Hazardous Material Releases due to Unsecured Openings and Lining Failures

U.S Department of Transportation
Federal Railroad Administration

Office of Research and Development
Washington DC 20590

Volume I

Arthur D. Little, Inc.
Acorn Park
Cambridge MA 02140

DOT/FRA/ORD-91/01

December 1990
Final Report

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Technical Report Documentation Page

1. Report No. DOT/FRA/ORD-91/01	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Hazardous Material Releases due to Unsecured Openings and Lining Failures		5. Report Date December 1990
		6. Performing Organization Code
7. Author(s) T.J. Rasmussen, A.B. Boghani and J.E.S. Venart		8. Performing Organization Report No.
9. Performing Organization Name and Address Arthur D. Little, Inc. Acorn Park Cambridge, MA 02140		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFR-53-87-C-00035
12. Sponsoring Agency Name and Address Federal Railroad Administration Office of Research and Development 400 Seventh Street, S.W. Washington, DC 20590		13. Type of Report and Period Covered Final Report 11/29/88-12/31/90
		14. Sponsoring Agency Code RRS-20

15. Supplementary Notes

16. Abstract

In response to the large number of unintentional releases of hazardous materials from railroad tank cars for which accidents were not the cause, the Federal Railroad Administration (FRA) initiated this study to (1) recommend procedures to ensure that tank car appurtenances are properly maintained and secured, (2) develop and recommend cost effective procedures for monitoring and controlling tank car corrosion, and (3) investigate the issue of excess flow valves on propane cars not operating properly when the valve above it is sheared off. Leaks due to frangible disk failure were not included in the scope of this study.

The study included review of all relevant literature, analysis of FRA Hazardous Material Inspector's reports, analysis of the Hazardous Materials Information System (HMIS) database maintained by the Research and Special Programs Administration (RSPA), and visits to tank car loading/unloading facilities and repair facilities. In addition, the University of New Brunswick conducted tests of Emergency Shut-off Valve (ESV) equipped propane cars.

17. Key Words Hazardous Materials, Tank Cars, Excess Flow Valve, Emergency Shut-off Valve, Tank Car Liner Failure, Corrosion Leaks, Unsecured Openings		18. Distribution Statement	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0		1		2		3		4		5		6		7		8		9							10
CENTIMETERS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25 / 25.40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

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Acknowledgements

The assistance of the following individuals and organizations was essential to the satisfactory completion of this work.

Mr. Bob Andre, T/C Therapy

Mr. Samuel E. Bates, E.I. DuPont De Nemours & Company

Mr. Donald J. Brown, Occidental Chemical Corporation

Futura Coatings, Inc.

Mr. James D. Jarvis, Association of American Railroads

Mr. Charles M. Jugla, Rohm and Haas Delaware Valley Inc.

Mr. P.G. Kinnecom, Association of American Railroads

Mr. Alton B. Lanier, The Texas A&M University System

Mr. Thomas S. Lapikas, General American Transportation Corporation

Master Corporal Beaubien, CFB Gagetown

Mr. D.J. Doucet, Training Officer, Atlantic Speedy Propane Ltd.

Captain J. Fraser, Combat Training Centre, CFB Gagetown

Mr. G. Heuchan, Procor Ltd.

Mr. P.L. Landry, Fire and Safety Co-ordinator, Irving Oil Limited

Brigadier General L.W. MacKenzie, CFB Gagetown

Mr. T. McQuinn, Engineer, Atlantic Speedy Propane Ltd.

Mr. E. Nickerson, Safety and Training Co-ordinator, RST Industries

Mr. C. Snow, Technical Supervisor, Atlantic Speedy Propane Ltd.

Mr. B.J. Stewart, Manager, Eastern Region, EMCO-Wheaton Ltd.

Mr. L. Webb, Coleson Cove Generating Station

1. Introduction

A large number of hazardous material releases take place every year due to causes other than derailments or collisions. While these releases are generally not very large, they still pose a threat to the safety of railroad personnel, employees of shippers, emergency response personnel, people living along the tracks and the environment.

The objective of Task Order No. 3, issued under Contract DTFR53-87-C-00035 was to examine three types of such releases:

- Those caused by loose or defective fittings, valves and closures,
- Those due to lining failures, and
- Those attributed to excess flow valves on propane cars.

For the first two types of releases, the detailed objectives were:

- To determine, through the study of data pertaining to the leaks, if the fault lies with the shipper of the commodity or if the problem lies in equipment design. This may involve making recommendations for further rulemaking on procedures used in handling the tank cars in hazardous materials transportation.
- To develop and recommend cost-effective procedures for monitoring and controlling leaks due to tank car corrosion.

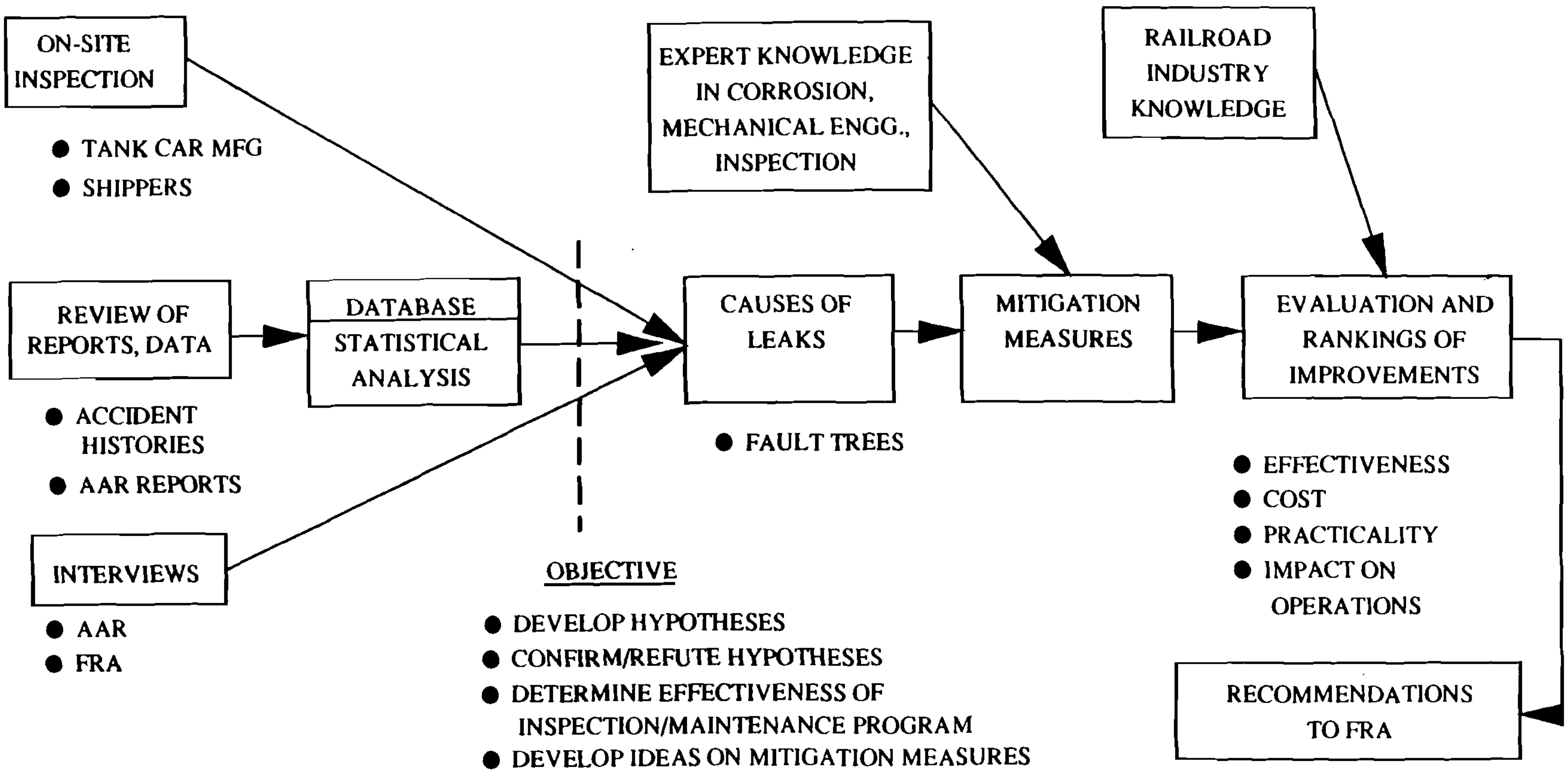
The third type of leak was to be examined through a full-scale test program.

This report summarizes the procedure used in performing the work and the results of the study. The general approach is described in Figure 1-1. As shown, we used several data sources, complemented by face-to-face interviews, to develop and confirm hypotheses on causes of the leaks attributed to loose or defective fittings, valves or closures, or to lining failures. We also developed a list of potential mitigation measures and created a ranking of the measures based on a preliminary evaluation of the effectiveness and cost.

The second chapter of this document summarizes the results of a comprehensive review of reports performed by us; the third chapter deals with analysis of causes of leaks; the fourth with mitigation measures, and the fifth with excess flow valves on propane cars. Finally, the sixth chapter provides conclusions and recommendations.

Figure 1-1

SUMMARY OF APPROACH



2. Review of Reports

The primary sources for data pertaining to the releases of interest were the Incident Reports for acid cars submitted to the FRA's Office of Safety Enforcement by the FRA's Hazardous Material Inspectors and several reports from the AAR on this subject. In addition, a literature search was conducted to identify any other relevant articles or reports pertaining to this subject.

After the review of the FRA and AAR materials we conducted an analysis of the Hazardous Materials Information System (HMIS) maintained by the Research and Special Programs Administration (RSPA). This data base includes reports of tank car leaks due to valves, fittings, and tank car lining failures. It was used in this study to further substantiate the characterization of hazmat releases due to unsecured openings and lining failures. Additionally, data on shippers and carriers frequently involved in the release of hazardous materials were extracted to identify any patterns. The complete analysis is included in section 2.6 of this report.

Our information search included talking to a number of people familiar with this problem, including pertinent staff members from the AAR, shipper community, and a tank car maintenance facility. In addition, we inspected a couple of tank cars that had suffered from corrosion leaks and attended a one-day training program for tank car safety. We also accompanied a FRA Hazardous Materials inspector on visits to large chemical production facilities to observe and interview the people responsible for loading and securing the tank cars. The findings from these other information gathering activities will be described in later chapters.

The following subsections briefly describe the contents of the reports we reviewed and discuss the most relevant information obtained from this review.

2.1 FRA Reports

A review was made of all FRA incident reports supplied to Arthur D. Little, Inc. There was 1 from 1984, 41 from 1985, 41 from 1986, zero from 1987, and 29 from 1988 which contained information about leaks. There were also 40 in which a shipper or carrier was cited for violating one or more parts of CFR 49. In most of these cases the car was not properly secured while containing residue, and no leak occurred.

A database has been compiled from the Hazardous Materials release reports provided by the Federal Railroad Administration. It is maintained on the PC package: KNOWLEDGEMAN. The fields on the data base and the frequency with which the information was provided or could be derived are listed in Table 2-1. It is presented by year (1984, 85, 86, and 88; no reports from 1987 were included in the data set). The top half of the page shows the number of reports for a given year and the number of times each of the fields was formatted. The lower portion depicts the same information except that the percentage of reports providing the information is displayed rather than the number of reports.

It is important to note that out of the 132 incident reports, only 92 are reports of actual leaks. The remaining 40 are reports of cars in violation of Federal regulations, for example, a car containing the residue of a hazardous material which has been offered for transportation while not properly secured.

These tables show that **even with improvements in the quality of incident reporting, there are still significant amounts of information which cannot be derived from the information provided**, notably, the age of the car and the age of the liner, both of which are marked on the car.

Additionally, the type of car is only provided in approximately three quarters of the reports.

The fields marked "primary cause" and "secondary cause" are not so much causes as the circumstance(s) under which the car leaked or was found to be in violation of Federal regulation.

An examination of the data provided in the FRA reports reveals that seventeen different hazardous materials were released during these incidents. Five commodities comprise 76.1% of the leak incidents and 90.0% of the non-leak incidents. More importantly, three materials were involved in 58 of the 92 leak incidents (see Table 2-2) and 20 of the forty non-leak incidents. These materials represent nearly 60% of all incidents. When the incidents involving sodium hydroxide are included, over 75% of all incidents involved just four commodities; all of them corrosive materials. These statistics are represented in Table 2-3.

The causes of the incidents can be divided into the following categories:

Unsecured openings 52 incidents
- -loose bolts on covers
- -loose plugs and caps
- -disassembled safety vents

Gasket failure 26 incidents
- -defective
- -damaged
- -dislodged

Corrosion 25 incidents
- -failure of the rubber liner

Other unknown cause 8 incidents

Almost half of the leak incidents involved two types of hazardous materials. Hydrochloric acid was released in 27.2% of the 92 incidents while phosphoric acid was released in 20.7%. Of these two commodities, 31.7% were released due to corrosion, 50% due to unsecured openings, and 18.3% due to gasket failures.

Figure 2-1 is a time series of release incidents by the location on the car where the leak occurred. This figure shows that most of the leaks occurred at the manway of the tank car. Also, of the 94 cars identified by car type, 88.3% were DOT 111 class tank cars. Table 2-4 depicts the number of cars identified by type.

Table 2-1

Frequency with which field is formatted by year (Count)

Field	1984	1985	1986	1988	Total
Reported Incidents	1	31	36	64	132
Date	1	31	36	64	132
Hour	1	20	29	36	86
Car Number	1	31	36	64	132
Type of Car	0	22	28	44	94
Age of Liner	0	4	7	0	11
Age of Car	0	6	4	9	19
Days since Inspct'd	0	2	1	0	3
Commodity Type	1	31	35	59	126
Number of Holes	1	30	35	13	79
Size of Hole	0	6	8	0	14
Horiz. Leak Position	1	20	34	64	119
Vert. Leak Position	1	21	34	64	120
Car Fixture Leaking	1	31	36	64	132
When/How Discovered	1	25	36	64	126
Primary Cause	1	31	36	64	132
Secondary Cause	0	20	23	23	66
Owner of Car	1	31	33	64	129
Operator of Train	0	20	26	51	97
Additional Notes	1	15	15	58	89

Table 2-2

Frequency with which field is formatted by year(%)

Field	1984	1985	1986	1988	Total
Car Number	100.0%	100.0%	100.0%	100.0%	100.0%
Type of Car	0.0%	71.0%	77.8%	68.8%	71.2%
Age of Liner	0.0%	12.9%	19.4%	0.0%	8.3%
Age of Car	0.0%	19.4%	11.1%	14.1%	14.4%
Days since Inspct'd	0.0%	6.5%	2.8%	0.0%	2.3%
Commodity Type	100.0%	100.0%	97.2%	92.2%	95.5%
Number of Holes	100.0%	96.8%	97.2%	20.3%	59.8%
Size of Hole	0.0%	19.4%	22.2%	0.0%	10.6%
Horiz. Leak Position	100.0%	64.5%	94.4%	100.0%	90.2%
Vert. Leak Position	100.0%	67.7%	94.4%	100.0%	90.9%
Car Fixture Leaking	100.0%	100.0%	100.0%	100.0%	100.0%
When/How Discovered	100.0%	80.6%	100.0%	100.0%	95.5%
Primary Cause	100.0%	100.0%	100.0%	100.0%	100.0%
Secondary Cause	0.0%	64.5%	63.9%	35.9%	50.0%
Owner of Car	100.0%	100.0%	91.7%	100.0%	97.7%
Operator of Train	0.0%	64.5%	72.2%	79.7%	73.5%
Additional Notes	100.0%	48.4%	41.7%	90.6%	67.4%

Table 2-3

Leak Occurrence by HAZMAT

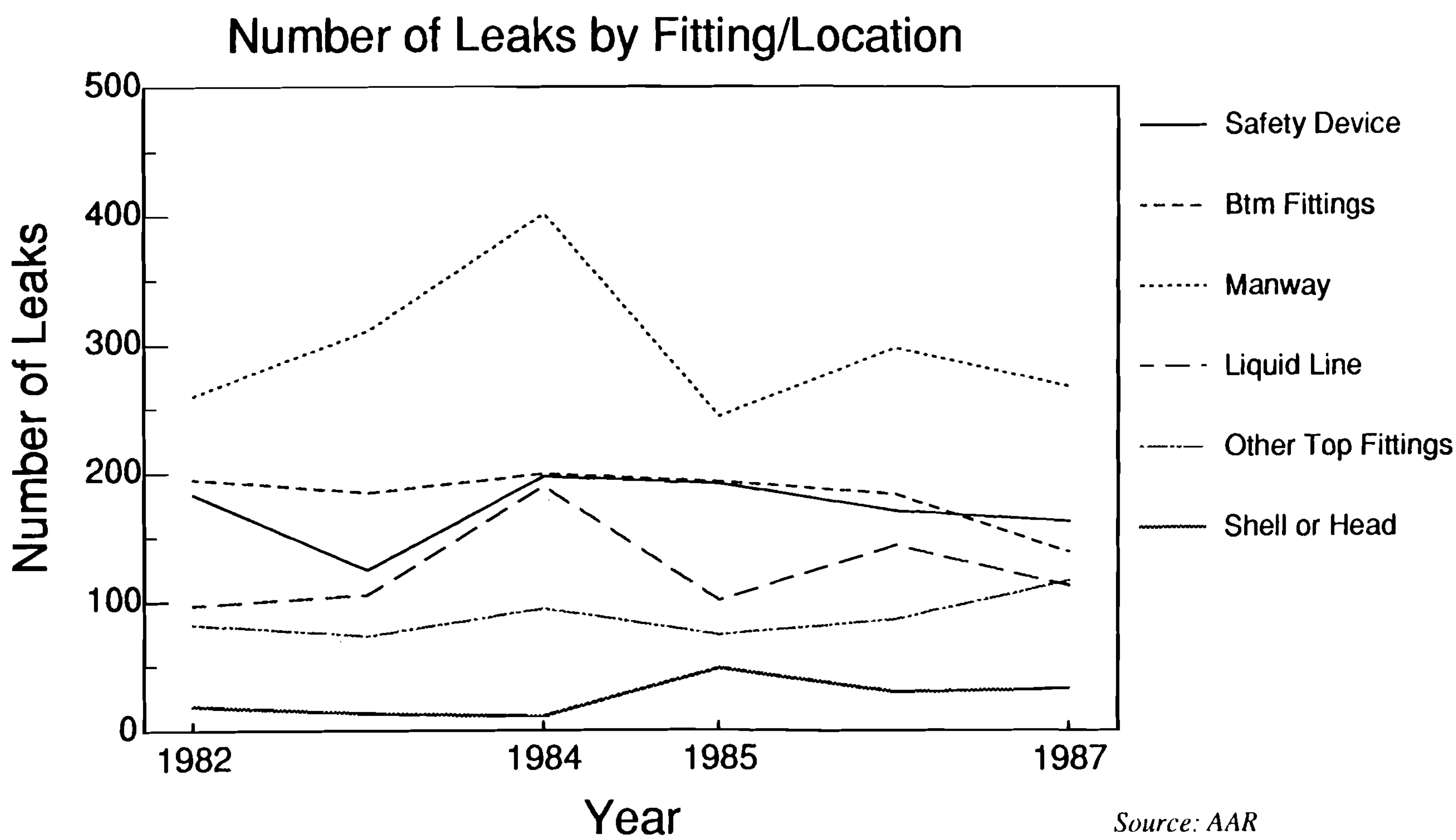
	Leak Occurred		No Leak Occurred		Total	
	Count	Percent	Count	Percent	Count	Percent
Corrosive Liquid, N.O.S.	8	8.7%	0	0.0%	8	6.1%
Hydrochloric Acid	25	27.2%	3	7.5%	28	21.2%
Phosphoric Acid	19	20.7%	11	27.5%	30	22.7%
Sodium Hydroxide	4	4.3%	16	40.0%	20	15.2%
Sufuric Acid	14	15.2%	6	15.0%	20	15.2%
Total for 5 Commodities	70	76.1%	36	90.0%	106	80.3%
Others	22	23.9%	4	10.0%	26	19.7%
Total	92	100.0%	40	100.0%	132	100.0%

Table 2-4

Leak Occurrence by Car Type

	Leak Occurred		No Leak Occurred		Total	
	Count	Percent	Count	Percent	Count	Percent
DOT Class 103	2	3.0%	1	3.6%	3	3.2%
DOT Class 105	1	1.5%	0	0.0%	1	1.1%
DOT Class 111	56	84.8%	27	96.4%	83	88.3%
DOT Class 112	0	0.0%	0	0.0%	0	0.0%
AAR Class 206	7	10.6%	0	0.0%	7	7.4%
Total	66	100.0%	28	100.0%	94	100.0%

Figure 2-1



Source: AAR

2.2 AAR Reports

Three reports published by the Association of American Railroads were reviewed:

- "Report of Railroad Tank Car Leaks of Hazardous Materials by Commodity By Source of Leak for the Year 1987"
- "Association of American Railroads Hazardous-Materials Systems, Hazardous Materials Statistics 1987"
- "Statistical Trends in Railroad Hazardous Materials Transportation Safety 1978 to 1986", Publication R-640

The first report details the number of leaks by commodity by type of leak for the calendar year 1987. It also contains the number of tank car movements for that commodity in that year to derive rate of release for the commodity. This is compared to the rate for calendar year 1986.

The data are grouped by hazardous material class. The summary tables are included in Figure 2-2.

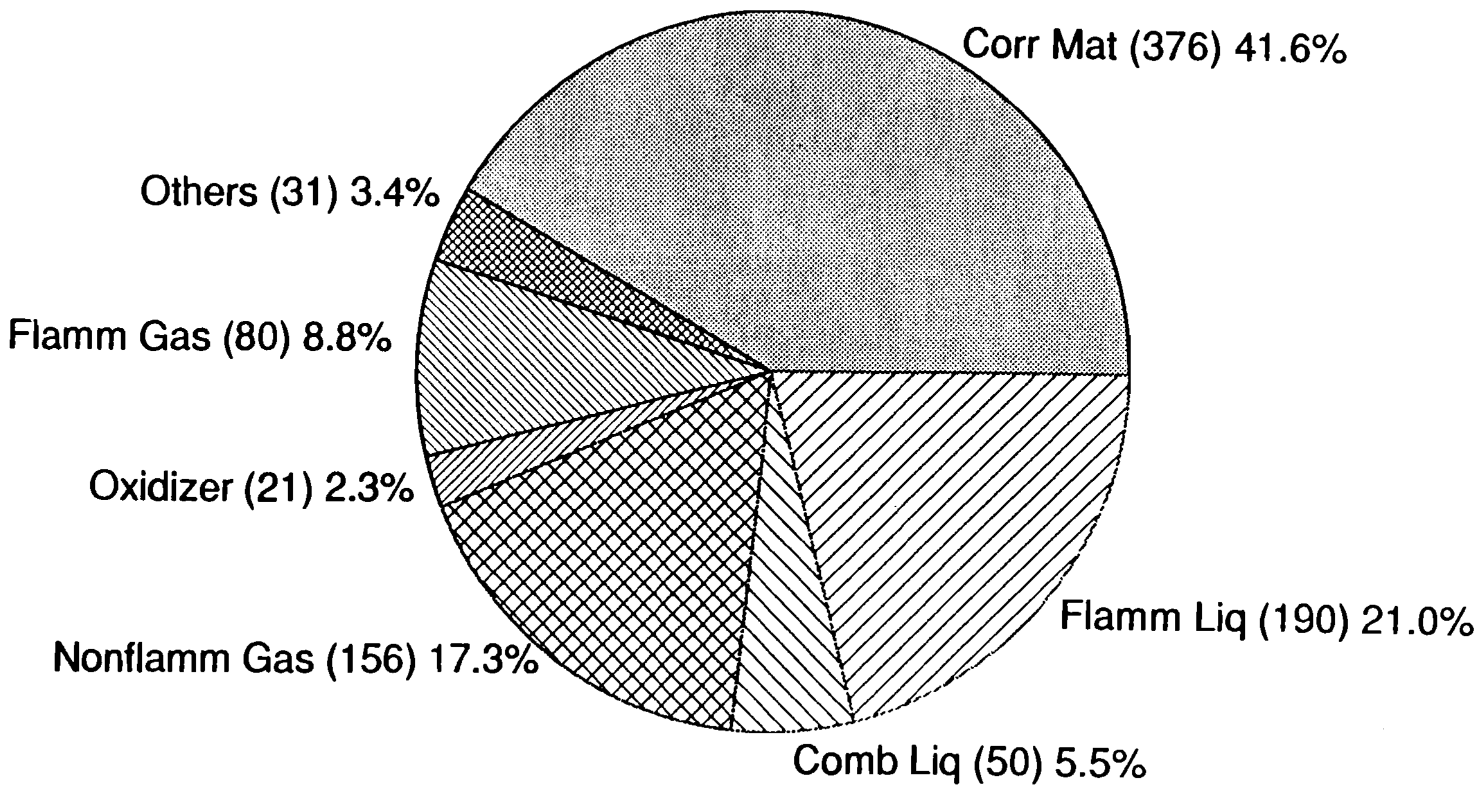
The second report includes:

- Details on the top 125 hazardous commodities which move in bulk, by tank car volume. These represent 80% of total U.S. carload movements.
- Details of the top 25 hazardous materials shipped grouped together with those with similar shipping names. These represent nearly 73% of all hazardous materials shipped by rail.
- A historical (5 year) ranking of the statistics captured in the previous section.
- A detailed summary of hazardous material incidents for the past six years. The information is drawn from AAR Hazardous Materials Inspectors' reports, Carrier Form 5800.1 of DOT (RSPA) and CTC reports, Chemtrec reports, and telephone reports.
- Leakage frequency by commodity class. This sometimes includes detail information on the commodity moving with the greatest frequency within the class for comparison.
- Graphs displaying the percentage of leaks by hazard class compared to tank car movements for that class.
- Statistics on derailments (outside the scope of the study).
- Maps and tables showing origins, destinations, and leaks by state.

This information is very revealing as it is the most complete time series data yet available. However, it does not contain data for calendar year 1988.

Figure 2-2

Tank Car Leaks by Hazard Class
Year 1987



Source: AAR

Table 2-5, taken out of the report, depicts the number of car movements, the number of leaks, and the rate of leaks per 1000 car movements. From this we can identify corrosive materials as the most frequently leaking commodity relative to the number of car movements. These materials leaked 1.64 times per thousand movements in 1987. Looking at the statistics from previous years it is clear that this has been the leader since 1981 with the exception of flammable liquids in 1982.

The ranking of commodities by frequency of leaks relative to movements in 1987 are:

Corrosive Material	1.64 leaks/1000
Nonflammable Gas	1.23 leaks/1000
Flammable Liquids	1.02 leaks/1000
Poison B	1.00 leaks/1000
Flammable Gas	0.52 leaks/1000

The ranking of commodities by absolute number of leaks are:

Corrosive Materials	376 leaks
Flammable Liquids	190 leaks
Nonflammable Gas	156 leaks
Flammable Gas	80 leaks
Poison B	7 leaks

It is interesting to note that while Poison B leaked only 7 times, it had one of the higher leak rates (1.00 leaks per thousand movements).

Figures 2-3 and 2-4 show that since 1981 there has not been significant reductions in either the number of leaks or the rate of leakage. Figures 2-5 and 2-6 depict the same information for all hazardous classes as well as tank car movements.

Publication R-640 contains additional information on car-miles. Figure 2-7 illustrates that DOT 111 class tank cars are utilized for approximately 65% of all hazardous material car-miles. This helps to explain the high incident rate noted in this report as well as in previous years (see Figure 2-8).

Another indicator of incident rate is depicted in Figure 2-9. This demonstrates that per million car-miles, non-pressurized DOT 111 class tank cars have a higher incident frequency than their pressurized counterparts. The high rate of release for DOT 103 class tank cars is attributed primarily to the use of lower pressure fittings than the DOT 111 class tank car, which means that the latter are "buttoned up" tighter, and to car age (Publication R-640, p. 51).

The report also describes a problem which has plagued efforts aimed at improving the safety of transporting hazardous materials by rail. There exists no complete data base of unintentional releases.

The AAR relies on its own Inspectors' reports, DOT Report Form 5800.1, or CTC reports, Chemtrec reports, and telephone notifications of leaks. While AAR has statistics on the greatest number of releases (80% of all releases by their estimation), the detail is missing in the documentation with regard to circumstances and cause of the release.

Table 2-5

Leakage Frequency by Hazard Class
(Source: AAR)

(1) Commodity/ HAZARD CLASS	1981 Car Leaks	1981 Cars Shipd	1981 Rate	1982 Car Leaks	1982 Cars Shipd	1982 Rate	1983 Car Leaks	1983 Cars Shipd	1983 Rate	1984 Car Leaks	1984 Cars Shipd	1984 Rate	1985 Car Leaks	1985 Cars Shipd	1985 Rate	1986 Car Leaks	1986 Cars Shipd	1986 Rate	1987 Car Leaks	1987 Cars Shipd	1987 Rate
Ammonia	66	43	1.55	68	33	2.08	86	37	2.32	93	44	2.11	49	43	1.13	82	43	1.9	94	54	1.74
NONFLAMMABLE GAS	132	94	1.40	139	78	1.78	140	88	1.59	145	105	1.38	125	103	1.41	137	102	1.23	156	126	1.23
LPG	84	86	0.98	87	81	1.07	81	105	0.77	254	105	2.42	110	106	1.03	91	111	0.82	69	127	0.54
FLAMMABLE GAS	109	118	0.93	107	110	0.97	128	130	0.98	276	130	2.12	121	131	0.92	101	136	0.74	80	155	0.52
FLAMMABLE LIQUID	250	126	1.98	228	109	2.10	253	143	1.77	269	153	1.76	242	144	1.68	229	157	1.46	190	185	1.02
COMBUSTIBLE LIQUID	83	89	0.93	76	78	0.97	84	75	1.12	80	77	1.04	73	64	1.14	47	74	0.64	50	68	0.74
POISON A	0	1	-	1	1	1.02	0	1	-	0	1	-	0	1	-	0	1	-	0	1	-
POISON B	9	14	0.63	10	15	0.69	9	19	0.47	12	15	0.80	7	13	0.54	12	12	1.00	7	7	1.00
Sulfuric Acid	134	46	2.93	92	36	2.56	111	43	2.6	97	48	2.02	124	54	2.29	123	54	2.27	81	51	1.58
Phosphoric Acid	20	32	.63	38	24	1.58	33	24	1.4	20	29	.68	44	30	1.46	47	28	1.68	45	30	1.50
Hydrochloric Acid	92	10	9.32	75	10	7.73	59	11	5.4	91	13	7.00	69	13	5.30	61	11	5.54	58	12	4.83
CORROSIVE MTL	455	192	2.37	335	177	1.89	344	180	1.9	404	202	2.00	376	195	1.93	387	203	1.91	376	229	1.64
OTHERS	32	27	1.19	69	23	3.00	20	165	0.12	49	40	1.23	33	43	0.77	27	51	0.53	55	74	0.74
TOTAL	1070	661	1.62	965	591	1.63	978	801	1.22	1235	723	1.43	977	694	1.41	940	736	1.28	914	845	1.08

NOTES:

1. Selected commodities are included in hazard class totals. TOTAL includes other hazard classes.
2. 'Cars Shipd' is loaded tank car originations (X 1000) as reported to TRAIN II.
3. 'Rate' is number of leakage incidents (LIC and SR) divided by Cars Shipped. (Leaks per 1000 cars shipped)

Figure 2-3

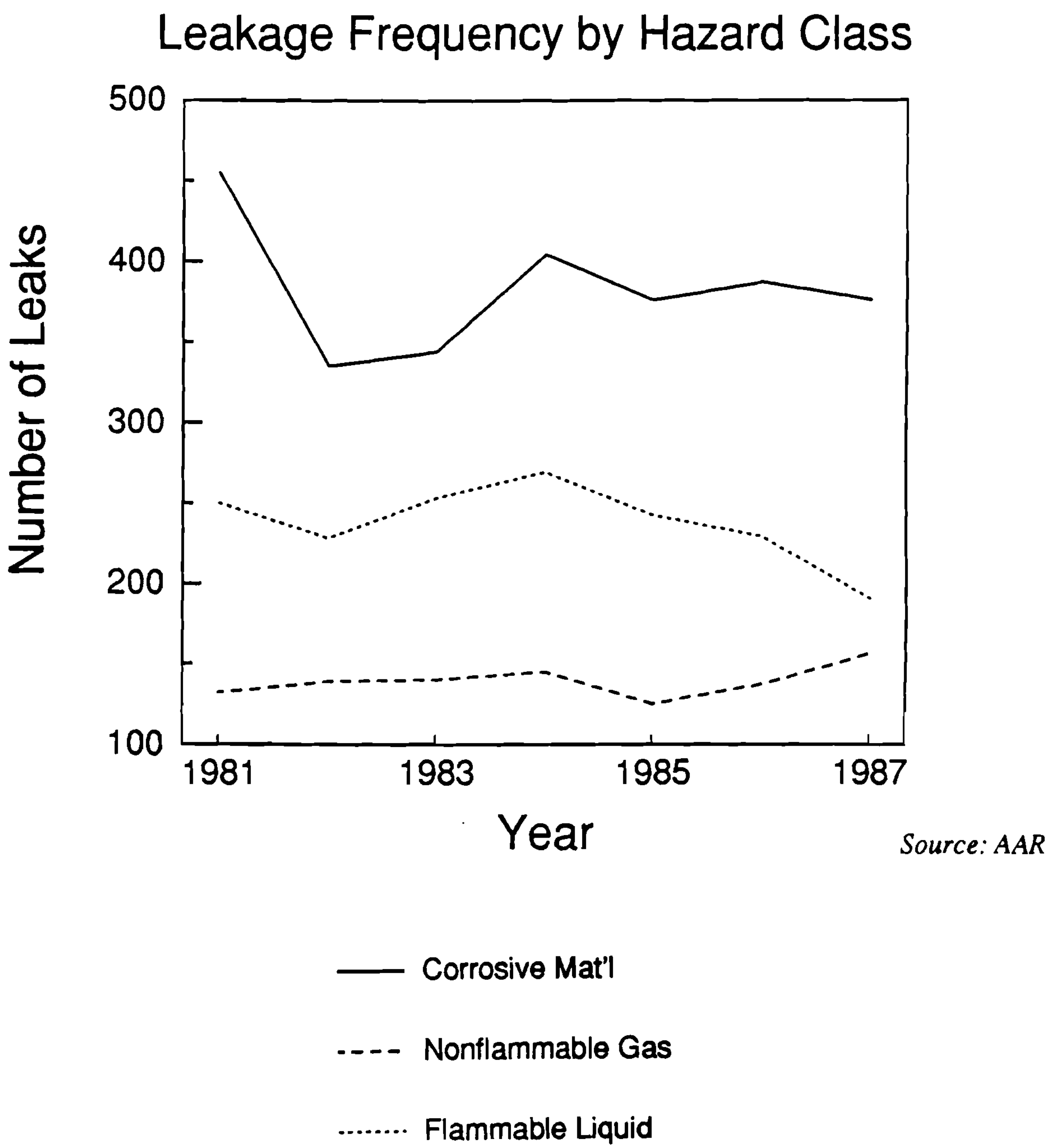
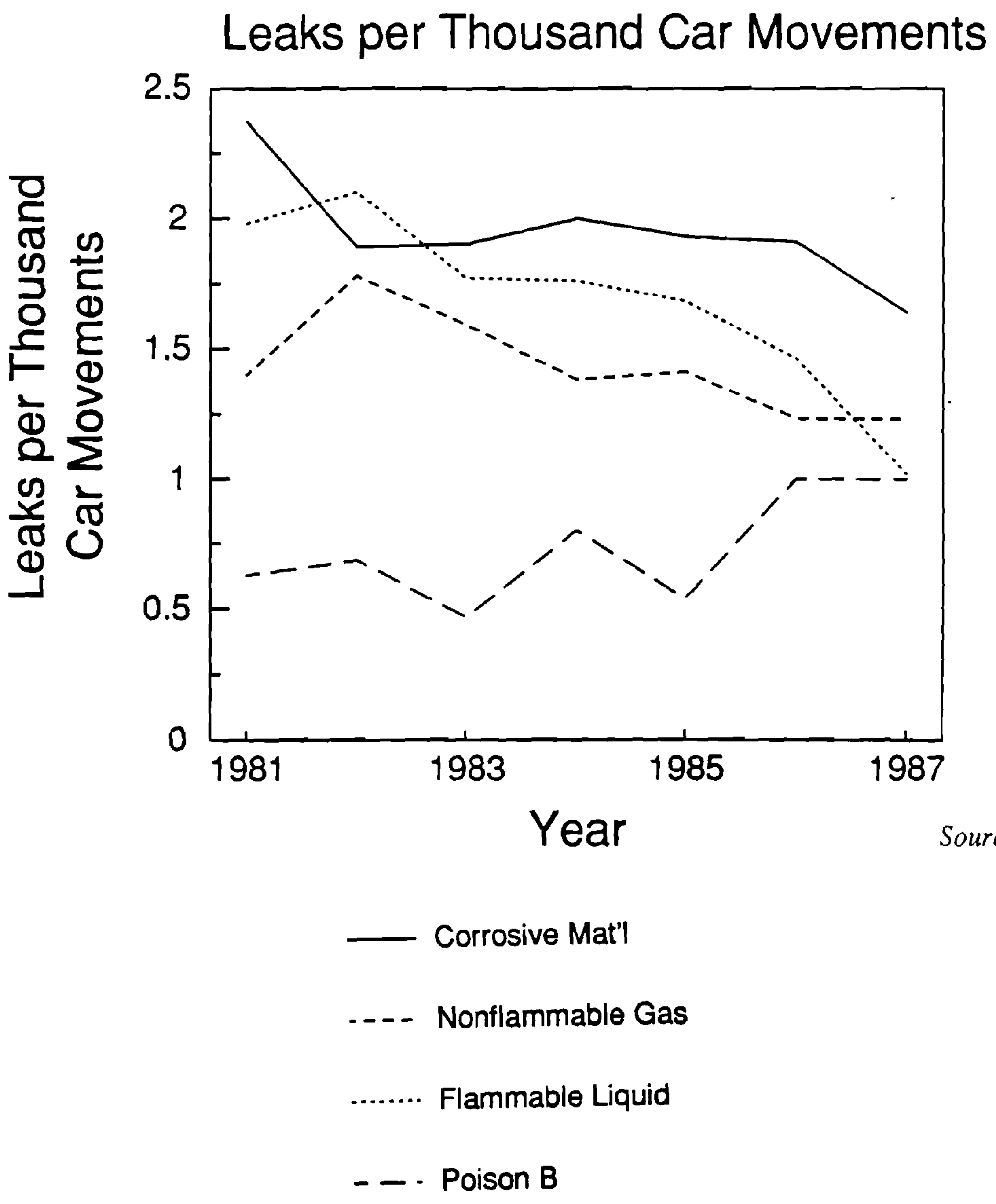
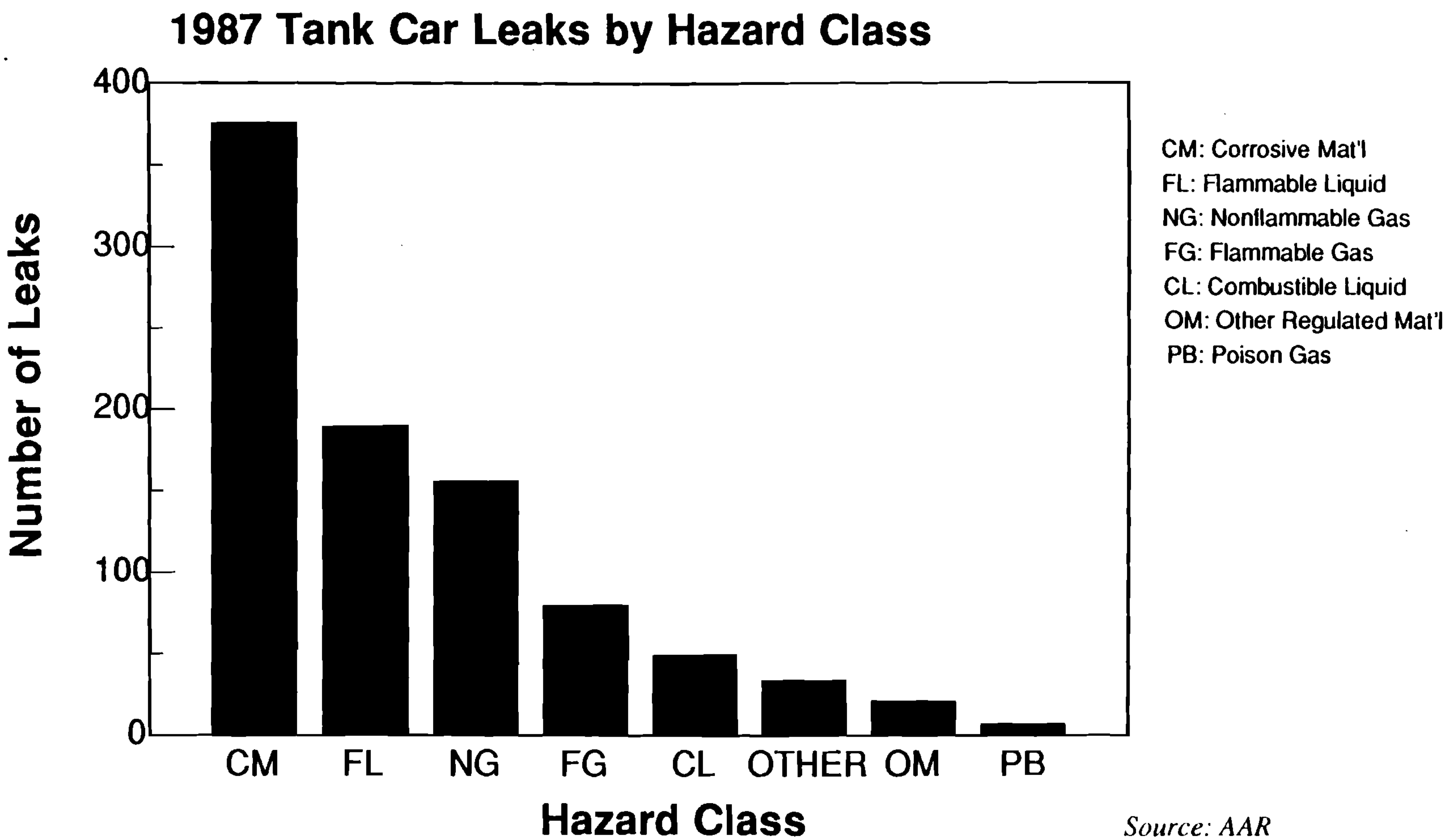

Leakage Frequency by Hazard Class
500
400
300
200
100
Number of Leaks
1981
1983
1985
1987
Year
Source: AAR
Corrosive Mat'l
Nonflammable Gas
Flammable Liquid

Figure 2-4



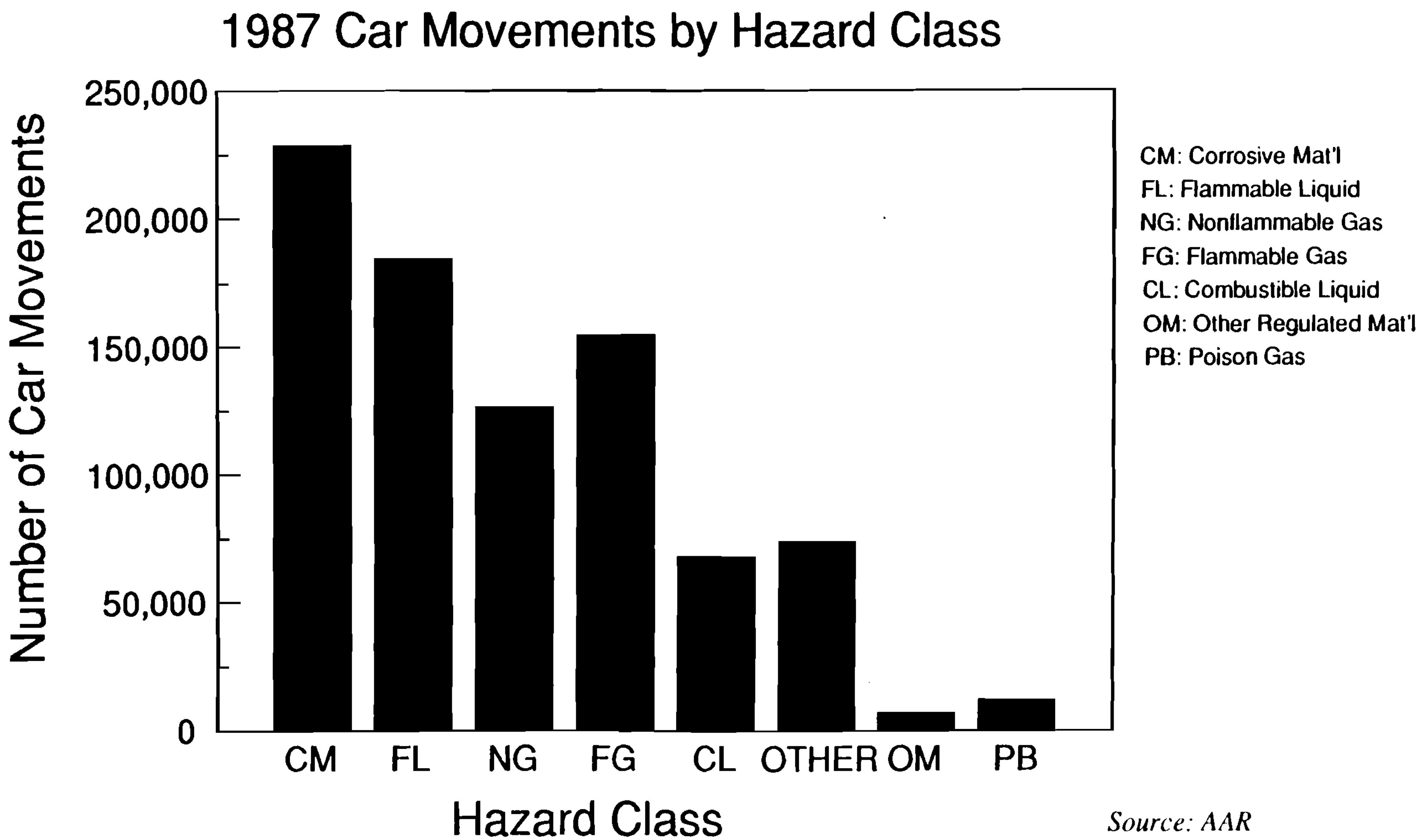
Source: AAR

Figure 2-5



Source: AAR

Figure 2-6



Source: AAR

Figure 2-7

Hazardous Material Car-Miles
By DOT Class Tank Car

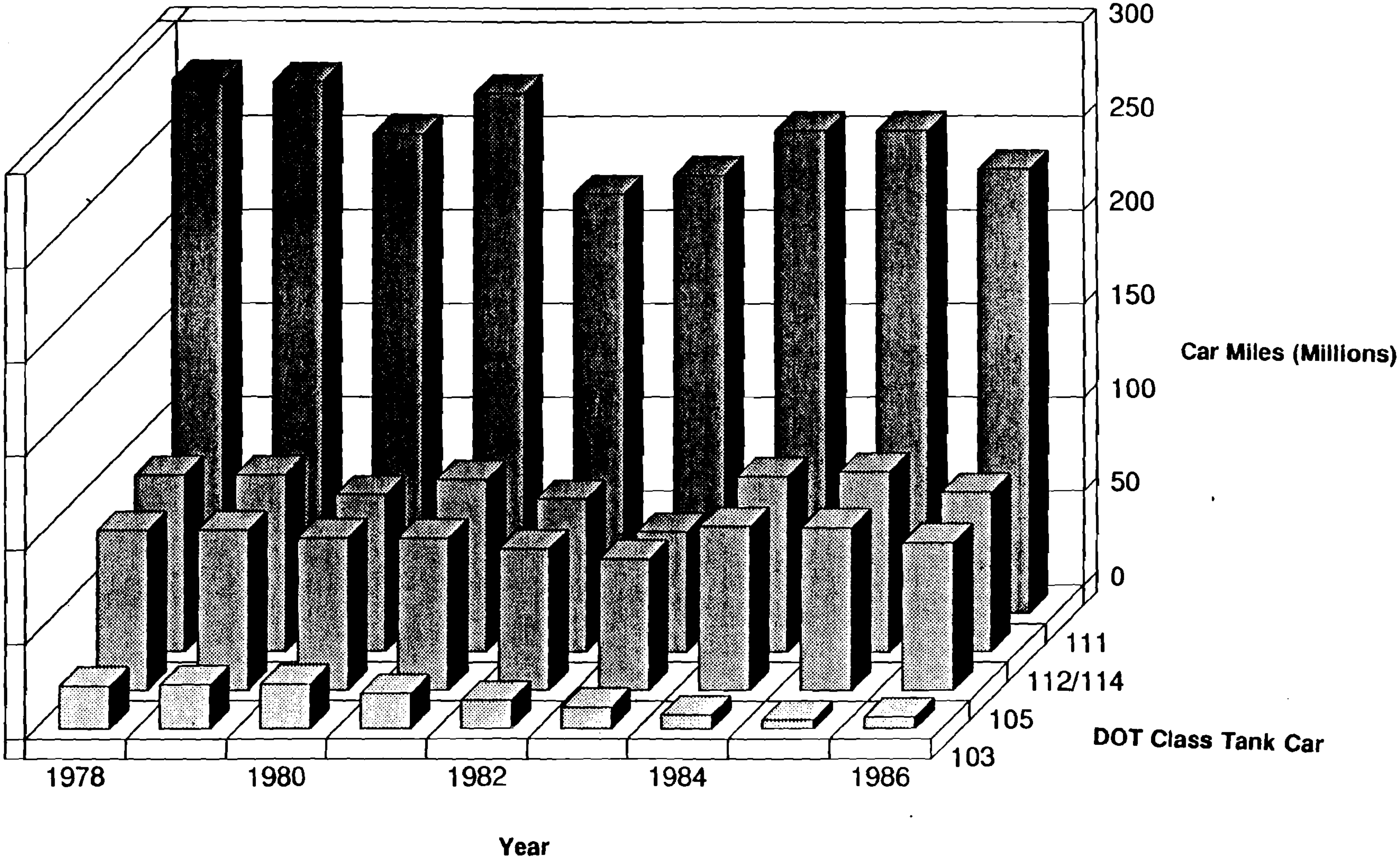


Figure 2-8

Incidents by DOT Tank Car Class

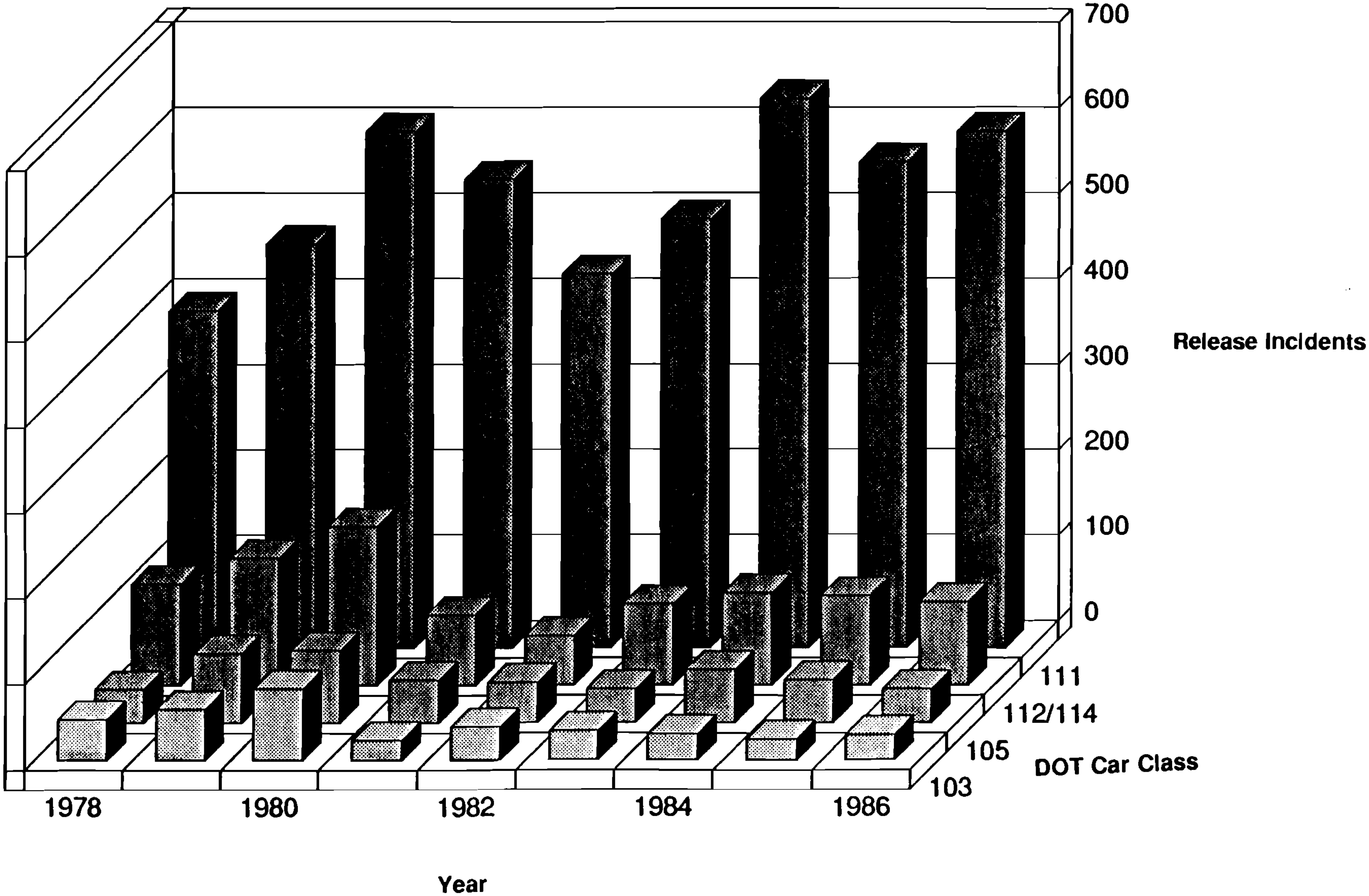
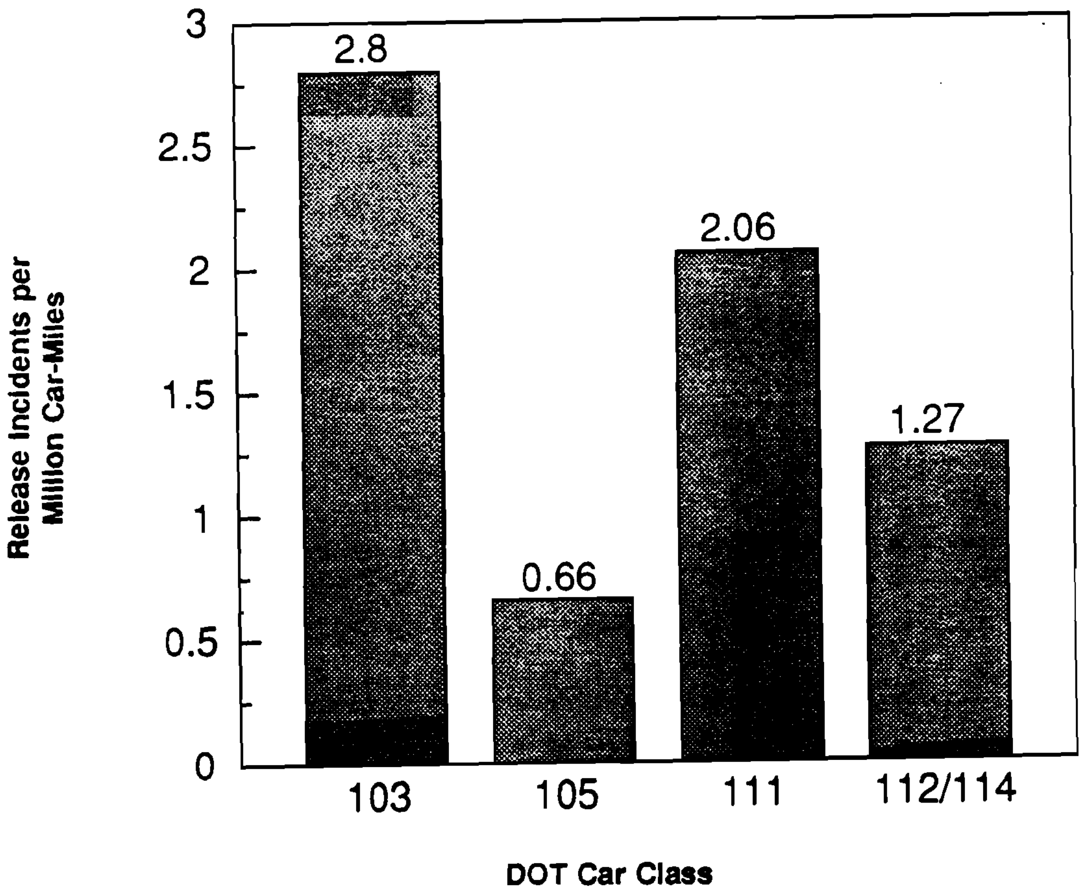


Figure 2-9
Incident Rate by DOT Tank Car Class
1978-1986



Source: AAR

The FRA tracks incidents in which the damage exceeds a certain monetary threshold. (Effective January 1, 1981, the reporting requirements were changed to exclude incidents in packaging of five gallons or smaller unless the incident results in death, injury, or property damage in excess of $50,000.)

2.3 Other Reports

We also reviewed the annual report on hazardous material transportation and conducted a literature search to identify other publications. The FRA and RSPA annual reports, published by the Department of Transportation, summarizes all incidents and regulatory activities surrounding the transportation of hazardous materials by all modes: air, water, highway, rail, and freight forwarder. Most of the information provided in this report is not relevant to the subject study.

Our literature search on this subject had surprisingly poor results. Four databases were accessed on-line.

- Pollution Abstracts - 70-89/JAN
- Enviroline - 70-88/DEC
- TRIS - 70-88/DEC
- NTIS

Of these only the NTIS database contained journal articles regarding the transportation and related release incidents from tank cars of hazardous materials.

These articles covered release incidents which were the subject of FRA inspection reports, or were about derailments which are beyond the scope of this study.

2.4 Statistical Analysis

We have performed some preliminary analysis of the release incident reports using cross-tabulations. The data are displayed in a matrix. The rows are the different causes of release, and the columns are the locations on the car from which the lading leaked.

There are more release incidents on the matrix than there were cars reported. This is because there was either more than one release per car, or there was more than one cause of release per car. In these instances one car was counted in more than one box on the matrix. For instance, a car may have leaked at the bottom outlet valve due to a bad gasket and also from the manway cover due to loose bolts. Alternatively, a car may have leaked from the manway cover due to a worn gasket and loose bolts. In this case, one release was treated as two because either of the factors could have caused the release, even in the absence of the other.

Table 2-6 is a summary of the data by each of the major causes for each year.

Tables 2-7 and 2-8 are cross-tabulation matrices which display details of the totals for all years reported: 1985-1988. One includes all of the data from both FRA and AAR; the other is just FRA data.

A note about how to read the matrices in Tables 2-7 and 2-9. Each box in each matrix has 4 numbers.

A B

C D

The number in position A is the number of incidents reported in the year at that location (column) and due to that cause (row). Position B is the percentage of incidents due to that cause reported at that location. Position C is the percentage of all reported incidents at that location attributable to that cause. Position D is the number reported in position A as a percentage of ALL reported incidents on the chart. As an example, in 1985 there were six reported leaks from the manway due to loose bolts. This represents 14.6% of all leaks reported. It is 40.0% of leaks due to

Table 2-6

Summary

	1985	1986	1987	1988	Total	Total *
Unsecured Openings	43.9%	36.6%	56.2%	65.5%	53.3%	46.8%
Gasket Failures	41.4%	14.6%	22.3%	27.6%	22.7%	23.4%
Corrosion	19.5%	36.6%	7.9%	6.9%	12.5%	22.5%
Unknown (not disc)	7.3%	12.2%	13.6%	0.0%	11.6%	7.2%
Incidents Reported	41	41	242	29	353	111
Source	FRA	FRA	AAR	FRA	BOTH	* FRA

loose bolts, and 33.3% of leaks at the manway cover.

At the end of each row is the total number of incidents reported for the row, and the percentage of that to all incidents reported. In 1985 there were 15 releases due to loose bolts representing 36.6% of all leaks.

At the bottom of each column is the total number of incidents reported at that location, and the percentage of all incidents reported which occurred at that location. In 1985, 18 tank cars reportedly leaked from the manway cover. This represents 43.9% of all leaks reported. Note that there is a key for the boxes in the lower left corner of each page.

It does appear that the number of releases due to unsecured openings is more significant than either of the other causes. In addition, we have inspection reports where no leak occurred, but the car was in violation of some section of the Code of Federal Regulations. In November and December of 1988 there were 29 cars offered for transportation with loose bolts, 10 with loose plugs, and 1 with loose fittings.

Of those with loose bolts, 26 of 29 contained residue and were unlikely to leak from the manway cover. This does, however, demonstrate that there may be many more cars which do not leak but were improperly secured. The three that were full may well have leaked while enroute had the FRA inspector not caught the problem.

While it is unclear from the data we have whether the number of releases is increasing, corrosion releases appear to be declining. This may be due to better testing of the linings in recent years or it may be an anomaly in the data.

Table 2-7

Release Incident Cross Tabulation; FRA and 1988 AAR Reports

1985-1989

Source: FRA Incident Reports and AAR 1988 Annual Report

Category	Release	Manway Cover	Btm Outlet	Fill Hole	Safety Vent/Valve	Sump	Wall	Liquid Line	Head	Eduction Pipe	Gauging Device	Other	Total	
Unsecured Openings	Bolts Loose	87 50.0 / 50.8 19.0	6 6.0 / 16.7 2.3	9 6.7 / 45.0 2.5	18 13.4 / 58.1 5.1			15 11.2 / 51.7 4.2				17 12.7 / 34.0 4.8	134 / 38.0	
	Bolt(s) Missing	1 25.0 / 0.6 0.3	2 50.0 / 4.2 0.6		1 25.0 / 3.2 0.3								4 / 1.1	
	Plug/Cap Off		1 20.0 / 2.1 0.3									4 80.0 / 8.0 1.1	5 / 1.4	53.3%
	Plug/Cap Loose		24 54.5 / 50.0 6.8		1 2.3 / 3.2 0.3			11 25.0 / 37.9 3.1				8 18.2 / 16.8 2.3	44 / 12.5	
	Item Warped			1 100 / 5.0 0.3									1 / 0.3	
Gasket Failures	Deteriorated	56 / 42.4	3 4.3 / 6.3 0.8	8 11.4 / 40.0 2.3	1 1.4 / 3.2 0.3					2 2.9 / 67.7 0.6			70 / 19.8	
	Cut	2 / 1.5	1 33.3 / 2.1 0.3										3 / 0.8	22.7%
	Dislodged	5 / 3.8		1 14.3 / 5.0 0.3						1 14.3 / 33.3 0.3			7 / 2.0	
Corrosion	Liner Failed		1 2.7 / 2.1 0.3	1 2.7 / 5.0 0.3		3 8.1 / 50.0 0.8	28 75.7 / 90.3 7.9				1 2.7 / 50.0 0.3	3 8.1 / 6.0 0.8	37 / 10.5	
	Liner Cut					3 100 / 50.0 0.8							3 / 0.8	12.5%
	Patch Failed						3 100 / 9.7 0.8						3 / 0.8	
	Bracket Broke				1 100 / 3.2 0.3								1 / 0.3	
	Unknown	1 2.4 / 0.8 0.3	8 19.5 / 16.7 2.3		9 22.0 / 29.0 2.5			3 7.3 / 10.3 0.8	1 2.4 / 100 0.3		1 2.4 / 50.0 0.3	18 43.9 / 36.0 5.1	41 / 11.6	
	Total	132 / 37.4	48 / 13.6	20 / 5.7	31 / 8.8	6 / 1.7	31 / 8.8	29 / 8.2	1 / 0.3	3 / 0.8	2 / 0.6	50 / 14.2	353	

Key

#	% Row
% Col.	% Tot.

Percentages may not sum to 100 due to rounding errors.

Table 2-8

Release Incident Cross Tabulation; FRA Reports

1985-1989

Source: FRA Incident Reports

		Manway Cover	Btm Outlet	Fill Hole	Safety Vent/Valve	Sump	Wall	Liquid Line	Head	Eduction Pipe	Gauging Device	Other	Total	
Unsecured Openings	Bolts Loose	21 50.0 50.0 18.9	8 19.0 44.4 7.2	5 11.9 62.5 4.5	7 16.7 50.0 6.3			1 2.4 100 0.9					42 37.8	46.8%
	Bolt(s) Missing	1 25.0 2.4 0.9	2 50.0 11.1 1.8		1 25.0 7.1 0.9								4 3.6	
	Plug/Cap Off												0 0.0	
	Plug/Cap Loose		4 80.0 22.2 3.6		1 20.0 7.1 0.9								5 4.5	
	Item Warped			1 100 12.5 0.9									1 0.9	
Gasket Failures	Deteriorated	15 75.0 35.7 13.5	1 5.0 5.6 0.9	1 5.0 12.5 0.9	1 5.0 7.1 0.9					2 10.0 67.7 1.8			20 18.0	23.4%
	Cut	2 67.7 4.8 1.8	1 33.3 5.6 0.9										3 2.7	
	Dislodged	2 67.7 4.8 1.8								1 33.3 33.3 0.9			3 2.7	
Corrosion	Liner Failed		1 5.6 5.6 0.9	1 5.6 12.5 0.9		3 16.7 50.0 2.7	9 50.0 75.0 8.1				1 5.6 50.0 0.9	3 16.7 75.0 2.7	18 16.2	22.5%
	Liner Cut					3 100 50.0 2.7							3 2.7	
	Patch Failed						3 100 25.0 2.7						3 2.7	
	Bracket Broke				1 100 7.1 0.9								1 0.9	
	Unknown	1 12.5 2.4 0.9	1 12.5 5.6 0.9		3 37.5 21.4 2.7				1 12.5 100 0.9		1 12.5 50.0 0.9	1 12.5 25.0 0.9	8 7.2	
	Total	42 37.8	18 16.2	8 7.2	14 12.6	6 5.4	12 10.8	1 0.9	1 0.9	3 2.7	2 1.8	4 3.6	111	

Key

#	% Row
% Col.	% Tot.

Percentages may not sum to 100 due to rounding errors.

2.5 Conclusions From this Review

From this review of literature and interviews of people in the industry, it is clear that the areas most involved in non-accident releases of hazardous materials are:

- Use of DOT Class 111 tank cars: DOT 111 class tank cars not only carry the most hazardous materials, but they exhibit the highest number of leaks of all tank car classes.

- Shipment of corrosive materials: corrosive materials, probably because they are carried in DOT 111 class tank cars, leak the most of any hazardous material. Particular attention should be paid to hydrochloric acid and phosphoric acid.

- Leakage through unsecured openings: The primary cause of unintentional releases of hazardous materials, other than disc failure, is unsecured openings.

2.6 Analysis of RSPA's HMIS Data Base

In order to substantiate the previous findings we analyzed a five year listing of non-accident releases of hazardous materials maintained by RSPA in its Hazardous Materials Information System (HMIS) Data Base. This system is based upon the Form 5800.1 Reports. There were 4,229 incidents in the data base between 1985 and 1989.

The HMIS data base uses different codes to denote the cause of the release. They are not clearly defined and overlap. For this reason it is difficult to compare precisely with the previous reports. However, it is clear that the majority of leaks occurred due to a loose or defective fitting of some sort (what portion of these were frangible disk failures is not exactly known).

2.6.1 Type of Hazardous Material Released

We analyzed the HMIS data base to determine the materials which leak most often. Table 2-9 shows the forty hazardous materials which leaked most often between 1985 and 1989. These forty account for over 80% of the releases during this period out of 256 different materials. Over half are either corrosive materials or flammable liquids. As discovered above, among the leading commodities released are sulfuric acid, hydrochloric acid, and phosphoric acid. Together they account for more than one fourth (26.0%) of all releases.

2.6.2 Type of Tank Car Involved

As had been shown in previous sections, DOT 111 class tank cars account for the majority of leaks reported (assuming that cars reported as "Tank Car" with no detail on actual type are not all of predominantly one type of car). This finding is not surprising since DOT 111 class tank cars carry corrosive materials and flammable liquids which leak most frequently (see Table 2-10). In addition, these two types of hazmat are loaded most frequently.

Table 2-9

Number of Leaks by Commodity (1985-1989)

Num	Code	Commodity Name	# of Leaks	Percent	Cumul. Percent
1	9930	Sulfuric Acid	497	11.75	11.75
2	5700	Hydrochloric Acid	377	8.91	20.67
3	6300	LP Gas	277	6.55	27.22
4	9575	Sodium Hydroxide LQ	265	6.27	33.48
5	1620	Ammonia Anhydrous	253	5.98	39.47
6	8365	Phosphoric Acid	226	5.34	44.81
7	5130	Flam. Liquids N.O.S.	169	4.00	48.81
8	10820	Methyl Alcohol	113	2.67	51.48
9	3730	Corr. Liq. N.O.S.	87	2.06	53.54
10	9874	Styrene Monomer INH	86	2.03	55.57
11	4005	Denatured Alcohol	84	1.99	57.56
12	8319	Petroleum Naptha CL	79	1.87	59.42
13	3475	Combustible Liquid N.O.S.	74	1.75	61.17
14	2711	Carbon Dioxide	65	1.54	62.71
15	2710	CO2 Liquified	53	1.25	63.96
16	5853	Hydrogen Perox $_>$52	51	1.21	65.17
17	8320	Petroleum Naptha	48	1.14	66.30
18	9760	Sulfuric Acid Spent	47	1.11	67.42
19	1270	Alka Cor. Liq. N.O.S.	37	0.87	68.29
20	10650	Vinyl Acetate	37	0.87	69.17
21	4668	Ethyl Alcohol	35	0.83	69.99
22	7950	Oleum	34	0.80	70.80
23	5203	Fuel Oil 1,2,4,5,6	33	0.78	71.58
24	4661	Ethyl Acrylate INHB	29	0.69	72.26
25	5852	Hydrogen Perox 40-52	29	0.69	72.95
26	8628	Potass Hydroxide LQ	29	0.69	73.63
27	10890	Xylene (Xylol)	29	0.69	74.32
28	10340	Toluene	28	0.66	74.98
29	6100	Isopropanol	26	0.61	75.60
30	5457	Hazard Subst L/S	24	0.57	76.16
31	5800	Hydrofluosilic Acid	24	0.57	76.73
32	3140	Chlorine	23	0.54	77.28
33	1010	Acetone	22	0.52	77.80
34	2460	Butadiene Inhibited	20	0.47	78.27
35	5459	Hazard Waste L/S	18	0.43	78.69
36	2463	Butyl Alcohol	17	0.40	79.10
37	4714	Ethylenediamine	17	0.40	79.50
38	7100	Methyl Methacrylate	17	0.40	79.90
39	1182	Alcoholic Beverage	16	0.38	80.28
40	1008	Acetic Anhydride	15	0.35	80.63

Table 2-10

Leaks by Tank Car Type (1985-1989)

TANK CAR CLASS	# OF LEAKS	PERCENT	CUMULATIVE PERCENT
111 All Types	2,576	60.91%	60.91%
TANK CAR	961	22.72%	83.64%
112 All Types	350	8.28%	91.91%
105 All Types	217	5.13%	97.04%
103 All Types	97	2.29%	99.34%
113 All Types	8	0.19%	99.53%
114 All Types	6	0.14%	99.67%
115 All Types	5	0.12%	99.79%
104 All Types	3	0.07%	99.86%
110 All Types	2	0.05%	99.91%
109 All Types	2	0.05%	99.95%
106 All Types	1	0.02%	99.98%
107 All Types	1	0.02%	100.00%
TOTAL	4,229		

However, while we were not able to analyze number of leaks by car class versus number of car loadings (data not on the HMIS data base), these findings do not contradict the findings above that the release rate for materials carried in DOT 111 class tank cars leaks more often than do other types of hazmat (see Figure 2-6 above).

2.6.3 Cause of Hazmat Release

The HMIS data base allows the formatting of multiple codes to describe the cause of the release. The user is allowed to enter as many as seem to be appropriate. This makes analysis of particular causes difficult.

We grouped the release incidents together when they shared several failure codes in common. Table 2-11 is a summary of releases by RSPA Failure Code, or combination of failure codes.

Loose fittings were noted in 45.9% of the releases while defective fittings were mentioned in 38.9%. Together they account for over 80% of the releases. This corroborates our findings from the FRA Inspectors' reports summarized above. Unfortunately, while it is quite likely that some number of these incidents involved the rupture of the frangible disc, we are not able to determine with any certainty how many of these were due to a ruptured disc.

Corrosion was only listed as a cause in 1.3% of the releases. This is interesting because corrosion was far more prevalent in the FRA Inspectors' reports. Approximately one out of five releases were attributable to corrosion according to the FRA inspectors (see Table 2-8).

Table 2-11

Leaks by Failure Code (1985-1989)

Cause Combination	Leaks	Percent
Loose Fitting, No Object	1,613	38.1%
Defective Fitting, No Object	1,430	33.8
Loose Fitting, Defective Fitting, No Object	297	7.0
Defective Fitting, No Object, Burst Internal Pressure	155	3.7
No Cause Listed	140	3.3
Venting, No Object, Burst Internal Pressure	100	2.4
Burst Internal Pressure	72	1.7
Defective Fitting, Venting, No Object, Burst Internal Pressure	60	1.4
Corrosion	54	1.3
Loose Fitting, No Object, Burst Internal Pressure	34	0.8
Other	274	6.5
Total	**4,229**	**100.0%**

2.6.4 Release Incidents by Shipper

The HMIS data base records the name of the shipper with each release incident. In order to determine if certain shippers accounted for a large number of incidents (shippers are usually responsible for ensuring that the tank car is properly maintained and closed prior to movement), we counted releases by shipper.

Table 2-12 shows the top forty shippers in terms of hazmat leaks reported through the HMIS data base between 1985 and 1989. It did not appear that any particular shippers stood out as bad examples. Those at the top of the list ship greater quantities of hazardous materials. Most of them are chemical manufacturers. It is important to note that this table are merely counts of releases, not rates of release incidents. In other words, shippers who ship large quantities of hazardous materials are going to experience more releases than infrequent shippers, all else equal.

2.6.5 Release Incidents by Carrier

Finally, we analyzed the number of release according to carrier. This was done to see if one carrier had a substantially higher rate of release than the others. Since our earlier findings showed that the railroads are generally not responsible for sealing the cars, or for maintaining them, this list is presented as information rather than as something from which conclusions can be drawn.

Table 2-13 lists the number of releases during the period 1985 to 1989 for the forty carriers cited most frequently. Not surprisingly, the major Class I railroads top the list. This is likely because they carry the most.

Table 2-12

Number of Leaks by Shipper (1985-1989)

Num	ID	Shipper's Name	# of Leaks	Percent	Cumul Percent
1	16259	Occidental Chemical Co	104	2.46	2.46
2	16668	Phelps Dodge Corp	92	2.18	4.63
3	18887	Union Carbide Corp	89	2.10	6.74
4	12836	Du Pont E I De Nemours	84	1.99	8.73
5	10334	American Cyanamid Co	79	1.87	10.59
6	12800	Dow Chemical Co	68	1.61	12.20
7	18167	Stauffer Chemical Co	65	1.54	13.74
8	16307	Olin Corp	63	1.49	15.23
9	19168	Vulcan Materials Co	61	1.44	16.67
10	13298	Farmland Industries Inc	59	1.40	18.07
11	10579	Asarco Inc	54	1.28	19.34
12	13223	Exxon Chemical Co	53	1.25	20.60
13	13495	FMC Corp	53	1.25	21.85
14	15760	Monsanto Co	53	1.25	23.10
15	20303	Tennessee Chem Co	51	1.21	24.31
16	20766	Arco Chem Co	49	1.16	25.47
17	16595	Pennwalt Corp	45	1.06	26.53
18	18500	Texas Gulf Inc	45	1.06	27.60
19	17657	Shell Chemical Co	42	0.99	28.59
20	20452	Interox America	41	0.97	29.56
21	20249	LCP Chemicals	40	0.95	30.50
22	16222	Not Reported By Carrier	39	0.92	31.43
23	11696	Celanese Chemical Co	38	0.90	32.32
24	15165	Liquid Carbonics Corp	38	0.90	33.22
25	20895	Vista Chem Co	38	0.90	34.12
26	11186	Borden Inc/Chemical Co	36	0.85	34.97
27	17075	Reagent Chemical Inc	36	0.85	35.82
28	11934	Chevron Chemical Co	35	0.83	36.65
29	16831	PPG Industries Inc	35	0.83	37.48
30	10414	Amoco Chemical Corp	30	0.71	38.19
31	22922	BASF Chemical	29	0.69	38.87
32	19955	Texaco Chemical	28	0.66	39.54
33	11610	Cardox Div Chemtron	27	0.64	40.18
34	20536	PVS Chem	27	0.64	40.81
35	22302	Georgia Gulf	27	0.64	41.45
36	17074	Reagent Chemical & Res	24	0.57	42.02
37	19793	Sun Refining and Marketing	24	0.57	42.59
38	10151	Agrico Chemical Co	23	0.54	43.13
39	10174	Air Products & Chemicals	23	0.54	43.67
40	10251	Allied Chemical Corp	23	0.54	44.22

Table 2-13

Number of Leaks by Carrier (1985-1989)

Num	ID	Carrier Name	# of Leaks	Percent	Cumul Percent
1	23029	CSX Transportation	701	16.58	16.58
2	18900	Union Pacific Railroad Co	602	14.24	30.81
3	19709	Consolidated Rail Corp	470	11.11	41.92
4	17923	Southern Railway System	421	9.96	51.88
5	17918	Southern Pacific Transp Co	406	9.60	61.48
6	16135	Norfolk & Western Railway	235	5.56	67.04
7	10620	Atchison Topeka & Santa Fe	230	5.44	72.48
8	14358	Houston Belt & Terminal	137	3.24	75.72
9	19714	Burlington Northern	129	3.05	78.77
10	14475	Illinois Central Gulf RR	93	2.20	80.96
11	19823	Seaboard System Railroad	63	1.49	82.45
12	13945	Grand Trunk Western RR	51	1.21	83.66
13	11927	Chessie System	49	1.16	84.82
14	16805	Port Terminal Railroad Assn	49	1.16	85.98
15	24133	Springfield Terminal RR	47	1.11	87.09
16	11941	Chicago & Northwestern	43	1.02	88.11
17	15708	Missouri Pacific Railroad	43	1.02	89.12
18	10802	Baltimore & Ohio RR Co	40	0.95	90.07
19	13029	Elgin Joliet & Eastern	35	0.83	90.90
20	14816	Kansas City Southern	33	0.78	91.68
21	17859	Soo Line Railroad	33	0.78	92.46
22	17203	Richmond Fredericksburg	31	0.73	93.19
23	10206	Alaska Railroad	25	0.59	93.78
24	23008	Midsouth Rail Corp	24	0.57	94.35
25	11197	Boston & Maine Corp	19	0.45	94.80
26	12628	Deleware & Hudson Railway	16	0.38	95.18
27	11922	Chesapeake & Ohio	15	0.35	95.53
28	17417	Santa Fe Railway	11	0.26	95.79
29	26841	Buffalo & Pittsburgh RR	8	0.19	95.98
30	17917	Southern Pacific Co	7	0.17	96.15
31	21123	Norfolk Southern Corp	7	0.17	96.31
32	12667	Denver & Rio Grande We	6	0.14	96.45
33	14815	Kansas City Southern Lines	6	0.14	96.59
34	15317	Maine Central Railroad	6	0.14	96.74
35	15762	Montana Sulphur & Chem	6	0.14	96.88
36	18467	Terminal Railroad Assoc	6	0.14	97.02
37	19080	Manufacturers Railway Co	6	0.14	97.16
38	26151	Terminal Railway	6	0.14	97.30
39	10295	Alton & Southern Railway	5	0.12	97.42
40	10370	American Oil Co (Amoco)	4	0.09	97.52

3. Analysis of Causes of Releases

The analysis described in the previous chapter clearly demonstrated that almost all non-accident leaks (that are not attributable to frangible disc failures) are caused by:

- Unsecured openings,
- Gasket failure, or
- Corrosion leaks.

In order to identify the causes of those releases, we reviewed the available data, talked to several people in the industry, visited a couple of facilities of cooperating shippers, and participated in a one-day course on tank car safety. As a result of this process, we developed several hypotheses on causes of leaks and developed fault trees for each of the major cause categories. These fault trees are provided in Figures 3-1, 3-2, and 3-3.

As shown in each fault tree, a release generally takes place because an incipient leak ends up getting undetected. In other words, a perfect inspection would generally be able to detect conditions that would lead to a leak prior to the actual release. Therefore, a leak prevention program can address either preventing the conditions for leaks from forming or creating a situation to help detect all types of incipient leaks.

A leak can be attributed to one of the following three factors:

- Design,
- Operation, or
- Installation.

These factors can be further elaborated depending on the type of leak.

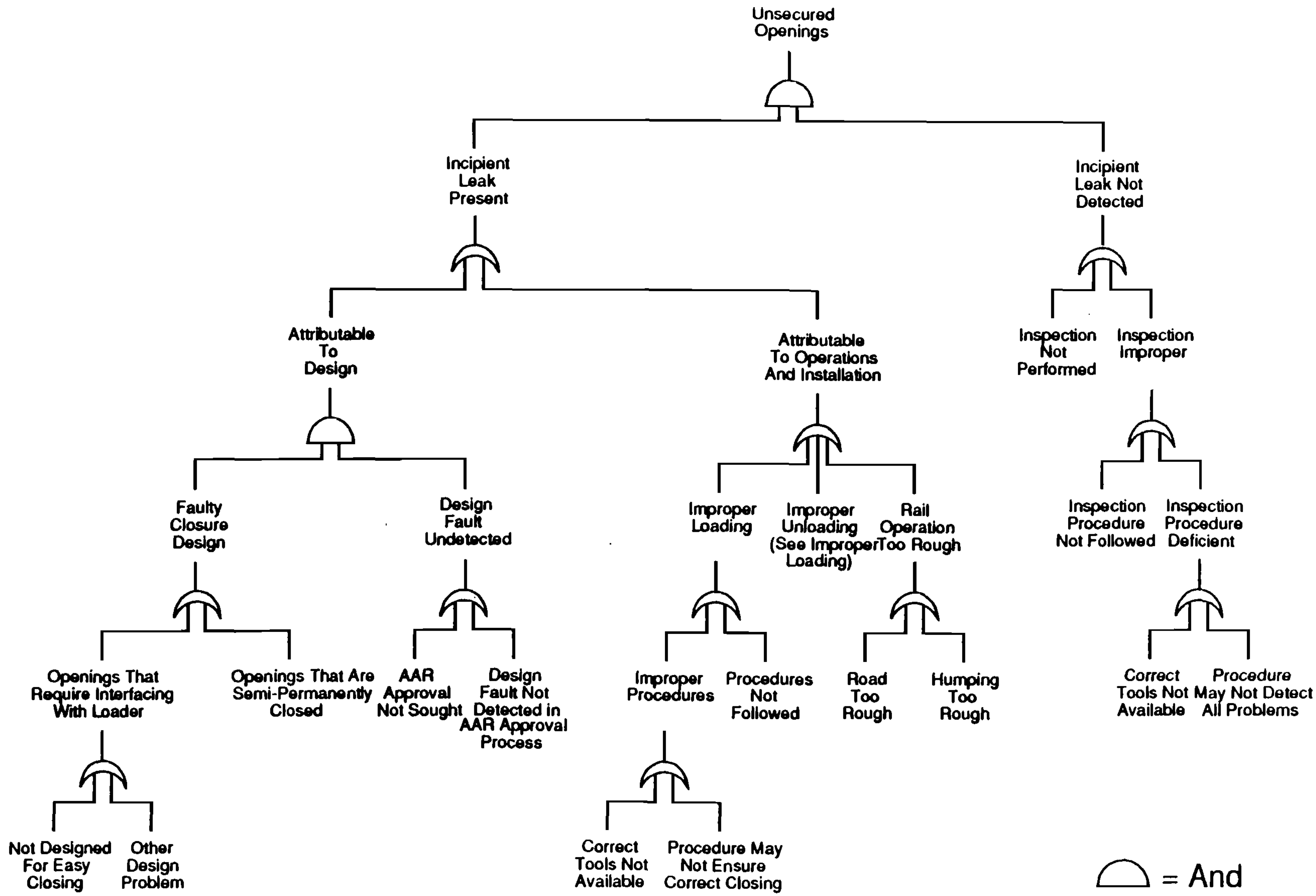
3.1 Causes of Leaks Due to Unsecured Opening

The fault tree for leaks attributed to unsecured openings is shown in Figure 3-1. As can be seen, this type of leak is caused by factors attributed to design operations or installation.

The design of opening itself could be faulty. The major design fault that can lead to a leakage is one related to the ease of closing. The opening should be designed in such a way that it is easy to close. For example, Figures 3-4a and 3-4b shows arrangements for two types of cars carrying sulfuric acid, the DOT specification 103AW (which is being phased out) and DOT specification 111A100W2 currently in use. It would seem that the fill hole lock bar with one eye bolt used in the older car would be easier to close and inspect than the four eye bolt arrangement for the current car. (Of course, there may be other problems with the lock bar arrangement, such as lack of redundancy.) Similarly, the openings that do not require frequent opening and closing (such as a manhole cover) could also be designed for ease of closing.

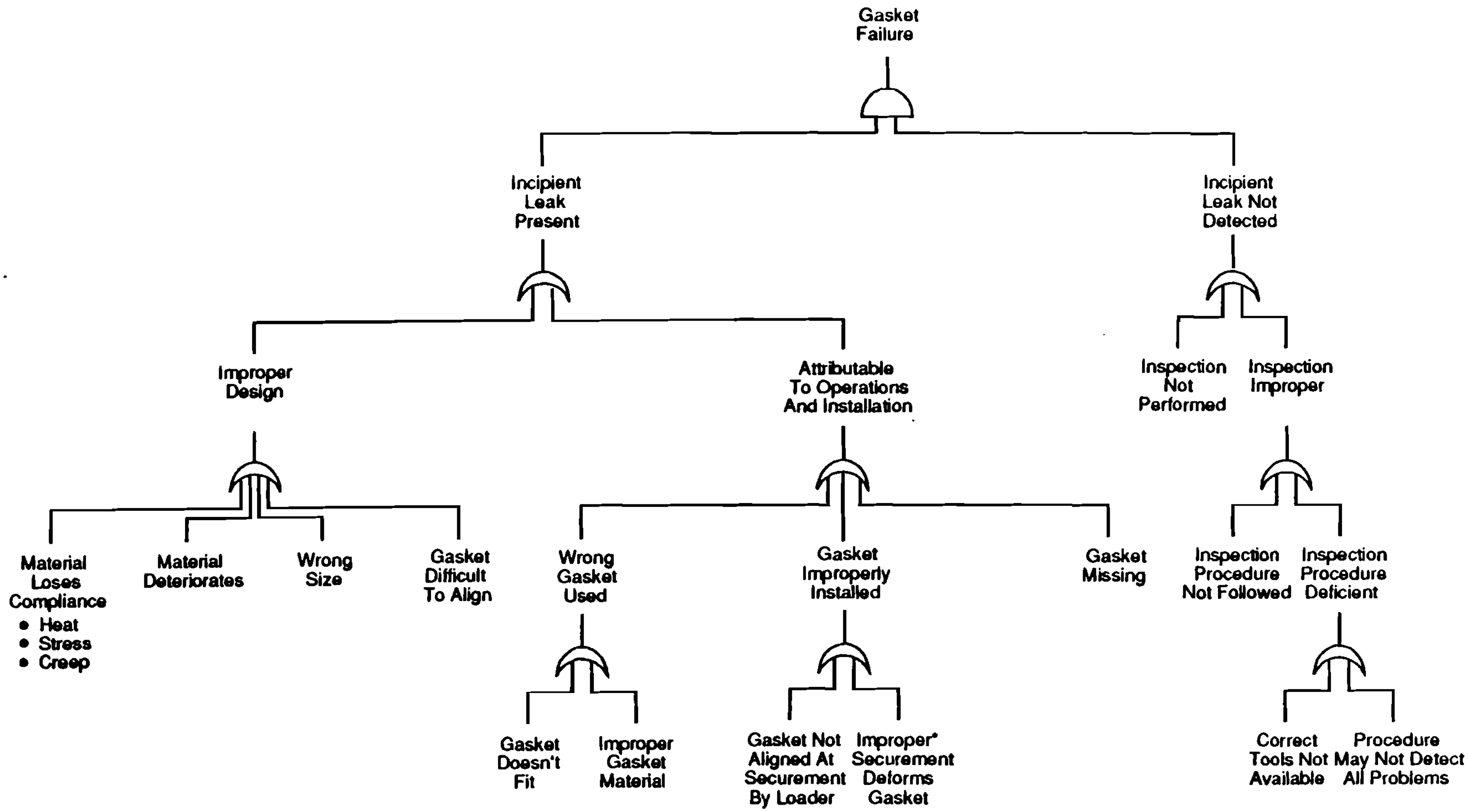
Furthermore, cars carrying corrosive materials face the problem of screw threads of these bolts getting stripped, corroded, or the head of the nut or bolt getting worn out. Both these problems lead to the closure being improper. An improved material can

Figure 3-1



A Fault Tree for Unsecured Openings

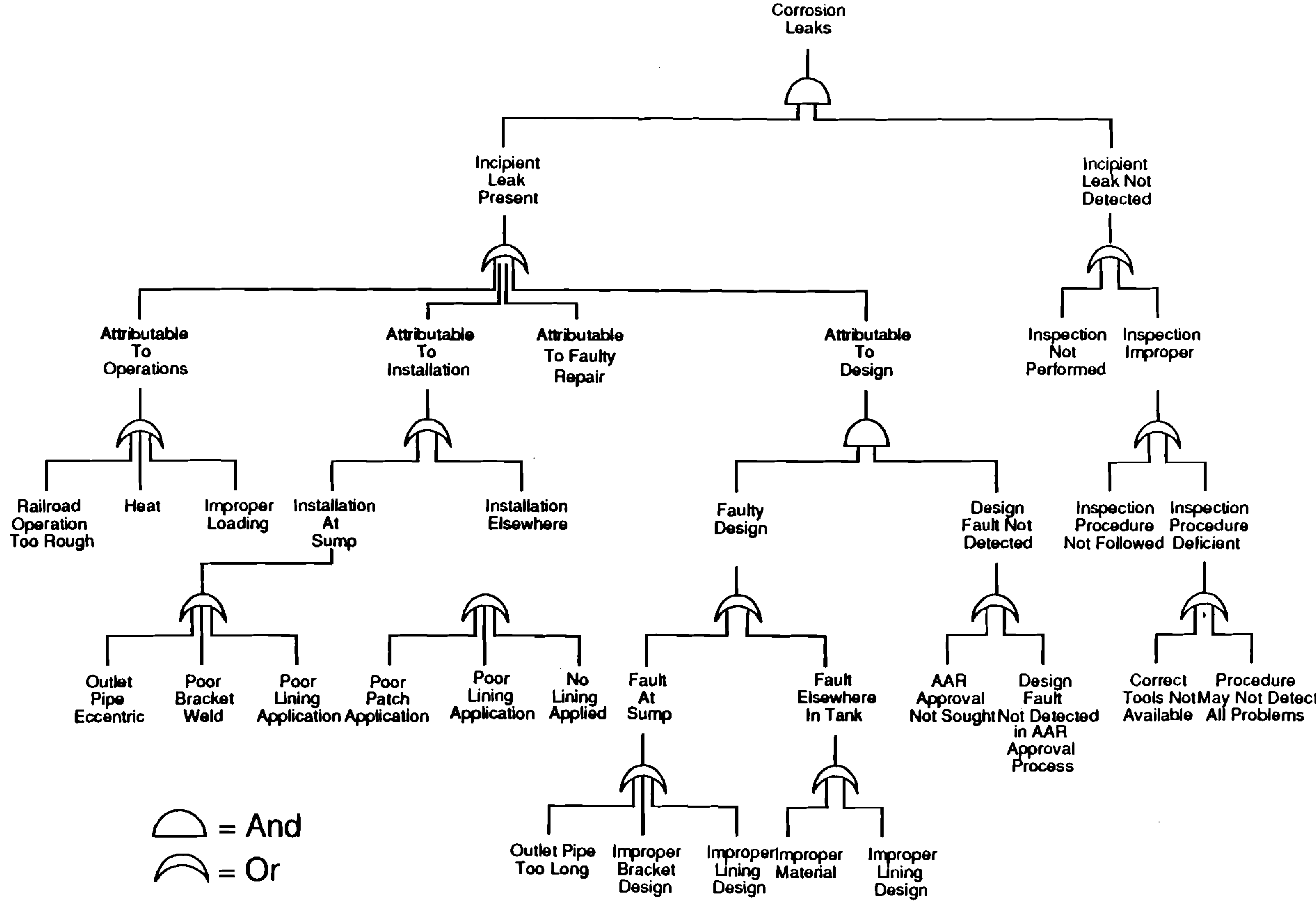
Figure 3-2



* Often the leak is classified under unsecured openings

A Fault Tree for Gasket Failure

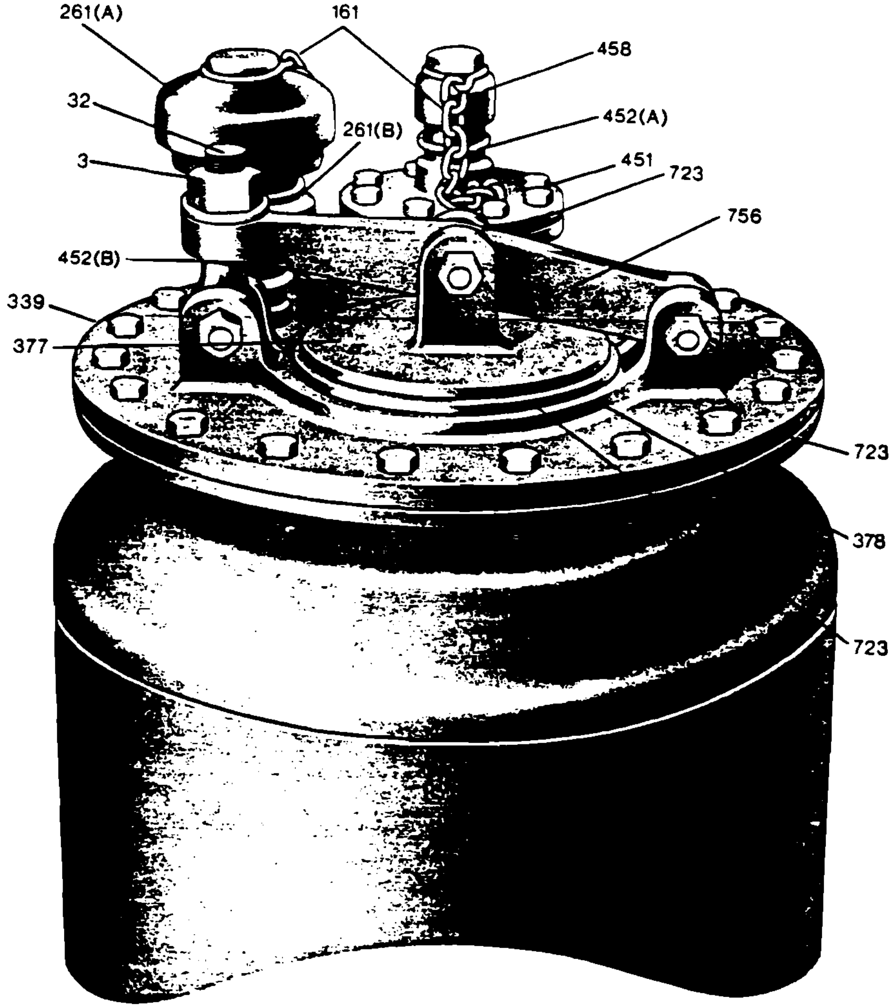
Figure 3-3



A Fault Tree for Corrosion Leaks

Figure 3-4a

EXAMPLES OF CLOSING ARRANGEMENTS



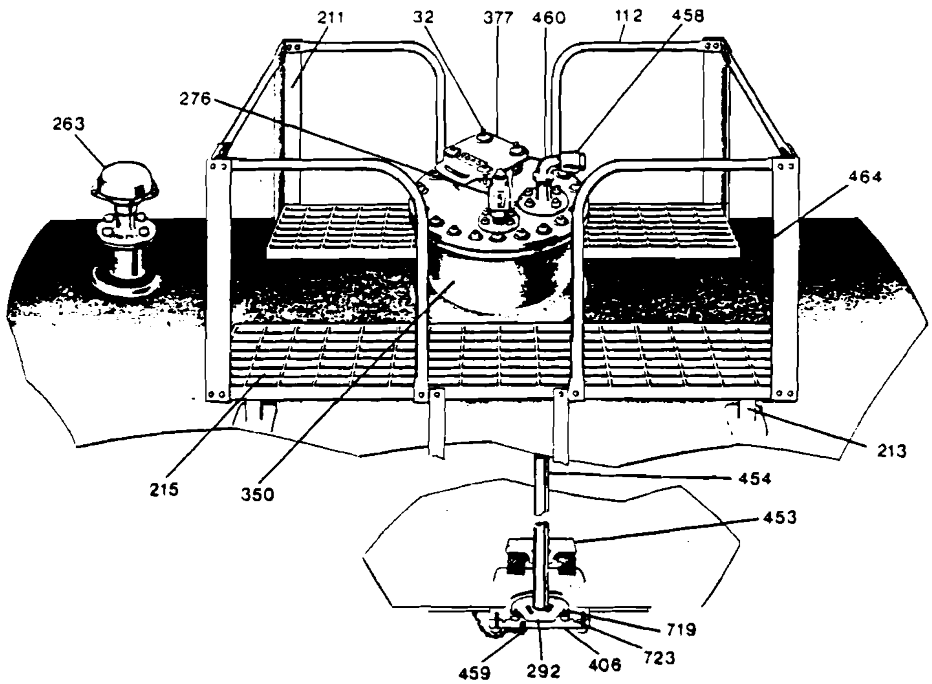
DOME ARRANGEMENT FOR DOT 103AW SULFURIC ACID CARS

PART NO.	DESCRIPTION	PART NO.	DESCRIPTION
3	HEXAGON NUT	378	FILL HOLE RING
32	EYE BOLT ASSEMBLY	451	DISCHARGE PIPE FLANGE
161	SAFETY CHAIN	452(A)	2" DISCHARGE PIPE NIPPLE
261(A)	SAFETY VENT TOP	452(B)	2" AIR CONNECTION NIPPLE
261(B)	SAFETY VENT BOTTOM	458	2" DISCHARGE PIPE CAP
339	MANWAY COVER PLATE	723	GASKET
377	FILL HOLE COVER	756	FILL HOLE LOCK BAR

DOT Specification 103AW Tank Car for Sulfuric Acid

Source: GATX Tank Car Manual

Figure 3-4b



LOADING AND UNLOADING ARRANGEMENT AND TOP OPERATING PLATFORM FOR SULFURIC ACID CARS

PART NO.	DESCRIPTION	PART NO.	DESCRIPTION	PART NO.	DESCRIPTION
32	EYE BOLT	292	WASHOUT PLUG	459	TELL TALE PLUG & CHAIN
112	HAND RAIL	350	FLUED MANWAY NOZZLE		
211	CORNER POST	377	8" FILL HOLE COVER	460	STREET ELBOW
213	SUPPORT BRACKET	406	WASHOUT NOZZLE FLG.	464	ANTI-SKID COATING
215	PLATFORM GRATING	453	PIPE GUIDE	719	"O" RING
263	SAFETY VENT ASSEMBLY	454	EDUCTION PIPE	723	GASKET
276	1" AIR CONNECTION VALVE	458	PIPE CAP		

DOT Specification 111A100W2 Tank Car for Sulfuric Acid

Source: GATX Tank Car Manual

help remedy this problem.

The Department of Transportation has delegated responsibility for tank car design approval to the AAR. The FRA maintains oversight responsibility.

Following is a brief description of how the procedure works.

Essentially, an application for approval of designs and materials for fabrication must be submitted to AAR any time a tank car needs to be changed in any way or a new tank car is to be built. The extent of review is determined by whether the changes are minor or major. The most extensive review is conducted if the tank car will be of a "new and untried type."

The review is conducted by the Secretary (AAR Mechanical), the Bureau of Explosives and the Tank Car Committee. The Secretary has authority to process the application on behalf of the Tank Car Committee for a tank car with minor changes from a "precedent design." The full committee approval is needed for major changes. For new and untried types of tank cars, additional approvals are needed from the Brake Equipment Committee and the Car Construction Committee. For approval of identical cars, only one application is needed. For alterations, conversions or welded repairs using previously approved procedures and materials, only a report needs to be submitted. The FRA becomes involved when there are questions regarding safety appliances and any deviations from 49 CFR Part 179 on tank car specifications. These deviations require a DOT exemption.

Once the application is submitted, a formal procedure is applied to seek opinions of members of the Tank Car Committee and reach a decision based on majority vote with no vote. The applicant is permitted to a hearing if the application is disapproved.

The AAR approval procedure is quite elaborate and should catch any faults in the design. However, it is possible that some tank cars have been modified without AAR approval. For instance, a tank car owner may believe that a tank car needs only minor repair and that the repair procedure has been approved. Further, the tank car owner may decide, albeit incorrectly, the repair procedure is not worth filing the necessary papers with the AAR. In this case, a faulty design may get used leading to leaks in the future.

The major cause of leaks attributed to unsecured openings, according to many sources, is improper loading. This could be because an improper procedure is used or the proper procedure is not followed. One common problem is uneven torque among the bolts, or over torque on a bolt leading to bolt failure. This comes about because of not following the correct sequence of tightening or using air guns to tighten the bolts: a common practice even though it is prohibited by DOT.

There is no easy way to detect uneven or over torque of the closure bolts. On the other hand, stripped or corroded heads of nuts and bolts should be easy to detect.

Some commodities (such as sulfuric acid) are loaded hot in the car. When they cool down, the pressure inside the car reduces, pulling the covers (such as the manhole cover) in. This results in loosening of the bolts. The absence of a correct loading procedure under these circumstances can lead to an unsecured opening at a later time.

The root cause of many of these problems is that car loading/unloading is generally a low paying entry level job that does not attract or retain people who can get a higher paying job. Also, very often there is little training given to the people performing this sensitive job. Finally, the loaders may not be held directly liable for their action, so the incentive to do a perfect job may be lacking.

A common problem in many operations is whether the skill level of people performing the operation should be improved or the design of the equipment made simpler, and this operation is no exception. One can argue that the devices used for closing the openings should be made simpler to use, as discussed earlier. One can also argue that the skill level of people should be improved. It is hard to draw the line. Perhaps, improvements in each area should be sought to provide some redundancy.

Incipient leak conditions usually exist prior to an actual leak. These are conditions, which if not detected and remedied would lead to an actual leak. The failure to detect these conditions can be the result of one of two things:

- an inspection of the car was not performed, or
- an improper inspection was performed.

Some car loaders are not closely supervised and there are many stories of pre-signed inspection sheets. After the car has been loaded, they do not perform the inspection, or the inspection they perform is inadequate. It is quite natural for a person not to inspect the job he or she just completed under the belief that they did it properly the first time. Unless a stronger action is taken to remedy the action (such as transferring some liability of release to loading/unloading supervisor), this abuse may continue.

The inspection can be considered improper because either the inspection procedure itself is in some way deficient, or because an otherwise appropriate inspection procedure is not followed, possibly because proper tools are not readily available. In either case, all problems cannot be detected by the inspector.

A good procedure to detect leaks is to pressurize the tank car and observe if it holds the pressure. This procedure is not used very often.

Ordinary railroad operation can also lead to loosening of bolts and leakage since it is possible for the impacts and vibrations associated with normal operation to dislodge a cover which has not been properly fastened down. This, however, has not been commonly identified as the cause of unsecured opening leakage (as is the case with frangible disk rupture). Vibrations can result from either humping operation or operations while on the road.

3.2 Cause of Leaks Due to Gasket Failure

As discussed in Chapter 2, gasket failures account for a large number of non-accident releases from tank cars. Figure 3-2 shows the fault tree for causes of gasket failure.

Once again, the failure will occur if there is an incipient leak present and it is not detected. The incipient leaks can be attributed either to improper design, or to improper operation or installation.

The gasket specification can be improper due to several reasons:

- The material deteriorates or loses compliance (especially in view of having to use non-asbestos materials).
- Wrong size is specified.
- The gasket is difficult to align.

These are, however, not considered to be the major causes. The major problems are attributable to improper installation.

The gaskets are occasionally missing. Sometimes a wrong gasket is used, one that does not fit or one of improper material. This is likely to be more of a problem with a small shipper who lacks a full supply of gaskets that a large shipper is likely to have. FRA inspectors have often found shippers using gaskets made out of rubber sheets instead of the proper gaskets.

Also, the gasket can be improperly installed. In this case, either the gasket is not aligned properly by the loader when sealing the car, or the bolts are tightened in such a way that the gasket gets deformed. In the latter case, the leak is often classified under unsecured openings.

The major issue in leaks attributable to operation/installation is the uncertainty of responsibility. Although it is the shipper's responsibility to ensure proper integrity of the car, an occasional loader may not pay attention to components like gaskets or may not be aware of the likely consequences of an error.

The fault tree for the inspection is similar to that used earlier under unsecured openings. Only in this case it is probably even more difficult to catch a problem through inspection because a gasket, by its very nature, is hidden from view. Pressurizing the car may identify some of these problems.

3.3 Causes of Corrosion Leaks

Corrosion leaks can be caused by many factors. Figure 3-3 shows a fault tree diagram of the potential causes of this type of leak. Once again, like the other types of non-accident leaks, the release would take place if an incipient leak were present and not detected through inspection. Also, the leak can be attributable to operation, installation or design of the lining or other tank car components.

Before discussing the lining problems, let us review how the lining gets installed.

The tank car manufacturers contract the lining installation to a lining shop. These shops are generally subsidiaries of the large car manufacturers and any company can contract with them for lining installation. Interior linings in all cars are the responsibility of the owner unless the car is leased, in which cases the lessee is responsible. The major lessees/owners of tank cars that carry hazmat are petrochemical companies like Exxon and Chevron and chemical companies like DuPont and OxyChem. These companies have their own staff that specify what liners to use and which manufacturer is chosen. In the case of the purchase or lease of new cars, lining shops are subcontracted by the car manufacturers when a tank car is purchased. When an accident or repair work is needed, the chemical companies send their own crew to the site and actually inspect, then repair the damage.

In summary, the tank lining industry is complex involving liner manufacturer, lining installer, tank car manufacturer, tank car owner, tank car lessee and lining repair services. There does not seem to be any standardized procedure for the application of the lining, its repair or inspection. The only AAR regulation states that places of high wear must have double width, and liner integrity must be checked every two years or less. In practice, liner integrity problems are only discovered after a spill.

The code of Federal Regulations 49 CFR 179.201-3 deals with lined tanks. It specifies the thickness of the lining for different materials. There is no performance based specification for materials, except that it be resistant to the corrosive or solvent action of the lading in the liquid or gas phase and is suitable for the service temperatures. The regulation also specifies reporting and certification requirements. No test procedure is identified.

With this as background, let us look at the corrosion leaks attributable to design.

The design fault can be at the sump of the tank car or elsewhere. By design, we mean the specifications that would be sent to the AAR for approval. (Unless we follow some cases in a great deal of detail, it is difficult to determine if a particular problem was related to design or installation. These problems discussed here are therefore grouped into these two categories according to what we think to be the most likely cause.) One design-related problem that has been encountered is that the outlet pipe is too long and there is not enough room between the bottom end of the pipe and bottom of the sump. Such a pipe may contact the sump bottom during extreme bending of the tank car and, like a cookie cutter, remove a piece of the lining. Corrosion will occur and a leak will develop in such a case in a relatively short period of time.

It should be noted that there is insufficient evidence to determine whether these cases of lining cuts at the sump are caused by excessive roughness or whether they occur as a result of standard operations of the train. This is important because if leaks are caused by the former the responsibility for reducing leaks is with the railroad. If the leak is caused as a result of normal operations then the responsibility shifts to the car design and manufacture.

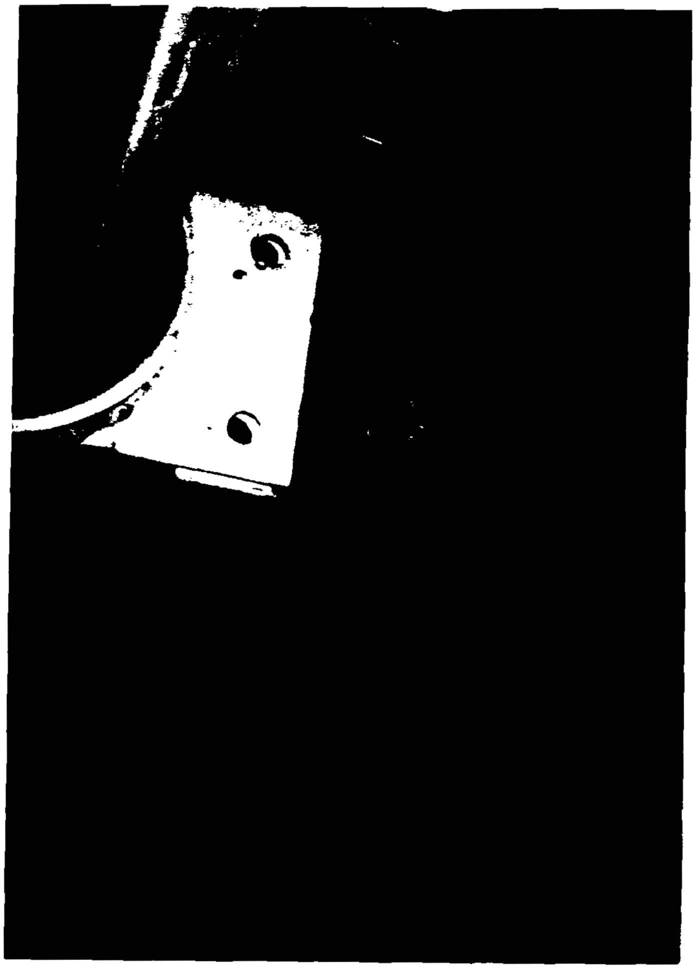
An improper design of a bracket may cause it to break in operation. Alternatively, it may allow the outlet pipe to deflect excessively, causing a break in the lining.

Improper design of a lining at the sump area may also cause problems. Figure 3-5 shows one situation in which the lining was applied to the bracket in such a way that, after a while the acid seeped into the gap between the lining and the tank and caused a leak as shown in the figure (here again, it is not clear whether this was a design fault or installation). In this case, the corrosion reaction was probably accelerated due to galvanic action caused by two dissimilar metals (316 stainless steel bracket and carbon steel shell) connected in the presence of a corrosive liquid. In such situations, the more chemically active metal (carbon steel shell in this case) experiences accelerated corrosion. Due to the corrosion reaction, the carbon steel shell was severely pitted and a hole developed.

The design fault could also be at other areas of the tank. Either use of improper lining material or improper design of the lining could lead to problems. Generally,

Figure 3-5

Leak Due to Improper Lining at Sump and Resulting Corrosion



Outlet Pipe Bracket
where Liner has Peeled Away

Resulting
Corrosion

the material of the lining undergoes "normal" deterioration due to reaction with the acid over an extended period.

A number of degradation modes are possible. Two possible examples are:

1. The liner reacts with the acid to form a compound that has lower strength and ductility than the unreacted areas. Repeated stress cycles (due to heat, car flexing, etc.) cause these regions to fracture. After fracture, fresh regions of the liner are exposed to react with the acid. Over time, the cracks penetrate the liner.

2. The acid may react with the cross-linking agent in the liner compound to reduce the strength of the cross-link bonds. Repeated stress cycles produce a liner failure as discussed above.

Acid degradation is complicated because each acid reacts differently with the various liner materials. What works well with hydrochloric acid may not work well with phosphoric or sulfuric acid. In addition, the <u>exact</u> method of rubber/elastomer compounding (processing history) will influence its resistance to degradation.

As before, the problems may not be detected in the AAR approval process or the AAR approval may not even be sought. In either case, the problem can manifest itself into causing a leak.

The problem of corrosion leak can be attributed to faulty installation also, either at the sump or elsewhere in the tank.

One problem at the sump is that the outlet pipe is installed eccentric to the sump. Figure 3-6 shows one such situation. The eccentric pipe can contact the lining, puncturing it and causing corrosion, as shown in the picture.

Poor welding of a bracket can lead to bracket failure and the pipe being unsupported. This is another likely cause of the situation shown in Figure 3-6. The bracket appeared to have failed due to corrosion of exposed welds. (Proper welding procedures would prevent such failures.)

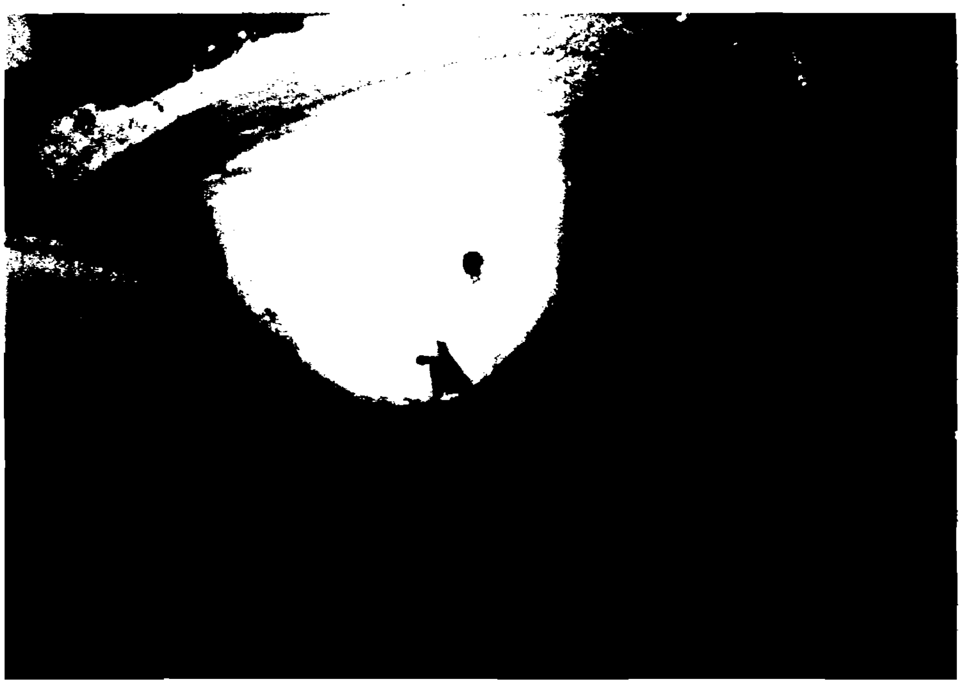
Similarly, improper lining installation elsewhere can also cause a problem. In at least one situation, a head of a tank car was replaced and the tank car was delivered without the lining on the head. Needless to say, a leak took place rather soon. A problem can also arise due to poor patching of the lining subsequent to a repair.

Finally, problems may arise due to operations. Again, sometimes it is a matter of controversy whether the cause was improper operation or improper design/installation. The "cookie cutter" problem, mentioned earlier, can arise if the pipe was too long for a given operation or if the operation was too rough for a given pipeline. Heat (or cold weather) could also cause lining failure, but it was never mentioned as a major cause in our discussions with the industry people. The maximum temperature recommendations for rubber linings appear to be around 175 degrees fahrenheit. The degradation of the lining will accelerate as this temperature is approached. Loading of improper material in a tank car with a lining not designed to survive that material can lead to a corrosion failure also.

Figure 3-6

Leak Due to Eccentric Outlet Pipe and Broken Bracket and Resulting Corrosion

Eccentric Outlet Pipe



Resulting Corrosion Leaks

It is likely that proper inspection can detect an incipient leak. As mentioned above, the lining of acid cars will deteriorate and inspection is recommended to alleviate the problem.

One method to perform inspection on certain types of hard linings (not rubber) is acoustic emission. This is a non-destructive technique that records sounds emitted by a crack or flaw in a stressed structure. A computer is then used to analyze the severity and pinpoint the location. In a method used by Physical Acoustics Corporation of Princeton, NJ, up to 30 sensors are mounted on the tank which is stressed in two ways: by filling with gas or liquid and by jacking the underframe. The first test identifies flaws in the tank, the second in the saddle, sills and head blocks. A typical test takes from 2-4 hours depending on the car.

Another method that is being used utilizes a measurement of conductivity between the top part of the liquid in the tank car and outer surface of the car. Any increase in the conductivity from normal may indicate a breach in the lining.

The lining of an empty tank car can be tested by a spark tester. A high voltage probe is passed over the lining. A breach in the lining causes sparks between the probe and the tank car.

A variety of methods are therefore now becoming available to determine the incipient leak. A proper inspection using an appropriate technique can prevent the corrosion leak from happening.

3.4 Correlation Between Type of Leak and Cause of Leak

The fault tree analysis presented in this section provides likely causes of leaks due to unsecured openings, gasket failure or corrosion, three main causes of non-accident leaks not attributable to frangible disks. This information was combined with the historical data presented in Table 2-8 to prepare a list of most likely causes for each type of release.

This list is provided in Table 3-1. As can be seen, in our judgment, most of the leaks attributed to unsecured openings are caused by improper loading, most of the gasket failures due to using improper material or undetected normal material deterioration, and most of the corrosion leaks due to undetected normal material deterioration or poor lining application.

In the next chapter the potential mitigation measures to reduce the number of leaks of this type are presented.

Table 3-1

Most Likely Causes of Leaks of Specific Types
Period: 1985-1989
(Source: FRA and AAR)

Type of Leak	Percent of Total	Most likely Causes
Unsecured Openings		
Bolts loose	38.0	Improper loading Faulty closure design
Bolt missing	1.1	Improper unloading Improper loading
Plug/cap off	1.4	Improper loading
Plug/cap loose	12.5	Improper loading
Item warped	0.3	Improper loading
Gasket Failures		
Deteriorated	19.8	Improper material Material deterioration
Cut	0.8	Improper securement Heat/pressure
Dislodged	2.0	Wrong size gasket Improper alignment
Corrosion Leaks		
Liner failed	10.5	Improper material Poor lining application No lining applied
Liner cut	0.8	Outlet pipe too long Railroad operation too rough Outlet pipe eccentric
Patch failed	0.8	Improper material Poor patch application
Bracket broke	0.3	Poor bracket weld

4. Mitigation Measures

The potential mitigation measures to reduce the incidence of releases due to unsecured openings, gasket failures and corrosion are discussed in this chapter. As in the previous chapter, the discussion is along the lines of type of release, although there may be some overlaps. For each measure, we have provided some estimate of cost in terms of high (H), medium (M) and low (L).

4.1 Unsecured Openings

It seems that the most common cause for leakage due to unsecured openings is improper loading. Therefore, the most effective measures that will address that problem are:

- Enforce personal liability issue. (L)
- Increase the importance of the loader's job through career path or salary adjustments. (M-H)
- Certify loaders/unloaders via educational course. (H)
- Supply shippers/receivers with a package of educational materials and instructions. (M)

Of course, any improvements in the design of the closure will make them more foolproof and provide redundancy. Examples are:

- Examine the trade-offs involved with designs requiring simpler closing operation (such as a lock bar with an eyebolt) vs. those requiring a more complex operation (e.g., four eyebolts). (H)
- Improve the material for bolts/nuts used in the cars carrying corrosive materials. (L)

Since proper inspection can catch many problems associated with unsecured openings, improvements in inspection procedure that may be effective in reducing these type of releases are:

- Create explicit policy and procedures for job performance with disciplinary measures for non-performance. (L)
- Create a cross-check system via inspection control so that the car cannot be released until the inspection report has been reviewed. (L)
- Develop an inspection form that is easier to fill out and requires a minimum of physical effort — based on a time/motion study. (L)

There are additional mitigating measures that are likely to be less effective and harder to implement than those mentioned above. These deal primarily with improving railroad operation and the AAR approval procedure.

4.2 Gasket Failures

Most of the gasket failures take place at the manhole cover and most of the time they are classified as deteriorated. This means that the following mitigation measures are likely to be effective:

- Conduct research in deterioration of gasket materials (non-asbestos) to develop more resilient materials. (M)
- Develop a foolproof system (e.g., reliable color coding) to prevent a wrong gasket from being used. (L)
- Investigate the pros and cons of using a permanent gasket formed by folding the lining over the opening (the pros — the gasket will always be there and of correct material; the cons — the deterioration of the gasket will mean relining the tank or creating a patch). (L)

Since the gaskets of the openings used during loading/unloading are generally installed by the loader, the mitigation measures mentioned earlier to improve the loading procedure and loader quality will apply here as well.

Improved opening design to prevent gaskets being misaligned or improperly secured will make some difference, but since the incidence rate of cut or dislodged gaskets is very small, these measures are unlikely to be very effective. Also, since it is difficult to inspect the gasket once installed, increased inspection at that stage is unlikely to improve the situation.

4.3 Corrosion Leaks

By far the most common corrosion problem is the failure of the liner at the wall (the failures at the sump are much less common). Therefore, the mitigation measures should be targeted to improving the lining material and improving the application method (or, more likely, the consistency).

- Perform extensive research and testing on long-term effects of various corrosive materials on lining to put together a document describing recommended material for the various materials (the National Association of Corrosion Engineers — NACE — does similar work to develop recommended metals and non-metals for corrosive applications, especially with regard to oil field and pipeline equipment). (M)
- Investigate the variations in the methods used by the lining installers to determine the correlation between the lining failure and application method. Identify and help standardize the best method. (M)
- Require installation and replacement of lining at shops using standardized procedures only (as determined, say, by AAR approval). (M)
- Require the shippers to conduct a thorough inspection of the lining prior to first use after repair, modification or building of a tank car. (L)

Improved inspection of the lining is also likely to be very effective in preventing lining failure caused leaks (unlike those related to gasket failure). Therefore, the following measures will also be effective:

- Improve the state-of-the-art in lining inspection. This includes improving the spark tester so that it can predict incipient problems under a variety of conditions. (L-M)

- Increase the usage of the conductivity measurement method — currently only a few shippers seem to be using this method. (L)

- Issue guidelines on liner wear, suggested replacement milestones, and what to look for regarding damage and wear. (L)

The corrosion leaks in the sump area have received some attention. However, the number of leaks due to bracket or cut in the liner at the sump are not too many. Thus, the following mitigation measures are not likely to be as effective as those discussed above.

- Investigate the use of a non-metallic, flexible outlet pipe (deterioration rate, cost, benefits, etc.). (M)

5. Excess Flow Valves on Propane Cars

The University of New Brunswick FIRE SCIENCE CENTRE was contracted by Arthur D. Little, Inc., Cambridge, Massachusetts (on behalf of the United States Federal Railroad Administration of the Department of Transportation) and Transport Canada (Transport of Dangerous Goods Directorate) to conduct full-scale field testing to determine the effectiveness of emergency shut-off valves (ESV) during LPG rail loading/unloading operations when full rupture of the transfer hose occurs. This work is complimentary to an extensive research program being conducted by the Fire Science Centre into safety aspects of the transport and storage of pressure liquefied gases sponsored by Transport Canada, the Natural Sciences and Engineering Research Council and others. The research program is designed to understand the basic thermohydraulics of pressure liquefied gas containers under a variety of accident conditions and to develop methods to minimize risk and damage in hazardous incidents.

5.1 Introduction

The basic requirement under the test series is to evaluate ESV protection in situations where total rupture of the loading/unloading line occurs. ESV protection on the loading/ unloading hose is recommended under NFPA 58 (3-2.7.9)[1] and CAN/CGA B149.2 M86[2]. Total rupture of the hose may occur with the accidental movement of the car during filling or unloading operations, adjacent yarding or humping operations, and/or fire "burn through".

The internal loading/unloading system for standard Class 112 LPG tank cars consists of a U-shaped eductor tube open at the bottom, fitted with an excess flow check valve in each limb prior to the external placement on the dome manway cover, of liquid line angle valves. The valves are welded to the eductor pipe and the inside of the dome cover. The liquid line angle valves are bolted and sealed to the exterior of the dome cover. Figure 5-1 illustrates the general arrangement of the fittings on a standard Class 112 tank car.

The purpose of the excess flow check valves on the tank car is to protect the container and product during transportation. The device is not designed for nor intended to be a constituent of any loading or unloading system [G. Heuchan, Procor, personal communication, 1989].

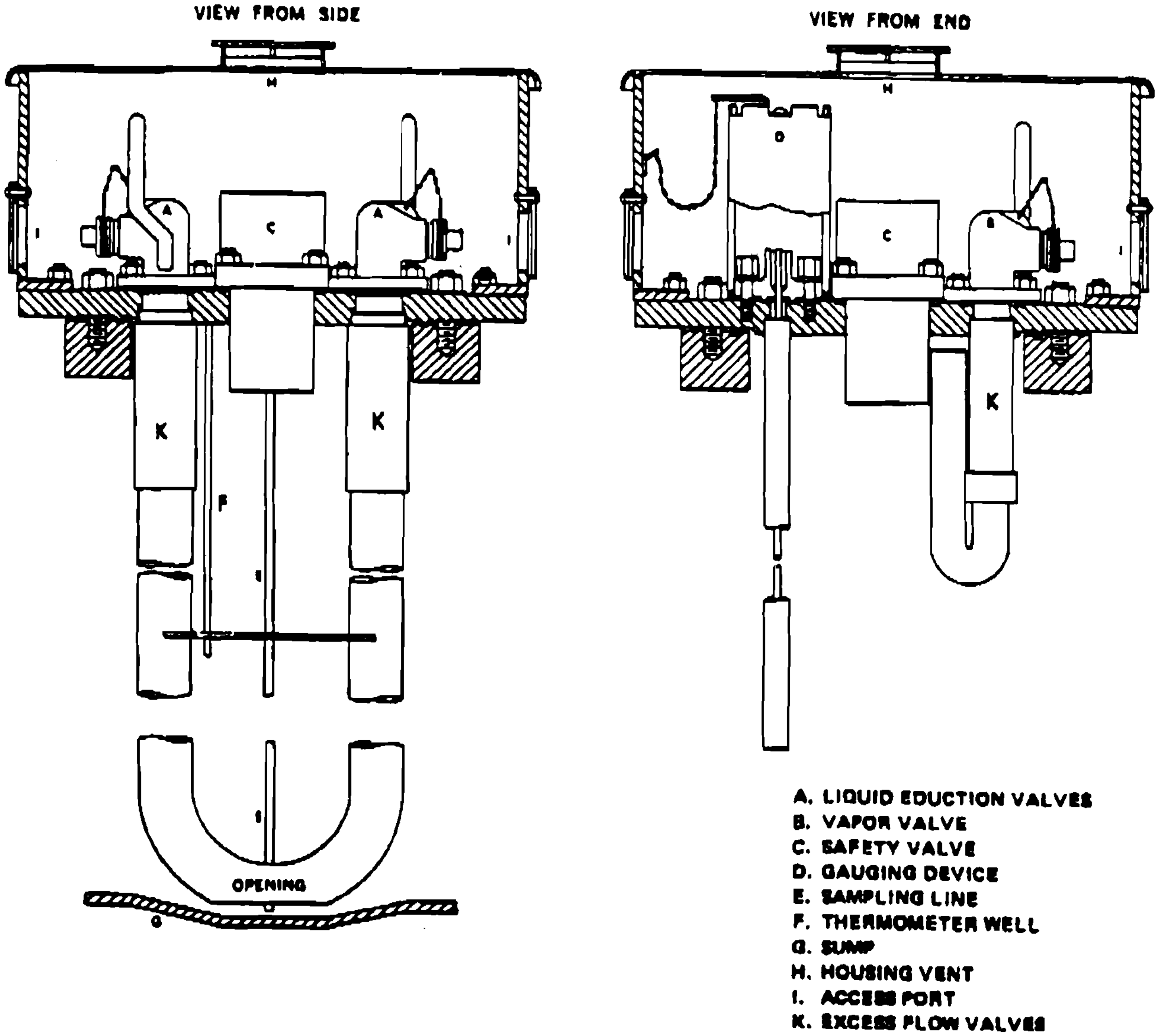
It is necessary that each plant site provide the necessary loading or unloading arrangements for the efficient transfer of product, protection of plant and equipment, and safety of all personnel.

NFPA 58 and CAN/CGA regulations call for ESV protection on both sides of the transfer hose or piping. One type of recommended unloading hose connections and fittings is shown in Figure 5-2. There are two liquid transfer hoses and one vapor hose. Usually, three ESVs, similar to that shown in Figure 5-3, are utilized on the hoses, two on the liquid lines and one on the vapor line. Three additional ESVs

[1]Anonymous. 1986. NFPA 58 Standard for the Storage and Handling of Liquefied Petroleum Gases: 1986. National Fire Protection Association, Batterymarch Park, MA.

[2]Anonymous. 1986. National Standard of Canada, Propane Installation Code. CAN/CGA-B149.2-M86. Canadian Gas Association, Don Mills, Ontario.

Figure 5-1

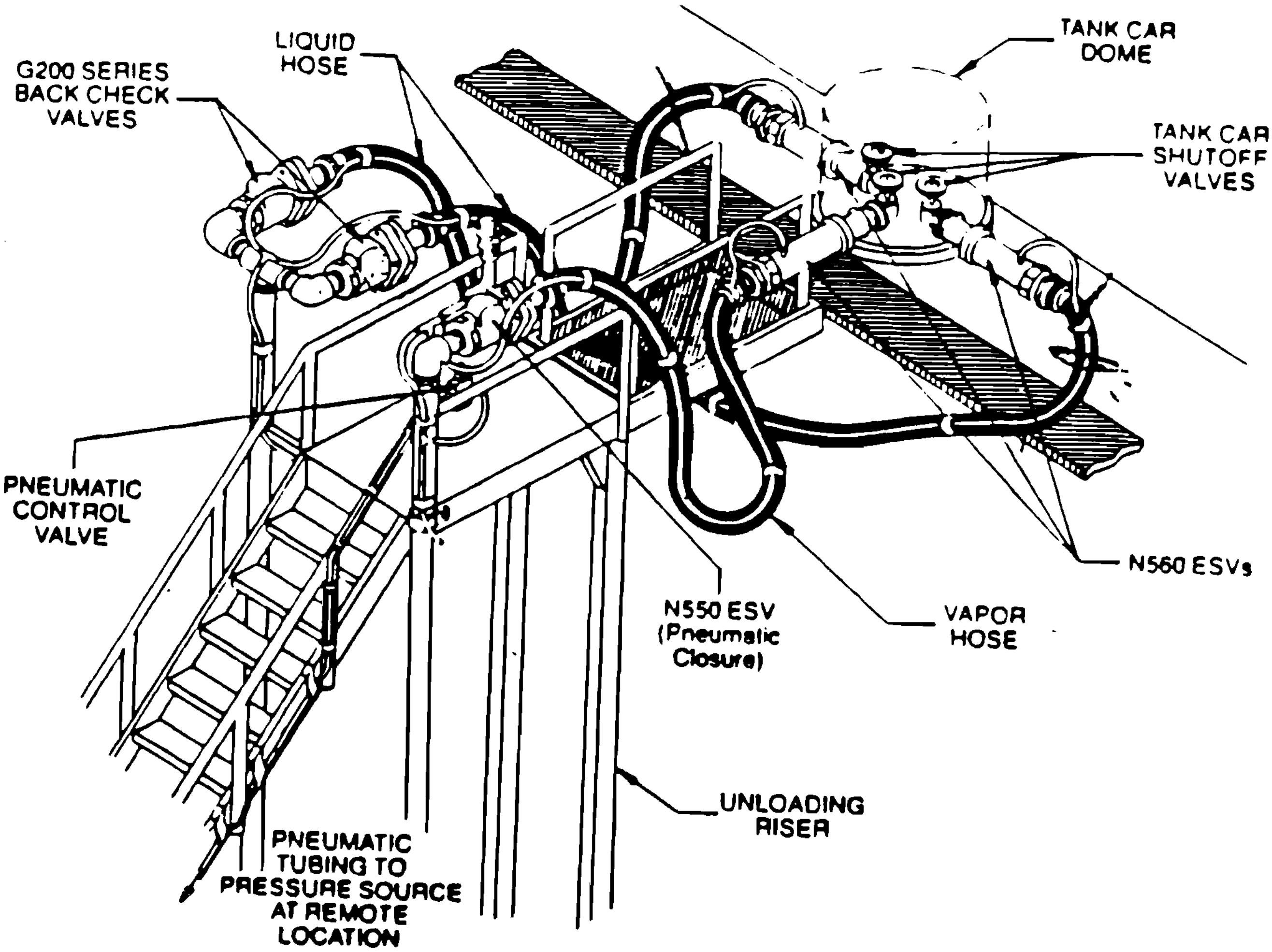


Housing and Fittings Arrangement for a CTC 112J340 Tank Car used for such Ladings as LPG and Anhydrous Ammonia

(Figure 5-4) are to be located at the hose end in the riser. Operational elements having pneumatic, manual and thermally-operated release mechanisms are recommended. The purpose of the ESVs is to prevent product discharge from either the tank car or the plant in the event of transfer hose rupture.

The hose end type ESV (Figure 5-3) is a pneumatically-opened and closed emergency shut-off valve. The valves incorporate additional thermal protection using a fuse plug which melts if exposed to 100°C. When the plug melts, pressure can escape from the piston chamber; closing the valve.

Figure 5-2



Installation Schematic of N560 and N550 ESVs and Related Equipment on an Unloading Riser (Courtesy Fisher Controls)

An excess flow valve is also incorporated into the design. The excess flow spring usually has a closing flow of 200 GPM for flow from the tank car.

The riser hose end type of ESV should also be a pneumatically-operated emergency shut-off valve. It may, however, be remotely- and manually-operated by a cable, as in Figure 5-4. A fuseable element which melts upon fire exposure, allows the poppet shaft to turn, closing the valve.

5.2 The Problem

In some situations, ESVs have not been fitted to both ends of the loading/unloading hoses. If complete hose rupture occurs and the excess flow check valves on either the tank car or loading/unloading riser fail to function, large quantities of LPG will be released, resulting in an extremely hazardous situation. Additionally, if product

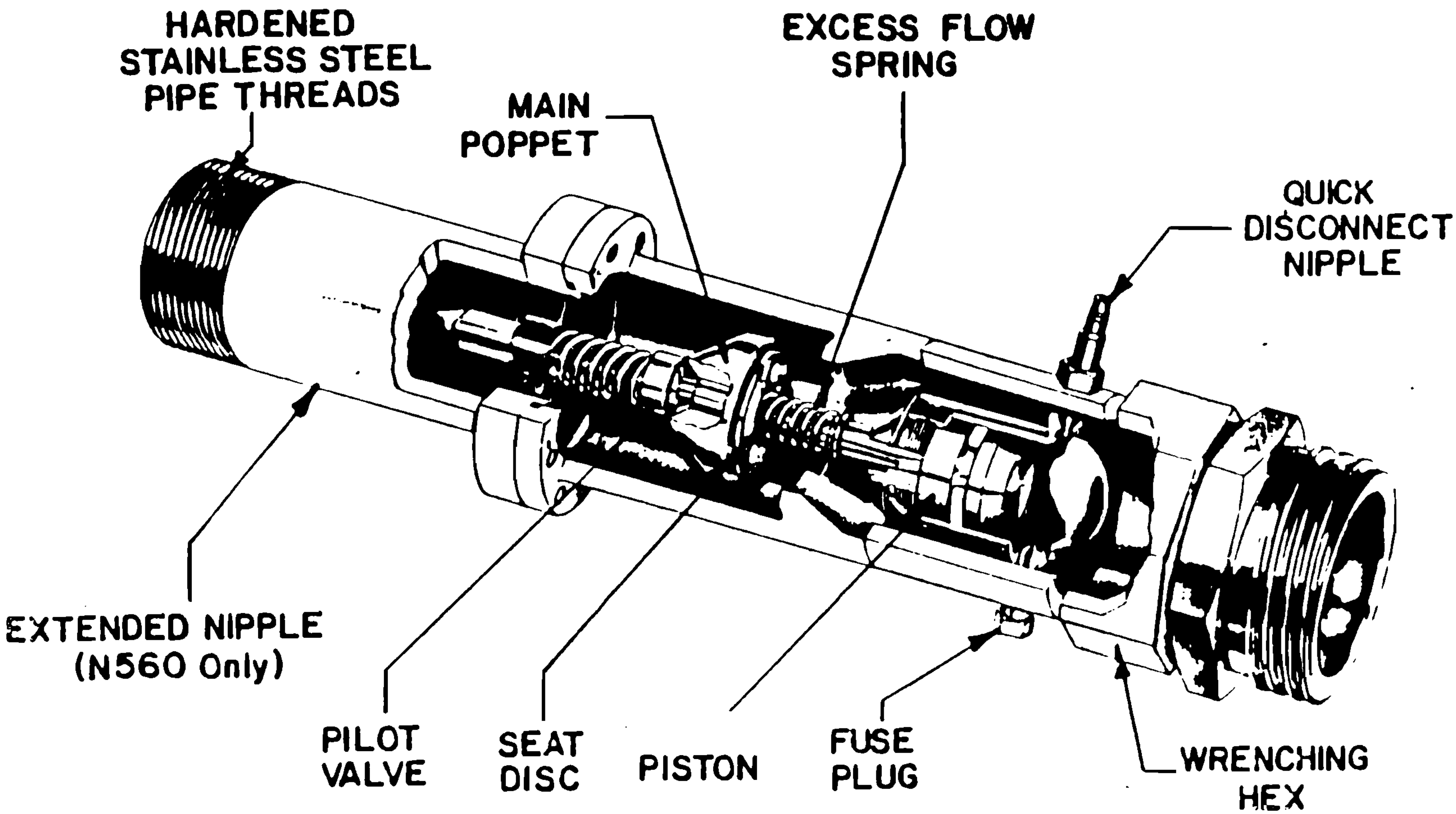


Figure 5-3
Hose End ESV (Fisher N560)

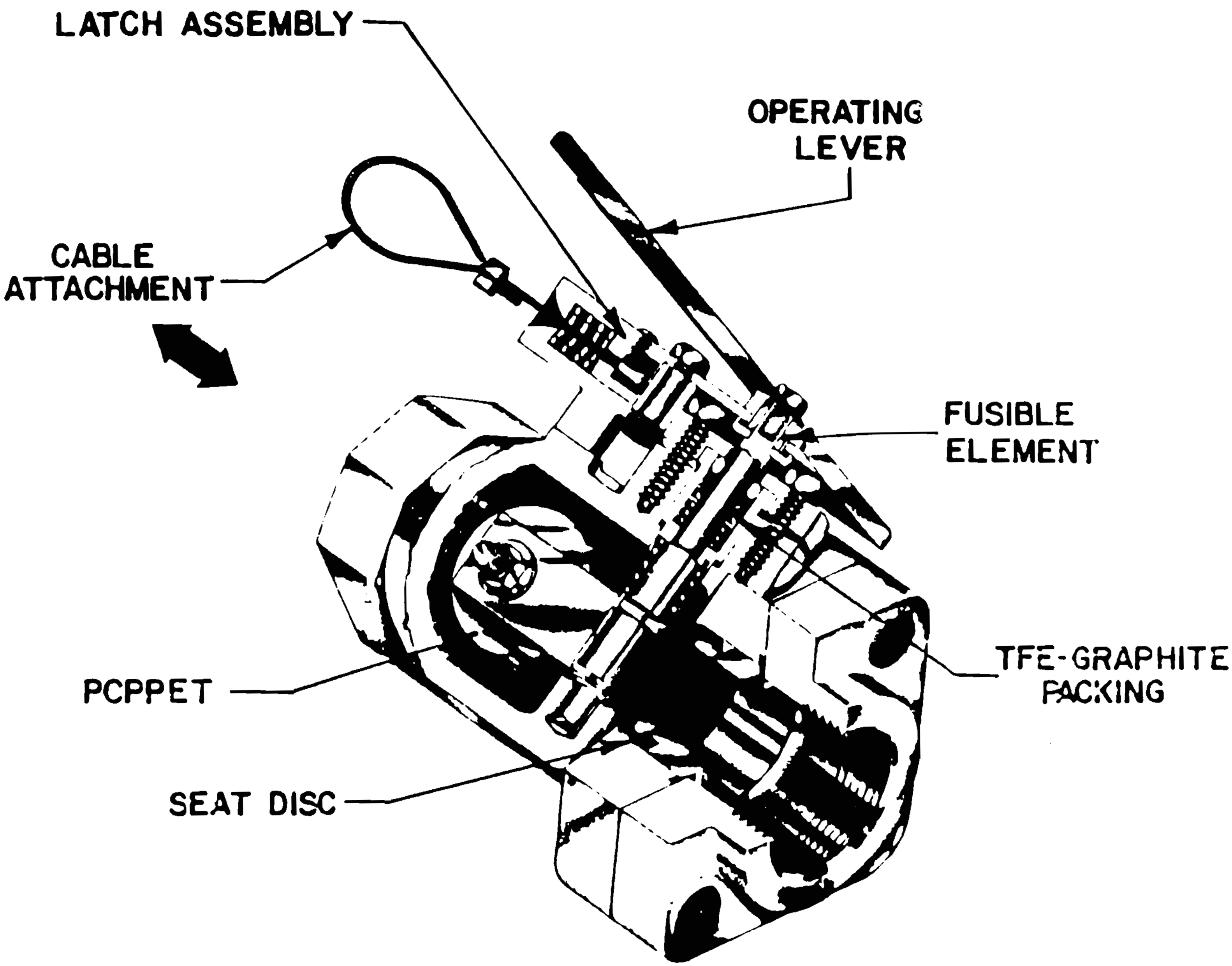


Figure 5-4
Riser Hose End ESV (Fisher N550)

loss occurs through a smaller hose fracture, flow may be insufficient to activate the excess flow valves.

The series of tests described here will illustrate the necessity of ESV placements at both ends of the loading/unloading hose assemblies.

5.3 Methodology

The upper half of one limb of an LPG eductor system complete with tank car excess flow check valve, shut-off valve and all normal fittings, was fabricated from components supplied by Procor. The overall test layout is shown in Figure 5-5. This assembly was affixed to a structural steel assembly and connected to a 45 m long, 50 mm diameter supply/return line provided from one LPG road tanker. The connection from the eductor assembly consisted of a length of 50 mm diameter pipe to simulate the flexible hose assembly. Provision was made for the tank car connection end of the simulated hose to be fitted with a pneumatically-controlled ESV. The other end of the simulated hose length also had a manually-operated ESV for control which was connected to a second LPG road tanker via a return length of 50 mm piping. The central portion of the simulated hose line was designed to simulate a full break hose rupture using a remotely-controlled full-opening three-inch diameter pneumatically-operated valve. Propane vented through this valve was flared from an expansion duct using pilot ignition sources (Figure 5-6).

Four tests were conducted with fully established flows between the tankers:

a) loading (i) with and (ii) without the ESV; and
b) unloading (iii) with and (iv) without the ESV.

Measurements of flow and selected line temperatures were made throughout the test period utilizing a HP 85-controlled HP3497A voltmeter switching data acquisition unit (Figure 5-7). Time-synchronized and other videos were recorded.

The tests were conducted on the demolition range of Canadian Forces Base (CFB) Gagetown with the assistance of Atlantic Speedy Propane, Irving Oil Ltd., RST Industries, and the Explosive Ordnance Disposal Centre, CFB Gagetown. The date of the tests was August 25, 1989; local weather conditions are given in Table 5-1.

5.4 The Experimental Procedure

The test procedure consisted of simulating a possible accident situation. Hose rupture, whether the result of tank car "pull away", localized fire exposure or wear and fatigue failure, is one of the most severe conditions that can be experienced in the loading/unloading area.

For each of the four tests the simulated rupture was initiated after adequate flow had been established between the two tankers. Figure 5-5 depicts the piping and component layout as well as the instrumentation. Dependent upon the chosen flow direction, one or other of the tankers was pressurized to approximately 150-200 kPa(g) (20-30 psid), utilizing a mobile vapor compressor extracting vapor from one tanker and transferring it to the other. The established liquid flow was monitored by two calibrated flow meters (A,B) located in the transfer lines adjacent to the road tankers. Copper constantan thermocouples at the flow meters (Ta,Tb) and on the

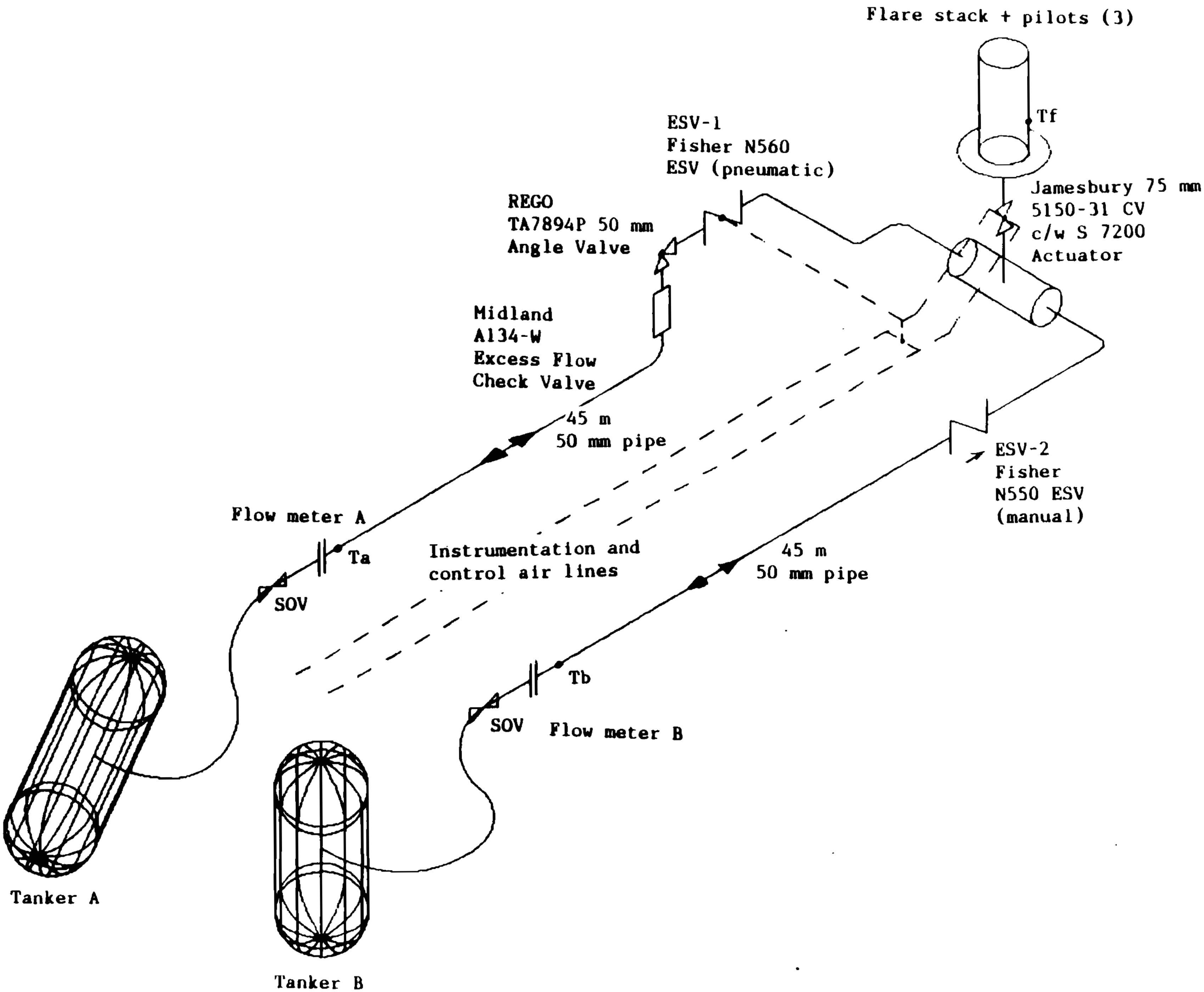


Figure 5-5
Line Diagram of Test Layout

Figure 5-6

Propane Flare During Vent

discharge vent line (Tf) were monitored to indicate fluid temperatures at these locations. Simultaneous control on the three inch ball valve simulating the break and the pneumatic ESV-1 was initiated at the instrumentation point. Manual control of ESV-2 was initiated after the flare of LPG was established.

The tests conducted are tabulated in Table 5-2.

5.5 Test Results and Comparisons

A discussion of the results follows for each test.

Table 5-1

Weather conditions, August 25, 1989
(a) Taken at the Fredericton Airport Weather Office (18.2 km from test site)
11:00 - Northwesterly 27 km/hr (51 km/hr)* 12:00 - Westerly 27 km/hr (49 km/hr) 13:00 - Northwesterly 29 km/hr (58 km/hr) 14:00 - Northwesterly 32 km/hr (59 km/hr) 15:00 - Northwesterly 32 km/hr (50 km/hr) 16:00 - Northwesterly 27 km/hr (51 km/hr)
Ambient temperature 10-15°C; clear skies with some high clouds.
(b) Taken at Building L4 (Helicopter Pad), CFB Gagetown (9.3 km from test site)
11:00 - Westerly 39 km/hr (50 km/hr) 12:00 - Westerly 40 km/hr (55 km/hr) 13:00 - Westerly 40 km/hr (63 km/hr) 14:00 - Westerly 44 km/hr (55 km/hr) 15:00 - Northwesterly 26 km/hr (44 km/hr) 16:00 - Northwesterly 35 km/hr (50 km/hr)
Ambient temperature 10-15°C; clear skies with some high clouds.
* Velocities in brackets indicate wind gusts within the last 15 minutes

5.5.1 Test 1. Flow A —> B; fitted pneumatic ESV-1

This tested the unloading from rail tanker to refinery line. The test was conducted with pneumatic (ESV1) and manual trip (ESV2) emergency shut-off valves installed. ESV activations were essential to the safe close down of the flow of product from both lines (i.e., from the tanker and the plant).

The test commenced at 11:58 with a flow established from tanker A to B prior to initiation of the release. At 135 seconds, the 75 mm Jamesbury and 50 mm Fisher N560 valves were simultaneously actuated. Indicated flow in line A peaked at over 300 USGPM (Figure 5-8) followed by a gradual indicated shut-down over 115 s. Flow in line B briefly continued until manual closure of ESV-2 was initiated. Subsequent evaluation of the flow metering indicated very low steady transfer flow rates and a problem with the interconnection valving and lines to permit flow meter B to function for flow in either direction. The temperature records and video analysis additionally indicated that full liquid flow had not been attained, perhaps due to inadequate prior transfer of liquid between tankers. The temperature record at the

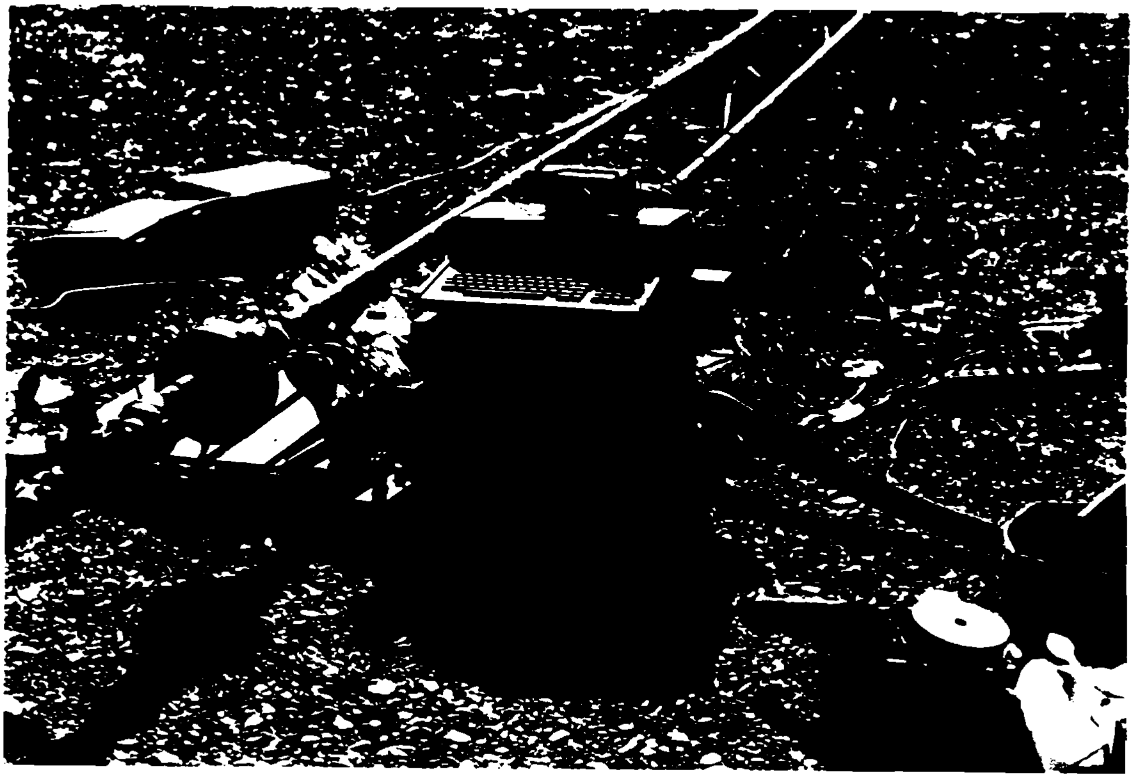


Figure 5-7

Data Acquisition System and Flow Metering Stations

Table 5-2

Tests conducted on August 25, 1989

Test # and Time	Flow Direction	Comment
1 (11:58)	A ---> B	ESV-fitted manual shut-off
2 (12:19)	B ---> A	ESV-fitted manual shut-off
2a (12:49)	B ---> A	ESV-fitted manual shut-off
3 (13:10)	B ---> A	No ESV
4 (13:35)	A ---> B	No ESV

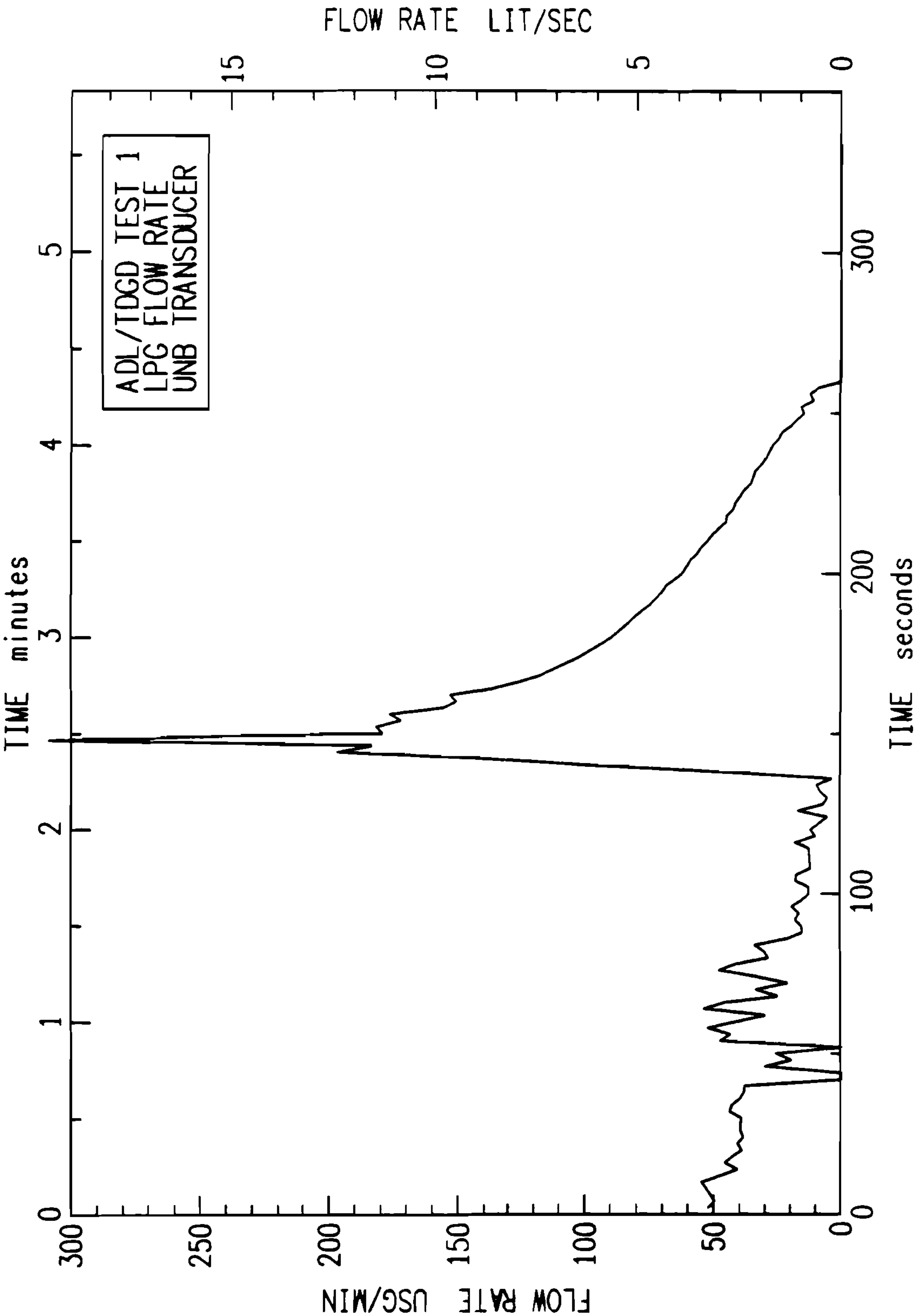


Figure 5-8

Test 1, Flow A —> B, LPG Flow Rate, Measuring Station A

flare (Tf) did not indicate any significant depression, such as should have occurred with flashing flow.

5.5.2 Test 2. Flow B —> A; fitted pneumatic ESV-1

Tests 2 and 2a tested the loading of a rail tanker from refinery line. The tests were conducted with pneumatic (ESV1) and manual trip (ESV2) emergency shut-off valves installed. Break was initiated at flow rates of 160-175 USGPM. ESV activations were essential to the safe close down of the flow of product from both lines.

The test commenced at 12:19 with a steady flow established between tanker B and A of approximately 175 USGPM commencing at 500 s (Figures 5-9 and 5-10). At approximately 700 s the Jamesbury valve and pneumatic ESV-1 were actuated, followed by an immediate manual shut-off of ESV-2. Flow in line A ceased upon ESV-1 activation while that in line B indicated a flow of 300 USGPM prior to shut-down by ESV-2. The temperature records confirmed that flashing two-phase flow from line B was responsible for the recorded Tf depression.

5.5.2.1 Test 2a. Flow B —> A; fitted pneumatic ESV-1

The test commenced at 12:49 with a steady flow of approximately 160 USGPM established between tanker B and A at 90 s. The flow in line A continued with significant oscillation until 158 s when there was an apparent activation of ESV-1, due perhaps to a loss of pressure in the pneumatic ESV activation line. Flow immediately appeared to cease in the line (Figure 5-11). Flow appeared to continue in line B for a further 25 s after this event prior to the opening of the Jamesbury valve (Figure 5-12). Upon opening of this valve, flow in line B peaked at 240 USGPM and rapidly reduced to about 100 USGPM. The flow was flared off for approximately 28 s prior to manual closure of ESV-2. Figure 5-13 illustrates the extent of flashing flow and the flare.

5.5.3 Test 3. Flow B —> A; no ESV-1

Test 3 tested the loading of a rail tanker from a refinery line. The tests were conducted <u>without</u> a pneumatic and <u>with</u> a manual trip (ESV2) emergency shut-off value installed. Break was initiated at a flow of 160 USGPM. The tanker excess flow valve immediately self-activated by flow reversal; however, manual activation of ESV2 was required to shut off flow from refinery.

The test commenced at 13:10 with a steady flow of approximately 160 USGPM established over the period 110 to 140 s between tanker B and A (Figure 5-14). At 140 s the simulation of hose rupture occurred. Flow in line A appeared to stop with activation of the tank car excess flow check valve. Flow in line B was manually terminated after 5 s with ESV-2 (Figure 5-15). Upon completion of the test, it was necessary to open the excess flow check valve by closing the tank car angle valve, allowing pressures to equalize on both sides of the excess flow check valve.

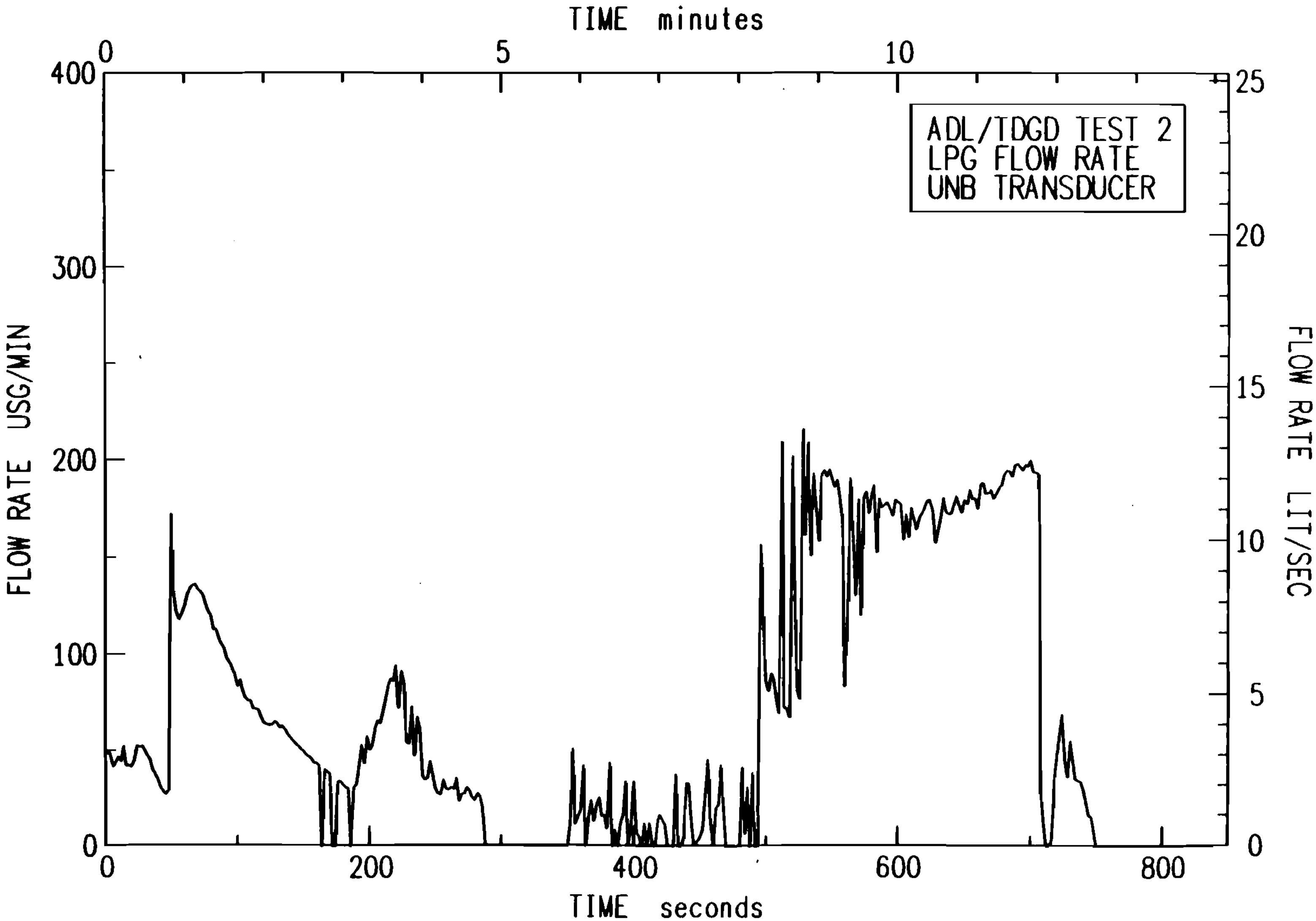


Figure 5-9

Test 2, Flow B —> A, LPG Flow Rate, Measuring Station A

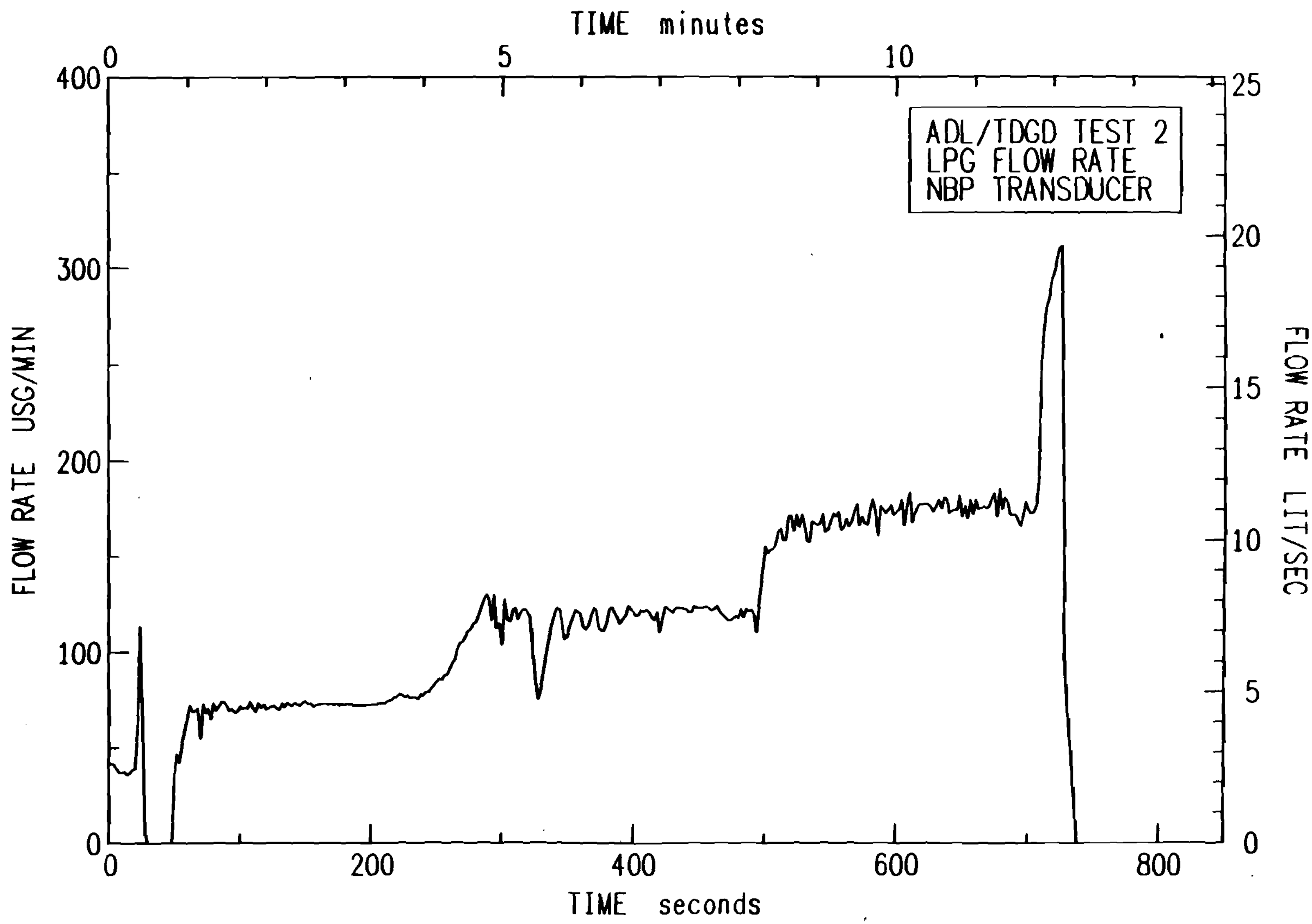


Figure 5-10

Test 2, Flow B --> A, LPG Flow Rate, Measuring Station B

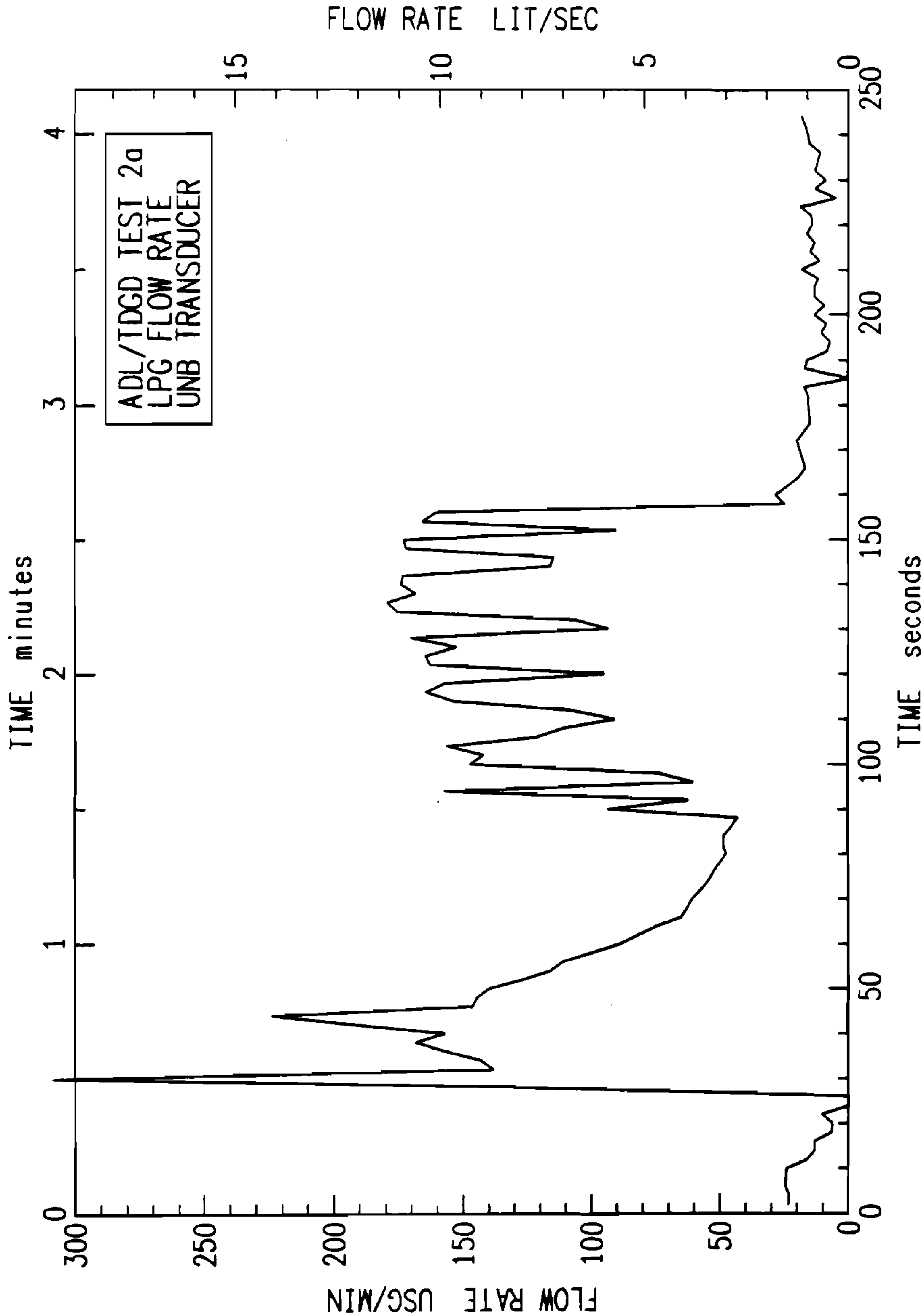


Figure 5-11

Test 2a, Flow B —> A, LPG Flow Rate, Measuring Station A

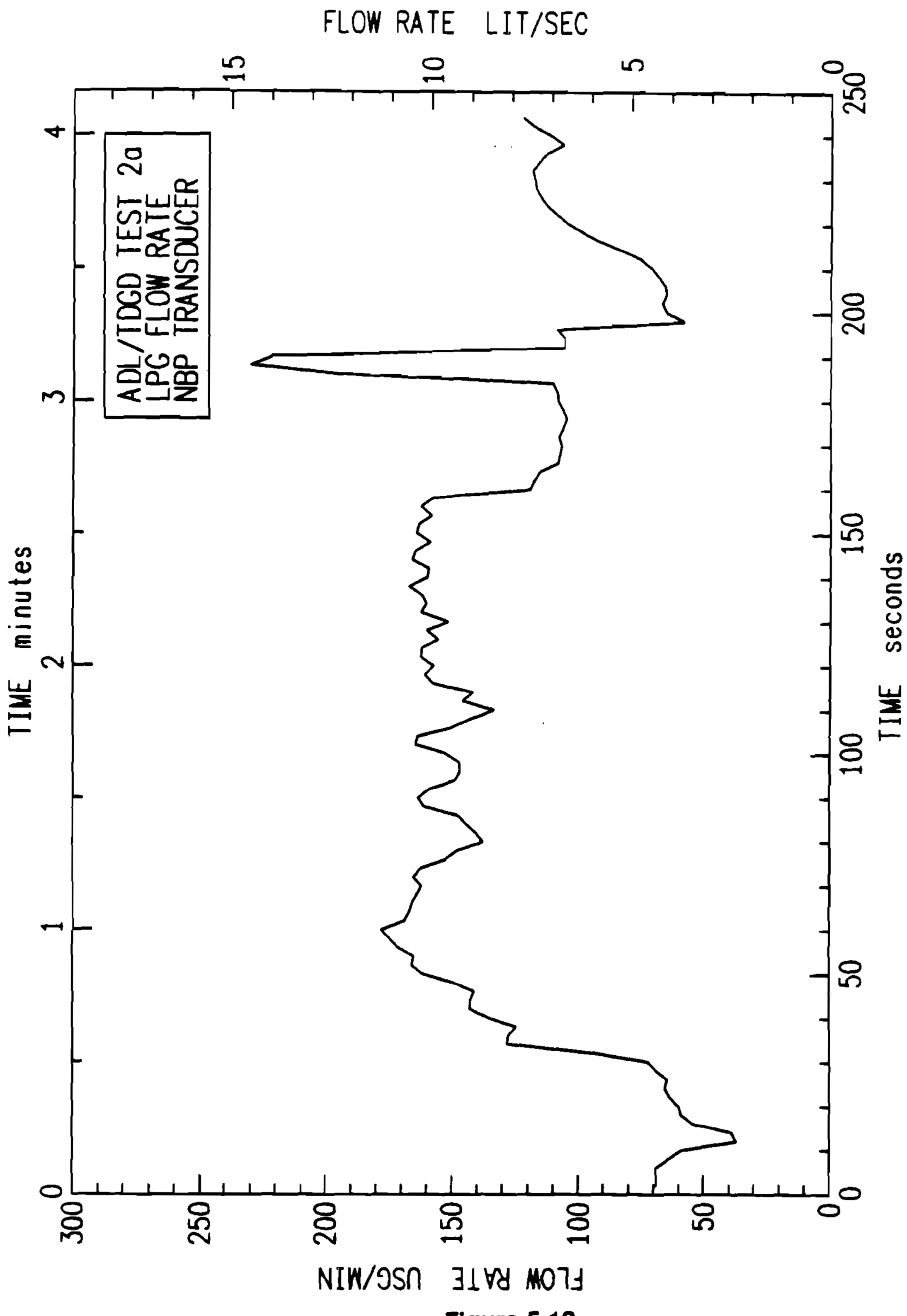


Figure 5-12

Test 2a, Flow B —> A, LPG Flow Rate, Measuring Station B

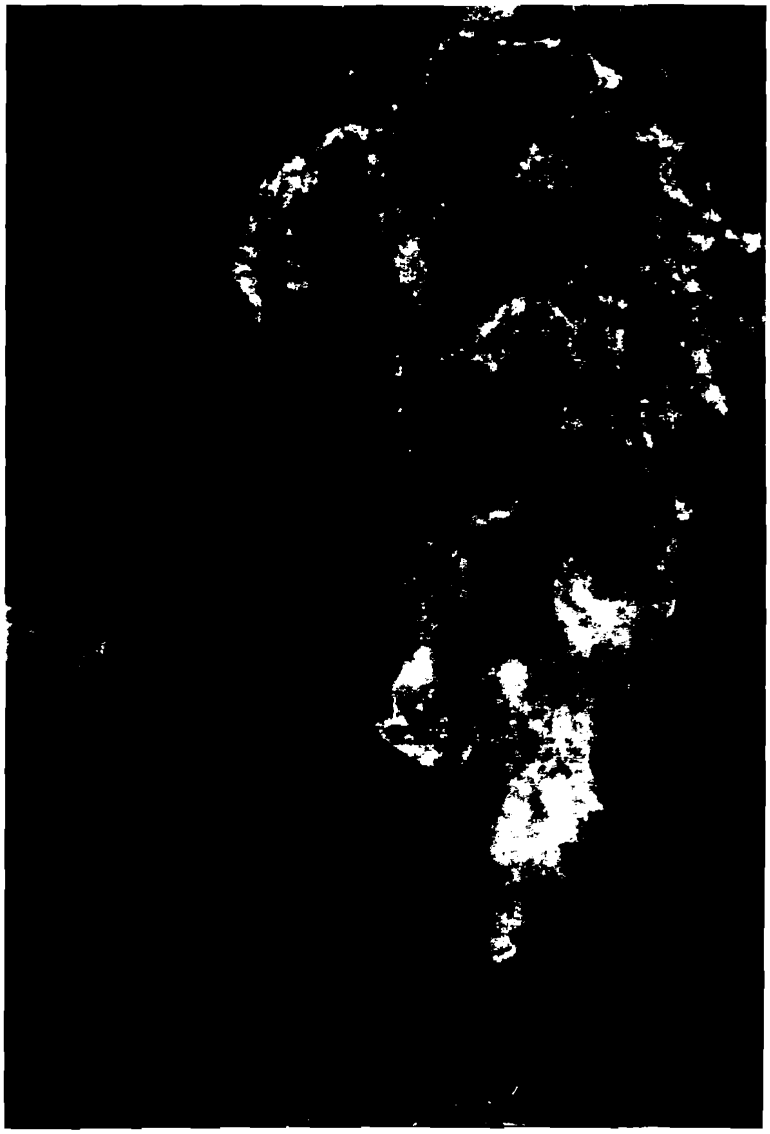


Figure 5-13

Flare of Test 2a Showing Extent of Flashing LPG and Flare

5.5.4 Test 4. Flow A —> B: no ESV-1

This tested the unloading of a rail tanker to a refinery line. The tests were conducted without a pneumatic and with a manual trip (ESV2) emergency shut-off valve installed. Break was initiated at a transfer flow rate of 180 USGPM. The tanker excess flow valve did not activate until the flow rate from the tanker increased to 350 usgpm. To prevent backflow from the refinery line required manual activation of ESV2.

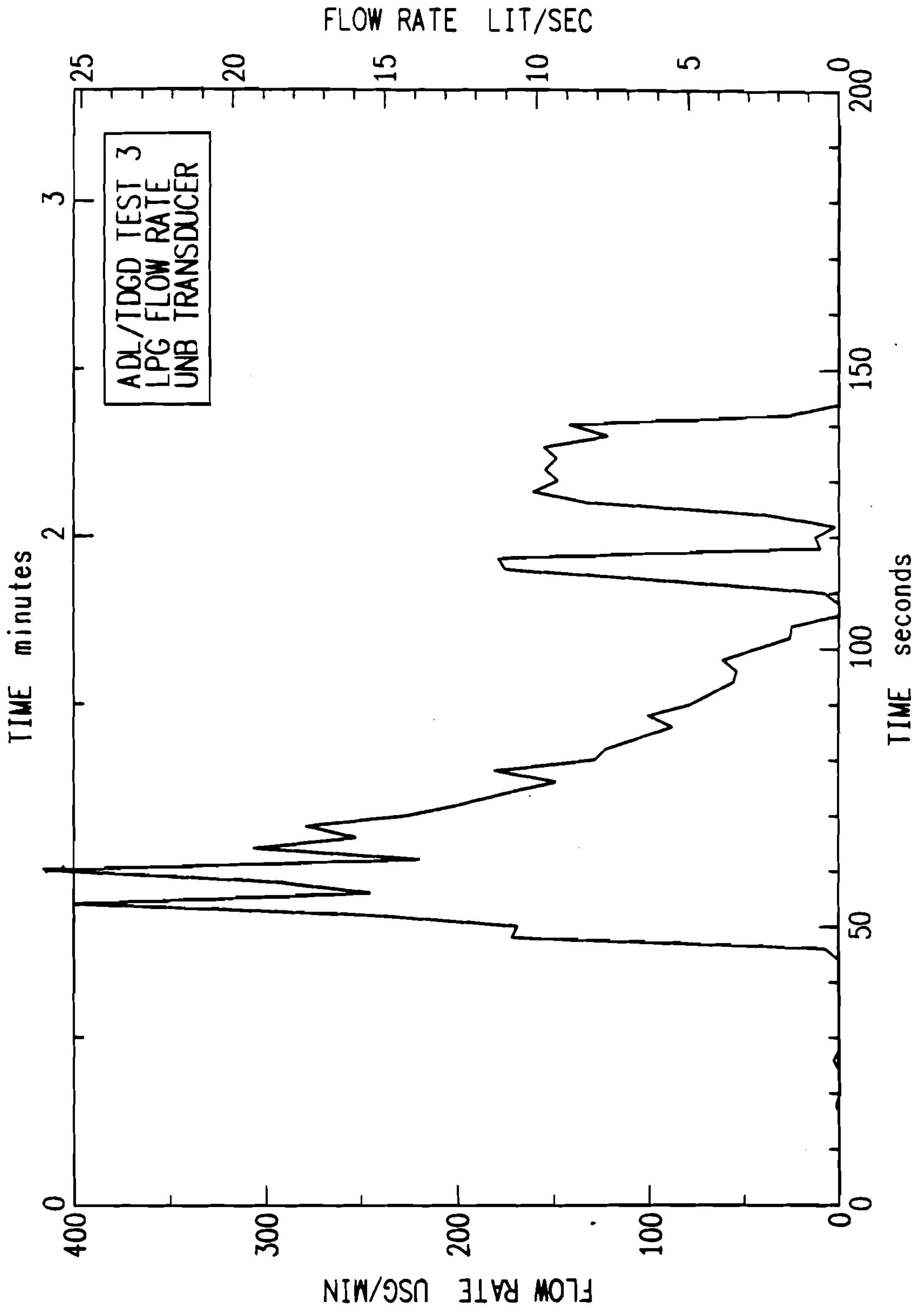


Figure 5-14

Test 3, Flow B ---> A, LPG Flow Rate, Measuring Station A

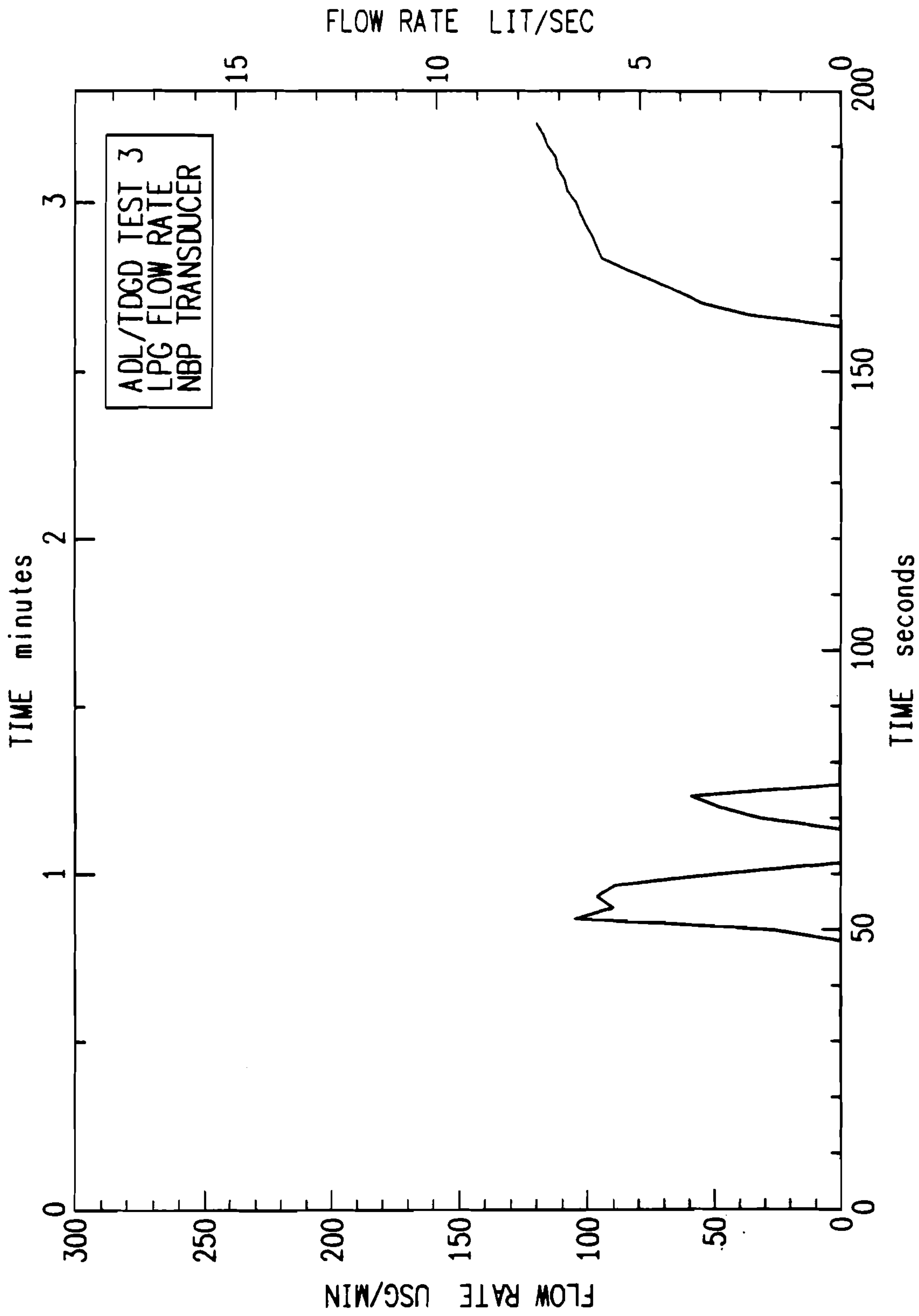


Figure 5-15

Test 3, Flow B —> A, LPG Flow Rate, Measuring Station B

The test commenced at 13:35 with a steady flow of over 200 USGPM between tanker A and B for 30 s (Figure 5-16). The excess flow check valve, though rated at 180 USGPM, did not function since there was insufficient pressure drop across it. At 30 s, the Jamesbury valve was activated. The tank car excess flow check valve did not operate despite a flow in excess of 200 USGPM on line A. The valve only operated after the simulated rupture and at an indicated flow of over 350 USGPM. Backflow from tanker B (Figure 5-17) was permitted for some 6 s prior to manual closure of ESV-2.

5.6 Summary and Conclusions

A series of full scale field trials of LPG loading and unloading operations were conducted. The tests were undertaken to determine the effectiveness of transfer line emergency shut-off valves, as recommended by NFPA 58, in situations where full hose rupture and activation of the ESV occurs.

An evaluation of the test results permits the following conclusions to be made.

1. Activation of the ESVs at both ends of the hose should be initiated simultaneously, preferably by pneumatic control in order to prevent substantial product loss.

2. The tank excess flow check valve should not be relied upon to provide protection in the event of hose rupture for unloading operations.

3. Emergency shut-off valve protection of the transfer line is essential at both ends of the loading/unloading hose in order to prevent product discharge from tank and/or plant in the event of a sudden total hose failure.

4. The tank excess flow check valve in loading operations may provide shut-off capability in situations where a sudden flow reversal occurs, caused by hose rupture.

5. The tank excess flow check valve should not be used to provide protection in the event of hose or fitting leaks for either loading or unloading.

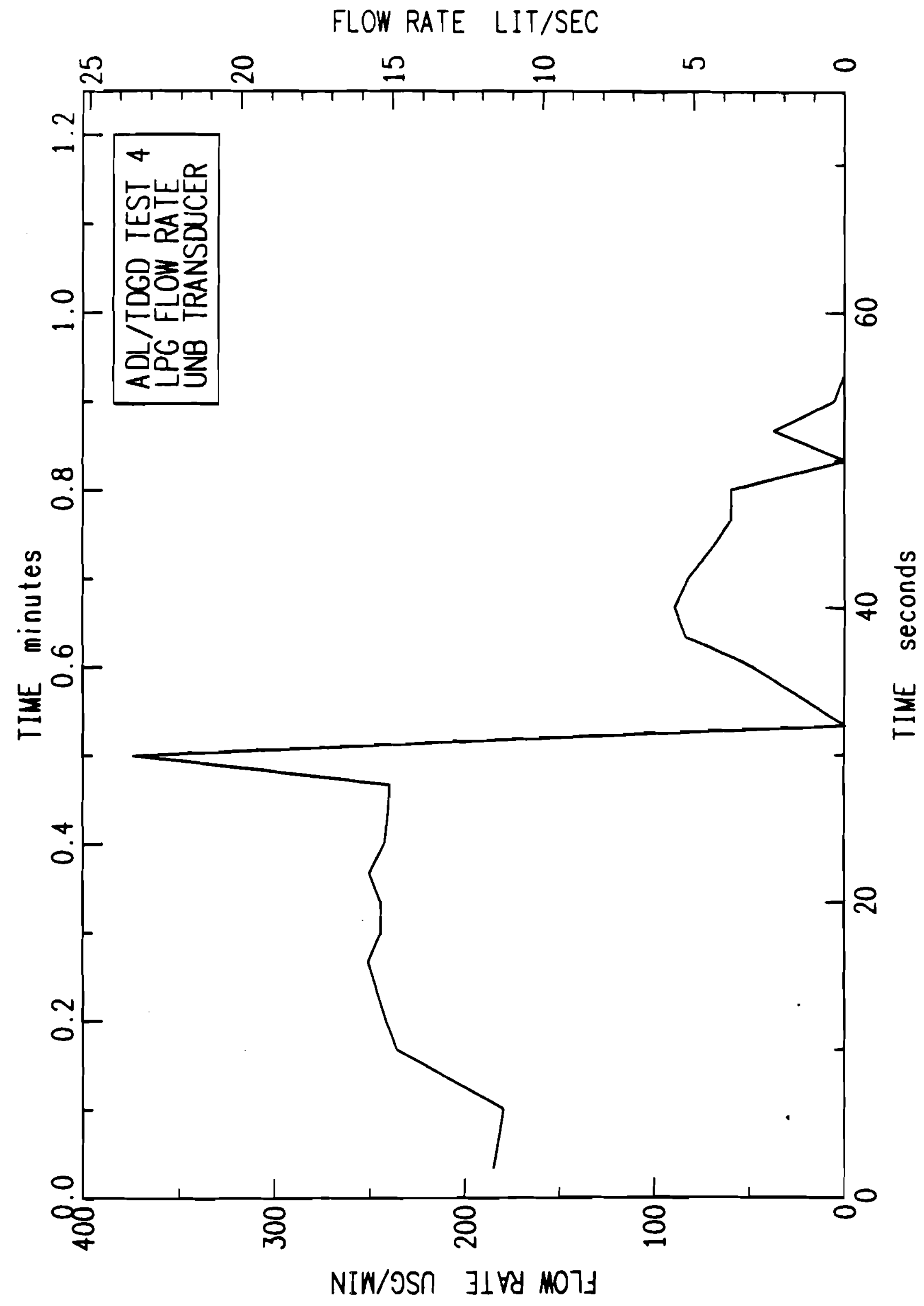


Figure 5-16

Test 4, Flow A —> B, LPG Flow Rate, Measuring Station A

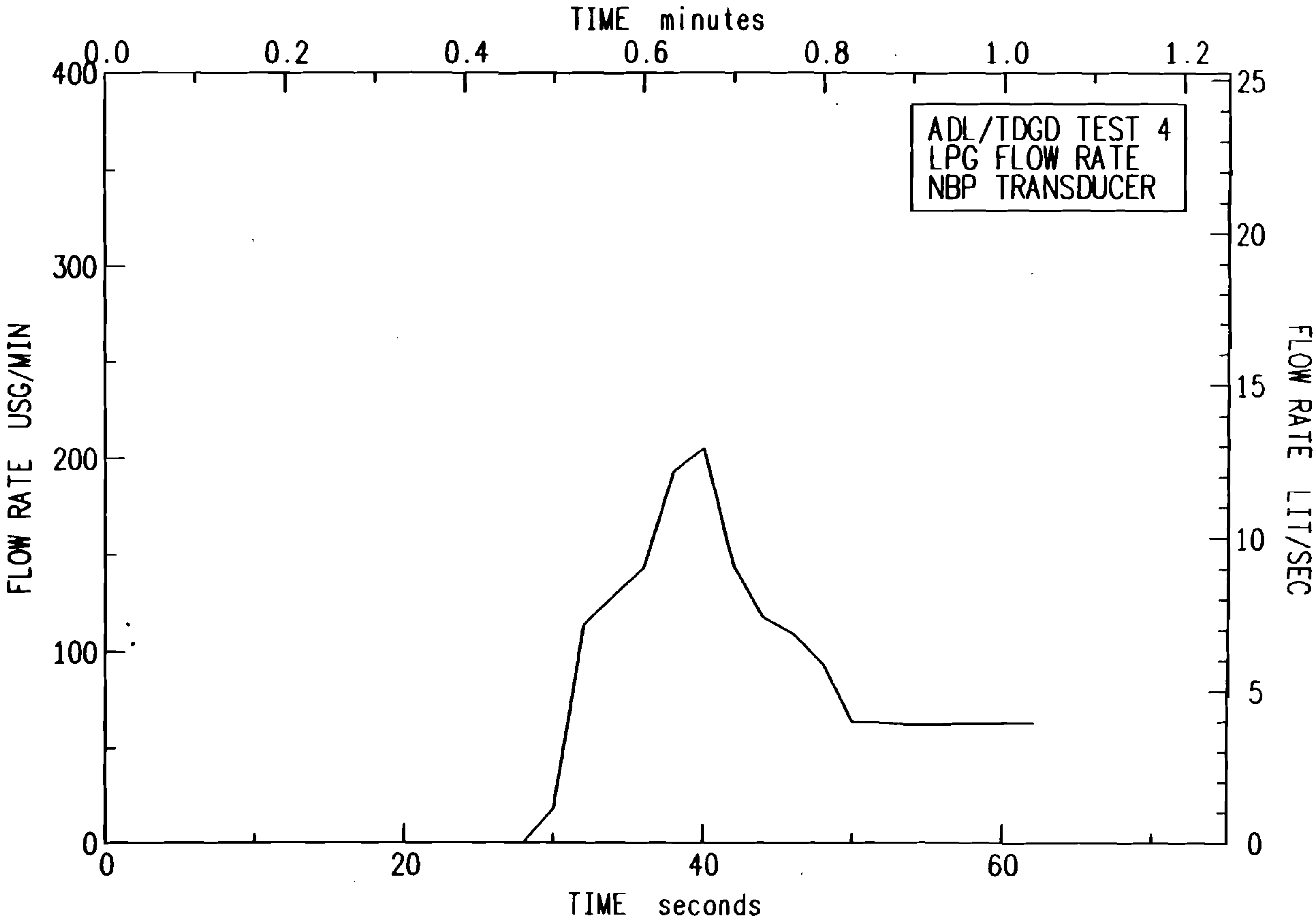


Figure 5-17
Test 4, Flow A --> B, LPG Flow Rate, Measuring Station B

6. Conclusions and Recommendations

This report summarizes an investigation of releases caused by:

- Loose or defective fittings, valves and closures,
- Lining failure, and
- Excess flow valve on propane cars.

For the first two types of releases, a list of likely causes was compiled and potential mitigation measures were investigated. For the third type, a full scale test was conducted by the University of New Brunswick.

The releases of the type investigated follow the classic "20/80" rule, in that a large number of releases are caused by a very few commodities and most of the leaks are attributable to only a few causes. The corrosive materials account for most of the leaks (41.6% in 1987) and are also most likely to leak (at the rate of 1.64 times per thousand movements in 1987). Also, of the corrosive materials, hydrochloric, phosphoric and sulfuric acid predominate as bad actors.

Since these materials are carried in DOT 111 class tank cars, this car type, not surprisingly, is the one most subject to the leaks of the type identified. Its rate of 2 releases per million car miles is higher than the rates for DOT Class 105, 112 and 114 tank cars (only the older DOT Class 103 cars exhibit a rate higher than the DOT Class 111 cars). Also, almost 600 hazardous material incidents involved the DOT Class 111 cars in 1986, while the number of incidents for each of the other car types was below 100.

The "20/80" rule also applies to the type of leak within each category. Most of the unsecured opening leaks are due to loose bolts (and that too at the manway cover), most of the gasket failures involve deteriorated gaskets (at manway cover) and most of the corrosion problems arise due to liner failure (at the wall of the tank car).

These problems are attributable to a variety of causes. Also, in most situations, they are not instantaneous failures, but of the type that could have been detected through inspection program. Also, the failure itself can be blamed on improper design, installation or operation. Since these events generally take place in a sequence, one can attribute cause to any one of these areas. For example, a release due to loose bolts can be attributed to design of the closure (which makes it difficult to tighten), approval process (the mistake not caught), the loader (he/she is responsible for using the equipment correctly), the inspector (he/she failed to find the problem) or the railroad (rough operation caused the bolt to become loose).

Thus, some judgment needs to be applied to define fuzzy boundaries between these overlapping responsibilities more clearly. Applying such judgment (and reviewing it with a number of people in the industry), we conclude that most of the unsecured opening problems are attributable to improper loading coupled with insufficient inspection, gasket failures to improper material and liner failures to improper material coupled with insufficient inspection. Thus, most of the blame lies with the shipper of the hazardous commodities.

With regard to the excess flow valves on LPG/NH_3 anhydrous tank car loading systems, several conclusions can be drawn.

For unloading product transfer lines not fitted with emergency shut-off valves, tank excess flow valves cannot be relied upon to shut off product flow in the event of full transfer line rupture since flows in excess of rated capacity may be permitted prior to valve activation. Due to flashing two-phase flow at the break, the pressure drop necessary to activate the valve requires a flow approximately twice rated capacity. Product flow control from the refinery line will require an appropriately fitted check valve.

For loading lines not fitted with emergency shut-off valves, tank excess flow valves appear, if new and clean, to be able to immediately shut off product flow in the event of full transfer line rupture. The activation of the valve appears to be successful due to flow reversal. To prevent product flow from the refinery line will require an automatic emergency shut-off valve. Since tank excess flow valves may be poorly maintained, the additional protection of an automatic emergency shut-off valve is recommended.

In situations where both loading and unloading may take place using the same transfer lines, provision of automatic emergency shut-off valves at both ends of the hose is recommended in order to prevent product from both the tank car and the depot being discharged.

Neither tank excess flow valves nor automatic emergency shut-off valves will provide shut-off protection in the event of hose or fitting leakage since developed pressure drops maybe insufficient to actuate these devices. Proper maintenance and inspection of transfer lines is thus the only protection in these circumstances.

A number of mitigation measures have been proposed. From this list, we recommend that FRA look into the following as priority items:

- From a human factors perspective, develop a set of actions that a shipper can take to improve the job of loader/unloader.
- Help develop a simplified but effective tank car inspection procedure.
- Conduct research to identify more resilient non-asbestos materials for gaskets and making their usage more foolproof.
- Perform research and testing on long-term effects of corrosive materials on tank linings.
- Improve the state-of-the-art lining inspection, including further development of the spark tester and conductivity measurement methods.
- Require all LPG/NH_3 anhydrous tank car loading systems to have emergency shut-off valves (ESVs) placed at both ends of the loading/unloading hose assemblies.

These steps will start the process of reducing the incidence of non-accident releases of the tank cars.