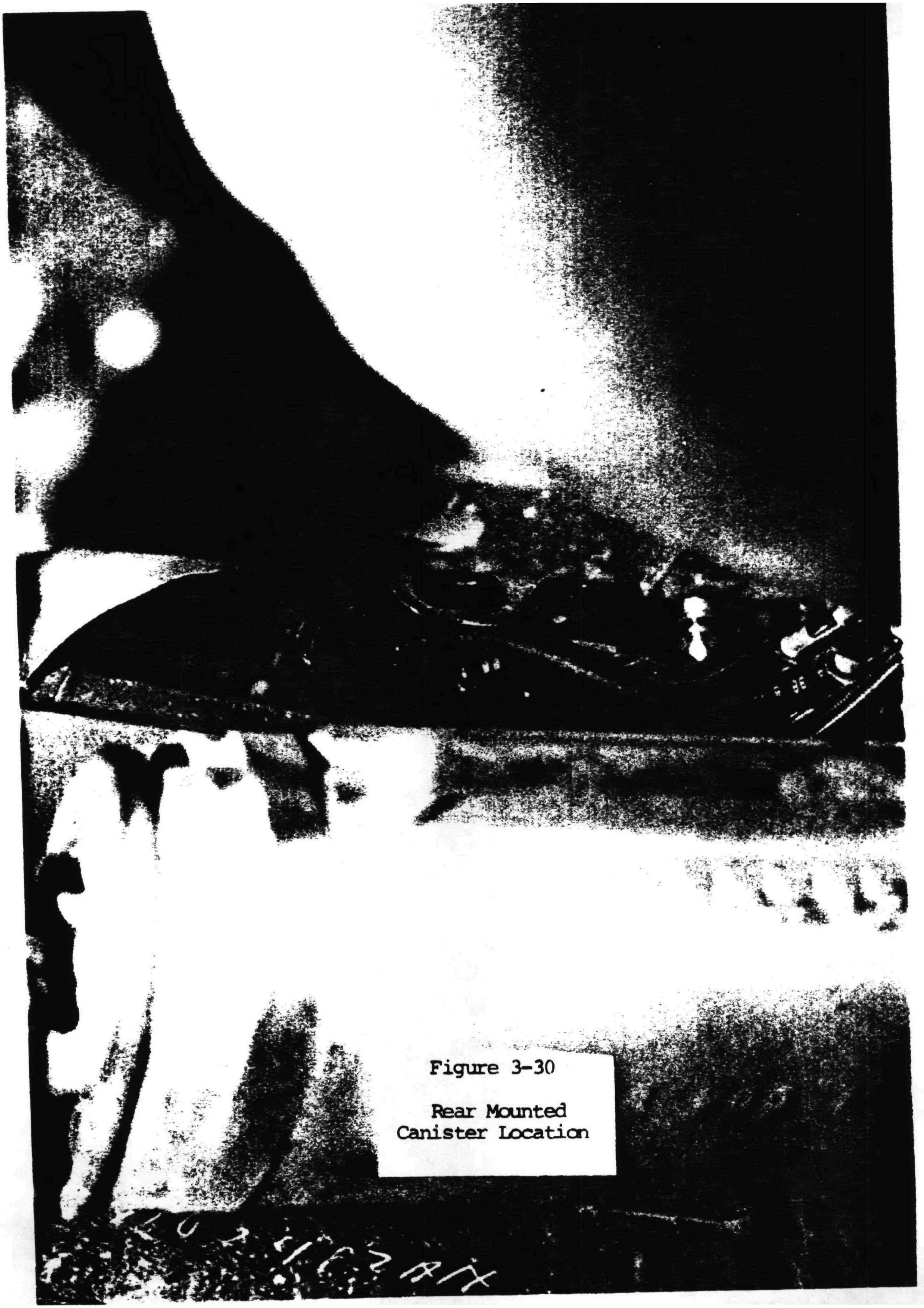


Figure 3-30

Rear Mounted
Canister Location

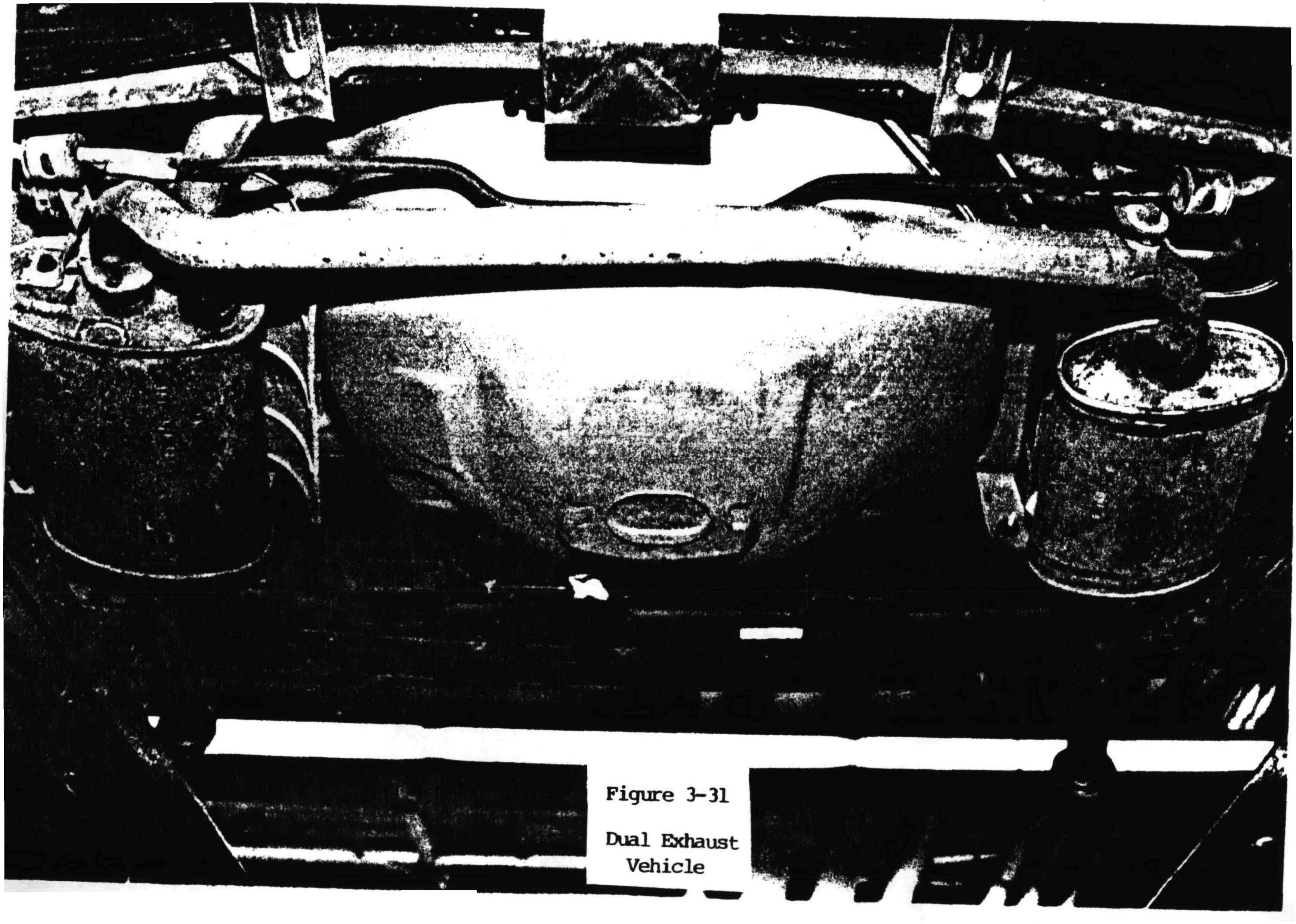


Figure 3-31

Dual Exhaust Vehicle

fuel tank size, cargo capacity, passenger compartment space, or crush zone to do so. Whether canisters are front or rear-mounted is a manufacturers design option; each has it's advantages and disadvantages. Finally, canister location is not a new concern brought about by an onboard requirement. Current canisters are located in a variety of places (underhood, fenderwells, rear quarter panels) all in crash and crush zones. The same design considerations which apply to evaporative canister locations are expected to also apply to onboard canisters.

6) Purge System Components

As was noted in the summary of the comments, manufacturers cited potential purge system related safety problems for onboard systems such as purge valve failure. As was the case for canisters and other components, purge system hardware is used on all vehicles with evaporative controls, so there are no unique issues for onboard systems. Purge system components are expected to remain the same, with perhaps new calibrations, so failure modes and effects would be the same as now exist for evaporative systems. Onboard controls introduce no new or unique safety concerns in this area. Incrementally there are no significant purge related safety issues for onboard systems relative to evaporative systems.

D. Other Safety Concerns

In addition to the onboard system design and safety comments summarized and analyzed above, comments were received in several other areas which fell somewhat outside the direct scope of the discussion above. These include comments related to onboard systems for heavy-duty gasoline vehicles (HDGVs), canister safety, the effect of onboard systems on the number of future safety recalls, crashworthiness, and failure modes and effects analyses. Each of these areas of comment is summarized and addressed below.

1. Heavy-Duty Gasoline Vehicles

a. Introduction

Relatively few of the many comments received regarding the NPRM dealt with heavy duty issues. Many of the heavy-duty issues raised could more properly be classified as evaporative emissions issues, since they were only marginally related to safety. However, they will be addressed in this section insofar as they pertain to onboard safety.

Heavy-duty comments were received from four general categories of commenters, based largely on where they fit into the production/distribution/usage scheme for HDGVs. Comments from the automotive industry reflect their role as the primary producers of truck and bus chassis and engines. There are three such manufacturers, Ford, Chrysler and GM, and they are also represented by the Motor Vehicle Manufacturers Association (MVMA). Comments were also received from two secondary manufacturing interests: truck and coach builders who produce commercial truck bodies on chassis purchased from the primary manufacturers, represented by the National Truck Equipment Association (NTEA), and the recreational vehicle (RV) industry, represented by the Recreational Vehicle Industry Association (RVIA). RV manufacturers produce campers and motor homes using chassis purchased from the primary manufacturers. Comments from these latter two groups tend to be generally similar in nature, but there are some differences in their concerns, as reflected in their comments. Comments were also received from the American Trucking Associations (ATA) and United Parcel Service (UPS) representing commercial vehicle operators. These comments tend to overlap the first three categories.

b. Summary and Analysis of the Comments

1) Ability to Use Liquid Seals

Summary of the Comments: Several commenters expressed doubts about the feasibility of liquid seals for HDGVs. Ford and the American Trucking Associations stated that some HDGV fuel tanks, particularly the side mounted or so-called "saddle" tanks, have short fillnecks or fillnecks that are integral with the tank and so may not be able to use liquid seals. They stated that manufacturers would thus be forced to rely on mechanical seals, which could present problems with durability of the seal or with inadvertent overpressurization of the tank, through failure of the automatic nozzle shutoff during a refueling event. Overpressurization could thus result in a fuel spill during refueling. Ford stated that a submerged fill might be feasible, but unvented pressure buildup from diurnal and other heating of the fuel tank could lead to expulsion of fuel when the filler cap was removed.

Response to the Comments: This issue was originally discussed in EPA's safety report, but will be summarized briefly here. The reader is referred to the safety report in Appendix II for additional detail.

As stated in the safety report, most HDGV's do not use side-mounted tanks. Some applications, particularly the more numerous class IIB vehicles, which comprise over 75 percent of HDGV sales, use tanks mounted inside the frame rails, and should have sufficient fill height for a liquid seal. Moreover, as Ford stated, even vehicles with very little fill height may be able to use the submerged fill, which is a type of liquid seal. However, provision must be made for adequate tank venting when the submerged fill approach is used, just as a pressure relief valve is needed in the case of the mechanical seal to prevent overpressurization of the tank. It should be noted that the issue of tank pressures is not unique to onboard systems. Current HDGV fuel tanks using evaporative control systems and meeting OMCS requirements must now be properly vented, and adding onboard controls does not affect this requirement or the manufacturers ability to do so. In fact, as discussed in Chapter 4, onboard controls may offer safety benefits with regard to tank pressures and tank venting. Finally, although the mechanical seal, with proper pressure relief provisions, may be a somewhat less desirable design choice compared to the liquid seal, EPA is unaware of any inherent safety problem.

2) Increased Size of Canisters and Other Components

Summary of the Comments: GM and MVMA stated that some HDGVs use fuel tanks of up to 100 gallons capacity, and would require 25-30 liter canisters for control of refueling emissions. GM felt that the risk of an underhood fire would be increased because of use of larger canisters. RVIA also felt that the increased size and complexity of onboard systems would increase the risk of fire, which would be further aggravated by the flammability of typical materials (i.e., wood and fiberglass) used in RV construction. MVMA stated that the size of onboard components might preclude the use of integrated systems and RVIA anticipated problems finding space to locate the larger canisters.

Response to the Comments: First of all, the canister size estimates given by GM and MVMA appear to be somewhat high, even for extreme cases. Ford estimated that only 12-14 liters of canister capacity would be required for the largest fuel tanks (i.e., 100 gallons). Secondly, very few if any HDGVs use 100 gallon fuel tanks. Information gathered under an EPA contract for 1985 model year HDGVs indicated that the largest single tank available is 60 gallons.[14] Some dual tank installations may total 100 gallons, although it appears that the average dual tank capacity is more like 75 gallons.[15] Moreover, as stated in the safety report, it is estimated that only about 15 percent of HDGVs in the over 20,000 lbs GVWR weight classes use dual tanks providing such a large capacity. Average tank capacity is likely to be more on the order of 35-40 gallons (single tank) which will require canisters eight to ten liters in size.

Second, with respect to canister safety, if manufacturers are genuinely concerned about the risk of fires, the canister should be located in a safe place, away from any potential sources of ignition. Because of their size and general configuration, HDGVs have a great deal more flexibility than do light duty vehicles or trucks as to where the canister can be located. Safe location of the canister would be further facilitated by the use of integrated evaporative and refueling control systems, particularly since the trend toward increased use of fuel injection in HDGVs virtually eliminates any need for a separate hot soak canister. Furthermore, studies cited by API in their comments as well as EPA in-house testing (discussed in the next section) have shown that the likelihood of underhood fires resulting from vapor or canister ignition is extremely small. It is also noteworthy that RVs routinely incorporate LP gas heaters and cooking units and/or gasoline-powered generators, all of which pose similar potential safety risks. Yet RV manufacturers have apparently been able to safely incorporate these devices into their RV designs. EPA concurs that manufacturers must carefully consider canister location as well as other factors to minimize safety risks, but does not find this to be a major obstacle for HDGVs.

Finally, it is worth noting that HDGVs provide an opportunity for development of vapor limiting devices such as bladder tanks. Some manufacturers, e.g., Ford, have already been investigating this alternative.

3) Purge Problems

Summary of the Comments: GM, Ford, MVMA, ATA and the United Parcel Service stated that HDGVs would experience difficulties purging the collected refueling vapors because HDGVs typically spend considerable time at low-vacuum wide open throttle (WOT) operating conditions. Ford stated that current evaporative systems are pushing purge systems to the limit due to this factor. Consequently, HDGVs would spend more time with canisters at or near saturation than would passenger cars and light trucks. ATA felt that supplemental purge air blowers or heaters would be required for proper purge operation, and that this could increase the risk of vehicle fires (for example if sparks came into contact with gasoline vapor as a result of component failure).

Response to the Comments: Manufacturers have considerable flexibility under the current EPA test procedure to balance purge rates/schedules against canister sizes to insure that canisters are properly purged. The same net effect can be achieved with a less stringent purge rate/schedule used with a larger capacity canister or with a more stringent purge rate/schedule and a smaller canister. Thus, there is sufficient latitude to accommodate varying usage conditions. Moreover, given the relative size and frequency of evaporative and refueling loads, it becomes evident that the evaporative emission load is the governing factor in determining purge requirements. The refueling load may be added to the typical daily evaporative emission total, but refueling loads are much more infrequent, and so they only occasionally constitute the bulk of the canister loading. EPA believes that the small incremental effect can be managed with due consideration to the tradeoffs described above without a substantial increase in purge rate/schedule.

Furthermore, with respect to the WOT issue, no data were presented to support claims of extended low-vacuum or WOT operation. The CAPE-21 data base, which forms the basis for both the EPA engine dynamometer cycle and the chassis dynamometer cycle used for evaporative emissions testing, indicates that only slightly more than ten percent of typical HDGV operation occurs at greater than 90 percent power conditions. It should also be remembered that most HDGVs are designed for intra-city operation, rather than long-haul operation, and do not normally carry maximum loads over extended distances. If the commenters' concerns are valid, it raises a question of the in-use effectiveness of current evaporative systems and whether EPA needs to increase the amount of operation at WOT conditions in the current certification test procedure to ensure that in-use canisters are in fact being properly purged. However, while there are certainly exceptions, no evidence has been presented to indicate that extended WOT operation is either typical or even fairly common.

With regard to purge hardware, it should be noted that current HDGVs use vacuum actuated/controlled purge valves which provide minimal sophistication in terms of varying purge rates and purge schedules. As fuel injection and electronic engine controls are phased into the HDGV market over the next few years, the use of electronically controlled purge valves, similar to those used in current LDVs and LDTs, offers the potential for greater flexibility in developing refueling and evaporative canister purge schedules. With regard to purge assist hardware, ATA presented no data in its comments to show a need for purge blowers or heaters. Furthermore, as shown above, the use of such devices will be driven by evaporative emissions control, rather than onboard control requirements. If these devices were to be used, prudent design considerations would dictate that they be constructed in such a way that they would be safely incorporated into the vehicle design.

4) Secondary Manufacturer Concerns

Summary of the Comments: Ford, GM, Chrysler, NTEA and RVIA commented on the problems arising from the fact that a significant number of HDGVs are not totally manufactured by a single entity, but rather have the coachwork installed by a secondary manufacturer on a chassis purchased from the primary manufacturer. Problems could arise when these secondary manufacturers modify fuel tanks, fillpipes, and other fuel system components to suit their individual vehicle configurations. Most commenters stated that this would increase the risk of fires, fuel leaks or malfunctions in the onboard control system. NTEA stated that bodies might have to be mounted higher on the chassis to avoid trapping fuel in the fillpipes, thus raising the vehicle center of gravity and increasing the risk of rollover or other handling problems. RVIA stated that most RV manufacturers were small businesses with limited resources and most lacked the necessary expertise to safely incorporate onboard systems into their designs. They feared that the risk of fires could then be increased due to the increased complexity of the systems and the inability of most secondary manufacturers to deal with the increased complexity. Secondary manufacturers also expressed concern over determination of the legal and recall liability for systems that had been designed by a primary manufacturer, but which may have been modified by a secondary manufacturer.

Response to the Comments: While EPA recognizes that difficulties can occur anytime that more than one manufacturer is involved in the manufacture of a given vehicle, this problem is hardly a new one. It has existed in the past and still exists now in conjunction with the modification and addition of fuel tanks, fillpipes and other fuel system components, as well as with the more recent incorporation of evaporative emissions control systems in HDGV fuel systems. Furthermore, secondary manufacturers have been required to comply with FMVSS 301 (for busses and vehicles less than 10,000 lbs GVWR) and applicable OMCS fuel system safety requirements for modifications to the primary manufacturers' fuel systems for a number of years. Yet these standards have apparently been met with a minimum of difficulty. Onboard control systems present few new problems with fuel system design relative to current evaporative/fuel systems, and most problems are merely incremental to those experienced with current evaporative systems. In fact, as discussed in Section 3C, incorporation of an onboard requirement could result in simplification of current systems. Straightforward solutions can be developed to address any problems involved. Onboard controls in fact afford an opportunity to alleviate some of the fuel system problems currently being experienced, e.g., overpressurization of fuel tanks. Vapor lines could also be shorter and external vent lines could be eliminated, thereby doing away with some current problem areas.

EPA also sees no technical reason why truck bodies would have to be mounted higher on the chassis because of onboard control requirements, and no supporting rationale was provided by the commenter. If, for example, a manufacturer wished to gain additional fill height for a liquid seal, it would be unreasonable to raise the body when the same result could be obtained by simply extending and/or raising the fillpipe on the existing body.

Although the general certification responsibility rests with the fuel system supplier, i.e., the chassis manufacturer, incorporation of onboard controls into a modified fuel system may be within the abilities of many secondary manufacturers, particularly given the relatively simple nature of such systems. Ford's suggestion of providing fillneck kits to secondary manufacturers may represent one way of assisting these secondary manufacturers. In two separate meetings on this issue with NTEA, EPA has asked for technical input and suggestions on how the proposed onboard requirement for HDGVs could be structured to alleviate their concerns but little input has been received thus far. EPA remains open to exploring ways in which the onboard requirement could be met while minimizing the concerns to the secondary manufacturers. However, the Agency does not see onboard technology as introducing any new fuel system concerns to these manufacturers.

The question of legal liability for fuel system modifications done to a primary manufacturer's fuel system by a secondary manufacturer is also not a new problem. This issue has arisen with current evaporative regulations. However, since this problem does not make a vehicle more or less safe but only addresses legal responsibility, it is a legal problem, rather than a technical question, and is not directly related to the current analysis.

2. Canister Safety

a. Introduction

As was mentioned in Section A of this chapter, many commenters expressed concern about the fire safety of canisters. These concerns fell in two general areas: flammability of refueling vapors and canisters. Each of these is summarized and analyzed below.

b. Summary and Analysis of Comments

1) Refueling Vapor Flammability

Summary of the Comments: Several commenters were concerned about the flammability of vapors released from the canister or vapor line due to breakthrough or tampering. General Motors provided written comments and a videotape which suggested that underhood onboard canisters would create a fire hazard under some conditions.

Response to the Comments:

i) Location Concerns

From the outset it must be clear that if a manufacturer genuinely believes that there is a risk of underhood fire due to system tampering, malmaintenance, defects or other problems, then the canister and any other component in the onboard system thought to be of concern should be located elsewhere. This applies not only to onboard systems, but also to current evaporative systems. As will be discussed below, some information presented by General Motors suggests possible fire risk with current evaporative systems under some unique circumstances, but the in-use safety record of these systems cited in Chapter 2 reflects no history of fire problems. In any case, with the strong move towards fuel injected vehicles there is less reason to locate the canister under the hood than there was with carbureted vehicles, on which the float bowl must be vented to the canister. There may even be additional benefits to a rear-mounted canister, since it allows for a shorter vapor line from the fuel tank to the canister. This represents a cost saving. Thus, even absent safety concerns, EPA would expect that many integrated refueling/evaporative canisters would be rear-mounted by preference. However, it is worth noting that information regarding vapor flammability submitted by API suggests that flammable vapor mixtures exist only at a few points, even on a tampered or malfunctioning onboard system.[10] With the exception of a very narrow transition zone, fuel/air mixtures are either too rich or too lean to be flammable. Furthermore, API's work shows that surface temperatures of the exhaust system and the engine compartment do not get high enough under normal operating conditions to ignite even flammable fuel/air mixtures. Evaporative controls may even represent a safety improvement over pre-evaporative control vehicles which vented directly to the atmosphere at the carburetor and fuel tank vents.

ii) General Motors' Vapor Flammability Tests

Several points need to be made about the videotape and written comments submitted by General Motors with respect to underhood fires on vehicles with tampered onboard systems. After closely reviewing the tape, EPA had discussions with GM and exchanged several pieces of correspondence concerning both the techniques used by GM's contractor in this testing and the significance of the testing. (The interested reader is referred to these letters, found in Public Docket A-87-11, for more detail: IV-E-30, IV-C-93, IV-D-524, IV-C-107, IV-C-117.)

In their testing, GM's contractor cut the refueling vapor line of a vehicle equipped with a prototype onboard system and then deliberately placed the cut end of the vapor line near a damaged spark plug wire. In the course of the videotape it was explained that the refueling vapor, vapor line, and some adjacent wires caught fire when the vehicle was started after a refueling event.

Despite discussions and correspondence with GM regarding this test, GM has not yet satisfactorily explained the source of the vapors which caught fire. GM's videotape explained that, following the end of the fuel dispensing: 1) the fuel cap was replaced, 2) the nozzle was returned to the dispenser, and 3) the driver walked to the vehicle, got in and started the engine. Considering the time it would take to accomplish these three steps, it is difficult to understand how refueling vapors could still be flowing out of the cut vapor line and continue to flow after the fire started. Furthermore, since the prototype onboard system used a nozzle-actuated positive shutoff valve to the refueling vapor line, vapor flow should be cut off when the nozzle was removed. GM's initial explanation that the vapors were those remaining in the line and being displaced by inertia did not seem plausible.

Upon inquiry by EPA, GM suggested that the vapor exiting the line might be driven by the pressure differential across the fuel tank limiting orifice, which remained after the refueling event ended. (The fillpipe was not open to the atmosphere after the refueling event since a J-tube seal was used.) While a possible source of vapors, this pressure differential would have quickly been diminished at the rate the vapors were exiting the end of the line.

Nevertheless, if this suggested pressure differential were actually the cause of vapors flowing out of the vapor line after dispensing is stopped, then a similar problem might also exist with present evaporative systems. Subsequent testing on the stock vehicle model without onboard controls confirmed this to be true. Using the same tampering mode, GM's contractor was able to start and sustain a small evaporative vapor fire after several minutes of idling following a refueling event. While this result is not surprising, it is important to reconize that the entire tampering sequence is highly unlikely, and in-use experience with evaporative control systems indicates problems of this nature do not apparently occur.

iii) Conclusion

The videotape presented by GM demonstrates a potential problem which would have to be evaluated on both onboard systems and present evaporative emission control systems. Incrementally, there appears to be little difference in the potential for occurrence of this problem between the two systems, since the GM testing showed that both were capable of causing a fire under the given conditions. Therefore, as is the case with current evaporative canisters, manufacturers would have to carefully evaluate potential canister locations and choose a location deemed acceptable by vehicle safety considerations.

2) Canisters

Summary of the Comments: In addition to comments regarding refueling vapor flammability, several commenters expressed concern about the flammability of activated carbon, and some were even concerned about the "explositivity" of canisters. Toyota was concerned that carbon scattered out of a canister broken in a crash would be a fire hazard. On the other hand, both Ford and Nissan felt that the canister was not a safety problem.

Response to the Comments: To begin with, it should be noted that any concerns over the safety of carbon canisters are not unique to onboard controls. Carbon canisters have been installed on vehicles since the early 1970's. To the extent that manufacturers have concerns over the safety of onboard canisters, these same concerns apply to today's evaporative systems. However, while commenters have raised concerns over onboard canisters, EPA is unaware of any specific safety concerns with respect to evaporative canisters. In addition, EPA has not been provided with any evidence to suggest that evaporative canisters have posed any safety hazards to vehicle owners since they were implemented 18 years ago. Since onboard controls will use the same activated carbon control technology as evaporative canisters, there is no reason to expect that onboard canisters will affect safety any differently than current evaporative canisters.

In addition, to confirm that no carbon canister (evaporative or onboard) poses a serious safety hazard, EPA ran a series of small scale in-house tests to address the concerns raised about carbon flammability and canister explositivity. The test method used was to saturate an evaporative emissions canister with gasoline vapor, open the canister and spill some of the activated carbon from the canister into a pile, and try to ignite the activated carbon with both spark and flame sources. Carbon that had been soaked in liquid gasoline was also tested as a worst case situation. Ignition sources used included sparks thrown from a flint starter and grinding wheel on steel, and flames from a match and burning paper.

The testing showed that neither gasoline-soaked carbon nor vapor-saturated carbon would ignite with either spark source. Carbon in both conditions would light only after a flame was held directly to its surface and enough heat was provided to release vapor adsorbed onto the activated carbon. There was no explosive effect to the carbon fire; it simply burned with a low steady flame which slowly spread over the surface of the carbon pile and extinguished as the fuel was consumed.

The results of this testing were precisely as EPA had anticipated. There is no reason to expect that carbon saturated with gasoline (hydrocarbon) vapor would pose a unique or significant safety hazard. Hydrocarbon vapor will remain adsorbed on a bed of activated carbon until sufficient energy is supplied to release the hydrocarbons. Even if a heat source is present to supply the necessary release energy, the hydrocarbons are desorbed slowly enough to prevent the possibility of rapid combustion. Based upon this information, EPA has concluded that the use of onboard canisters on vehicles does not introduce any new or added risk, and that the flammability of carbon in any vapor control canister is not a fire hazard on a vehicle.

3. The Effect of Onboard Refueling Control Systems on Future Recalls and Technical Service Bulletins

a. Introduction

As was discussed in Chapter 2 for evaporative control systems, one way to assess the effect of onboard refueling controls on vehicle safety is to evaluate the extent to which these systems might affect future safety recalls and technical service bulletins. NHTSA was the first to suggest this approach, proposing that since onboard controls do not yet exist in-use, EPA should examine past recalls and service bulletins for problems involving components similar in nature to those which might be used on onboard systems, to identify the types of problems that might accompany the implementation of onboard systems.

Also with regard to future recalls and service bulletins, NHTSA raised the general concern about the effect of increased complexity. NHTSA believes that if onboard controls require the use of more/larger components or the modification of others, recalls and service bulletins may increase in number due to a greater opportunity for design/production errors, in-use problems (e.g., disconnections), and interference with other systems. While suggesting that this analysis would be useful, NHTSA also stated that an analysis of onboard controls' effect on future recalls can only be qualitative (i.e., identify types of problems), not quantitative, since onboard systems do not exist in use today and that any effort to predict the number or severity of future onboard related recalls is likely to be speculative.[16]

Both NHTSA and the manufacturers have provided information on recalls and service bulletins involving types of problems they believe to be relevant to onboard control systems. The purpose of this section is to describe the information received, and discuss the implications of this information for onboard control system safety.

b. Summary and Analysis of Comments

i. Recalls

Summary of the Comments: After considerable discussion and correspondence between NHTSA and EPA on the issue of recalls relevant to onboard controls, NHTSA arrived at a list of 38 recalls which they consider to be relevant.[17] These 38 recalls, shown in Table 3-3, fall into the following four categories: 1) Fillpipe-Related (10), 2) Vent/Vapor Line-Related (9), 3) Pressurized Fuel System/Volatility-Related (6), and 4) Evaporative Control System-Related (13). (These four categories represent EPA's characterization of the 38 recalls since NHTSA did not provide such classifications).

In addition, NHTSA recently provided information on over 350 recalls which they believe might be characteristic of the types of problems which future onboard systems could contribute to indirectly in the future.[16] These include 31 recalls concerning stalling/driveability, 20 related to exhaust emissions/temperatures, and 314 involving fire. NHTSA suggested a review of these cases might help identify ways in which onboard controls might adversely affect the performance of other vehicle systems.

EPA also received information from several manufacturers on this subject. EPA and NHTSA asked manufacturers to include as part of their comments on the NPRM information on any recalls and service bulletins which they believed would be relevant to onboard control systems. Most manufacturers responded by providing information on all problems related to

Table 3-3

NHTSA's 38 Recalls Relevant to Onboard Controls

Fillpipe-Related

NHTSA Campaign Number	Model Year(s)	Vehicle Type	Number of Affected Vehicles	Description of Problem
76V069	1975-76	Pass. Veh.	67,633	Defective rivets used in fabrication of fuel filler inlet assembly.
78V249	1978	Lt. Truck	5,317	Fuel filler pipe can disconnect in 301 collision.
79V139	1979	Motor Home	46	Fuel filler hose can come in contact with exhaust pipe.
80V019	1978-80	Pas. Veh.	9,429	Cut fuel filler tube in 301 crash.
81V047	1982	Pass. Veh.	5,200	Poor design of fuel filler & vent pipe leads to 301 failure.
82V021	1982	Pass. Veh.	519,329	Fillpipe hose clamp can fracture.
82V088	1983	Pass. Veh.	2,800	Cut rubber filler pipe connecting hose in 301 test.
82V109	1983	Pass. Veh.	1,849	Fuel filler hose breaks during 301 crash.
83V085	1982	Lt. Truck H. Truck	215	Hose type 3 piece pipe fails in 301 test.
86V101	1986	Pass. Veh.	27,000	Pierced fuel filler pipe in rear collision.

Table 3-3 (cont.)

Return/Vent Line-Related

NHTSA Campaign Number	Model Year(s)	Vehicle Type	Number of Affected Vehicles	Description of Problem
77V063	1977	Motor Home	242	External vapor line not connected to fill spout.
78V016	1973-74	Pass. Veh.	20,661	Cracking of fuel tank vent hose allowing fumes to enter trunk area.
78V195	1979	Pass. Veh.	13	Fuel line filter and vapor return line may deteriorate.
78V208	1977-78	Pass. Veh.	16,238	Insufficient clearance between floor pan and vent tube can damage vent tube.
81V004	1981	Pass.Veh.	14,000	Improper design/installation of fuel system such that it restricts fuel supply.
83V115	1984	Lt. Truck	1,548	Fuel or vapor line damaged due to assembly error.
85V014	1984	Motor Home	750	Auxiliary fuel tank is subject to overfill and pressure build up due to improper vent tube placement.
85V132	1985	Pass. Veh.	11,000	Bumper causes damage to air vent hose in accident.
85V154	1982-85	Bus	1,520	Fuel pipe vapor line disconnects in accident.

Table 3-3 (cont.)

Volatility/Tank Pressure-Related

NHTSA Campaign Number	Model Year(s)	Vehicle Type	Number of Affected Vehicles	Description of Problem
82V076	1982	Pass.Veh.	24,455	Pressure buildup in tank causes fuel spitback.
85V106	1979-85	Motor Home	28,545	Filler cap disengages suddenly when removed for refueling. May cause expulsion of vapor and gasoline.
87V052	1986-87	Van	15,500	RVP problem - expulsion of gasoline.
87V113	1983-87	Truck (Ambulance)	16,000	RVP problem - expulsion of fuel.
87V144	1983-87	Vans	188,000	Expulsion of fuel due to use of high RVP fuel.
87V155	1985-87	Motor Home	9,041	Expulsion of fuel due to use of high RVP fuel.

Table 3-3 (cont.)

Evaporative System-Related

NHTSA Campaign Number	Model Year(s)	Vehicle Type	Number of Affected Vehicles	Description of Problem
76V126	1976	Pass. Veh.	9,137	Erroneously installed piping for the "check and cut valve".
78V036	1977-78	Lt. Truck	20,000	Blockage of tank vent system can lead to pressure buildup and force fuel or vapor leakage through cracks in tank.
78V106	1977-78	Pass. Veh.	10,500	Defective fuel tank vent valve.
78V145	1973-77	Med. Truck	2,500	Liquid gasoline may discharge from bottom of canister because evap system may lack adequate capacity under certain fuel expansion conditions.
78V181	1978-79	Lt. Truck	23,000	Obstructed evap line causes pressure build up in tank.
79V019	1976-78	Pass. Veh.	17,800	Possibility of kinked evaporative system hose.
79V032	1977-79	Pass. Veh.	83,000	Obstructed evap line causes pressure build up in tank.
79V045	1979	Pass. Veh.	3,700	Misrouted vapor line to canister.
79V048	1975-76	Pass. Veh.	61,000	Defective pressure control valve.
79V212	1973-78	School Bus	2,950	Defective liquid/vapor separators.
84V116	1985	Pass. Veh.	2,385	Improper functioning of vacuum line valve.
87V111	1984-87	Van (Ambulance)	250	Defective vapor valve grommet on fuel tank. (This component was installed as part of a preliminary attempt at correcting the fuel expulsion problem of Recall No. 87V113).
87V157	1984-88	Pass. Veh.	25,000	Overfilling of the fuel tank can increase fuel system pressure to the point where fuel vapors escape from the charcoal filter and cause an engine compartment fire.

fuel/vapor lines and connections, clamps, valves, FMVSS 301 failures, addition of protective shields, etc. Many of these recalls were the same as those provided by NHTSA and those reviewed by EPA as part of the characterization of evaporative system safety presented in Chapter 2.

Response to the Comments: The first group of recalls addressed in this section are the 38 identified by NHTSA as being directly relevant to onboard controls. Before describing the relationship of these recalls to onboard controls, it is important to have a perspective on these 38 recalls are relative to other types of recalls. Since 1966, there have been over 4,200 safety recalls of over 130 million vehicles. The 38 recalls identified by NHTSA represent a very small fraction (less than one percent) of the total number of recalls issued to remedy other types of problems. Further, EPA did not receive any information to suggest that any of the 38 recalls involved problems that caused any deaths or serious injuries.

It is also important to understand that assessing the safety implications of onboard controls through an examination of past recalls of similar components must be done with full consideration of two very important concepts. First, onboard controls' effect on future recalls is highly dependent on the designs selected by manufacturers. Manufacturers can choose unnecessarily complex approaches such as some of those shown in Appendix I, or they can select simple approaches such as that demonstrated by EPA and discussed in Section 3C. This design dependence leads to the second key consideration - the incremental nature of the analysis. Any effect of onboard controls on future recalls must be viewed incrementally to the current recall situation. The incremental nature of the analysis applies to different subsystems and components of the fuel/evaporative system as well. If recalls for a given subsystem/component happened in the past, it does not necessarily imply that adding onboard controls would impact future recalls. In fact, even without onboard controls, recalls of this nature might continue in the future. With these two considerations in mind, we are now prepared to examine the relationship between onboard refueling controls, and the 38 recalls identified by NHTSA as being directly relevant. These 38 recalls will be examined according to the four groups shown in Table 3-3.

The first set of ten recalls shown in Table 3-3 involve problems related to the fillpipe. Onboard control systems should not have any effect on fillpipe failure problems. These problems happen without onboard systems, and there is no technical reason why onboard systems will affect the frequency or severity of FMVSS 301 fillpipe failures, or fillpipe installation, fabrication, and placement problems. Virtually all of these types of problems are not relevant to onboard hardware. In fact, the system design presented in Section 3C suggests that the fillneck and related components can be even simpler than at present. If one accepts the complexity argument, this could represent a potential safety improvement.

Furthermore, while some comments have suggested that the information in Table 3-3 provides evidence that the potential use of fillneck mounted valves in onboard systems would increase recalls, there is nothing inherent about onboard controls which drives the use of fillneck mounted valves. Some proposed onboard designs (including ones depicted in the NPRM) have shown valves mounted at the fillneck. However, after a closer examination, EPA has not identified any compelling reasons for relocating the vent valve currently used on most fuel tanks from its present position to the fillneck. In fact, it is anticipated that many manufacturers will elect to simply modify the current tank-mounted vent valve to perform the necessary refueling control functions. Even if a manufacturer chooses to use a fillneck mounted valve, this will not be unique to onboard systems, nor does it have to represent a safety hazard. As discussed in Section 3B, there are several current fuel/evaporative system designs which mount valves and other hardware in the fillpipe area, and presumably without compromising safety.

NHTSA also included nine return/vent line problems as being relevant to onboard control systems. Six of these nine recalls involved the external vent line which runs along the fillpipe. Onboard systems are not expected to have any adverse effect on these problems since onboard controls will not inherently increase the number of vent line connections (77V063 and 85V154), or change material selection (78V016), or placement (85V014, 78V208, and 85V132). In fact, some onboard designs are likely to eliminate this external vent line thereby reducing these types of problems in the future. Further, the other three recalls in this category are not at all related to onboard control systems, since two involve fuel return lines (78V195 and 83V115) and the other involves a restricted fuel supply system (81V004). Onboard controls will not affect the design of the fuel supply or return system.

The third group of recalls involves six problems related to pressurized fuel systems and/or high volatility fuels. Five of these six recalls involved fuel expulsion problems due to pressurized fuel systems operating with high RVP fuels. Some commenters believe these recalls resulted because of the evaporative system. However, as was discussed in Chapter 2, a multitude of factors are responsible for these problems, and evaporative systems cannot be identified as the sole cause. For example, most of the vehicles in Recall No. 85V106 and some in 87V113 were not even equipped with evaporative control systems. (A Federal evaporative emission standard for heavy-duty gasoline vehicles was not in place prior to 1985.)

Therefore, these problems were really caused by other factors such as high tank temperatures and/or high volatility fuel.

High fuel tank pressures are the result of a combination of three factors. First, fuel tanks normally operate under a slight pressure to reduce vapor generation and fuel leakage as required by FMVSS 301. Second, tank operating temperatures have increased recently as a result of the trend toward fuel injection and fuel recirculation. Third, the recent increasing trend in fuel volatility has combined with the first two factors to raise fuel tank operating pressures to higher than normal levels. The fuel/evaporative control system is sometimes modified to remedy high fuel tank pressure problems. This is because the evaporative system is the only one of the three contributing factors which can be practically modified by manufacturers. Therefore, it is not appropriate to fault the evaporative control system as the cause of high tank pressure problems.

It should also be noted that revisions to the onboard test procedure (discussed at the June 30, 1988 workshop held at EPA's Motor Vehicle Emission Laboratory in Ann Arbor) will help to alleviate pressurized fuel system problems in the future. The revised test procedure will encourage manufacturers to increase tank venting thereby insuring pressure is not allowed to build up substantially in the fuel tank. High fuel tank pressures have been identified as a contributor to safety problems such as fuel spurting, fuel leaks, and increased fuel dispersion in the event of a ruptured tank in an accident. Consequently, by encouraging the lowering of fuel tank operating pressures, the revised test procedure will enhance safety. As an aside, it is worth noting that in a separate action EPA has proposed to reduce the volatility of in-use fuel.[18] Any level of volatility control would help eliminate problems of this nature for present and future vehicles.

The final group of recalls on NHTSA's list are 13 recalls concerning the evaporative emission control system. These 13 recalls are the most directly relevant to onboard vapor recovery because they involve the type of components that would also be used on onboard systems such as vapor lines and vent valves. Once again though, the incremental nature of onboard relative to evaporative systems must be considered when analyzing the effects of these types of problems.

As was shown in Section 3C, an onboard refueling/ evaporative control system can use essentially the same valving and vapor line routing as is currently used in the evaporative system. In fact, onboard designs incorporating rear mounted canisters are likely to reduce current vent line lengths, with only a small increase in vapor line diameter. Consequently, the incremental impact of onboard controls on vapor line problems such as blockage (78V181 and 79V032), kinking (79V019), or misrouting (79V045), should be negligible and may in fact be positive. Similarly, since onboard controls will have a minimal effect on vent valves (the principal modification is a larger orifice), there should be virtually no effect on recalls of this nature (78V106 and 79V048). Pressure control valves such as that listed in recall 79V048 could not be used in an integrated onboard system. Furthermore, with regard to vacuum valve recalls (84V116), these types of components are used on present vehicles and will continue to be used on future vehicles (with or without onboard controls), so no incremental effect should occur. Finally, with respect to canister overloading problems (78V145 and 87V157), onboard systems together with the test procedure revisions will increase canister capacity under normal operating conditions and thus reduce these problems in the future. Thus, no increase in recalls of this type would be expected, and some decreases are possible.

As was stated in the beginning of this discussion, the potential effect of onboard controls on future recalls is design-dependent. The same is true for current fuel/evaporative systems. It is expected that for cost, engineering, packaging and other reasons in addition to safety, manufacturers will ultimately implement integrated onboard systems using liquid seals and tank-mounted valves. However, as is the case for most EPA emission standards, the refueling emission standard is a performance standard and not a design standard. As such, EPA does not, by regulation, mandate which onboard system designs must be used. Therefore, it is possible that some manufacturers may elect alternative designs that may introduce more complexity.

However, whether a particular design will lead to a recall appears to be independent of the complexity of that design. As was shown in Section 3B, there is a wide range of current fuel/evaporative designs with respect to complexity. In spite of the complexity that exists in some current systems, we are unaware of any information from NHTSA or manufacturers that demonstrates or suggests that system complexity contributes to more safety problems/recalls on current vehicles. Absent this information, we assume manufacturers have accommodated more complexity into fuel systems without compromising safety. Consequently, EPA expects manufacturers can accommodate a "complex" onboard design using methods similar to those used to insure other added fuel system complexities in today's vehicles (such as fuel injection and complex evaporative designs) have not degraded safety.

Even if one chooses not to accept the conclusion that increased complexity does not inherently lead to increased safety problems/recalls, as was explained in Section 3B, onboard systems do not have to add complexity. In fact, onboard systems can simplify features of current systems. Thus, if the complexity rationale is adhered to, it follows that the use of a simple onboard approach provides the opportunity to reduce the number of recalls in three of the four areas analyzed, and some decrease in frequency of occurrence is possible for the types of problems identified by NHTSA in their list of 38 onboard related recalls.

In addition to the four categories of recalls supplied by NHTSA, six manufacturers included information on 82 recalls they believe to be relevant to onboard controls. Some of the recalls had been identified previously in EPA's review of evaporative system recalls, or were included in NHTSA's list of 38 discussed above. These include those in the categories such as fillpipes, volatility, and canisters shown in Table 3-4, and EPA's view on the relevance of these recalls is unchanged. Table 3-4 also shows a number of other recall categories which the manufacturers suggested could be relevant to onboard controls. Many of these were related to the fuel delivery system and were included in the comments without explanation as to how they relate to onboard controls. EPA reviewed the summary information on these closely, but could not see any connection between these fuel system recalls and onboard systems.

Another area of recalls supplied by manufacturers involves problems related to crash shields. Some manufacturers use crash shields to protect hardware such as fuel tanks and fillpipes in accident situations, and it has been suggested that onboard control systems may require additional crash shields which could lead to additional problems. However, there is nothing inherent about onboard controls which drives the use of crash shields. Crash shields are a design choice which appear on some vehicles and not others with the same design feature. Similarly, some onboard designs may incorporate crash shields, but incrementally, there is no reason to believe that onboard controls will increase the use of crash shields. Consequently, onboard controls are not expected to affect crash shield recalls.

In addition to the 38 recalls NHTSA believes to be directly related to onboard controls, several hundred recalls involving fire, exhaust temperatures, and driveability problems were also recently provided by NHTSA,[16] with the suggestion that EPA evaluate these recalls for the possibility that that vapor recovery systems may indirectly create problems for other vehicle systems. NHTSA's letter also provided some specific examples as evidence for their concerns. For instance, NHTSA identified the five recalls in Table 3-5 as examples of how an emission control system could adversely affect exhaust temperatures. NHTSA further implied that emission control systems such as onboard refueling controls could similarly lead to stalling/driveability and fire recalls.

Table 3-4

Manufacturer Submitted Recalls Suggested To Be Relevant to Onboard Control Systems

Category	No. of Recalls
Fuel Lines	31
Fillpipes	3
Fuel Line Clamps/Connections	17
Fuel Tank	7
Fuel Pump	3
Crash Shields	6
Fuel Reservoir	1
Volatility	1
Fuel Line Plugs	5
Fuel Tank Caps	2
Diesel Fuel/Water Separator	2
Fuel Rail	1
Fuel Switching Valve	1
Canister	2
Total:	82

Table 3-5

Exhaust System Recalls Identified by
NHTSA as Relevant to Onboard Controls

NHTSA Campaign Number	Model Year(s)	Vehicle Type	Number of Affected Vehicles	Description of Problem
78V203	1978	Pass. Veh.	218,500	Defective "pulse air reed valve." (part of exhaust emission control system).
80E003	1977-78	Pass. Veh.	49	Missing exhaust pipe heat shield.
82V033	1983	Lt. Truck	24	Muffler grass shield inadvertently omitted.
85V077	1984-85	Pass. Veh.	8,671	Heat shields for catalytic converter outlet pipe were omitted.
87V165	1983	Pass. Veh.	126,319	"Pulsair check valve" could permit exhaust gas to melt plastic shut off valve.

EPA examined the more than 350 recalls provided by NHTSA to evaluate the possible indirect effects of onboard controls on other types of recalls. We first looked at the 20 exhaust related recalls with particular attention placed on the five specifically identified by NHTSA (see Table 3-5). Three of these five recalls (80E003, 82V033, and 85V077) simply dealt with the addition of a heat shield, with no relation whatsoever to vapor recovery controls. The other two (78V203 and 87V165) concerned an adverse exhaust emission control interaction. These two recalls had absolutely no connection to either evaporative or onboard controls. Further, none of the other 15 exhaust recalls supplied by NHTSA were influenced by the inclusion of an evaporative control system or would be influenced by onboard controls.

EPA also examined 31 stalling/driveability recalls for some possible connection to vapor control systems. However, no recalls in addition to ones included on NHTSA's list of 38 (Table 3-5) were found in which the evaporative control system adversely affected (directly or indirectly) a recall for a driveability problem. Stalling/driveability was raised as an onboard issue because of the increased purge capability allegedly required by an onboard system. However, increased purge rates would already be required by the evaporative-only test procedure described in the August 19, 1987 volatility proposal, regardless of whether the onboard requirement becomes final.[18] Incremental to the purge rates dictated by the test requirements of the volatility proposal, onboard controls will have no effect on these problems. Indeed, for both evaporative and refueling controls, manufacturers have a wide degree of latitude in trading off purge rate versus canister size and could keep purge rates at near current levels if desired. Therefore, no problems are expected from either the refueling requirements or the evaporative control requirements of the volatility NPRM.

Finally, EPA examined the 314 recalls related to fire for some possible relation to current evaporative or potential future onboard control systems. A careful examination found about half a dozen recalls related to fuel spurting from overpressurized fuel tanks, which some commenters have attributed to the evaporative control system. However, there are several reasons why the evaporative control system cannot be held responsible for these problems. As discussed in Chapter 2 and previously in this chapter, high volatility fuels are the major causes of these problems, along with the need to pressurize the fuel tank to reduce vapor generation and limit spillage during FMVSS 301 testing. These problems would have occurred even without evaporative control systems. As described above, EPA is including a provision in the reproposal test procedure to discourage pressurized fuel tanks. Therefore, this problem is likely to be reduced in the future as a result of the revised test procedure requirements.

Further, even apart from onboard and evaporative requirements, this problem would likely be reduced in the future as a result of EPA's proposed volatility controls.[18]

In addition, EPA also found two fire recalls involving problems which some commenters have suggested are relevant to onboard controls. One concerned a solenoid problem (82V091), and the other involved an electrically ungrounded filler inlet (81V092). These components are in common use in today's systems, and their use is expected to be continued regardless of onboard controls. Problems such as these indicate the types of concerns that must be considered by any manufacturer when designing systems (including ones on today's vehicles) which utilize solenoid vent valves or plastic fillnecks. These concerns are not new or unique to onboard vapor recovery. Therefore, it is difficult to conclude that onboard systems would noticeably affect the number of these types of recalls. Furthermore, the fact that only two recalls related to these concerns have appeared in NHTSA's records spanning more than twenty years, indicates that these types of problems are not widespread and are likely to continue to be a minor concern in the future.

Summary of Recall Information: As was mentioned in the beginning of this discussion, the number of recalls involved in this analysis represent a small fraction of the total number of safety recalls. The 38 recalls identified by NHTSA as being directly relevant to onboard controls represent less than one percent of the more than 4200 safety recalls that have occurred during the past two decades. This small number of recalls demonstrates that manufacturers have successfully designed safe fuel/evaporative systems.

In addition, although it has been shown that onboard system designs can be quite simple, such as that developed by EPA, or more complex such as those provided by several commenters, it is important to recognize that a wide range of complexity exists in today's vehicles. In fact, a general trend has been toward increased complexity in recent years. Despite this increase complexity, there is no suggestion from the recall data that indicates fuel/evaporative system safety has degraded. Given the similarity between onboard and evaporative systems, EPA has concluded that the addition of onboard controls will not increase the number of future fuel/vapor system recalls.

This is not to say that onboard controls will not be involved in any future recalls. We would expect that with or without an onboard requirement, some level of recalls would continue to occur with vapor recovery systems simply due to deficient designs, mistakes in production, defective components, etc. Any future problems would likely be minor since the problems that have occurred with current vapor recovery systems have been infrequent with minimal consequences. Further, since onboard control systems are essentially an extension of evaporative systems, their incremental effect on recalls is expected to be undetectable. Manufacturers can build on the experience gained in 18 years of designing and implementing complementary evaporative systems, and there is no reason to expect any significant number of problems with onboard systems over those that happened in the last and would occur in the future regardless of onboard systems.

ii. Technical Service Bulletins

Summary of the Comments: As part of their April 12, 1988 letter, NHTSA supplied EPA with a large number of service bulletin summaries.[16] The categories contained in the bulletins included all fuel system, carburetor, exhaust, and emission system bulletins (over 6800 bulletins in total). NHTSA included these 6800 service bulletins so that EPA might be able to identify ways in which onboard refueling controls might directly or indirectly lead to problems affecting other vehicle systems.

In addition, EPA and NHTSA asked manufacturers to include as part of their comments on the NPRM information on any service bulletins which they believed would be relevant to onboard control systems. In response, 5 manufacturers provided a total of 62 bulletins which they stated might be relevant to onboard controls. A summary listing of the service bulletin information provided by the manufacturers is given in Table 3-6. Like recalls, the service bulletins that were provided by manufacturers were intended to demonstrate the generic increased complexity argument which postulates that the use of more/bigger components can lead to more service bulletins. Examples of service bulletins provided by manufacturers include broken or defective canisters, vapor line problems, tank vent/overpressurization difficulties, and improper purging.

Response to the Comments: As with recalls, any analysis of service bulletins with respect to onboard vapor recovery will depend on designs selected by manufacturers and must be viewed incrementally to current fuel/evaporative systems. The analysis of service bulletins is not as confined to specific bulletins as was the recall analysis because NHTSA had not stated explicitly which individual bulletins they believe to be relevant to onboard controls. Rather, NHTSA provided EPA with thousands of bulletins to examine with the possibility of some being relevant to onboard controls.

As discussed in Chapter 2, a review of these 6800 bulletins revealed between 70 and 120 which were directly relevant to vapor control systems. These 70 to 120 bulletins essentially represent all potential problems which may be

Table 3-6

Manufacturer Submitted Service Bulletins Said To Be Relevant to Onboard Control Systems

Category	No of Service Bulletins
Driveability	15
Purge	10
Evaporative System Related	10
Fuel System (Tank, Lines, Pump, Filter, Switch)	15
Fuel Fill Difficulty	1
Noise/Odor	6
Fuel Filler Door/Cap	2
Water in Fuel Light-Diesel	1
Diagnosis Information	2
Total:	62

relevant to onboard vapor recovery, because no other bulletins were found which might even tangentially involve onboard controls without involving evaporative systems. It should be noted that EPA identified two bulletins involving problems that some commenters suggested would be relevant to onboard controls. One involved static charge build up on plastic parts, and the other involved the grounding of a solenoid. However, as was discussed above for recalls, there is nothing inherent about onboard controls which drives the use of additional ground wires, and incrementally, onboard should have no effect on these problems. In addition, EPA reviewed the service bulletin information provided by the manufacturers and found no new potential problem areas. Concerns with regard to driveability-, purge-, and evaporative-related hardware exist now and will not be incrementally affected by an onboard requirement. The remainder of the service bulletins suggested by the manufacturers were not related to onboard systems or had no associated safety implications. Therefore, in total, 70 to 120 service bulletins were identified as relevant to vapor control systems.

Even so, as discussed in Chapter 2, 70 to 120 service bulletins represent a minute fraction (approximately 0.1 percent) of the total number of service bulletins issued over the years. Because onboard systems are modifications of current evaporative control systems, and consequently will be similar, additional problems over and above those which would normally occur with evaporative control systems are not expected. Further, depending on the design, onboard systems have the potential to decrease problems, such as those with external vent lines or fuel system overpressurization and fuel spurting.

c. <u>Conclusions</u>

After a careful review of all recalls and service bulletins provided by NHTSA and the manufacturers, EPA has determined that problems most relevant to onboard controls are those which have occurred with current evaporative control systems, since the components of these two systems are so similar. Past experience with evaporative control systems (in the form of recalls and service bulletins) indicates very minimal problems with the types of components envisioned for use on onboard systems. As a matter of fact, since onboard systems are expected to require only marginal changes to the current evaporative control systems, the incremental increase in recalls/service bulletins with onboard systems is expected to be insignificant relative to current systems. Also, if one adheres to the complexity/risk rationale, EPA has demonstrated that onboard systems can be designed to reduce the usage of such components as external vent lines and certain evaporative hardware, so that current problems in these areas can be reduced in the future as a result of onboard controls.

Further, because of test procedure requirements, onboard systems will reduce tank operating pressures, and decrease the number of recalls related to tank overpressurization/fuel spurting. The incremental effect of onboard controls on future recalls and service bulletins, relative to current evaporative controls, is likely to be of insignificant magnitude to be detected, and may in fact be an improvement.

4. Crashworthiness

a. Introduction

One principle concern regarding the in-use safety of onboard systems involves the crash resistance of the system. In particular, some commenters questioned the strength of plastic parts and the consequences of onboard system components interfering with designed crash spaces. These concerns were addressed in Sections B and C of this chapter. However, one commenter (General Motors) had a contractor, Failure Analysis Associates (FaAA), crash test an onboard equipped vehicle to demonstrate the susceptibility of onboard components in a crash. The significance of this crash test is discussed below.

b. Summary and Analysis of Comments

Summary of the Comments: Aside from General Motors, no other commenter submitted crash test results or challenged EPA's finding that onboard systems could be designed to pass NHTSA's fuel system integrity standard (FMVSS 301). General Motors, however, submitted a videotaped demonstration of an onboard equipped vehicle being crash tested and also provided written documentation of the results.[19] In this particular crash test, the onboard equipped vehicle was subjected to a thirty mile per hour side impact. Following the crash, a measurement was made of the fuel leakage rate and was found to be 5.3 ounces in 5 minutes. The test conditions were similar to those required by part of FMVSS 301, except that the crash impact point on the test vehicle was centered directly at the fuel fillneck instead of the centerpoint of the side of the vehicle, and another vehicle was used in the collision instead of a barrier. The test vehicle was equipped with a replica of an onboard system prototype originally designed by Mobil Oil which was not intended to be production quality (IV-D-329). Even though it was not an official FMVSS 301 test of a production quality onboard system, the 5.3 ounces per 5 minute leak rate of the test vehicle was compared unfavorably against the 5.0 ounces per 5 minute standard of FMVSS 301.

Response to the Comments: Several aspects of the crash test performed by FaAA for General Motors combine to produce a test which yields results of questionable value. The use of the test results to characterize those which might be expected of a legitimate production quality onboard system is misleading at best. The key problems with the testing are discussed below.

To begin with, the stock fuel/evaporative system was not subjected to a crash test identical to that imposed on the onboard equipped vehicle to establish a baseline for comparison. The performance of the stock system under these same conditions is unknown. It may or may not have passed the FMVSS 301 standard under these conditions. While it might be assumed that the stock vehicle would pass FMVSS 301 testing, the onboard equipped vehicle was not subjected to a FMVSS 301 test. A lack of comparable tests for the stock and modified vehicle makes it difficult to draw any conclusions about the effect of the onboard system relative to the stock vehicle.

Second, the onboard system configuration chosen for the crash test was a replica of a prototype design intended only to demonstrate the feasibility of a particular onboard refueling control concept. This particular onboard configuration was not constructed with regard to safety or passing a crash test. The system had not yet been adapted to "common automotive production methods and materials as prescribed by Mobil as a necessary step before implementation." It is obvious that any production ready system would not incorporate a common paint thinner can for a liquid/vapor separator, or copper tubing connected to rubber hose with radiator clamps for vapor lines. Without first adapting this prototype or any other onboard system design to common automotive production methods and standards, it would not be surprising for a fuel leak to occur.

In fact, taking into consideration the fact that the onboard equipped vehicle was subjected to a crash situation involving one of the most vulnerable portions of the fuel system (the fillpipe), and that crash safety was not accounted for during the construction of the particular onboard prototype tested, a leakage rate of 5.3 ounces in 5 minutes indicates that insuring crashworthiness of an onboard system will not be a difficult task. If a system which did not consider crash safety in its construction could perform this well, this is a good indication that a system which incorporates correct automotive materials, and production, design and assembly methods could pass FMVSS 301 readily.

Finally, it is not technically valid to compare the leakage rate of a crash test involving conditions other than those required by FMVSS 301 against the FMVSS 301 standard and then to assert that this system was less safe than a baseline vehicle which was not tested under the same conditions.

Taking into consideration all of the inadequacies of this crash test, EPA has concluded that no results can be extracted from this testing that apply to any onboard system (well designed and production ready or otherwise). Nevertheless, EPA understands that the crashworthiness of an onboard system is an important element in the design and development of an onboard system. However, no other commenters suggested that onboard systems could not be designed to pass FMVSS 301 crash tests or provide a high level of in-use fuel system integrity, and EPA expects that any onboard system can be designed with the same or better level of crash resistance as current systems if crashworthiness is given proper consideration in the design and development process.

5. Failure Modes and Effects Analyses

a. Introduction

Failure Mode and Effect Analysis (FMEA) is a structured analytical technique that is widely used in the automotive industry to assess the potential risks of a new system. The primary objective of an FMEA is to minimize the risk and in-use consequences (effects) by determining corrective actions to prevent identified failure modes. NHTSA and other safety organizations have suggested an FMEA would be a useful technique for EPA to use to evaluate the risks of onboard systems.

b. Summary and Analysis of Comments

Summary of the Comments: To support various viewpoints regarding onboard safety, three commenters submitted FMEAs for onboard and evaporative systems. As part of their critique of the Mobil onboard system, General Motors submitted two FMEAs, one was the FMEA originally prepared for the stock fuel/evaporative system selected for modification by Mobil, and the second was a contractor prepared FMEA of the prototype onboard system developed by Mobil.[19] In addition, Ford submitted an FMEA type analysis which compared the potential failure modes and effects of a current evaporative system to those of three different onboard control approaches.[20] API also submitted an FMEA type analysis which compared the relative risks of several different onboard configurations against those of a simple current evaporative system.[10]

Response to the Comments: EPA examined the four FMEAs submitted by commenters and reached the following conclusions. First, the design FMEA submitted by General Motors on the stock fuel/evaporative system provided good insight on the scope and depth that the automotive industry typically enters into with this type of analysis, the failure modes and effects identified for a typical fuel/evaporative system, and the manner which risks are considered. It also provided good background information for the FMEA now being conducted for EPA (see below). The other three FMEAs were not particularly useful to EPA's safety analysis for the following reasons.

The contractor prepared FMEA of the Mobil prototype onboard system is not directly relevant to an objective analysis of onboard safety. The Mobil prototype system was an early design prototype intended only to demonstrate the feasibility of a refueling control concept. Before a serious evaluation of the safety of this system could be performed, it would be necessary to adapt this system approach and its components to common automotive industry standards for design, production methods, and materials. Component design and material selection for the prototype were based on ease of assembly for test purposes. It is obvious that this prototype was never intended to be production quality. Aside from identifying corrective actions for gross system inadequacies, an FMEA of a concept demonstration prototype system yields meaningless results regarding the safety risks of a properly designed, production ready system.

EPA also received FMEA type analyses from Ford and API. (The API analysis was performed by ICF). The Ford analysis only indicated whether potential failures and associated effects were possible for a particular system. It did not evaluate the likelyhood of failure or the severity of the effects for comparison among the systems. The ICF analysis compared the risks of generic onboard systems to those of a generic evaporative system. While the analyses performed by Ford and ICF identified general problem and improvement areas for the systems, neither analysis was sufficiently complete to yield conclusive results.

Although the FMEAs submitted to EPA did not produce any significant revelations about the safety of onboard controls, EPA recognizes the value of a properly performed FMEA as a risk analysis tool. Subsequent to the NPRM, based on suggestions by NHTSA and others, EPA entered into a contract in the spring of 1988 to perform a comparative risk assessment of onboard controls. In this work assignment, the contractor will use FMEAs to evaluate the incremental risks of a few different onboard system configurations for comparison to the incremental risks associated with other recent fuel system changes such as carburetion to fuel injection. Once it is completed, EPA will use the findings of this FMEA as one input in its deliberations regarding a final rule for onboard vapor recovery systems.

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3. "Design Considerations for Plastic Fuel Lines," M.J. Harrigan, SAE 880683

4. "Nylon 12 in the Automotive Fuel System Environment," Edward K. Gray, Gerhard Hopf, SAE 880684

5. "Study of Motor Vehicle Fires," Draft Report Prepared for NHTSA by Data Link, Inc., February, 1988.

6. National Truck Equipment Association's Comments on Onboard Proposal, February 11, 1988.

7. Onboard/Volatility Hearing Transcript, Washington/ Dulles Holiday Inn, Sterling, VA, October 27-29, 1987.

8. Letter to Charles L. Gray, Jr., U.S. EPA, from Gordon E. Allardyce, Manager, Certification and Regulatory Programs, Chrysler Motors, May 11, 1988.

9. Attachments to Memorandum "EPA/Exxon Meeting Regarding Onboard Controls," Glenn W. Passavant, U.S. EPA, March 1, 1988.

10. Comments of API in response to Onboard NPRM, February 11, 1988, available in public docket A-87-11 at IV-D-358 plus sub-entries.

11. Memorandum "Status of In-House Refueling Loss Measurements," Martin Reineman, SDSB to Robert E. Maxwell, SDSB, March 6, 1979.

12. "Vehicle Onboard Refueling Control," API Publication No. 4424, March 1986.

13. Memorandum "EPA Meetings With Potential Onboard Rollover/Vent Value Manufacturers," Jean Schwendeman, U.S. EPA, June 16, 1988.

14. "Characterization of Fuel/Vapor Handling Systems of Heavy-Duty Gasoline Vehicles over 10,000 pounds GVW," Jack Faucett Associates, September 30, 1985.

15. "Evaluation of Air Pollution Regulatory Strategies for Gasoline Marketing Industry - Response to Public Comments," March, 1987.

16. Letter to Chester J. France, U.S. EPA, from George L. Parker, NHTSA, April 12, 1988.

17. Letter to Glenn W. Passavant, U.S. EPA, from Paul H. Yoshida, NHTSA, January 7, 1988.

18. "Air Pollution Control; Fuel and Fuel Additives and New Motor Vehicles and Engines, etc.: Gasoline and Alcohol Blends Volatility and Evaporative Emissions; Notice of Proposed Rulemaking," 52FR31274, August 19, 1987.

19. Comments of General Motors on Onboard NPRM, plus attachments. Available in public docket A-87-11, IV-D-360 and additional sub-entries a through f.

20. Comments of Ford Motor Company on Onboard NPRM. Available in public docket A-87-11, IV-D-362.

CHAPTER 4

Potential Safety Benefits

The previous chapter summarized and addressed onboard system design and design related safety comments. In this chapter, potential safety benefits of onboard vapor recovery systems will be discussed and the basis for EPA's view that onboard systems can enhance automotive safety will be described. This includes EPA's analysis of the potential effects of onboard systems on the safety of service station refueling operations, as well as other safety improvements which could result due to the effects which the onboard system design could have on fuel system and evaporative system safety and on overall vehicle crashworthiness. Each of these aspects will be discussed in this section of the safety analysis.

A. Effect on Service Station Safety

1. Introduction

As was discussed in EPA's June 1987 report, from a technical view point it seems reasonable to expect that onboard vapor recovery systems would have a positive effect on the safety of automotive refueling at service stations. Refueling vapors that are currently vented to an area which poses somewhat of a safety hazard will instead be routed away from potential external ignition sources to a safer location (the charcoal canister). Also, due to test procedure requirements, onboard controls would be likely to bring about a decrease in the amount of gasoline spilled during normal vehicle refueling. Both of these are likely to improve service station safety. Refueling-related fires are likely to be reduced in number and other non-fire safety problems related to refueling should also decrease. Both EPA and Failure Analysis Associates (FaAA, a contractor for General Motors) have attempted to quantify the impact of onboard systems on service station fires. These analyses, along with a discussion of non-fire service station safety effects, are presented in this section.

2. Effect of Onboard Controls on Service Station Fires

a. Service Station Fires

EPA's preliminary analysis of refueling related service station fires is based primarily on information contained in the National Fire Incident Reporting System (NFIRS). NFIRS is a fire data base which is operated and maintained by the United States Fire Administration of the Federal Emergency Management Agency (FEMA). It should be noted that EPA is currently having a contractor further examine other information on service station safety. This additional work will further refine the analysis of the risks and benefits pertaining to service station safety, but is unlikely to significantly alter the conclusions drawn in the current analysis. The contractor's analysis should be available in time to be considered before any final rule on refueling vapor controls is promulgated.

The NFIRS data base compiles reports and information on all types of fires, including service station fires. The system receives fire marshall reports from different states and extrapolates national statistics from these. Approximately 40 percent of the total reported nationwide fires were reported to NFIRS from 1982 to 1985. However, a 1985 survey of member service stations by the Minnesota Service Station Association showed that there are about 19 annual fires per 200 service stations, and historically only about 1.75 of the 19 service station fires (or 9.2%) are reported to a fire department.[1] If this low reporting rate is a nationwide trend, then the number of NFIRS projected national fires may be much lower than the actual number of fires which occur since NFIRS only contains reported fires.

A second problem with the data used is that about 10 percent of the reported fires in the NFIRS data base occurred in the state of California (see Appendix III, Tables 9-15). A large percentage of California service stations are outfitted with Stage II vapor recovery systems, and therefore already provide refueling vapor containment which may help to reduce fires at these stations. Consequently, different assumptions may need to be made when considering how onboard systems would affect those fires. Not only do Stage II systems complicate the treatment of benefits from vapor control, but the treatment of benefits from spilled fuel control are also not clear. For this reason, the California statistics were subtracted from the nationwide statistics, and a 49 state data base (non-stage II) was used in this analysis.

Table 1 - Service Station Fires, in Appendix III, shows the actual service station fire information reported to NFIRS for the period 1982-1985 inclusive and the national statistics extrapolated from those reports. California fire data are contained in Table 9 but the average annual statistics are based only on 1982-1984 reports and do not include 1985 data, as the national average statistics do. Subtracting the California data from nationwide data gives 2466 average annual service station fires and $6,900,000 estimated dollar losses from these fires in the remaining 49 states. The number of fires are reported by category (structure, vehicle, other) along with an estimate of the dollar value of the property loss involved. These two tables also show the reported injuries and deaths caused by service station fires. The reported estimated dollar losses shown do not include any costs related to the reported injuries and deaths.

NFIRS data can also be used to characterize fires by several different factors as shown in Tables 2 through 8 in Appendix III. The nationwide NFIRS data is categorized by what type of fire occurred (Table 2), the mobile property involved (Table 3), the area of fire origin (Table 4), the equipment involved in ignition (Table 5), the form of heat ignition (Table 6), the form of material ignited (Table 7), and the ignition factors that caused the fires (Table 8). Tables 9 through 15 categorize the California data in this same method, except that a breakdown of the California fires by mobile property type (as in Table 3 for nationwide fires) was not available. In any event, this information was not used in the analysis.

Refueling-related events are not one of the categories directly reported in the NFIRS data. The characterizations of service station fires must be studied in an attempt to determine the percentage of fires directly related to refueling events. Close review of the information contained in Tables 2 through 8 in Appendix III indicates the following information which could have some connection to vehicle refueling fires:

Type of Situation Found - Tables 2 and 9	Percent of 49 State Fires
Outside of Structure Fire	≃ 22%
Vehicle Fire	≃ 45%
Outside Spill/Leak	≃ 18%
Area of Fire Origin - Tables 4 and 11	
Fires which Started in Service/Equipment Areas but not in Maintenance Shop/Area	≃ 8%
Fires which Originated at Fuel Tank Area of a Vehicle	≃ 5%
Open Areas	≃ 2%
Equipment Involved in Ignition - Tables 5 and 12	
Internal Combustion Engine	≃ 6%
Other Special Equipment	≃ 5%
Vehicle	≃ 27%
No Equipment Involved	≃ 25%
Form of Heat Ignition - Tables 6 and 13	
Heat from a Liquid Fuel-Powered Object	≃ 2%

Heat from a Smoking Material and Match/Lighter	≃ 4%
Backfire from Engine	≃ 14%

<u>Form of Material Ignited</u> - Tables 7 and 14

Fuel	≃ 78%
Atomized/Vaporized Liquid	≃ 1%
Gas/Liquid from Pipe	≃ 15%

<u>Ignition Factors</u> - Table 8

Fuel Spilled Accident	≃ 10%
Improper Fueling Technique	≃ 3%
Backfire	≃ 14%

If taken at face value, a summation of the applicable individual data in each table suggests that refueling-related fires could constitute between 15 and 94 percent of all service station fires. The 15 percent low is obtained by summing the potential refueling-related fires by Area at Fire Origin (Tables 4 and 11). The 94 percent high is obtained when the potential refueling-related fires are tallied from the fires categorized according to the Form of Material Ignited (Tables 7 and 14). Even though the categories of fires listed above have been identified as potentially being associated with the refueling process, only a certain percentage of the fires in most of them are actually directly caused from refueling emissions and/or spillage. The data base is only detailed enough to allow estimating a range of gasoline service station fires associated with these causes rather than a point estimate.

In several of the fire categories initially identified as potentially refueling-related it is probable that many of the fires could be totally unrelated to refueling. For example, fires identified in Tables 2 and 10, Outside of Structure Fires (22 percent), may not be all refueling-related. Along the same lines, Vehicle Fires (45 percent) could be in the engine or numerous other places on the vehicle, far from refueling vapors or fuel spilled during refueling. This is confirmed by the information in Tables 4 and 11. The figure which suggests that internal combustion engines were involved in six percent of the fires is not very informative for two different reasons. First, since a separate listing is provided for vehicles, apparently these internal combustion engines are not on vehicles but on other power equipment. Second, even if they are vehicles, the engine is far from the fuel tank, so any engine-related ignitions during refueling would have to be due to vaporized gasoline, which is said to attribute to only one percent of the fires (Tables 7 and 14).

Several other categories, both of high- and low-percentage frequency, although related, are far too general to be useful in estimating the percentage of refueling-related fires. Examples are service/equipment area fires (eight percent), open area fires (two percent), fires ignited by vehicles (27 percent) or ignited with no equipment involved (25 percent). Other examples are heat ignition from a fuel-powered object (22 percent), from a smoking material and match lighter (four percent) or from an engine backfire (14 percent in Tables 6 and 13, or 13 percent in Tables 8 and 15). The knowledge that fuel was the material ignited in 78 percent of the fires (Table 7) is also too broad a category to be useful in determining the percentage of refueling-related fires.

The remaining five categories in the list of potential refueling-related fires are those which may be the best predictors of the actual percentage of refueling-related fires. First, with regard to vapor, gasoline vapor (atomized/ vaporized liquid, Table 7) was the material ignited in one percent of the fires. It is not unreasonable to assume that many of these fires were due to vapors generated during refueling, since the refueling process is probably the most common source of vapor generation at a service station. Second, with regard to gasoline spills, outside spill/leak situations (18 percent) can be narrowed somewhat by looking instead at fuel-spilled accidents (10 percent), which would seem to be a subset of the former category. Furthermore, fires caused by improper fueling techniques (3 percent) are a separate category from the fuel-spilled accidents. While fires which occur due to improper fueling technique (3 percent) may be a subset of fuel-spilled accidents (10 percent) one cannot preclude the possibility that some portion of the difference in these percentages (7 percent) is also related to fuel spilled during refueling. For example, the fires which originated at the fuel tank area of the vehicle (five percent, Table 4) likely occurred during refueling.

Thus we are left with four useful pieces of data. As discussed above, it appears that about one percent of service station fires are related to atomized vapor/liquid such as that which occurs with each refueling event. With regard to spillage, the data suggests that ten percent of fires are due to spilled fuel, but clearly spill-related fires could occur in service/maintenance areas as well. To narrow this estimate, other characterizations in the data suggest that about three percent of fires are related to improper fueling technique (presumably causing a spill) and that five percent occur in the tank area of the vehicle being refueled (where spills occur). Using these values, about three to five percent of service station fires are related to fuel spilled during refueling. Assuming that the vapor and spillage data are mutually exclusive (no overlap in the data) this analysis suggests that approximately four to six percent of all service station fires are due to refueling emissions and/or spillage. In actual numbers of fires, this amounts to approximately 99 to 148 annual fires in the 49 non-Stage II states (based upon NFIRS 1982-1985 average projected national incidents and 1982-1984 average projected California incidents).

b. <u>Impacts of Onboard on Reducing Refueling-Related Service Station Fires</u>

Up to this point in the analysis, an attempt has been made to use the NFIRS data base to estimate the number of service station fires which may be due to refueling emissions and/or spillage. The goal of the analysis is to estimate the percentage of these refueling-related fires which might be prevented by onboard controls. In order to achieve this goal, two additional estimates must be made, the first concerning the efficiency with which onboard controls could prevent fires related to vapors and the second concerning the efficiency with which onboard controls could prevent fires related to spillage. For the first estimate it is assumed that a properly functioning onboard system could prevent essentially 100 percent of the approximately 25 fires due to atomized vapors or liquids (approximately one percent of the total fires), since refueling vapors are controlled almost completely with onboard technology.

In order to make the second necessary estimate of the percentage of these refueling spill related fires which would be prevented if onboard controls were implemented, EPA referenced the 1972 Scott Research Laboratories report "Investigation of Passenger Car Refueling Losses".[2] This report categorizes refueling spillage into the following groups: prefill drip, spitback, overfill and postfill drip. Based on actual field studies of consumer refueling, it estimates the probability and average amount for each spillage type. The study found that over 50 percent of the volume of fuel spilled during refueling is due to spitback and that the average emission factor associated with spitback spillage is 0.15 g/gallon of dispensed fuel. This is an important finding, since EPA's refueling proposal necessitates the design of vehicles which can accommodate in-use dispensing rates without premature nozzle shut-offs and spitback spillage. According to the test procedure requirements and the proposed emission standard (0.10 g/gallon dispensed), a test vehicle would fail the certification test if almost any spitback spillage occurred (0.15 g/gallon dispensed). Therefore, the occurrence of in-use spitback spillage should be substantially reduced with the onboard proposal.

Applying the Scott Research Lab finding that 50 percent of refueling spills are due to spitback to the NFIRS fire data implies that 50 percent of the estimated 74-123 annual fires due to refueling spills (see analysis in Section 1), or 37-61 fires, may be prevented by onboard controls. This may even be a conservative estimate, since spills due to spitback might actually result in a higher rate of fires than the other types of spills (overfill, prefill drip and postfill drip) because a relatively larger volume of fuel is spilled at each spitback event. The Scott Report found that the spit-back spills result in an average of 13.7 grams of lost fuel whereas overfill, prefill, and postfill on average result in 8.6, 5.9, and 1.8 grams of fuel loss, respectively.

Adding these estimates of fires which can be prevented by onboard refueling controls (25 fires due to atomized vapors and 37-61 fires due to spitback spills during refueling) gives a total nationwide estimate of 62-86 annual service station fires which could potentially be prevented with onboard refueling control. This is 2.5-3.5 percent of the projected nationwide service station fires. It is about 60 percent of the fires associated with the refueling process, which make up between 4 and 6 percent of the nationwide service station fires, as was determined earlier in the analysis. Table 4-1 summarizes the breakdown of service station fire data included in this analysis.

In addition to estimating the number or percentage of fires that can be prevented with onboard refueling controls, a monetary benefit was placed on the occurrences of property damage, injuries and lost lives which would be avoided if these fires were altogether prevented. As can be seen in Table 4-2, annual losses from service station fires in the 49 non-Stage II states are estimated to be between $50.0 million and $76.2 million dollars. This amount includes the property damage (as presented in the fire marshalls' property damage reports) caused by the fires and also assumed dollar amounts for each injury and fatality that occurred ($7.5 million per life and $100,000-$300,000 per injury, depending on the severity). Since it is estimated that onboard controls could prevent 2.5-3.5 percent of the 49-state non-Stage II fires then as an initial estimate it is reasonable that 2.5 to 3.5 percent of the $50.0-$76.2 million annual dollar losses ($1.25-$2.67 million) could be saved with the implementation of onboard controls.

It should be restated that these conclusions are the result of a preliminary analysis conducted by EPA. A more detailed analysis is being conducted by an EPA contractor. Additional sources will be used in this analysis, which should result in increased confidence in the results. As previously mentioned, the low reporting rate of fires by service stations which was made apparent by the Minnesota Service Station

Table 4-1

Analysis of NFIRS Service Station Fire Data*
(Average Annual Data for 49 Non-Stage II States)

Total Fire Incidents		2466
Refueling Related Fires		
Atomized Vapors/Liquids	25	(1% of total fires)
Fuel Spillage During Refueling	74-123	(3-5% of total fires)
Total Refueling Related Fires	99-148	(4-6% of total fires)
Expected Reduction in Refueling Related Fires with Onboard Controls		
Atomized Vapors/Liquids	25 @ 100% reduction =	25
Fuel Spillage During Refueling	74-123 @ 50% reduction =	37-61
Total Reduction in Refueling Related Fires		62-86 (2.5-3.5% of total fires)

* From NFIRS Fire Data Base, Appendix III Tables 1-15.

Table 4-2

Annual Dollar Losses From Service
Station Fires in 49 Non-Stage II States

(Data taken from Appendix III, Tables 1 and 9 NFIRS Data)

Average Numbers Over 1982-1985

	.9-State (Projected)	Estimated Dollar Loss
Fires (incidents)	2466	$6,915,588 (projected)
Fatalities	4	$30,000,000*
Injuries *	131	($13,100,000- $39,300,000)**

Total ≈$50.0-76.2 mil

* Assumes $7.5 million per life.
** Assumes $100,000-$300,000 per injury.

Association Survey could imply that the NFIRS fire data base underestimates the actual number of fires which occur. Also, the NFIRS fire data base only covers fires at public service stations. It does not include private stations, such as at an airport and it is not clear whether it includes "convenience store" service stations. Accounting for these possible problems in a more thorough analysis should lead to more accurate results.

c. Failure Analysis Associates' (FaAA) Analysis

As was mentioned earlier, FaAA also analyzed service station safety and the possible effects of refueling vapor control systems on service station fires. They did this in their report "Safety Issues in Systems Designed to Recover Gasoline Vapor During Motor Vehicle Refueling," prepared for General Motors and dated February 5, 1988.[3]

FaAA used two different approaches to analyze the fire risk reduction achieved by California's Stage II vapor recovery system. The first method of analysis was simply to compare the overall service station gasoline fires (number of fires reported to NFIRS per gallons of gasoline dispensed) in California versus an aggregate total of 18 non-Stage II states. A 50 percent lower overall fire rate was found in California. FaAA attributed all of this difference to the added safety of Stage II systems, but failed to make a link between the cause and effect of this lower fire rate in California. There is no apparent reason why Stage II equipment would have caused a lower rate of non-refueling related fires in California, such as structure fires and vehicle engine fires. However, FaAA presented the statistics without offering any technical basis to support their claims. The FaAA analysis fails to account for many important factors other than Stage II controls which influence the differences between California fire data and fire data from any other state.

FaAA's analysis ignores the difference in fuel volatility levels in California as compared to the other states. The Center for Auto Safety's "Study and Comments on Environmental Protection Agency Rulemakings on Gasoline and Alcohol Blend Volatility and Refueling Emissions From Gasoline Vehicles," shows high probability of a strong link between states with high fuel volatility and an increased frequency of fuel system fires, complaints, overpressurization and spitback. California has a lower volatility level (9.0 ASTM RVP in the summer and less than ASTM levels the rest of the year) than the other states analyzed. Also, based on Department of Transportation reports for the period studied, California uses a lower amount of alcohol blend fuel; about 4 percent for California versus a weighted average of about 7 percent for the other states. FaAA's failure to include the effect of differing in-use state volatility levels in their analysis introduces a considerable uncertainty into the validity of their conclusions.

There are additional differences between California and other states which could affect FaAA's analysis of service station fires. First, it is likely that California has better inspection and enforcement programs than most other states. This is a reasonable assumption in view of the fact that California commits a high level of resources to air pollution control and automotive emission compliance programs. Also, the fire codes used in California are different than those used in other states. This lessens (by some unknown amount) the degree of confidence that can be assumed in making a direct comparison of California fire statistics to those of other states and throws further uncertainty on FaAA's claim that Stage II alone is responsible for the lower fire rate in California.

The second approach used by FaAA, targeted solely at refueling related fires, was to categorize fire reports by NFIRS fire codes to determine the percentage of all gasoline fires which could be classified as vehicle refueling fires. FaAA reviewed fire reports for California and four non-Stage II states and found that vehicle refueling fires represent approximately 3 percent of all gasoline fires at gas stations in those five states. They found that California had a 55 percent less frequent occurrence of these types of fires than the other four states, and attributed the reduction to the Stage II system. Further, they reasoned that onboard could only control these types of fires and could be no more effective than Stage II in doing so, therefore only 55 percent of three percent (1.65 percent) of all gasoline fires at gas stations could be eliminated by onboard vapor recovery systems. FaAA also argued that the reduction in overall fire rates attributed to Stage II could not be achieved by onboard.

Several points must be made in response to the analysis presented by FaAA. First, with regard to the effect of Stage II and onboard controls on refueling-related fires, it is reasonable to assume that either method has the potential to reduce these types of fires. However, FaAA made an analytical error which led to a substantial underestimate of the number of refueling related fires in non-Stage II areas. As is discussed in the paragraph directly above, FaAA combined the refueling related fire reports information for California and four other states (Ohio, Texas, Michigan, and Illinois) and concluded that refueling related fires make-up about 3 percent of the total in those five states. They then argue that since the California refueling fire rate is only 55 percent of that in the other four states, and if onboard performed as well as Stage II, the most reduction one could expect in total service station fires with onboard controls is 1.65 percent.

However, FaAA inappropriately combined fire information for Stage II and non-Stage II states and then used this information to suggest that on a nationwide basis, refuelings account for 3 percent of all service station fires. The California data should not have been combined with the non-Stage II state data, due to the effect of Stage II controls on refueling emissions. Using data in FaAA's report for only the other 4 states shows that 5.7 percent, rather than 3 percent, of all service station fires are refueling-related. Applying FaAA's 55 percent reduction efficiency yields a 3.1 percent reduction in overall service station fires. Both of these figures are comparable to the EPA estimates presented above, i.e., that 4 to 6 percent of service station fires are refueling related (versus 5.7 percent for the corrected FaAA) and that onboard controls could cause a 60 percent reduction in these types of fires (versus 55 percent for FaAA). Obviously, the percentage reductions in overall fires is now also comparable, with EPA estimating 2.5-3.5 percent and FaAA estimating 3.1 percent.

Despite the cited problems with FaAA's analysis it directionally supports EPA's premise that controlling refueling vapors reduces the risk of service station fires. After making the above adjustments FaAA's analysis suggests a 3.1 percent reduction in overall service station fires which falls within EPA's estimated range of 2.5 to 3.5 percent. This level of agreement is surprisingly good considering the number of judgments which had to be made when analyzing the NFIRS data base.

d. Potential Benefits of Onboard Controls on Non-Fire Property Damage and Health Effects at Service Stations

As was discussed earlier, the proposed onboard refueling control procedure should essentially eliminate the occurrence of gasoline spitback during refueling. In addition to the reduction in service station fires which would be realized because of this, there are also non-fire property damage benefits and health benefits which would occur. According to the 1972 Scott Research report mentioned above [2], spitback spills occur in about 13 percent of all refueling events and result in an average spill of about 14 grams of fuel. The range on this value varies from zero to in excess of 40 grams per refueling. Clearly, some fraction of spitback spills cause damage to the shoes and/or clothing of the person dispensing the gasoline. As Table 7 shows, clothing is the material ignited in 0.08 percent of service station fires. Of course only a small percentage of the clothing damaged by spilled gasoline actually ignites, so spillage on clothing is more frequent than this small figure might lead one to believe. Also, some health benefits are gained by the elimination of spitback spills. Repeated or prolonged dermal contact with liquid gasoline due to spillage can cause irritation and dermatitis for some individuals. Reducing spillage will help to address this problem and will also help to eliminate the need to use refueling mitts or gloves purchased by some individuals or provided gratis at some service stations. It is acknowledged that these benefits may exist, but no attempt will be made to quantify them at this point. These benefits are expected to be relatively small but, as mentioned previously, further contract work is being undertaken which may help to quantify them.

B. Potential Vehicle Safety Benefits Due to Onboard System Design

1. Introduction

The implementation of integrated refueling/evaporative control systems such as those developed by EPA, API, and described in comments provided by Ford, Chrysler, GM, Nissan and others provides the opportunity for safety enhancements over current fuel and evaporative systems. As is discussed below, these enhancements lie in three separate areas: 1) lower fuel tank pressures, 2) control of non-FTP evaporative emissions, and 3) simplification and improvements over current fuel/evaporative systems

2. Lower Fuel Tank Pressures

Over the past 5 to 10 years, several factors have caused a significant increase in the fuel tank operating pressures. One major reason for this is that the volatility of in-use gasoline has climbed over the years. Also, alcohol blended with gasoline now has fairly widespread use, and these alcohol blends or oxygenated fuels have a higher volatility than the straight gasoline used as blend stocks. Additionally, there has also been a growing percentage of fuel injected vehicles with high fuel system pressures and recirculation of heated fuel to the fuel tank, which enhances fuel evaporation and thus increases tank pressure.

To assist in passing NHTSA's FMVSS 301 rollover test and EPA's evaporative emission standard, fuel tanks have been designed with extremely small diameter venting orifices to contain liquid/vapor within the tank. While this design approach has apparently been successful in assisting compliance efforts to meet these regulations, these small orifices have decreased the venting capability of the tanks and thus increased tank pressures.

These three factors taken together, higher volatility gasolines, higher tank temperatures due to fuel recirculation, and limited tank venting have all acted to increase in-use tank pressures.

These increased tank operating pressures can contribute to several different vehicle safety problems. As is discussed in detail in the comments provided by the Center for Auto Safety these include fuel spurting, fuel tank overpressurization, and as mentioned by API, fuel dispersion in tank rupture accidents. Fuel spurting occurs when gasoline spurts or sprays from the fuel tank upon removal of the fuel cap. This fuel release is often due to the excess pressure in the fuel tank. Fuel tank overpressurization problems, caused when pressures occur in excess of those considered in the tank design process, can be manifest as "fuel leaks from the tank and vent lines, poor vehicle performance, excessive gasoline odor," and other problems.[4] Of course, in the extreme, excess pressures can blow vent lines and gas tank seams. Finally, fuel dispersion could be increased when fuel tanks are ruptured or punctured in accidents, since the fuel in the tank could initially be at a pressure significantly in excess of atmospheric.

Manufacturers have clearly been alerted to the problems of fuel tank overpressurization as there have been many complaints raised to them about this problem occurring with their current vehicles, several resulting in recalls and service bulletins. Some manufacturers have taken steps to remedy the problem. Some General Motor's fuel caps have a warning label to alert the owner of the potential for fuel spurting upon cap removal. Other manufacturers such as Chrysler have incorporated an anti-spitback valve in their vehicles fillnecks to address this problem.

While an onboard system alone would not necessarily address increased fuel volatility or higher fuel tank temperatures, it would require an increase in the size of the fuel tank venting orifice and thus provide the opportunity to decrease fuel tank pressures. The onboard system design contemplated by EPA (see Chapter 3, Section C) incorporates a larger fuel tank venting orifice. The larger activated carbon canister associated with an integrated refueling/evaporative system would have excess capacity during a large portion of the time between refuelings, and so could accommodate much of the evaporative vapor now contained in the fuel tank by the limiting orifice. Thus fuel tank pressures could be reduced, enhancing safety, while still controlling evaporative emissions. Also, EPA is preparing revisions to the test procedure which will ensure that proper provision for tank venting is incorporated in evaporative/onboard control system designs.

3. <u>Non-FTP Emissions</u>

As was explained in the previous section, there has been a trend toward increasing fuel volatility and fuel system temperatures and pressures over the past several years. Since

EPA's evaporative emissions test procedure does not evaluate worst case conditions, there are many in-use conditions that could overload the evaporative canister. The large quantity of vapors generated under such conditions are called Non-Federal Test Procedure or Non-FTP emissions, since actual in-use conditions (ambient temperatures, driving patterns or volatilities) exceed those prescribed in the Federal Test Procedure.* Recent EPA work suggests that these uncaptured emissions can be quite high in some circumstances. This is one reason for EPA's preference for integrated evaporative and refueling control systems, rather than separate systems. The larger integrated canister has excess capacity most of the time, which should allow for non-FTP emissions to be captured and controlled. Also, emitting gasoline vapors such as these near potential ignition sources in the engine compartment or near the hot exhaust system has been identified by several groups as a potential safety hazard (although API found no fire risk due to these conditions[5]). In any case, the larger venting orifice and carbon canister on an integrated onboard system allows for these excess vapors to be captured and controlled. Therefore onboard systems may offer a safety advantage over current evaporative emission control systems.

4. <u>Simplification of Current Fuel/Evaporative Control Systems</u>

Several commenters have said that onboard systems will be more complex than existing evaporative systems and will therefore inherently increase safety risks. However, the integrated onboard system design presented by EPA to the manufacturers is actually significantly less complex than some of the current evaporative systems discussed in Chapter 3, Section B. For example, there are fewer external fuel/vapor carrying components, such as the external (or internal) vent tube which is found on even relatively simple current evaporative systems. Decreasing the number of components also means that fewer connections such as clamps are necessary. The integrated onboard system presented by EPA also has fewer and shorter vapor lines and fewer fuel tank connections than many current evaporative systems. Thus, if one accepts the premise suggested by some commenters that more complexity increases risk, then the simplifications made possible with an integrated onboard system should reduce the crash and non-crash safety risks associated with evaporative and refueling control systems. Along the same lines, manufacturing and misassembly mistakes and the resulting effects should also be reduced.

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* Information presented at June 30, 1988 EPA Onboard Test Procedure Workshop.

C. Summary and Conclusions

In conclusion, the analyses presented in this chapter support EPA's view that onboard refueling control systems could enhance service station and automotive safety. First, onboard systems have the potential to reduce the number of service station fires and the non-fire property damage and health hazards at service stations. Review of the NFIRS service station fire data base shows that 4 to 6 percent of all service station fires are refueling-related. It is expected that onboard refueling controls will prevent about 60 percent of the refueling-related fires, or 2.5 to 3.5 percent of all service station fires. Such a reduction in fires would also prevent 2.5 to 3.5 percent of the $50.0 to $76.2 million annual losses due to property damage, injuries and deaths resulting from service station fires which is a savings of $1.25 to $2.67 million. Onboard controls could also prevent the damage to shoes and clothing by preventing spitback spillage during refueling. By controlling spitback spills, onboard systems could eliminate the potential health problems caused by dermal contact with gasoline.

Furthermore, the implementation of onboard refueling controls could also enhance vehicle safety in both crash and non-crash situations. An integrated onboard systems design like the one described in Chapter 3, section C, could lower fuel tank pressure levels thereby decreasing the occurrence of fuel spurting, and fuel system leaks and ruptures caused by overpressurization. In addition, the larger canister of an integrated onboard system could control non-FTP evaporative emissions. This addresses the perceived safety risks of gasoline vapor contacting a hot engine or exhaust system or a spark ignition source. Finally, the integrated onboard design described by EPA is less complex than many of the current evaporative control systems discussed in Chapter 3, section B. Since many commenters have equated increased complexity with increased safety risks than the design simplifications allowed by EPA's integrated system design could also be equated with improved safety.

As stated previously, further contract work is being done to quantify both the fire and non-fire safety risks at service stations and the potential impact of onboard systems on these risks. Contract work is also being undertaken to evaluate the comparative risk of an integrated onboard system and current evaporative control systems.

References for Chapter 4

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2. "Investigation of Passenger Car Refueling Losses, 2nd Year Program," Scott Research Laboratories, Inc. SRL-2874-12-0972, September 1, 1972.

3. "Safety Issues in Systems Designed to Recover Gasoline Vapor During Motor Vehicle Refueling," Failure Analysis Associates, February 5, 1988.

4. "Center for Auto Safety Study and Comments on Environmental Protection Agency Rulemakings on Gasoline and Alcohol Blend Volatility and Refueling Emissions from Gasoline Vehicles," March 24, 1988.

5. Comments of API in response to Onboard NPRM, February 11, 1988, available in public docket A-87-11 at IV-D-358 plus sub-entries.

Chapter 5

Summary and Net Assessment

A. Introduction

As prescribed in Section 202(a)(6) of the Clean Air Act, safety is one of the key factors to be evaluated in the determination of whether onboard vapor recovery systems should be implemented, and indeed the potential safety implications of this technology have been a key issue in the rulemaking. EPA began its in-depth analysis of the safety issue in the Spring of 1986, more than a year before the NPRM, and since that time has been engaged in an ongoing evaluation of all aspects of the issue.

Even prior to the NPRM, EPA completed a comprehensive study of the onboard safety issue. This study, the June 1987 onboard safety report shown in Appendix II, discussed the design of safe onboard systems and identified and evaluated both general and specific onboard safety concerns raised prior to the NPRM. In-use concerns addressed by the 1987 report included both crash and non-crash situations. In addition to the general area of crashworthiness, the study addressed non-crash concerns such as tampering, defects, misrepair, and refueling operation safety. The study concluded that straightforward, reliable, relatively inexpensive solutions exist for each of the potential problems identified, and that no increase in risk need occur or be accepted because of the presence of an onboard system. The study further concluded that onboard-equipped vehicles could in fact provide a level of in-use fuel system integrity equal to or better than that achieved on present vehicles, and that the changes which would accompany onboard controls could improve safety on in-use vehicles. Few of the comments received on the NPRM directly addressed technical aspects of EPA's safety report. The most substantive comment amounted to a suggestion that additional analysis was needed to support EPA's conclusions.

However, while EPA received few comments on the safety report itself, many concerns about the safety issue were expressed in the comments. Although a few commenters, notably vehicle manufacturers, expressed some specific concerns in areas such as potential onboard system hardware, many commenters stated that one issue in particular required further consideration by EPA: the effect of increased complexity on safety. In general, manufacturers did not disagree that solutions could be developed for identifiable, or predictable, types of problems such as those discussed in EPA's 1987 safety report. Rather, the main contention centered on the inability to foresee and avoid previously unidentified problems that could potentially accompany the implementation of a new or more complex system. Of course this concern is based on the premise that onboard vapor recovery systems would increase the complexity of current fuel systems through the addition and/or enlargement of components, connections, etc. Because these modifications involve the fuel system and allegedly introduce the potential for problems that cannot be predetermined, manufacturers claimed onboard systems would add an "unquantifiable" increase in the risk of both crash and non-crash fires. While this risk could not be quantified, manufacturers characterized it as unacceptable.

EPA disagrees with the manufacturers' concern over the effect of increased complexity on risk for four reasons. First, even a casual review of the increases in fuel system complexity over the past decade or so (such as the increased complexity resulting from the movement toward fuel-injection) made EPA question the validity of an argument which asserts increased complexity is unacceptable from a safety perspective. Second, a review of evaporative control system configurations revealed a trend toward increased complexity in recent years. Third, EPA has always maintained that onboard systems need only be a relatively simple extension of the current evaporative system, and as such much of the added complexity displayed in manufacturers' proposed designs appears unnecessary. Fourth, most manufacturers overlooked the potential for added safety benefits of onboard controls.

Consequently, in order to address manufacturers' concerns regarding complexity and risk, the analysis in this document studied onboard safety from three perspectives. First, since onboard systems are, in several respects, analogous to evaporative systems which have been used for 18 years, the performance and design of evaporative systems was assessed to: 1) put the onboard complexity/risk issue into perspective, and 2) evaluate the relationship between complexity and safety. Second, EPA investigated the feasibility of an improved and simplified onboard refueling control approach to determine whether the added complexity suggested by the manufacturers was even necessary. Third, the potential safety benefits of onboard systems were characterized to determine whether onboard controls can actually improve safety. EPA's results regarding complexity/risk, simple onboard designs, and safety benefits are summarized below.

B. Defining the Relationship Between Complexity and Risk

A major aspect of assessing any added safety risk resulting from the implementation of onboard controls involves defining the relationship between complexity and risk. In order to adequately characterize this risk, EPA established a baseline to gauge the potential safety effects that are possible when vapor recovery devices such as onboard controls are implemented. Because of the inherent similarity between onboard and evaporative control systems,* an appropriate baseline to put the complexity/risk of onboard controls into the proper perspective is the safety performance exhibited by evaporative control systems. In order to develop this baseline, the overall impact of evaporative control systems on safety was assessed first, and then the varying degrees of evaporative control system complexity were evaluated in the context of the relationship with safety.

1. Evaporative System Safety

The investigation into the safety of evaporative control systems involved an examination of evaporative control systems' effect on historical fire rates and a thorough review of the in-use safety performance of evaporative systems. In-use performance was gauged according to the number of problems (and seriousness of consequences) resulting in safety recalls, technical service bulletins, and owner complaints.

An analysis of fire rates for post- and pre-evaporative model year accident involved vehicles involving fatalities revealed that the implementation of evaporative control systems had no discernible effect on crash fire rates. Fire rates fluctuate to a small degree from model year to model year, but overall have remained rare events.

In addition, a thorough review of NHTSA's computer files of safety recalls, technical service bulletins and owner complaints showed that evaporative control systems have operated with very few problems since they were first implemented eighteen years ago. In total, only 20 recalls (less than 0.5 percent of the more than 4200 safety recalls in the past 20 years) involving 415,000 vehicles (less than 0.3 percent of the 130.8 million vehicles recalled since 1966), between 70 and 120 technical service bulletins (about 0.1 percent of the 88,000 service bulletins issued), and approximately 100 owner complaints (which represents less than 0.05 percent of the 210,000 owner complaints in NHTSA's computer files), have involved the evaporative control system.

Therefore, while evaporative control systems have been integrated into the fuel systems of over 200 million vehicles, only a minute fraction may have experienced safety problems. Further, of the rare problems that did occur, no serious consequences such as deaths or serious injuries appear to have been reported. The basic conclusion that can be drawn from this information is that evaporative control systems have not compromised fuel system safety.

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* Both systems operate on the same basic principles using similar components performing similar functions (such as vapor routing and vapor storage).

It is also worth noting that the same concerns over complexity that are being raised in connection with onboard controls were also raised 15 years ago with regard to evaporative control systems. An August 20, 1973 Federal Register Notice (38 FR 22417) regarding the implementation of FMVSS 301 explains NHTSA's concern that "Regulations of the EPA for fuel evaporative emission control will increase the number of components related to fuel systems in all new vehicles with a GVWR of 6,000 pounds or less, and a corresponding increase in points of potential system failure that could result in the loss of fuel in crashes." However, the concerns about increased risk to fuel systems as a result of implementing evaporative systems nearly 20 years ago has yet to materialize as a problem creating any serious consequences. Thus, even if added complexity is a concern, evaporative control system experience demonstrates that added complexity does not necessarily result in any significant actual increase of risk.

While examining the overall impact evaporative systems have had on safety, EPA found that levels of complexity vary considerably from one vehicle model to another. In fact, many features proposed for onboard systems that were characterized by manufacturers as an increased safety risk were found to already exist in-use on numerous fuel/evaporative system designs. The existence and variety of complexity on current vapor recovery systems led EPA to evaluate whether or not complexity has affected current fuel system safety, as many commenters indicated it invariably would.

2. Evaporative System Complexity/Safety

A review of manufacturers' shop manuals and other pertinent literature revealed that evaporative system complexity has generally increased over time, but that even in today's systems the complexity varies widely. Some systems are still fairly simple (few components/connections, etc.) while others are relatively more complex and involve more external components, multiple vapor lines, extra connections and other design features. Yet despite this increase in complexity there is no evidence that any one design or design approach is any more or less safe than any other. EPA presumes that the range in evaporative system complexity exists for good cause, and that this complexity was incorporated without compromising the safety of the systems involved. In fact, while complexity has increased over time, safety recalls and service bulletins regarding evaporative systems have actually decreased. Apparently increased complexity has not affected safety.

EPA's review also found that some current evaporative control systems designs incorporate features such as fillneck mounted valves, liquid/vapor separators, numerous vapor lines, and plastic components. When considered for use on an onboard system, all of these features were characterized by manufacturers as posing an unacceptable risk because of their increased complexity, and yet, several manufacturers have incorporated these design features into their current fuel/evaporative systems, apparently without compromising safety.

In summary, EPA has reached the following conclusions from its investigation of evaporative control system design complexity and safety. First, evaporative control systems have performed safely. Only a few infrequent problems have occurred, and none of the rare problems that did occur resulted in any serious consequences. Second, EPA did not find any inherent connection between increased complexity and decreased safety. Despite the increased complexity of fuel/evaporative systems over time and the wide variety of complexity in current systems, there is no evidence to suggest a direct, adverse relationship between safety and complexity for evaporative systems. Third, given the similarity between onboard refueling and evaporative emission control technology, the experience with evaporative systems suggests that onboard controls can be implemented safely also. In fact, the evidence suggests that even a wide range of complexity in onboard systems would not impact safety.

Evaporative systems were added to vehicle fuel systems 18 years ago and apparently have caused no significant safety problems. This safety record was accomplished even though an entire new system was added to the vehicle. Onboard and evaporative system technology are similar and in many ways onboard is more an extension or modification of the current evaporative system rather than an entirely new system. Given this view of the technology involved, and the directly relevant experience gained in implementing safe evaporative control systems, EPA still believes that manufacturers can, given reasonable leadtime, readily implement onboard control systems with similar levels of safety.

Even with the proven safety performance of evaporative control systems and the established lack of a record of complexity's effect on safety, EPA recognizes that some commenters will maintain that increased complexity would inherently result from onboard controls and that this increased complexity would degrade safety. However, EPA has always maintained that onboard controls would only require relatively simple modifications to the current fuel/evaporative system. Consequently, EPA initiated a development program for a simple onboard refueling control design which incorporated features that could even improve safety. The next section briefly summarizes the results of this initiative.

C. EPA's Onboard System Design

In response to EPA's proposal of onboard controls, manufacturers indicated their preference for designs much more complex than those anticipated by the Agency. Along with their suggested designs, manufacturers postulated possible problems that could accompany the implementation of their complex designs. Possible solutions to these problems were rarely discussed. Many of the problems postulated by manufacturers concerned added components and complexity which did not appear to be necessary to control refueling emissions. Since EPA has always anticipated that onboard control would require relatively simple designs, a development program was undertaken to design a simple onboard system to alleviate concerns over added complexity.

In order to develop a simplified onboard system, EPA established the following two basic design constraints. First, the simple system should incorporate the fewest features possible and should yet perform all necessary functions. Second, components used in the simple system should be based on current production hardware. Following these two constraints, EPA modified a typical current (and relatively simple) fuel/evaporative system (Figures 3-20 and 3-21) to control refueling as well as evaporative emissions. The system developed by EPA is shown in Figures 3-22 and 3-23.

Only a few modifications were necessary to convert the evaporative system in Figure 3-20 and 3-21 to the onboard system in Figure 3-22 and 3-23. First, the orifice size of the float/rollover valve was moderately increased by replacing the stock valve with a modified version of another valve which had been designed for higher vapor flow rates. The valve was also modified and relocated to a location where it could serve as a fill limiter. Second, the current refueling vapor vent line was removed since the vapors were now to be routed to the canister. Third, the carbon canister was enlarged approximately two fold over its current size. Fourth, the canister was moved to the rear of the vehicle, which greatly shortened the length of the vent line from the fuel tank to the canister. In addition, it should be noted that no significant modification to the current system was necessary to form a fillneck seal. The current fillpipe is inherently sized to form a liquid seal and required only minor optimizing to insure effective performance at low fuel dispensing rates. Lastly, the particular fuel tank system used by EPA (from General Motors "A" body vehicle line) did not actually include the anti-spitback (anti-fuel spurting) valve shown in Figure 3-24. Therefore, for this system, an anti-spitback valve was also added. The valve chosen was a production Chrysler unit which has been in use since 1984.

The result of these modifications was a refueling control system which was an overall simplification of the onboard design provided in the NPRM. It was indeed very similar to the stock evaporative system in terms of design, configuration, and function. When tested with nominal 9.0 RVP Federal test fuel, this system consistently met the proposed refueling standard by a substantial margin. In addition, the added anti-spitback valve completely eliminated fuel spitback from the stock system.

In summary, EPA feels that much of the added complexity suggested by manufacturers in their proposed designs (Appendix I) is not necessary to successfully control refueling emissions. Onboard systems can be simple extensions or modifications of present evaporative systems. Further, modifications that are necessary can even simplify certain aspects of the current design. With the proper design, no risk need be added, and in fact, refueling controls can offer several safety benefits.

D. Safety Benefits of Onboard Controls

Onboard refueling controls offer the potential to enhance safety through two general mechanisms: improved design features and reduced service station risks. The extent to which benefits available through improved design features are realized will ultimately depend on design choices selected by manufacturers. Improved service station safety, however, inherently accompanies refueling controls irrespective of design selection.

1. Design Improvements

Safety enhancements from design improvements could lie in three areas: 1) lower fuel tank pressures, 2) control of non-FTP evaporative emissions, and 3) simplification of current fuel/evaporative design features. These three areas are discussed below.

First, onboard systems provide the opportunity to increase the size of the fuel tank venting orifice and thus cause a decrease in fuel tank pressures. Fuel tank operating pressures have increased significantly in the past 5-10 years due to increased fuel volatility, higher tank temperatures (e.g., due to fuel injection), and limited tank venting (to assist in compliance efforts to pass NHTSA's FMVSS 301 rollover test and reduce vapor generation). Increased tank operating pressures have contributed to safety problems such as fuel spurting, fuel leaks, and increased fuel dispersion in the event of a ruptured tank in an accident. The proposed onboard refueling test procedures would require improved tank venting. This should lead to lower operating pressures and enhanced safety.

Second, integrated onboard/evaporative systems likely will result in added control of certain in-use (non-FTP) evaporative emissions. Current evaporative control systems do not contain adequate capacity to contain vapors generated under conditions that exceed those prescribed in the Federal Test Procedure (FTP). FTP test conditions were designed to represent average in-use conditions. Consequently, it is not uncommon for a substantial amount of excess evaporative emissions to "breakthrough" the evaporative control system under worse than average in-use conditions. These vapors are emitted either through the evaporative canister or some pressure relief device such as the fuel tank cap. Emitting vapors such as these near potential ignition sources in the engine compartment has been identified by several groups as a potential safety hazard. Integrated onboard/evaporative systems would control these excess vapors and provide a safety benefit over current systems.

Third, onboard systems (such as the simple design developed by EPA) can reduce the complexity of some aspects of the current fuel tank and evaporative system design. For example, an onboard system can eliminate the external vent line that is currently used to vent refueling emissions. Also, an onboard system utilizing a rear-mounted canister will shorten the vent line from the fuel tank to the canister. Also, moving the canister to the rear of the vehicle may have same safety advantages with regard to vapor release due to breakthrough, tampering, or defects relative to under-the-hood locations. Thus, if one accepts the premise that increased components, connections, etc. increases risk, an onboard system that simplifies features of the current fuel/evaporative system will improve safety.

2. Service Station Safety

In addition to design improvements, onboard systems would have a positive effect on the safety of automotive refueling at service stations. Refueling vapors that are currently vented to an area which poses something of a safety hazard would instead be routed away from potential external ignition sources to a safer location (the charcoal canister). Also, due to test procedure requirements, onboard controls are likely to bring about a decrease in the amount of gasoline spilled during normal vehicle refueling. Therefore, onboard controls are likely to reduce the number of fires that result from ignited refueling vapors or fuel spills and improve service station safety. EPA estimates that onboard controls have the potential to prevent between 63-77 service station fires annually.

E. Net Safety Impact

Overall, EPA still believes that onboard control systems will have no negative effect upon vehicle safety and actually provide the opportunity to improve safety in several areas.

The added complexity of evaporative control systems was found not to affect vehicle safety. EPA feels onboard controls can and will be implemented with the same or a better safety level as current systems. Further, because of the potential design improvements and service station benefits, EPA believes onboard control systems will have the potential for an overall beneficial impact on safety.

Of course, EPA expects to receive additional comment on these safety issues, both as part of its consultations with DOT and from manufacturers and others during the comment period on its reproposal. EPA will consider and address all of the relevant safety-related issues in its final analysis, and will continue to consult with DOT before making a final decision on whether to require onboard controls.

Appendix I

Onboard System Designs

Submitted by Manufacturers

Fig. #	Commenter	Citation	Description
1	Ford	A-87-11	Separate Systems, Mechanical Seal
2	Ford	A-87-11	Separate Systems, Liquid Seal
3	Chrysler	IV-D-39	Integrated System, Mechanical Seal
4	Chrysler	IV-D-366(a)	Separate Systems, Mechanical Seal
5	General Motors	IV-D-360	Integrated System, Mechanical Seal
6	General Motors	IV-D-360	Integrated Systems, Liquid Seal
7	Generals Motors	IV-D-360	Integrated System, Liquid Seal
8	General Motors	IV-D-360	Integrated System, Sleeve Seal
9	Volkswagen	IV-D-361	Integrated System, Mechanical Seal
10	Peugeot	IV-D-340	Integrated System, Mechanical Seal
11	Saab	IV-D-368	Integrated System, Mechanical Seal
12	Nissan	IV-D-08	Integrated System, Mechanical Seal
13	Nissan	IV-D-08	Integrated System, Mechanical Seal
14	Nissan	IV-D-08	Separate Systems, Liquid Seal
15	Subaru	IV-D-364	Separate Systems, Mechanical Seal
16	Toyota	IV-D-363	Separate Systems, Liquid Seal

Fig. #	Commenter	Citation	Description
17	Toyota	IV-D-363	Separate Systems, Liquid Seal
18	Toyota	IV-D-363	Integrated System, Liquid Seal
19	Mitsubishi	IV-D-377	Integrated System, Mechanical Seal
20	Mitsubishi	IV-D-377	Integrated System, Mechanical Seal
21	American Petroleum Institute (Exxon Design)	IV-D-358e	Integrated System, Liquid Seal
22	American Petroleum Institute (Mobil Design)	IV-D-358e	Integrated System, Liquid Seal
23	Mobil	IV-D-329	Integrated System, Liquid Seal
24	Multinational Business Systems	IV-D-01	Integrated System, Mechanical Seal
25	Multinational Business Systems	IV-D-01	Separate Systems, Liquid Seal
26	Multinational Business Systems	IV-D-01	Integrated System, Mechanical Seal

0377X

MECHANICAL DESIGN

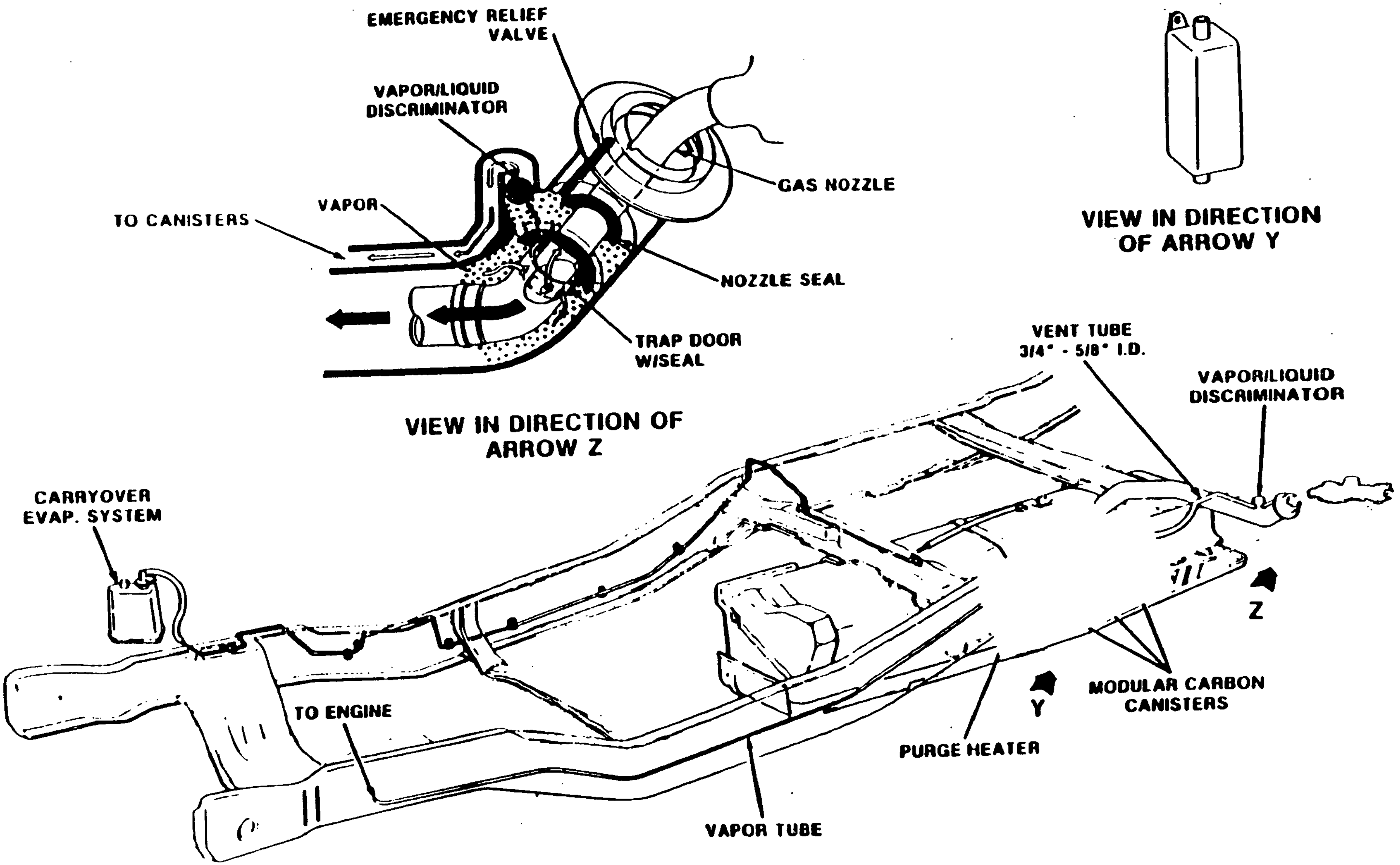


FIGURE III-5

Appendix I
Figure 2 - Ford

CONCEPT LIQUID SEAL SYSTEM

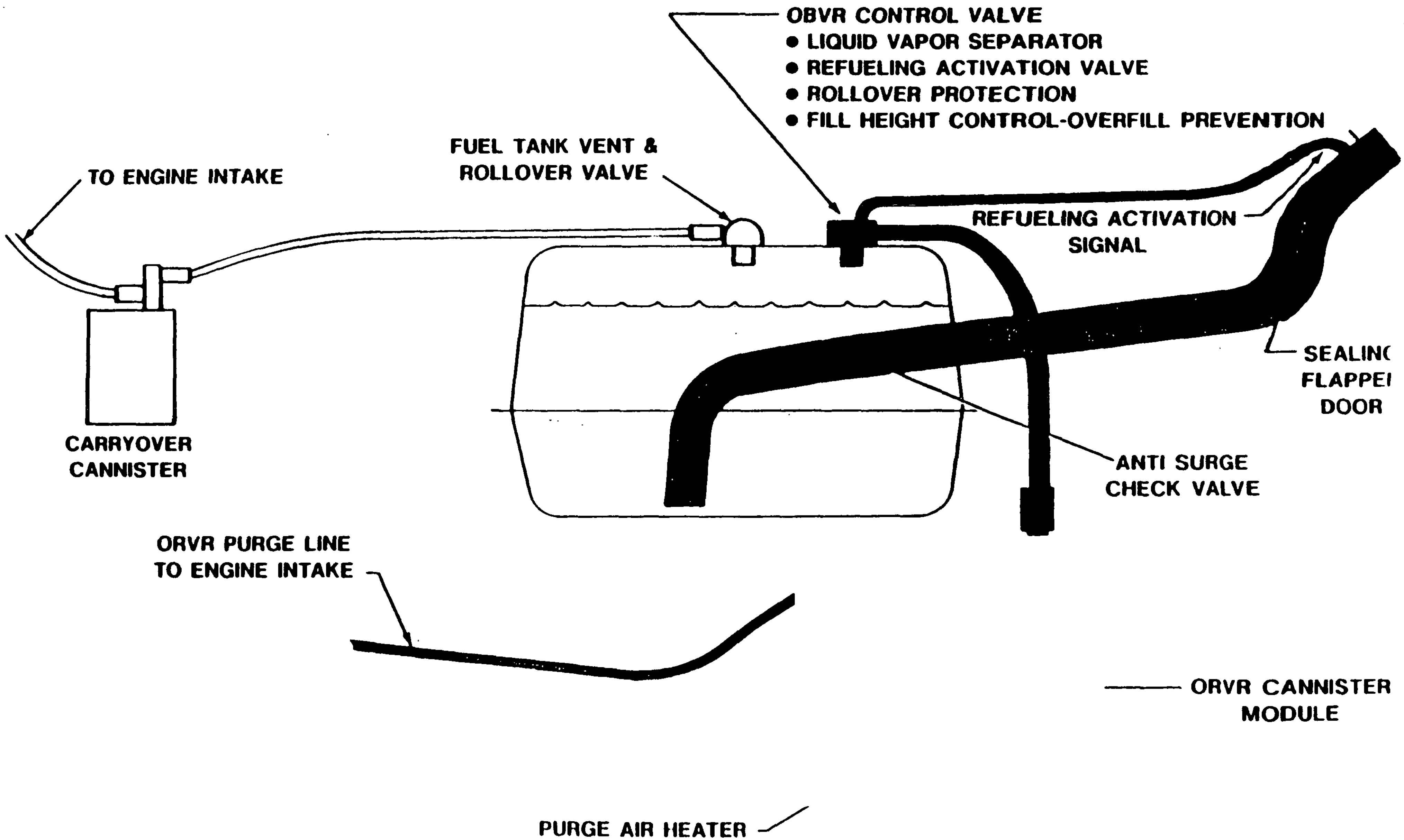
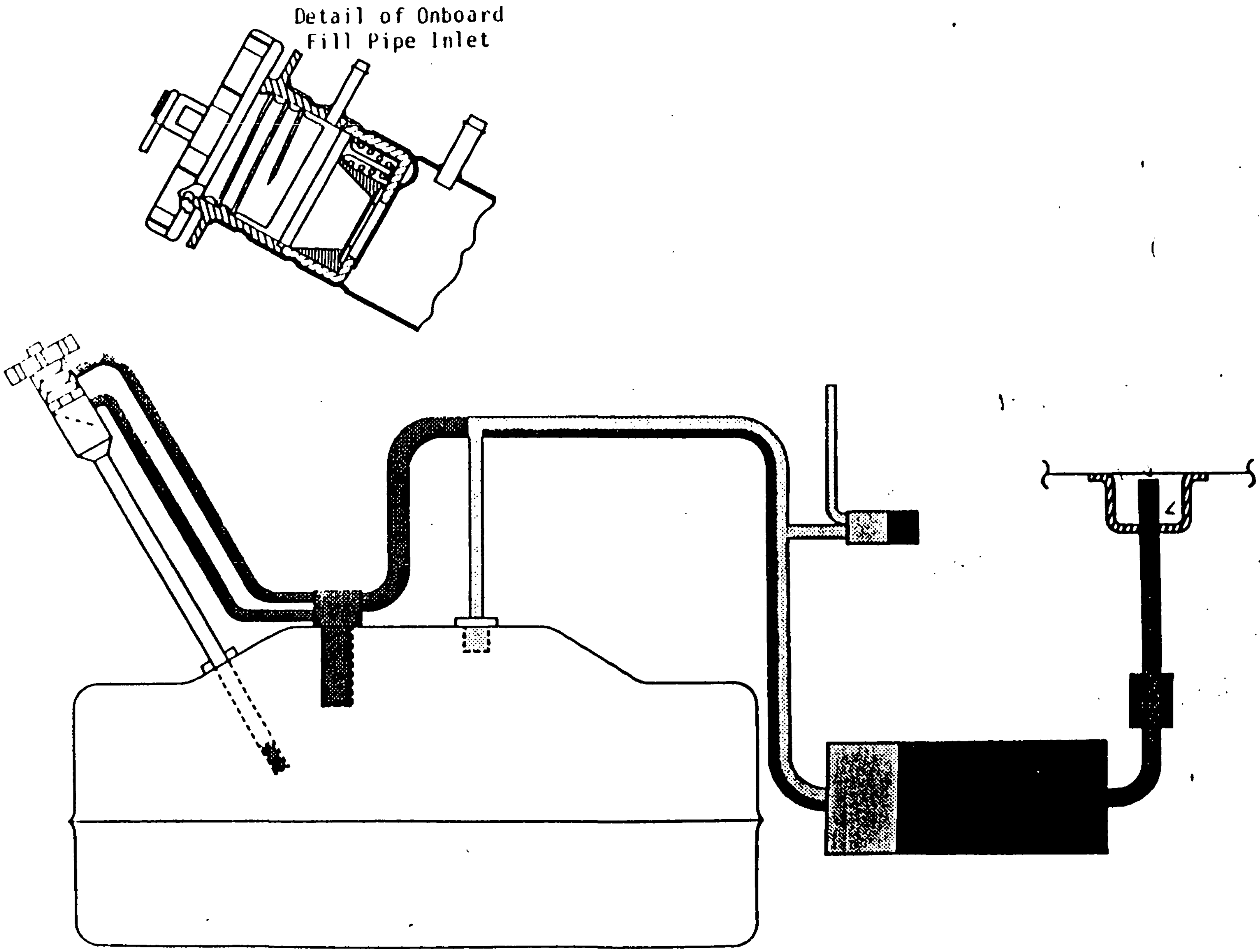


FIGURE III-6

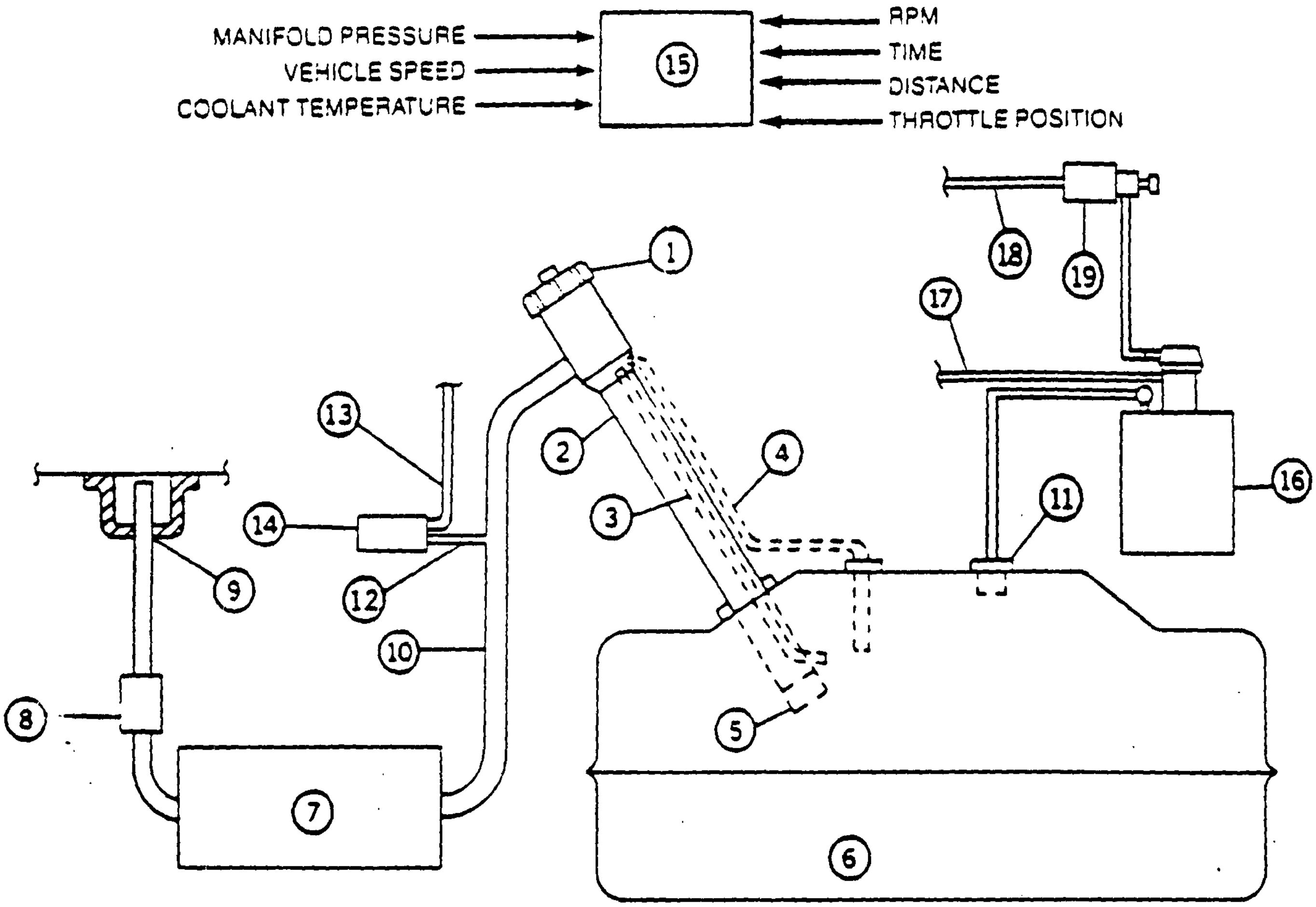
Appendix I
Figure 3 - Chrysler



SCHEMATIC COMPARISON OF EVAPORATIVE (LIGHT) AND ONBOARD REFUELING (DARK + LIGHT) CONTROL SYSTEMS

Appendix I
Figure 4 - Chrysler

EVAPORATIVE/REFUELING VAPOR RECOVERY SYSTEM



SYSTEM COMPONENTS

1 FUEL CAP
2 FUEL FILLER TUBE - TOP VENTED
3 FUEL TANK VENT - INTERNAL PASS. CAR
4 FUEL TANK VENT - EXTERNAL TRUCK
5 DIFFERENTIAL PRESSURE CHECK VALVE
6 FUEL TANK
7 REFUELING VAPOR CANISTER
8 FILTER
9 PURGE AIR INLET - REMOTE
PASS. CAR—REAR SUSPENSION CROSSMEMBER ·
TRUCK - UNDERHOOD
10 VAPOR LINE - 5/8" I.D.
11 TANK VENT/ROLLOVER VALVE
12 PURGE LINE - 5/16"
13 PURGE LINE - 1/4"
14 PURGE SOLENOID - DUTY CYCLE CONTROLLED
15 ELECTRONIC CONTROL UNIT
16 EVAPORATIVE VAPOR CANISTER
17 TO BI-LEVEL PURGE
18 MANIFOLD VACUUM LINE
19 VACUUM SOLENOID - ON/OFF

REFUELING FILLER TUBE FEATURES:

- NOZZLE SEALING DEVICE
- REFUELING EVENT DEVICE
- PRESSURE RELIEF DEVICE(S)
- NOZZLE SHUT-OFF (LIQUID)
- VAPOR CONNECTION TO CANISTER
- LIQUID CARRYOVER PREVENTION

Figure 1

REFUELING EMISSION CONTROL SEALED FILLER NECK SYSTEM

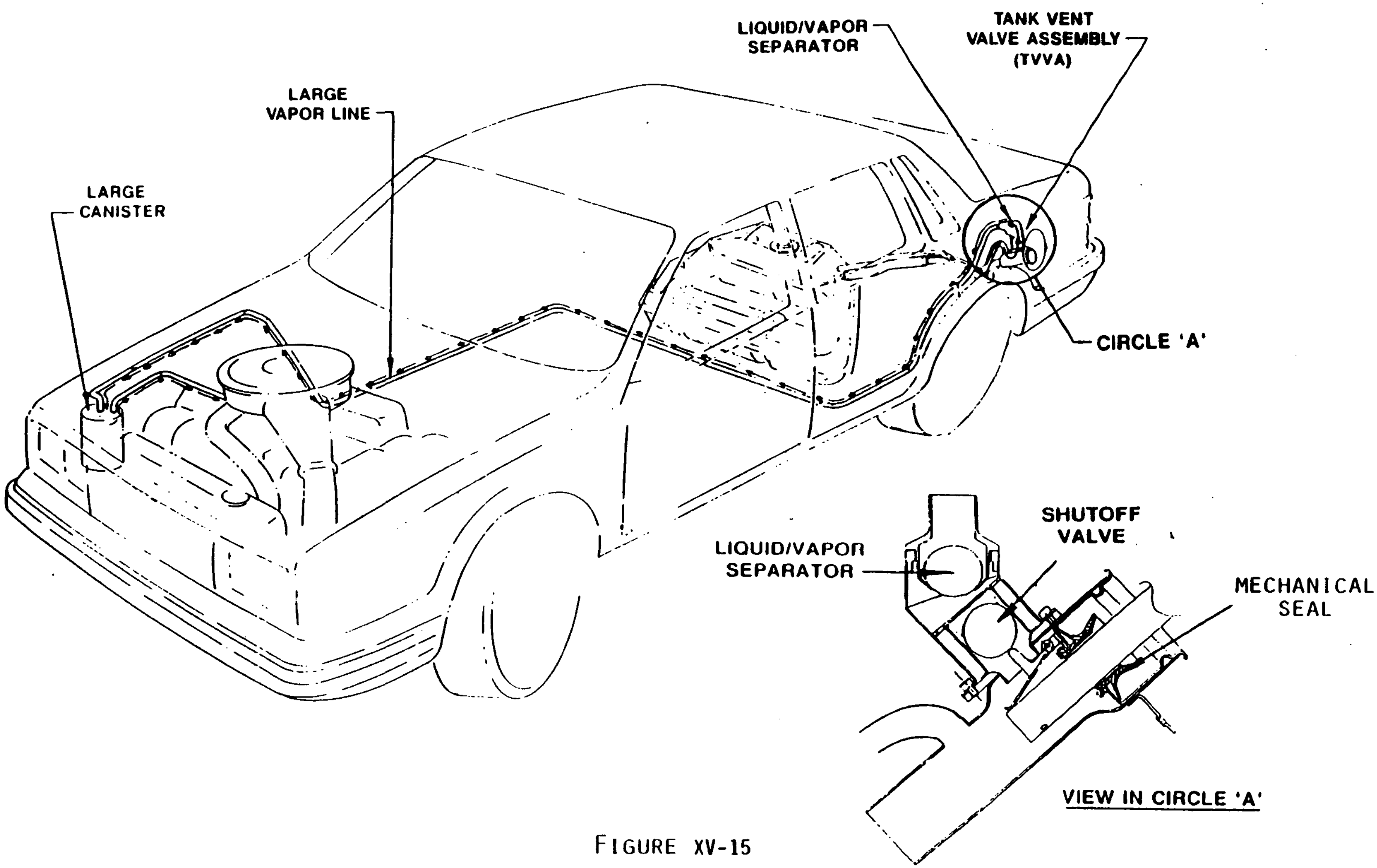


FIGURE XV-15

REFUELING EMISSION CONTROL LIQUID SEAL SYSTEM

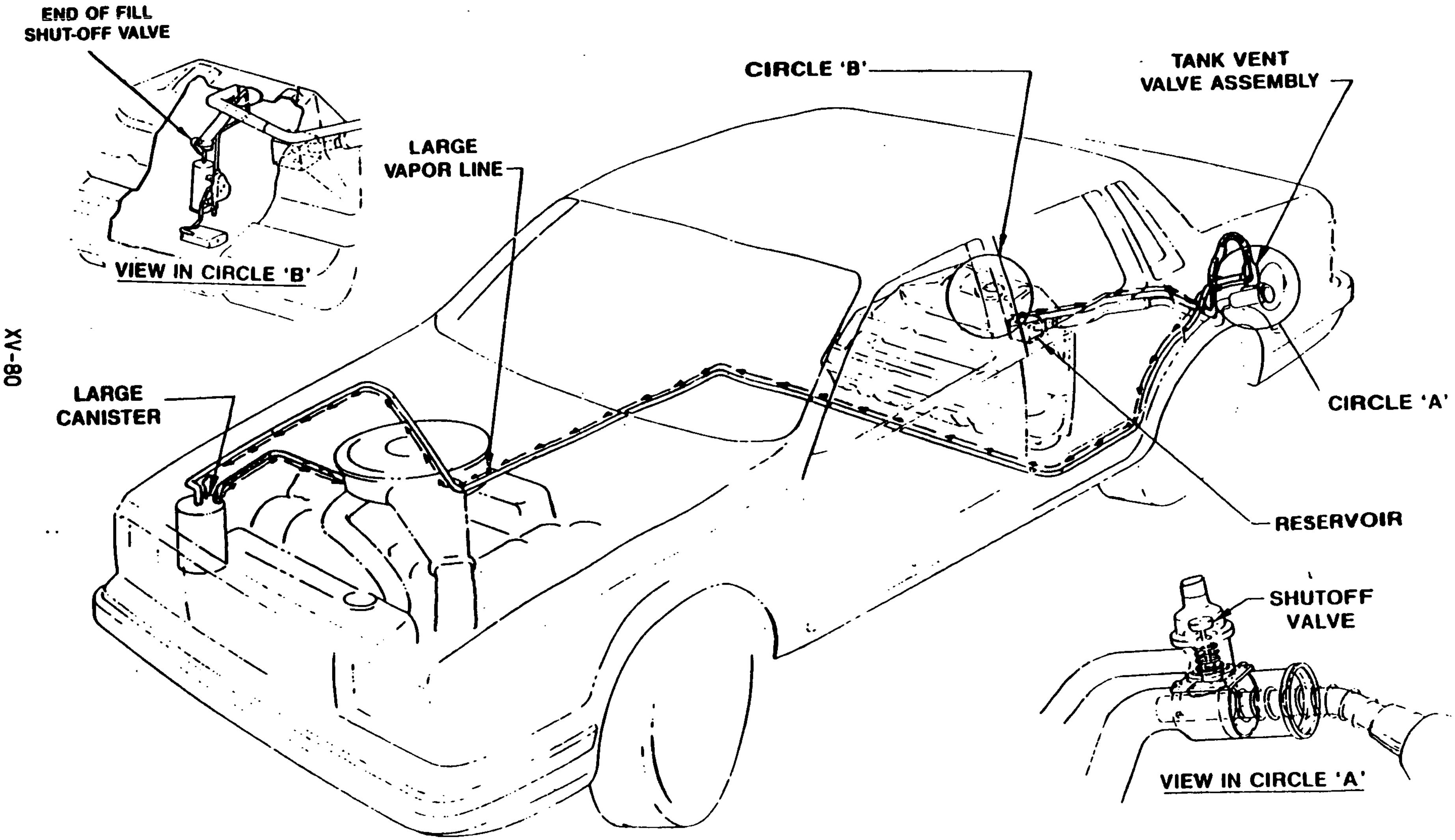


FIGURE XV-16

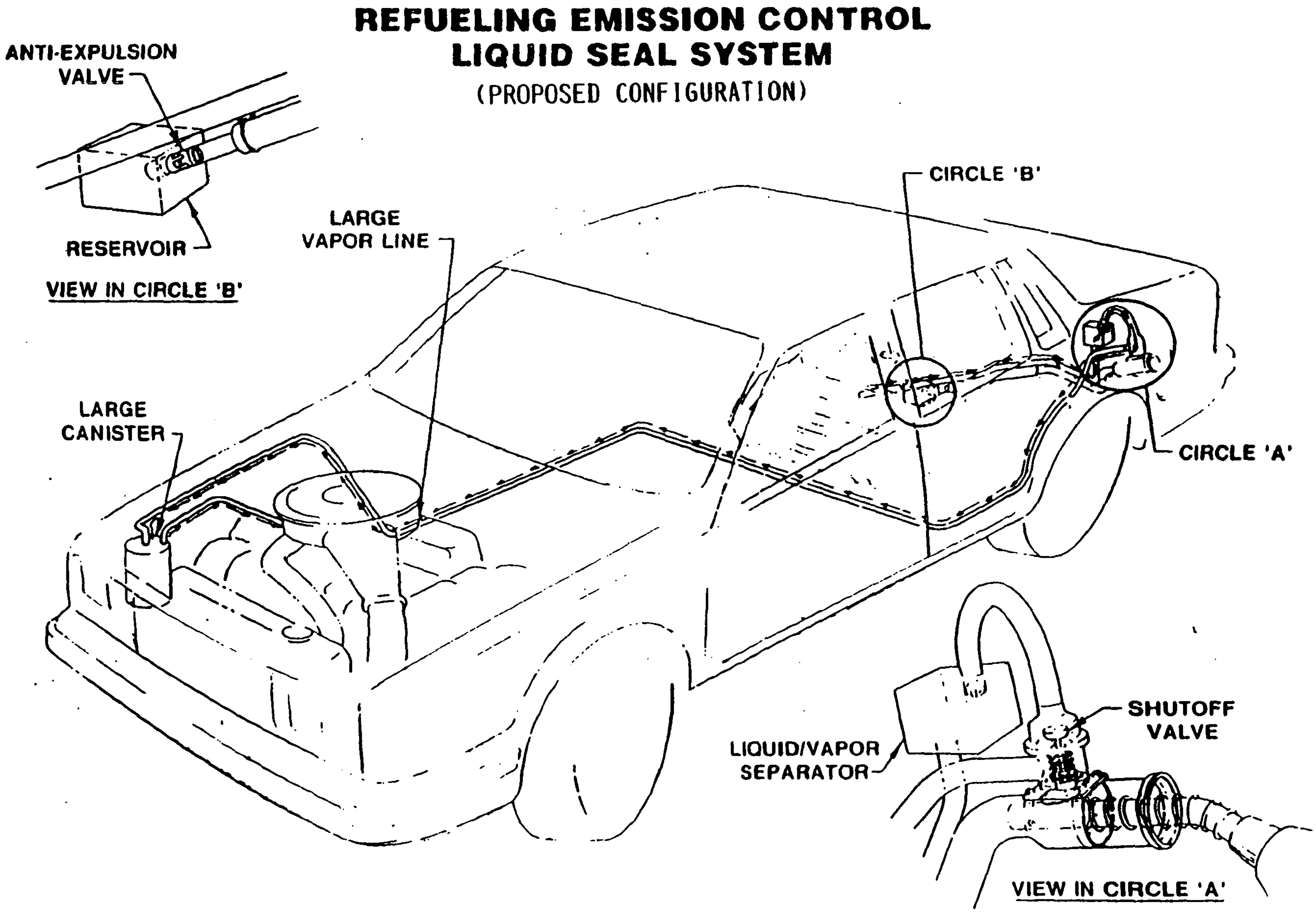

REFUELING EMISSION CONTROL
LIQUID SEAL SYSTEM
(PROPOSED CONFIGURATION)
ANTI-EXPULSION VALVE
RESERVOIR
VIEW IN CIRCLE 'B'
LARGE VAPOR LINE
CIRCLE 'B'
LARGE CANISTER
CIRCLE 'A'
SHUTOFF VALVE
LIQUID/VAPOR SEPARATOR
VIEW IN CIRCLE 'A'

FIGURE XV-17

Appendix I
Figure 8 - General Motors

REFUELING EMISSION CONTROL SLEEVE SEAL SYSTEM

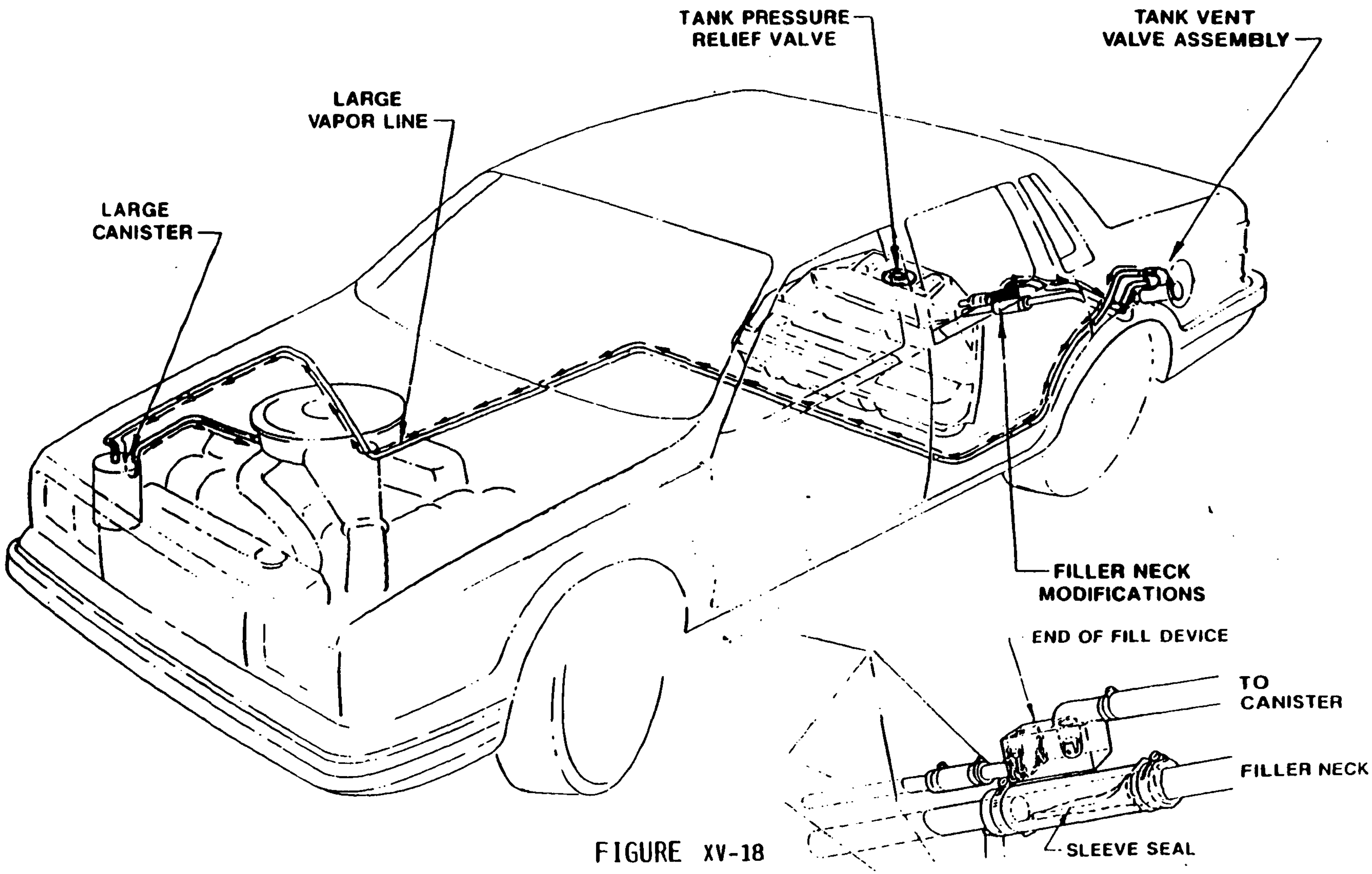


FIGURE XV-18

Appendix I
Figure 9 - Volkswagen

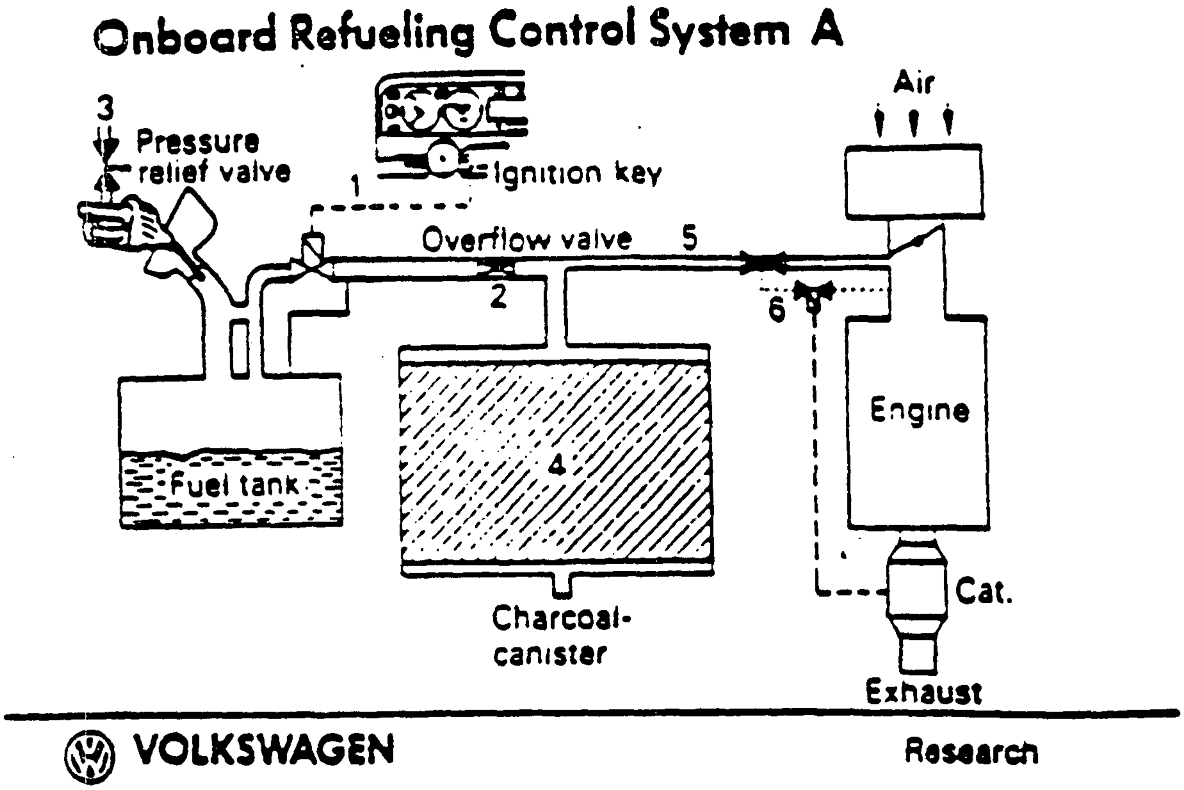
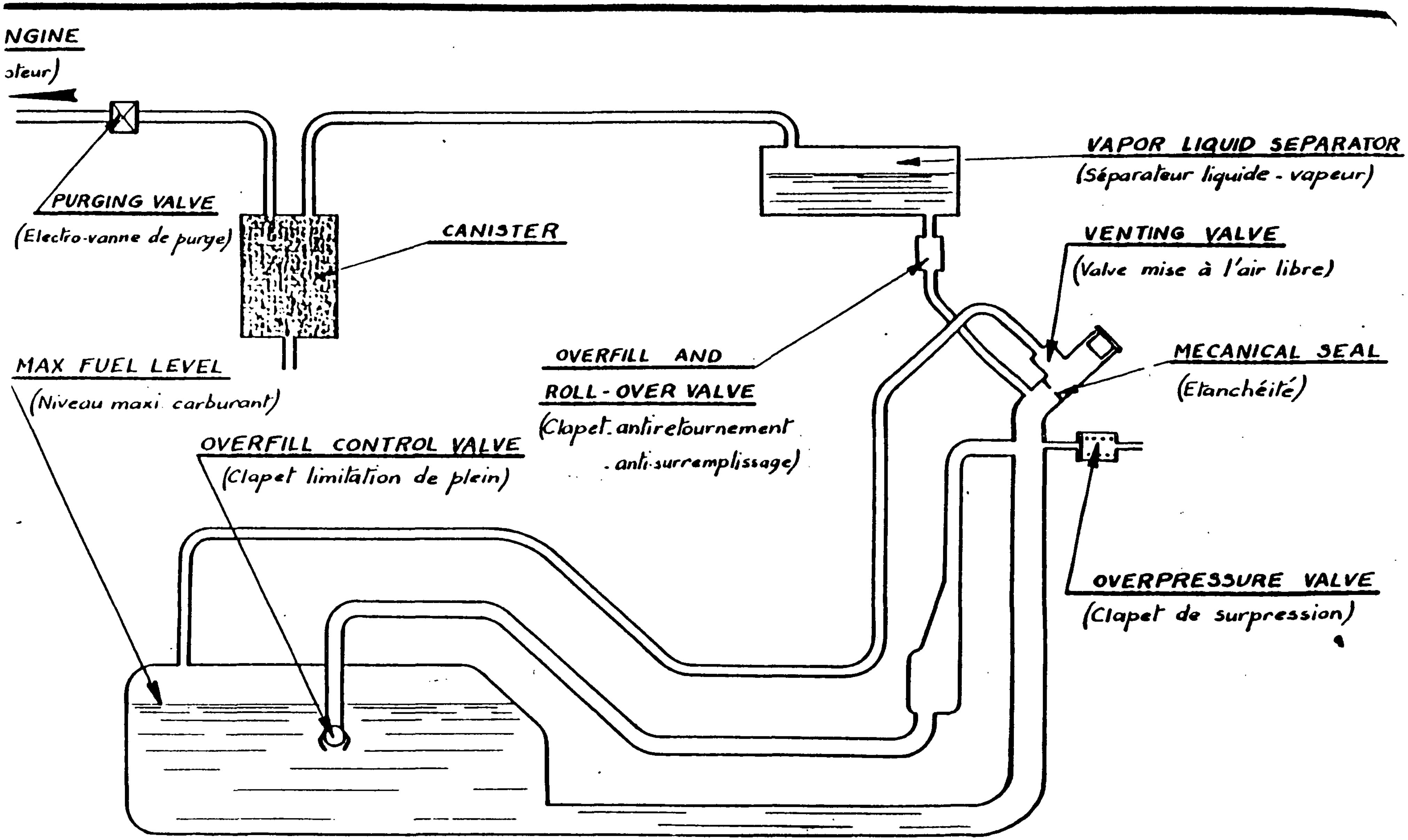


Figure 10 - Peugeot

SCHEMATIC OF PRINCIPLE : ON-BOARD SYSTEM

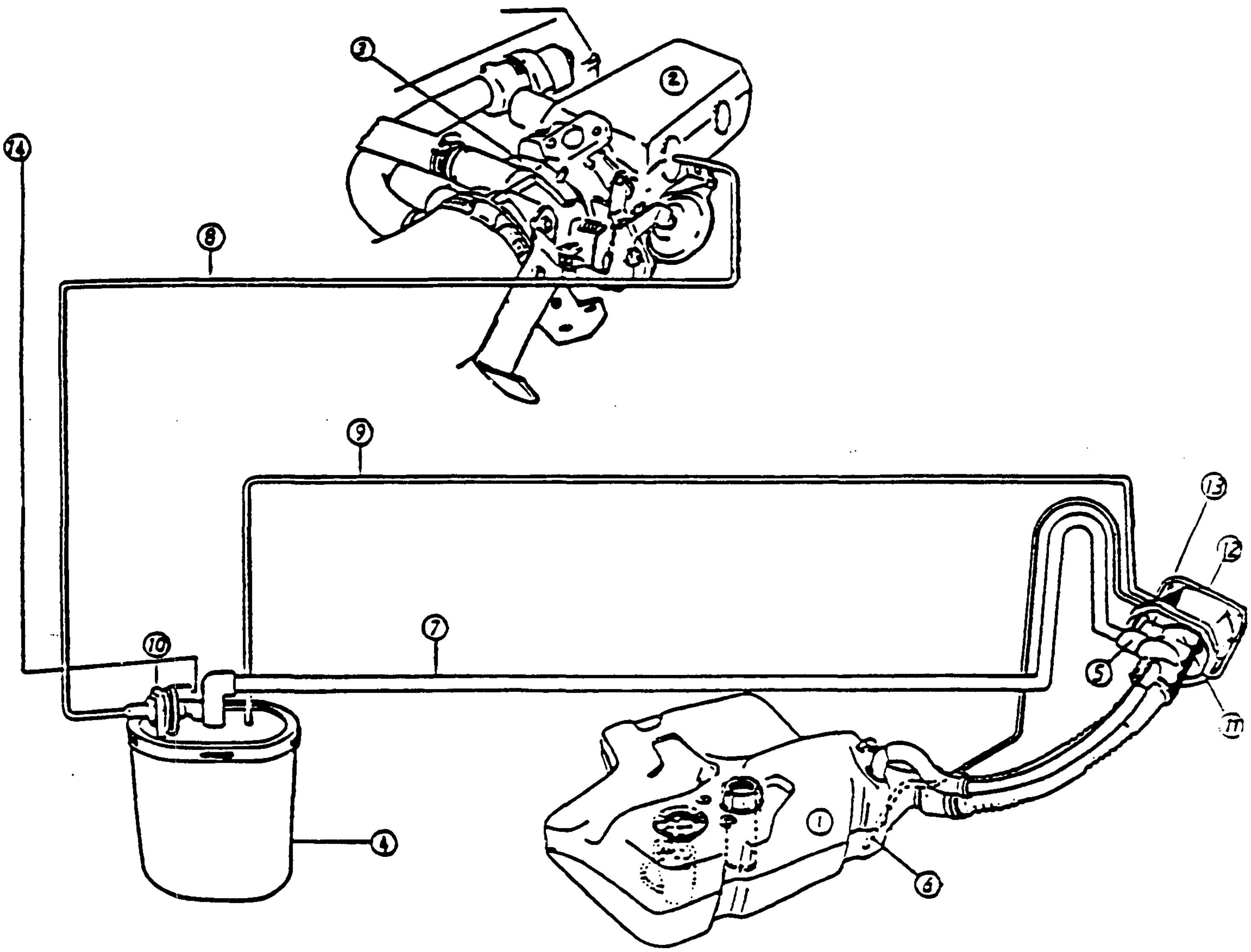
(SCHEMA DE PRINCIPE DE RECUPERATION DES VAPEURS AU REMPLISSAGE)



Appendix I
Figure 11 - Saab

PROTOTYPE ONBOARD REFUELING VAPOR CONTROL SYSTEM

Saab 9000



1. FUEL TANK
2. INLET MANIFOLD
3. THROTTLE
4. CANISTER
5. VENT CUT VALVE (VCV)
6. OVERFILL LIMITER PIPE
7. VENT LINE VCV - CANISTER
8. PURGE LINE
9. VENT LINE ROLLOVER VALVE - CANISTER
10. PURGE CONTROL VALVE
11. REFUELING SEAL
12. FILLER NECK
13. ROLLOVER VALVE VENT
14. PURGE CONTROL UNIT

Appendix I
Figure 12 - Nissan

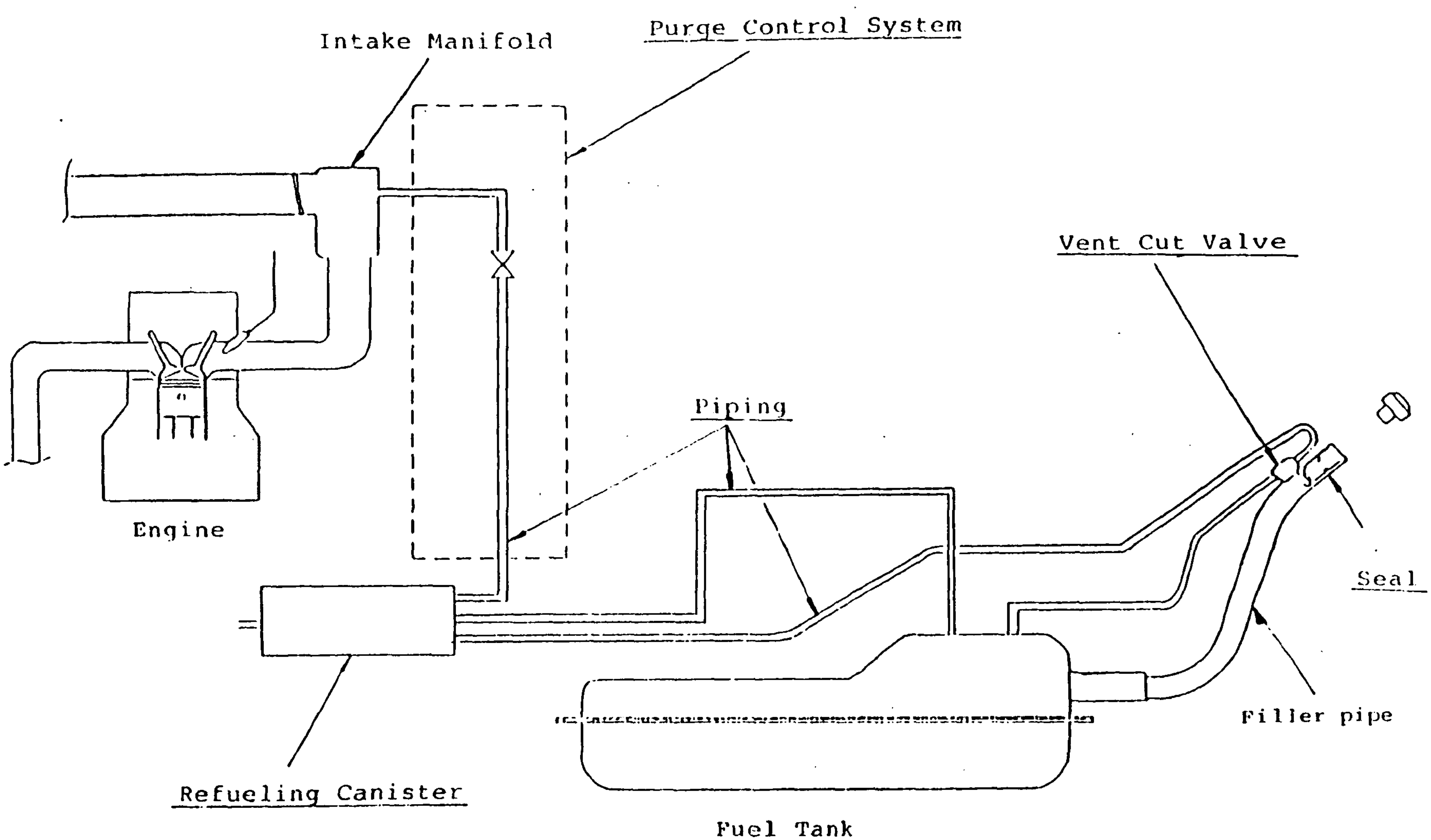


FIG. 1-1 BASIC ONBOARD VAPOR CONTROL SYSTEM

Appendix I
Figure 13 - Nissan

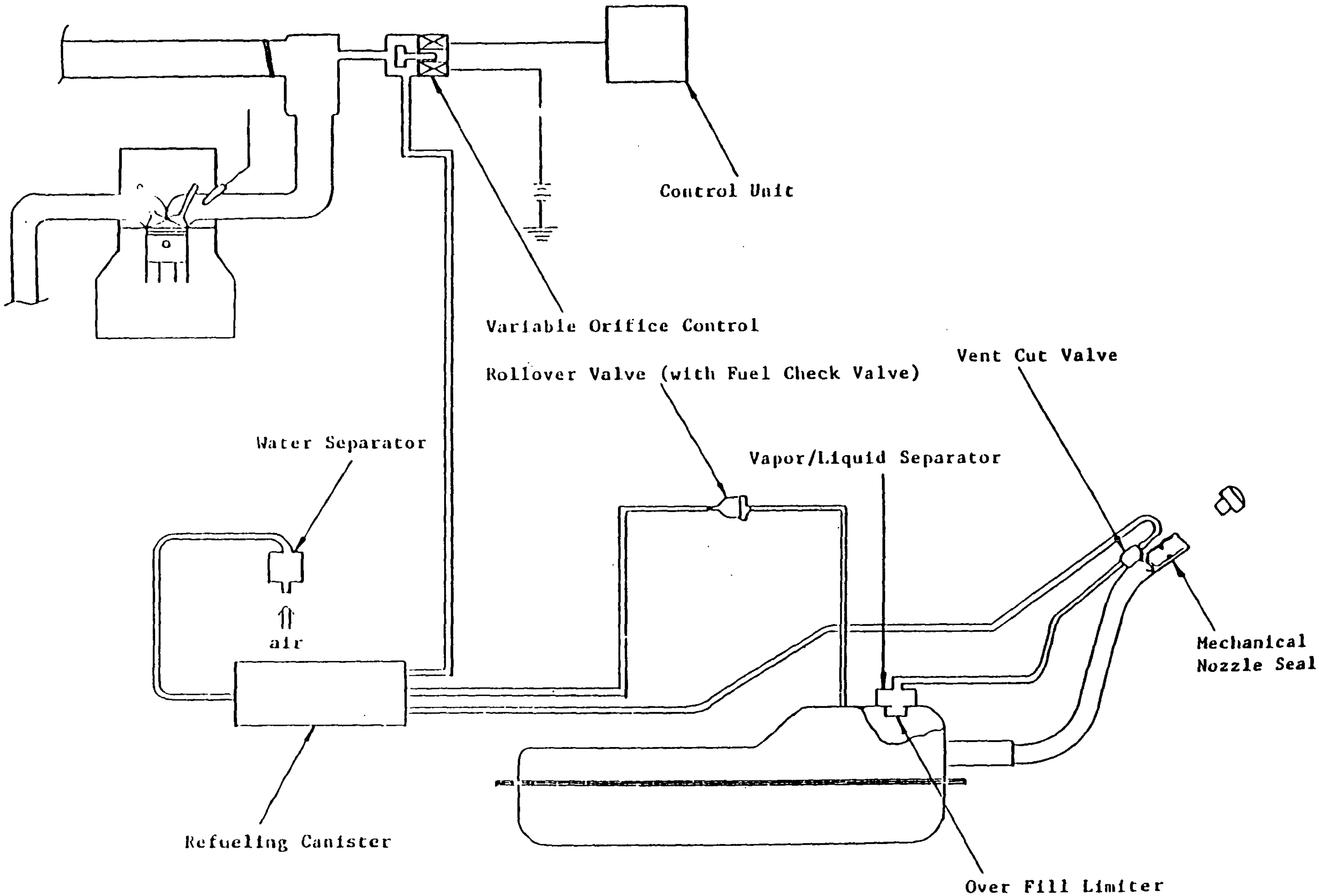


FIG. 3-1 SYSTEM A (SENTRA)

Appendix I
Figure 14 - Nissan

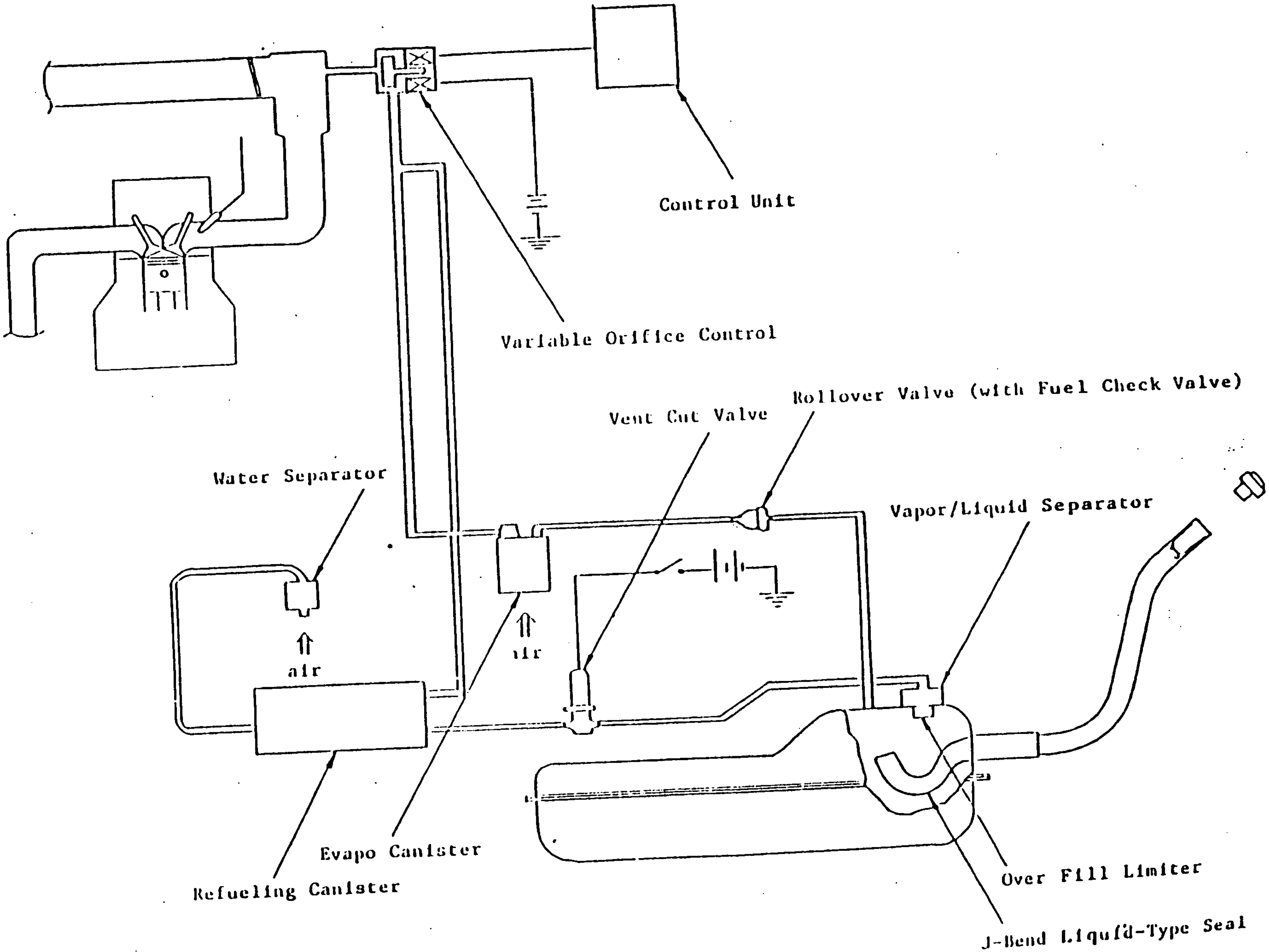


FIG. 3-2 SYSTEM B (300ZX)

Appendix I
Figure 15 - Subaru

Figure 2 Refueling Emission Control System

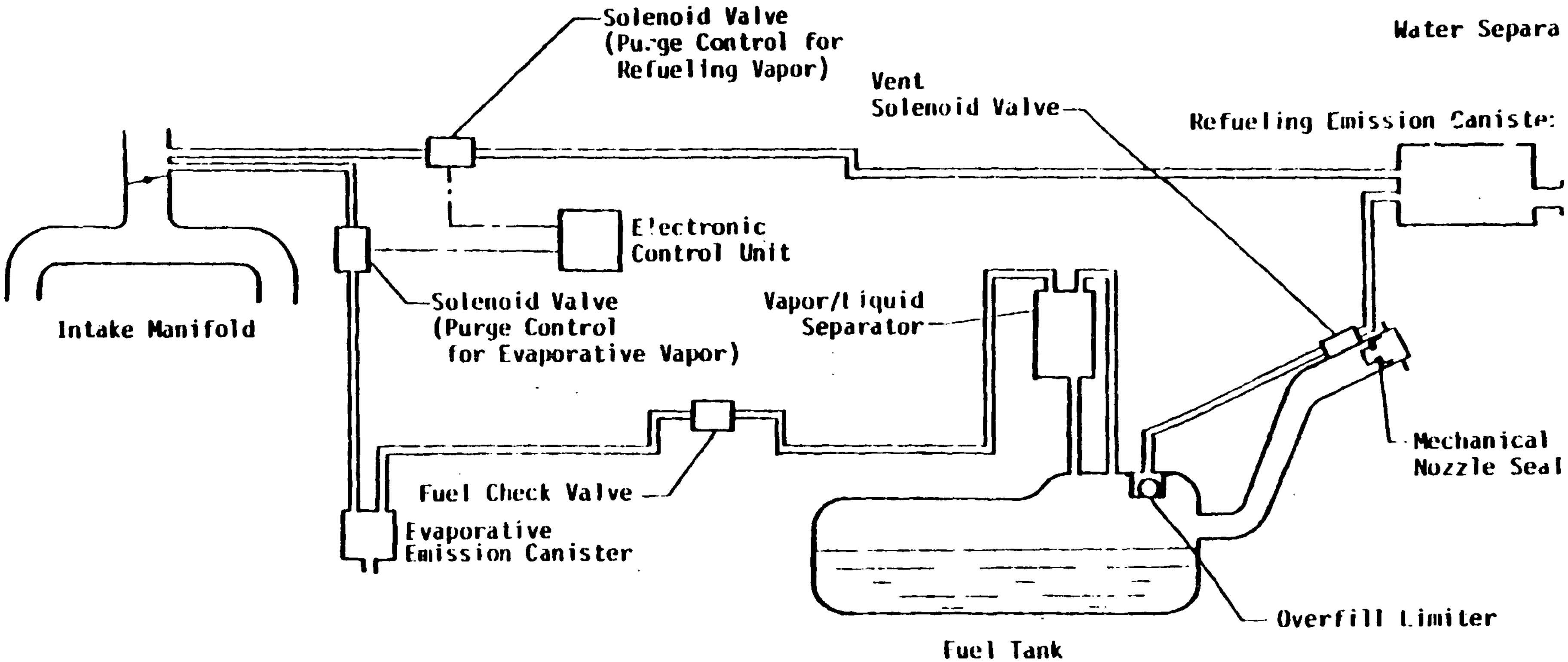


Figure 16 - Toyota

ONBOARD VAPOR RECOVERY SYSTEM

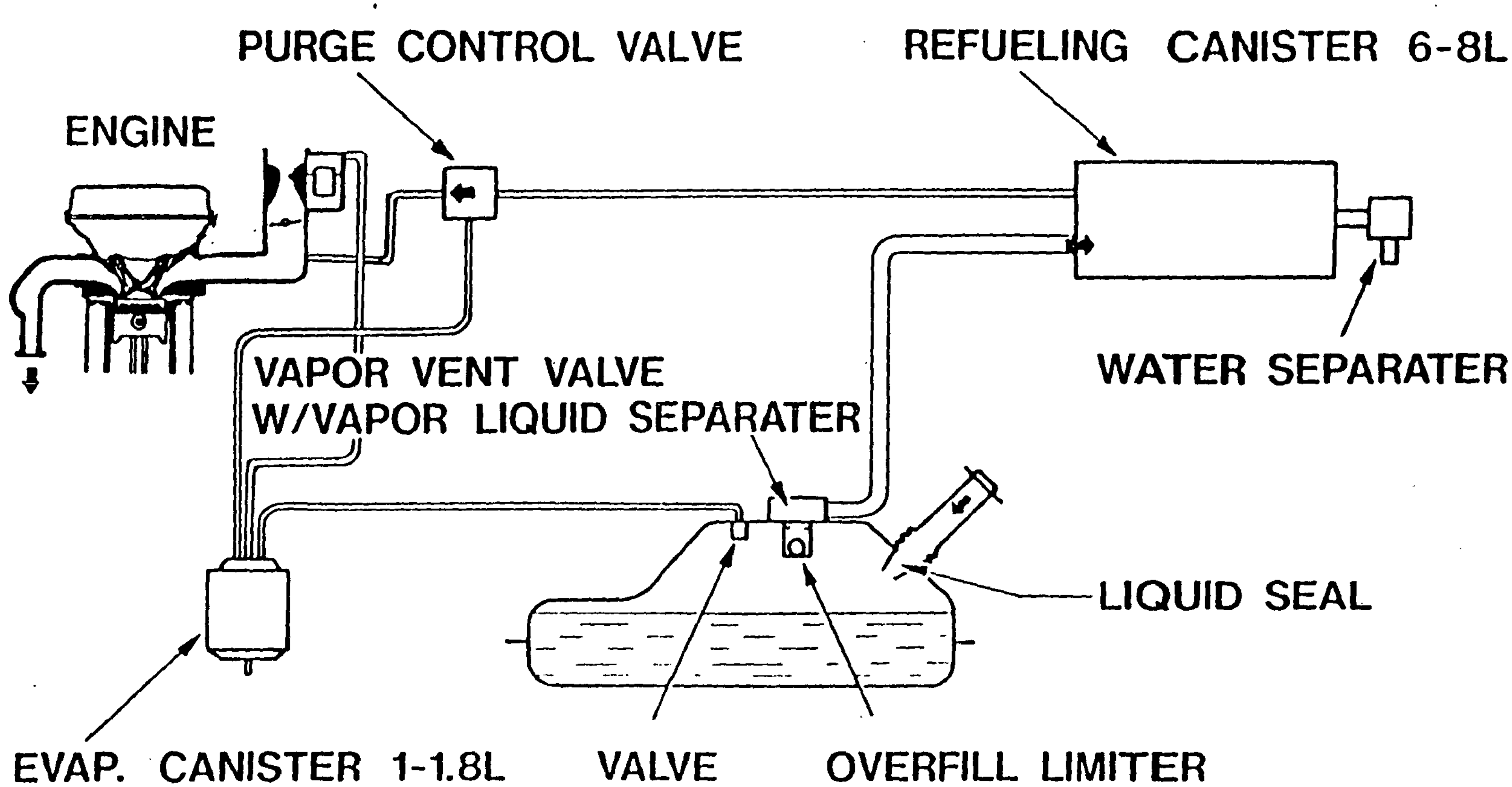


FIG 1-5 ONBOARD VAPOR RECOVERY SYSTEM NON-INTEGRATED (CARB.)

Figure 17 - Toyota

ONBOARD VAPOR RECOVERY SYSTEM

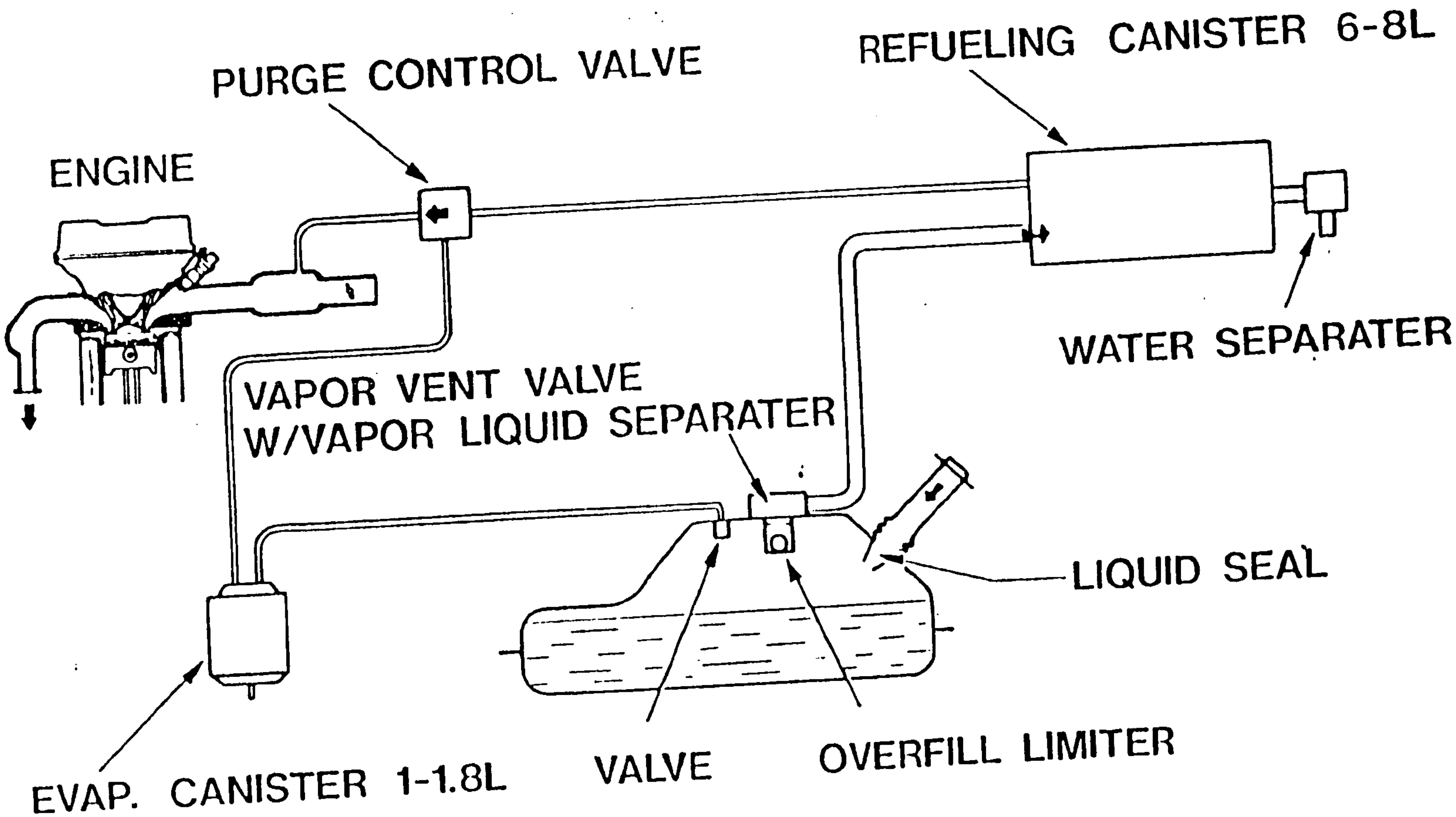


FIG 1-3 ONBOARD VAPOR RECOVERY SYSTEM NON-INTEGRATED (EFI)

Appendix I
Figure 18 - Toyota

ONBOARD VAPOR RECOVERY SYSTEM

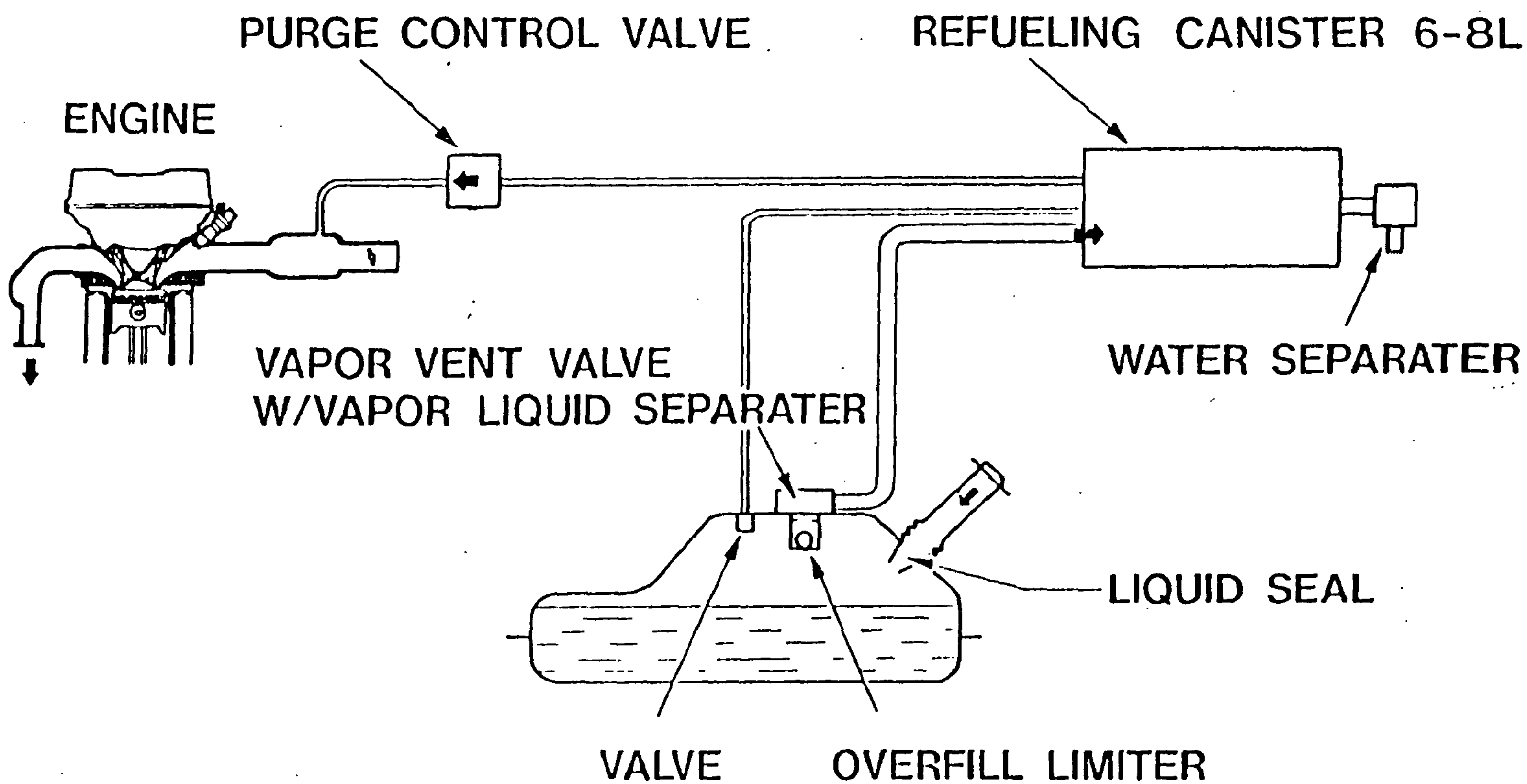


FIG 1-4 ONBOARD VAPOR RECOVERY SYSTEM INTEGRATED (EFI)

Appendix I
Figure 19 - Mitsubishi

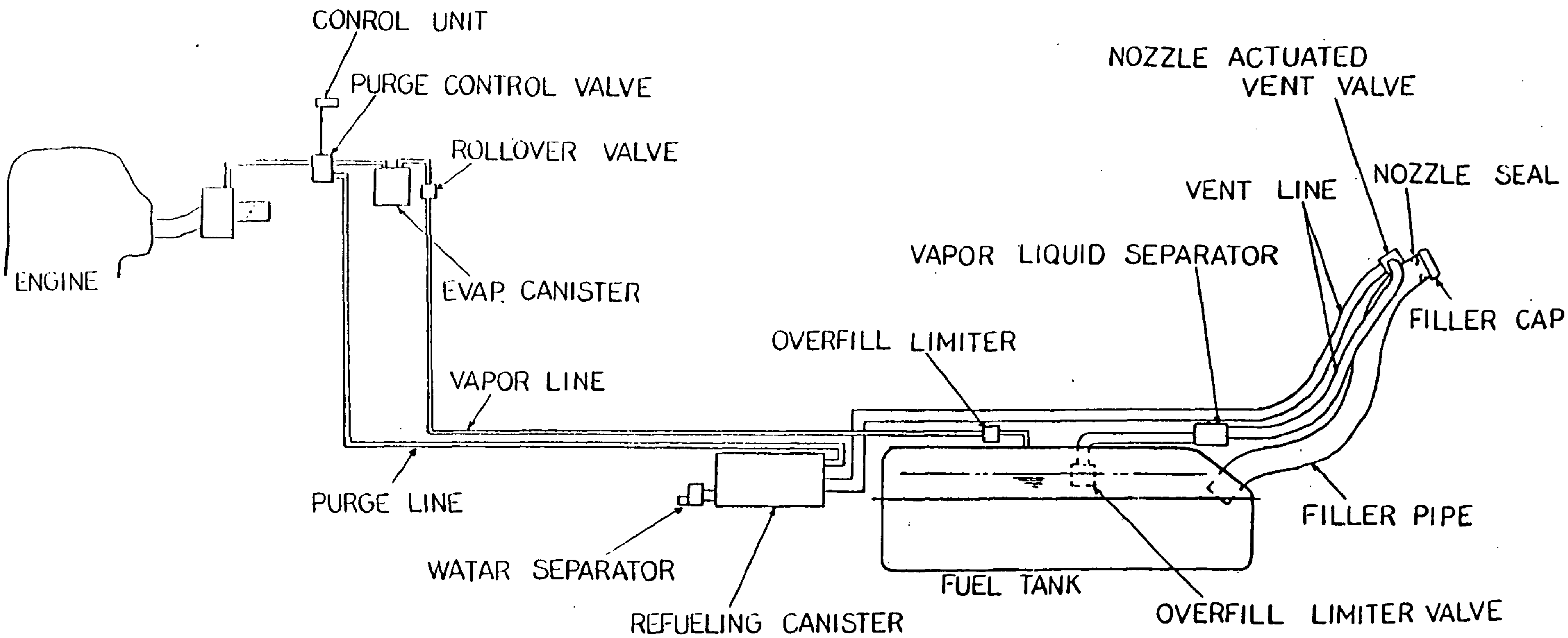


Fig. 3 ONBOARD VAPOR RECOVERY SYSTEM (UNESTABLISHED TECHNOLOGY NON INTEGRATED SYSTEM)

Figure 20 - Mitsubishi

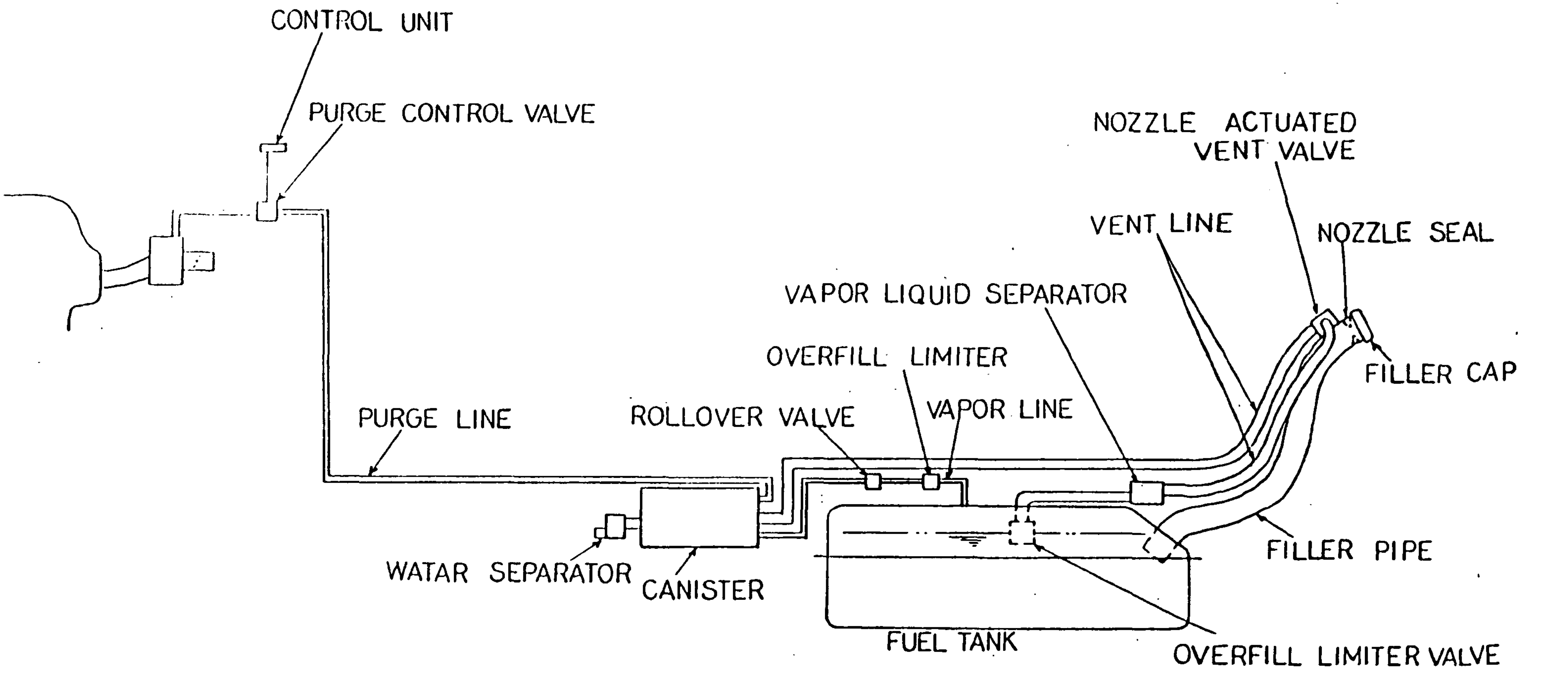
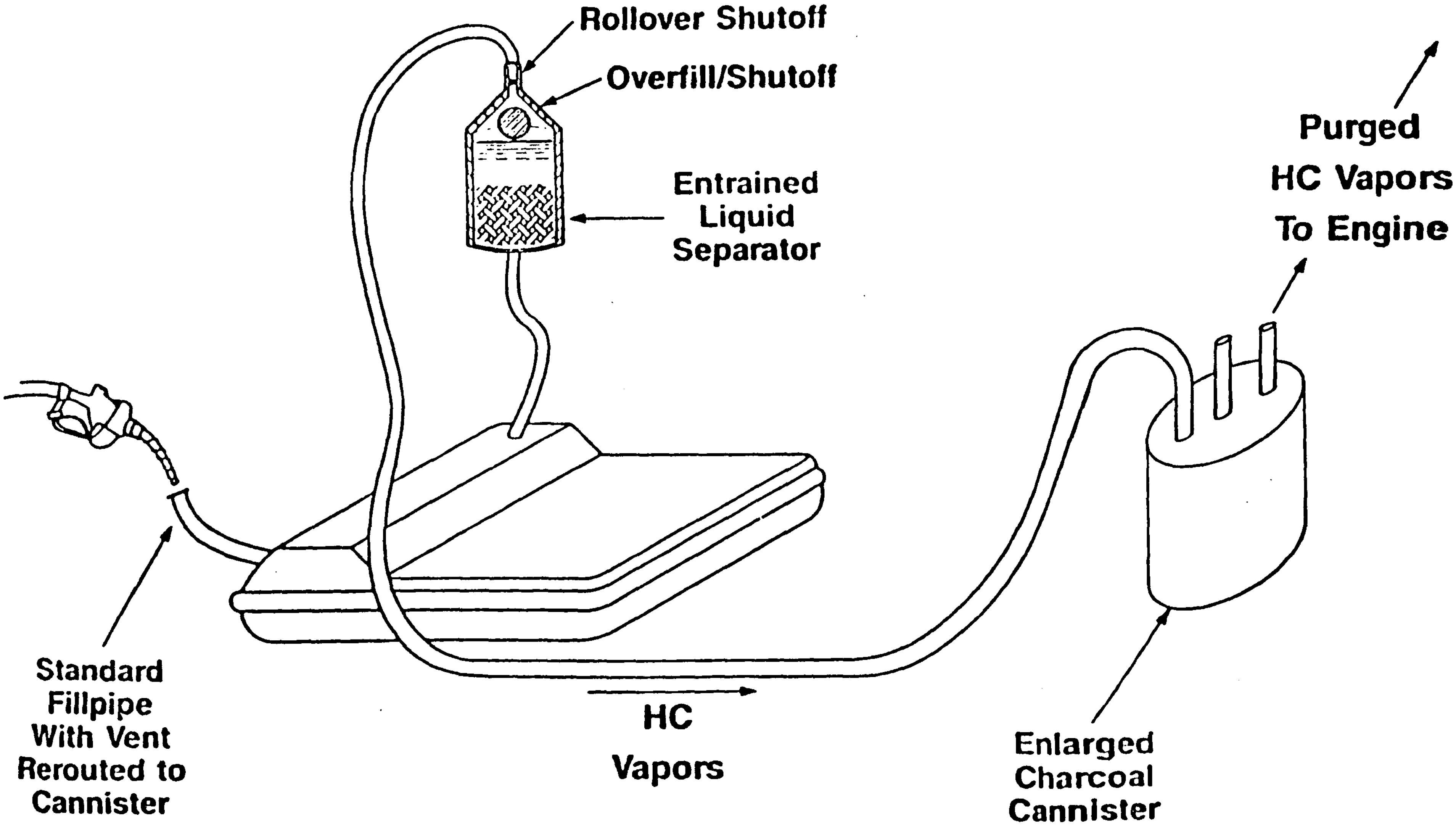


Fig. 2 ONBOARD VAPOR RECOVERY SYSTEM (UNESTABLISHED TECHNOLOGY INTEGRATED SYSTEM)

Appendix I
Figure 21 - American Petroleum Institute
(Exxon Design)

PRINCIPAL ELEMENTS OF ENHANCED ON-BOARD SYSTEM



Appendix I

Figure 22 - American Petroleum Institute
(Mobil Design)

ONBOARD REFUELING EMISSION CONTROL SYSTEM

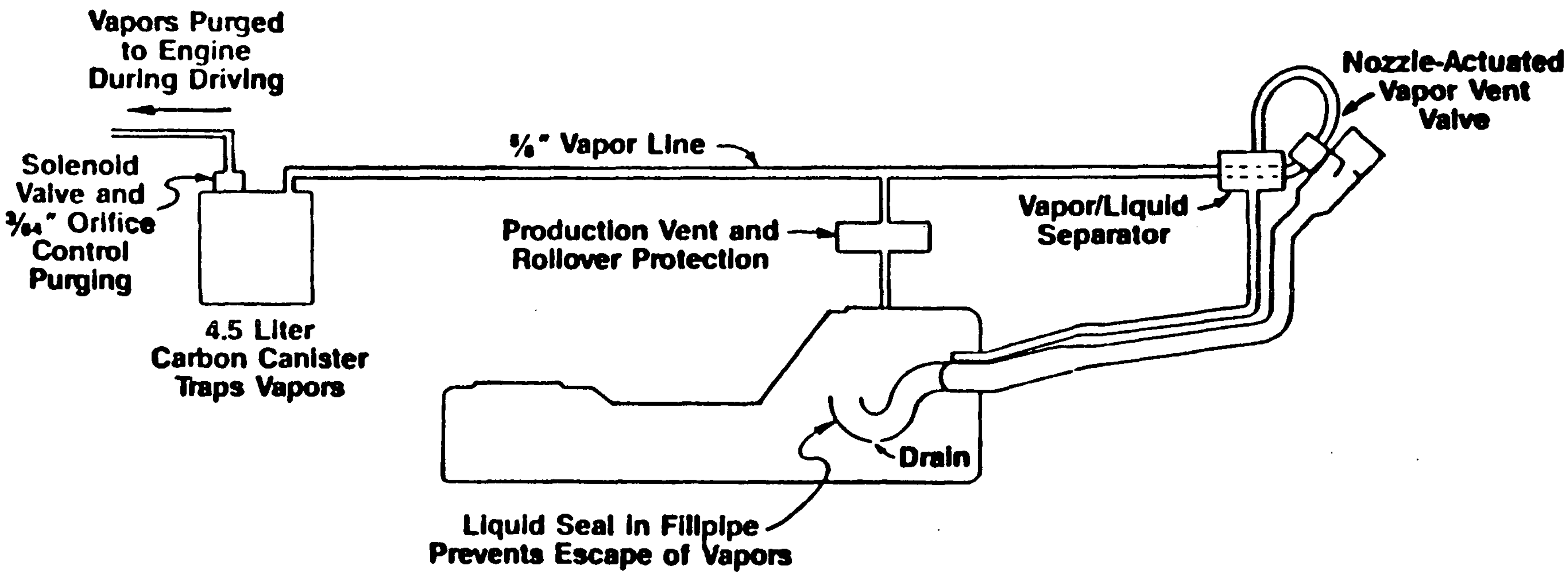
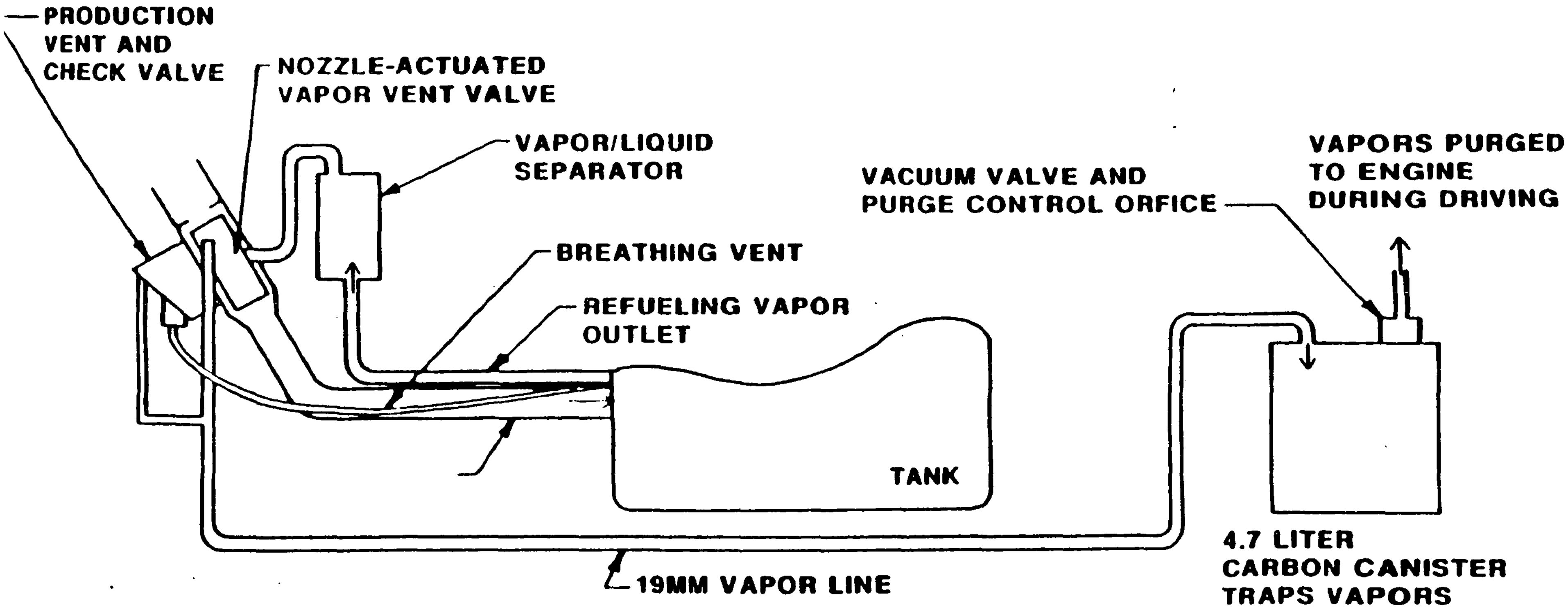


FIGURE 1
SCHEMATIC OF ONBOARD REFUELING EMISSION CONTROL SYSTEM FOR OPEL ASCONA



NOT TO SCALE

Appendix I
Figure 24
Multinational Business Systems

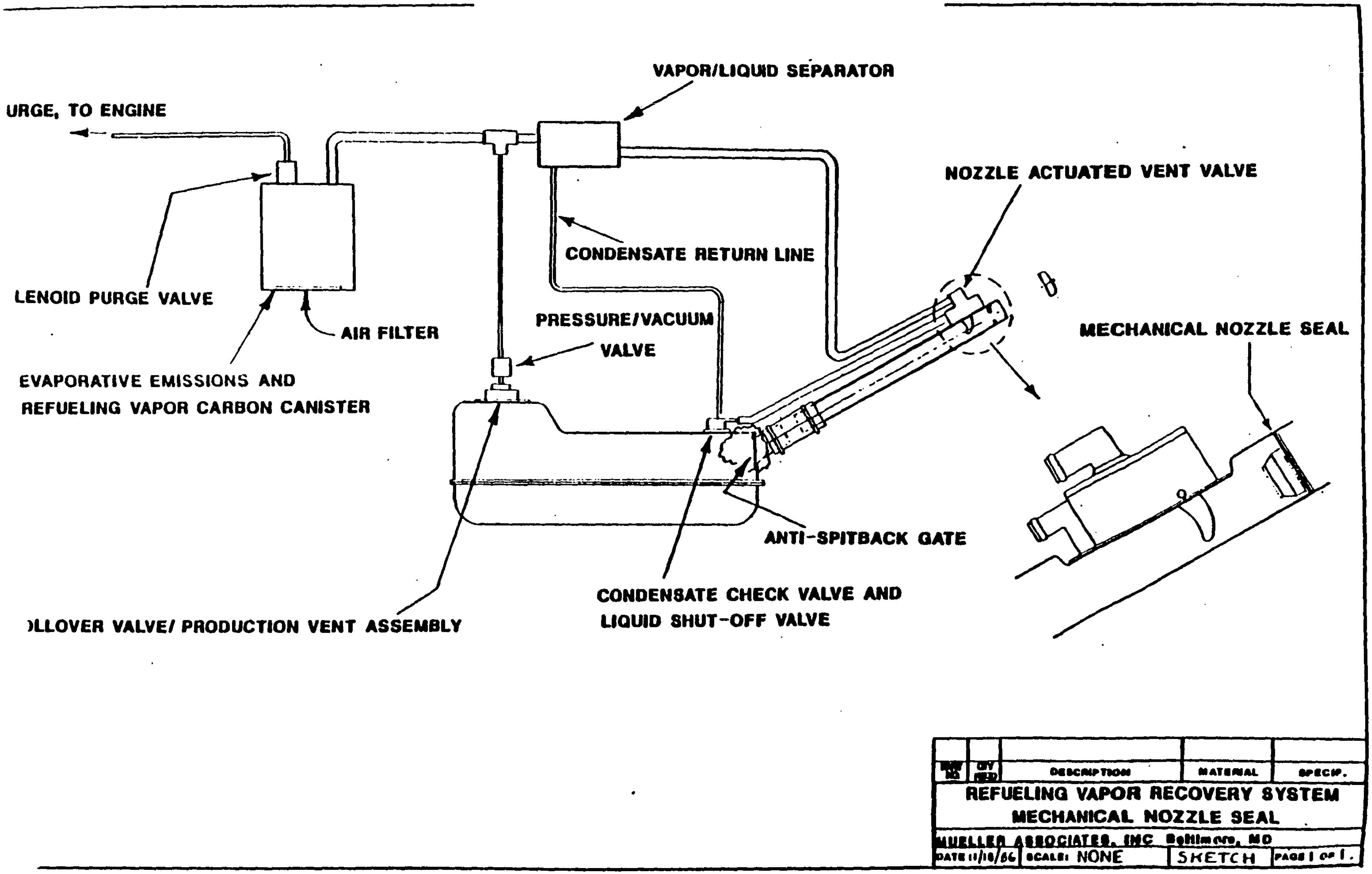


Figure I-1

Figure 25
Multinational Business Systems

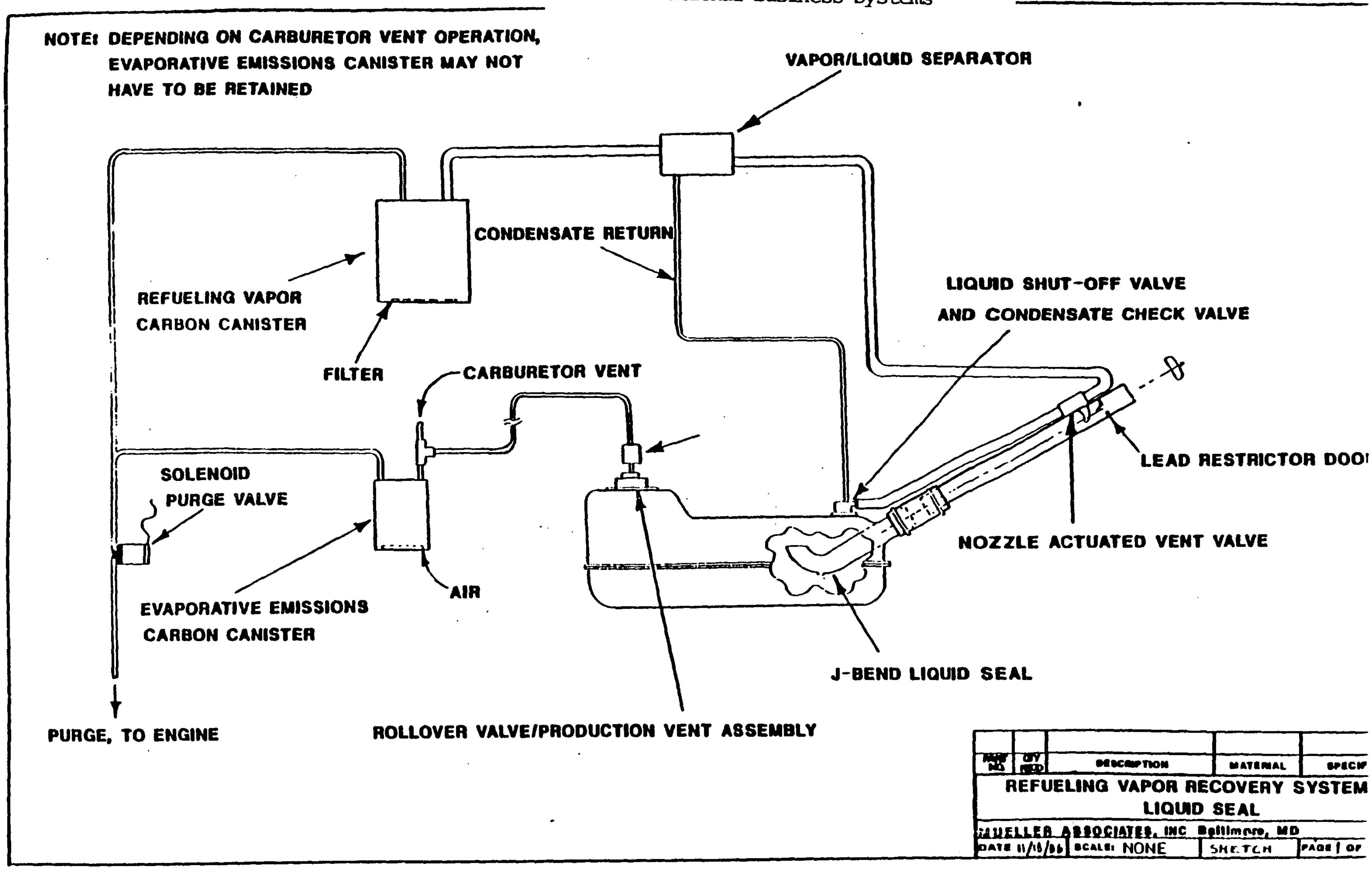


Figure I-2

Figure 26
Multinational Business Systems

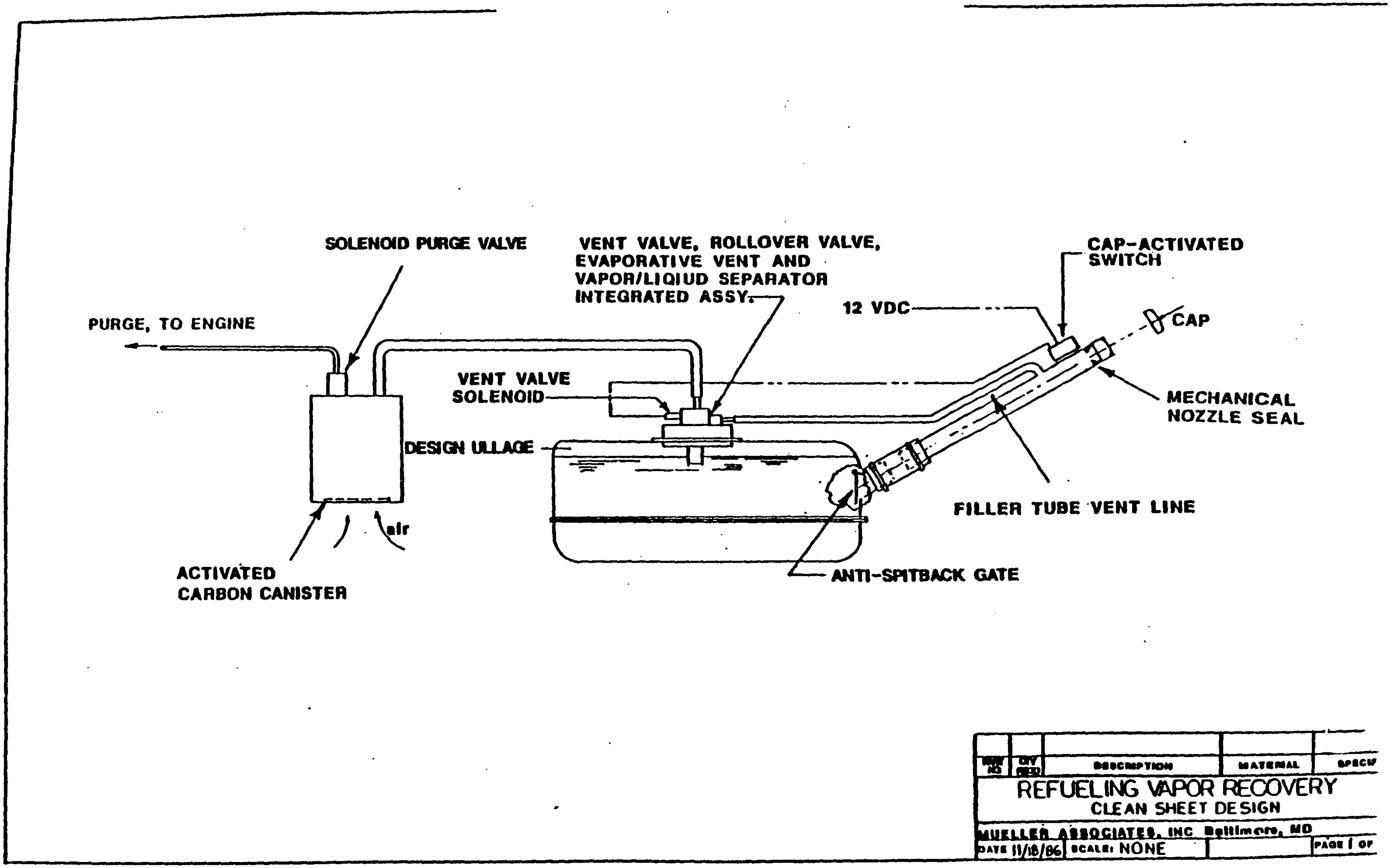


Figure IV-1.

Appendix II

Safety Implications of Onboard

Refueling Vapor Systems

EPA-AA-SDSB-87-05

Technical Report

Safety Implications of Onboard Refueling Vapor Recovery Systems

June 1987

FINAL REPORT

Technical Reports do not necessarily represent final EPA decisions or positions. They are intended to present technical analysis of issues using data which are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position or regulatory action.

Standards Development and Support Branch
Emission Control Technology Division
Office of Mobile Sources
Office of Air and Radiation
U. S. Environmental Protection Agency

Table of Contents

Section		Page
I.	Executive Summary	3
II.	Introduction	7
III.	Onboard Control System Description	9
IV.	Design Considerations for a Safe System	27
V.	In-Use Fuel System Safety	50
VI.	Cost and Leadtime Considerations	61
VII.	Heavy-Duty Gasoline Vehicle Requirements	74
VIII.	Conclusion	95
IX.	References	97

I. Executive Summary

The purpose of this technical report is to evaluate the safety implications of requiring onboard refueling vapor recovery systems on gasoline-powered passenger cars, light trucks and heavy-duty vehicles. In that light, special attention is given to the analysis of the design considerations for a safe onboard system and the other measures necessary to insure that the design considerations incorporated are capable of providing a high level of in-use fuel system integrity.

Onboard refueling systems are in many ways similar to present fuel tank evaporative emission systems. The emissions emanate from the same location on the vehicle and the basic technology used to control the two types of emissions is quite similar. Many of the components are analogous, if not essentially identical, and the configuration/layout of the systems on the vehicle is also expected to be about the same. In fact, these two systems and system functions are so similar that many manufacturers will likely combine their onboard refueling and fuel tank evaporative emission systems into one integrated system which can serve both purposes. The fact that these systems are similar and will be integrated has two effects on the safety of onboard systems. First, many of the approaches and techniques used to safely implement evaporative emission control systems can also be applied to insure the safe implementation of an integrated onboard refueling/evaporative emission system. Second, any safety problems related to integrated onboard/evaporative systems should be evaluated incremental to present evaporative systems. Quite simply, there is no need to add a whole new system to the vehicle.

Concerns over the potential safety implications of onboard systems have, however, been raised. These concerns can be grouped into four general areas. These include requirements to pass the National Highway Traffic Safety Administration (NHTSA) safety tests, the effects of tampering and system defects, refueling operations, and in-use fuel system safety.

Concerns with the design requirements necessary to comply with the NHTSA safety tests focused on the need to integrate an onboard system into a vehicle in a manner which would provide the crashworthiness and rollover protection demanded by Federal Motor Vehicle Safety Standard (FMVSS) 301. EPA's analysis indicates that crashworthiness for the key vapor lines and other system components could be accomplished using many of the same approaches and techniques now applied successfully to evaporative emission systems. Further, the rollover protection now provided for the fuel tank through the use of a limiting orifice can be gained through the application of one of the several rollover valve designs now available.

Concerns have also been expressed that canister tampering and component defects could lead to in-use safety problems. While canister tampering is infrequent, the rate can be reduced and the potential safety effects eliminated through proper placement. Manufacturers are expected to consider the safety implications of tampering when evaluating canister location options on the vehicle as they do now with evaporative control system canisters. While the concern has been expressed that defects in onboard system components could have safety implications, no data or other bases have been found that suggest onboard systems would influence the nature or frequency of such occurrences as compared to those seen on current evaporative emission systems. In fact, given the experience gained by the manufacturers in safely implementing evaporative controls, it is likely that an integrated onboard/evaporative system could be implemented with no more (and perhaps less) problems than present evaporative emissions systems.

Concerns over the safety of refueling operations are centered on the potential to overpressurize the fuel system. EPA's analysis finds that use of a liquid seal solves all overpressure problems, and that if a mechanical seal is used a simple pressure relief device can be used to eliminate any overpressure concerns. As discussed in the analysis, a few other less significant potential problems have very straightforward engineering solutions.

Finally, while it is clear that onboard-equipped vehicles can be designed to comply with FMVSS 301 requirements, there has been concern expressed that fuel system integrity in-use may decrease by some non-quantifiable amount because FMVSS 301 can't cover all potential accident situations and an onboard system requires modifications and additions to the present evaporative emission system. While no test procedure can cover all potential situations, it does not necessarily follow that system modifications or additions will cause an increase in risk over present systems.

Both vehicle and fuel system safety are evaluated as an integral part of the overall design and development process. This involves multiple trade-offs, balances, and compromises with other key design considerations. Given the need to consider all key design criteria, manufacturers accept or manage a certain amount of risk. Since the safety demands of Federal standards such as FMVSS 301 must be incorporated into vehicles/systems, these standards represent the minimum. In many cases the level of safety achieved in-use goes beyond that required by Federal standards, being driven by in-use liability concerns.

If a manufacturer perceives that the added risk mentioned above may exist for one or more of its vehicle models, there are ways to respond through direct measures or through keeping the overall risk in-use at acceptable levels through other design flexibilities. EPA's analysis identifies and describes a number of these measures. Manufacturers can make vehicles safer than they are now; an onboard requirement does not increase the amount of risk a manufacturer need incur or accept. Manufacturers are expected to integrate onboard controls into their fuel systems without compromising safety.

Further, as part of overall risk management, implementing onboard controls provides the opportunity to improve overall fuel handling and fuel system safety. Refueling spills will be reduced and flammable vapors will be trapped in the canister instead of being vented out the fillpipe near the nozzle operator where inadvertent ignition is possible. Also, installing rollover valves could improve the safety for those vehicles now using external fillpipe vent lines without rollover valves. The positive seal provided by a rollover valve is an improvement over the "controlled leak" rollover protection currently provided by a limiting orifice. In addition, implementing onboard systems could further enhance safety by providing the opportunity to make other safety related fuel systems changes which have been delayed for economic or other reasons (e.g., changing from rear to side fill). Finally, if a manufacturer chooses to use a collapsible fuel bladder to control refueling emissions, this would eliminate all of the potential concerns raised relative to the canister based onboard system, and would provide improvements in safety over the present fuel system.

Other key considerations include safety related costs and the leadtime needed to implement onboard controls safely. This analysis estimates that safety costs related to implementing onboard systems will range from $4.50-$9.00 per vehicle. While the cost estimates for the needed hardware, modifications and fuel consumption impacts are reasonably accurate, there is some uncertainty in the development and safety crash testing cost estimates. However, safety related onboard costs are quite insensitive to even large changes in the estimates for development and safety certification.

In a general sense, EPA's estimates are supported by the fact that the modifications needed for present vehicles to insure fuel system safety in-use have been acquired relatively inexpensively, and vehicles with evaporative emission systems comply with FMVSS 301 today. Much of the groundwork needed to implement an integrated onboard refueling/evaporative emission control system safely has been completed and many of the same techniques and approaches can be used. The fact that integrated systems will be used means that some costs incurred to implement evaporative emissions systems safely will not reoccur. EPA's analysis has adequately accounted for safety costs in its estimate of the total onboard system cost. Safety costs contribute about 25 percent of the $20 cost estimated for a passenger car onboard system.

With regard to leadtime, given the magnitude of the task and past experience with implementing evaporative emission and fuel system integrity standards (FMVSS 301), this analysis indicates that 24 months leadtime is adequate. However, EPA is committed to providing the leadtime needed to implement onboard controls safely and effectively, and is open to considering additional leadtime or a short phase-in of controls to assist manufacturers in dealing with problems on unique vehicle models.

Finally, the onboard systems which would be installed on HDGVs are quite similar to those expected for passenger cars and light trucks, even though the safety test requirements are different for HDGVs. With the exception of school buses, the fuel system integrity testing centers more on evaluation of fuel tank integrity than vehicle crash testing. Nevertheless, many of the concerns raised and addressed above regarding onboard safety for lighter-weight vehicles also apply to HDGVs and support the judgment that onboard systems can be applied safely to this class of vehicles within the leadtime laid out above and for a reasonable cost.

II. Introduction

EPA has received several comments from the Motor Vehicle Manufacturers Association, Automobile Importers of America (and their member companies), and the Insurance Institute for Highway Safety which have expressed various levels of concern about the potential safety implications of onboard vapor recovery systems.[1,2] Also, some preliminary comments regarding onboard safety have been received from NHTSA's technical staff.[3] The American Petroleum Institute (which has independently developed several onboard-equipped vehicles) and the Center for Auto Safety have expressed support for the implementation of onboard vapor recovery systems.[4,5] The purpose of this report is to discuss and analyze the safety related concerns raised regarding onboard vapor recovery systems.

Motor vehicle manufacturers face many difficult technical decisions in the design and development of vehicle systems and the integration of these systems into new vehicle models. The difficulty of these decisions often arises from the fact that this design, development and integration process requires the simultaneous consideration of a number of key criteria. One of the most important of these criteria, safety, is normally given a high priority in the design and integration process. However, the process also includes careful and prudent consideration of the trade-offs necessary to deal with other important criteria such as performance, reliability, cost, styling, and regulatory requirements such as fuel economy and emissions. In each case, manufacturers must find the appropriate balance of all the important criteria. Since the design of emission control systems has the potential to affect the overall safety of vehicles, EPA views safety as a primary concern when evaluating the feasibility of an emission control device.

EPA is presently evaluating the use of onboard vapor recovery systems (onboard systems) as a means of controlling refueling emissions. The potential safety implications of such controls require special consideration, because implementing onboard systems will involve some minor modifications of the vehicle fuel system. While safety influences all aspects of vehicle design, fuel system safety and integrity is a key concern in the design and integration process.

In evaluating the safety implications of requiring onboard controls, EPA has applied the philosophy that no increase in overall risk should be caused or accepted, beyond that now present with today's fuel/evaporative system. This applies to both compliance with the applicable Federal safety standards and the in-use safety of vehicles equipped with onboard systems. The following analysis will show that straight forward engineering solutions are available for all of the potential safety problems which have been identified, and that while final choices regarding exact system designs lie with the manufacturers, safe fuel system designs are achievable by all. This analysis of onboard safety issues and the associated cost and leadtime generally applies to any canister-based onboard system design. Further, as will be discussed below, this analysis indicates that it is quite possible that overall fuel system safety improvements could accompany the implementation of onboard controls.

The importance of evaluating the safety of onboard systems is highlighted by the Clean Air Act (Section 202 (a)(6)) which directs EPA to consult with the Department of Transportation (DOT) before requiring the use of onboard vapor recovery systems. This requirement is intended to insure that all safety issues have been properly identified and addressed. This report will also help to assist in the fulfillment of this requirement.

As outlined below, the remainder of this report is divided into five sections. The first section following this introduction (Section III), provides a general description of an onboard system to aid in the understanding of any related safety issues. Section IV summarizes and provides EPA's analysis of the comments received regarding the design of a safe onboard system, and Section V discusses onboard effects on in-use fuel system safety. Section VI discusses the effects safety considerations have on other important factors such as vehicle costs and leadtime. Heavy-duty gasoline-fueled vehicles (HDGV) pose similar yet distinct onboard control system safety issues, and Section VII addresses these similarities and differences. The final section provides conclusions.

III. Onboard Control System Description

Before considering any safety issues, it is important to have a clear understanding of onboard refueling vapor recovery systems (onboard systems) and how they work. Likewise, before considering the characteristics of the control system, it is important to understand the nature of refueling emissions. The purpose of this section is to provide the reader with both a clear understanding of what refueling emissions are and how onboard systems operate to control these emissions.

In many respects, onboard systems are similar to the evaporative emission control systems now in use on most gasoline-powered vehicles. In fact, it has been suggested that onboard systems are more an extension or modification of current evaporative emission systems than the implementation of a new control technology. An explanation of the differences and similarities between the two systems will provide a better understanding of the incremental nature of onboard systems relative to current evaporative systems, and will be useful in assessing the design, cost, and leadtime implications of implementing onboard controls safely, which are to be discussed later in the report.

This section will first briefly describe evaporative emissions and how they are currently controlled. Next, refueling emissions will be discussed and similarities between onboard systems and current evaporative emission systems will be presented. The section will end with a discussion of the differences between the two control systems.

A. Evaporative Emissions

Evaporative emissions emanate from two basic sources: the fuel tank and the fuel metering system (either a carburetor or fuel injectors). Evaporative emissions arising from the fuel tank are primarily "diurnal" emissions while those from the fuel metering system are termed "hot soak" emissions.* This analysis is primarily concerned with fuel tank evaporative or diurnal emissions since these emissions are currently controlled using an approach similar to that envisioned for an onboard system.

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* It should be noted that a small amount of hot soak emissions come from the fuel tank; the fuel tank evaporative control system would handle these as well as the diurnal emissions.

Diurnal evaporative emissions consist of gaseous hydrocarbons that are displaced from the tank when fuel in the tank is heated. Fuel heating can result from changes in ambient temperature or during vehicle operation due to the vehicle exhaust system and/or recirculation of fuel heated by the engine. In either case, as fuel in the tank and vapor above the fuel heat up, more of the liquid fuel evaporates, and the vapor itself expands, thus causing hydrocarbon vapor to be released into the atmosphere (unless captured by a control system). Fuel volatility, size of the vapor space, initial tank temperature, and the degree to which the tank is heated can all impact the quantity of hydrocarbons emitted. Diurnal emissions occur on at least a daily basis, and a system designed to control these emissions must be capable of handling repeated evaporative emission loads. Since the early 1970's, most vehicles have come equipped with a control system to limit the amount of diurnal evaporative emissions. The next section discusses the type of control system typically used on today's vehicles.

B. Evaporative Emission Control System

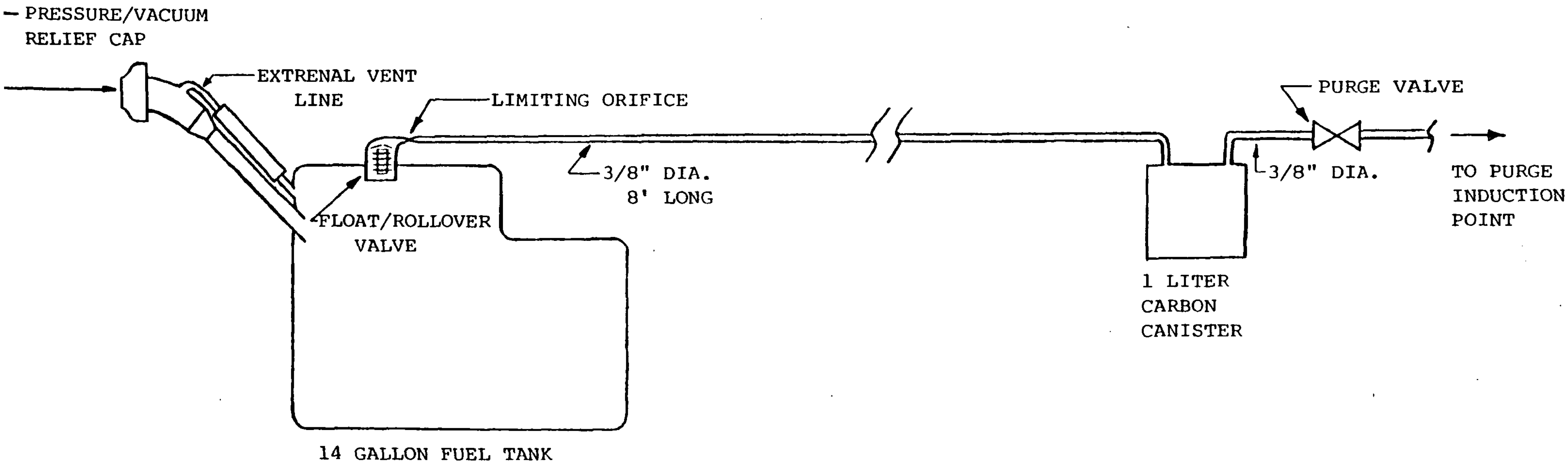
Figure 1 depicts a fuel tank equipped with an evaporative emission control system.[6] As can be seen from this figure, the control system is relatively simple in design and requires very few components. The purpose of this section is to describe each of the system's components in terms of both physical appearance and function.

In order to effectively prevent the escape of fuel tank vapors to the atmosphere, an evaporative control system must perform three basic functions. First, the system must limit the number of exits through which fuel tank vapors might escape. Second, the exit that does allow fuel tank vapors to escape must lead to a container where the vapors can be captured. Third, the system must eventually restore the capacity of the storage container by purging it of the trapped vapors. The discussion below describes how an evaporative emission system performs these three functions.

The first function an evaporative emission system must perform is to limit the outlets through which vapors can escape. As can be seen in Figure 1, there are only three openings through which vapors can pass: 1) the fillpipe opening, 2) the external vapor vent line to the fillpipe top (about 1/2" diameter), and 3) the small limiting orifice (approximately 0.050-0.055 inch) in the top of the tank. The fuel tank cap is designed to form a tight seal with the fillneck so that once the cap is secured in place, vapors from the fillpipe opening and the external vent line are trapped within the system. Thus, only one outlet exists through which fuel tank vapors can escape. This single available outlet is the small limiting orifice in the top of the tank.

Figure 1

Typical Current Evaporative System

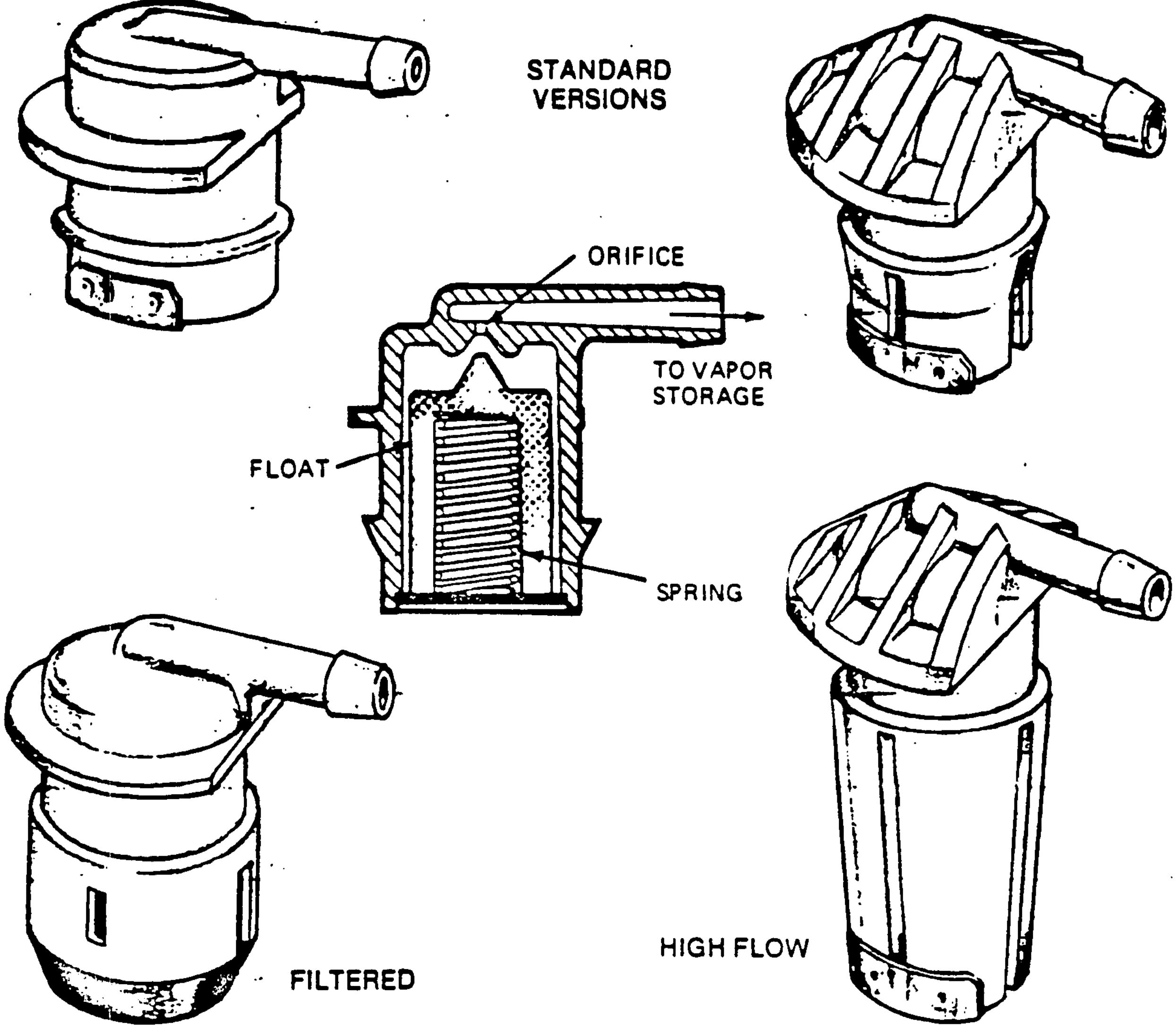


As the tank undergoes temperature changes, and hydrocarbon vapors are generated, pressure builds up in the tank (as long as the fuel tank cap is secure in place). This pressure build-up is slowly relieved as gas tank vapors eventually force their way through the only available exit: the small limiting orifice in the top of the fuel tank which leads to the vapor storage device (charcoal canister). By limiting the number of vapor escape passages and routing the evaporative hydrocarbons to a single point, the control system has successfully performed the first of its three basic functions. Before discussing the evaporative emission system's second function, it is important to understand why the orifice in the top of the tank is so limited in size.

The orifice in the top of the tank is very small in size for three reasons. First, it allows pressure to build up in the tank when vapors are generated. This pressure build-up inhibits further evaporation and creates a pressure differential which eventually leads to hydrocarbon vapor being forced through the limiting orifice. Second, the limiting orifice acts as a liquid/vapor separator. If liquid gasoline were to splash up into the vent line leading to the evaporative emission control storage device (charcoal canister), damage could potentially occur to the storage media (charcoal). However, the orifice in the top of the tank is so small that liquid passes through it at only a very slow rate. Essentially only vapor is allowed to continue to the canister. This point leads to the final reason for limiting the size of the vent orifice to such an extent. Were the vehicle ever to be in a rollover accident, a very little amount of liquid fuel would be able to leak from the tank through such a small orifice. Thus, the limiting orifice is sized large enough to allow for adequate escape of evaporative emissions, but is small enough to permit only a slow leak from the fuel tank in the case of a vehicle rollover and thus provides the protection needed to comply with FMVSS 301. The cost for this is low. However, some manufacturers incorporate an additional valve for added protection; an example is shown in Figure 2.[7]

Storing the evaporative hydrocarbons is the second basic function an evaporative emission system must perform. Once the vapors escape from the fuel tank through the small limiting orifice, they proceed through a vent line (usually about 1/4"-3/8" inside diameter and made of some type of flexible rubber compound) that leads to a canister containing charcoal. The canister itself is usually made of plastic and is generally a cylindrical or rectangular container. Once inside the canister, the hydrocarbons are adsorbed onto activated charcoal where they are stored temporarily.

Figure 2



The tank mounted spring balanced float valve is a low cost unit designed for venting fuel tank vapor to the carbon canister. The device employs a float which remains open under normal conditions. Should the tank level reach a critical height, the float will close the canister vent line. In the event of extreme vehicle attitude or roll-over, the float will close the canister vent line.

A filtered tank mounted spring balanced float valve is available that performs the same functions as the above sketches except the tank side of the part is filtered to prevent contaminates from entering the part which might effect float closing of the canister vent line.

For high flow applications that require a large volume of vapor venting, such as fuel injection applications, a high flow valve has been developed that has more than twice the present flow capacity without loosing other critical performance parameters.

FLOAT VALVE

Borg-Warner Automotive, Inc.
707 Southside Dr., Decatur, Illinois 62525
Phone 217/428-4631

437
SKETCH NUMBER

The working capacity of the charcoal, the quantity and frequency of the evaporative emissions, and the capability of the system to restore its working capacity all affect the amount of charcoal required. Current passenger car evaporative emission control systems typically utilize a 0.85-1.5 liter canister.[8] (This size is sufficient for both diurnal and hot soak evaporative emissions.) However, a finite amount of charcoal is used in the canister, so the storage capability of the canister is limited. Once the evaporative hydrocarbons have been adsorbed onto the charcoal in the storage canister, they will remain there until removed. The hydrocarbons must be stripped from the charcoal periodically in order to restore enough working capacity to adequately capture each successive evaporative emission load.

While the vehicle is operated, the evaporative emission system performs its third basic function of restoring the storage capability of the charcoal canister. After the vehicle's engine is running, manifold vacuum is used to draw hydrocarbon-free air through the charcoal canister. Hydrocarbons stored in the canister are desorbed into the air stream which flows into the fuel metering system via a flexible rubber purge line of about 3/8" diameter. Once purged, the evaporative hydrocarbons are burned as fuel through normal combustion in the engine. This process "empties" the canister, thereby preparing it for the next evaporative emission load.

One aspect of the purge process which needs to be mentioned but will not be explained in great detail is the fact that the canister is not continuously purged during vehicle operation.[8,9] A valve located between the canister and the fuel metering system is opened and closed at opportune times to control the purge process and limit disturbances which affect engine performance and exhaust emissions.

To summarize, the current evaporative emission control system performs three basic functions: 1) it limits the exits through which fuel tank vapors can escape; 2) it traps the vapors in a storage device; and 3) it restores the capacity of the storage device to prepare it for the next evaporative emission load.

Onboard systems are very similar to evaporative emission control systems because they must also effectively perform the same three basic functions to efficiently control refueling emissions. However, due to differences in the quantity of vapors and the rate of generation of evaporative and refueling emissions, equipping vehicles with onboard systems will require that some minor modifications be made to current fuel and evaporative emission control systems.

The next section provides additional detail regarding refueling emissions to help explain the fuel and evaporative system modifications that would be required to equip vehicles with onboard systems.

C. Refueling Emissions

Three processes contribute to the release of hydrocarbons during a refueling operation. The first two are collectively termed displacement losses, the third spillage. First, the hydrocarbon vapor present in the tank is displaced from the fuel tank by liquid fuel entering through the fillpipe. If the vehicle fuel tank is equipped with an external vapor vent line (as shown in Figure 1), much of the fuel tank vapor escapes via the external vent line which is connected to the top of the fillpipe. However, if no such vapor passage exists, the vapor makes its way out through the fillpipe concurrent to the incoming liquid fuel. Hydrocarbons are also generated and released during refueling as a result of liquid fuel evaporating as it is dispensed into the tank. This second type of displacement loss is caused by the turbulence in the liquid/air interface during the refueling process and is enhanced by the higher volatility of the dispensed fuel relative to the fuel in the tank. A third source of hydrocarbon refueling emissions is the evaporation of any liquid fuel spilled during the refueling operation. Of the three refueling emission sources, the two displacement sources are generally much greater (by far), unless a large spill occurs.

Because the bulk of refueling emission emanate from within the fuel system, refueling emissions are in many ways similar to diurnal evaporative emissions. Therefore, it follows that an effective onboard system can be designed which utilizes the same basic technology and approach utilized by current evaporative emission systems. In fact virtually all onboard systems considered by manufacturers in their comments incorporate this approach as do the prototype systems developed to date.[10,11,12,13,14,15] The similarities between onboard and evaporative emission systems are discussed below.

D. Onboard Refueling Control Systems

1. Similarities with Evaporative Emission Control Systems

In order to control refueling emissions, onboard systems must perform the same three basic functions as described previously for diurnal evaporative emission systems. These include limiting the number of exits through which refueling vapors can escape, storing refueling emissions temporarily in a charcoal canister, and purging the charcoal canister of the stored refueling vapors to restore its capacity prior to the next refueling operation. Because these three functions are so similar to the three functions a diurnal evaporative emission control system must perform and the emissions arise from the same location, extrapolation of known technology leads to the conclusion that an onboard system would use the same approach and similar hardware to that which is currently used to control evaporative emissions. Figures 3 and 4 depict two representative onboard systems and a comparison with Figure 1 shows that onboard controls are very similar in overall design to current diurnal evaporative emission control systems. However, while onboard systems do use many of the same basic components as evaporative systems, (i.e., charcoal canisters, flexible rubber tubing, purge control valve, etc.), the basic differences between refueling and evaporative emissions require a few additional components, and an enlargement of certain existing hardware is required for the onboard system. These are the key differences between the two systems.

Before discussing the component additions and enlargements, an important aspect of the onboard refueling vapor recovery system must be introduced.

Since both emissions emanate from the same location, a properly designed onboard system could control both refueling emissions and diurnal evaporative emissions. Thus, if an onboard refueling system were incorporated into a vehicle's fuel system, the current diurnal evaporative emission control system would no longer be needed. This aspect of onboard systems has several implications. First, it reduces the conceived degree of complexity the system adds to the vehicle's fuel system. An entirely new, larger, more complex system would not be needed in addition to that which currently exists. Rather, the current control system would be modified to be somewhat larger with a small increase in the number of components. Second, since onboard systems are basically modified evaporative emission systems, many of the safety design concerns associated with onboard systems have already been addressed in current evaporative emission control system designs. These approaches could also be used in the integrated system. One final effect a "dual function" control system has is it requires less "packaging" space and is less expensive to produce than two separate systems.

Figure 3

Integrated Evaporative/Refueling System

Nozzle Actuated Valve
Front Mounted Canister
Mechanical Seal

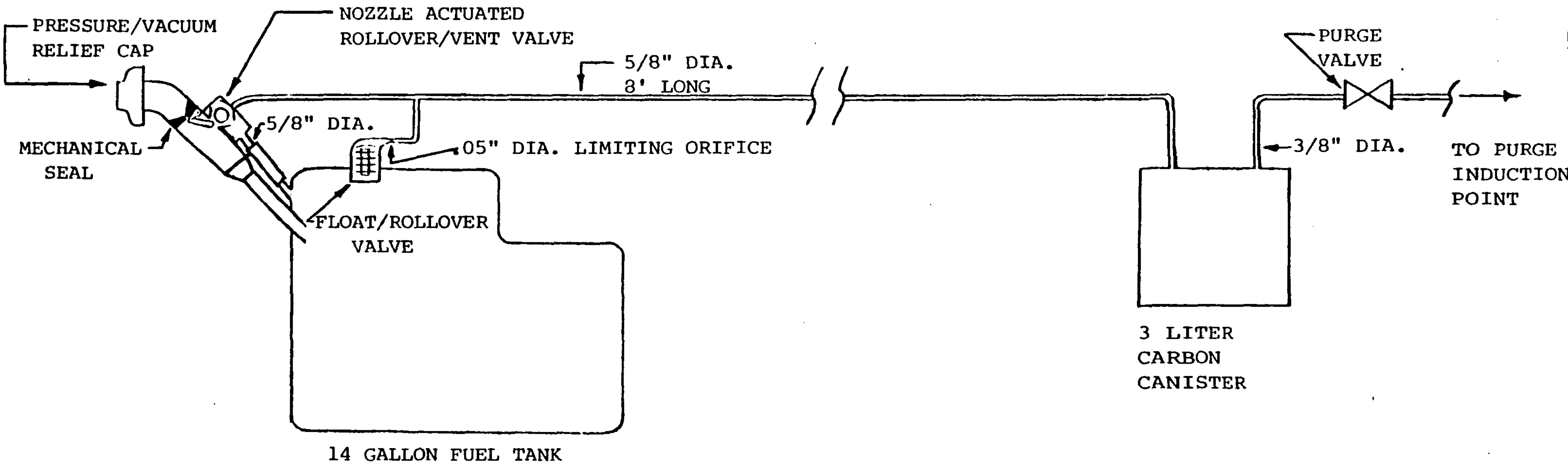
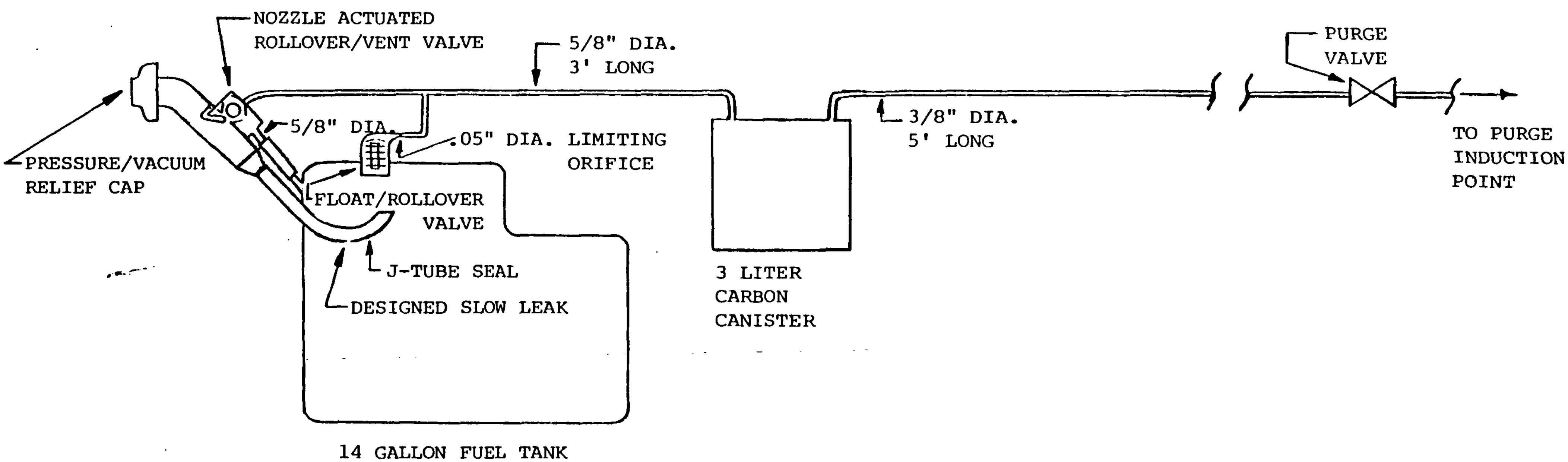


Figure 4

Integrated Evaporative/Refueling System

Tank Mounted Valves
Rear Mounted Canister
J-Tube Seal



2. Additions/Modifications to Evaporative Emission Control Systems.

The differences between onboard systems and current diurnal evaporative emission control systems can be separated into two broad categories: 1) those related to the sealing of the system, and 2) those related to the magnitude and frequency of the refueling emissions. Because of these differences, onboard systems require several additional components, and several components of the current evaporative system must be increased in size or slightly modified.

a. Additions to the Present System

Diurnal evaporative emission control systems limit the number of vapor exits by using a fuel tank cap to close off the fillneck. However, during a refueling operation, the fuel tank cap is not in place, and consequently, onboard systems must rely on some other type of sealing mechanism to prevent the escape of vapor through the fillneck opening. Currently, two types of fillneck seals are available for use on onboard systems -- liquid and mechanical.

Liquid fillneck seals utilize modified fillpipe designs to route incoming gasoline in such a way that a column of gasoline is formed which prohibits the vapors in the fuel tank from escaping to the atmosphere via the fillneck. While this may sound somewhat complicated at first, the concept is fairly easy to understand with the help of a drawing. Several liquid seal configurations have been developed, but one design which has been shown to be particularly attractive from both a design and cost perspective is the "J-tube" (shown in Figure 5).[16] As fuel is dispensed into the fillneck, it is forced to pass through the "U" shaped portion of the fillpipe. A liquid trap is formed in the "U" shaped portion of the fillpipe which prevents vapors from escaping via the fillneck. The "J-tube" extension could be made of metal, plastic or hard rubber.

Another type of fillneck seal which has been shown to be effective is the mechanical type seal.[14,15] The mechanical type seal (see Figure 6) is basically an elastomeric device which forms a close connection with the inserted fuel nozzle and thereby eliminates any space in the fillneck opening through which vapor could escape. While both the liquid and mechanical type seals perform the same basic function of limiting the available vapor exits, the liquid type seal is inherently a simpler design.

Figure 5

J-Tube Liquid Seal

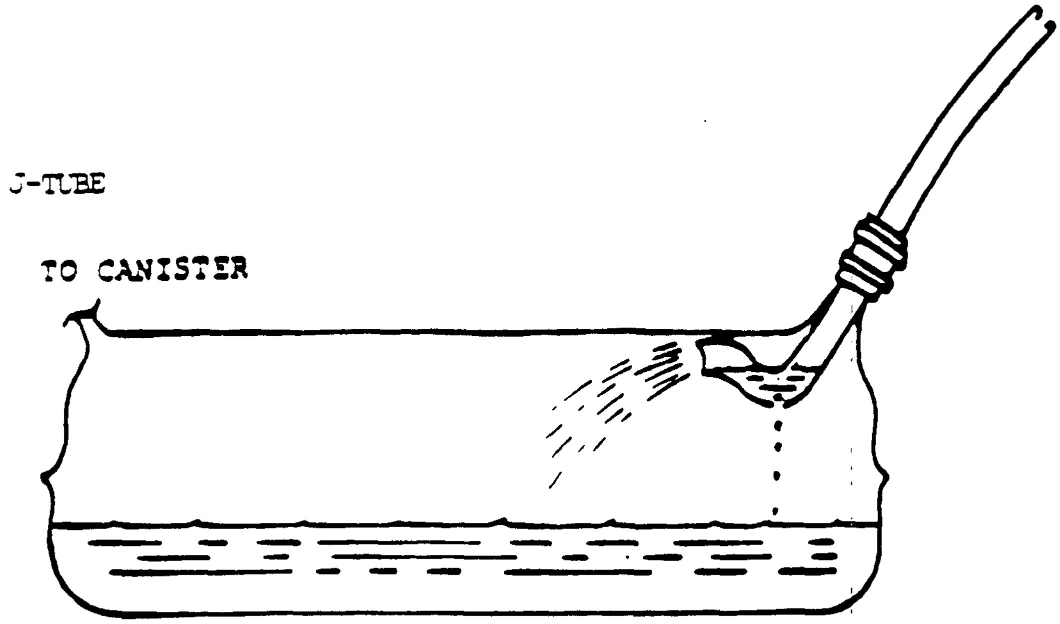
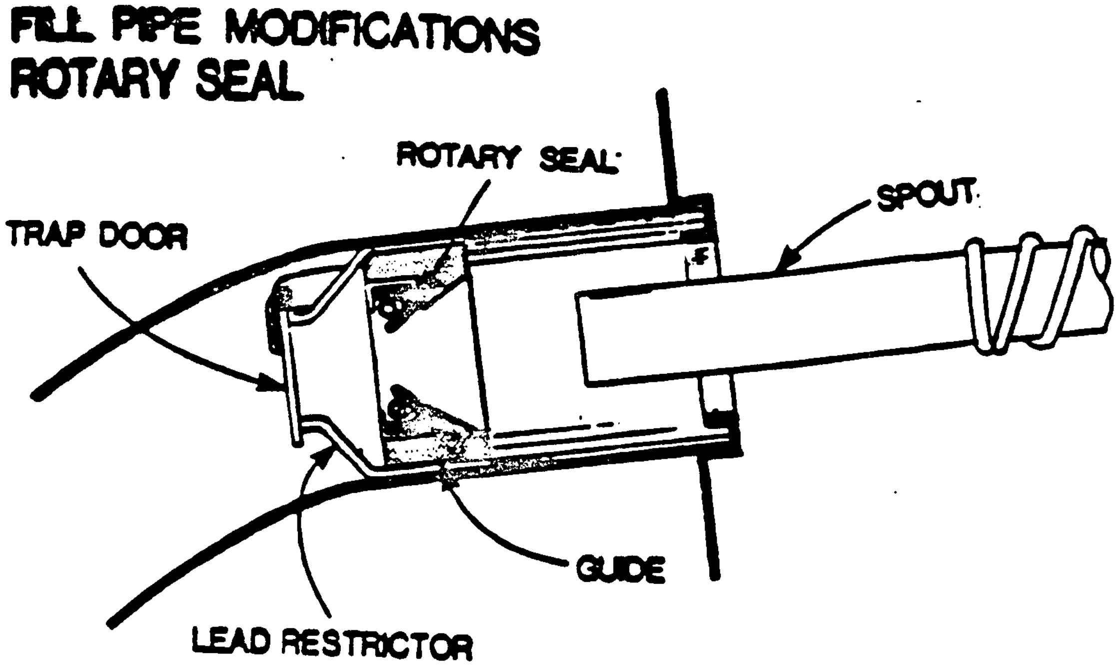
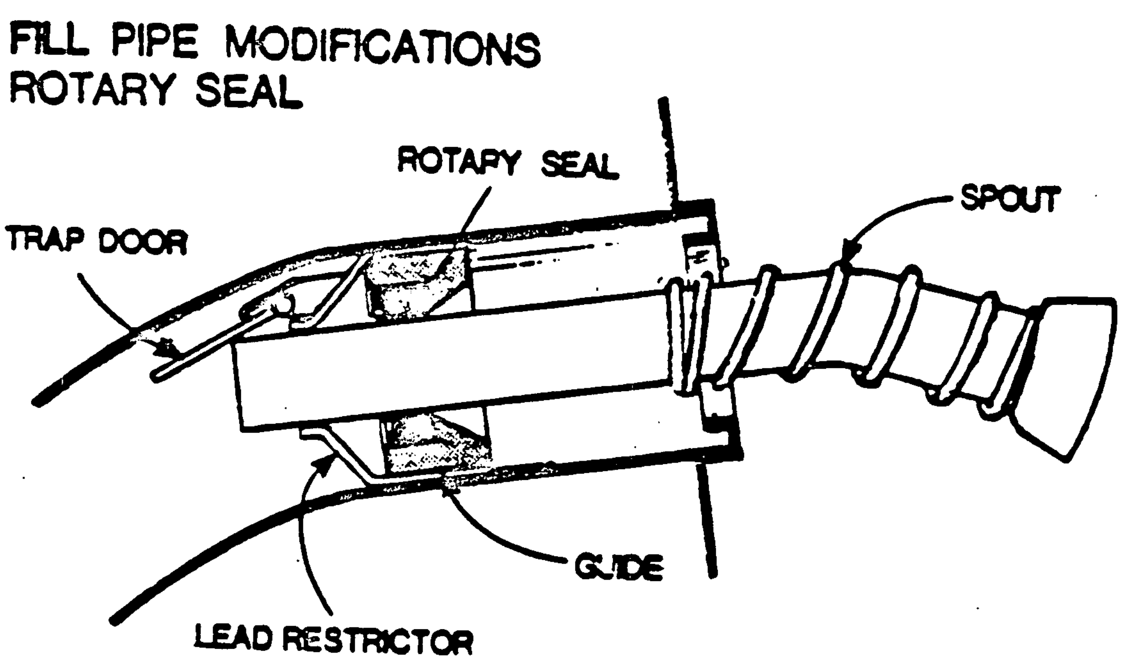


Figure 6

Mechanical Seal





If a mechanical type seal were used, excessive pressure could build in the fuel tank if the fuel nozzle automatic shut off mechanism failed, or if for some unusual reason the vapor line leading to the charcoal canister became blocked. To avoid the possibility of a fuel spitback which could be caused by this overpressure, a simple pressure relief device would be needed. More detail on this device will be provided in Section IV.

Therefore, either type of sealing mechanism - liquid or mechanical - can be used to prevent the escape of refueling vapors to the atmosphere via the fillneck. Both sealing approaches have been tested and provide similar control efficiencies.[14,15]

b. Modifications to the Present System

The differences in the frequency, magnitude, and rate of generation of refueling and diurnal evaporative emissions leads to the need for several modifications to the present evaporative system. Each of these is discussed below.

(1) Charcoal Canister Size

Generally speaking, on a per event basis, refueling emissions are produced less frequently but are larger in magnitude than diurnal evaporative emissions. Consequently, more hydrocarbon storage capacity (larger charcoal canister) is needed to control refueling emissions than is needed for evaporative emissions.

For any given vehicle, the size of the canister needed depends primarily on the fuel tank volume and the refueling emission rate. The refueling emission rate is chiefly a function of the fuel volatility (RVP), dispensed fuel temperature, and the temperature of the fuel in the vehicle's tank prior to refill. For canister design purposes the temperatures and fuel volatility specified in EPA's draft refueling emission test procedure would be used to determine the design emission rate which the canister would need to be able to capture. Canister sizing would then be a function of tank volume, the design emission rate, as well as considerations for safety and deterioration factors to assure an adequate working capacity over the life of the vehicle.

The size of the canister needed for an integrated refueling/evaporative control system cannot be stated categorically since there are several other variables which must be considered such as purge rate, charcoal working capacity, and canister geometry. However, on average it is expected that a canister for an integrated refueling/evaporative system would be approximately 3 times as large as the one used for the present evaporative system.[17]

While the larger canister does not present any technical problems it may cause packaging problems on a few smaller vehicle models which could lead to canisters being placed in locations other than under the vehicle hood. While virtually all evaporative emission system canisters are now located under the vehicle hood there is nothing inherent in the design of an onboard system which requires that canisters for integrated systems also be located there. In fact, there may be some cost advantage to locating the canister near the fuel tank since the amount of larger vapor lines can be minimized. It is expected that manufacturers would place canisters in a location which provides the optimum mix of safety, cost, and performance characteristics.

(2) Refueling Vent Line Modifications

Also, in order to accommodate the higher vapor flow rates associated with refueling emissions, a larger vent line between the fuel tank and charcoal canister is needed along with a larger opening in the top of the fuel tank to accommodate the larger vent line. The current vent line to the canister associated with the evaporative system is about 3/8 inch. The vent line with the integrated evaporative/refueling system would be approximately 1/2 - 5/8 inch in diameter.[16] The larger vent line (and larger opening in the top of the fuel tank) introduce a few added complexities.

Unlike the limiting orifice used in evaporative emission systems, the larger opening required for an onboard system cannot provide liquid/vapor separation or rollover protection. Consequently, additional devices are required on an onboard system to meet these needs. The liquid/vapor separator, examples of which are shown in Figures 7 and 8, is simple in design and purpose.[14,18] It acts to remove gasoline droplets from the vapor stream and returns the liquid to the fuel tank to prevent liquid gasoline from entering the charcoal canister. Many design approaches are available in addition to those shown here. The separator itself may be a distinct component, or its function may be built into another component such as shown later in Figure 21. In terms of rollover protection, several simple devices are available which can prevent fuel spills during an accident, and also provide the benefits of a limiting orifice described above. These will be discussed in more detail in Section IV of this document since rollover and accident protection for the fuel system is primarily a safety issue.

Aside from the differences discussed above, onboard and evaporative emission control systems are very similar in design. They both act to direct, trap, and consume hydrocarbon vapor. Onboard systems require only a few additional components, and because they could be integrated into vehicle fuel systems to handle both refueling and evaporative

Figure 7

VAPOR-LIQUID SEPARATOR

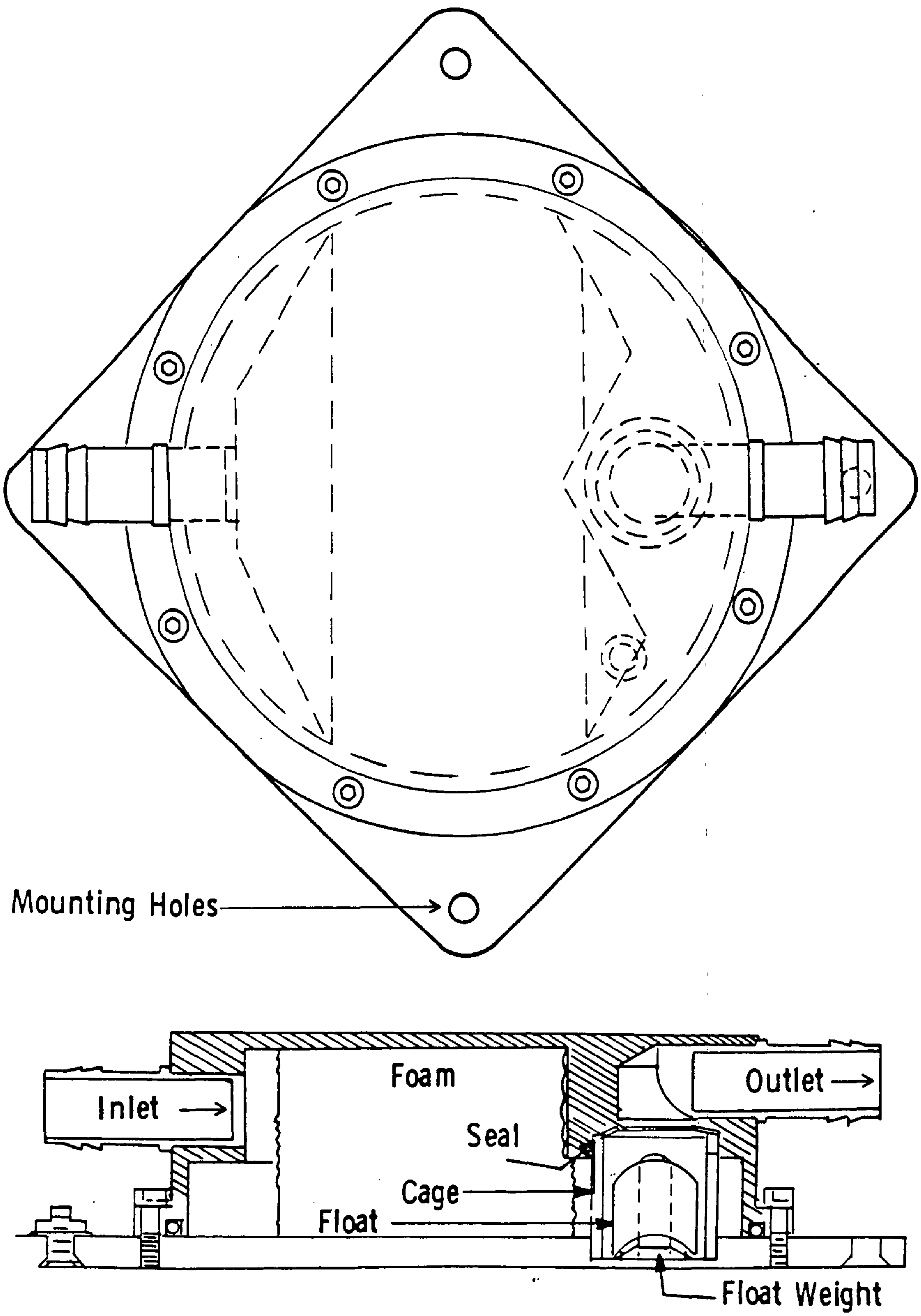
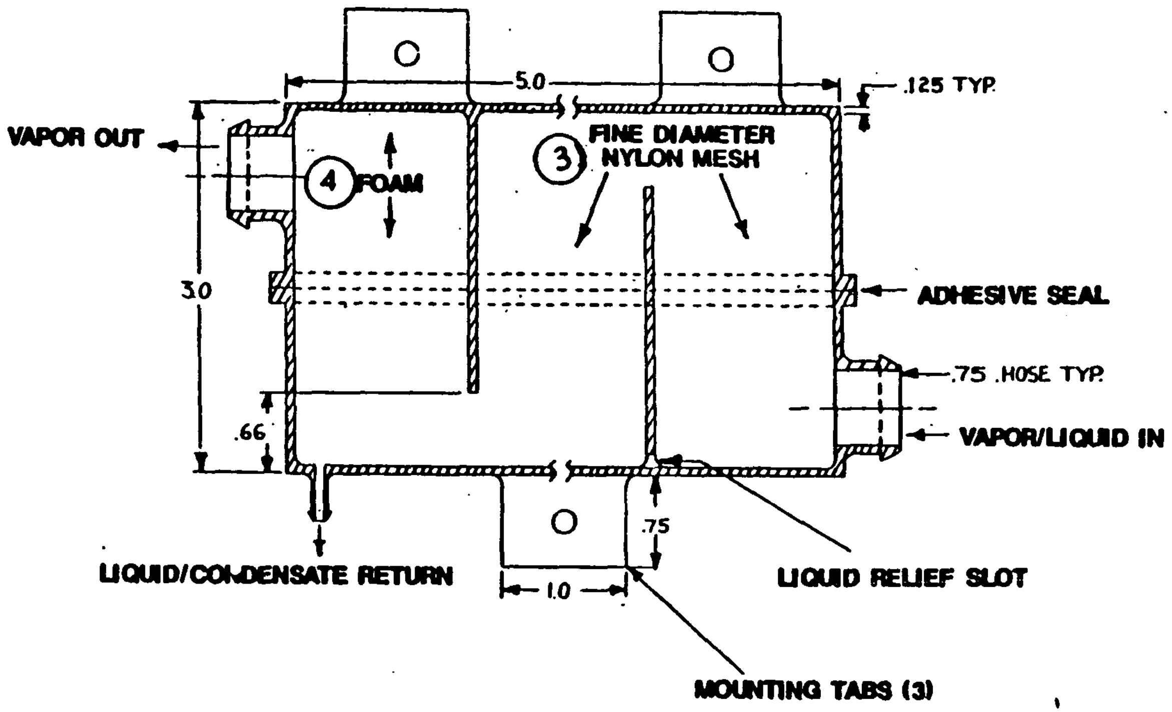


Figure 8



[illegible]	[illegible]	DESCRIPTION	MATERIAL	SPECIF.
4	AR	OPEN CELL FOAM		
3	AR	MESH FABRIC	NYLON	
2	1	UPPER HOUSING	PLASTIC	
1	1	LOWER HOUSING	PLASTIC	

VAPOR – LIQUID SEPARATOR

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DATE 11/18/86 SCALE: FULL PAGE 1 OF 1.

emissions, overall control system complexity is not increased significantly. Also, because of the integration of the refueling/evaporative emission control functions, it should be apparent that many of the safety concerns associated with onboard systems have already been considered in designs of the present evaporative emission systems. The experience and knowledge gained in implementing safe evaporative emission systems provides a substantial base of information to use in designing and developing safe integrated evaporative/refueling systems.

3. Volatility Effects

As was mentioned above, the refueling emission rate is a key factor in the size of the onboard system canister, and the refueling emission rate itself varies with the fuel volatility and the dispensed and fuel tank temperatures. For design purposes, the canister would be sized based on the volatility and temperature specifications prescribed in EPA's refueling emissions test procedure. The parameters prescribed in EPA's procedure are based on near worst case summer season conditions, so the onboard canister would have capacity to achieve control under virtually all summer conditions.

However, as average temperatures decrease in the winter, RVP levels increase and dispensed and fuel tank temperatures decrease.[19] The question arises as to whether the onboard canister would have adequate capacity to capture winter emissions with higher RVP fuels. If the capacity is inadequate canister breakthrough may occur and some emissions may be uncontrolled.

Previous studies and analyses conducted by EPA and others have shown that the refueling emission rate increases with the fuel volatility (RVP) and fuel tank temperature and decreases with the dispensed fuel temperature.[19] One study (CAPE 9) used volatilities and temperatures typical of winter conditions.[20] Using winter season fuel volatilities and temperatures in the relationship derived from this study yields winter refueling emission rates less than the design load emission rate for the canister dictated by the refueling emissions test procedure. Winter season values (Dec - Feb) range from 5.1 to 5.9 g/gal for the northern states where RVPs are quite high (14-15 psi) while the design load value is 7.25 g/gal. Thus winter emissions would be controlled as well.

EPA is presently considering a program to control the volatility level (RVP) of in-use fuels during the summer months (mid-May to mid-September). As part of that program, in-use volatility levels nationwide would be limited to levels about 21.7 percent less than the current ASTM level for that area during the affected months. If that program was enacted, the volatility of the fuel for refueling emissions testing would be set at 9.0 psi RVP, the design load emission rate for the canister could drop to 6.0 g/gal, and onboard canisters could be somewhat smaller. However, as can be seen from comparison with the emission rate figures presented above, winter emissions would still be controlled.

While not the primary motivator, in-use volatility control may have some attendant safety benefits. Lower RVP fuels generate less vapor and thus could be considered somewhat safer in a general sense. More specifically, lower volatility fuels generate less fuel tank evaporative emissions and thus could reduce fuel tank pressurization problems which occur on some vehicles with damaged or altered evaporative emission systems (e.g. non-standard gas caps) operating under extremely atypical conditions. This pressurization could lead to some fuel/vapor being released from the fillpipe when the gas cap is removed, especially if the fuel tank was relatively full at the time. Lower vapor pressure fuel would reduce the degree of pressurization which could occur under these circumstances and thus reduce or eliminate the spillage which may result. Thus the safety of refueling operations would be improved.

IV. Design Considerations for a Safe System

As was discussed previously, several commenters have expressed concern regarding the potential safety implications of onboard systems. A review of these comments indicates that these concerns fall into two broad areas: the design of a safe onboard system and effects on in-use fuel system safety. Concerns in the first area will be addressed in this section. The section which follows (Section V) will address the later area of concern.

Comments received regarding the design of a safe onboard system fall in three categories: 1) safety test design requirements, 2) safety effects of maintenance, defects, tampering and repairs, and 3) refueling operation safety. EPA's summary and analysis of the comments in each category is presented below.

A. Safety Test Design Requirements

1. Introduction

Before analyzing the safety test design requirements it is interesting to look at fuel system safety from an in-use perspective for passenger cars meeting FMVSS 301. Presently, about 1.6 percent of all accidents involve a vehicle rollover of some type and about 0.5 percent of the rollover accidents result in a fire.[21] This results in a fire rate of 0.008 percent. Thus, neither rollover accidents or subsequent fires are common. Similarly, 0.14 percent of all front and rear end collisions lead to a vehicle fire.[21] Although vehicle crash fires are seemingly uncommon, approximately 1,600 fatalities result each year from these fires.[22] Thus, from an in-use perspective, vehicle crash fires are unusual but serious events.

One of the most effective ways to protect against vehicle crash fires is to restrict fuel leakage during accidents by insuring the overall integrity of the vehicle's fuel system. To insure fuel system integrity during a crash, all currently manufactured passenger cars and light-duty truck's with a Gross Vehicle Weight Rating (GVWR) of 10,000 lbs or less, must comply with Federal Motor Vehicle Safety Standard (FMVSS) 301.[23] Basically, FMVSS 301 requires a vehicle to restrict fuel leakage to less than one ounce per minute when subjected to a rollover test following front and rear collisions at 30 miles per hour (mph), and side collision(s) at 20 mph. In a rollover test, a vehicle is turned on each of its sides and completely upside down and held in each of these three positions for a period of five minutes. Onboard system designs must take into account and protect against fuel leakage or other fire hazards which could occur in FMVSS 301 testing.

Along these lines, two issues exist regarding the design of an onboard system capable of passing FMVSS 301. These include rollover protection and the crashworthiness of key onboard system components and connections. As was discussed previously, onboard systems require the use of a somewhat larger vent line (about 1/2"-5/8" diameter as compared to 1/4"-3/8" on current vehicles) between the fuel tank and charcoal canister, and a similar sized orifice would exist in the fuel tank. While the external vent line used on many current fuel tanks also requires a 1/2" orifice, manufacturers' onboard system designs may incorporate a rollover protection device to protect against fuel leakage during an FMVSS 301 rollover test even though present designs do not. Also, vehicle crashes present the possibility of direct or indirect damage to fuel system components. In some cases this damage could lead to a fuel leak or increase the potential for a vehicle fire in some other portion of the fuel system. Thus a properly designed onboard system must not compromise the crashworthiness of the system and key components.

2. Rollover Protection

A rollover protection device is basically a valve that would close off the refueling vent line whenever the risk of fuel leakage existed. Several rollover protection designs have been proposed by auto manufacturers and other interests which could adequately perform this safety function. Several of these are discussed below.

One design which has been proposed by several sources can be termed the nozzle actuated valve. The valve is integral to the fillpipe and is located near the top of the fillpipe, perhaps near the leaded fuel restrictor. During refueling, the valve is opened by the insertion of a fuel nozzle. With the valve open, a clear passage through the vent line is available to allow for the routing of refueling vapors to the charcoal canister. Other than during refueling, the valve remains closed and effectively eliminates the potential for fuel leakage through the refueling vent line during a rollover accident. Figures 9 thorough 15 show five different nozzle actuated valve assemblies capable of performing the rollover protection function.[13,15,18,24] Figures 9 through 13 also demonstrate how nozzle insertion would open the valve to provide a large orifice for the venting of fuel tank vapors during refueling and when the nozzle is removed the vent line would be closed.

Also, while a rollover protection device might be necessary, it is interesting to note that many current production passenger car and light truck models (mostly side fill) employ an external vapor vent line of about 1/2" diameter that connects the fuel tank to the top of the fillpipe (see Figure 1). This external vent line is approaching the size needed for a refueling vent line, and yet manufacturers have included these external vent lines without any rollover protection device. As will be discussed below, depending on the design used, a rollover protection system may actually enhance safety over current designs.

This analysis has presented several basic rollover valve designs capable of providing the protection required by FMVSS 301 tests. Manufacturers could choose to implement one of these approaches, or could develop another. The approach ultimately selected will be that which provides cost efficient protection, is compatible with the other components of the manufacturers onboard system, and can be integrated effectively into the vehicle design from both safety and operational perspectives.

3. Component/System Crashworthiness

The second issue regarding safety test design requirements involves the crashworthiness of the key components of an onboard system. This includes those components most susceptible to damage in an accident (nozzle actuated rollover valve, charcoal canister) and the structural integrity of the vapor line (and connections) which may exist between the top of the fuel tank and the rollover valve. A problem in one of these three areas could cause a vehicle to fail FMVSS 301 tests and must be addressed in proper system design. Each of these concerns is discussed below.

Figure 9

SEALED FILLER NECK SYSTEM
TANK VENT VALVE ASSEMBLY
(DURING NORMAL VEHICLE OPERATION)

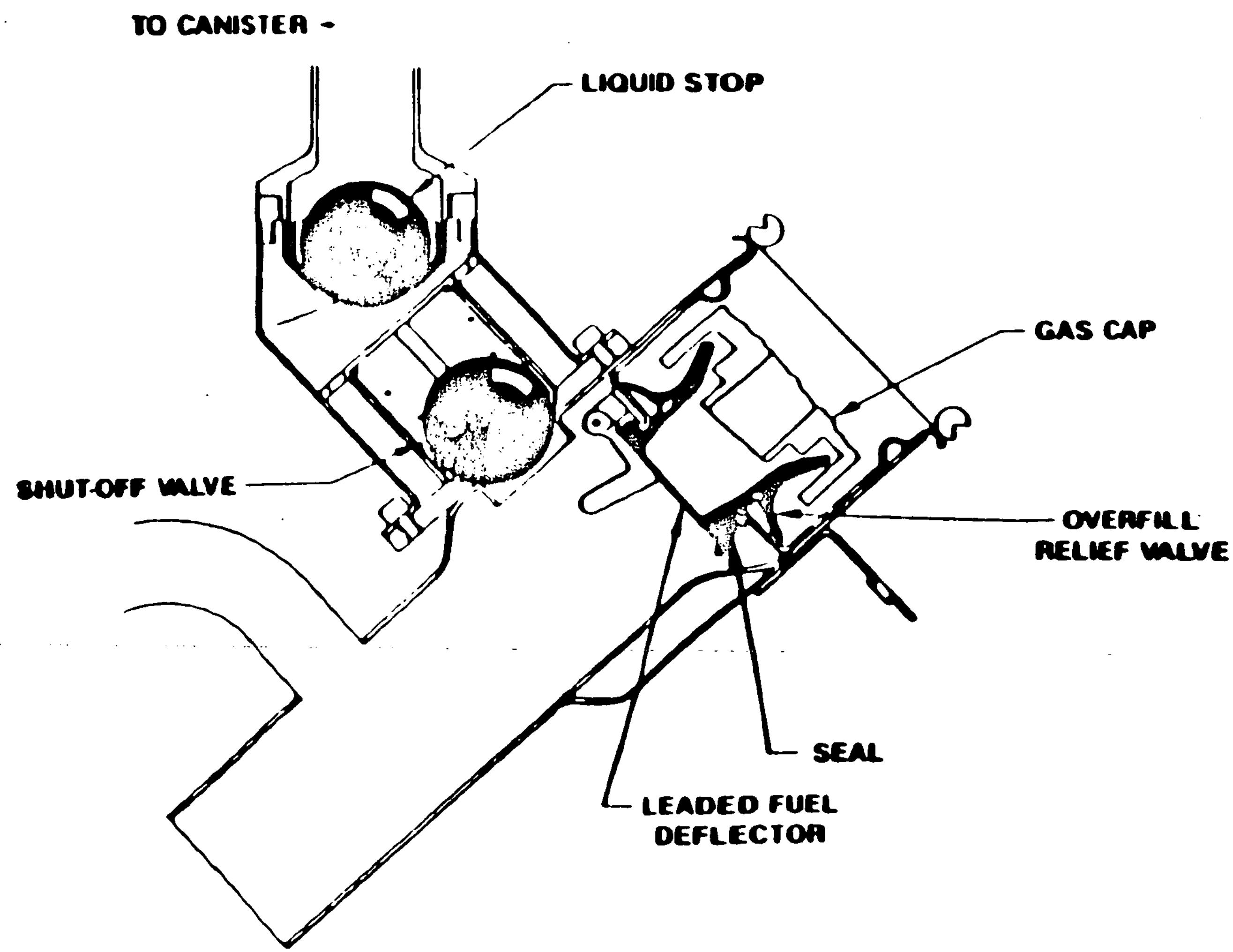


Figure 10

SEALED FILLER NECK SYSTEM TANK VENT VALVE ASSEMBLY (DURING REFUELING EVENT)

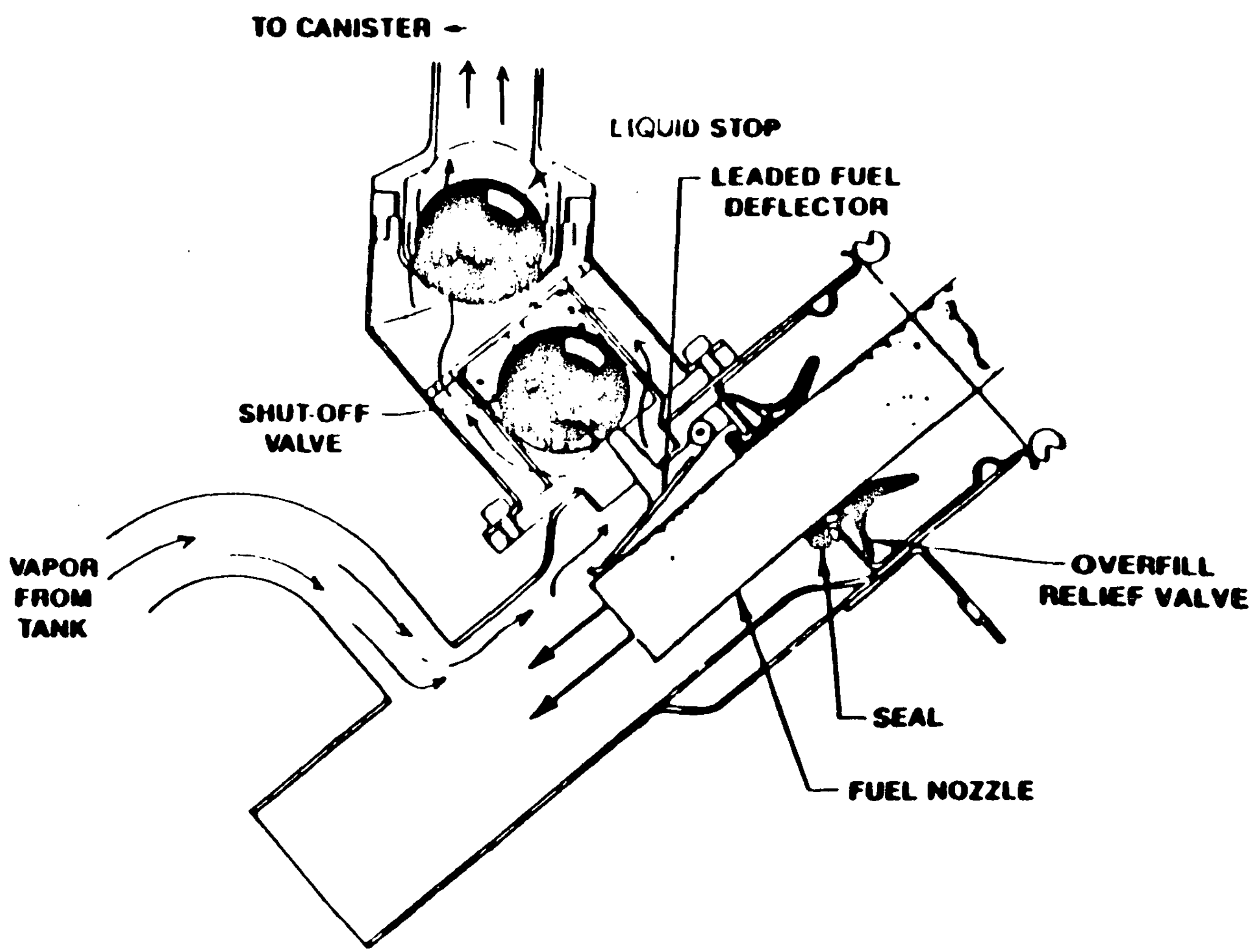


Figure 11

LIQUID SEAL SYSTEM
TANK VENT VALVE ASSEMBLY
(DURING NORMAL VEHICLE OPERATION)

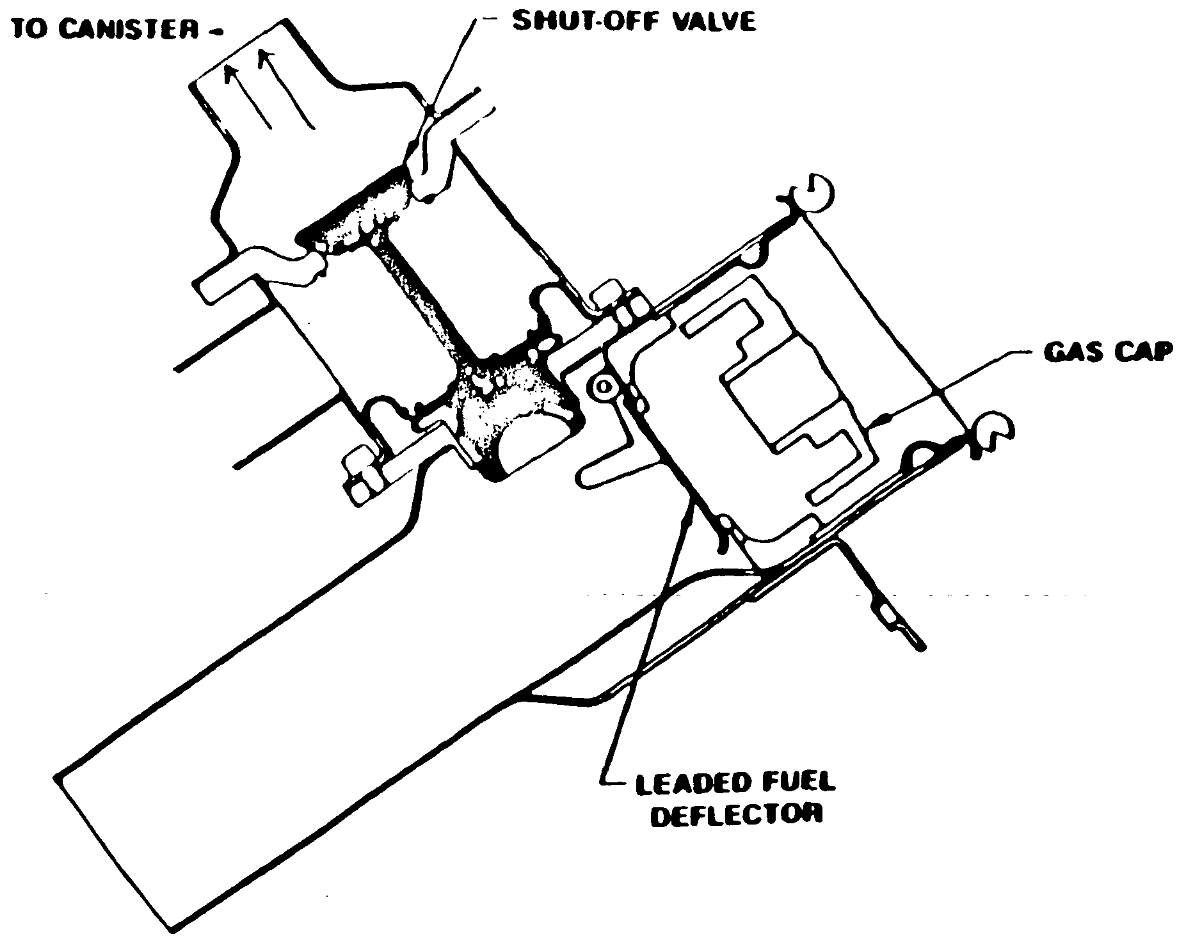


Figure 12

LIQUID SEAL SYSTEM
TANK VENT VALVE ASSEMBLY
(DURING REFUELING EVENT)

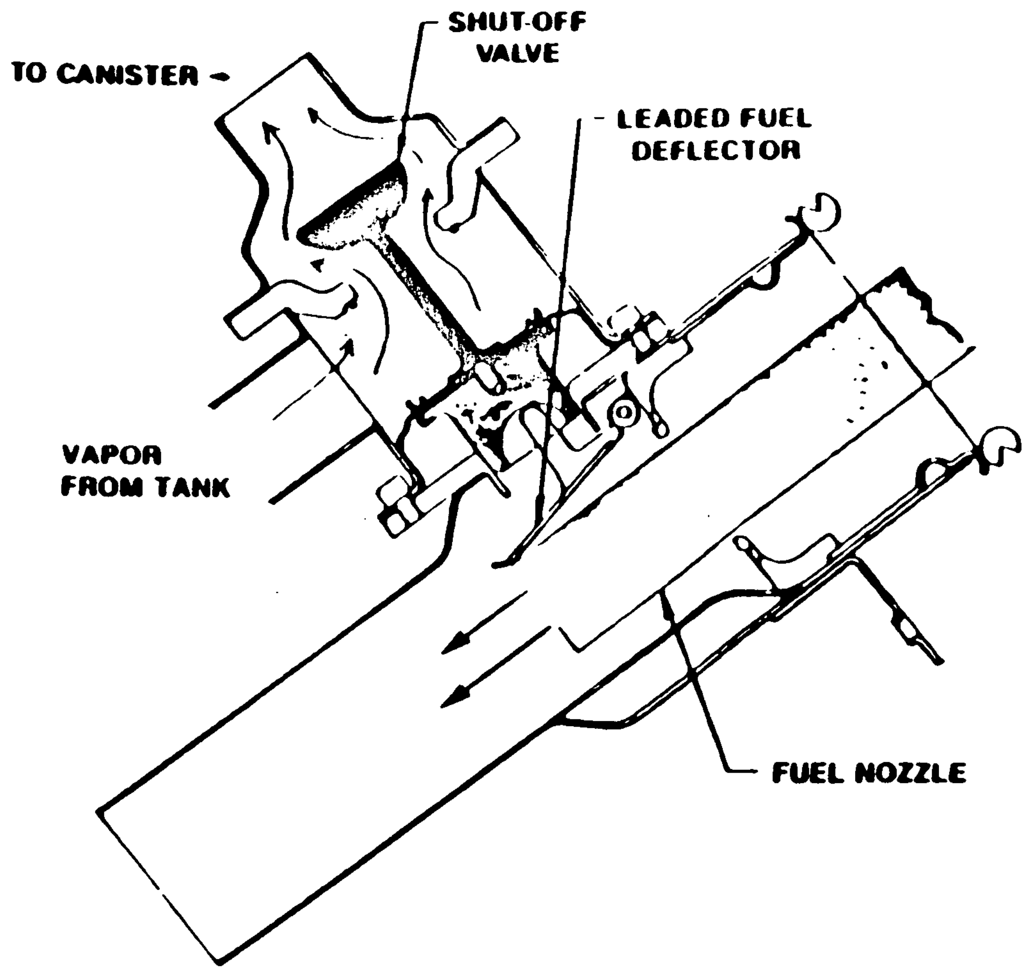


Figure 13

NOZZLE-ACTUATED REFUELING EMISSIONS VAPOR VENT VALVE

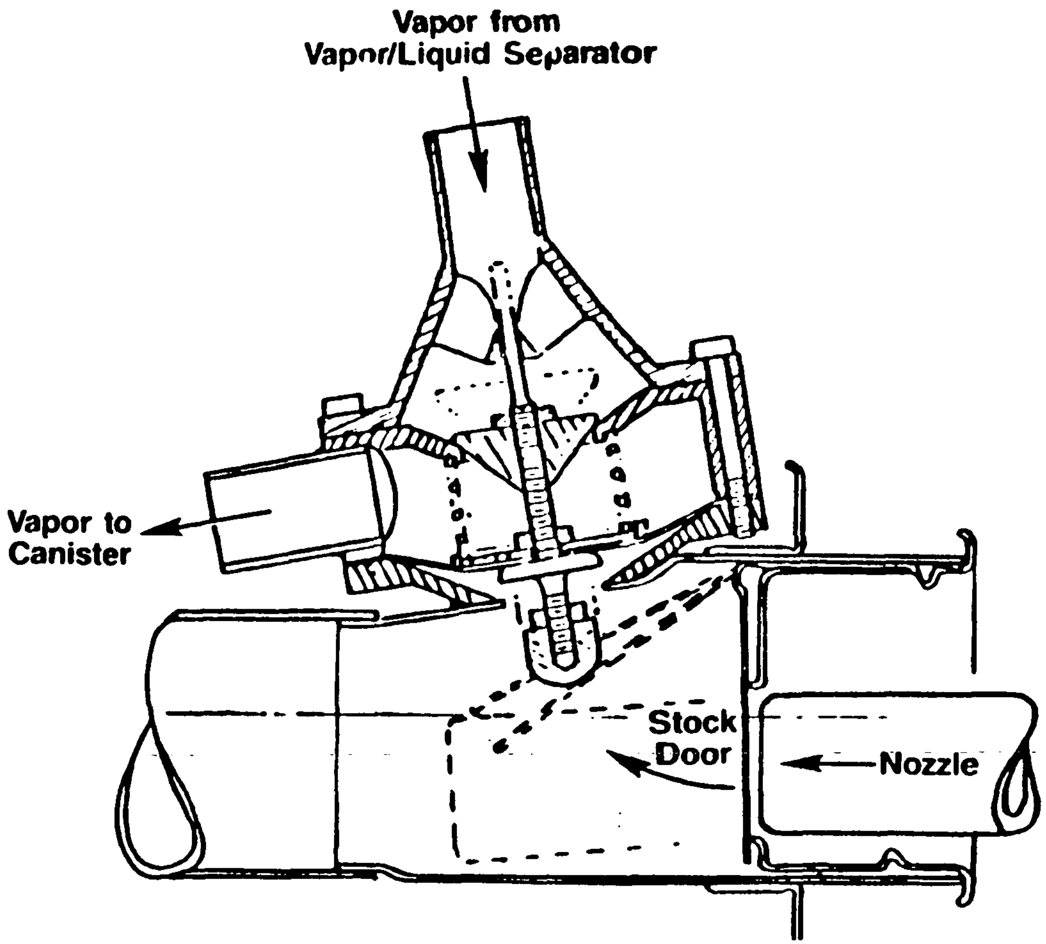
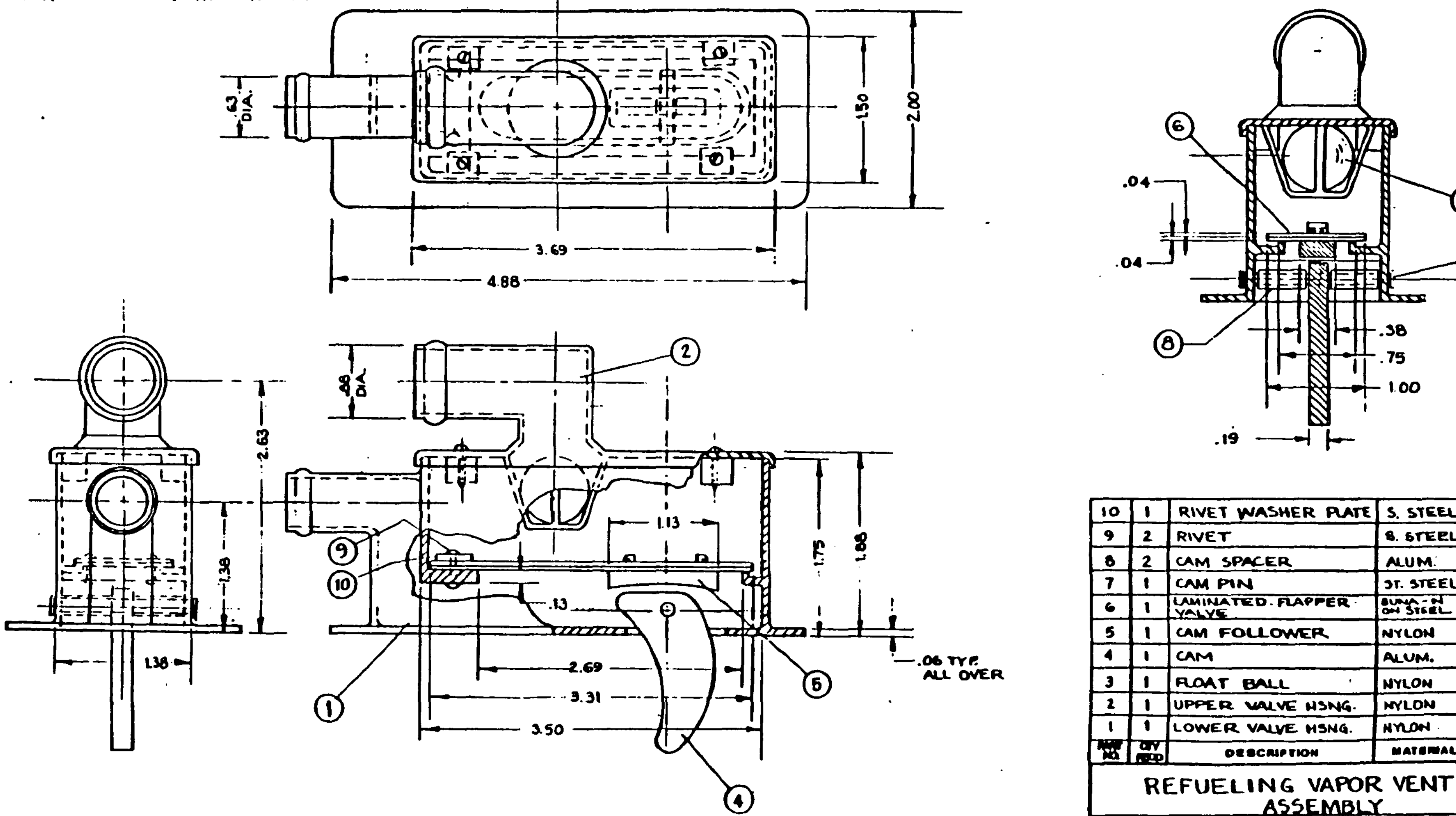


Figure 14

NOTES:

1. REMOVE ALL BURRS & SHARP EDGES.
2. NYLON PARTS MAY BE FABRICATED FROM PLASTIC COMPATIBLE W/ GASOLINE & METHANOL.
3. ALL DIMENSIONS NOT SHOWN.



PART NO.	QTY REQD	DESCRIPTION	MATERIAL	SPECIF.
10	1	RIVET WASHER PLATE	S. STEEL	316
9	2	RIVET	S. STEEL	316
8	2	CAM SPACER	ALUM.	6061-T6
7	1	CAM PIN	ST. STEEL	316
6	1	LAMINATED FLAPPER VALVE	BUNA-N ON STEEL	
5	1	CAM FOLLOWER	NYLON	
4	1	CAM	ALUM.	6061-T6
3	1	FLOAT BALL	NYLON	
2	1	UPPER VALVE HSNG.	NYLON	
1	1	LOWER VALVE HSNG.	NYLON	

REFUELING VAPOR VENT VALVE ASSEMBLY

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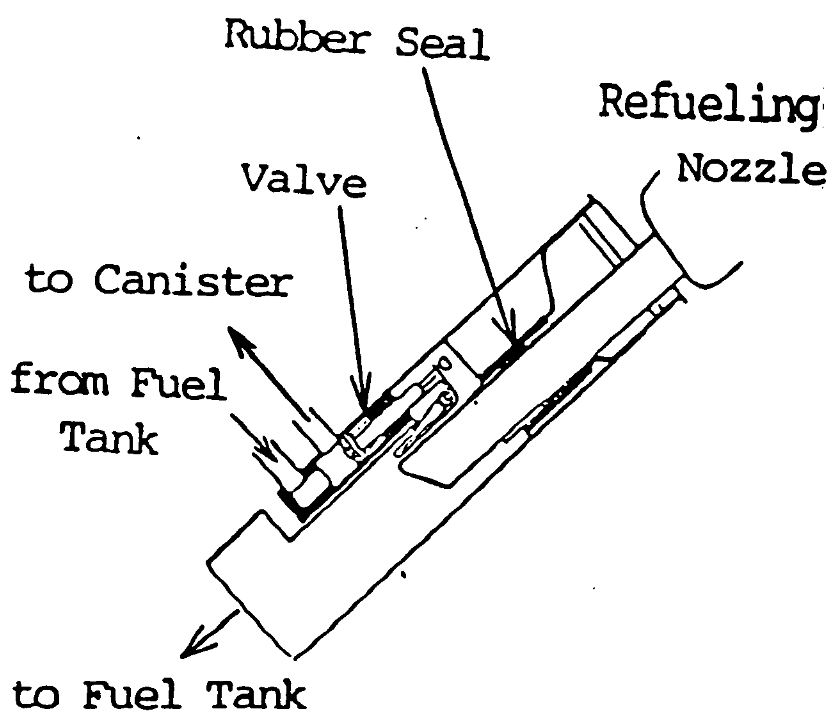
DATE 11/17/84 SCALE: FULL PAGE 1 OF 1.

Figure 15

"Toyota Concept"



However, before beginning these discussions, it should be noted that component/system crashworthiness is not at all a new concern. Manufacturers must address these same concerns in the design of the current evaporative emission systems. Given the similarity of onboard refueling and evaporative controls, and that many systems will be integrated, there should be no new or unique problems in this area.

a. Rollover Valve

First, the crashworthiness of the rollover protection device is a design consideration for nozzle actuated valves, since they would be located near the exterior shell of the vehicle. Integration of nozzle actuated valves into the overall vehicle design would have to include a consideration of the potential to sustain damage if struck in a collision.

However, this design consideration is straightforward, and it is reasonable to expect that manufacturers can and will integrate rollover valves into their fillpipe designs without decreasing the structural integrity of the fillpipe while providing crashworthiness for the valve. For example, it is worth noting that vehicle manufacturers have dealt with similar problems in their designs of fillpipes, external vapor vent lines, and gas caps, and in fact, one would not expect the nozzle actuated rollover valve to be any more susceptible to damage than these components. As was mentioned previously, the 1/2" external vent line lies in this same area on the vehicle, and yet manufacturers have included such vent lines without a rollover protection device.

b. Vapor Line

Similarly, manufacturers will have to be cognizant of the structural integrity of the vapor line and vapor line connections, if any, between the fuel tank and the rollover valve. These would have to be designed to withstand the stresses which might occur in a crash in order to maintain fuel system integrity. However, there is no significant engineering challenge to accomplishing this objective.

The integrity of this portion of the vehicle's vapor line can be assured through use of a vapor line material of proper strength, flexibility, and durability. A number of vapor lines of different material, wall thickness, and construction are currently available. In addition, routing of this portion of vapor line is another design parameter available to manufacturers. As a matter of course, manufacturers are expected to insure that the line is protected from abrasion and normal wear and that it is not in a vulnerable location in the event of a collision. This is considered straightforward given that on integrated systems the refueling vapor line now replaces that used for control of diurnal evaporative emissions. Similar routings would be expected. Vapor line integrity and connections in current vehicles must meet similar requirements, and it is reasonable to expect that similar materials and connecting approaches would be used.

Finally with regard to vapor line integrity and connections, it is worth noting that many vehicle models now use a flexible insert between the fillpipe and fuel tank to enhance the fuel system safety in-use (see Figure 16).[15] Similarly, in many vehicle models the external vent line actually incorporates a flexible vapor line which connects the metal portions of the external vent line from the top of the fuel fillpipe and the fuel tank (see Figure 16). These connections are subject to the same performance requirements as would be needed for onboard system vapor lines and in some cases are even more critical and demanding. Evidence is that these have been incorporated safely. The manufacturers' experience with current vehicle evaporative and fuel systems described above demonstrates that vapor line and vapor line connections can be made to withstand the stresses which occur in a vehicle accident.

c. Charcoal Canister

Concerns regarding the crashworthiness of the charcoal canister center on the possibility that a canister ruptured in an accident could present a fire hazard if an ignition source exists nearby.

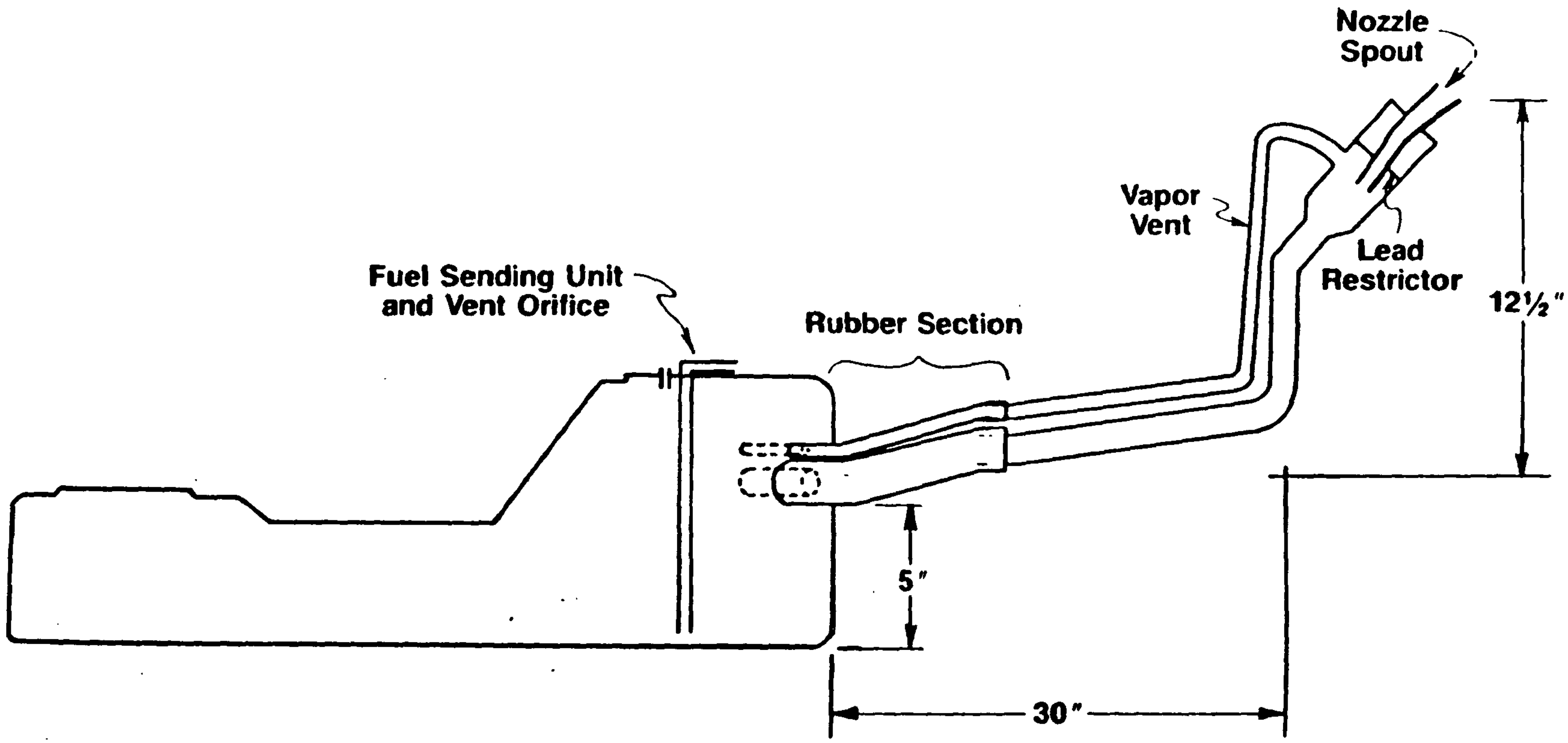
Even if the rupture of the integrated refueling/evaporative canister occurred in some cases, the potential hazard should not be overstated. While carbon canisters do contain gasoline vapor, they are strongly adsorbed to active sites within the carbon bed and not easily released to the atmosphere. Thus, even if a canister were crushed and its contents dumped, gasoline vapor would not be present in the atmosphere in sufficient quantity to be flammable. There is no available evidence of "canister fires" in any accidents involving vehicles with evaporative systems. The fact that onboard canisters would be larger and would hold more vapors initially than current evaporative systems makes no difference. While the refueling load to the canister is larger than the evaporative load, after the first few miles of driving the canister would be purged such that the amount of vapor remaining in the canister is essentially the same as that present in current evaporative emission canisters alone.* The

---

* Due to the nature of the charcoal used to trap hydrocarbon vapors, and strict certification test requirements, hydrocarbons would be quickly stripped from the charcoal early in the purge process. Therefore, during most of the operation of the vehicle (90 percent), the charcoal canister does not contain enough hydrocarbon vapor to present any safety risks.[9]

Figure 16

BUICK CENTURY FUEL TANK AND FILLPIPE PRODUCTION CONFIGURATION



lack of risk from charcoal canisters is supported by a recent submission from Nissan to EPA, stating that no safety problems would be expected with refueling canisters.[25] Thus it could be argued that the hazard, if any, is not significantly different than that now found on present systems. Thus, it is hard to perceive any added risk from the use of a larger charcoal canister.

Nevertheless, if a manufacturer believed that the canister posed a potential risk, the risk could be eliminated through placement of the canister in a protected area such as the rear of the engine compartment or in some underbody area as has been suggested by some manufacturers.[12,13] In most cases it is expected that manufacturers would simply place the integrated refueling/evaporative canister where the present canister is now located; in these cases no new design issues really exist.

d. Summary

In summary, current fuel and evaporative emission systems must meet the same FMVSS 301 requirements and much of the experience gained in designing and building current systems can be directly extrapolated to implementing an onboard system. The analysis presented above leads to the conclusion that straightforward, viable engineering solutions exist to address any potential safety design concerns, and that onboard systems can be incorporated into the vehicle's fuel/evaporative system without compromising fuel system integrity or reducing the vehicle's ability to pass FMVSS 301 requirements.

While an onboard system can be designed to provide fuel system integrity both in FMVSS 301 testing and in-use, it is prudent to consider the effects of maintenance, defects, tampering, and repairs on these systems, and means to address any potential problems which may exist. These issues will be addressed next.

B. Maintenance, Defects, Tampering and Repairs

Even if a system is designed properly and functions safely under "normal" and "extreme" in-use conditions, some question remains as to the potential effects of maintenance, defects, tampering and repairs on onboard system safety.

Maintenance is the prescribed actions needed to keep a system operating as designed. Defects involve the improper operation of the system or system components caused by design, manufacturing, or assembly errors. Tampering involves the intentional disablement (partial or total) or removal of the system or a component within the system, and repairs involve restoring or replacing the system or system components because of malfunction or damage. Each of these events and their safety effects are discussed below.

1. Maintenance

First, an onboard system is expected to be essentially maintenance free (no scheduled maintenance) as are current evaporative control systems. EPA's emission factor testing has found that non-tampered fuel-injected vehicles generally comply with the evaporative emission standards without maintenance. Furthermore, EPA's requirements for light-duty truck and heavy-duty gasoline vehicle emissions certification do not allow evaporative system maintenance up to 100,000 miles, and a similar requirement is being considered for an onboard system. The technology used here can be used for passenger cars as well. Thus, maintenance will not be necessary for proper functioning of an onboard system over the life of a vehicle. Therefore, lack of prescribed maintenance will not lead to safety problems.

2. Defects

Second, with regard to defects, the primary safety related concern deals with the possibility that defects in the operation of one or more components of the onboard system in-use might lead to safety problems for the vehicle. This includes possible problems with components such as the liquid/vapor separator, purge valve, charcoal canister and rollover valve.

Since onboard system components such as the liquid/vapor separator, purge valve, and charcoal canister are very similar to those used in evaporative systems, one method to assess the potential safety effects of defects is to review the experience seen with evaporative systems. In an effort to quantify the potential for defect problems regarding onboard systems, three different computer files provided by NHTSA were reviewed for evidence as to defects pertaining to the evaporative emission system which could impact vehicle safety in-use.[26] The files reviewed covered recalls, service bulletin reports, and owner complaints current as of November, 1986 for all three vehicle classes (passenger car, light truck, and heavy-duty gasoline). A review of the recall files revealed only 12 cases that could be even remotely linked to the evaporative emission system out of an estimated 3,000 families which have been certified with evaporative emission systems. Service bulletin reports for dealers added an additional 21 cases for a total of 33 possible problems out of over 3,000 families. None of these were identified as having caused an accident; the vast majority were more emission system performance than safety defects. Finally, a review of the owner complaints indicated only about 100 problems out of over 180 million vehicles sold with evaporative emission controls. In only a few of the owner complaints did safety problems actually occur, and no significant damage was reported. On a percentage basis these potential problems are very small.

Two other valuable observations can be drawn from a review of these files. Problems/complaints have diminished with newer model year vehicles with evaporative controls, which demonstrates that gaining experience leads to product improvement. Given the similarity between onboard refueling and evaporative emission controls, and the fact that the two systems will be integrated in most cases, much of this experience will be directly transferable to onboard systems and thus improve in-use performance. Second, the review of the owner complaints files indicated no trends other than those related to improvements in newer model year vehicles; thus no systematic problems in components or systems were evident.

Further, it is important to note that the very mechanisms used to generate the files for this survey would actually act to help eliminate any potential in-use safety effects of onboard systems defects. Dealer service bulletin reports are effective in dealing with problems raised at the dealerships, and owner complaints assist the manufacturers and NHTSA in assessing the need to conduct voluntary or mandatory recalls. Finally, to place the potential for defect problems from onboard systems in context, it should be noted that the onboard risk is essentially incremental to that now seen for evaporative systems, since in most cases the refueling and evaporative systems would be integrated. On an incremental basis, the frequency of defects would likely be unaffected.

Finally, since a rollover valve could be used on some onboard system designs specifically to enhance safety and they are not used on current vehicles, it is worth discussing the possibility of valve defects. First, it should be noted that defects in these valves should be rare. Manufacturing engineering techniques permit the development and production of highly reliable valves and statistical quality control techniques are available to insure that production valves meet design standards. In fact, if a rollover valve is defective at the vehicle assembly point, the vehicle will probably not be able to accept the fuel provided at the end of the assembly line, and repairs will be needed even before the vehicle leaves the plant. Second, to insure in-use protection, rollover valves must be designed to fail in the closed position. This would be considered "safe" because a closed position valve failure would never cease providing rollover protection and it would effectively block the refueling vent line and make refueling the vehicle extremely difficult. This difficulty would provide incentive for the vehicle operator to identify and repair the failure. If the valve failed during operation of the vehicle, the fuel tank would vent any vapors through the limiting orifice or gas cap to prevent any pressure build up (See Figures 3 and 4). Also, rollover valve failure might be one component of an onboard system which could be incorporated into onboard vehicle diagnostics and thus allow the operator notice of the problem when it occurs and provide an opportunity for repair before the fuel level becomes critical. Fail safe designs would be effective in achieving both protection and repair, and that the other measures discussed above would assist in eliminating or addressing any in-use defects.

3. Tampering

A third area of potential safety problems involves the effects of possible system tampering. While several types of tampering occur with evaporative emission systems (see Table 1), past in-use experience with these systems shows that only one type, disconnection and/or removal of the charcoal canister, might be a safety problem for onboard systems. This type of tampering poses a possible safety hazard because during the refueling operation it would lead to a flow of gasoline vapor into the atmosphere at the point where the missing canister had been located. While the gasoline vapor mixture reaching the canister location in this situation would be well above the upper flammability limit, it would briefly be flammable as the vapor dissipates and at the air/vapor transition zones. If a spark or other ignition source were present, the mixture could briefly burn. While this situation is likely to be rare, the possible safety effects of such an occurrence must be considered in the onboard system design.

There are several points which need to be made relative to canister tampering. First, this is not unique to onboard systems - similar potential problems now exist with evaporative emission canisters but a safety concern regarding tampering with evaporative emission system canisters has not surfaced. Second, using current evaporative emission canisters as an indicator, this situation is likely to be rare for integrated onboard refueling/evaporative canisters. As is shown in Table 2, current average canister tampering is only about 3 percent of all vehicles, and similar rate would be expected for integrated refueling/evaporative emissions canisters. Third, if the canister were located in an area which would be difficult to access, tampering could be further discouraged.

Further, the potential problem could be reduced through proper placement of the canister in a location distant from any ignition sources. Possible locations include the rear of the engine compartment (as is done with some evaporative canisters) or in some underbody area as has been suggested by some manufacturers for packaging reasons. Placing the canister in an underbody area would also reduce the potential for tampering by making it less accessible to the owner as mentioned above. While canister tampering is infrequent, and means exist to discourage such actions even further, good engineering judgment dictates that canisters not be placed in a location where tampering could create a safety hazard. It is expected that manufacturers will take all reasonable steps necessary to reduce tampering, and that refueling canisters would not be placed in locations where their removal could create a safety risk.

Table 1

Types of Tampering Problems
And Typical Rates of Occurrence

Problem	Rate of Occurrence (%)
Gas Cap Removed	1.2%
Canister Vacuum Disconnected	1.7
Cap Removed & Canister Vacuum Disconnected	0.1
Canister Removed	0.3
Non-vacuum Canister Disconnection	0.2
Total Disablements	3.5%

* Tampering rates calculated from the combined data from the EPA Tampering surveys performed in 1982, 1983 and 1984 (9,142 vehicles).

Table 2

Canister Tampering Survey Results
By Year*

Passenger Car and Light Truck**

Year	% Tampered
1978	3
1979	2
1980	No Report
1981	2
1982	2
1983	5
1984	3
1985	4
Avg	3

* Motor Vehicle Tampering Survey - 1985, US EPA, OAR, OMS, FOSD, November 1986.

** Since HDGVs did not require evaporative controls until 1985, survey data is currently not available for these vehicles.

4. Repairs

Finally, repairs of onboard systems may have some safety implications. Since an onboard system is essentially maintenance free, any damage to the system (besides that from defects or tampering) would in most cases result from a vehicle accident. An accident which damages the vehicle's fuel system would be relatively severe and require critical vehicle repairs. Such vehicle repairs, in general, would demand a professional certified mechanic in a licensed facility. These mechanics should be properly trained and have access to current shop manuals to repair and package the fuel system and onboard components correctly to ensure effective and safe performance. They also should be aware of any potential safety hazards of improper installation or omission of onboard system components. Furthermore, these mechanics would normally have no economic incentive for improperly repairing an onboard system or omitting some components since the facility would be compensated for all of the parts and time spent repairing the vehicle.

In any repairs of the fuel system with an onboard control system, there is only one critical area with respect to safety. This critical area is the connecting line between the top of the fuel tank and the rollover valve at the top of the fillpipe. An improper installation or connection in this area could result with fuel leakage in the event of a vehicle rollover. This connection, however, is not unique to fuel tanks with onboard systems. It is very similar to the external vapor vent line that appears on many of today's vehicles, and thus incrementally the situation may be no different than on today's vehicles. Thus, repairs of onboard systems should not create any potential safety hazards as compared to present day fuel systems.

5. Summary

In summary, component maintenance, defects, tampering, or repairs should not create the potential for in-use safety risks. An onboard system is expected not to require any scheduled maintenance. Thus, any lack of maintenance by the vehicle owner should not introduce safety hazards.

There is no evidence to indicate that possible defects in other onboard system components would lead to safety problems. There are very few defects with present evaporative emission systems, and since it is likely that refueling and evaporative emission systems would be integrated, the overall defect rate is likely to be no different than that seen in present vehicles. Further, methods are available to assure that reliable rollover valves are installed in vehicles and to insure rollover protection in the unlikely event of a valve failure.

While canister tampering effects must be considered, it should be noted that it presently is uncommon, and this low rate is expected to continue for onboard systems. Also, tampering could actually decrease through judicious canister placement on the vehicle. Nevertheless, prudent design practices dictate that manufacturers not place canisters in a location where tampering could lead to a safety problem, and it is expected that this approach would be followed.

Any repairs of an onboard system, besides those resulting from defects or tampering, will probably occur as a consequence of accident damage to the vehicle. Since the damage will most likely be severe, it will require the use of a certified mechanic who is properly trained for such repairs. Further, the only critical area of the onboard system which could impose any safety hazard if improperly repaired are the components and connections between the fuel tank and fillpipe top. Repairs are also critical in this area for current vehicles using external vapor vent lines, so there may be no change in risk over present vehicles. Repairs to an onboard system should not inherently increase the potential for in-use safety risks.

An onboard system design must also include consideration of potential effects on the safety of refueling operations. This is discussed in the next section.

C. Refueling Operation Safety

1. Fuel Tank Overpressure During Refueling

The first potential safety issue involves the possibility of pressure build-up in the fuel tank during the refueling of a vehicle equipped with an onboard system. Whenever a system is designed to be "sealed" from its environment, some forethought must be exercised to evaluate the possibility and consequences of an overpressure within the system.

Although an onboard system does not completely seal off a vehicle's fuel tank, it is designed to allow for only one opening, the refueling vapor vent line. If for some unusual reason, the vent line were to become fully or partially blocked or the nozzle automatic shut-off mechanism failed during a full refill, excess pressure could build in the fuel tank. This concern is only associated with an onboard system utilizing a mechanical seal as illustrated in Figure 3. With a liquid seal system (see Figure 4), excess pressure cannot build up in the tank during refueling because fuel would simply flow out the fillneck opening (the same way it currently does) and the nozzle operator could then stop the fuel flow. Liquid seal systems would function in the same manner as current fuel systems. From the nozzle operator's viewpoint, the refueling operation remains the same.

If a manufacturer elects the mechanical seal design, he must incorporate a simple pressure relief device capable of relieving fuel tank pressure. In the event of a nozzle failure or vent line blockage, this device would eliminate potential tank overpressurization by opening an "emergency" passage to the atmosphere through which pressurized vapor and any gasoline would spill onto the pavement or some other location noticeable to the nozzle operator. This spillage would make the fuel pump operator aware of the problem and fuel flow could be stopped without causing damage to the fuel system or causing fuel to spitback on to the operator.

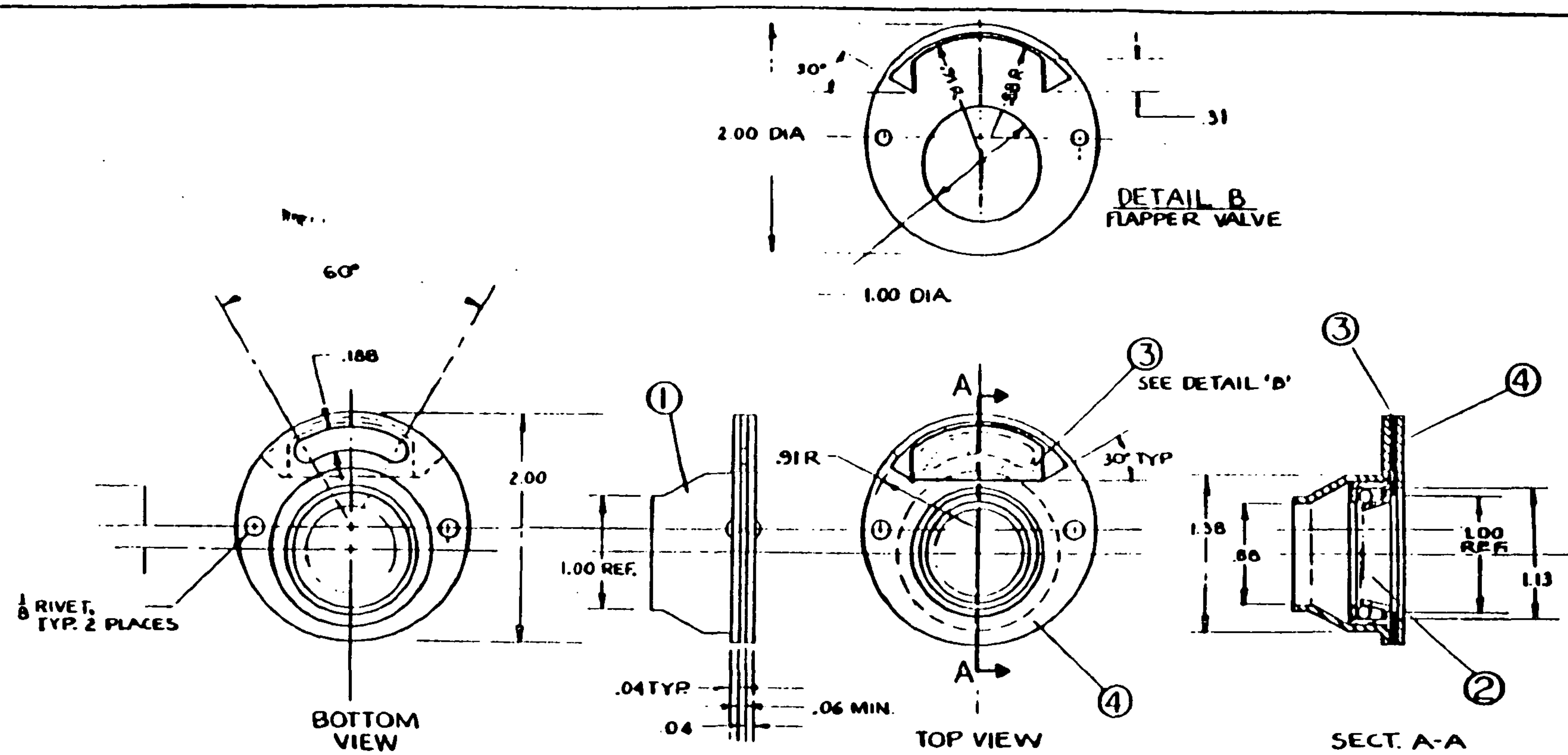
There have been several different designs suggested for such pressure relief devices. A sample design is shown in Figure 17 which would be incorporated directly into the design of the fillpipe so that the condition would be noticeable by the operator.[18] The operator would then be prompted to repair any problems in order to resume normal refueling actions. (The need for prompt repair would have positive safety and air quality implications.) As was shown in Figure 9, it might also be possible to incorporate the pressure relief function into some other component of the system such as the rollover valve. Any overpressure concerns can be eliminated through a simple pressure relief device such as these.

2. Pre-Refueling Overpressure Effects

Another potential safety issue raised relating to refueling operations has to do with the "U" bend in the "J-tube" fillneck seal. If the tank vent became blocked, and pressure built up substantially in the tank, upon removal of the fuel cap, the liquid gasoline which was left standing in the "U" bend could be spit back out the fillpipe.

This concern can be easily addressed by drilling a small hole in the bottom of the "U" bend (see Figure 4 and 5), which would allow any fuel left standing in the fillpipe subsequent to a refueling event to drain out into the fuel tank. Given the range of fuel dispensing rates seen in-use, this hole can be sized to quickly provide drain capacity and still provide the seal needed during refueling. Furthermore, the hole size can be sized so that no foreign object will block it during a refueling event. By evacuating the column of fuel left standing in the fillpipe, the potential for spitback to occur upon removal of the fuel tank cap would be eliminated. Fillpipes with a "J-tube" seal employing a drain hole have been tested. These tests show that these seals provide refueling emission control efficiencies comparable to those of mechanical seals.[16]

Figure 17



NOTES:

1. REMOVE ALL BURRS AND SHARP EDGES. .01 R MAX. OR CHAMFER
2. ROTARY SHAFT SEAL IS A PURCHASED PART. PART NO. TBD.

PART NO.	QTY REQD	DESCRIPTION	MATERIAL	SPEC.
4	1	UPPER RETAINER	STEEL	
3	1	VALVE FLAPPER	VITON	
2	1	ROTARY SHAFT SEAL		PURCHASED
1	1	LOWER RETAINER	STEEL	

NOZZLE SEAL / RELIEF VALVE ASSEMBLY

MUELLER ASSOCIATES, INC Baltimore, MD

DATE 11/18/86 | SCALE: FULL | PAGE 1 OF 1.

3. Summary

The analysis presented above demonstrates that simple, straightforward engineering solutions exist for the specific concerns raised by the commenters. In all cases, manufacturers have a number of design options available to address these concerns.

V. In-Use Fuel System Safety

1. Summary of Concerns

Some concern has been expressed that any time a system increases in size or complexity, the potential for a failure within the system also increases. Applying this line of thinking to vehicle emission control systems, it has been suggested that onboard systems would inherently decrease overall fuel system safety because several components are larger and a few more components are needed than for current evaporative emission systems. In-use vehicles are subject to innumerable accident situations, and some concern exists as to whether or not an increase in component size/number could lead to safety problems.

Further, it has been stated that even if a vehicle fuel system is safe enough to pass FMVSS 301, it does not insure that it is free of all safety risks in-use as evidenced by the number of vehicle crash fires that occur each year. It has been argued that vehicles equipped with an onboard system could pass all FMVSS 301 tests and yet directionally increase risk in-use by some unquantifiable (presumably small) amount. Thus, it follows that because some in-use situations differ from FMVSS 301 tests, onboard systems must not only be designed to be capable of passing Federal safety standards, but these systems must also be designed so as not to increase in-use risk for fuel system related hazards.

2. Analysis of Issues

Fundamentally, EPA believes that overall risk in-use should not increase. And, while it is true that FMVSS 301 cannot protect against every conceivable in-use situation, manufacturers are motivated to consider fuel system safety implications for reasons other than insuring that their vehicles pass Federal safety standards. Manufacturers must determine what they consider to be an appropriate level of safety and in-use risk, and then design their vehicles to meet this level. Often this leads to different overall levels of safety in different vehicle models. Before discussing how to address this issue, it is valuable to discuss how safety concerns are integrated into the overall vehicle design and development process.

First, safety is an integral part of the design process and is normally not considered incrementally. However, managing risk involves a series of trade-offs, balances, and compromises with other key design criteria. Manufacturers choose not to make their vehicles free of all risk because of other valid design considerations such as performance, styling, weight, cost, and other factors. It is generally accepted that no technological constraints exist which would prevent the production of a nearly "fire-proof" vehicle, and certainly vehicles could be made safer than they currently are as evidenced by numerous "safety car" designs.[27] However, cost and other considerations are valid and they prevent "zero" risk (or a perfectly safe vehicle) from being considered appropriate. One analyst has stated, "It is definitely not reasonable to expect manufacturers to produce 'Sherman Tanks' ... as such vehicles would neither serve the needs of societal safety, mobility, or economy."[28]

This same logic and risk management process applies to fuel system safety. Factoring safety into fuel system design is a complicated process that involves numerous tradeoffs and compromises as above. Fuel system designs are not all alike, and fuel system safety considerations vary from one design to another. For example, fuel tank size and location on the vehicle have a substantial impact on a vehicle's safety during a collision. Rear fill tanks are in a more accident prone location than side fill tanks, and are usually located closer to the exterior shell of vehicle. Side fill tanks are generally considered safer than rear fill tanks, and consequently, rear fill fuel tanks are gradually being phased out of vehicle designs. However, it should be noted that this change over has not occurred immediately due to other design considerations such as cost and conflicting interaction with other aspects of the total vehicle design. A similar set of arguments can be made with plastic versus metal fuel tanks. These simple examples demonstrate how risks are managed relative to other considerations. Even current fuel systems could be safer but some risk is accepted.

Another interesting example lies in the area of fuel system external plumbing such as emission control vapor lines or external vent lines along the fillpipe. At one time added piping connections similar to the external vapor vent lines that appear on some of today's vehicles were characterized as an unacceptable added safety risk by General Motors.[29] After further testing and design, that same manufacturer incorporates an external vapor vent line into many of its current vehicle's fuel systems. With safety engineering and field testing any potential safety risks associated with these external vent lines has been managed.

This particular design change illustrates a very significant aspect of fuel system safety. Even though concern existed over the potential safety aspects of additional fuel system plumbing, the mere fact that these additional lines appear on today's vehicles confirms that safety concerns can be technically addressed if desired. Any perceived in-use risk can be managed. Safety does not have to be an obstacle to fuel system improvements or modifications. The technology to reduce safety risks is currently available, and the degree to which it is utilized depends on how much risk a manufacturer is willing to accept.

As illustrated in the discussions above, manufacturers accept or manage varying amounts of risk in order to strike a balance or compromise with all of the important design criteria. Clearly safer vehicles could be made, and the amount of in-use risk reduced. As considerations change, the amount of risk accepted may also change. Often the level of acceptable risk may be more constrained by in-use liability concerns than government safety tests. For example, crash testing results from NHTSA's new car assessment program show that the vehicles' ability to protect its occupants from injury vary by vehicle model.[30] Different vehicle models provide different levels of protection for the head, chest, and femur during barrier crash testing at 35 mph. Some manufacturers chose to incorporate safer designs on some models for liability and perhaps marketability reasons.

Similarly, the safety of an onboard system on in-use vehicles will depend on the design decisions made by the manufacturers. Onboard systems would increase the size and number of fuel system emission control components, and some concern has been expressed that the safety of these components in FMVSS 301 testing may not necessarily be indicative of in-use performance. However, adding these systems does not need to affect the level of risk a manufacturer is willing to or can afford to accept. As with any other system change, manufacturers would integrate onboard systems into their vehicles' fuel systems without increasing overall system risk, and clearly, there are no inherent technical constraints prohibiting them from doing so.

Further, there is little merit to the assertion that an onboard system must be inherently less safe than an evaporative emission system because it is more "complicated". Adding a few components and enlarging a couple of others presents no risk which cannot be managed to levels now deemed acceptable. As a matter of fact, many of the improvements recently implemented on passenger cars and light trucks have resulted in vehicles/systems which are increased in both safety and complexity. Consider for example advances made in vehicle/engine control systems. Electronic engine controls have increased vehicle engine complexity tremendously over previous systems, yet there is no evidence that these system "complications" have jeopardized safety. In fact, manufacturers are now considering computer controls for other vehicle systems such as the suspension and handling, with the direct purpose of improving vehicle safety.[31] A more complicated system does not imply a less safe one if given proper consideration during design.

As discussed in detail earlier, manufacturers have many options available in the design of an onboard system which can manage or eliminate any perceived increase in in-use risk. However, for manufacturers with special concerns regarding in-use safety there are even more design options available. Fail safe, redundant, or breakaway rollover valves could be used. The integrity of the critical portion of vapor line between the fuel tank and rollover valve could be assured through the use of steel braid covered rubber hose in key areas or steel tubing.[32] Both rubber and steel vapor line have been used on past vehicle models. If chafing of this critical portion of vapor line is a concern, the affected areas could be wrapped in a spiral spring for protection. Also, slack could be provided in this critical portion of vapor line to minimize the possibility of separation or rupture in an accident. Improved or additional fittings, adhesives, or clamps could be used to increase the strength of key vapor line connections between the fuel tank and the rollover valve. Concerns related to the charcoal canister can be addressed by using a reinforced canister shell or a protective barrier. While these may be somewhat extraordinary, this brief listing demonstrates that further design options are available which if used could improve safety over current vehicles.

In summary, manufacturers can manage their in-use risk and can choose to make an onboard system as safe as they deem appropriate. Onboard systems present no safety concerns which cannot be eliminated through proper design, and each manufacturer will develop the fuel system design which represents the best balance for each particular vehicle model, with full consideration of the safety risks and all other key factors.

3. Opportunities for Improvement

Implementing onboard controls could actually result in a net improvement in overall fuel system safety. Since manufacturers would need to redesign some aspects of their vehicles' fuel systems to incorporate onboard systems, the opportunity would be provided to reexamine other aspects of fuel system safety as well. Some of the potential fuel system improvements that could result from this reexamination include an acceleration of the transition from rear fill to side fill, integration of the current external vapor vent line inside the fillpipe, better placement of the fuel tank, or even improvement in the fuel tank integrity itself. Also, any number of other minor modifications or improvements in the fuel or emission control systems could be made which could enhance safety and performance and perhaps reduce cost. These include areas such as tank venting, purge valve operation, and eliminating many problems identified through owner complaints and other similar survey measures.

Also, it is likely that an onboard refueling control requirement would lead to a decrease in the amount of fuel spilled in-use and thus improve the overall safety of refueling events. In the certification refueling test, vehicles would have to be designed to accommodate a refueling dispensing rate near the high end of the present range of in-use values (8-10 gallons per minute) without any spillage or spitbacks. This is because any fuel spilled during the test is considered as part of the test results. Since one tablespoon of gasoline evaporates to a substantial amount of vapor (about 10 grams), almost any spillage that occurred during the certification test would result in a failure. Thus, the test procedure requirements will insure that manufacturers' fuel system fillpipe designs are capable of handling dispensed fuel at flow rates up to 10 gallons/minute without allowing any spitback. The use of these fillpipe designs are predicted to lead to a reduction in the amount of fuel spilled in-use. This is compared to some current vehicle fillpipe designs which have difficulty accepting fuel at the lower end of the in-use range (8-10 gpm) without spitback. To assure this benefit accrues in the long term, EPA is considering an in-use dispensing rate limit of 10 gallons per minute along with any onboard requirement.

Also, from the analysis presented above, it is evident that implementing onboard controls would provide at least three other direct safety benefits over present systems. First, depending on the design used, adding a rollover protection device may improve the safety of present fuel tank systems which use a 1/2" external vent line without rollover protection. Second, adding a rollover valve may enhance the safety for those vehicles which now use a limiting orifice for rollover protection, since a rollover valve will provide a positive seal in lieu of the "controlled leak" approach provided by the limiting orifice. Last of all, it should be noted that refueling vapors are currently vented to an area which poses somewhat of a safety hazard. This is because the potential exists for refueling vapors to ignite inadvertently as they escape from the fillneck opening. However, as onboard controls are phased in, and more and more vehicles route refueling vapors away from the fuel pump operator to a safer point (the charcoal canister) the overall risk involved in refueling a vehicle will be reduced.

Finally, to address any special concerns regarding onboard system crashworthiness and to perhaps improve crashworthiness over current vehicles, there is an alternative onboard system design available which manufacturers may elect. As is shown in Figure 18, this system is similar to Figure 4, except all the needed valves (rollover, vent, liquid/vapor separator) are built into the top of the fuel tank, instead of externally.

A solenoid activated rollover valve could be used (Figure 19) which is located on top of or inside the fuel tank.[33] This valve would normally be closed except during refueling when it would be electronically opened by a switch located near the opening of the fillpipe. The switch could be activated either by the opening of the door over the fuel cap or removal of the fuel cap itself (see Figure 20).

Yet another approach is a mechanical ball valve. This device would normally remain open to provide a clear vapor passage. However, in the event of a rollover accident gravity causes a metal ball to roll into a fitted seat and seal off the vent line. One variation on this design (see Figure 21) would be simple mechanical ball valve built in combination with other needed valves.[15]

As is shown in Figure 18, this onboard system design may need a fill limiter to allow for normal refueling operations (i.e., automatic shut-off) and to prevent overfilling the tank during full refills. A sample design is shown in Figure 22.[33] The operation of the fill limiter is quite simple. When the tank is full the float rises in the fill limiter and closes off the refueling vent line. This causes pressure to rise in the tank, subsequently fuel runs up the fillpipe and activates the nozzle automatic shut off mechanism. While incorporation of a fill limiter is quite simple from an engineering perspective, the design would have to incorporate a "soft close" to avoid back pressure "spikes" and possible spills at the end of a full refill.

From a safety perspective this alternative is attractive because all the external components are either removed or mounted in a more protected location. The external vent line (Figure 1) can be eliminated and the other system valves and vapor lines are moved away from the vehicle shell to a more protected area within the vehicle body. Also, no vapor line exists between the fuel tank and the rollover valve, so vapor line integrity and connections are less critical.

Finally, depending on how high a priority a manufacturer assigns to safety or if significant in-use risk is perceived, a collapsible bladder tank design could be used to meet the onboard requirement. Bladder tanks could lead to a substantial improvement in fuel system safety by providing an additional shell of protection to help reduce fuel spillage in case of an

Figure 18

ALTERNATIVE INTEGRATED EVAPORATIVE/REFUELING SYSTEM

TANK MOUNTED VALVES
REAR MOUNTED CANISTER
J-TUBE SEAL

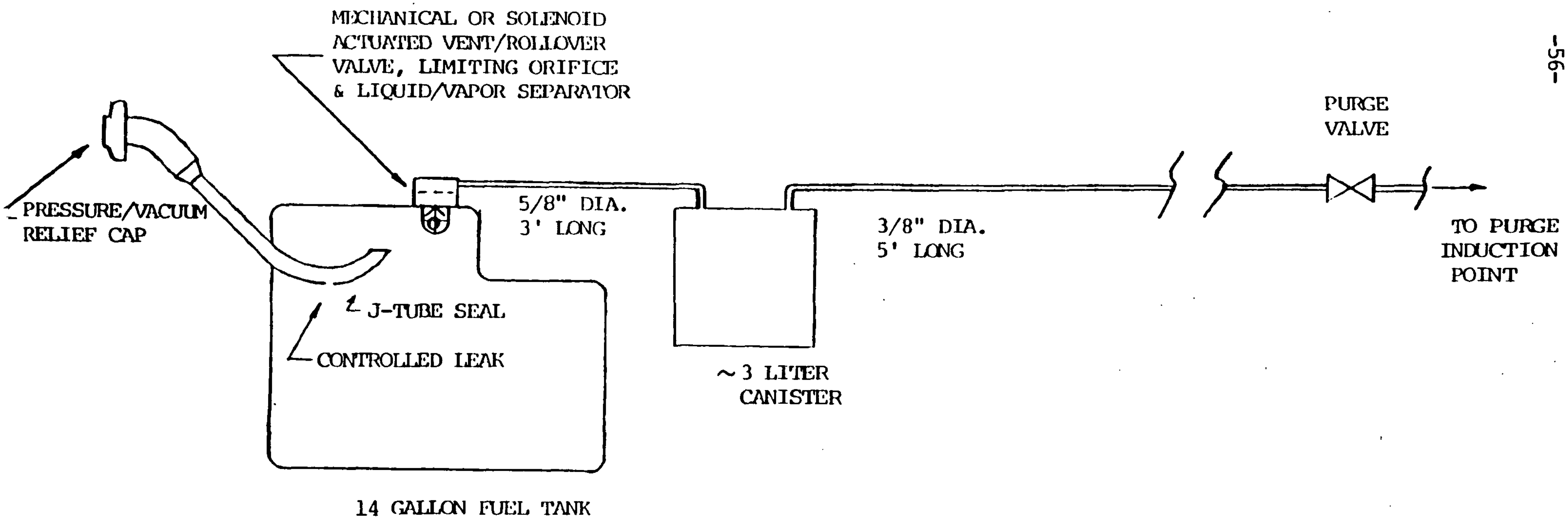
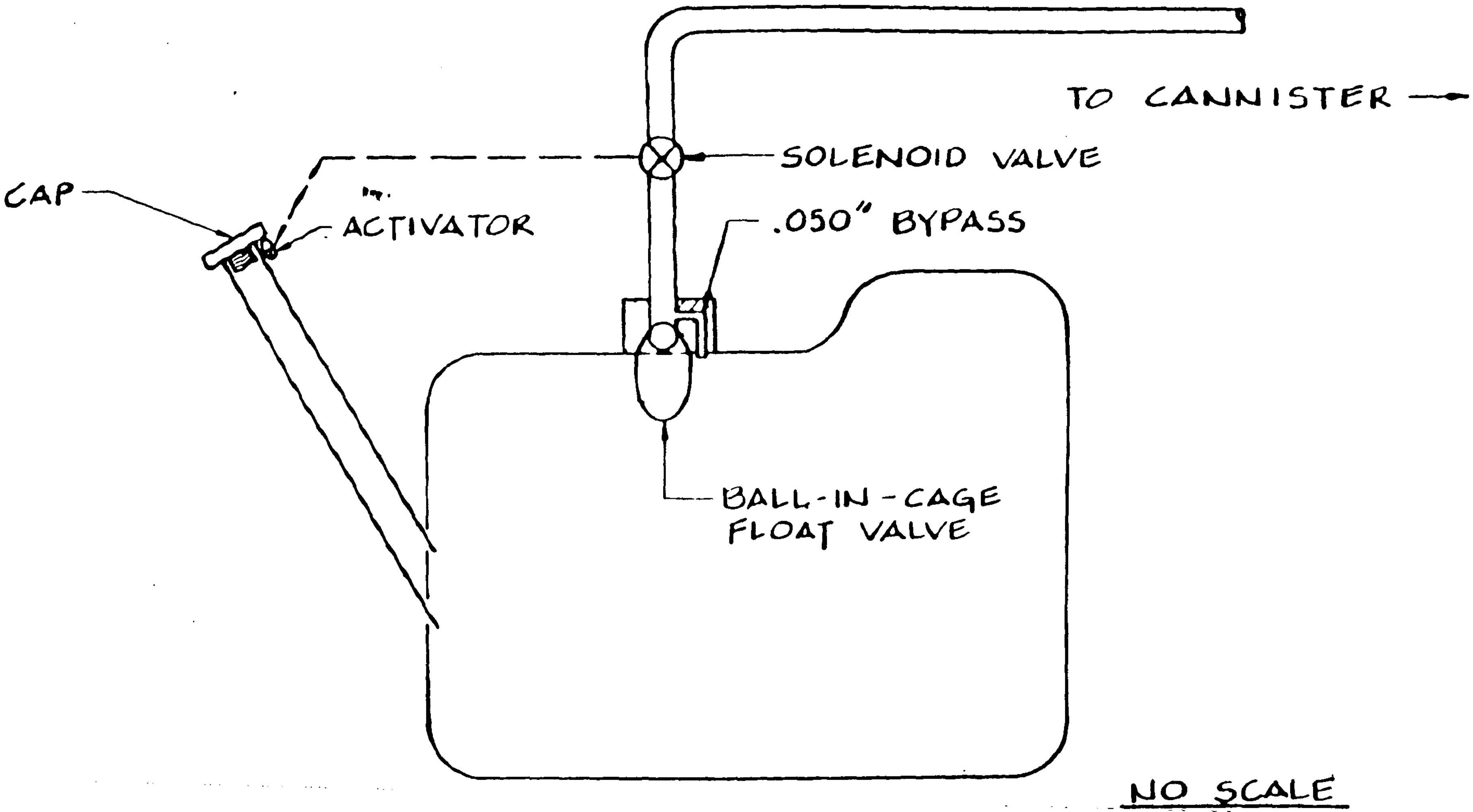


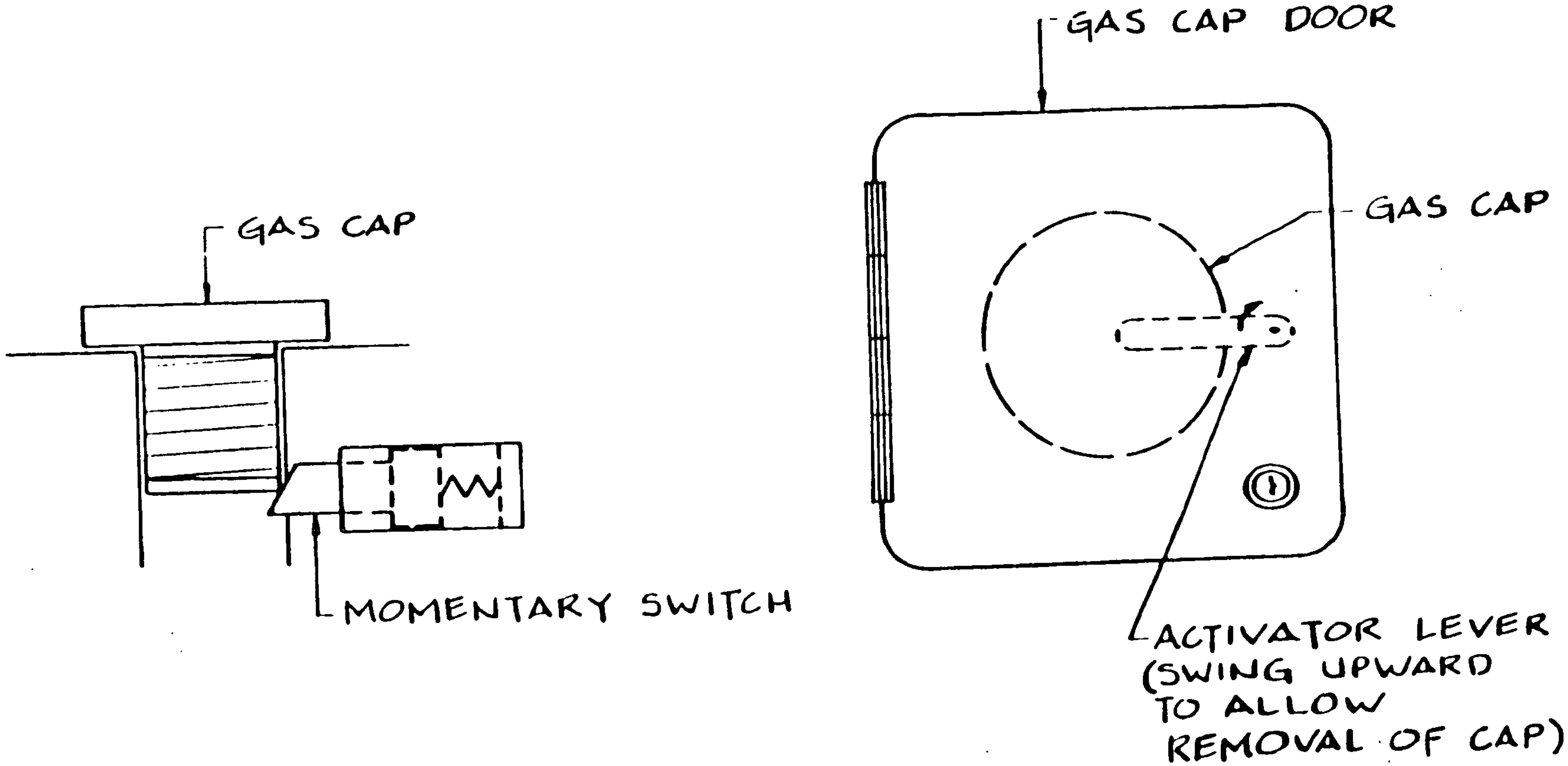
Figure 19



SCHEMATIC OF POTENTIAL ONBOARD VAPOR RECOVERY SYSTEM

MUELLER ASSOCIATES, INC.
1401 S. EDGEWOOD STREET
BALTIMORE, MARYLAND 21227
JANUARY 31, 1985

Figure 20



POTENTIAL MOMENTARY SWITCH LOCATIONS

NO SCALE

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BALTIMORE, MARYLAND 21227
JANUARY 31, 1986

Figure 21

COMBINATION VALVE

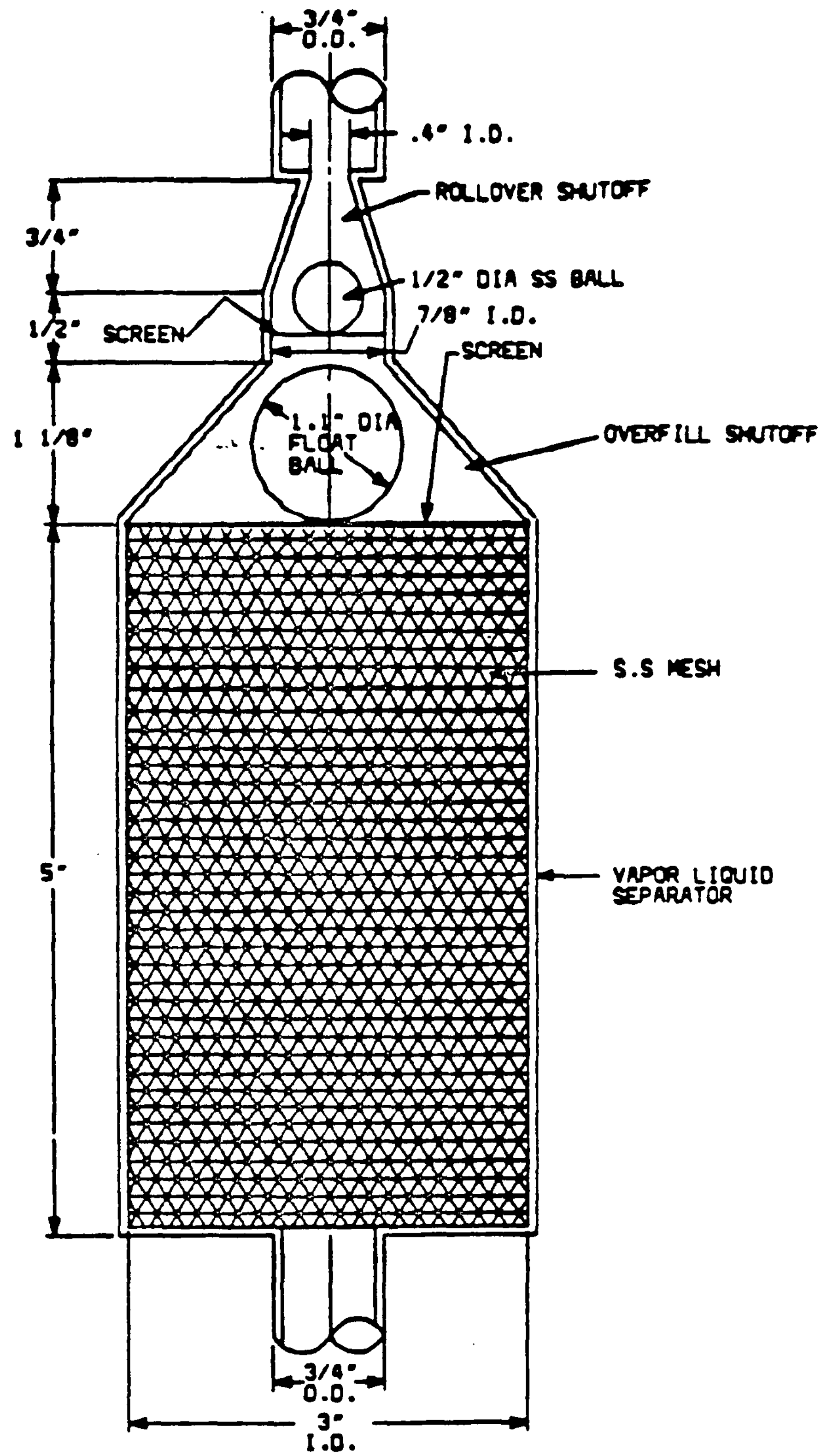
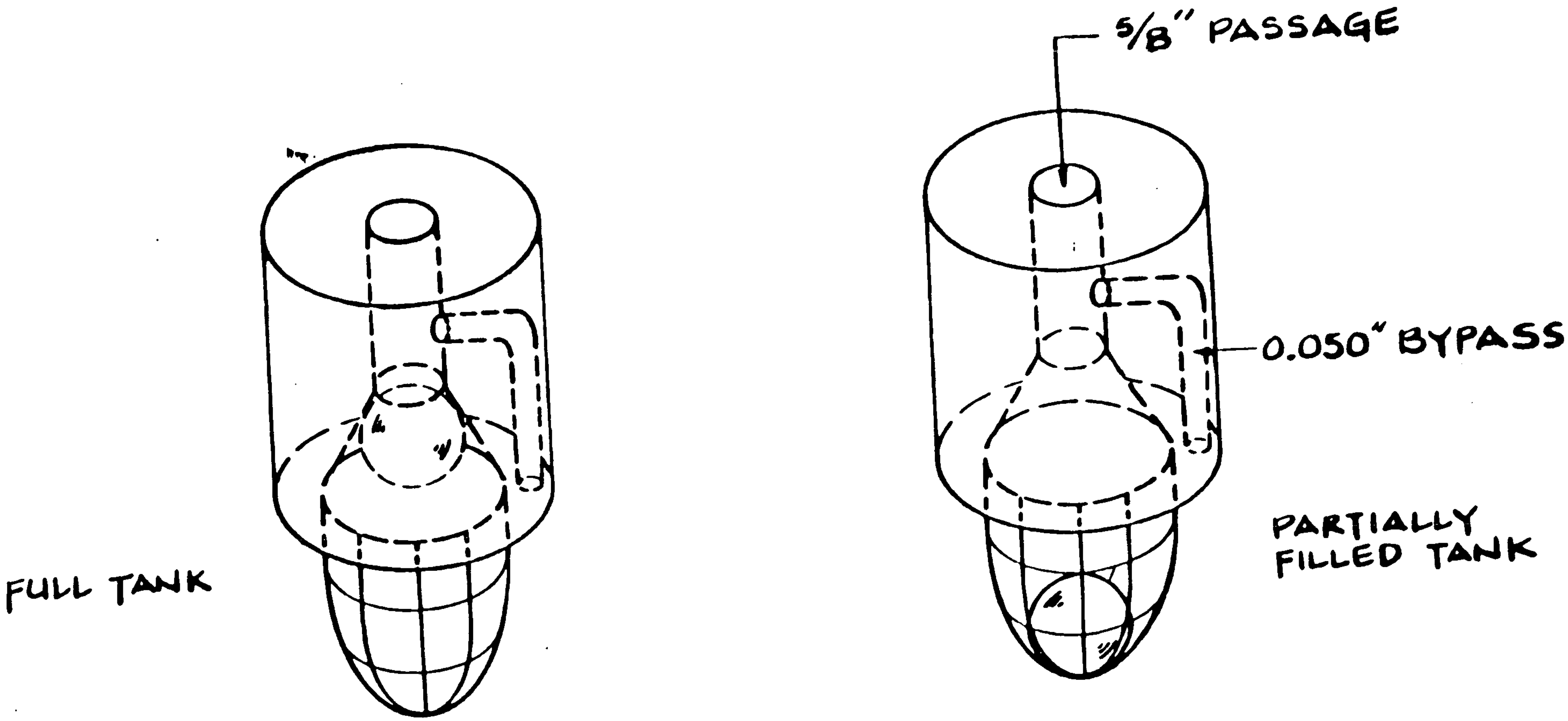


Figure 22



BALL-IN-CAGE FLOAT VALVE

NO SCALE

MUELLER ASSOCIATES, INC.
1401 S. EDGEWOOD STREET
BALTIMORE, MARYLAND 21227
JANUARY 31, 1985

accident. Also, a bladder tank could eliminate essentially all of the safety concerns raised regarding control of refueling emissions. This is because a vapor space would not be present in a bladder tank, and without a vapor space, refueling emissions would not occur. Thus neither a refueling emissions canister, external plumbing, or a rollover valve would be needed. It might even be possible to eliminate the present evaporative system and enhance safety even more. Also, bladders should be an attractive option for those who claim high costs or packaging problems with canister-based onboard systems. EPA is quite interested in collapsible bladder tanks as an option to canister-based onboard systems. This analysis of design and in use safety issues and the associated costs and leadtime is not directly applicable to collapsible bladder tanks. However, EPA plans to further explore the cost and technological feasibility of bladders as well as their safety and emission benefits.

In conclusion, the information and rationale presented above refute the assertion that adding an onboard system would directionally increase in-use risk, even if only by some unquantifiable (presumably small) amount. Any perceived risk is manageable, and furthermore, it appears that the net effect of an onboard refueling control requirement could be a potential increase in fuel system safety. As discussed above, and in Section IV there are numerous design alternatives to address the safety concerns raised. To varying degrees all options have the potential to improve the safety of fuel systems in-use.

VI. Cost and Leadtime Considerations

The comments received regarding onboard vapor recovery systems also addressed the cost and leadtime implications of implementing such controls. More specifically, several of the comments addressed onboard safety costs in some form (usually addressing hardware costs), and several commenters expressed some concern over EPA's leadtime estimate. An analysis of the costs and leadtime necessary to implement onboard controls safely is an integral part of the overall evaluation of the feasibility of this control approach. As was mentioned above, cost is one of the other key considerations which is often balanced carefully against safety concerns, and the costs needed to implement onboard systems safely must be reasonable relative to other safety costs and the overall costs of onboard systems. Further, the analysis must carefully consider the manufacturer leadtime needed to implement onboard controls on their production vehicles. This includes the time needed to identify, evaluate, and address all safety concerns and to comply with the test requirements prescribed in FMVSS 301.

The first portion of this section addresses onboard safety costs; the second discusses leadtime and describes the basis for EPA's leadtime estimate. Some of the cost figures cited in the safety cost analysis are drawn from a broader EPA analysis which develops total onboard system costs in 1984 dollars.[17]

A. Safety Costs

As is evident from the discussion presented in Section IV, the costs needed to implement onboard controls safely fall in several areas. R&D type costs will be incurred, some new or modified components will be needed which may slightly affect vehicle operating costs, and safety certification testing will be necessary. However before beginning a discussion of these costs, it is valuable to discuss how the FMVSS 301 standards and EPA's evaporative emission control requirements impact onboard safety costs.

The control of refueling emissions through an onboard system would not be the first Federal regulation to require an investment to improve fuel system safety. The first fuel system integrity standards (FMVSS 301) were implemented by NHTSA for 1968 vehicles, and since then there have been 2 major additions to these requirements. Each of these new requirements has caused a small cost increase, but each has also led to an improvement in fuel system safety on in-use vehicles. In the mid 1970's, FMVSS 301 was substantially upgraded to extend the coverage of impact types to include rollover events and, rear end and side collisions. A 1983 NHTSA Technical Report describes the nature of the modifications made in response to the upgrading of the standard and estimates the costs incurred by vehicle manufacturers in order to meet the revised standard and provide a higher level of in-use assurance.[21]

Table 3 describes modifications that were made to 1977 model year vehicle fuel systems in response to the increased requirements of FMVSS 301. These modifications ranged from minor changes such as the slight revision of mounting bolts or clips to more major ones such as recontouring the fuel tank. Based on information submitted to NHTSA by vehicle manufacturers, the average (sales-weighted) cost increase required to make these modifications was $4.60 per vehicle.* These modifications were also estimated to increase vehicle weight slightly (an average of three pounds per vehicle), which would tend to marginally increase the amount of fuel consumed over the life of the vehicle (about 3 gallons of fuel). When these two costs are added, NHTSA estimated the total safety cost resulting from the 1977 revisions to FMVSS 301 averaged about $8.50 per vehicle (1982 dollars).

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* A Bureau of Labor Statistics analysis estimated that vehicle costs incurred to meet the 1977 revision to FMVSS 301 were $4.70 and costs to meet the 1976 revision to the standard (added rollover test) cost $2.10.[34,35]

Table 3

Summary of Vehicle
Modifications in Response to 301-77

Vehicle Components

Fuel System Components	Modification(s) to Improve Crashworthiness
Fuel Tank	- Increase gauge of tank material - Add protective shield - Recontour to minimize contact/puncture by other adjacent vehicle components. - Strengthen/shield filler neck - Increase strength of solder/weld seams - Strengthen mounting by adding brackets, revising mounting bolts, increasing torque of mounting straps - Strengthen filler cap seal, improve impact resistance
Fuel Gauge Sensor	- Strengthen mounting
Fuel Lines	- Recontour
Fuel Vapor Lines	- Recontour, revise, revise clamps
Fuel Pump	- Provide shield

Other Vehicle Components Changed to Improve Fuel System Integrity

Rear Floor Pan/Support Rails/Wheel Housing	- Revise, add supports
Rear Suspension (Springs, Shock Absorbers)	- Change support brackets, revise mounting bolts, revise mounting procedure, and shield
Rear Axle Assembly	- Minor changes in contour of lines, screw heads, mounting clips, recontour vent cover
Rear Axle Assembly	- Revise hinge assembly
Seat Belt Brackets	- Revise anchorage
Engine Mount	- Slight revision
Power Steering Pump Bracket	- Slight revision

Based on an evaluation of in-use accident information for 1977 and later model year vehicles, NHTSA's 1983 Technical Report also estimated that the upgrading of FMVSS 301 would in the long term annually prevent 400 fatalities, 630 injuries, and 6500 post crash fires. This indicates that FMVSS 301 has been effective in substantially improving many aspects of overall fuel system safety and that these improvements were purchased relatively inexpensively.

The second area of interest is the effect of current evaporative emission systems on potential onboard system safety costs. As was described in Section III of the report, an onboard system is in many ways an extrapolation of current evaporative emission control technology and the two systems are quite similar. Many of the control techniques and basic system components used would be similar, and the same system and vehicle assembly approaches could be used. In fact, many manufacturers will likely integrate their refueling and fuel tank evaporative control systems. All current vehicle fuel systems incorporate fairly sophisticated evaporative emission control systems. Since these fuel systems have all been designed to meet the most recent and most stringent version of FMVSS 301 and also provide a high level of in-use safety performance, it follows that a thorough evaluation of the potential safety implications of evaporative control systems has already been conducted. Since onboard systems are basically extensions of evaporative emission systems, clearly many of the safety design considerations associated with onboard systems related to passing FMVSS 301 or providing in-use assurance have already been resolved or at least addressed in evaporative emission system designs. Consequently, much of the "ground work" required to insure onboard safety has already been performed. Therefore, it is important to keep the magnitude of the onboard safety design process in perspective, because clearly much of the safety technology needed for onboard is simply an extension of that which already exists.

Remembering the relatively inexpensive and yet effective nature of current fuel system integrity measures and the "incremental" nature of onboard safety in terms of the magnitude of the task and actual cost relative to evaporative systems, it is now possible to describe the components which factor into onboard safety costs. Basically, the integration of safety into a fuel system incorporating an onboard controls involves four types of costs. These four costs are for 1) design and development (R&D), 2) specific hardware, 3) safety testing, and 4) weight penalty (or added fuel consumption). The paragraphs that follow describe how each of the cost components are affected by onboard safety.

To begin with, some research and development will have to be performed to safely integrate onboard controls into vehicle fuel systems. EPA has estimated that the total design and development cost required to incorporate onboard systems in vehicle fuel systems is about $112,000 per family or in the range of $0.35 to $0.55 per vehicle (passenger car and light truck). This cost is for any development effort involved in combining the components of an onboard system with the rest of the vehicle to form a unit that interacts safely and effectively. Because safety is evaluated inherently in the design and development process and yet is only one part of the total effort, only a fraction of the total cost should be directly allocated to safety. Also, because much of the safety related system development work has already been completed it is not unreasonable to expect that onboard safety development costs would only be a small fraction of the total cost in this area. In addition, because of the incremental nature of the onboard system, much of the research and development that went into making evaporative control systems safe can be applied directly to onboard controls.

Given that manufacturers are designing an onboard system in the context of many requirements and certain design features serve multiple functions, it is very difficult to isolate the level of expenditures directly attributable to safety. For this analysis it was assumed that about 20 percent of R&D expenditures relate to safety, which translates to about $0.10 per vehicle. However, total onboard cost is quite insensitive to this assumption, even if the safety related development costs were tripled, per vehicle costs would increase by only one percent.

The second component of onboard safety costs relates to specific hardware that may be required to insure fuel system safety. EPA has estimated costs for three specific items which have been identified as potential components to be included as part of the onboard system design explicitly for safety reasons. These three items are 1) a rollover valve, 2) a pressure relief mechanism, and 3) fuel system modifications necessary to safely incorporate a rollover valve, pressure relief mechanism, or other onboard hardware. EPA has estimated the cost of a solenoid rollover valve (like the one shown in Figures 19 and 20) to be $4.60.[17] This price included the cost of the valve, an actuator located at the fillcap, and the necessary wiring and connectors. Manufacturers estimate the cost of a valve assembly similar to that described by EPA's cost estimate would be in the range of $5.00 to $6.00. It should be noted that these estimates are for the most complex rollover valve type, and that the cost of a simpler valve assembly such as the fillneck mounted type (see Figures 9-15) is estimated to be more in the $3.00 to $4.00 range. The available information indicates that an appropriate rollover valve cost falls into a range of $3.00 to $6.00.

The second safety hardware cost is for a pressure relief mechanism. This mechanism would only be needed for onboard systems incorporating a mechanical fillneck seal, and consequently not all vehicles would require its use. However, for those systems that would require a pressure relief mechanism, EPA has estimated that this device would increase system costs by approximately $0.50. This estimate is based on pressure relief mechanisms currently used in automotive applications which perform the same basic function and are similar in complexity.[36]

The final onboard safety hardware cost accounts for any fuel system modifications that would be necessary in order to safely accommodate any onboard control hardware. For example, a vehicle's fuel tank or fillpipe might have to be re-shaped or modified in order to accept a rollover valve. Also, for safety reasons, some slight re-routing of the fuel system's vapor lines may be required. EPA has estimated a total modification cost to be $0.50 per vehicle. Only part of this total cost would be required for safety purposes. However, because safety inherently enters into the decision to make any modifications, it is difficult to access what part of the total modification cost should be allocated to safety; perhaps half or more ($0.25 to $0.30 per vehicle) could be considered as driven by safety related concerns.

Summing up the three individual safety hardware costs yields a total estimated figure in the range of $3.25 to $6.80. However, this cost estimate does not include manufacturer overhead and profit. In order to obtain the retail price equivalent cost, these estimates must be multiplied by a markup factor. Presently, a markup factor value of 1.26 appears representative.[37] Therefore, after inclusion of the markup factor, a total retail price equivalent safety-related hardware cost falls within the range of $4.10 to $8.60.

The third component of safety costs accounts for any safety crash testing that would be necessary. EPA has estimated the cost of FMVSS 301 crash testing to assure fuel system integrity for onboard systems to be about $34,000 per bodyline/style or about $0.12 per vehicle.[38] This estimate is based on four tests for FMVSS 301 only required per body line/style with two vehicles required for each sequence of four tests. Clearly safety crash test costs are very minimal in the long term and do not pose an obstacle to the adoption of onboard controls. In some cases these costs may be higher but even if total costs were double the estimate, the overall per vehicle cost would rise by less than one percent. Also, costs could be lower if FMVSS 301 test were combined with crash testing required for compliance with other safety standards.

The fourth component of safety costs is the estimate of the added fuel consumed over the life of the vehicle due to the increase in vehicle weight resulting from added safety hardware. The amount of weight added to a vehicle for a rollover valve and pressure relief mechanism is very small (0.4 lbs), and EPA estimates that only about $0.25 in added fuel costs will result from their inclusion into the onboard system.[17]

A total onboard safety cost is calculated by summing all four individual component costs. Total capital costs per family average about $56,000. The per vehicle safety-related costs range from $4.50 to $9.00, or about 25 percent of EPA's estimate of the total cost, depending on the type of rollover valve used.

One final point needs to be made with regard to these safety cost estimates. To the degree that manufacturers take the opportunity introduced by an onboard requirement to further reduce in-use risk beyond that now accepted with present systems, some additional costs might be involved which have not been identified or quantified. On a fleetwide basis these would be quite small. Also, it should be noted that the added benefits of these measures have not been included either.

EPA estimates safety related onboard costs to be $4.50-9.00 per vehicle. While there is some uncertainty in the development cost portion of the estimate, the total range shown here is quite insensitive to any error. These costs are quite similar to those previously incurred by manufacturers to insure fuel system safety. Many of the potential problems related to implementing onboard systems safely have already been considered in the design and development of present evaporative systems. The manufacturers previous experience in implementing evaporative systems safely and the incremental nature of onboard systems reduces costs and the level of potential problems. This analysis demonstrates that high levels of in-use fuel system safety can be achieved at low cost, and there is no need for a manufacturer to "cut corners" on onboard safety to reduce costs.

B. Leadtime

If EPA were to implement an onboard requirement, it would be necessary to allow a sufficient period of leadtime between the date the rule is promulgated and the model year the systems are to be required on production vehicles. This leadtime is provided so that manufacturers will be able to adequately prepare for the requirement through system design, development, testing, tooling, certification, and safety evaluation. Some of the tasks involved in the preparation process could be worked on simultaneously, while some tasks cannot begin before others are complete. While EPA estimates that none of the individual tasks require more than twelve months to complete, due to the sequential nature of some of the tasks, a leadtime period of approximately 24 months will be required by manufacturers.

Figure 23 shows how the individual leadtime components result in a total estimate of 24 months. First, four to six months are included for manufacturers to develop and optimize working prototype systems applicable to all of their different vehicle models. This is not at all unreasonable given the fact that working prototypes already exist and many manufacturers have evaluated these or their own prototype to some degree. Not all manufacturers have developed working prototype onboard systems, but the technology required to develop such systems is readily available and in-depth technical descriptions of such systems have been described in publicly available literature. Four to six months should be adequate time for these manufacturers to develop and evaluate prototype systems.

Once the prototype development is complete, initial durability testing of the prototype could be conducted under laboratory conditions. This laboratory testing is not expected to last more than two months.

Following laboratory testing, three separate actions can begin simultaneously. These three tasks are: 1) in-vehicle testing, 2) safety optimization, and 3) tooling and prove out of the overall control system through efficiency and durability verification. Similar in-vehicle testing programs have required four to six months for completion. Safety evaluation is the second task which could begin subsequent to the completion of the prototype laboratory testing. Safety evaluation would involve the use of computer crash simulation models and vehicle crash testing (four tests per body line/style) to verify the crashworthiness of the vehicle's modified fuel system. Because this evaluation could begin immediately after the completion of laboratory testing, a full 14 months of leadtime would be available to manufacturers if needed to perform this task. Based on discussions with NHTSA, 6 months is normally enough time to complete a safety evaluation. Therefore, 14 months appears more than adequate to perform the necessary safety optimization and testing for a manufacturer's product line. Tooling could also begin once laboratory testing is complete. Figure 23 shows EPA's estimate that tooling could require as little as 3 months and as much as 12 months depending on the magnitude of the task. Different factors are weighed before a manufacturer commits to various tooling changes. Manufacturers can commit to some tooling changes for onboard controls immediately after the in-vehicle testing (e.g., purge valves), whereas they may choose to wait until after safety analysis before committing to other tooling changes (e.g., rollover valves). However, in an overall sense, 12 months would provide manufacturers with enough time to delay some tooling changes and still complete the task well within the 24-month leadtime.

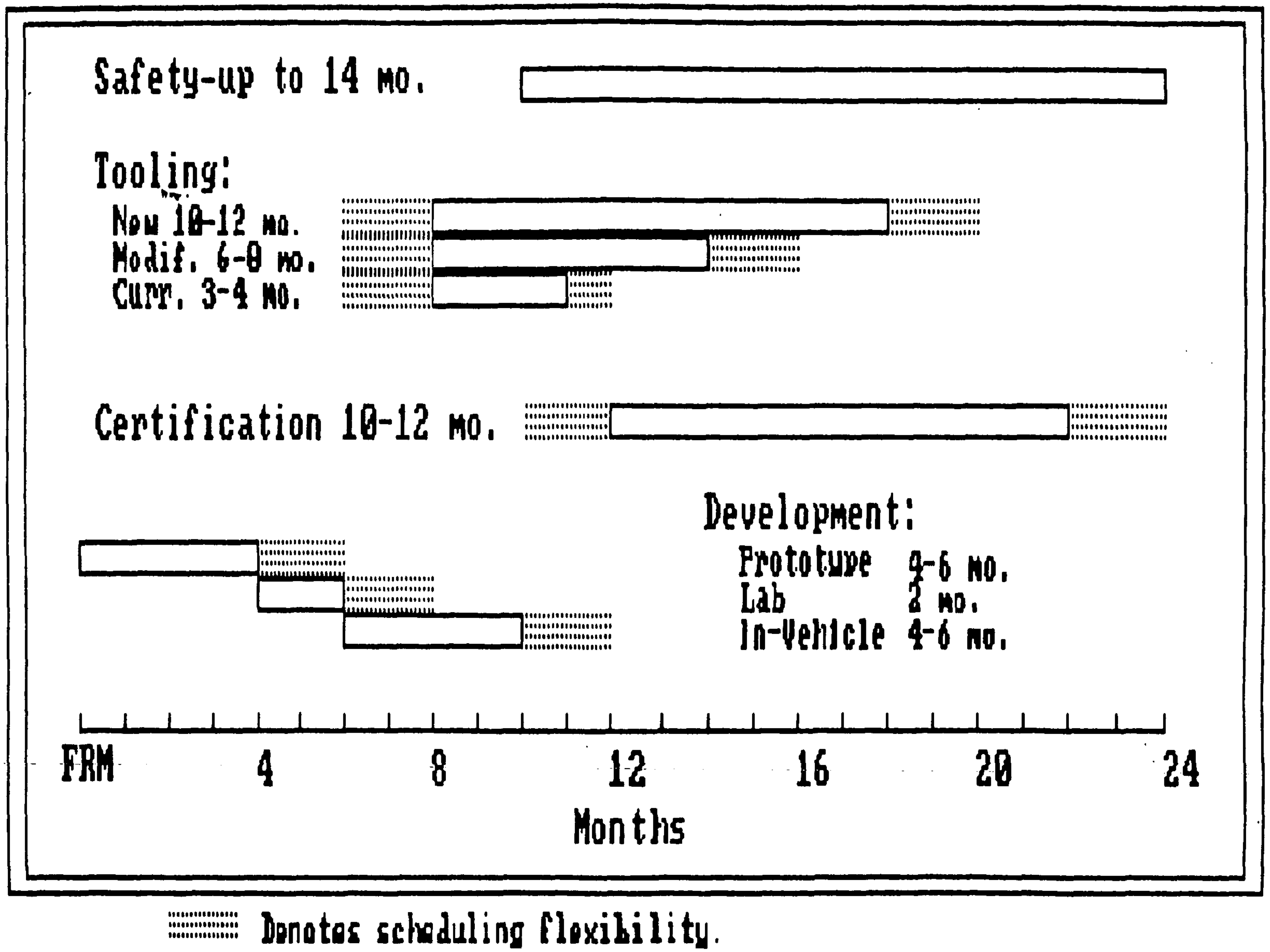


FIGURE 23 ONBOARD LEADTIME

The only other process which requires completion within the 24-month leadtime period is emissions certification. EPA has found from past experience that a manufacturer normally requires between 10 to 12 months to certify its product line.[39] This estimate is based on a 10 month engine family certification schedule which allows time for durability, emission data, fuel economy, and confirmatory testing. Because certification cannot begin prior to the completion of in-vehicle testing, certification is critical path, and EPA estimates a total leadtime period of 24 months will be needed overall.

Twenty-four months of leadtime is quite reasonable, especially since most of the fundamental development work is already complete. Onboard system prototypes are presently available, and many aspects of the system's performance have already been tested and proven to be effective. Also, because onboard control technology is incremental in nature to evaporative emission controls, there is no need to design and develop entirely new systems. As a matter of fact, many of the critical onboard design issues have already been incorporated into current fuel system designs with the inclusion of evaporative emission control systems. For example, evaporative emission control systems have already added the following to fuel systems: vapor vent lines, vapor storage device, canister purge capability, and corresponding safety provisions associated with each of these additions. Since much of the development work is already complete, implementing onboard systems should be no more of a problem to vehicle manufacturers than was implementing evaporative emission control systems.

EPA's 24-month leadtime estimate is supported by past experience with three previous evaporative emission rulemakings. These rulemakings included the original 1978 6.0 g/test LDV/LDT evaporative emission standard which was implemented with just 12 months of leadtime, the 1981 2.0 g/test LDV/LDT evaporative emission standard which was implemented with 24 months of leadtime, and the 1985 HDGV evaporative standard which was implemented with 24 months of leadtime. In each of these three rulemakings, manufacturers faced leadtime factors identical to the ones that would accompany an onboard requirement, including safety. Since manufacturers were able to safely and effectively integrate evaporative emission controls into their vehicles' fuel systems with 24 months of leadtime, and since the magnitude of the onboard implementation task is similar, this suggests that manufacturers should also be able to safely and effectively integrate onboard into vehicle fuel systems with 24 months of leadtime.

As far as safety development and evaluation is concerned, EPA's leadtime estimate is also supported by the past experience of NHTSA in implementing the various versions of

FMVSS 301. Table 4 shows the chronological history of FMVSS 301. The original 1968 FMVSS 301 applicable to passenger cars was implemented with less than 12 months of leadtime. When the standard was revised for 1976 model year passenger cars, 17 months of leadtime was provided. For 1977 model year passenger cars, manufacturers had to contend with the most substantial upgrade to the standard, and this was accomplished with only 29 months of leadtime, and only 12 months between new requirements. Also, beginning in the 1977 model year, FMVSS 301 was extended to include light trucks. This extension involved a 29-month leadtime period with further crash requirements in effect 12 months later, thus requiring recertification. Finally, in 1977, FMVSS 301 was extended to include school buses (with a GVWR greater than 10,000 lbs), and this requirement was implemented with 17 months of leadtime. This experience indicates that 24 months of leadtime allows manufacturers sufficient time to factor in safety.

Based on the information provided above, 24 months appears to be adequate time to implement onboard controls, with full consideration of all safety concerns. Because safety evaluation can proceed in parallel to three other tasks, more than a year is available for computer simulation and actual safety crash testing. This allows adequate leadtime to properly integrate safety into onboard systems especially since manufacturers can utilize and expand safety technology used in current evaporative emission control systems to develop effective onboard systems. Also, much of the safety development which would be required has already taken place with the identification and resolution of such potential safety issues as rollover protection and fuel tank pressure relief. Consequently, a 24-month leadtime period would provide manufacturers with sufficient opportunity to develop safe and effective onboard systems.

While this analysis indicates that the current leadtime estimate of 24 months is reasonable for most if not all vehicle models, EPA is sensitive to manufacturers concerns regarding leadtime requirements. Public comments regarding EPA's 24-month leadtime estimate were submitted as part of comments on EPA's original Gasoline Marketing Study (July 1984).[40] While most commenters did not object to the 24-month leadtime estimate presented in the Gasoline Marketing Study, auto manufacturers felt that a 24-month leadtime was insufficient to implement onboard controls. The leadtime periods suggested by these commenters ranged from three to six years. Those commenters suggesting that four or more years would be necessary also suggested that onboard controls should be phased-in gradually as normal vehicle model redesign and turnover occurs. Using this approach, implementing onboard controls would be less burdensome and would allow extra time to deal with implementation or packaging problems on unique vehicles. However, it is worth noting that comments received

Table 4

Chronology of FMVSS 301 Requirements

Model Year Requirement	Vehicle Type	Promulgation Date	Effective Date	Leadtime (Months)	Time Since Last Requirements
1968[1]	PC	2-3-67	1-1-68	11	
1976[2]	PC	3-21-74	9-1-75	17	7 2/3 yrs.
1977[2]	PC	3-21-74	9-1-76	29	12 mos.
1977[2]	Class 1 LDT	3-21-74	9-1-76	29	
1978[2]	Class 1 LDT	3-21-74	9-1-77	41	12 mos.
1977[2]	Class 2 LDT	3-21-74	9-1-76	29	
1978[2]	Class 2 LDT	3-21-74	9-1-77	41	12 mos.
1977[3]	School Buses	10-15-75	4-1-77	17	

[1] Motor Vehicle Safety Standard No. 301, Fuel Tanks, Fuel Tank Filler Pipes, and Fuel Tank Connections - Passenger Cars; 32 FR 2416, February 3, 1967, Part 571; S 301-1.

[2] Federal Motor Vehicle Safety Standard No. 301, Fuel System Integrity, 39 FR 10588, March 21, 1974.

[3] Federal Motor Vehicle Safety Standard No. 301, Fuel System Integrity, 40 FR 48352, October 15 1975.

from the manufacturers suggesting the need for a longer leadtime were not supported with any compelling arguments which would substantiate the insufficiency of a 24-month leadtime.

While the analysis above indicates that approximately 24 months of leadtime should be sufficient, there are some factors which must be considered but are difficult to factor into the analysis. First, as was mentioned above, some manufacturers have not developed working onboard prototypes due to resource or facility constraints and the possibility exists that these manufacturers will take no definitive action on systems development prior to a final action by EPA. Some have commented that these manufacturers should not be penalized because of this and may require a greater amount of leadtime. Second, vehicles with atypical duty cycles (ambulances, mail trucks, etc.) may require more leadtime to implement onboard controls safely. Vehicles assembled by secondary manufacturers such as recreational vehicles and airport mini-buses could also require more time especially if adding an onboard system requires other vehicle changes. Finally, more leadtime may be necessary because manufacturers may not have the test facility and safety engineering resources to effectively comply with multiple vehicle safety standard requirements concurrently. A similar concern may exist for emissions recertification since manufacturers would in most cases have to recertify virtually all gasoline powered vehicles for exhaust and evaporative emissions in addition to the new refueling requirement. Because of these concerns, more leadtime may be necessary for the implementation of safe onboard control systems.

EPA is committed to providing manufacturers the leadtime necessary to implement onboard controls safely and effectively. Consequently, EPA is open to considering the need for more leadtime and/or a short phase-in period for onboard controls. Such a phase-in period would provide manufacturers with additional time to solve any onboard system packaging and testing problems for unique vehicle models. Also, if a manufacturer had unique safety concerns on one or two body lines/styles, this approach would offer a manufacturer more leadtime to properly address them. In addition, it could improve the cost efficiency of controls by allowing manufacturers to forego development of onboard systems for vehicle models scheduled for retirement or permit manufacturers other flexibilities with new models being planned and those now in production. The implementation of other unique control strategies, such as bladder systems, would require more leadtime.

It is also important to note that if onboard controls are required, the date of promulgation of the final rule may be such that more than 24-months leadtime is actually available. The model year generally begins in September or October. If the publication of the final rule is much beyond that period, the manufacturers would have the remainder of that model year in addition to the 24 months discussed previously. Therefore, in actuality manufacturers could have substantially more than 24 months, but EPA's analysis indicates that only 24 months is needed.

In conclusion, given the magnitude of the task, this analysis indicates that 24 months of leadtime is adequate to allow manufacturers to safely and effectively implement onboard controls. This estimate is supported by EPA's experience with implementing evaporative emission standards and NHTSA's experience with implementing the various versions of FMVSS 301. However, EPA is committed to providing the leadtime necessary to implement onboard controls both safely and effectively. Thus EPA is open to considering more leadtime and/or a short phase-in period or other approaches which are pertinent.

Up to this point, this report has addressed onboard safety issues from primarily a passenger car and light truck point of view. It should be noted however that just as evaporative emission control technology was extended to heavy-duty gasoline fueled vehicles (HDGVs), onboard control technology could also be applied to HDGVs. While many of the safety issues discussed thus far would be identical in an HDGV application, some aspects of HDGV onboard safety would be distinct from light-duty issues. The next section in this report has been included to address the similarities and differences between heavy-duty and light-duty onboard safety issues.

VII. Heavy-Duty Gasoline Vehicle Requirements

Since an EPA onboard refueling control requirement would cover heavy-duty gasoline vehicles (HDGVs), in addition to passenger cars and light trucks, it is important to evaluate any potential HDGV onboard system safety considerations as well as those encountered in light-duty applications. (It is important to note that an onboard requirement will not apply to heavy-duty diesel trucks and buses.) While none of the comments received regarding the safety implications of onboard specifically addressed HDGVs, overall light-duty concerns discussed earlier are expected to apply. However, it is important to note that HDGV fuel system configurations differ somewhat from those found on passenger cars and light trucks, and the fuel system safety requirements also differ.

This section of the report identifies distinct HDGV onboard safety issues and discusses the implications these distinctions could have on manufacturers fuel system safety designs. It begins with a brief description of some of the more common HDGV configurations. Following these descriptions, a discussion of the HDGV fuel system safety standards will be presented, and differences between light- and heavy-duty vehicle onboard systems due to fuel system configurations and safety test requirements will be discussed. Next, HDGV onboard safety issues will be introduced and analyzed. Finally, this section will end with a brief segment concerning the effect of HDGV onboard safety on costs and leadtime.

Before beginning this analysis one key clarification is needed. FMVSS 301 covers all vehicles with a gross vehicle weight rating (GVWR) of 10,000 lbs or less (plus school buses over 10,000 lbs GVWR). For emission control purposes EPA classifies all gasoline-powered vehicles with a GVWR of 8,501 lbs or more as HDGVs. Out of EPA's HDGV category only 90,000 vehicles (or approximately 25 percent) have a GVWR greater than 10,000 lbs. Thus most (or approximately 75 percent) of EPA's HDGV class (those vehicles with a GVWR between 8,501 and 10,000 lbs-Class IIb) is covered by the LDT requirements in FMVSS 301. Since the fuel systems on Class IIb HDGVs are essentially identical to those on lighter weight LDTs, and FMVSS covers all LDTs up to 10,000 lbs GVWR, the previous portion of this analysis applies to the Class IIb HDGVs. The remainder of this analysis will focus on gasoline-powered vehicles whose GVWR exceeds 10,000 lbs.

This analysis addresses compliance costs with the assumption that HDGV manufacturers will use only certified fuel tanks on their vehicles. Currently, it is the owner's responsibility to purchase and use a certified tank if required by regulation. The current Motor Carrier Safety Regulations exempts a vehicle or driver used entirely within a municipality or commercial zone, although they may voluntarily comply with the regulations. These regulations may be changed in the future to be applicable to all HDGVs and eliminate the aforementioned commercial zone exemption. Therefore, this analysis assumes that all HDGVs will use fuel tanks certified to comply with the regulations discussed below.

A. HDGV Fuel System Configurations

Just as there are chassis and drivetrain differences between heavy and light-duty vehicles, there are also some differences in their fuel system configurations. Fuel tanks are generally of a heavier construction and are larger in volume; dual fuel tanks are also more common. Fuel tank shapes vary somewhat as does the location of the tanks on the vehicle. Also, it is often the case that the fillpipe is integral with the fuel tank, or has a very limited length as compared to lighter weight vehicles.

As a part of a recent contract study, EPA surveyed the characteristics of the fuel/vapor handling systems of HDGVs over 10,000 lbs GVWR.[41] The key results of the survey portion of that report are summarized in Table 5, which will serve as the basis for the remainder of this discussion.

Table 5

Selected Characteristics of Heavy-Duty Gasoline Vehicle Fuel/Vapor Handling Systems by Vehicle Model/Series

Manufacturer	Model or Series	Fuel Tank Shape	Fuel Tank Location	Number of Canisters	Size of Canisters	Diameter of Vent Lines	Diameter of Purge Lines
GM	P4T042	Rectangular	30 gal. Mount On Right Hand Frame	2	1500 and 2500 cc	0.312 in.	0.375 in.
	P6T042	Rectangular	30 and 60 gal. Mounted on Left Hand Frame	2	1500 and 2500 cc	0.312 in.	0.375 in.
	C5D042	Rectangular and Rectangular Step	20 gal. Mounted Right Hand Frame	2	1500 and 2500 cc	0.312 in.	0.375 in.
			50 gal. Step Mounted Right or Left Hand Frame				
	C6D042 C7D042 C7D064	Rectangular and Rectangular Step	20 gal. Mounted Right Hand Frame	2	1500 and 2500 cc	0.312 in.	0.375 in.
			50 gal. Step Mounted Right or Left Hand Frame				
			Dual 50 gal. Step Mounted Left and Right Hand Frame				
	B6P042	Rectangular	30 gal. Mounted Right Hand Frame	2	1500 and 2500 cc	0.312 in.	0.375 in.
			60 gal. Mounted Right Hand Frame				
FORD	F-Series	Rectangular	35 gal. Right Hand Side Frame Mounted	2	1400 ml. ea.	3/8 in.	3/8 in.
	B-Series	Rectangular	30 gal. Right Hand Side Frame Mounted	2	1400 ml. ea.	3/8 in.	3/8 in.
	C-Series	D-Type	50 gal. Right Hand Side Frame Mounted	2	1400 ml. ea.	3/8 in.	3/8 in.

First, as can be seen in Table 5, there are only two manufacturers which market HDGVs. Between them they offer only about 10 different chassis models to which any number of different bodies or payloads can be attached (tanks, dumps, cargo boxes, motor homes, school buses, flat beds, etc).

The second area of interest is the fuel tanks. Essentially three different tanks shapes are used: standard rectangular, step rectangular, and D-shape. Examples of these tanks are shown in Figure 24. The tank volumes range from 20 gallons to 60 gallons, with an average in the range of 35 to 40 gallons for single tank HDGVs and 75 gallons for dual-tank HDGVs. EPA estimates that about 15 percent of HDGVs use dual tanks, with most of those being in heavier weight trucks (>20,000 lbs GVWR).[17] Most passenger car and light truck fuel tanks are located under the vehicle body and this is also the case for some HDGV configurations (e.g., school buses). However, on some HDGV configurations, the fuel tanks are mounted on the outer side of the vehicle frame (right or left hand side for single tanks, both sides for dual tanks) and are exposed to the road rather than shielded by the vehicle body. As was alluded to above, most HDGV tanks have only a limited fillpipe length (<8") and some have essentially none at all, with the fuel cap being integral to the tank.

Finally, with regard to the HDGV evaporative emission systems two observations are important. (See Figure 25 for an example of a HDGV evaporative system.) First, for the same reasons as described for passenger cars and light trucks, HDGVs use a limiting orifice in the evaporative emission system. Second, the total evaporative emission canister capacity on an HDGV is more than twice the average on passenger cars and LDTs (2.8-4.0 liters). However, on HDGVs diurnal emissions from the fuel tank and hot soak emissions from the fuel metering system are routed to different canisters. Hot soak emissions are somewhat more of a concern on HDGVs because presently most are carbureted rather than fuel injected. To the degree that HDGV engines fuel systems are converted from carbureted to fuel injected as is now projected, concerns over hot soak emissions may diminish and allow the elimination of the second canister on those vehicles.[42,43]

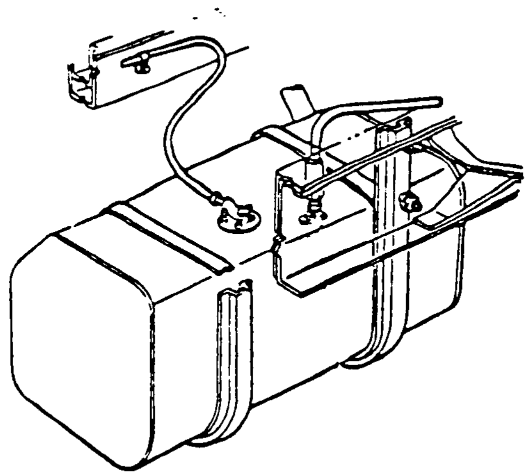
With this brief background on HDGV fuel/evaporative systems we turn now to a discussion of the fuel system safety standards which apply to HDGVs over 10,000 lbs GVWR.

B. HDGV Fuel System Safety Standards

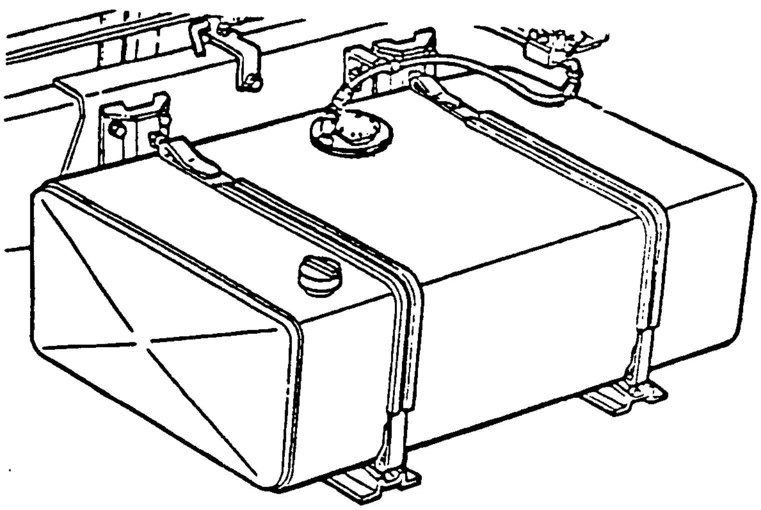
Fuel system safety regulations differ according to vehicle and fuel system configuration. The Department of Transportation/Office of Motor Carrier Safety (OMCS) has requirements which apply to all HDGVs over 10,000 lbs GVWR. In addition, school buses must meet the requirements prescribed specifically in FMVSS 301. The OMCS and FMVSS 301 requirements are summarized below.

Figure 24

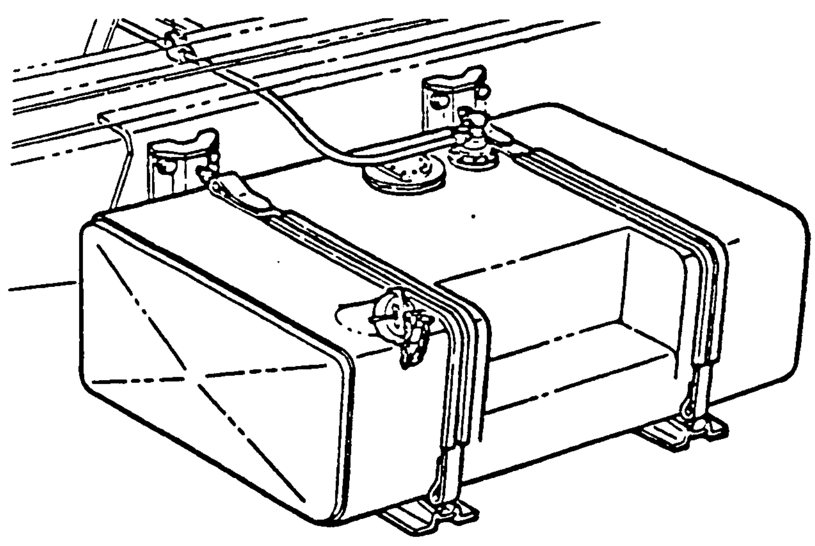
HDGV Fuel Tanks



D-Shape



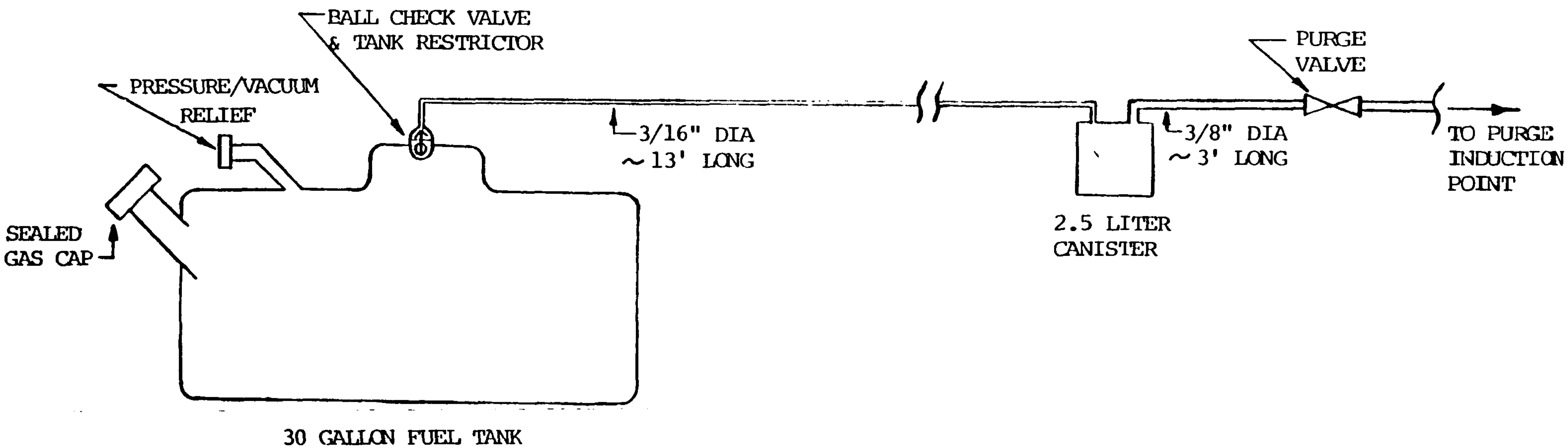
Standard Rectangular



Step Rectangular

Figure 25

TYPICAL HDGV EVAPORATIVE SYSTEM



1. Office of Motor Carrier Safety Requirements

OMCS safety regulations include both specific design requirements and actual fuel tank safety tests.[44] The design requirements contain rules governing the location, installation, and construction of fuel tanks used on HDGVs. Also, fuel lines, fittings, and fillpipes must conform to certain requirements.

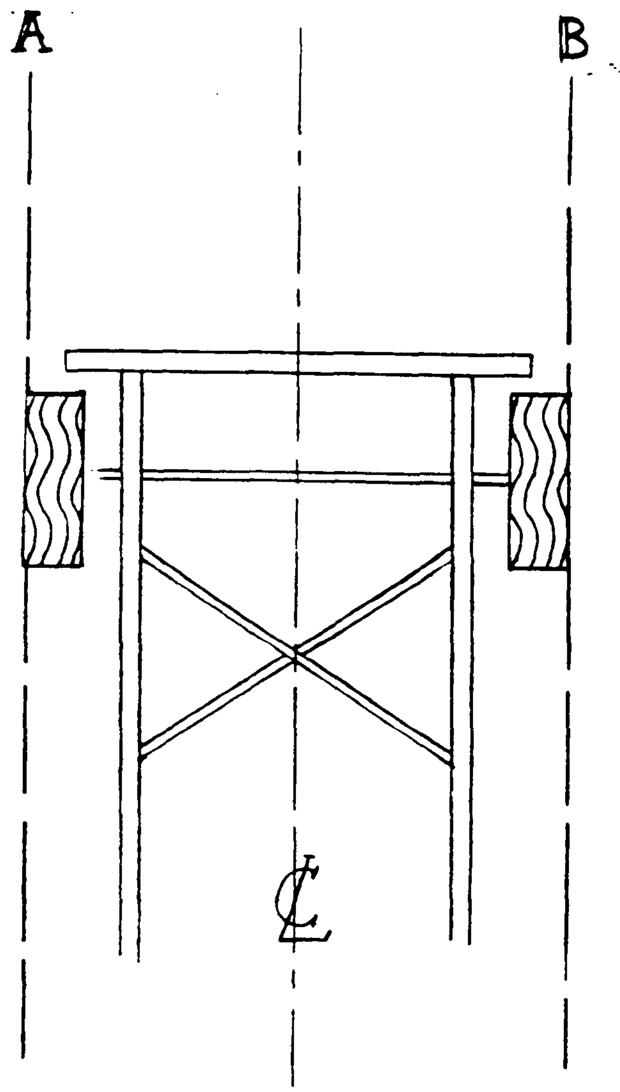
The actual testing requirements depend on whether a fuel tank is side-mounted or non-side mounted. To paraphrase the definition, a truck fuel tank is considered side mounted if it extends beyond the outboard side of a front tire positioned in the straight ahead position. This is shown pictorially in Figure 26. Any fuel tank which does not have this characteristic is considered non-side mounted, and in this analysis will be referred to as frame mounted. The testing requirements for frame-mounted tanks will be discussed first.

A frame mounted HDGV fuel tank has to be able to pass two fuel tank safety tests. The first of these two tests, the safety venting system test, involves applying an enveloping flame to an inverted fuel tank to insure that the fuel tank's safety venting system activates prior to the tank's internal pressure exceeding fifty pounds per square inch. The second fuel tank safety test is a leakage test which involves filling the tank to capacity and rotating the tank through an angle of 150° in any direction from its normal position to insure that neither the tank nor any fitting leak more than one ounce of fuel per minute in any position the tank assumes during the test.

HDGVs with side mounted fuel tanks must pass two other tests which involve dropping the fuel tank to test impact resistance. The first test, termed the drop test, involves dropping a fully loaded (equivalent weight of water) tank from 30 feet onto an unyielding surface, so that it lands squarely on one corner. A second similar test (termed the fillpipe test) requires that a fully loaded tank be dropped from 10 feet onto an unyielding surface, so that it lands squarely on its fillpipe. In neither case, may the tank nor any fitting leak more than one ounce per minute.

Based on conversations with the two HDGV manufacturers, the vast majority of HDGV fuel tanks are frame mounted (non-side mounted). No side mounted tanks are offered as standard equipment, and only occasionally one is sold as a special order.[45,46] Thus, this analysis will focus primarily on the safety venting and leakage test requirements which apply to frame mounted tanks. However, the drop tests for side mounted tanks will also be considered.

Figure 26



Pictorial Definition of Side-Mounted Fuel Tank.
If the tank extends to the left of line A or to the right of line B, then the tank is side-mounted. Lines A and B are tangent to the outer sides of the front tires.

2. School Bus Requirements

In addition to the OMCS requirements for frame-mounted tanks, outlined above, school buses are required to meet specific FMVSS 301 standards. However, this coverage does not include all of the test requirements as prescribed for passenger cars and light trucks. FMVSS 301 for school buses over 10,000 GVWR requires an impact with a contoured moving barrier at any speed up to and including 30 mph, at any point and angle. Depending on the design and location of the fuel tank and its protective structure, the "worst case" point and angle of contact is determined for each school bus model, and the contoured moving barrier impacts there. In this test, the fuel system must be designed so as not to leak more than one ounce of fuel per minute.[47]

This briefly summarizes the current Federal safety standards applicable to fuel systems on HDGVs over 10,000 GVWR. It is important to note that more safety requirements could be applied to HDGVs over 10,000 GVWR in the future. The Department of California Highway Patrol recently submitted a petition to NHTSA to amend FMVSS 301 to include fuel system integrity testing for heavy-duty vehicles over 10,000 GVWR.[48] With this background information we are now prepared to discuss how the differences in vehicle/fuel system configurations and the Federal safety standards may affect the design of an onboard system for an HDGV relative to the design for passenger cars and light trucks.

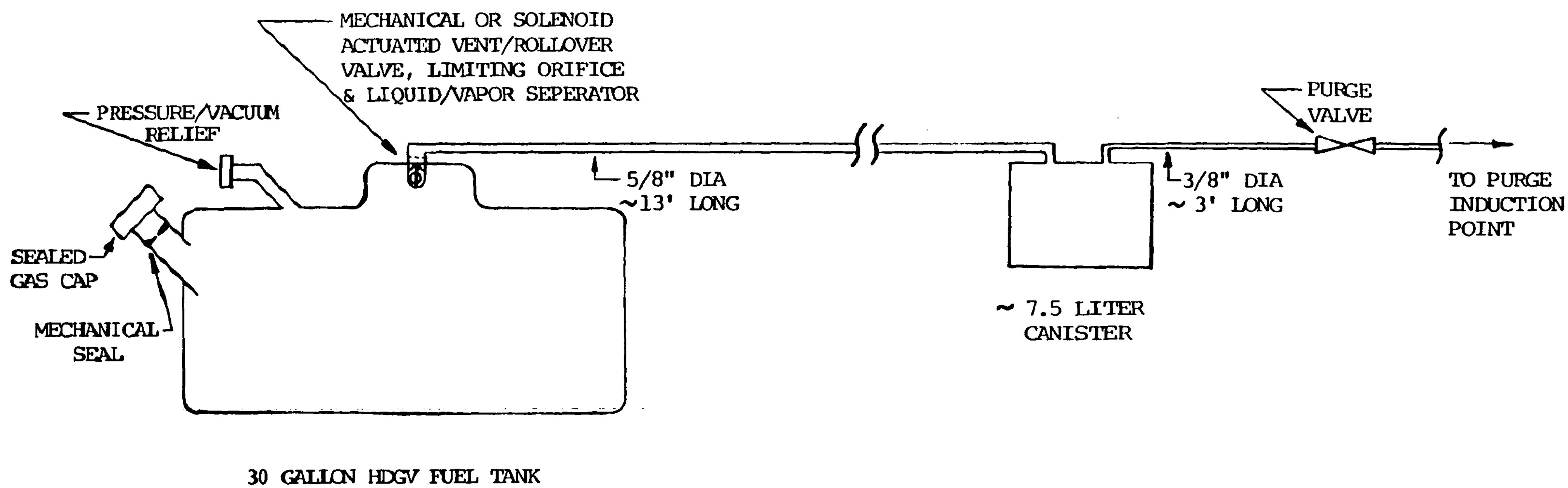
C. Distinctions in HDGV Onboard Systems

Just as the evaporative emission control systems used on HDGVs are very similar to those used on passenger cars and light trucks, it is also expected that an HDGV onboard system would be very similar in design and approach to that conceived for lighter-weight vehicles (a possible HDGV onboard system is shown in Figure 27). However, some minor variations would exist due to differences in HDGV fuel system configurations and the requirements levied by the applicable Federal safety standards. Before beginning a discussion of these minor variations, it is valuable to reiterate a few key points raised previously with regard to the magnitude of the task of implementing onboard controls.

First, like passenger cars and light trucks, all HDGVs now incorporate evaporative emission control systems (see Figure 25) and their fuel systems must meet the present Federal fuel system integrity standards (OMCS and NHTSA). Thus, as before with the lighter weight vehicles, the application of onboard systems is best evaluated incrementally to the measures already taken to incorporate evaporative emission controls and meet safety standards. Much of the ground work has already been completed, the needed modifications made and components added.

Figure 27

POSSIBLE HDGV INTEGRATED EVAPORATIVE/REFUELING SYSTEM



In many cases no changes to present fuel system safety assurance or evaporative emission control measures will be needed. Second, it is important to note that HDGV onboard refueling and fuel tank evaporative emission control systems will likely be integrated as with lighter weight vehicles. This is quite easy to accomplish on HDGVs, since they now have separate canisters and control systems for fuel tank and fuel metering system evaporative emissions. Thus a whole new system will not be added to control HDGV refueling emissions; instead the refueling and fuel tank evaporative emission control systems will be integrated into one (compare Figure 25 with Figure 27). Thus many of the primary design considerations which applied for the evaluation of onboard systems to passenger cars and light trucks also apply to HDGVs.

Remembering the expected similarities between light and heavy-duty vehicle onboard systems and that the factors affecting the implementation are also the same, the expected minor variations in HDGV onboard systems can now be discussed. For sake of presentation, discussion will begin at the fillpipe and follow along the system to the canister. The analysis will assume an integrated onboard refueling/fuel tank evaporative control system as discussed above.

To begin with, because the fillpipes on HDGV fuel tanks are either relatively short or integral with the tank, liquid fillneck seals which require an appreciable fill height may not be a practical approach in some configurations. Due to this lack of fill height, HDGV manufacturers might elect to utilize a mechanical seal approach and thus would need to incorporate some type of pressure relief device such as was described previously. HDGV fuel tanks, which are made of steel or aluminum, now use a pressure-vacuum relief valve, and it is conceivable manufacturers will simply modify that valve for this application. However, under the proper backpressure conditions, it might be possible to use a liquid fillneck seal by extending the fillpipe horizontally in the tank as has been demonstrated in a prototype light-duty program.[15]

A second potential difference lies in the diameter of the refueling vapor line and related fuel tank vent. From a design perspective, the tank vent and refueling vapor line size (diameter) could be affected by the fuel dispensing rate. As part of the refueling emissions test procedure, EPA is proposing that HDGV fuel systems be designed for refueling at a maximum rate of 10 gallons per minute, the same rate as prescribed for other vehicles.* This 10 gallon per minute

* Discussions with gasoline marketing interests and nozzle manufacturers indicate that gasoline available to passenger cars, light trucks, and HDGVs (either at retail or private pumps) is normally not dispensed at rates greater than 10 gpm.

dispensing rate results in an increase in the current orifice and evaporative vapor line diameter from about 3/8 inch to about 5/8 inch for an HDGV onboard system.

However, to minimize spillage during refueling, the OMCS has requirements that any liquid fuel tank over 25 gallons in capacity must be able to accept fuel at a rate of 20 gallons per minute.[49] For an onboard system this requirement could lead to a increase in the diameter of the tank vent outlet and refueling vapor line. It should be noted, however, that while this requirement applies to all heavy-duty liquid fuel tanks (both diesel and gasoline), fundamentally it is aimed more at diesel fuel tanks. It is not uncommon to encounter an in-use diesel fuel dispensing rate of 20 gpm or more to reduce the time needed to fill a diesel tank since these tanks are typically much larger than gasoline tanks and dual diesel tanks are also more common.[50] In-use gasoline dispensing rates on the other hand normally do not exceed 10 gpm. Since in-use gasoline dispensing rates usually do not exceed 10 gpm, and EPA's refueling certification test would involve a 10 gpm maximum dispensing rate, OMCS's requirement in this area may not be needed. EPA has discussed this matter with DOT/OMCS, and they have expressed a willingness to consider changing this requirement to apply only to diesel fuel tanks.[51,52] If this standard is not changed, and a 10 gpm dispensing rate limit is enacted, the only effect would be that the refueling vent orifice/line for these vehicles would be over sized.

Nevertheless, because HDGV fuel tanks do not use long fillnecks, fuel dispensing operations would not be as sensitive to higher backpressure as they would be in light-duty. Even if the refueling vent orifice/line were sized for a 10 gallon per minute dispensing rate, fuel could be dispensed at a greater rate without premature shutoffs. Thus it may not be necessary to size the refueling orifice/vent line to match the dispensing rate requirements. However, in optimizing system designs with regard to fuel tank pressure, manufacturers may choose to use a slightly larger refueling vent orifice than seen on light-duty applications.

One final manner in which HDGV onboard systems might differ from those on lighter weight vehicles is in the design of the rollover protection device. The solenoid activated rollover valve (Figure 19) or the combination valve (Figure 21) could be applied to HDGV fuel tanks in their present configurations. One manufacturer's fuel tank design now incorporates a ball type check valve similar in principle to the combination valve.[41] Also, the nozzle actuated valves shown in Figures 9-15 could also be used on HDGV fuel tanks which have a fillpipe length of 6 inches or more. However, nozzle actuated valve designs would have to be modified slightly to perform on fuel tanks whose fillneck is essentially integral with the tank. Nonetheless, the basic approach and operation would be the same.

Any of the three rollover valve designs mentioned above could be used on HDGV fuel tanks. However the best choice for any tank would depend on the fillpipe length or other trade-offs relative to cost, packaging etc. With proper design and integration any of these valve designs could provide rollover protection in-use.

With this background on HDGV fuel system configurations, safety requirements, and HDGV onboard system characteristics, it is now possible to address some of the unique safety concerns related to HDGV onboard. The next segment of this report discusses and addresses potential impacts of HDGV onboard on fuel system safety considerations.

D. HDGV Onboard Safety Issues

1. Introduction

While none of the comments received regarding the safety implications of onboard controls specifically addressed HDGVs, it is reasonable to expect that overall concerns would be similar because of the expected close resemblance between light and heavy-duty vehicle onboard systems. To avoid repeating much of what has previously been discussed, this segment will primarily focus on unique HDGV onboard safety considerations. The analysis presented in Section IV regarding maintenance, repair, tampering and defects and refueling operation safety apply equally to HDGVs and will not be repeated here. The potential problems are similar and the same basic approach and straightforward engineering solutions can be used. Also, the extensive analysis in Section V regarding in-use fuel system safety also applies to HDGVs. As before, manufacturers are expected to manage risk appropriately; there is no reason that adding an onboard system would directionally increase in-use risk over that now accepted with present HDGV fuel/evaporative emission systems.

However, as was discussed above the fuel system configurations and the safety test requirements for HDGV fuel tanks are somewhat different from light-duty, so some discussion of distinct safety test design requirement issues is appropriate.

2. Safety Test Design Requirements

As mentioned above, there are two separate areas of safety test design considerations for HDGV fuel systems. The Office of Motor Carrier Safety (OMCS) has fuel system safety regulations which apply to all HDGVs, and NHTSA has additional requirements for school buses. This segment begins with a summary and analysis of safety design considerations related to OMCS requirements. Following this is a discussion of the effects of NHTSA's crash test requirements.

a. OMCS Requirements/Considerations

OMCS has established fuel system requirements for HDGVs to insure their structural and in-use integrity. As part of the current requirements, HDGV fuel tanks must be capable of passing the safety venting system and the leakage tests described previously. Currently HDGV fuel tanks employ a ball check valve and pressure vacuum relief valve to pass these two tests. Since the refueling vent orifice would be somewhat larger with an onboard system (5/8") the ball check valve would have to be upgraded to provide the necessary protection. Little or no change to the pressure vacuum relief valve would be needed.

For an HDGV onboard system, the protection now supplied by the ball check valve could be supplied by the rollover valve designs described previously. The same three general types of rollover protection devices that were discussed for use in light-duty applications (nozzle actuated, solenoid, and mechanically activated valves) would all be feasible in various heavy-duty applications as well. However, for tanks with little or no fillpipe (<6") the nozzle actuated valve design would probably have to be modified slightly and mounted in the tank instead of on the fillneck. A solenoid or mechanical rollover (ball) valve design could essentially be used as shown earlier.

HDGV and light-duty onboard systems would be functionally identical and would be very similar in design and configuration except for canister size and vapor line length. Of course, to meet safety requirements and to provide in use protection, manufacturers will have to consider the structural integrity and the materials used in key system components just as they do now with other components of the fuel/evaporative system. Thus, some components of the HDGV onboard system (notably the rollover valve) may need to be constructed of metal to provide impact resistance and the flammability protection demanded in the safety venting test.

Also, with regard to impact resistance, any one optional side-mounted tank model, would be subject to two additional safety tests (drop tests) designed to evaluate the tank's impact resistance. A side-mounted fuel tank would likely utilize a rollover valve mounted integral to or within the tank to insure its integrity during the drop tests. While this would not be difficult to design (many current fuel tanks contain interior components), it would represent an additional design consideration for side-mounted fuel tanks. From an in-use safety perspective, the impact resistance and overall integrity of rollover valves on frame mounted tanks would be enhanced if they were mounted integral or internal to the tank. Thus, this approach would be attractive for all HDGV fuel tanks.

In conclusion, the only HDGV onboard safety design feature introduced by the need to meet OMCS safety requirements is the upgrade of the current rollover protection device. All of the rollover protection approaches discussed for light-duty applications (nozzle actuated, solenoid, or mechanically activated valves) could be used to meet this requirement. The design, placement, and construction of the rollover valve on a particular HDGV fuel tank would depend in part on fillpipe configuration, impact resistance concerns, and flammability potential.

b. NHTSA Requirements/Considerations

In addition to OMCS requirements, all school buses over 10,000 lbs. GVWR must also meet specific requirements of NHTSA's FMVSS 301. As described earlier, this involves a single moving contoured barrier test at a maximum of 30 mph and does not include a rollover test. In this test, the barrier impacts the school bus at the most vulnerable location of the fuel tank, and the fuel system must be designed so as not to leak more than one ounce of fuel per minute. As was true of OMCS requirements, an acceptable school bus onboard system is one which does not impair the fuel tank's ability to meet this requirement.

As in the light-duty test, the crashworthiness of all the onboard system components (rollover valve, charcoal canister, critical vapor line and vapor line connections between the top of the fuel tank and the rollover valve) would all be evaluated in the test. Design measures similar to those described for passenger cars and light trucks would have to be taken to assure the integrity of these three key components.

The crashworthiness discussion in Section IV-A and the further options discussed in Section V addressed specific safety design approaches for these components which could also be applied to school buses, so this will not be addressed further. As before with light-duty applications, evaporative emission systems provide directly relevant techniques and experience to assist in proper design, and specific engineering measures have been suggested to deal with potential concerns.

Furthermore, the in-use safety of onboard refueling controls for HDGVs must be considered. The location of onboard system components, as with the current fuel tank and evaporative emission controls, must minimize any potential safety risks. Much of the HDGVs fuel system damage seen today is caused by foreign objects from the road surfaces. Therefore, critical onboard control system component should be located on the HDGV in a position which will minimize any foreign object damage.

In conclusion, HDGV onboard systems do not introduce any new or significant problems to manufacturers' attempts to design safe fuel systems capable of meeting NHTSA and OMCS safety requirements. Straightforward, viable engineering solutions are available to address all problems that have been identified. Therefore, onboard systems are expected to be integrated into HDGV fuel systems without reducing the system's ability to meet all applicable Federal safety requirements.

3. Summary

As was mentioned in the light-duty section of this report, EPA's philosophy in evaluating the safety implications of requiring onboard controls (including those for HDGVs), is that no increase in overall risk should be caused or accepted, beyond that now present with today's fuel/evaporative system. This applies to both compliance with the applicable Federal Safety standards and the in-use safety of vehicles equipped with onboard systems. This portion of the analysis has addressed the safety test design requirements related to implementing HDGV onboard systems, and as was the case for light-duty it concludes that straightforward engineering solutions are available for all of the potential safety problems which have been identified, and safe fuel system designs are achievable by all.

E. Cost and Leadtime Considerations

EPA has received no comments which directly address specific HDGV onboard safety cost and leadtime implications. However, an analysis of the costs and leadtime necessary to implement HDGV onboard controls safely is an integral part of the overall evaluation of the feasibility of this control approach. The first portion of this section addresses HDGV onboard safety costs; the second discusses HDGV leadtime requirements and describes the basis for EPA's leadtime estimates. Some of the cost figures cited in the safety cost analysis are drawn from a broader EPA analysis which develops total HDGV onboard system costs in 1984 dollars.[17]

1. Safety Costs

As was true of light-duty onboard safety costs, the costs needed to implement HDGV onboard controls fall in several areas. R&D type costs will be incurred, some new or modified components will be needed which may slightly affect vehicle operating costs, and safety certification testing will be necessary. However, before beginning a discussion of these costs, it is valuable to discuss how EPA's HDGV evaporative emission control requirements impact onboard safety costs.

As was described in the light-duty section of the report, an onboard system (even those for HDGVs) is in many ways an extrapolation of current evaporative emission control technology and the two systems are quite similar. Since onboard systems are basically extensions of evaporative emission systems, clearly many of the safety design considerations associated with onboard systems related to meeting OMCS/NHTSA requirements or providing in-use assurance have already been addressed in evaporative emission system designs. Consequently, much of the ground work required to insure onboard safety has already been performed. It is important to keep the magnitude of the HDGV onboard safety design process in perspective, because much of the safety technology needed is simply an extension of that which already exists. Noting the "incremental" nature of onboard safety in terms of the magnitude of the task and actual cost relative to evaporative systems, it is now possible to describe the components which factor into onboard safety costs.

Basically, the integration of safety into a fuel system incorporating an onboard system involves four types of costs. These four costs are for: 1) design and development (R&D), 2) specific hardware, 3) safety testing, and 4) weight penalty (or added fuel consumption). The paragraphs that follow describe how each of the cost components are affected by onboard safety.

To begin with, some research and development will have to be performed to safely integrate onboard controls into HDGV fuel systems. EPA has estimated that the total design and development cost required to incorporate onboard systems in HDGV fuel systems is about $34,200 per family or $1.50 per vehicle (over 10,000 lbs GVWR). This cost is for any development effort involved in combining the components of an onboard system with the rest of the vehicle to form a unit that interacts safely and effectively. Because safety is evaluated inherently in the design and development process and yet is only one part of the total effort, only a fraction of the total cost should be directly allocated to safety. The light-duty cost section explained why this fraction is likely to be small. The same reasoning is also applicable for heavy-duty applications, and therefore it was assumed that about 20 percent of R&D expenditures relate to safety, which translates to about $0.30 per vehicle.

The second component of HDGV onboard safety costs relates to specific hardware that may be required to insure fuel system safety. EPA has estimated costs for three specific items which have been identified as potential components to be included as part of the onboard system design explicitly for safety reasons. These three items are 1) a rollover valve, 2) a pressure relief mechanism, and 3) fuel system modifications necessary to safely incorporate a rollover valve, pressure relief mechanism, or other onboard hardware. HDGV rollover valves should not differ in cost from light-duty valves since they would essentially be the same. Therefore, the light-duty estimate of $3.00 to $6.00 will also be used here.

The second safety hardware cost is for a pressure relief mechanism. Since this mechanism would be needed for onboard systems incorporating a mechanical fillneck seal, many HDGVs would require its use. EPA's analysis prices this device at $2.50.[13] At this point, this estimate is considered to be very conservative, since the possibility exits that the present pressure relief device can be modified to perform this function.

The final onboard safety hardware cost accounts for any fuel system modifications that would be necessary in order to safely accommodate any onboard control hardware. For example, a HDGV fuel tank or fillpipe might have to be re-shaped or modified in order to accept a rollover valve. Also, some slight re-routing of the fuel system's vapor lines may be required. EPA has estimated a total modification cost to be $0.50 per fuel tank. Only part of this total cost would be required for safety purposes. However, because safety inherently enters into the decision to make any modifications, it is difficult to access what part of the total modification cost should be allocated to safety; perhaps half ($0.25 per fuel tank) could be considered as driven by safety related concerns.

Summing up the three individual safety hardware costs per fuel tank yields a total estimated figure in the range of $5.75 to $8.75. However, this cost estimate does not include manufacturer overhead and profit. Consequently, in order to obtain the retail price equivalent cost, these estimates must be multiplied by a markup factor. Presently, a markup factor value of 1.27 appears representative.[37] Therefore, after integration of the markup factor, a total retail price equivalent HDGV safety-related hardware cost per fuel tank falls within the range of $7.30 to $11.10. Since 15 percent of HDGVs have dual tanks, the total HDGV safety-related hardware cost range is $8.40 to $12.80

The third component of safety costs is for any safety testing that would be necessary. Unlike light-duty test costs, EPA has not thoroughly investigated HDGV safety test costs. However, safety test costs were estimated in an attempt to determine the approximate magnitude of the per vehicle HDGV safety test cost. Table 6 shows that even when fairly liberal safety test costs are assumed, the resulting cost/vehicle of $0.70 is very minimal in the long term.

The fourth component of safety costs is the estimate of the added fuel consumed over the life of the vehicle due to the increase in vehicle weight resulting from added safety hardware. The amount of weight added to vehicle from a

Table 6

HDGV Fuel Tank Safety Test Costs Estimate

1. OMCS Requirements:

   2 tests per HDGV fuel system configuration (Safety Vent Test and Leakage Test)

   Conservative Cost/Test Estimate: $2,000

   8 HDGV Fuel Tank Configurations

   Total OMCS Safety Test Cost: $32,000

2. NHTSA Requirements:

   1 test per HDGV fuel system configuration (30 mph moving barrier)

   Conservative Cost/Test Estimate: $30,000

   7 School Bus Configurations (7 manufacturers, 1 config./manufacturer)

   Total NHTSA Safety Test Cost: $210,000

3. Total HDGV Fuel Tank Safety Test Cost: $242,000

4. Cost/Vehicle (Amortized at 10 percent over 5 years of vehicle sales*): $0.70

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* Assumed that all bus manufacturers will crash test their vehicles.

** Vehicle sales were estimated at 90,000/year.

rollover valve or pressure relief mechanism is very small (0.4 lbs), and because HDGVs are less sensitive to weight changes than lighter weight vehicles, on average less than $0.30 in added fuel costs will result from their inclusion into the HDGV onboard system.[24]

A total onboard safety cost is calculated by summing all four individual component costs. Total safety-related onboard costs per family average about $270,000, and the per vehicle costs range from $9.70 to $14.10 or about 20-25 percent of the total cost depending on the type of rollover valve used.

2. Leadtime

If EPA were to implement an HDGV onboard requirement, it would be necessary to allow manufacturers enough leadtime to adequately prepare for the requirement. The HDGV preparation process would involve the same individual tasks that would enter into the light-duty process: system design, development, testing, tooling, certification, and safety evaluation. Although two of these leadtime tasks (certification and safety evaluation) would involve somewhat different procedures for HDGVs, they will essentially require the same amount of time and would factor into the total process in the same manner as in light-duty. Therefore, it is estimated that 24 months would be the total amount of leadtime required by HDGV manufacturers, and Figure 25 which shows the parallel/sequential progression of the individual leadtime components would be essentially the same for HDGVs.

Of the various leadtime components shown in Figure 25, all but two would be essentially the same for HDGVs as they would for light-duty applications. These two are certification and safety evaluation. In both cases, the HDGV processes appear as though they would take less time to complete than their light-duty counterparts because these tasks would be likely to be less difficult to perform. For example, in some cases, durability assessments for certification of HDGVs does not require any actual vehicle testing; bench evaluations can be substituted based on the manufacturers engineering judgment. This could save considerable time.

As far as safety evaluation goes, HDGV fuel tank tests performed to meet OMCS requirements would be much simpler to perform than NHTSA's safety crash tests for passenger cars and light trucks. Also, when NHTSA requirements do apply (as in the case of school buses) they only involve a single crash test with no rollover. (This is minor in comparison to tests which involve multiple crashes with rollover.) Therefore, the amount of time allowed for light-duty certification (10-12 months) and safety evaluation (>12 months) should also be sufficient for HDGVs since the heavy-duty processes are less involved. Overall, 24 months of leadtime for HDGV onboard is quite reasonable. This is especially true when one considers the development work already completed and the "incremental" nature of onboard in relation to current evaporative emission systems.

EPA's 24-month leadtime estimate is supported by past experience with previous HDGV evaporative emission rulemakings. These rulemakings include the California Air Resources Board original 1978 6.0 g/test HDGV evaporative emission standard which was implemented with just 21 months of leadtime.[53] The stringency of this standard was increased for 1980 model year HDGVs allowing only 2 g/test.[54] While this stricter standard was promulgated with 37 months of leadtime, manufacturers had to meet the 1978 standard first, which effectively limited the leadtime for the 1980 standard to about 24 months. One final evaporative emission standard which was implemented with 24 months of leadtime was EPA's 1985 HDGV standard. In each of these three rulemakings, manufacturers faced leadtime factors identical to the ones that would accompany an onboard requirement, including safety. Since manufacturers were able to safely and effectively integrate evaporative emission controls into their vehicle's fuel systems with 24 months of leadtime, and since the magnitude of the onboard implementation task is similar, manufacturers should also be able to safely and effectively integrate onboard into vehicle fuel systems with 24 months leadtime.

As far as safety development and evaluation is concerned, EPA's HDGV leadtime estimate is also supported by the past experience of OMCS and NHTSA in implementing various HDGV fuel system requirements. In 1973, OMCS extended its safety test requirements to include previously unaffected non-side-mounted (frame-mounted) HDGV fuel tanks. This requirement was implemented with just 18 months of leadtime.[55] Also in 1977, FMVSS 301 was extended to include school buses, and this requirement was implemented with 17 months of leadtime.[56] This experience indicates that 24 months of leadtime allows manufacturers sufficient time to factor in safety.

Based on the information provided above, it appears that 24 months is adequate time to implement HDGV onboard controls, with full consideration of all safety concerns. Because safety evaluation can proceed in parallel to three other tasks, more than a year is available for actual fuel tank safety tests, school bus crash testing, or any desired computer simulation. This allows adequate leadtime to properly integrate safety into HDGV onboard systems especially since manufacturers can utilize and expand safety technology used in current evaporative emission control systems to develop effective onboard systems. Also, much of the safety development which would be required has already taken place with the identification and resolution of such potential safety issues as rollover protection and fuel tank pressure relief. Consequently, a 24-month leadtime period would provide manufacturers with sufficient opportunity to develop safe and effective onboard systems.

While the current leadtime estimate of 24 months is reasonable for all vehicle models including HDGVs, EPA is sensitive to manufacturers concerns regarding leadtime requirements. EPA is committed to providing manufacturers the leadtime necessary to implement onboard controls safely and effectively. Designing safe onboard controls for some unique HDGVs may require more leadtime. Such HDGVs include those with atypical duty cycles, unique fuel tank or body configurations, and those HDGVs from secondary manufacturers. Consequently, EPA would include HDGVs as part of any overall consideration of additional leadtime or a short phase-in period for onboard controls.

F. Summary/Conclusion

The purpose of this section was to identify and address the potential effects onboard controls could have on a HDGV manufacturer's fuel system safety designs. After analyzing the potential safety concerns related to implementing HDGV onboard systems, EPA has found that like passenger cars and light trucks, heavy-duty onboard systems are extensions of current evaporative systems and corresponding safety considerations are similar in nature to those discussed for light-duty applications. While a few unique considerations do exist (in part because of differences in testing requirements, tank designs/locations, structural integrity, size etc.), no increase in overall risk should be caused or accepted, beyond that now present with today's HDGV fuel/evaporative system. This applies to both compliance with the applicable Federal safety standards and the in-use safety of HDGVs equipped with onboard systems. As was the case for light-duty, straightforward engineering solutions are available for all of the potential safety problems which have been identified, and that while final choices regarding exact system designs lie with the manufacturers, safe fuel system designs are achievable by all. EPA estimates that HDGV safety costs contribute about 20-25 percent of the total HDGV onboard system cost and should fall within the range of $9.70 to $14.10. With regard to leadtime, this analysis indicates that 24 months appears to provide HDGV manufacturers with adequate time to prepare for the safe and effective implementation of onboard controls, but as before with passenger cars and light trucks the possibility of the need for more leadtime for some vehicle models may exist.

VIII. Conclusion

EPA has investigated and analyzed each of the potential onboard system safety issues raised by the commenters. After carefully considering all of the potential impacts an onboard system could have on the overall safety of a vehicle's fuel system, it is concluded that straightforward, reliable, relatively inexpensive engineering solutions exist for each of the potential problems identified. Furthermore, no increase in risk need occur or be accepted because of the presence of an onboard system. Onboard equipped vehicles can be designed to pass FMVSS 301 and provide a level of in-use fuel system integrity equal to or better than that achieved on present vehicles which incorporate evaporative emission control systems. Of course final choices regarding exact onboard system designs lie with the manufacturers, and each manufacturer will choose the approach/system which provides the best balance of cost, safety, and other key factors. EPA would not adopt an onboard requirement unless it was clear that safe fuel system designs were available. This report demonstrates this to be the case. Safe fuel system designs are achievable by all manufacturers.

Furthermore, it it is quite possible that overall fuel system improvements could accompany the implementation of onboard controls and lead to a net improvement in the level of fuel system safety on in-use vehicles. For example, collapsible bladder tanks are one design option that could control refueling emissions, reduce evaporative emissions and at the same time improve fuel system safety.

Manufacturers can and are expected to design and implement onboard systems in a manner which provides at least the same level of fuel system safety as achieved on present vehicles. In addition, a number of design options and other measures are available with onboard systems, which suggest that fuel system safety in-use can be improved along with the incorporation of onboard control systems.

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★U.S. GOVERNMENT PRINTING OFFICE: 1987 - 744-622

Appendix III

Service Station Fire Data

APPENDIX III

TABLE 1
SERVICE STATION FIRES

NFIRS DATA ONLY

	1982	1983	1984	1985	AVERAGE
INCIDENTS	776	789	872	1068	876
SERVICE INJURIES	8	5	9	5	7
OTHER INJURIES	40	37	43	35	39
SERVICE DEATHS	0	0	0	0	0
OTHER DEATHS	0	2	2	1	1
STRUCTURE FIRES	101	105	88	117	103
MOBILE FIRES	327	350	392	504	393
OTHER FIRES	348	334	392	447	380
EST. DOLLAR LOSS	2166[illegible]	2459474	2116459	3140544	2470783

NATIONWIDE PROJECTIONS

	1982	1983	1984	1985	AVERAGE
INCIDENTS	2739	2384	2392	2696	2553
SERVICE INJURIES	28	15	25	13	20
OTHER INJURIES	141	112	118	88	115
SERVICE DEATHS	0	0	0	0	0
OTHER DEATHS	0	6	5	3	4
STRUCTURE FIRES	357	317	241	295	303
MOBILE FIRES	1154	1058	1075	1272	1140
OTHER FIRES	1228	1009	1075	1128	1110
EST. DOLLAR LOSS	7648296	7432530	5805447	7926733	7203252

APPENDIX III

TABLE 2

TYPE OF SITUATION FOUND

NFIRS DATA ONLY

	1982	1983	1984	1985	AVERAGE	% OF TOTAL
STRUCTURE FIRE	101	105	88	117	103	11.73
OUTSIDE OF STRUCTURE FIRE	179	181	200	206	192	21.85
VEHICLE [illegible]	327	350	392	504	393	44.88
BRUSH [illegible]	3	0	2	1	2	0.17
RE[illegible]	2	4	3	4	3	0.37
[illegible])	7	2	3	4	4	0.46
[illegible]	128	131	155	198	153	17.46
[illegible]	0	1	2	1	1	0.11
[illegible]	29	15	27	33	26	2.97
[illegible]	776	789	872	1068	876	100.00

NATIONWIDE PROJECTIONS

	1982	1983	1984	1985	AVERAGE	% OF TOTAL
STRUCTURE FIRE	357	317	241	295	303	11.85
OUTSIDE OF STRUCTURE FIRE	632	547	549	520	562	22.01
VEHICLE FIRE	1154	1058	1075	1272	1140	44.65
BRUSH FIRE	11	0	5	3	5	0.18
REFUSE FIRE	7	12	8	10	9	0.37
EXPLOSION (W/O FIRE)	25	6	8	10	12	0.48
OUTSIDE SPILL/LEAK	452	396	425	500	443	17.36
INSUFFICIENT INFO	0	3	5	3	3	0.11
OTHER	102	45	74	83	76	2.99
TOTAL	2739	2384	2392	2696	2553	100.00

APPENDIX III

TABLE 3
MOBILE PROPERTY TYPE

NFIRS DATA ONLY

	1982	1983	1984	1985	AVERAGE	% OF TOTA
MOBILE PROP UNKNOWN	6	11	12	30	15	1.71
NOT APPLICABLE	333	328	361	419	360	41.1
AUTOMOBILE	252	293	328	436	327	37.33
TERRAIN VEHICLES	11	12	11	14	12	1.37
MOTOR HOME	7	3	6	10	7	0.8
PASS. ROAD TRANS, OTHER	5	5	1	3	4	0.46
TRUCK-OVER 1 TON	11	5	9	11	9	0.69
TRUCK-UNDER 1 TON	29	35	45	38	37	4.22
SEMI-TRAILER TRUCK	1	3	0	3	2	0.23
TANK TRUCK-FLAM LQD	3	0	3	8	4	0.46
FREIGHT RD TRANS, OTHER	1	1	0	1	1	0.11
WATER TRANSPORT	1	1	2	0	1	0.11
HEAVY EQUIPMENT	2	0	3	1	2	0.23
OTHER, INVALID CODE	3	3	2	6	4	0.46
BLANK	111	89	89	88	94	10.73
TOTAL	776	789	872	1068	876	100

NATIONWIDE PROJECTIONS

	1982	1983	1984	1985	AVERAGE	% OF TOTA
MOBILE PROP UNKNOWN	21	33	33	76	41	2
NOT APPLICABLE	1175	991	990	1058	1054	41
AUTOMOBILE	890	885	900	1100	944	37
TERRAIN VEHICLES	39	36	30	35	35	1
MOTOR HOME	25	9	16	25	19	1
PASS. ROAD TRANS, OTHER	18	15	3	8	11	0
TRUCK-OVER 1 TON	39	15	25	28	27	1
TRUCK-UNDER 1 TON	102	106	123	96	107	4
SEMI-TRAILER TRUCK	4	9	0	8	5	0
TANK TRUCK-FLAM LQD	11	0	8	20	10	0
FREIGHT RD TRANS, OTHER	4	3	0	3	2	0
WATER TRANSPORT	4	3	5	0	3	0
HEAVY EQUIPMENT	7	0	8	3	4	0
OTHER, INVALID CODE	11	9	5	15	10	0
BLANK	392	269	244	222	282	11
TOTAL	2739	2384	2392	2696	2553	100

APPENDIX III

TABLE 4
AREA OF FIRE ORIGIN

NFIRS DATA ONLY

	1982	1983	1984	1985	AVERAGE	% OF TOTA
MEANS OF EGRESS	8	8	6	13	9	1.00
ASSEMBLY/SALES AREAS	11	10	6	10	9	1.06
FUNCTION AREAS	27	26	30	22	26	3.00
STORAGE AREAS						
PRODUCT STORAGE ROOM	51	50	56	65	56	6.33
GARAGE/CARPORT/STORAGE	17	14	10	22	16	1.80
OTHER	12	12	15	13	13	1.48
SERVICE FACILITIES	35	45	35	56	43	4.88
SERVICE/EQUIPMENT AREAS						
MAINTENANCE SHOP/AREA	36	38	22	30	32	3.59
OTHER	15	9	11	7	11	1.20
NOT CLASSIFIED	55	58	64	73	63	7.13
STRUCTURE AREAS	8	12	7	12	10	1.11
TRANSPORT/VEHICLE AREA						
PASSENGER AREA	7	5	7	11	8	0.86
TRUNK AREA	3	7	3	8	5	0.60
ENGINE AREA	280	299	333	447	340	38.77
FUEL TANK	37	40	54	43	44	4.96
EXTERIOR SURFACE	3	5	12	14	9	0.97
NOT CLASSIFIED	6	11	9	8	9	0.97
OTHER						
HIGHWAY/PUBLIC WAY	49	41	55	67	53	6.05
LAWN/FIELD/OPEN AREA	14	12	24	16	17	1.88
NOT APPLICABLE	17	13	24	28	21	2.34
OTHER	[illegible]	71	89	103	88	10.01
TOTAL	776	789	872	1068	876	100.00

NATIONWIDE PROJECTIONS

	1982	1983	1984	1985	AVERAGE	% OF TOTA
MEANS OF EGRESS	28	24	16	33	25	1.00
ASSEMBLY/SALES AREAS	39	30	16	25	28	1.08
FUNCTION AREAS	95	79	82	56	78	3.05
STORAGE AREAS						
PRODUCT STORAGE ROOM	180	151	154	164	162	6.35
GARAGE/CARPORT/STORAGE	60	42	27	56	46	1.81
OTHER	42	36	41	33	38	1.49
SERVICE FACILITIES	124	136	96	141	124	4.87
SERVICE/EQUIPMENT AREAS						
MAINTENANCE SHOP/AREA	127	115	60	76	94	3.70
OTHER	53	27	30	18	32	1.25
NOT CLASSIFIED	194	175	176	184	182	7.14
STRUCTURE AREAS	28	36	19	30	28	1.12
TRANSPORT/VEHICLE AREA						
PASSENGER AREA	25	15	19	28	22	0.85
TRUNK AREA	11	21	8	20	15	0.59
ENGINE AREA	988	904	913	1128	983	38.52
FUEL TANK	131	121	148	109	127	4.98
EXTERIOR SURFACE	11	15	33	35	23	0.92
NOT CLASSIFIED	21	33	25	20	25	0.97
OTHER						
HIGHWAY/PUBLIC WAY	173	124	151	169	154	6.04
LAWN/FIELD/OPEN AREA	49	36	66	40	48	1.88
NOT APPLICABLE	60	3[illegible]	66	71	59	2.31
OTHER	300	224	244	260	257	10.06
TOTAL	2739	2384	2392	2696	2553	100.00

APPENDIX III

TABLE 5
EQUIPMENT INVOLVED IN IGNITION

NFIRS DATA ONLY

	1982	1983	1984	1985	AVERAGE	% OF TOTA
UNKNOWN	55	41	77	77	63	7.13
HEATING SYSTEMS	24	9	11	12	14	1.60
AIR COND/REFRIG EQUIPMENT	2	0	1	2	1	0.14
ELECTRIC DISTRIBUTION EQUIP						
FIXED WIRING	41	50	56	66	53	6.08
OTHER	29	34	17	21	25	2.88
APPLIANCES/EQUIPMENT	15	10	17	14	14	1.60
SPECIAL EQUIPMENT						
SEPRT PUMP/COMPRESSOR	83	73	84	105	86	9.85
INTERNAL COMBUST. ENGINE	43	48	39	70	50	5.71
OTHER	58	37	46	32	43	4.94
PROCESSING EQUIP	0	1	0	3	1	0.11
SERVICE/MAINT EQUIP	32	38	32	46	37	4.22
OTHER						
VEHICLE	184	236	250	286	239	27.28
NO EQUIPMENT INVOLVED	188	186	211	279	216	24.66
OTHER	14	12	16	42	21	2.40
BLANK	8	14	15	13	13	1.43
TOTAL	776	789	872	1068	876	100.00

NATIONWIDE PROJECTIONS

	1982	1983	1984	1985	AVERAGE	% OF TOTA
UNKNOWN	194	124	211	194	181	7.09
HEATING SYSTEMS	85	27	30	30	43	1.69
AIR COND/REFRIG EQUIPMENT	7	0	3	5	4	0.15
ELECTRIC DISTRIBUTION EQUIP						
FIXED WIRING	145	151	154	167	154	6.03
OTHER	102	103	47	53	76	2.98
APPLIANCES/EQUIPMENT	53	30	47	35	41	1.62
SPECIAL EQUIPMENT						
SEPRT PUMP/COMPRESSOR	293	221	230	265	252	9.88
INTERNAL COMBUST. ENGINE	152	145	107	177	145	5.68
OTHER	205	112	126	81	131	5.13
PROCESSING EQUIP	0	3	0	8	3	0.10
SERVICE/MAINT EQUIP	113	115	88	116	108	4.23
OTHER						
VEHICLE	650	713	686	722	693	27.13
NO EQUIPMENT INVOLVED	664	562	579	704	627	24.57
OTHER	49	36	44	106	59	2.31
BLANK	28	42	41	33	36	1.42
TOTAL	2739	2384	2392	2696	2553	100.00

APPENDIX III

TABLE 6
FORM OF HEAT IGNITION

NFIRS DATA ONLY

	1982	1983	1984	1985	AVERAGE	% OF TOTA
UNKNOWN	53	56	97	95	75	8.59
HEAT/FUEL-PWRD OBJECT						
SPARK/GAS FUELED EQP	34	31	43	48	39	4.45
HEAT/GAS FUELED EQP	26	24	18	39	27	3.05
SPARK/LIQ. FUELED EQP	49	41	35	41	42	4.74
HEAT/LIQ. FUELED EQP	49	46	50	63	52	5.94
OTHER	24	33	25	35	29	3.34
HEAT/ELEC. EQP. ARCING						
SHORT CIRCUIT	164	202	190	232	197	22.49
ARC-FAULTY CONTACT	28	14	25	24	23	2.60
ARC-SPARK FROM EQP/SWT	58	40	48	48	49	5.54
OTHER	10	9	6	10	9	1.00
HEAT/SMOKING MATERIAL	12	10	14	13	12	1.40
HEAT/OPEN FLAME, SPARK						
[illegible]	5	11	11	14	10	1.17
[illegible]	16	25	28	35	26	2.97
[illegible]	101	97	124	177	125	14.24
[illegible]	16	23	23	19	20	2.31
[illegible]						
[illegible]	37	[illegible]	53	42	44	4.97
[illegible]CAL EQUIPMENT	17	10	12	17	14	1.60
[illegible]	41	31	37	64	43	4.94
[illegible]	7	2	4	1	4	0.40
HEAT/NATURAL SOURCE	9	20	6	18	13	1.51
HEAT/FIRE SPREAD(EXPOSURE)	8	9	11	12	10	1.14
OTHER	5	6	7	11	7	0.83
BLANK	7	7	5	10	7	0.83
TOTAL	776	789	872	1068	876	100.00

NATIONWIDE PROJECTIONS

	1982	1983	1984	1985	AVERAGE	% OF TOTA
UNKNOWN	187	169	266	240	216	8.44
HEAT/FUEL-PWRD OBJECT						
SPARK/GAS FUELED EQP	120	94	118	121	113	4.43
HEAT/GAS FUELED EQP	92	73	49	98	78	3.06
SPARK/LIQ. FUELED EQP	173	124	96	103	124	4.86
HEAT/LIQ. FUELED EQP	173	139	137	159	152	5.96
OTHER	85	100	69	88	85	3.34
HEAT/ELEC. EQP. ARCING						
SHORT CIRCUIT	579	610	521	586	574	22.48
ARC-FAULTY CONTACT	99	42	69	61	68	2.65
ARC-SPARK FROM EQP/SWT	205	121	132	121	145	5.66
OTHER	35	27	16	25	26	1.02
HEAT/SMOKING MATERIAL	42	30	38	33	36	1.41
HEAT/OPEN FLAME, SPARK						
TORCHES	18	33	30	35	29	1.14
MATCH/LIGHTER	56	76	77	88	74	2.91
BACKFIRE FROM ENGINE	357	293	340	447	359	14.07
OTHER	56	70	63	48	59	2.32
HEAT/HOT OBJECT						
FRICTION	131	127	145	106	127	4.98
ELECTRICAL EQUIPMENT	60	30	33	43	42	1.63
OTHER	145	94	101	162	125	4.91
HEAT/EXPLOSIVE, FIREWKS	25	6	11	3	11	0.43
HEAT/NATURAL SOURCE	32	60	16	45	39	1.51

HEAT/[illegible]	[illegible]	60	16	[illegible]	39	1.51
HEAT/FIRE SPREAD(EXPOSURE)	28	27	30	30	29	1.13
OTHER	18	18	19	28	21	0.81
BLANK	25	21	14	25	21	0.83
TOTAL	2739	2384	2392	2696	2553	100.00

APPENDIX III

TABLE 7
FORM OF MATERIAL IGNITED

NFIRS DATA ONLY

	1982	1983	1984	1985	AVERAGE	% OF TOTA
UNKNOWN	6	4	3	4	4	0.49
STRUCTURE COMPONENT/FINISH	7	5	4	3	5	0.54
FURNITURE	0	1	2	1	1	0.11
CLOTHES	0	0	2	1	1	0.09
SUPPLIES/STOCK	6	1	3	1	3	0.31
POWER TRANS EQUIP/FUEL						
ELECTRICAL WIRE	17	13	15	20	16	1.86
FUEL	595	613	664	854	682	77.80
OTHER	1	6	3	3	3	0.37
RUBBISH/TRASH	2	1	0	1	1	0.11
SPECIAL FORM						
ATOMIZED/VAPORIZED LIQUID	14	8	13	11	12	1.31
GAS/LIQUID FROM PIPE	110	120	144	151	131	14.98
OTHER	1	1	1	0	1	0.09
OTHER	17	16	18	18	17	1.97
TOTAL	776	789	872	1068	876	100.00

NATIONWIDE PROJECTIONS

	1982	1983	1984	1985	AVERAGE	% OF TOTA
UNKNOWN	21	12	8	10	13	0.51
STRUCTURE COMPONENT/FINISH	25	15	11	8	15	0.57
FURNITURE	0	3	5	3	3	0.11
CLOTHES	0	0	5	3	2	0.08
SUPPLIES/STOCK	21	3	8	3	9	0.34
POWER TRANS EQUIP/FUEL						
ELECTRICAL WIRE	60	39	41	50	48	1.87
FUEL	2100	1852	1821	2155	1982	77.65
OTHER	4	18	8	8	9	0.37
RUBBISH/TRASH	7	3	0	3	3	0.12
SPECIAL FORM						
ATOMIZED/VAPORIZED LIQUID	49	24	36	28	34	1.34
GAS/LIQUID FROM PIPE	388	363	395	381	382	14.95
OTHER	4	3	3	0	2	0.09
OTHER	60	48	49	45	51	1.99
TOTAL	2739	2384	2392	2696	2553	100.00

APPENDIX III

TABLE 8
IGNITION FACTORS

NFIRS DATA ONLY

	1982	1983	1984	1985	AVERAGE	% OF TOTA
UNKNOWN	28	32	55	50	41	4.71
INCENDIARY	18	15	21	24	20	2.23
SUSPICIOUS	2	10	7	9	7	0.80
MISUSE OF HEAT IGNITION					0	0.00
ABANDONED MATERIAL	8	7	9	9	8	0.94
CUTTING/WELDING	5	9	11	9	9	0.97
OTHER	6	11	17	12	12	1.31
MISUSE OF MATERIAL IGNITED					0	0.00
FUEL SPILLED ACCIDENT	82	76	80	103	85	9.73
IMPROPER FUELING TECHNIQUE	22	24	29	41	29	3.31
WASH/CLEAN/PAINT PART	10	4	5	9	7	0.80
OTHER	16	16	15	20	17	1.91
MECH. FAILURE/MALFUNCTION					0	0.00
PART FAILURE/LEAK/BREAK	135	147	144	209	159	18.12
SHORT CIRCUIT/GROUND FAULT	27	23	25	37	28	3.20
OTHER ELECTRICAL FAILURE	5	9	10	10	9	0.97
LACK OF MAINTENANCE	6	10	7	12	9	1.00
BACKFIRE	103	95	115	146	115	13.10
OTHER MECHANICAL FAILURE	25	16	16	20	19	2.20
OTHER	0	1	3	3	2	0.20
DESIGN/CONSTRCT/INSTAL DEFICIENCY	16	11	7	14	12	1.37
OPERATIONAL DEFICIENCY					0	0.00
COLLISION/OVERTURN/KNOCKDOWN	202	225	236	274	234	26.74
OTHER	34	18	36	23	28	3.17
NATURAL CONDITIONS/WINDS	10	8	4	3	6	0.71
OTHER	16	22	20	31	22	2.54
TOTAL	776	789	872	1068	876	100.00

NATIONWIDE PROJECTIONS

	1982	1983	1984	1985	AVERAGE	% OF TOTA
UNKNOWN	99	97	151	126	118	4.63
INCENDIARY	64	45	58	61	57	2.22
SUSPICIOUS	7	30	19	23	20	0.78
MISUSE OF HEAT IGNITION						
ABANDONED MATERIAL	28	21	25	23	24	0.95
CUTTING/WELDING	18	27	30	23	24	0.96
OTHER	21	33	47	30	33	1.29
MISUSE OF MATERIAL IGNITED						
FUEL SPILLED ACCIDENT	289	230	219	260	250	9.78
IMPROPER FUELING TECHNIQUE	78	73	80	103	83	3.26
WASH/CLEAN/PAINT PART	35	12	14	23	21	0.82
OTHER	56	48	41	50	49	1.92
MECH. FAILURE/MALFUNCTION						
PART FAILURE/LEAK/BREAK	477	444	395	528	461	18.05
SHORT CIRCUIT/GROUND FAULT	95	70	69	93	82	3.20
OTHER ELECTRICAL FAILURE	18	27	27	25	24	0.95
LACK OF MAINTENANCE	21	30	19	30	25	0.99
BACKFIRE	364	287	315	369	334	13.07
OTHER MECHANICAL FAILURE	88	48	44	50	58	2.26
OTHER	0	3	8	8	5	0.18
DESIGN/CONSTRCT/INSTAL DEFICIENCY	56	33	19	35	36	1.41
OPERATIONAL DEFICIENCY						
COLLISION/OVERTURN/KNOCKDOWN	713	680	647	692	683	26.75
OTHER	120	54	99	58	83	3.24
NATURAL CONDITIONS/WINDS	35	24	11	8	20	0.76
OTHER	56	66	55	78	64	2.51
TOTAL	2739	2384	2392	2696	2553	100.00

APPENDIX III

TABLE 9
CALIFORNIA SERVICE STATION FIRES

NFIRS DATA ONLY

	1982	1983	1984	AVERAGE
INCIDENTS	89	74	71	78
SERVICE INJURIES	0	0	0	0
OTHER INJURIES	2	4	6	4
SERVICE DEATHS	0	0	0	0
OTHER DEATHS	0	0	1	0
STRUCTURE FIRES	14	20	18	17
MOBILE FIRES	28	17	13	19
OTHER FIRES	47	37	40	41
EST. DOLLAR LOSS	223973	239995	313501	259156

CALIFORNIA PROJECTIONS

	1982	1983	1984	AVERAGE
INCIDENTS	99	82	79	87
SERVICE INJURIES	0	0	0	0
OTHER INJURIES	2	4	7	4
SERVICE DEATHS	0	0	0	0
OTHER DEATHS	0	0	1	0
STRUCTURE FIRES	16	22	20	19
MOBILE FIRES	31	19	14	21
OTHER FIRES	52	41	44	46
EST. DOLLAR LOSS	248610	266394	347986	287664

APPENDIX III

TABLE 10
TYPE OF SITUATION FOUND

CALIFORNIA NFIRS DATA ONLY

	1982	1983	1984	AVERAGE	% OF TOTAL
STRUCTURE FIRE	14	20	18	17	22.22
OUTSIDE OF STRUCTURE FIRE	26	23	20	23	29.49
VEHICLE FIRE	28	17	13	19	24.79
BRUSH FIRE	1	0	0	0	0.43
[illegible]E FIRE	1	2	0	1	1.28
[illegible]ION (W/O FIRE)	2	1	1	1	1.71
[illegible]DE SPILL/LEAK	0	0	0	0	0.00
[illegible]FICIENT INFO	0	0	0	0	0.00
OTHER	17	11	19	16	20.09
TOTAL	89	74	71	78	100.00

CALIFORNIA PROJECTIONS

	1982	1983	1984	AVERAGE	% OF TOTAL
STRUCTURE FIRE	16	22	20	19	22.22
OUTSIDE OF STRUCTURE FIRE	29	26	22	26	29.49
VEHICLE FIRE	31	19	14	21	24.79
BRUSH FIRE	1	0	0	0	0.43
REFUSE FIRE	1	2	0	1	1.28
EXPLOSION (W/O FIRE)	2	1	1	1	1.71
OUTSIDE SPILL/LEAK	0	0	0	0	0.00
INSUFFICIENT INFO	0	0	0	0	0.00
OTHER	19	12	21	17	20.09
TOTAL	99	82	79	87	100.00

APPENDIX III

TABLE 11
AREA OF FIRE ORIGIN

CALIFORNIA NFIRS DATA ONLY

	1982	1983	1984	AVERAGE	% OF TOTA
MEANS OF EGRESS	1	1	1	1	1.28
ASSEMBLY/SALES AREAS	1	1	2	1	1.71
FUNCTION AREAS	3	5	5	4	5.56
STORAGE AREAS					
PRODUCT STORAGE ROOM	3	3	5	4	4.70
GARAGE/CARPORT/STORAGE	2	2	2	2	2.56
OTHER	2	3	6	4	4.70
SERVICE FACILITIES	4	6	4	5	5.98
SERVICE/EQUIPMENT AREAS					
MAINTENANCE SHOP/AREA	3	5	2	3	4.27
OTHER	1	3	1	2	2.14
NOT CLASSIFIED	16	13	16	15	19.23
STRUCTURE AREAS	3	2	3	3	3.42
TRANSPORT/VEHICLE AREA					
PASSENGER AREA	0	1	0	0	0.43
TRUNK AREA	0	0	0	0	0.00
[illegible] AREA	21	14	12	16	20.09
[illegible]	6	1	1	3	3.42
[illegible] SURFACE	0	0	0	0	0.00
[illegible]	1	2	2	2	2.14
[illegible]					
HIGHWAY/PUBLIC WAY	8	2	1	4	4.70
LAWN/FIELD/OPEN AREA	4	4	4	4	5.13
NOT APPLICABLE	7	5	4	5	6.84
OTHER	2	1	0	1	1.71
TOTAL	89	74	71	78	100.00

CALIFORNIA PROJECTIONS

	1982	1983	1984	AVERAGE	% OF TOTA
MEANS OF EGRESS	1	1	1	1	1.28
ASSEMBLY/SALES AREAS	1	1	2	1	1.70
FUNCTION AREAS	3	6	6	5	5.53
STORAGE AREAS					
PRODUCT STORAGE ROOM	3	3	6	4	4.68
GARAGE/CARPORT/STORAGE	2	2	2	2	2.55
OTHER	2	3	7	4	4.68
SERVICE FACILITIES	4	7	4	5	5.95
SERVICE/EQUIPMENT AREAS					
MAINTENANCE SHOP/AREA	3	6	2	4	4.25
OTHER	1	3	1	2	2.13
NOT CLASSIFIED	18	14	18	17	19.14
STRUCTURE AREAS	3	2	3	3	3.40
TRANSPORT/VEHICLE AREA					
PASSENGER AREA	0	1	0	0	0.43
TRUNK AREA	0	0	0	0	0.00
ENGINE AREA	23	16	13	17	19.99
FUEL TANK	7	1	1	3	3.40
EXTERIOR SURFACE	0	0	0	0	0.00
NOT CLASSIFIED	1	2	2	2	2.13
OTHER					
HIGHWAY/PUBLIC WAY	9	2	1	4	4.68
LAWN/FIELD/OPEN AREA	4	4	4	4	5.10
NOT APPLICABLE	8	6	4	6	6.80
OTHER	3	1	0	1	1.70
TOTAL	99	82	79	87	100.00

APPENDIX III

TABLE 12
EQUIPMENT INVOLVED IN IGNITION

CALIFORNIA NFIRS DATA ONLY

	1982	1983	1984	AVERAGE	% OF TOTA
UNKNOWN	7	0	4	4	4.70
HEATING SYSTEMS	3	1	0	1	1.71
AIR COND/REFRIG EQUIPMENT	0	0	0	0	0.00
ELECTRIC DISTRIBUTION EQUIP					
FIXED WIRING	10	20	13	14	18.38
OTHER	4	5	2	4	4.70
APPLIANCES/EQUIPMENT	3	1	2	2	2.56
SPECIAL EQUIPMENT					
SEPRT PUMP/COMPRESSOR	2	1	1	1	1.71
INTERNAL COMBUST. ENGINE	9	10	4	8	9.83
OTHER	4	4	6	5	5.98
PROCESSING EQUIP	0	0	0	0	0.00
SERVICE/MAINT EQUIP	3	2	2	2	2.99
OTHER					
VEHICLE	21	15	18	18	23.08
NO EQUIPMENT INVOLVED	21	15	19	18	23.50
OTHER	2	0	0	1	0.85
BLANK	0	0	0	0	0.00
TOTAL	89	74	71	78	100.00

CALIFORNIA PROJECTIONS

	1982	1983	1984	AVERAGE	% OF TOTA
UNKNOWN	8	0	4	4	4.68
HEATING SYSTEMS	3	1	0	1	1.70
AIR COND/REFRIG EQUIPMENT	0	0	0	0	0.00
ELECTRIC DISTRIBUTION EQUIP					
FIXED WIRING	11	22	14	16	18.29
OTHER	4	6	2	4	4.68
APPLIANCES/EQUIPMENT	3	1	2	2	2.55
SPECIAL EQUIPMENT					
SEPRT PUMP/COMPRESSOR	2	1	1	1	1.70
INTERNAL COMBUST. ENGINE	10	11	4	9	9.78
OTHER	4	4	7	5	5.95
PROCESSING EQUIP	0	0	0	0	0.00
SERVICE/MAINT EQUIP	3	2	2	3	2.98
OTHER					
VEHICLE	23	17	20	20	22.97
NO EQUIPMENT INVOLVED	23	17	21	20	23.39
OTHER	2	0	0	1	0.85
BLANK	0	0	0	0	0.00
TOTAL	99	82	79	87	100.00

APPENDIX III

TABLE 13
FORM OF HEAT IGNITION

CALIFORNIA NFIRS DATA ONLY

	1982	1983	1984	AVERAGE	% OF TOTA
UNKNOWN	6	0	7	4	5.56
HEAT/FUEL-PWRD OBJECT					
SPARK/GAS FUELED EQP	2	0	0	1	0.85
HEAT/GAS FUELED EQP	4	0	0	1	1.71
SPARK/LIQ. FUELED EQP	5	4	3	4	5.13
HEAT/LIQ. FUELED EQP	6	3	2	4	4.70
OTHER	1	2	0	1	1.28
HEAT/ELEC. EQP. ARCING					
SHORT CIRCUIT	18	30	20	23	29.06
ARC-FAULTY CONTACT	1	4	3	3	3.42
ARC-SPARK FROM EQP/SWT	6	7	4	6	7.26
OTHER	2	2	0	1	1.71
HEAT/SMOKING MATERIAL	3	0	1	1	1.71
HEAT/OPEN FLAME, SPARK					
TORCHES	0	0	1	0	0.43
MATCH/LIGHTER	4	5	5	5	5.98
BACKFIRE FROM ENGINE	6	3	3	4	5.13
OTHER	3	3	4	3	4.27
HEAT/HOT OBJECT					
FRICTION	8	8	9	8	10.68
ELECTRICAL EQUIPMENT	0	0	0	0	0.00
OTHER	8	1	4	4	5.56
HEAT/EXPLOSIVE, FIREWKS	4	1	3	3	3.42
HEAT/NATURAL SOURCE	1	0	1	1	0.85
HEAT/FIRE SPREAD (EXPOSURE)	1	0	1	1	0.85
OTHER	0	0	0	0	0.00
BLANK	0	1	0	0	0.43
TOTAL	89	74	71	78	100.00

CALIFORNIA PROJECTIONS

	1982	1983	1984	AVERAGE	% OF TOTA
UNKNOWN	7	0	8	5	5.53
HEAT/FUEL-PWRD OBJECT					
SPARK/GAS FUELED EQP	2	0	0	1	0.85
HEAT/GAS FUELED EQP	4	0	0	1	1.70
SPARK/LIQ. FUELED EQP	6	4	3	4	5.10
HEAT/LIQ. FUELED EQP	7	3	2	4	4.68
OTHER	1	2	0	1	1.28
HEAT/ELEC. EQP. ARCING					
SHORT CIRCUIT	20	33	22	25	28.92
ARC-FAULTY CONTACT	1	4	3	3	3.40
ARC-SPARK FROM EQP/SWT	7	8	4	6	7.23
OTHER	2	2	0	1	1.70
HEAT/SMOKING MATERIAL	3	0	1	1	1.70
HEAT/OPEN FLAME, SPARK					
TORCHES	0	0	1	0	0.43
MATCH/LIGHTER	4	6	6	5	5.95
BACKFIRE FROM ENGINE	7	3	3	4	5.10
OTHER	3	3	4	4	4.25
HEAT/HOT OBJECT					
FRICTION	9	9	10	9	10.63
ELECTRICAL EQUIPMENT	0	0	0	0	0.00
OTHER	9	1	4	5	5.53
HEAT/EXPLOSIVE, FIREWKS	4	1	3	3	3.40
HEAT/NATURAL SOURCE	1	0	1	1	0.85
HEAT/FIRE SPREAD (EXPOSURE)	1	0	1	1	0.85
OTHER	0	0	0	0	0.00
BLANK	0	1	0	0	0.43
TOTAL	99	82	79	87	100.00

TABLE 14
FORM OF MATERIAL IGNITED

CALIFORNIA NFIRS DATA ONLY

	1982	1983	1984	AVERAGE	% OF TOTA
UNKNOWN	0	0	0	0	0.00
STRUCTURE COMPONENT/FINISH	0	1	1	1	0.85
FURNITURE	0	0	0	0	0.00
CLOTHES	0	0	0	0	0.00
SUPPLIES/STOCK	0	0	2	1	0.85
POWER TRANS EQUIP/FUEL					
ELECTRICAL WIRE	0	0	0	0	0.00
FUEL	78	63	58	66	85.04
OTHER	0	0	0	0	0.00
RUBBISH/TRASH	0	1	0	0	0.43
SPECIAL FORM					
ATOMIZED/VAPORIZED LIQUID	2	0	1	1	1.28
GAS/LIQUID FROM PIPE	9	9	8	9	11.11
OTHER	0	0	0	0	0.00
OTHER	0	0	1	0	0.43
TOTAL	89	74	71	78	100.00

CALIFORNIA PROJECTIONS

	1982	1983	1984	AVERAGE	% OF TOTA
UNKNOWN	0	0	0	0	0.00
STRUCTURE COMPONENT/FINISH	0	1	1	1	0.85
FURNITURE	0	0	0	0	0.00
CLOTHES	0	0	0	0	0.00
SUPPLIES/STOCK	0	0	2	1	0.85
POWER TRANS EQUIP/FUEL					
ELECTRICAL WIRE	0	0	0	0	0.00
FUEL	87	70	64	74	84.63
OTHER	0	0	0	0	0.00
RUBBISH/TRASH	0	1	0	0	0.43
SPECIAL FORM					
ATOMIZED/VAPORIZED LIQUID	2	0	1	1	1.28
GAS/LIQUID FROM PIPE	10	10	9	10	11.06
OTHER	0	0	0	0	0.00
OTHER	0	0	1	0	0.43
TOTAL	[illegible]	82	79	87	100.00

APPENDIX III

TABLE 15
IGNITION FACTORS

CALIFORNIA NFIRS DATA ONLY

	1982	1983	1984	AVERAGE	% OF TOTA
UNKNOWN	3	1	1	2	2.14
INCENDIARY	10	4	7	7	8.97
SUSPICIOUS	1	2	2	2	2.14
MISUSE OF HEAT IGNITION					
ABANDONED MATERIAL	2	0	1	1	1.28
CUTTING/WELDING	0	0	0	0	0.00
OTHER	1	6	0	2	2.99
MISUSE OF MATERIAL IGNITED					
FUEL SPILLED ACCIDENT	6	5	10	7	8.97
IMPROPER FUELING TECHNIQUE	4	3	1	3	3.42
WASH/CLEAN/PAINT PART	0	0	0	0	0.00
OTHER	1	0	1	1	0.85
MECH. FAILURE/MALFUNCTION					
PART FAILURE/LEAK/BREAK	16	12	10	13	16.24
SHORT CIRCUIT/GROUND FAULT	0	3	1	1	1.71
OTHER ELECTRICAL FAILURE	0	0	1	0	0.43
LACK OF MAINTENANCE	2	1	1	1	1.71
BACKFIRE	0	0	0	0	0.00
OTHER MECHANICAL FAILURE	6	1	1	3	3.42
OTHER	0	0	1	0	0.43
DESIGN/CONSTRCT/INSTAL DEFICIENCY	3	1	1	2	2.14
OPERATIONAL DEFICIENCY					
COLLISION/OVERTURN/KNOCKDOWN	25	33	27	28	36.32
OTHER	5	1	4	3	4.27
NATURAL CONDITIONS/WINDS	0	0	0	0	0.00
OTHER	4	1	1	2	2.56
TOTAL	89	74	71	78	100.00

CALIFORNIA PROJECTIONS

	1982	1983	1984	AVERAGE	% OF TOTA
UNKNOWN	3	1	1	2	2.13
INCENDIARY	11	4	8	8	8.93
SUSPICIOUS	1	2	2	2	2.13
MISUSE OF HEAT IGNITION					
ABANDONED MATERIAL	2	0	1	1	1.28
CUTTING/WELDING	0	0	0	0	0.00
OTHER	1	7	0	3	2.98
MISUSE OF MATERIAL IGNITED					
FUEL SPILLED ACCIDENT	7	6	11	8	8.93
IMPROPER FUELING TECHNIQUE	4	3	1	3	3.40
WASH/CLEAN/PAINT PART	0	0	0	0	0.00
OTHER	1	0	1	1	0.85
MECH. FAILURE/MALFUNCTION					
PART FAILURE/LEAK/BREAK	18	13	11	14	16.16
SHORT CIRCUIT/GROUND FAULT	0	3	1	1	1.70
OTHER ELECTRICAL FAILURE	0	0	1	0	0.43
LACK OF MAINTENANCE	2	1	1	1	1.70
BACKFIRE	0	0	0	0	0.00
OTHER MECHANICAL FAILURE	7	1	1	3	3.40
OTHER	0	0	1	0	0.43
DESIGN/CONSTRCT/INSTAL DEFICIENCY	3	1	1	2	2.13
OPERATIONAL DEFICIENCY					
COLLISION/OVERTURN/KNOCKDOWN	28	37	30	31	36.15
OTHER	6	1	4	4	4.25
NATURAL CONDITIONS/WINDS	0	0	0	0	0.00
OTHER	4	1	1	2	2.55
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]