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PIPELINE ACCIDENT EFFECTS FOR HAZARDOUS LIQUID PIPELINES

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FINAL REPORT

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1.0 EXECUTIVE SUMMARY

The executive summary for this report is divided into two parts. Part 1.1 is a summary of observations made in the report which are based on patterns found on analysis of the LIQUID (accident data for 1968-1985) and LIQLCK (accident data for 1985-present) databases. Part 1.2 is devoted to conclusions.

1.1 OBSERVATIONS

The format of this summary of observations will follow the format of the subsequent report. Each factor that was examined will be highlighted and the main points of the analysis will be given.

1.1.1 ANALYSIS OF CAUSE OF HAZARDOUS LIQUID ACCIDENTS

- The current data that is available from OPS contains significant errors and omissions. NJIT made an attempt to enhance the data by using additional information from other sources, such as The American Society of Mechanical Engineers' (ASME) Committee B31.4/B31.11 reports and the National Transportation Safety Board (NTSB).

- Between 1968 and 1973, a large number of accidents due to corrosion were reported. After 1973, the number of accidents in this category remained relatively constant and at a reduced level from the prior reporting period.

- A large number of accidents which were reported with the cause category termed "other" had a common source of failure. Using "other" as the cause of accident is not very beneficial when one attempts to use accident information to correct potential high risk elements of the pipeline system. This is especially relevant when considering that "other" is often related to pipe system components failure such as O-rings, nipples and gaskets.

1.1.2 ACCIDENTS BY CAUSE AND COVER DEPTH

- There is generally an increased number of accidents when the depth of cover is between 0" and 18" in comparison with greater depth of cover. The number is relatively stable between 1 8 and 36," and then drops further at greater burial depth.

- In shallow cover of 0 to 12," the category "equipment ruptured line" is the most frequent cause of accidents. In fact, 51% of all causes of accidents for pipe buried 6" or less are due to "equipment ruptured line."

- The depth of cover is not given (because it is not required) in the LIQLCK database. The only information for the years 1985 and on is whether the pipe was above or below the ground.

1.1.3 ACCIDENTS BY CAUSE AND PIPE DIAMETER AND WALL THICKNESS

The following comments relate the actual wall thickness to the specifications for standard wall thickness which were established by the American Petroleum Institute (API).

- Pipe with wall thickness that is equal to or greater than standard is much less susceptible to an accident. This is especially true for cause categories "damage by outside force" and "failed weld."

1.1.4 ACCIDENTS CAUSED BY CORROSION

- The LIQLCK database indicates that more accidents occur on coated and cathodically protected pipelines. What does this mean? Should the operators be asked to stop coating and protecting their pipe? The answer is that one cannot analyze this data without knowing how many miles of pipeline are protected. The data must be normalized before any analysis is performed.

1.1.5 ACCIDENTS RELATED TO YEAR OF INSTALLATION AND YEARS IN OPERATION

- Pipe that was installed prior to the 1940s has a substantially larger number of accidents due to "corrosion" than any other cause. For pipe installed during the 1940s, "corrosion" and "equipment ruptured line" are about equal. After 1950, the number of accidents due to "equipment ruptured line" (Le., damage by outside force) becomes the dominant cause of accidents.

- Accidents caused by "corrosion" increase almost linearly until a pipe age of 45 years. After age 50 there is a sharp drop which could be related to a sharp decrease in the mileage of pipe still in service that is more than 50 years old. One can observe that there is a correlation between age and corrosion. This may mean that there is a finite limit to the effectiveness of corrosion prevention measures.

- In the LIQUID database, cause "equipment ruptured line" is relatively high at ages between 10 and 30 years. In fact, it is the number one cause for accidents until pipe reaches the age of 25. One explanation for this is that newer pipe is perhaps built in more populated areas with extensive development activities. Thus, the potential for damaging the pipe by equipment is greater.

- The dominant category of causes of accidents during the first 20 years of pipe life is "other." Most accidents categorized as "other" result from the failure of a component on the pipe system.

- The **LIQLCK** database shows an increase in the number of accidents due to damage by outside forces for pipe age 50 or older.

  One possible explanation for this is that new land developments have encroached upon the pipe and consequently exposed it to higher risks. Another explanation for the increase in the number of accidents by outside force is that older pipe is weaker and less resilient to inflicted impacts, i.e., it may exhibit low toughness. In order to resolve this observation, additional information is needed such as the location of the pipe at the time of the accident.

1.1.6 ORIGIN OF THE RELEASE RELATED TO THE YEAR OF INSTALLATION AND THE AGE OF THE COMPONENT

- About 60% of the liquid or vapor release is caused by factors relating to the pipeline itself. This finding is the same for both databases LIQUID and LIQLCK. As the pipe becomes older, the dominance of the pipeline as a factor increases.

- Most of the problems related to components are high initially and then decrease as age increases. This may have at least two possible explanations. The first is that these components do not have a long life span. The other explanation could be related to quality control (or lack of) of the installation and/or manufacturing process exhibited early in the operation of the pipeline .

- Two thirds of the reported origin of release are in category “other” (LIQLCK). As stated earlier with respect to the determination of the cause, the category “other” is of very little value when one is attempting to use accident data for devising improved measures to reduce the risk of accidents. One reason for the large number of “other” causes could be an inadequate list of categories to select from on **OPS’s** reporting form.

- Malfunctioning tanks and valves are also rather common problems associated with releases of hazardous liquids and vapors.

1.1.7 PROPERTY DAMAGE AND THE CAUSE, THE YEAR OF INSTALLATION AND THE AGE OF THE PIPE

- Most of the property damage in the LIQUID database is related to cause “other.” As mentioned previously, cause “other“ consists mostly of failures related to pipe components such as O-rings, gaskets and nipples. The second most damaging cause is “equipment ruptured line” and the third is “operator error.” Corrosion is a distant fourth cause.

- In LIQUID, the cause with the most expensive damages (per accident) is “incorrect operation by operator personnel,” followed by “other,” and “equipment ruptured line” is third.

- In LIQLCK, ”failed weld and ”failed pipe” are the most costly accidents.

- There are relatively high damages at a very early age (0 to 4 years) and at a very old age (around 80 years of age) of the pipe.

1.1.8 OPERATING PRESSURE AND THE CAUSE OF ACCIDENTS

- Most accidents caused by operator error occurred when the actual pressure was at 100% or more of the maximum operating pressure.

- Outside force accidents occur mostly in low operating pressure pipe and pipe failure occurs most often at higher pressures.

- Relatively high operating pressures (i.e., near maximum allowed) cause larger property damage.

1.1.9 LINE MARKING AND THE CAUSE OF ACCIDENTS

- The LIQUID database has information on the actual distance from the point of the accident to the nearest line marker. **LIQLCK** does not have this information.

- Twenty five percent (25%) of the accidents caused by "equipment ruptured line" occurred within 50 feet of the closest line marker and 33% occurred within 100 feet. This means that one third of the accidents occurred within a very short distance of the line marker.

1.1.10 FREQUENCY OF RIGHT-OF-WAY PATROLS AND THE CAUSE OF ACCIDENTS

- Most right-of-way inspection occurred within one week prior to the accident.

1.1.11 ONE-CALL SYSTEM AND CAUSE OF DAMAGE

- The majority of excavators (73%) did not call for information prior to excavating and damaging the pipeline. This raises the question of the effectiveness of the one-call systems. However, it does not give us a measure of how many excavations called the one-call system and thereby prevented an accident.

1.2 CONCLUSIONS

It is very difficult to draw clear cut conclusions from the data available to NJIT. Without additional information for normalizing the data some of the conclusions may be erroneous. For example, when the data indicates that most of the corrosion related accidents occurred on coated pipelines, one may conclude that it is wrong to coat the pipe - not coating the pipeline would decrease the risk of accidents. This conclusion is obviously incorrect. It is well established that coating protects the pipeline from corrosion. If, however, one knew that 90% of the pipe is coated and only 60% of the accidents occur on coated pipe, the conclusion would be that coating does work. Instead of having 90 out of 100 accidents on coated pipe we have an accident rate of only 60%.

The following is a list of conclusions that could be reasonably drawn from the data:

- There is a correlation between age and accidents caused by corrosion. Old pipe is also vulnerable to damage by outside forces and failed welds. This may mean that there is a finite limit to the effectiveness of the corrosion prevention measures for preserving the integrity of the pipeline.

- Measures should be taken to improve the quality control and installation processes of components such as valves, O-rings, gaskets and nipples. The new measures should be aimed at reducing the number of accidents that occur due to failure of these components shortly after installation.

- Prevention programs such as one-call systems, line marking, and right-of-way patrolling seem to be deficient. Too many accidents occur within a very short distance of the nearest line marker. Also, too many accidents occur due to damage impacted on the pipe that was undetected by the existing right-of-way patrolling practice. Another concern is that **73%** of the excavators did not call in for information prior to excavating, which means that something is lacking. It may be an issue **of** awareness, education, or enforcement. The potential solutions for this problem are beyond the scope of the investigation.

1.2.1 OTHER CONCLUSIONS

- The most important conclusion of this study is that there is need for better data. Data must be collected in a more complete fashion in terms of the current requirements (accident report form) and in terms of devising an annual report on the status of the hazardous liquid industry (similar to those compiled in the gas industry). The annual report information is essential for improving the statistical significance of the accident data analysis. Without this data it is very difficult, and in some cases impossible, to evaluate the safety of transmitting hazardous liquids via pipelines.

- It is necessary to increase the number of categories for the cause of an accident. The 20 category cause determination used by **ASME** could be used as a model for improving data collection. It is also necessary to increase the number of categories for the origin of the release, to specify the depth of cover, and to specify the exact location of the accidents in terms of position, land use and environmental factors. In general, it is necessary to revise the accident reporting form DOT Form 7000-1 **(4-85).**

2.0 INTRODUCTION

The purpose of this report is to analyze the factors that affect hazardous liquid pipeline accidents. The main data sources for the analysis are two **OPS** databases. The first is named LIQUID which contains hazardous liquid accident information from **1968** to **1985.** The second is LIQLCK which contains accident data from **1985** to the present. The databases have some different data input because of modifications made in the reporting form in **1985.** These differences will be discussed in the next section. The transition from the **old** reporting form to the new one in **1985** resulted in some **1985** accidents being reported in LIQUID and others in LIQLCK.

There are **19** parameters that this report was to address. The list of parameters was compiled for both gas transmission and hazardous liquid pipelines assuming that data would be available. This assumption proved to be inaccurate. Some of the parameters could not be analyzed because there was no data to support an analysis. The following is the list of parameters to be analyzed and whether or not data was available from OPS databases to perform the analysis.

PARAMETER	LIQUID[1]	LIQLCK[1]
THIRD PARTY EXCAVATION	Y	Y
CORROSION/CATHODIC PROTECTION	Y	Y
LOCAL LAND USE POLICY	N	N
ACCURACY OF PIPELINE MAP	N	N
PIPELINE PRESSURE	Y	Y
FREQUENCY/TYPE OF RIGHT-OF-WAY PATROLLING	Y	N
LINE MARKING	Y	Y
PIPELINE INSPECTION FREQUENCY	N	N
EXCAVATION DAMAGE PROGRAM/ONE-CALL SYSTEM	N	Y
PIPE MATERIALS		
• TOUGHNESS	N	N
• PROPERTIES	N	N
• MANUFACTURING PROCESS	N	N
TERRAIN/SOIL/SUBSIDENCE/GEOLOGY/SEISMIC	N	PARTIAL
MAXIMUM ALLOWABLE OPERATING PRESSURE	Y	Y
DIAMETER	Y	Y
HUMAN ERROR	Y	Y
AGE OF PIPELINE	Y	Y
DEPTH OF BURIAL	Y	PARTIAL

Based on availability of data, as indicated in the above table, not all the initially sought parameters could be analyzed.

An additional limitation of the analysis presented in this report is the lack of the total system (industry wide) data essential for normalization. Explanation for the need to normalize the data, and how the problem was dealt with within the analysis, is included in this report.

3.0 ANALYSIS OF CAUSE OF HAZARDOUS LIQUID ACCIDENTS

Before analyzing the factors that affect hazardous liquid pipelines accidents, it is prudent to first review the sources of data which define the cause of an accident. As mentioned earlier there are two OPS databases, LIQUID and LIQLCK. LIQUID contains hazardous liquid accident information from **1968** to **1985.** LIQLCK contains accident data from **1985** to the present. The databases have some different data input resulting from the modification of the reporting form in

[1] *Y* indicates sufficient data in *the* database to *perform* an analysis; N means that there was no data to support an analysis; and Partial means insufficient data.

1985. To verify the accuracy of these databases one can compare the reported cause determination in LIQUID and LIQLCK with a written description of the accident.

Written descriptions were available to **NJIT** for accidents occurring for **1984** and later. The information exists in two forms. The first is the written description in Part K of the accident report form 7000-1 and the second is a brief explanation of what is recorded on the reporting form at specific entry points. For example, in the new form (LIQLCK database), if the cause selected was "other" there is a field for specifying the cause. Analyzing this field was very useful in verifying the actual cause for an accident.

The number of categories for the cause of an accident involving hazardous liquid pipelines increased from six to seven in **1985.** The additional category was "malfunction of control or relief equipment." In addition, some of the categories were renamed. For example, "equipment ruptured line" was renamed to "outside force damage." The following table presents the "cause" categories in the two OPS databases.

	LIQUID
1	CORROSION
2	DEFECTIVE WELD
3	INCORRECT OPERATION BY CARRIER PERSONNEL (OPERATION ERROR)
4	DEFECTIVE PIPE
5	EQUIPMENT RUPTURE LINE
6	OTHER

	LIQLCK
1	CORROSION
2	FAILED WELD
3	INCORRECT OPERATION BY CARRIER PERSONNEL (OPERATION ERROR)
4	FAILED PIPE
5	OUTSIDE FORCE DAMAGE
6	MALFUNCTION OF CONTROL OR RELIEF EQUIPMENT
7	OTHER

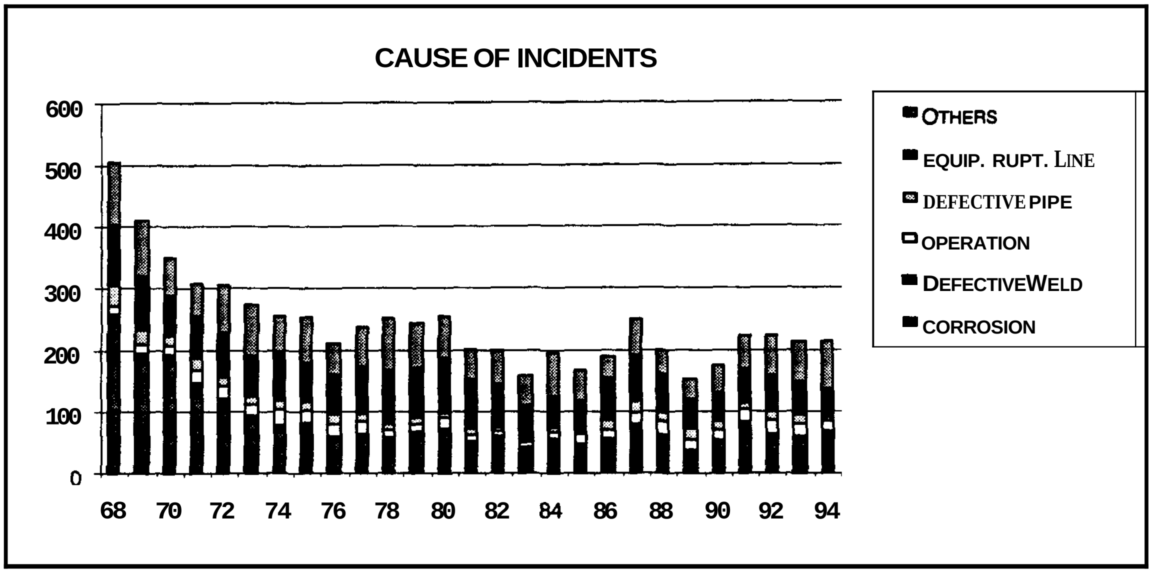
In order to study the causes of accidents from 1968 to the present, categories 6 and 7 in LIQLCK were combined into a single category "others". It should be noted that later on in this report LIQUID and LIQLCK are analyzed separately so that this aggregation will not be used while examining specific causes for accidents. Based on the **OPS** data, the causes for all hazardous liquid accidents reported from **1968** to **1994** were as follows:

YEAR

CAUSE	68	69	70	71	72	73	74	75	76	77	78	79	80	81
1	241	178	178	125	100	83	66	73	53	60	51	53	62	48
2	18	18	16	21	23	12	13	10	7	5	7	16	10	4
3	12	14	14	22	20	18	25	20	20	19	13	12	19	11
4	35	24	16	20	15	11	15	13	17	12	9	10	8	9
5	98	87	65	68	72	68	78	64	65	78	88	81	88	82
6	101	90	62	52	76	82	59	74	49	64	83	71	69	48
TOTAL	**505**	**411**	**351**	**308**	**306**	**274**	**256**	**254**	**211**	**238**	**251**	**243**	**256**	**202**

YEAR

CAUSE	82	83	84	85	86	87	88	89	90	91	92	93	94
1	55	42	51	48	49	73	56	33	49	73	46	51	43
2	6	1	5	0	8	7	6	6	6	11	18	9	26
3	8	8	11	16	14	19	23	16	15	20	22	21	16
4	6	4	7	3	16	18	13	17	14	11	14	14	6
5	70	56	50	52	68	75	63	49	46	55	59	55	46
6	55	48	71	48	35	58	38	32	46	53	65	64	77
TOTAL	200	159	195	167	190	250	199	153	176	223	224	214	214



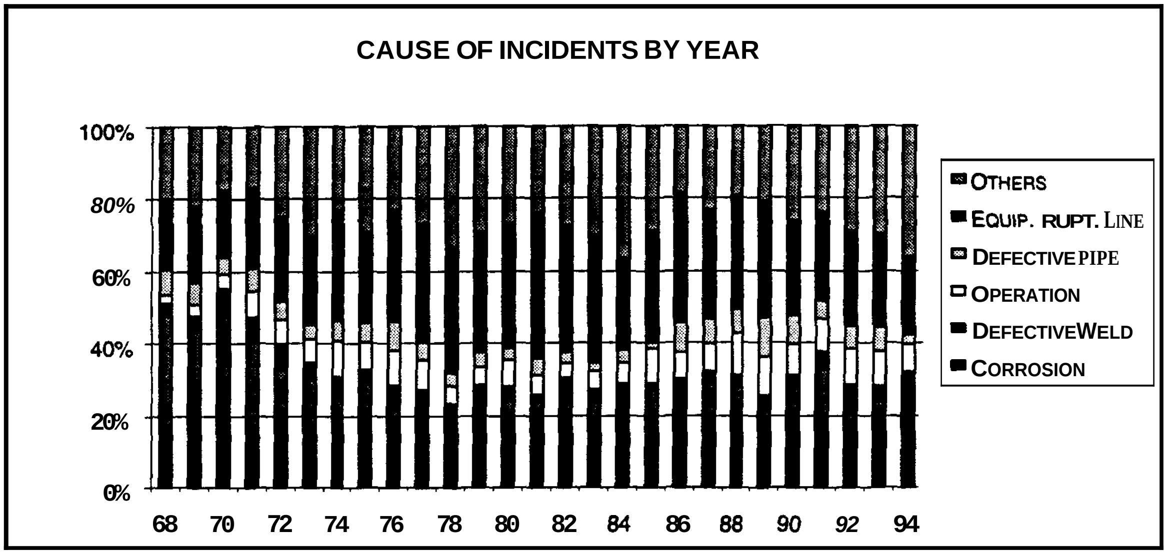
The same data expressed in terms of annual percentages *is:*

YEAR

CAUSE	68	69	70	71	72	73	74	75	76	77	78	79	80	81
1	48%	43%	51%	41%	33%	30%	26%	29%	25%	25%	20%	22%	24%	24%
2	4%	4%	5%	7%	8%	4%	5%	4%	3%	2%	3%	7%	4%	2%
3	2%	3%	4%	7%	7%	7%	10%	8%	9%	8%	5%	5%	7%	5%
4	7%	6%	5%	6%	5%	4%	6%	5%	8%	5%	4%	4%	3%	4%
5	19%	21%	19%	22%	24%	25%	30%	25%	31%	33%	35%	33%	34%	41%
6	20%	22%	18%	17%	25%	30%	23%	29%	23%	27%	33%	29%	27%	24%

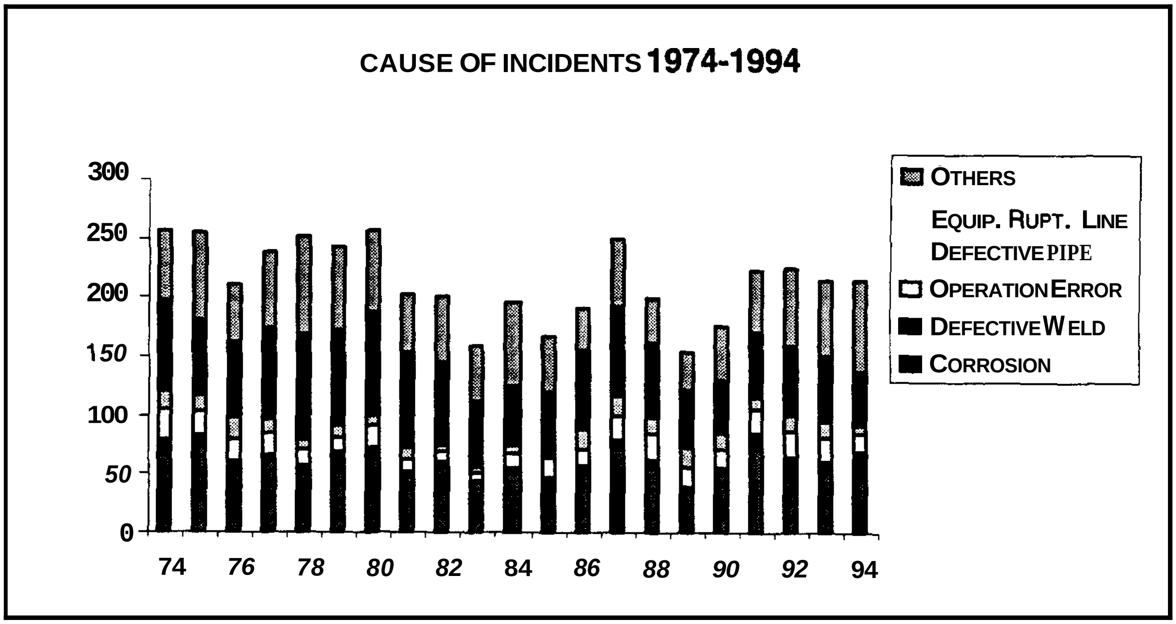
YEAR

CAUSE	82	83	84	85	86	87	88	89	90	91	92	93	94
1	28%	26%	26%	29%	26%	29%	28%	22%	28%	33%	21%	24%	20%
2	3%	1%	3%	0%	4%	3%	3%	4%	3%	5%	8%	4%	12%
3	4%	5%	6%	10%	7%	8%	12%	10%	9%	9%	10%	10%	7%
4	3%	3%	4%	2%	8%	7%	7%	11%	8%	5%	6%	7%	3%
5	35%	35%	26%	31%	36%	30%	32%	32%	26%	25%	26%	26%	21%
6	28%	30%	36%	29%	18%	23%	19%	21%	26%	24%	29%	30%	36%



The above figures show that between **1968** and **1973** there were a large number of accidents due to corrosion. After **1973,** the number of accidents in this category remained relatively constant and at a reduced level from the prior reporting period. This can be verified by computing the standard deviation of the annually reported accidents from the mean. The standard deviation for corrosion and for the total number of accidents reported annually between **1968** and **1994** was **(±49)** and **(±78),** respectively. Conversely, the same standard deviation for accidents reported annually between **1974** and **1994** was only about (±10) and (±32) respectively. These values remain constant thereafter.

The data for cause of an accident for **1974-1994** only is presented in the following figure.



In ranking the different accident causes as reported to OPS, the mean, the standard deviations and the ratio between the standard deviation and the mean (coefficient of variation - CoV) were computed and are presented in the following table: ·

RAW DATA 1968-1994

CAUSE	MEAN	STD. DEV.	COV	RANK
1	75.56	49.391	0.654	1
2	11.12	6.50	0.584	6
3	16.59	4.58	0.276	4
4	13.22	6.59	0.498	5
5	67.63	14.17	0.210	2
6	61.85	16.88	0.273	3
TOTAL	**245.56**	**77.85**	**0.317**	

RAW DATA 1974-1994

CAUSE	MEAN	STD. DEV.	COV	RANK
1	54.05	10.611	0.1961	3
2	9.05	5.671	0.6271	6
3	16.57	4.83	0.292	4
4	11.24	4.44	0.395	5
5	65.14	13.73	0.211	1
6	57.48	14.11	0.245	2
TOTAL	**213.10**	**32.62**	**0.153**	

From the above table one can see that the data for the accidents between 1968 and 1974 is not (statistically) consistent with the rest of the data. Corrosion (cause 1) and defective weld **(2)** have a CoV value larger than 0.5. The standard deviation for corrosion is 5 times larger for 1968 to 1994 than the standard deviation for 1974 to 1994. Also, note that for 1968 to 1994, corrosion is ranked as the number one (1) cause for accidents but drops to number 3 if one uses only data from 1974 to 1994.

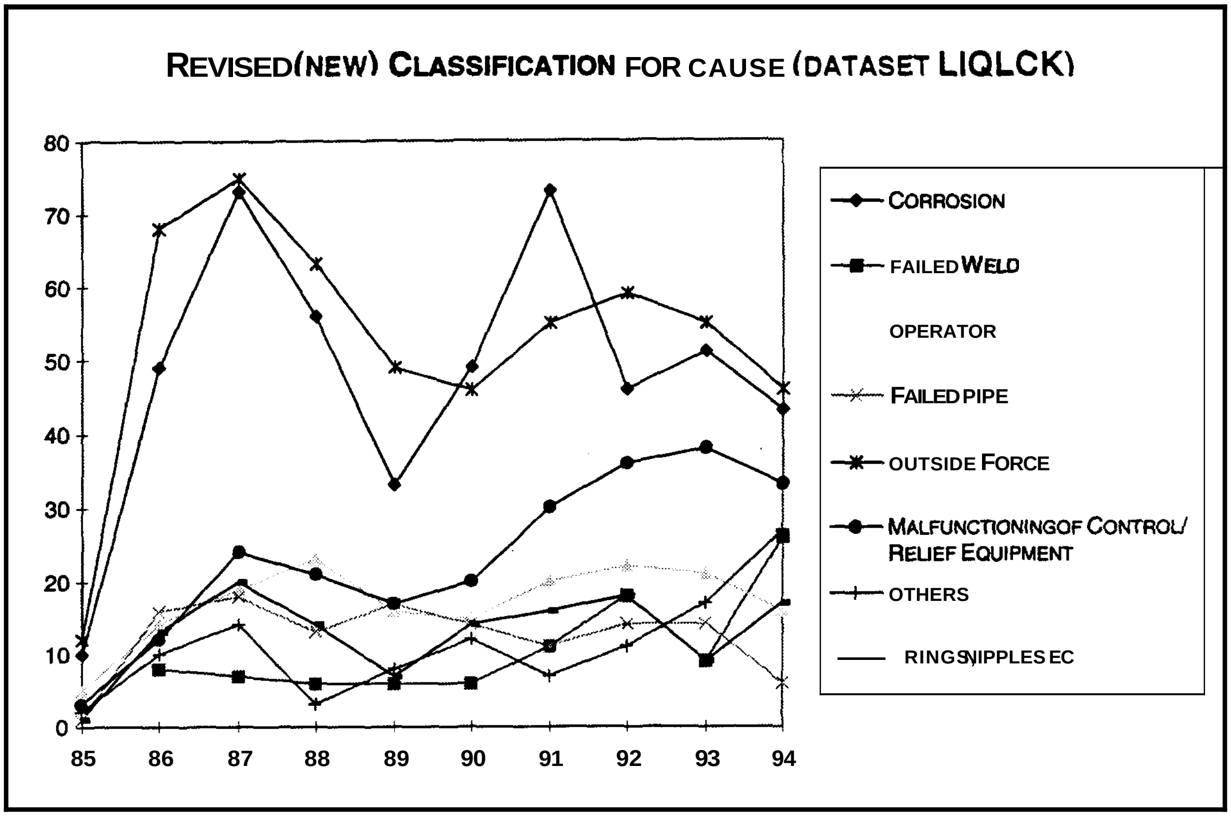
It is interesting to note that while corrosion related accidents are problematic for the period between 1968-1974, other causes did not change very much. One should investigate the significance of this time period. Why was there such a profound drop in the number of accidents caused by corrosion after 1973? Did the change occur due to technological development? reporting? data input?

3.1 EVALUATING ACCIDENT CAUSE FROM OTHER SOURCES

The first examination of the classification for cause of an accident was done by analyzing the text from the field "cause others" in LIQLCK and the supplementary accident descriptions submitted to OPS. In addition, the reported **"cause"** in Part D of DOT Form 7000-1 was compared with data reported in Parts I (cause by corrosion) and J (cause by outside forces).

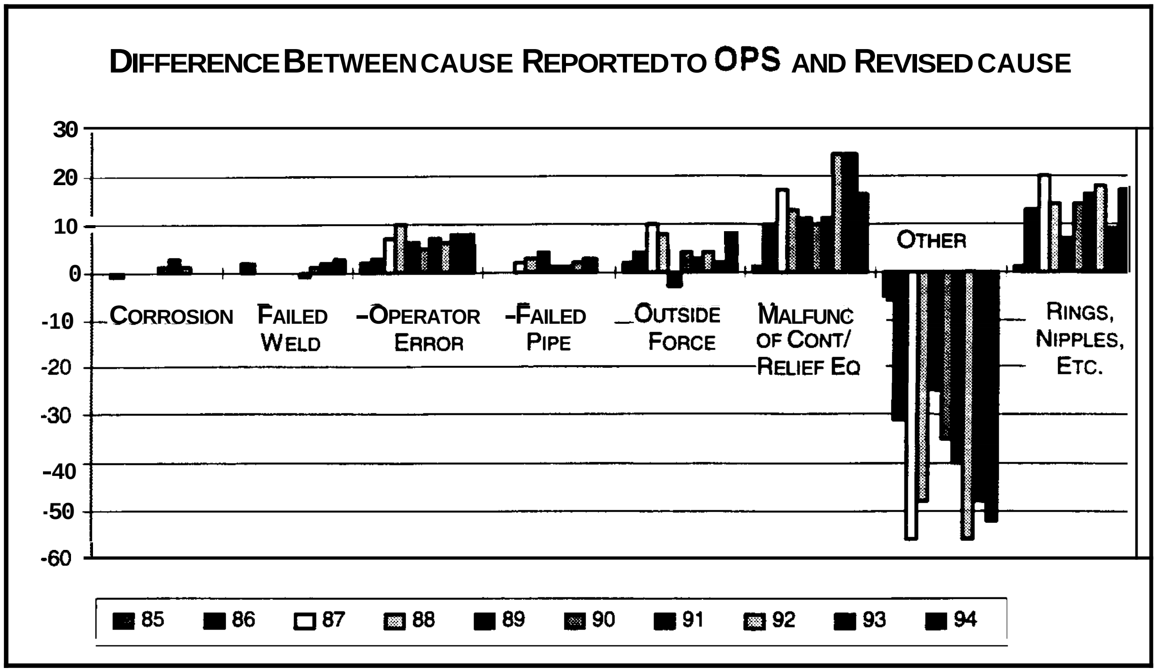
From the above analysis it is clear that a large number of accidents which were reported with a cause "other" had a common source of failure. The cause of these accidents was often related to pipe system components failure such as O-rings, nipples and gaskets. To enhance the quality of the analysis it was decided to create an eighth cause category for failures to reflect these pipe system component failures.

The new classification for the cause of accidents with the additional category is presented in the following figure for the LIQLCK database from 1985 to 1994:



It is interesting to compare the original data (LIQLCK) with the revised data by subtracting the number of accidents in LIQLCK from those in the new classification. The following table and figure depicts this change in classification:

	85	86	87	88	89	90	91	92	93	94
CORROSION	0	-1	0	0	0	1	3	1	0	0
FAILED WELD	0	2	0	0	0	0	-1	1	2	3
OPERATOR ERROR	2	3	7	10	6	5	7	6	8	8
FAILED PIPE	0	0	2	3	4	1	1	2	3	0
OUTSIDE FORCE	2	4	10	8	-3	4	3	4	2	8
MALFUNCTION C/R EQ.	1	10	17	13	11	10	11	24	24	16
OTHERS	-6	-31	-56	-48	-25	-35	-40	-56	-40	-52
RINGS. NIPPLES. ETC.	1	13	20	14	7	14	16	18	9	17



Another valuable source for verifying the accuracy of "cause" for hazardous liquid pipelines is the ASME B31.4/B31.11 Committee report, published annually. In contrast to 7 categories for cause in the current reporting form (LIQLCK), ASME has 20 categories. The larger number of categories is very helpful in providing a more accurate determination of the cause and results in a significant reduction in the number of accidents classified as "other". A more accurate determination of the cause is essential in analyzing risks and probabilities for the occurrence of a particular accident.

In order to compare the findings of the ASME committee with the LIQLCK database, the 20 categories have been consolidated into 7(or 8). The following table provides information on the findings of the committee and the equivalent LIQLCK category.

CAUSE		YEAR										
ASME	**LIQLCK**	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**Total**
DP	4	6	3	5	1	4	4	4	2	7	3	39
DPS	4	4	2	6	11	6	7	6	5	4	5	56
RPDP	4	2	4	10	11	10	6	12	4	5	11	75
DGW	2	2	1	6	1	4	3	1	3	3	0	24
DRW	2	0	0	1	4	1	0	1	2	3	0	12
DFW	2	0	0	1	0	0	0	0	1	1	3	6
RLG	8	6	4	7	13	6	4	10	4	26	7	87
RLSPP	8	2	3	6	5	5	6	5	3	1	5	41
TSBPC	8	4	11	7	7	7	6	6	6	4	3	61
MCRE	6	2	12	6	12	11	8	5	2	5	8	71
IO	3	13	22	15	12	12	15	10	11	14	14	138
V	5	2	0	1	1	2	1	2	1	3	1	14

ASME	LIQLCK	84	85	86	87	88	89	90	91	92	93	Total
LIGHT	5	1	2	4	1	1	0	0	2	0	1	12
CW	5	6	1	0	0	2	2	2	2	3	1	19
HRF	5	2	2	0	3	0	2	1	3	0	4	17
MISC	7	28	8	16	24	18	7	15	18	15	37	186
IC	1	0	16	11	10	6	2	12	14	9	8	88
EC	1	53	38	38	61	49	20	21	30	18	18	346
TP	5	54	55	66	59	50	25	17	29	24	31	410

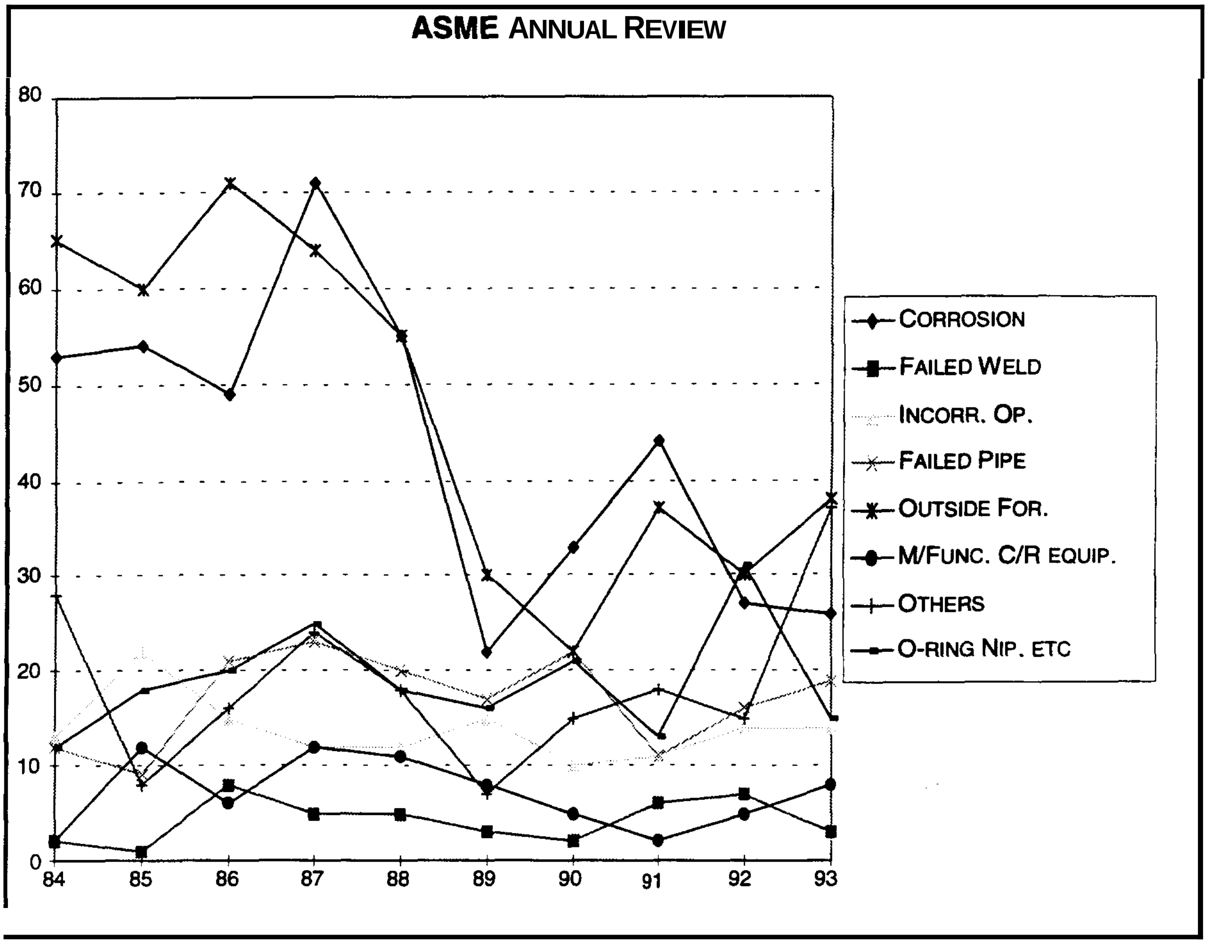
Where:

DP	DEFECTIVE PIPE	IO	INCORRECT OPERATION BY CARRIER PERSONNEL
DPS	DEFECTIVE PIPE SEAM	V	VANDALISM
RPDP	RUPTURE OF PREVIOUSLY DAMAGED PIPE	LIGHT	LIGHTNING
DGW	DEFECTIVE GIRTH WELD	CW	COLD WEATHER
DRW	DEFECTIVE REPAIR WELD	HRF	HEAVY RAIN OR FLOOD
DFW	DEFECTIVE FABRICATION WELD	MISC	MISCELLANEOUS
RLG	RUPTURED OR LEAKING GASKET OR O-RING	IC	INTERNAL CORROSION
RLSPP	RUPTURED OR LEAKING SEAL OR PUMP PACKING	EC	EXTERNAL CORROSION
TSBPC	THREADS STRIPPED, BROKEN NIPPLE, OR COUPLING FAILURE	TP	THIRD PARTY INFLICTED DAMAGE
MCRE	MALFUNCTION OF CONTROL OR RELIEF	O	OTHERS

The above table of **ASME** criteria provides the following, modified to reflect the 7 (or 8 if we add our new category) categories of LIQLCK:

CAUSE	84	85	86	87	88	89	90	91	92	93
CORROSION	**53**	**54**	**49**	**71**	**55**	**22**	**33**	**44**	**27**	**26**
FAILED WELD	2	1	8	5	5	3	2	6	7	3
INCORR. OP.	13	22	15	12	12	15	10	11	14	14
FAILED PIPE	12	9	21	23	20	17	22	11	16	19
OUTSIDE FORCE	65	60	71	64	55	30	22	37	30	38
M/FUNC. C/R EQUIP.	2	1 2	6	1 2	1 1	8	5	2	5	8
OTHER	28	8	16	24	18	7	15	18	15	37
O-RINGS NIP. ETC	12	18	20	25	18	16	21	13	31	15
TOTAL IN ASME	**187**	**184**	**206**	**236**	**194**	**118**	**130**	**142**	**145**	**160**
TOTAL IN LIQLCK	**195**	**167**	**190**	**250**	**199**	**153**	**176**	**223**	**224**	**214**

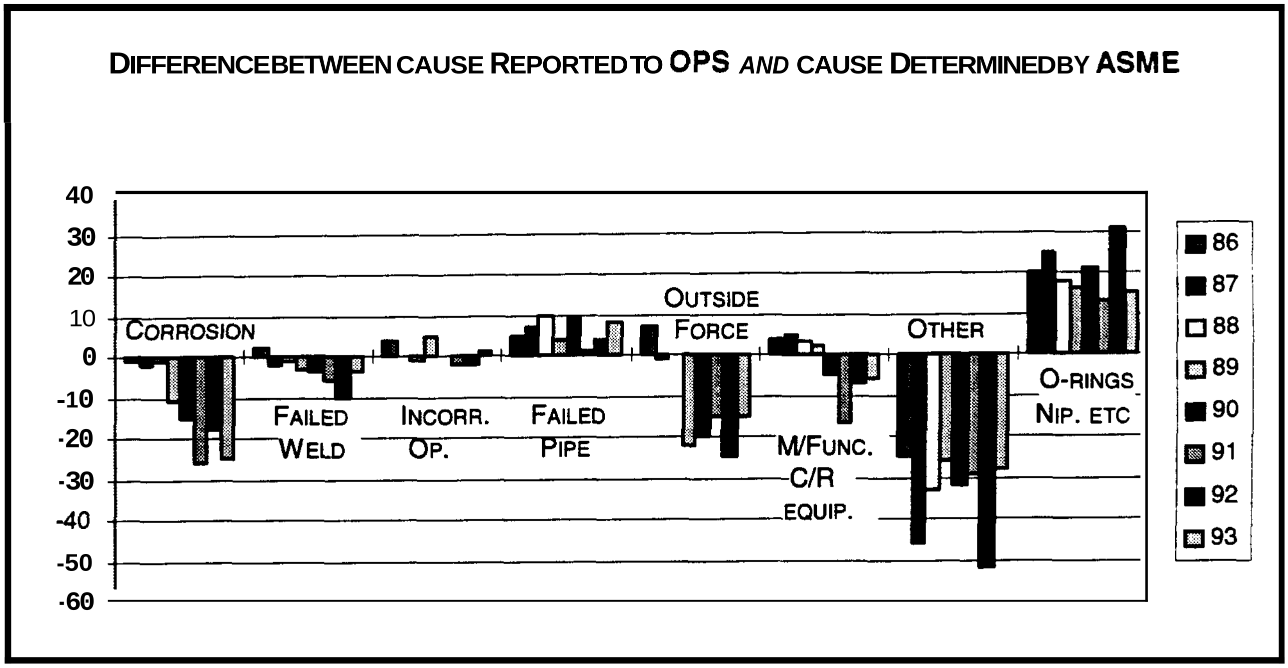
One should note that there are discrepancies between the number of accidents reported to OPS in LIQLCK vs. those analyzed by **ASME.** The number of accidents in the **ASME** report are mostly lower than in LIQLCK except for 1985 and 1986. The reason for this discrepancy is not known.



The difference between LIQLCK and ASME is:

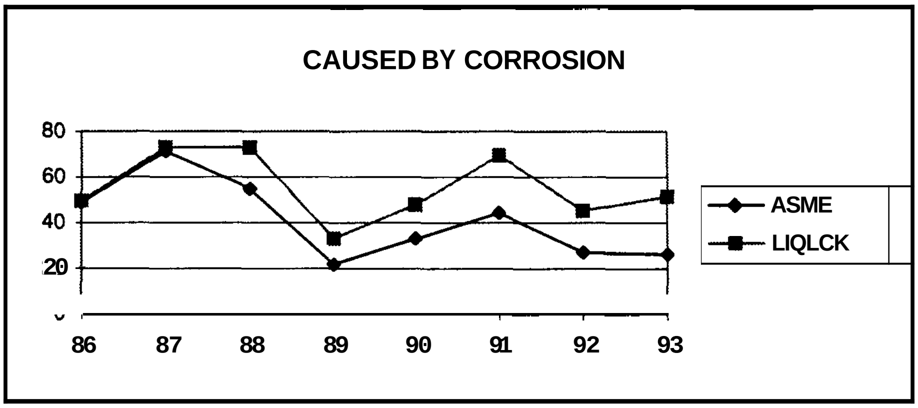
ASME - LIQLCK

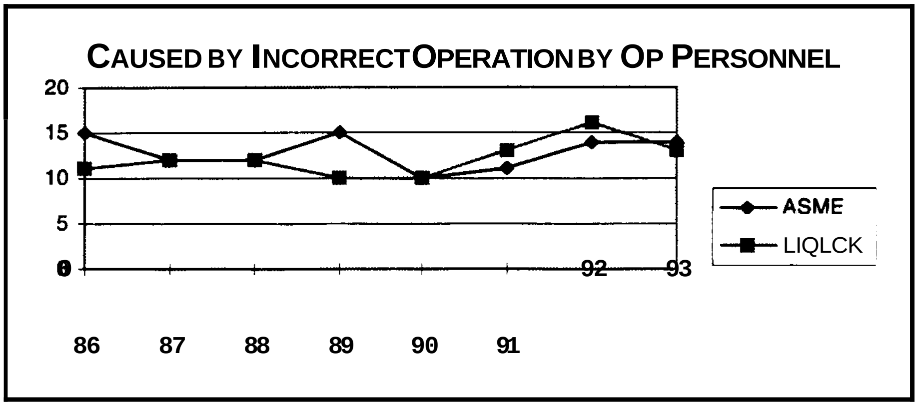
	86	87	88	89	90	91	92	93
CORROSION	-1	-2	-1	-11	-15	-26	-18	-25
FAILED WELD	2	-2	-1	-3	-4	-6	-10	-4
INCORR. OP.	4	0	-1	5	0	-2	-2	1
FAILED PIPE	5	7	10	4	9	1	4	8
OUTSIDE FOR.	7	-1	0	-22	-20	-15	-25	-15
M/FUNC. C/R EQUIP.	4	5	3	2	-5	-17	-7	-6
OTHERS	-25	-46	-33	-26	-32	-29	-52	-28
O-RING NIP. ETC	20	25	18	16	21	13	31	15

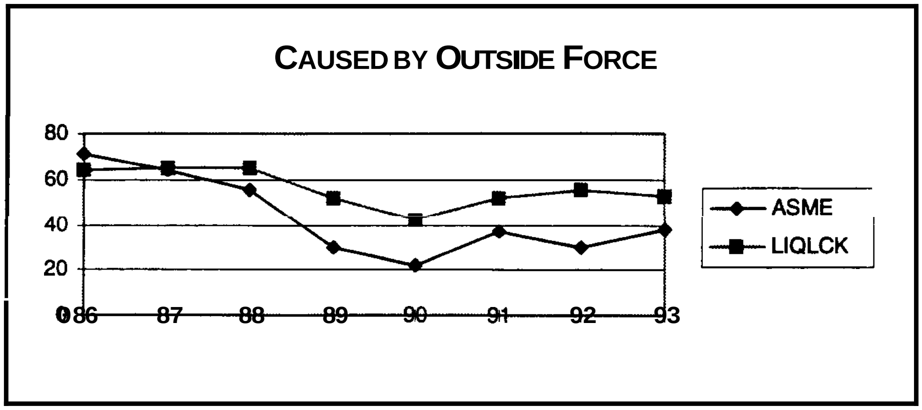


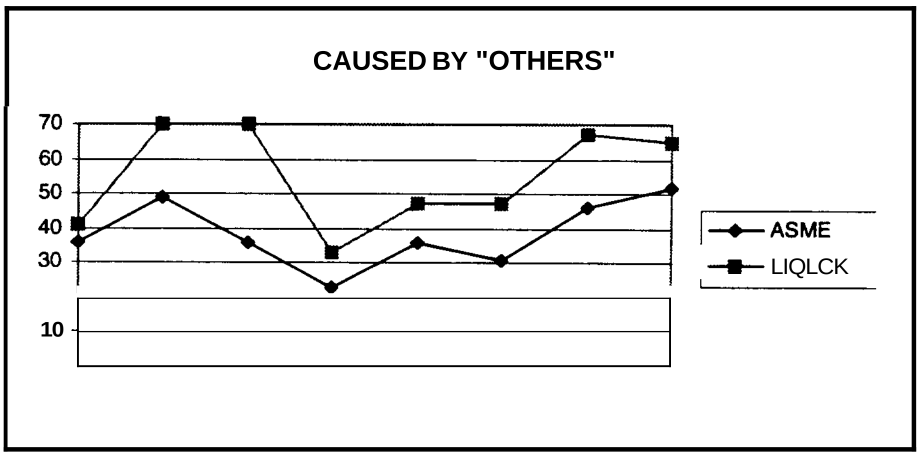
The comparison between LIQLCK and ASME is performed for the years 1986-1993 because complete data from both sources exists only for these years. 1985 was a transition year from the old reporting form to the new one and accidents are recorded in different databases. The last year analyzed for this report by ASME was 1993.

It is interesting to examine some of the more frequent causes for hazardous liquid accidents. The following figures show that the number of accidents due to corrosion, damage by outside force, and the "other" categories are generally higher in LIQLCK than in the **ASME** report. This is somewhat expected for the "other" category but not for corrosion and damage by outside forces. One possible explanation is that when more categories are used (such as in the case of ASME) a more accurate cause can be determined. Thus, the cause is spread out into more categories. In addition, when an independent group (not the operator who reports about its own accident) evaluates an accident, a different conclusion may be reached.









To summarize the issue of cause determination, it is clear that information in the LIQUID and LIQLCK databases lacks both accuracy and completeness.

The database revised by the **ASME B31.4/B31.11 Committee** was not available for this report. Therefore, the analysis presented in this report is based on the original OPS databases.

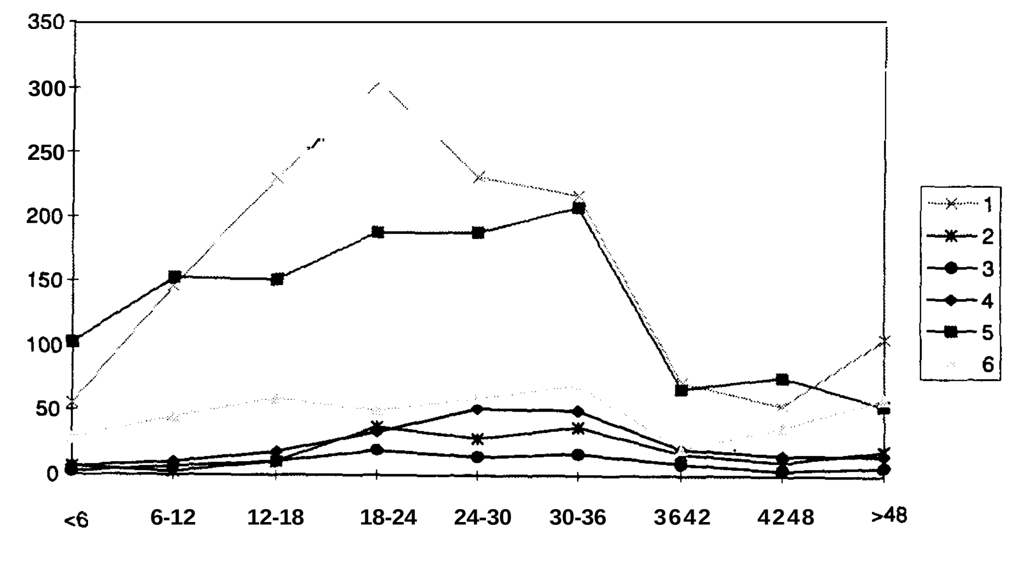
4.0 ACCIDENT BY CAUSE AND COVER DEPTH

USDOT pipeline safety regulation 49 CFR Part 195.248 requires a minimum cover of pipe between 3 0 and 48" with some exceptions (such as rock excavation). Pipe buried at depths less than the above minimum must implement additional protection equivalent to the minimum required cover. The depth of cover is given in the LIQUID database but there is no information on extra protection applied for pipe with less than the minimum cover. The depth of cover in **LIQLCK** is not given. The only information for the years 1985 and after is whether the pipe was above or below the ground.

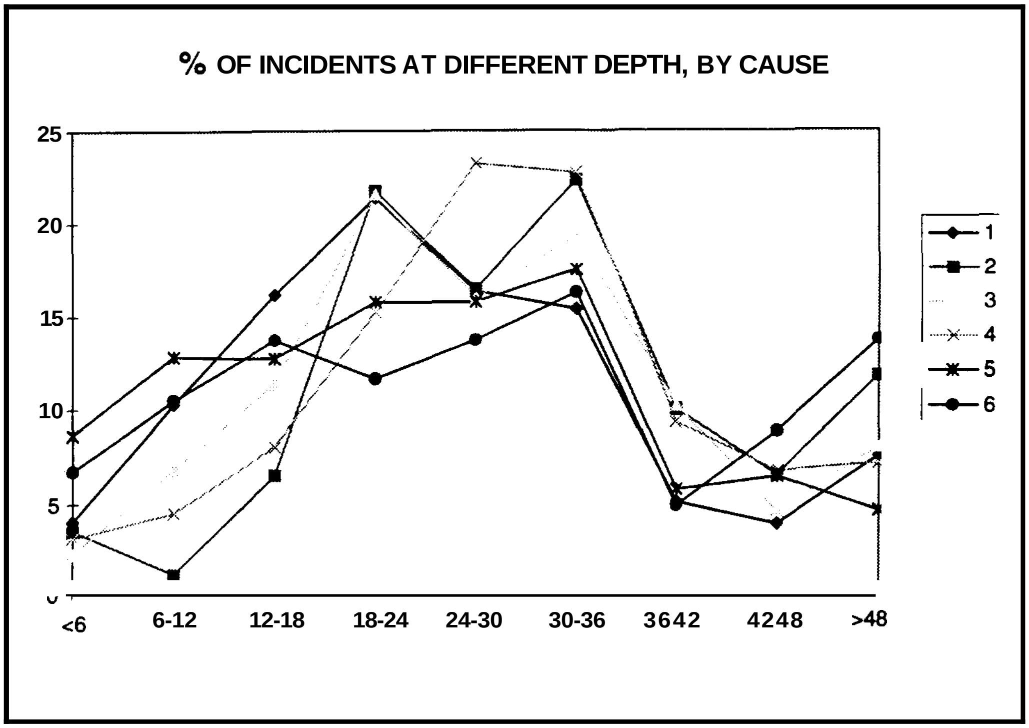
4.1 ANALYSIS OF LIQUID DATA 1968-1984 FOR NUMBER OF ACCIDENTS AT DIFFERENT DEPTHS BY CAUSE

	CORROSION		DEFECTIVE WELD		OPERATION ERROR		DEFECTIVE PIPE		EQUIP RUPT LINE		OTHERS	
DEPTH COVER		1		2		3		4		5		6
<6	56	4%	6	4%	2	2%	7	3%	103	9%	29	7%
>6-12	146	10%	2	1%	6	7%	10	4%	153	13%	45	10%
>12-18	229	16%	11	6%	10	11%	18	6%	152	13%	59	14%
>18-24	303	21%	37	22%	19	22%	34	15%	188	16%	50	12%
>24-30	231	16%	28	16%	14	16%	52	23%	188	16%	59	14%
>30-36	217	15%	38	22%	17	19%	51	23%	208	17%	70	16%
>36-42	72	5%	17	10%	9	10%	21	9%	68	6%	21	5%
>42-48	55	4%	11	6%	4	5%	15	7%	76	6%	38	9%
>48	106	7%	20	12%	7	8%	16	7%	54	5%	59	14%
Total	**1415**		**170**		**88**		**224**		**1190**		**430**	

NUMBER OF INCIDENTS AT DIFFERENT DEPTH, BY CAUSE



The above data in terms of percent of accidents is:



From the figure depicting the percent of accidents by cause, one can observe that there is a general increase in the number of accidents when the depth of cover is between 0" to 18". It is relatively stable between 18" and 36", and then it drops. Since this pattern is common to all causes, one may conclude that most of the pipe is positioned between 18" and 3 6 below the ground surface.

Another observation that can be made is that except for "corrosion" and "equipment ruptured line" the depth of coverage is inconsequential. The number of accidents is very small for the remaining categories regardless of the depth of cover. On the other hand, in a shallow cover of 0 to 1 2, the category of "equipment ruptured line" is the most frequent cause of accidents. In fact, 51% of all causes of accidents for pipe buried 6" or less is due to "equipment ruptured line."

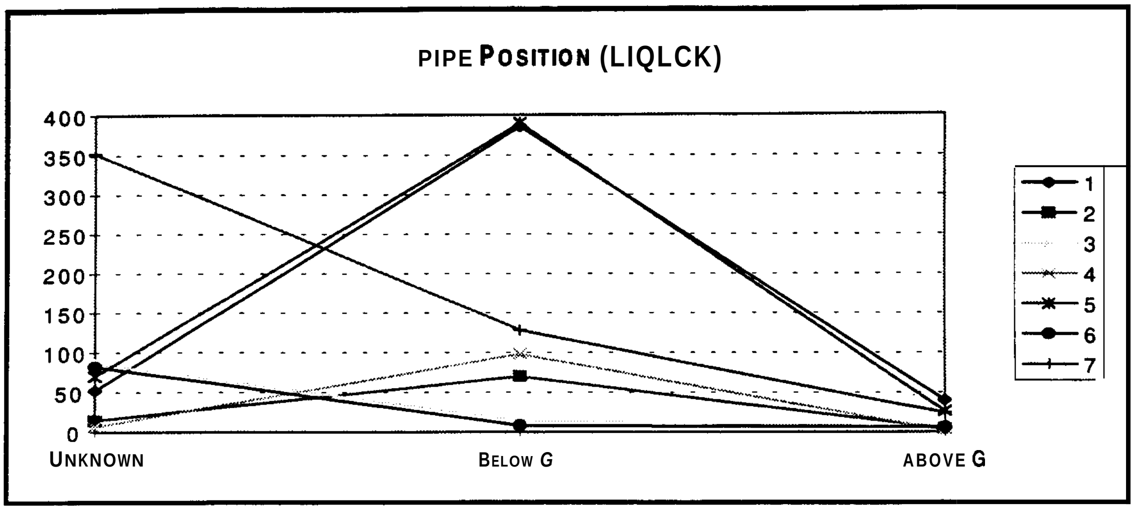
A final observation is that if all pipe had been covered according to 49 **CFR** Part 195.248, many accidents might have been avoided (i.e., 20% to 30% of all accidents occur in pipe installed below the present minimum DOT cover requirements).

4.2 ANALYSIS OF LIQLCK DATA 1984-PRESENT FOR NUMBER OF ACCIDENTS AT DIFFERENT DEPTHS BY CAUSE

With regard to accident data from 1984 to the present, the new form does not require operators to specify depth of cover. The figure below presents the data for relating the cause of accident to whether the pipe was above or below ground.

When the cause was classified as "other" the position of the pipe (above/below ground) was not given. This could be because there was sincere difficulty in making this determination or because of a lax approach in filing the report. Since it **is** not difficult to determine whether the pipe was above or below the ground, it seems that the latter explanation is more likely.

The data provided in LIQLCK is inadequate for any correlation of the cause with the position of the pipe.



5.0 ACCIDENT BY CAUSE AND PIPE DIAMETER AND WALL THICKNESS

Pipe with different nominal diameters have different wall thicknesses. API has established some specifications for standard wall thickness associated with a given nominal diameter size. They also have specifications for extra strong wall thickness, which intuitively should lead to better protection against failure. Thus, it is interesting to examine whether there is a correlation between the number of accidents in pipe that have wall thicknesses smaller or larger than **API's** standards.

The analysis presented here is for pipe with a nominal diameter size larger than **4** inches. The reason is that only **1.4%** of the accidents occur in pipe smaller than **4"** in diameter. **Also,** there are a large number of variations in wall thicknesses of pipe with nominal diameter size between **1"** and *4"*.

According to API specification the following represents the standard wall thickness for pipe:

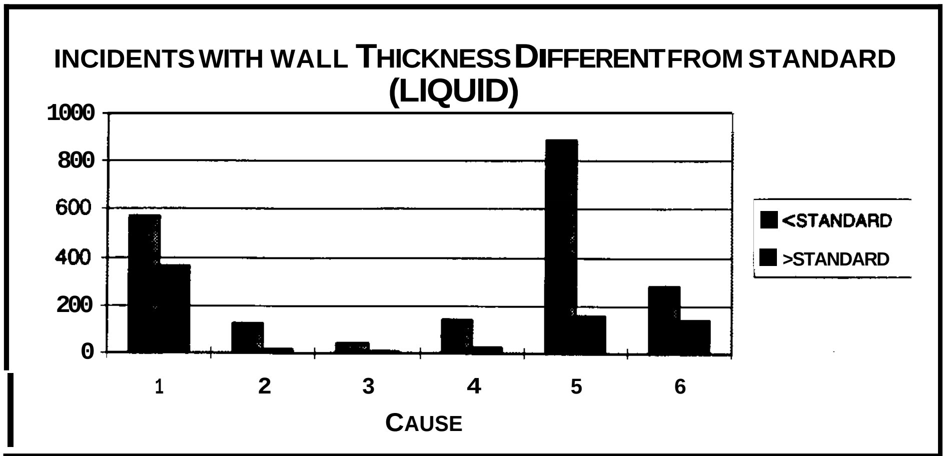
NOM. DIAMETER (IN)	4	4 1/2	59/16	6 5/8	8 5/8	10 3/4	12 3/4 -52
WALL THICKNESS (IN)	0.226	0.237	0.258	0.280	0.322	0.365	0.375

Both databases (LIQUID and LIQLCK) have been analyzed by counting the number of accidents that occurred on pipe which deviate from the above standards. The results of the analysis are presented in the following tables and figures.

5.1 ANALYSIS OF LIQUID DATABASE

CAUSE

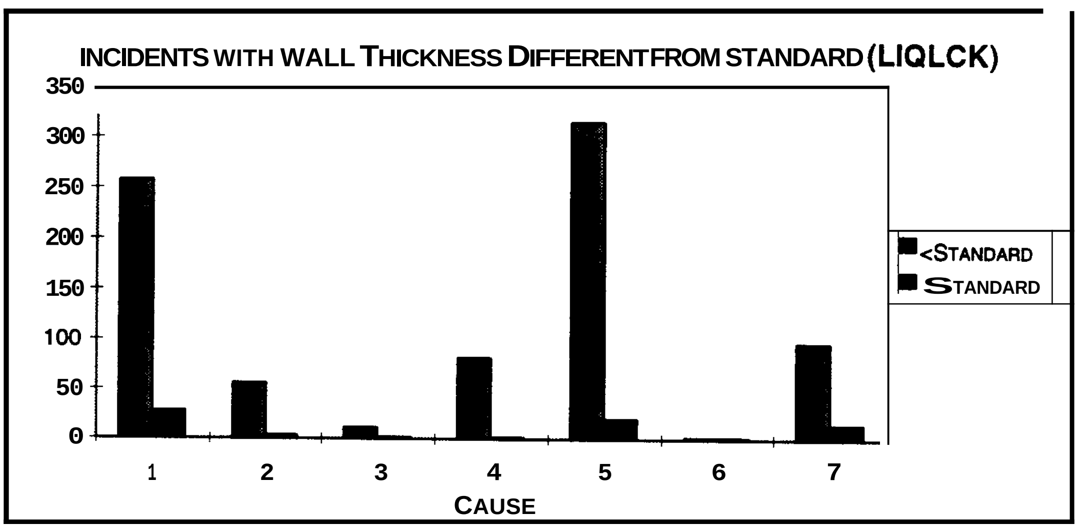
WALL THICKNESS	1	2	3	4	5	6
< STANDARD	574	126	39	141	881	278
> STANDARD	362	14	11	25	159	141



5.2 ANALYSIS OF LIQLCK DATABASE

CAUSE

WALL THICKNESS	1	2	3	4	5	6	7
<STANDARD	257	55	12	81	315	2	97
>STANDARD	28	4	1	1	20	2	14



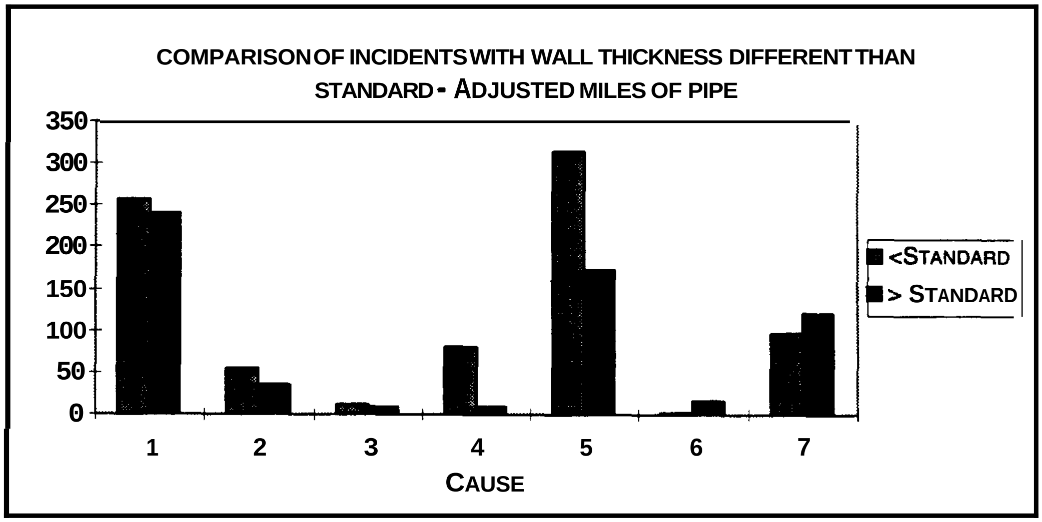
It is obvious that if the pipe wall thickness is greater than the standard the probability of an accident occurring on that pipe is significantly reduced. This observation is true especially for "damage by outside force" or "equipment ruptured line," which is cause Number 5, and for "failed weld," which is cause Number 2.

The problem with the above observation is that it is not known how many miles of pipe from each category are presently in the ground. If most of the pipe has a wall thickness which is less than the API standard wall, one would expect to have more accidents on that type of pipe. Thus, the data must be normalized to the number of miles of pipe with wall thickness smaller than the standard and miles of pipe with wall thickness larger than the standard. This data is not available to NJIT on an industry-wide basis. However, data for one pipeline company is available, which may provide an insight into the industry.

The company whose data will be used has about 5,000 miles of pipe. Of the total, 3913 miles are pipe with wall thickness less than the standard and 456 miles are pipe with wall thickness greater than the standard. The apparently large number of miles of pipe with wall thickness less than the standard can be explained by the fact that most of the pipe was installed before the standard was developed. The rest of the pipe is exactly according to the standard. This means that one would expect to have about 8.58 times more accidents on thinner pipe than on thicker ones. Based on the above, the number of accidents on pipe with wall thickness larger than the standard was adjusted, and the results are presented in the following table and figure.

5.3 ANALYSIS OF LIQUID DATABASE AFTER ADJUSTMENT TO MILES OF PIPE

Wall Thickness	1	2	3	4	5	6	7
<Standard	257	55	12	81	315	2	97
>Standard	240	34	9	9	172	17	120



From the above, one can see that "damage by outside force" in pipe with wall thickness below the standard is still almost twice as much as in thicker pipe. Also, the number of "failed pipe" (Cause 4) is much larger in thinner pipe.

CONCLUSION: Assuming that the data from the sampled pipeline company is representative of the hazardous liquid pipeline industry, it is reasonable to conclude that using pipe with extra thick walls can generally reduce the number of accidents, particularly where damage by outside forces is the causative agent.

6.0 ACCIDENT CAUSED BY CORROSION

When the cause of an accident is determined to be corrosion, the operator is required to specify whether the failed pipeline was coated and whether it was under cathodic protection. This information could be used to determine the effectiveness of, and/or the necessity of protecting the pipeline by these measures. The ability to make this determination in a responsible fashion depends on whether the data can be normalized. For this report, such data was not available. There are no detailed annual reports on the hazardous liquid pipelines similar to those that are filed by the gas industry. NJIT did not have information on total mileage of pipelines which are coated or bare, and the total mileage of pipelines which are cathodically protected. Thus, definite conclusions from the data presented here are not prudent.

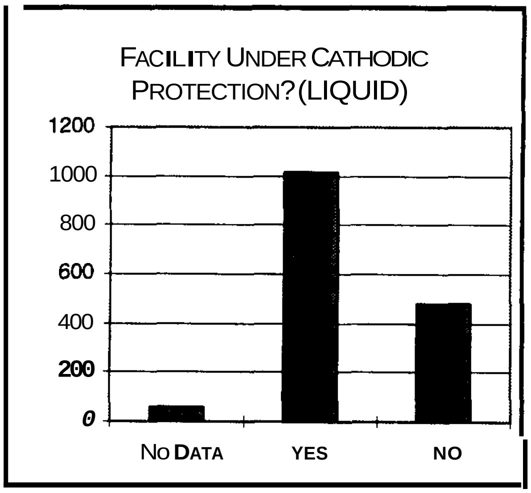
6.1 ANALYSIS OF LIQUID DATABASE

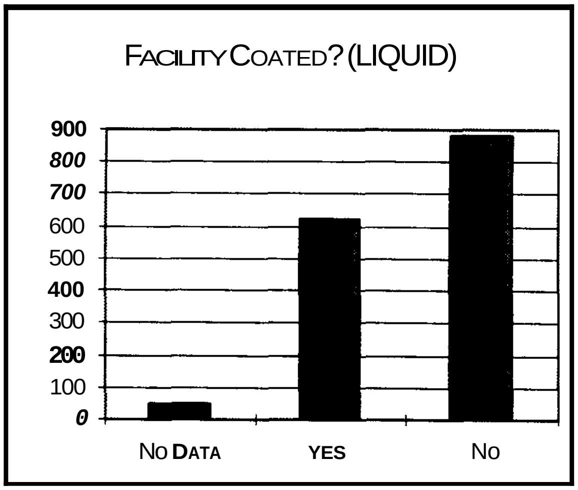
FACILITY UNDER CATHODIC PROTECTION

NO DATA	60
YES	1017
NO	480

FACILITY COATED

NO DATA	51
YES	624
NO	882





The above tables and figures indicate that it is very important to coat the pipeline because most of the accidents occurred on uncoated pipelines. In addition, it is important to have the pipeline under cathodic protection since about one half of the accidents caused by corrosion occurred on pipe which was not under this protection. The gravity of these finding could be more severe if, in the hazardous liquid pipeline industry, most of the pipelines are coated and are under cathodic protection. This will increase the relative risk in not implementing these corrosion protection measures.

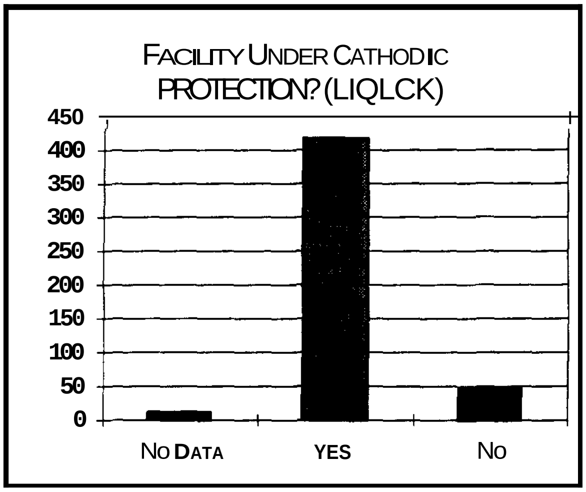
6.2 ANALYSIS OF LIQLCK DATABASE .

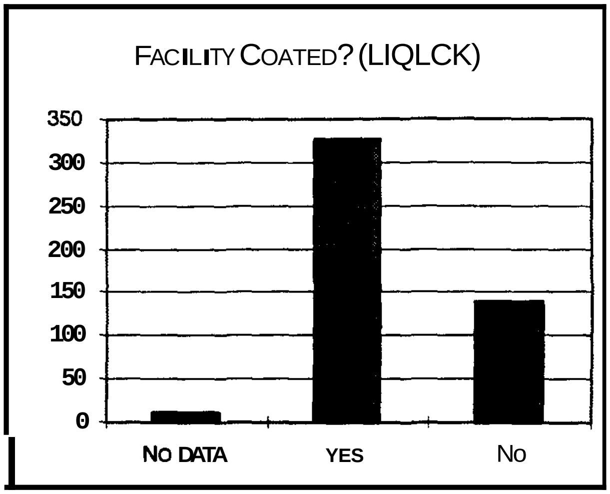
FACILITY UNDER CATHODIC PROTECTION

NO DATA	13
YES	419
NO	47

FACILITY COATED

NO DATA	12
YES	327
NO	140





From the above figures and tables one can see that, compared to the LIQUID data, less accidents occurred on coated pipelines and on pipelines that are under cathodic protection. The probable reason for the decrease in the number of accidents on pipelines that are not coated and not protected is that fewer pipelines are uncoated and unprotected. Again, it is crucial to have normalized data in order to make a reasonable analysis. Otherwise one may conclude from the above data that because more accidenfs occur on coated and cathodically protected pipelines, we should avoid utilizing these corrosion preventive measures to make pipelines safer.

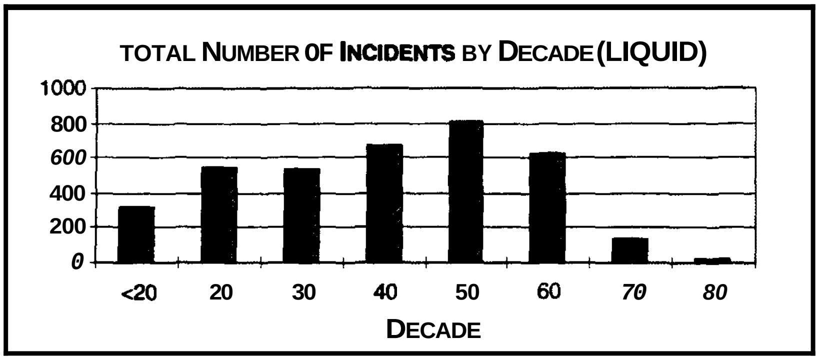
7.0 ACCIDENTS RELATED TO YEAR OF INSTALLATION AND YEARS IN OPERATION

Both the year in which the pipe was installed and the age of the pipe (years in service) should be analyzed. The first may provide an insight into specific problems occurring in a given decade, which in turn could be related to the prevailing technology and practice at the time.

7.1 ANALYSIS OF LIQUID DATABASE

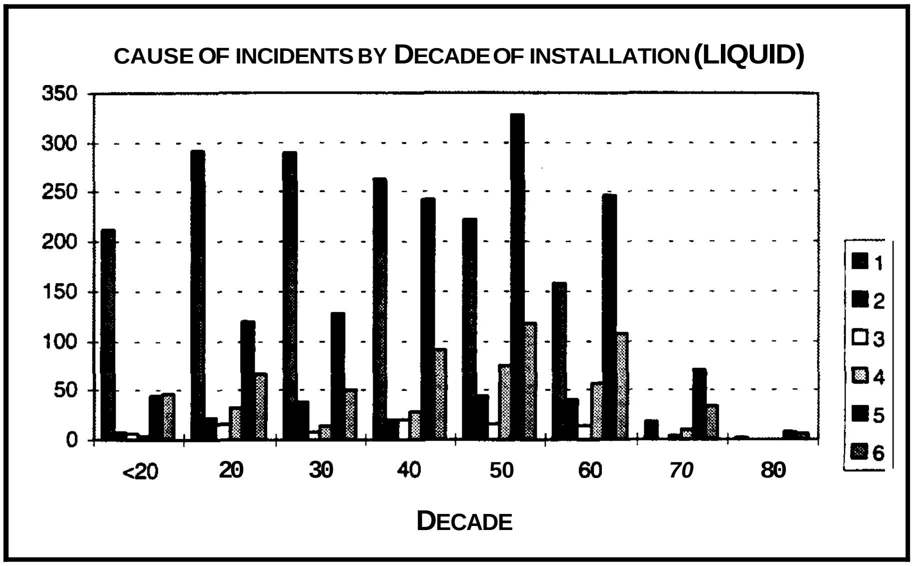
The following presents the total number of accidents by year of installation grouped by decades

DECADE	TOTAL ACCIDENTS
<1920s	322
1920s	549
1940s	665
1950s	804
1960s	622
1970s	140
1980s	18



The following is a table and a chart describing the number of accidents for different causes for each decade.

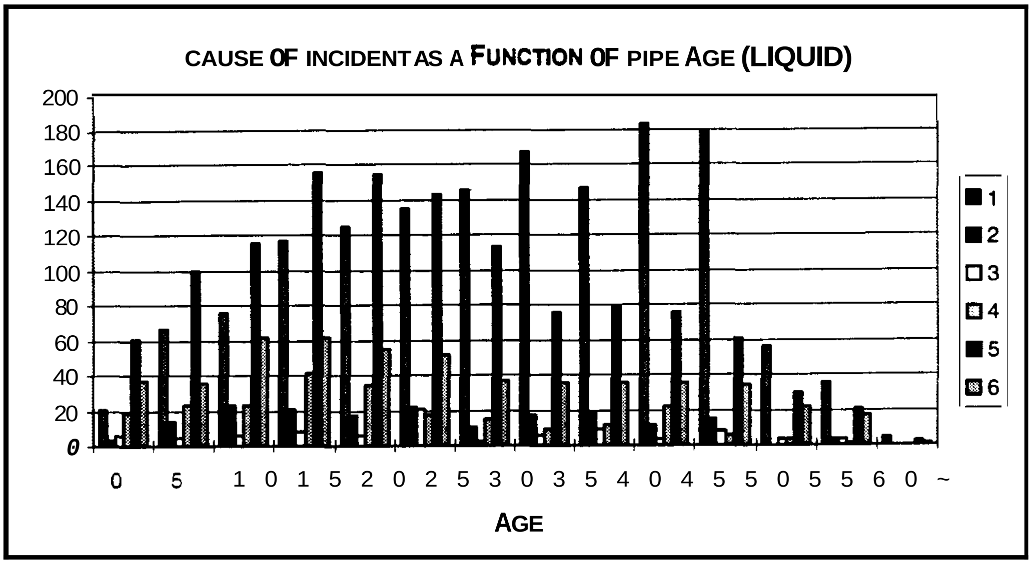
YEAR	CAUSE 1	2	3	4	5	6
<20s	212	8	7	5	44	46
20s	292	22	17	33	119	66
30s	289	38	9	15	128	50
40s	262	21	20	29	242	91
50s	223	44	17	75	327	118
60s	158	40	14	57	246	107
70s	18	1	4	11	71	35
80s	2	1	0	0	9	6

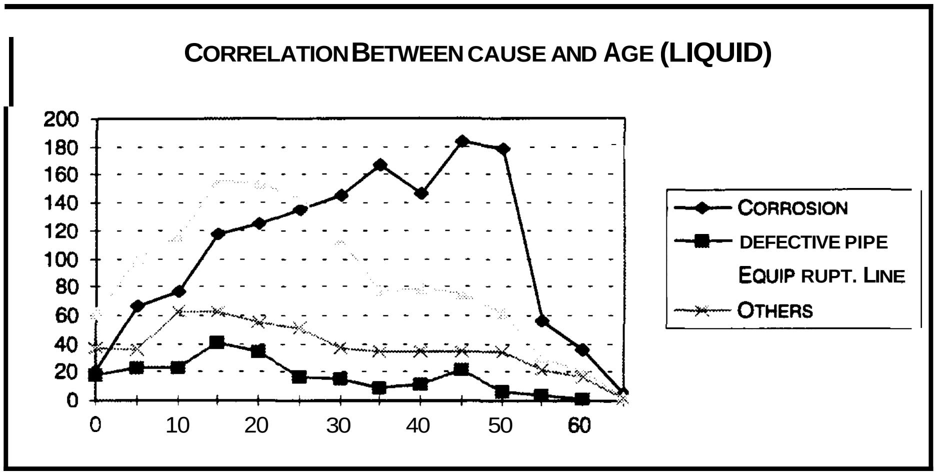


One can see from the above that pipe installed prior to the **1940s** has a substantially larger number of accidents due to corrosion (1) than any other cause. For pipe installed during the **1940s,** corrosion (1) and equipment ruptured line (5) are about equal. After 1950 the number of accidents due to equipment ruptured line (i.e., damage by outside force) becomes the dominant cause for accidents.

Equipment ruptured line (5) approximates a "bell" shape similar to a normal distribution, with most of the accidents occurring on lines constructed during the **1950s.** This may be related solely to a large number of pipe constructed during that period. As for corrosion (1), it appears that the age, the pipe, and the construction technology at the time of installation are more dominant factors in analyzing the accident records.

Analyzing the factor of age of the pipeline supports the previous observation. Accidents caused by corrosion (1) increase almost linearly up until the age of pipe of **45.** After age **50** there is a sharp drop which could be related to a sharp decrease in the mileage of pipe still in service that is more than 50 years old. Thus, one can observe that there **is** a correlation between age and corrosion. This may or may not mean that there is a finite limit to the effectiveness of corrosion prevention measures.



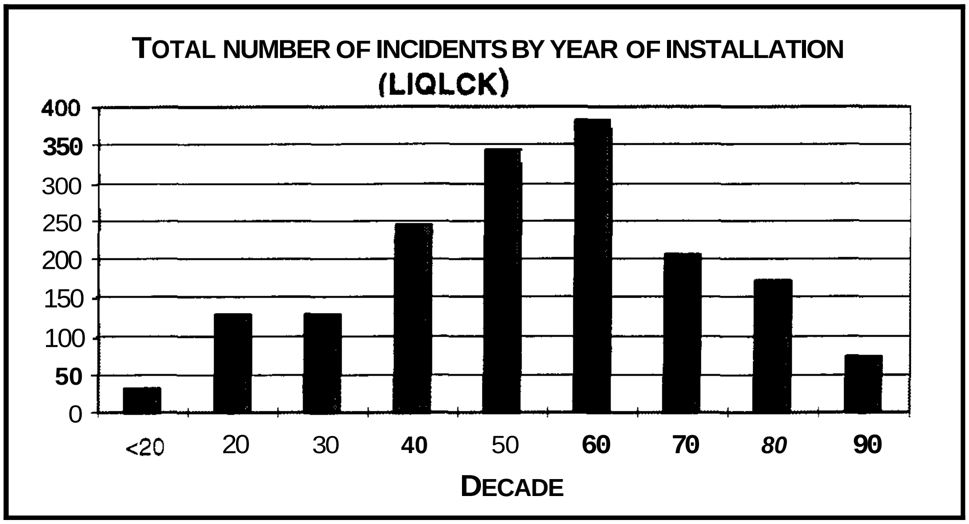


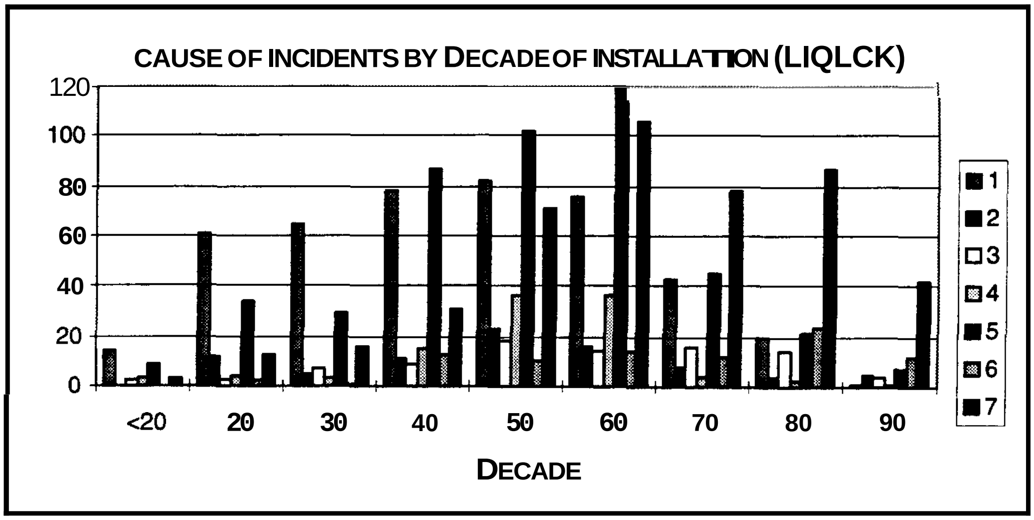
The above figure shows that "equipment ruptured line" is relatively high at ages between 10 and 30 years. In fact, it is the number one cause of accidents until the pipe reaches age 25. One explanation for this is that in more populated areas with extensive development, activities occur around newer pipe. Thus, the potential for damaging the pipe by equipment is greater.

7.2 ANALYSIS OF LIQLCK DATABASE

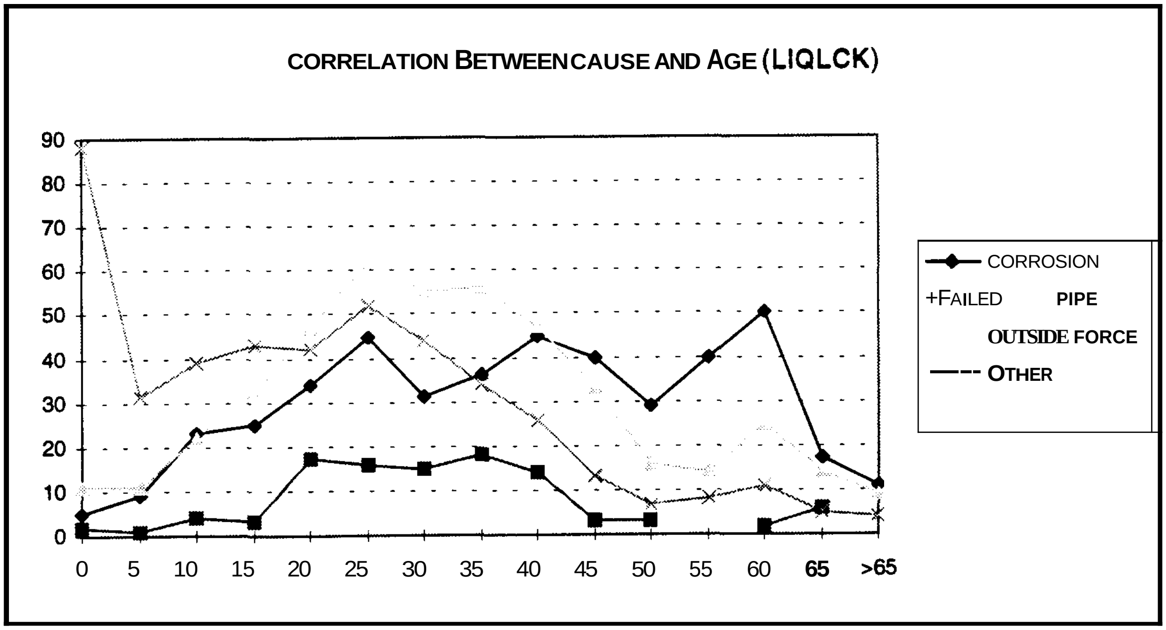
The analysis of LIQLCK data reveals a pattern similar to what was found in the LIQUID data. There is a shift in the decade with the largest number of accidents from the 1950s to the 1960s. This can be explained by the fact that the large number of newly constructed lines during the 1960s are not reflected in the old database.

An interesting observation is that the number of accidents classified as "other" (7) has increased substantially for pipe installed since the 1960s. Most of the causes under the category "other" are due to rupture or to leaks in pipe system components such as O-rings, gaskets and nipples. This could indicate a weakness in that part of the hazardous liquid pipeline system.





As before, one should examine not only the year of installation but also the number of years the pipe was in service. The following is a chart which presents the number of accidents for each cause category as a function of pipe age.



From the above it can be seen that the most dominant category of causes of accidents during the first 20 years of pipe life is "other". As mentioned earlier, most of the accidents for which the cause was reported as "other" involve the failure of a component on the pipe system. Corrosion-related accidents become dominant only after the pipe age is 40 years or older.

When comparing the data from LIQUID with the data from LIQLCK, one can see that corrosion becomes the dominant factor causing accidents as the age of the pipe increases. Also common for both databases is the large number of "damage by outside force" that is reported for pipe at the same relative age. In LIQUID it is between 10 and 25 years old and in LIQLCK between 20 and 40. Since LIQUID data is about 10 to 15 years older than LIQLCK (1968-1984 vs. 1985-1994) the number 1 cause of accidents corresponds to the same age of pipe in both databases. If more data were available on factors such as the location of this pipe, it would be possible to gain an insight into why this pipe is vulnerable to outside forces.

The above analysis is not complete without relating the number of miles in service of a particular pipe age to the total number of accidents. The fact that a certain factor increases or decreases has to be related to the corresponding increase/decrease of miles of pipe.

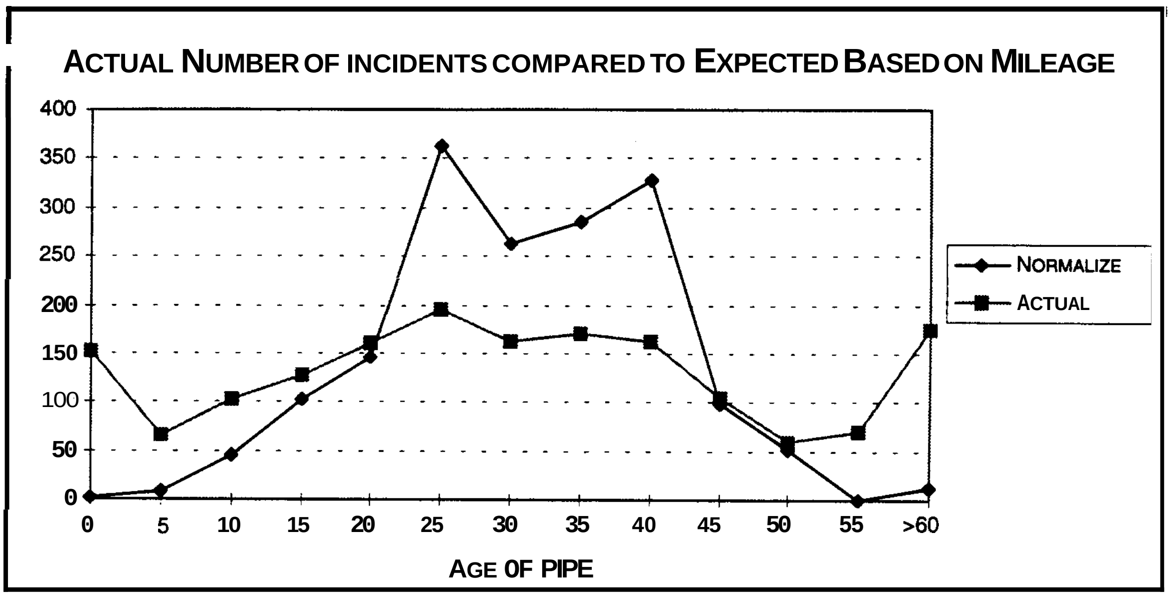
8.0 A MODEL OF A HAZARDOUS LIQUID PIPELINE SYSTEM

As mentioned earlier, NJIT was able to receive detailed data on the pipeline system of a large hazardous liquid pipeline operator. The data included miles of pipe with different characteristics, age, and year of installation. This data will be used for normalizing the probability of an accident occuring as a function of miles of pipe. In order to maintain confidentiality of the data, the company who provided the information will be named Operator X.

The following is a summary of the nominal mileage of pipe for different age categories in the Operator X system. Presented also is the percent within each age category with respect to the entire system. Using this percentage and the total number of accidents in LIQLCK, a normalized (or expected) number of accidents was computed for various pipe ages.

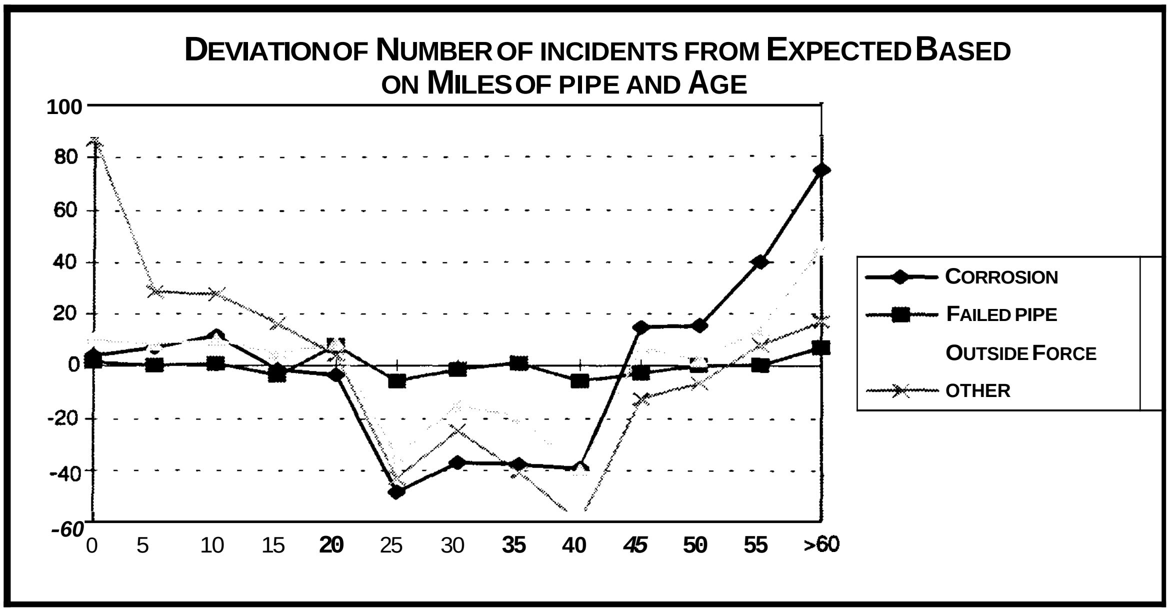
AGE	MILES	%
0-4	7.023	0.1
5-9	25.749	0.5
10-14	130.191	2.6
15-19	300.635	6.0
20-24	424.923	8.5
25-29	1059.889	21.3
30-34	768.102	15.4
35-39	833.916	16.7
40-44	958.223	19.2
45-49	288.706	5.8
50-54	150.576	
55-59	0.204	
	4984.334	100.0

AGE	ACTUAL ACCIDENTS	NORM. ACCIDENTS
0-4	151	2
5-9	65	9
15-19	127	103
20-24	159	145
25-29	195	362
30-34	163	262
35-39	171	285
45-49	104	99
50-54	60	51
55-59	69	0
60-	174	12
	1703	1703



From the above one can deduce that pipe between age 0 to 20 and beyond the age of 50 can expect to have more problems on a per mile basis. Pipe that is already in service for 20 years can expect to have fewer accidents per mile than newer or older pipe. If the data of Operator X represent the makeup of the pipe in the entire industry, one can expect to have 75 times more problems in the first 5 years of service than one should have based on pipe mileage. This is because in years 0-4 there are 7.023 miles out of a total system of 4984.334 miles, or 0.14%. One would expect that the number of accidents in years 0-4 should be 0.14% of the total number of accidents, *i.e.*, 1703 x 0.14% = 2.4 accidents. The actual number of accidents in years 0-4 were 151, or about 75 times more than the expected number.

The figure below depicts the deviation of the number of actual accidents reported to OPS from the expected ones based on pipe mileage and age of pipeline Operator X. A closer examination of particular causes reveals that, for cause by failed pipe, the normalized accidents and the actual ones are reasonably similar. On the other hand, for corrosion and "other", the pattern is different. Accidents caused by corrosion increase more rapidly as the pipe becomes older (45 years and older) and accidents categorized as "other" are very frequent at an early age (up to 20 years). Pipe that is 50 years or older is twice as vulnerable to corrosion than to any other cause.



A conclusion from this analysis is that failed pipe and damage by outside force occurs independent of age. The more pipe one constructs, the more proportional increase in accidents due to these causes can be expected. In contrast to the above, causes in the category of corrosion and "other" have a pattern that is age dependent. The older pipe produces more corrosion. The older the pipe the less "other" can be expected. Since most causes classified as "other" are due to components such as O-rings and gaskets, the life expectancies of these components are not that long and they are replaced after a limited number of years. The fact that many of these components fail and cause accidents in the first few years of service raises a question of the adequacy of quality control and installation.

With regard to corrosion, there may be a rationale for considering a finite life for pipelines. It is evident from the data that pipe which is 50 years old or older becomes vulnerable to corrosion.

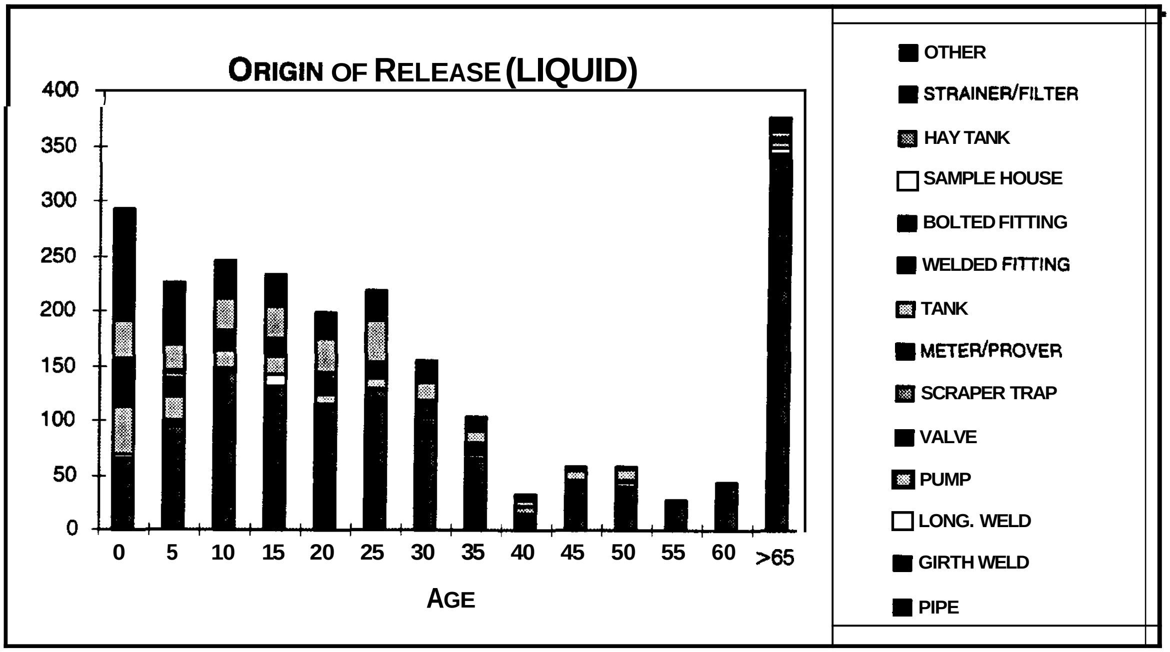
The data on damage by outside forces also shows an increase in the number of accidents after 50 years of pipe age. One possible explanation for this is that new developments have encroached upon the pipe and consequently have exposed it to higher risks. Another explanation for the increase in the number of accidents by outside force is that older pipe is weaker and less resilient. In order to resolve which explanation is more feasible, additional information is needed, such as the location of the pipe at the time of the accident. A minimum type of location information that could be useful is something equivalent to the class locations found in the gas pipeline industry. The best location information is a Geographic Information System (GIS) with detailed spatial and attribute information describing the vicinity of the pipeline.

9.0 ORIGIN OF THE RELEASE RELATED TO THE YEAR OF INSTALLATION AND THE AGE OF THE COMPONENT

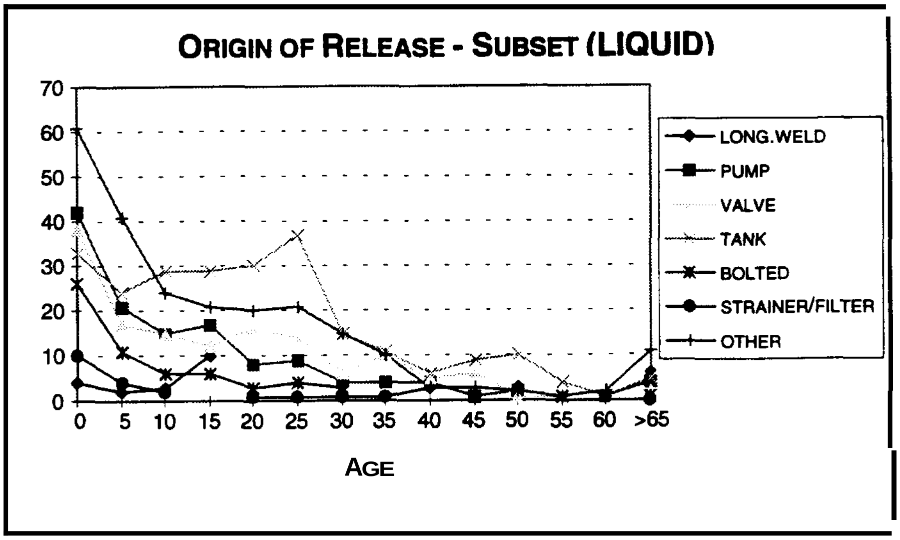
About 60% of the origin of liquid or vapor release is related to characteristics of the pipe used in the pipeline. This finding is the same for both databases LIQUID and LIQLCK.

9.1 ANALYSIS OF LIQUID DATABASE

From the figure below it can be seen that the majority of the origin of liquid releases is related to the pipe. As the pipe becomes older, the dominance of the pipe as a factor increases. Only for the first 10 years of age is the pipe category less than 50 %. For pipe that is 65 years or older the release occurs over 90% of the time. This observation reinforces the conclusion reached earlier that older pipe is more vulnerable to accidents.

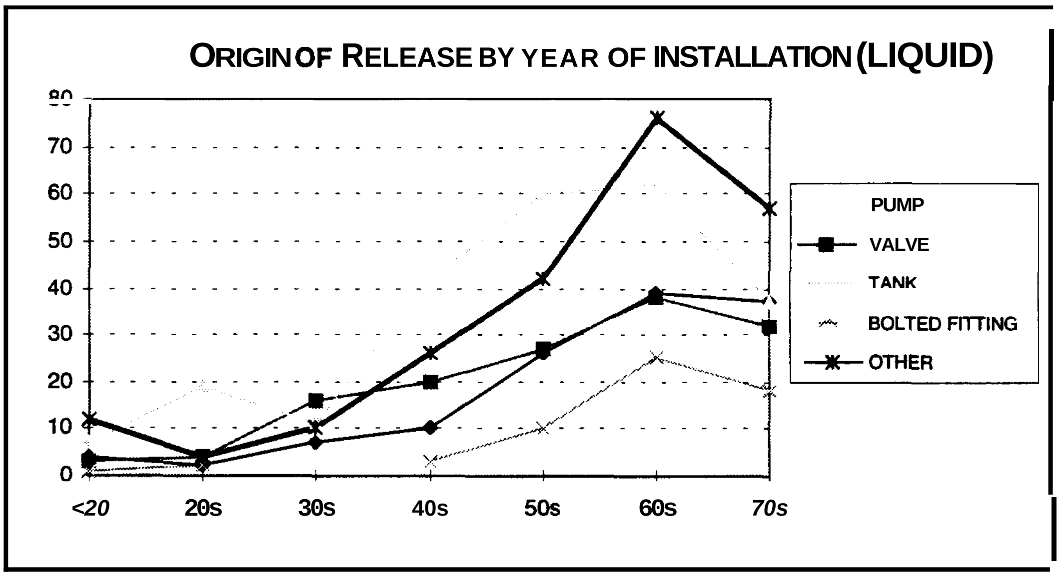


Some of the 14 parameter categories shown above rarely cause problems. In fact, the "hay tank" category was never attributed as a cause for a single accident. Consequently, another figure is presented where pipe and the very infrequent components have been removed from the data. The result of this is given in the next figure.



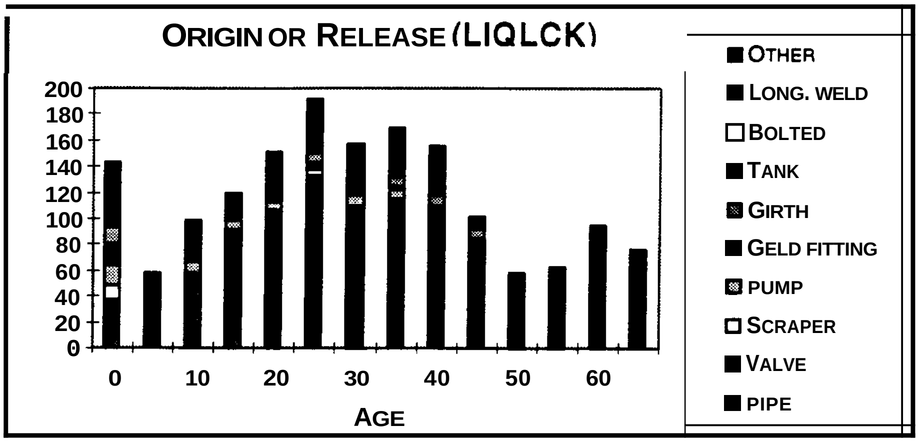
From the above figure, one can see that most of the problems related to these components are high initially and decrease as age increases. This may have at least two possible explanations which are addressed herein. The first is that these components do not have a long life span. For example, how many valves are in continuous operation for 40 years without replacement? The second is that potential deficiencies in the quality control of the installation and/or manufacturing process are exhibited early in the operation of the pipeline.

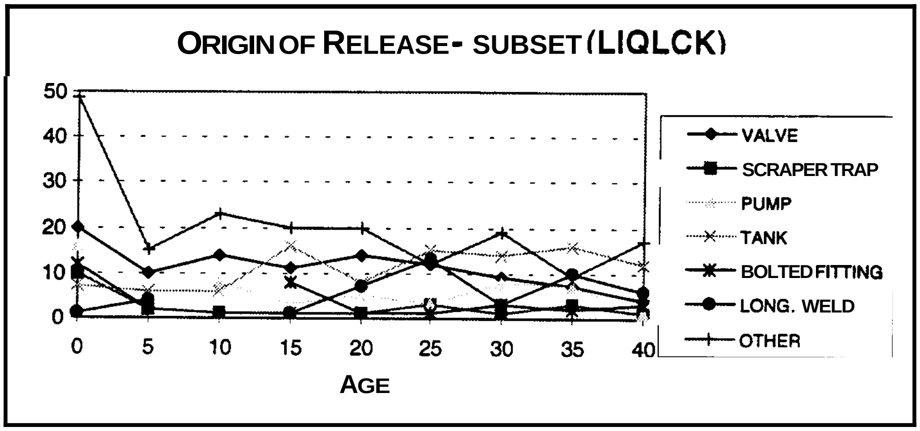
In order to examine whether certain components have a problem associated with the year installed the following figure can be analyzed. Again, only components (excluding pipe) with the most frequent problems are presented. The figure reveals a large number of problems in the 50s and **60s.** However, this can be explained by the large development of pipelines that occurred during those years.

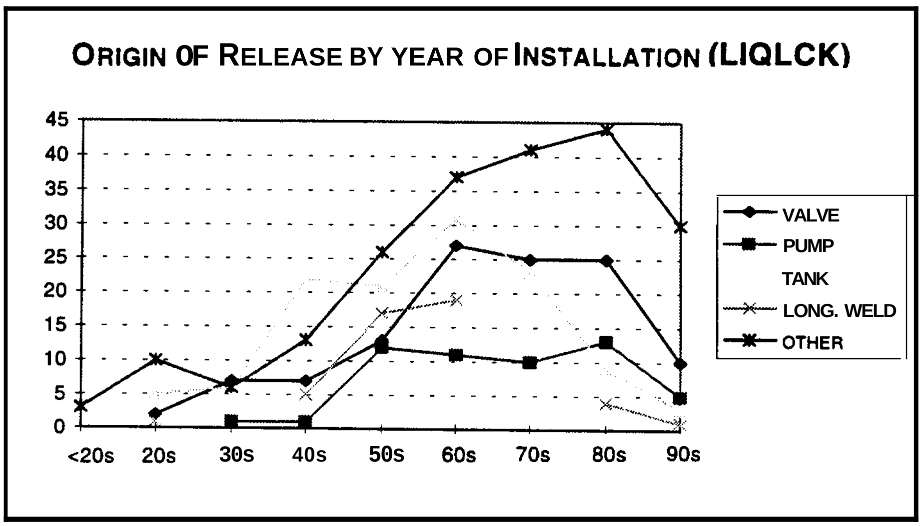


9.2 ANALYSIS OF LIQLCK DATABASE

Similar to the observation made when analyzing the LIQUID database, one can see that for the first 10 to 15 years components other than the pipe fail and cause most of the accidents. After 15 years most accidents originate in the pipeline itself.







The category “other“ appears to dominate for the more recent installations. This trend can be found also in the previous reporting on the cause of the accidents. It would be interesting to further investigate why this is the case. In viewing the above figure, although we have not reached a data review to the mid-point of the 1990s, already more than 2/3 of the “other“ category for origin of release have been reported, compared to the entire decade of the 1980s. One reason for the large number of ‘other“ in determining the origin of the release could be due to an inadequate list of categories to select from on the OPS reporting form. In other words, if the operator identifies a certain pipeline system component as the origin of the release for a particular accident, but that component is not listed on the OPS form, he will select “other” as the origin of release. If, however, the failed component is listed on the form, the operator will select that component as the origin of release. Including on the form more pipeline system components that could potentially fail will result in better and more focused data rather than a large number in the generic category “other.” Knowledge of potential sources of failure, combined with historical data, will assist in devising mitigating measures.

Malfunctioning tanks and valves also seem to be rather common problems associated with releases of hazardous liquids and vapors.

10.0 PROPERTY DAMAGE AND THE CAUSE, THE YEAR OF INSTALLATION, AND THE AGE OF THE PIPE

LIQUID and LIQLCK databases were examined to determine the relationship between the severity of the property damage and the cause of the accident, the year of installation, and the age of the pipe.

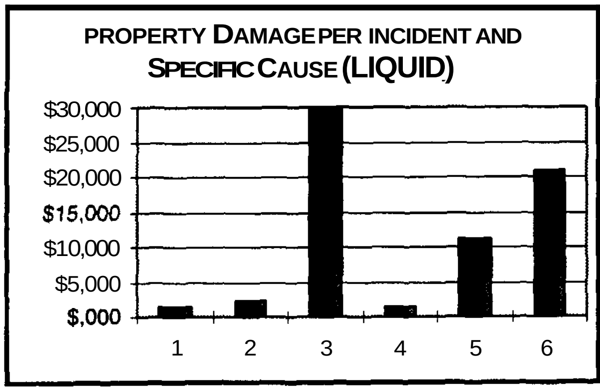
10.1 ANALYSIS OF LIQUID DATABASE

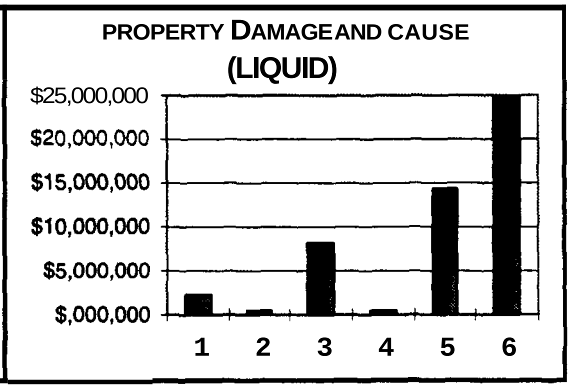
PROPERTY DAMAGE AND CAUSE

CAUSE	PROPERTY DAMAGE	NUMBER OF ACCIDENTS	DAMAGE per I ACCIDENT
1	$2,159,202	1557	$1,387
2	$422,409	192	$2,200
3	$8,205,600	277	$29,623
4	$351,638	233	$1,509
5	$14,278,298	1298	$11,000
6	$24,783,596	1196	$20,722

Most of the property damages in the LIQUID database are related to cause “other.” As mentioned previously, cause “other“ is comprised mostly of failures related to pipe components such as O-rings and gaskets. The second most damaging cause is ‘equipment ruptured line” and the third is “operator error.” Corrosion is a distant fourth place.

It is interesting to analyze the average cost of an accident for a specific cause. There could be a particular cause that is a rare occurrence but causes high damage when it does occur. From the figure below one can see that the most damaging cause (per accident) is “incorrect operation by operator personnel,” followed by “other,” and “equipment ruptured line.”

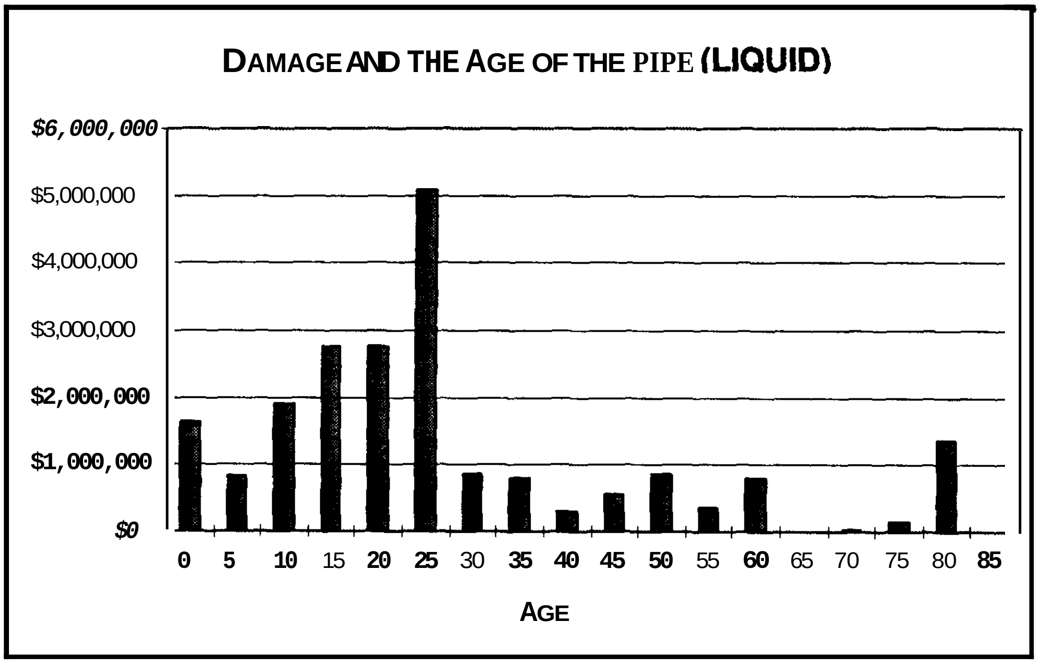




PROPERTY DAMAGE AND AGE

AGE	PROPERTY DAMAGE
0-4	$1,632,308
5-9	$840,295
10-14	$1,887,127
15-19	$2,776,836
20-24	$2,749,632
25-29	$5,092,095
30-34	$854,220
35-39	$791,419
40-44	$308,860

AGE	PROPERTY DAMAGE
45-49	$573,675
50-54	$875,742
55-59	$367,611
60-64	$799,207
65-69	$14,063
70-74	$39,631
75-79	$162,197
80-84	$1,372,569
85-	$1,000



The above figure reveals relatively high damages at a very early pipe age (0 to 4 years) and at a very old pipe age (around 80 years of age). The relatively high damage figures at age 20 to

25 are expected because of the large amount of pipe in use at that age category. However, the sharp drop after age 25 to 50 is somewhat better than expected based on the assumed mileage of pipe in service. Without additional information on the location of these accidents and the mileage of pipe in service, it is difficult to draw conclusions from the above data.

10.2 ANALYSIS OF LIQLCK DATABASE

Before analyzing the LIQLCK database it is helpful to present an example of some potential problems associated with utilizing the data as presently constituted without reasonable scrutiny. A careful examination of the accidents with the top ten (10) largest recorded property damage values can be used to illustrate concerns with regard to the quality of the data.

The top 10 property damage accidents in LIQLCK (raw data) are:

CAUSE		PROPERTY DAMAGE
OUTSIDE FORCE	(5)	$25,000,000
FAILED PIPE	(4)	$20,000,000
FAILED WELD	(2)	$12.000.000
CORROSION	(1)	$11,000,000
OUTSIDE FORCE	(5)	$10,000,000
FAILED WELD)	(2)	$7,500,000
CORROSION	(1)	$4,000,000
OUTSIDE FORCE	(5)	$4,000,000
FAILED WELD	(2)	$3,000,000
FAILED PIPE	(4)	$3.000.000

Since these accidents caused a significant amount of property damage, it was decided to study them in detail. The objective of the study was to gain a better understanding of the causes of accidents with disastrous consequences. A close examination of the accident with the largest property damage ($25M) revealed that it had the following characteristics:

- Actual pipeline pressure at the time of accident: 80 psi
- Maximum design operating pressure: 1177 psi
- No fatalities and no injuries were caused by the accident
- No fire and no explosion were caused by the accident
- 600 barrels of crude oil were lost, but 600 barrels were also recovered.

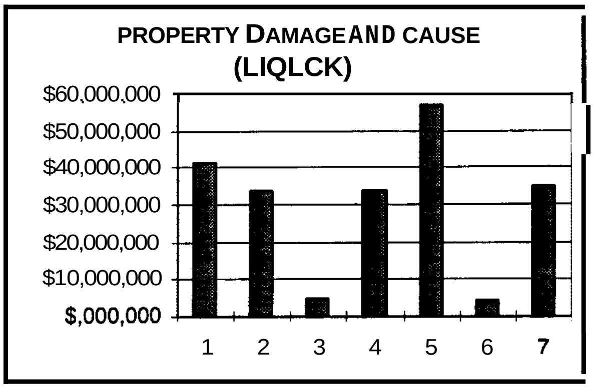
The above circumstance could hardly cause an accident resulting in $25,000,000 damage. It is obvious that something is wrong with either the accident information or with the estimate of the property damage. The accident information was cross-checked with the **ASME** report. It was found that the damage assessment was $25,000, a more reasonable figure. The report also determined that the accident was caused by a company contractor, not by a third party.

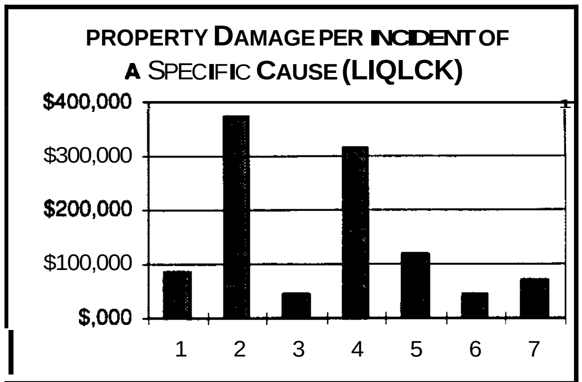
The accident with the fifth largest property damage was a petroleum products line rupture in Fairfax, Virginia. The reported cause of the accident was "outside forces." From NTSB's analysis of this accident, it is not clear whether the accident was caused by outside forces or by metal fatigue of the pipe. Thus, it is difficult to arrive at a firm conclusion of the effect of pipeline accidents when one has doubt about the quality of the data used in the analysis.

The following analysis is based on the reduced damage assessment of $25,000 previously noted.

PROPERTY DAMAGE AND CAUSE

CAUSE	PROPERTY DAMAGE	NUMBER OF ACCIDENTS	AVERAGE PROPERTY DAMAGE per ACCIDENT
1	$40,996,191	479	$85,587
2	$33,519,666	90	$372,441
3	$4,961,155	109	$45,515
4	$33,929,248	108	$314,160
5	$57,045,563	486	$117,378
6	$4,419,218	97	$45,559
7	$34,877,298	508	$68,656





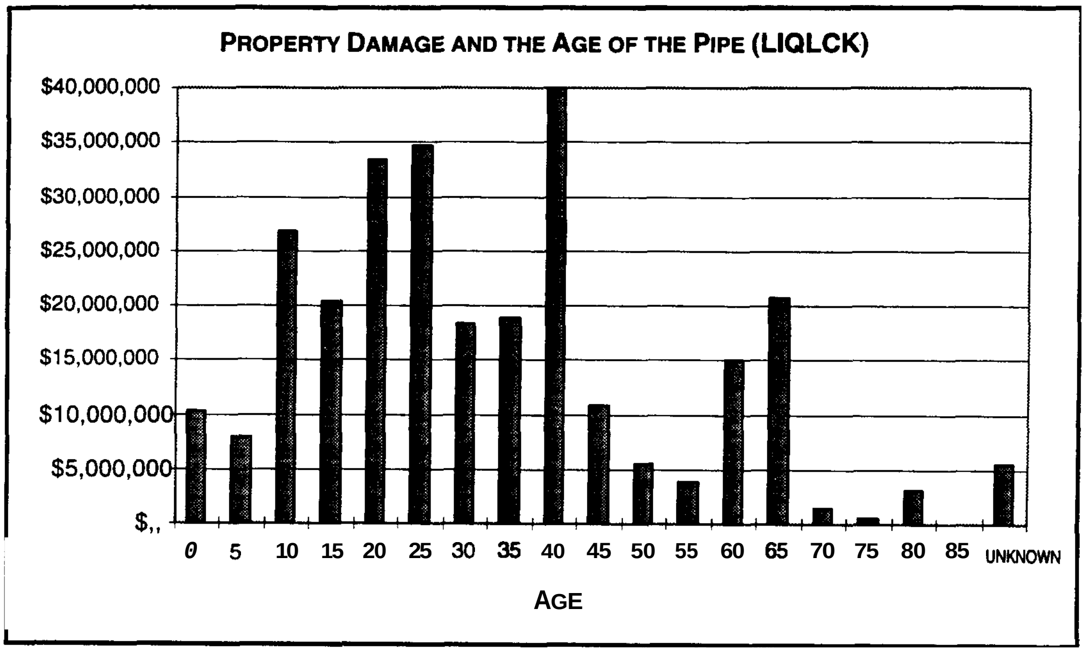
In comparing LIQLCK and LIQUID databases on property damages and cause, it is clear that there are significant differences between the two datasets. The first is that the largest damage reported in LIQUID is $3,250,000 for an accident occurring in 1984 versus a reported $20,000,000 in damages for an accident occurring in 1989. This is an increase of 515%, although from 1984 to 1989 the Consumer Price Index (CPI) has increased by only 19%. A second observation is that in LIQUID there were only 7 accidents (out of 4753) with damages of 1 million dollars or more versus 37 accidents (out of 1877) with reported damages of 1 million dollars or more in LIQLCK. These findings make it difficult to make a continuous and consistent analysis from these two databases.

In comparing which cause resulted in more property damage, it can be seen that there is not a single dominant cause. Only "incorrect operation by operator personnel" (3) and "malfunctioning of control or relief equipment" (6) are significantly lower than the rest of the other categories. The others are just about the same. This is a major departure from what was found in LIQUID where "corrosion" (1), "failed weld" (2) and "failed pipe" (4) produced relatively low damage. One reason for this change could be more stringent environmental regulations and more stringent accountability for damages to the environment.

In evaluating the average property damages per cause of an accident, it can be seen that "failed weld" (2) and "failed pipe" (4) are the most costly accidents. This could be perhaps attributed to the nature of these failures which cause slow and undetected spills for a longer period of time. Assuming that the above reasoning is correct, it leads one to consider employing improved leak detection measures for preventing longer undetected spills.

PROPERTY DAMAGE AND AGE

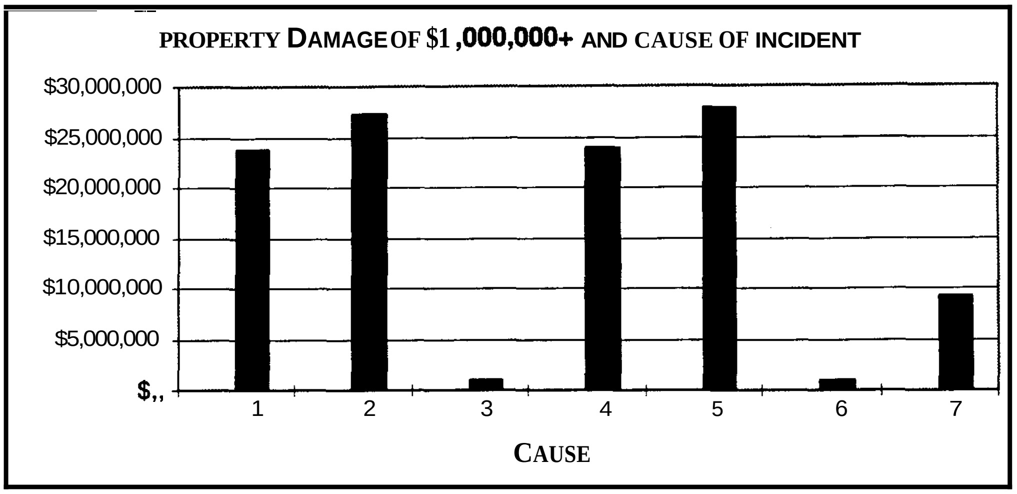
AGE	PROPERTY DAMAGE	AGE	PROPERTY DAMAGE
0-4	$10,267,852	45-49	$10,776,164
5-9	$7.927.871	50-54	$5,568,402
10-14	$26,729,412	55-59	$3,914,308
15	$20,339,987	60	$14,998,689
20	$33,436,811	65	$20,669,253
25	$34.685.535	70	$1,485,136
30	$18,347,959	75	$,515,740
35	$1 8.821.579	80	$3,147,400
40	$39,964,713	85	$,20,000
		unkn.	$5.531.528

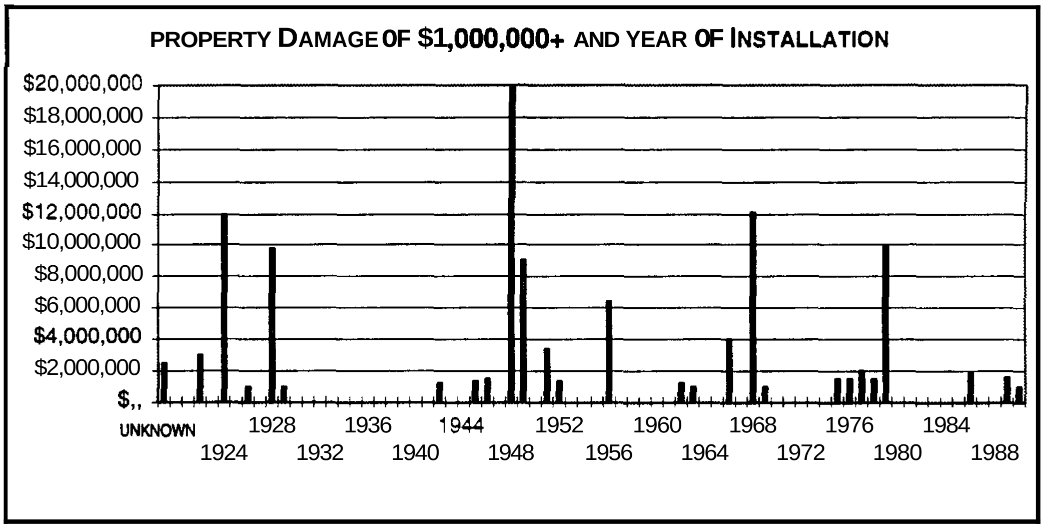


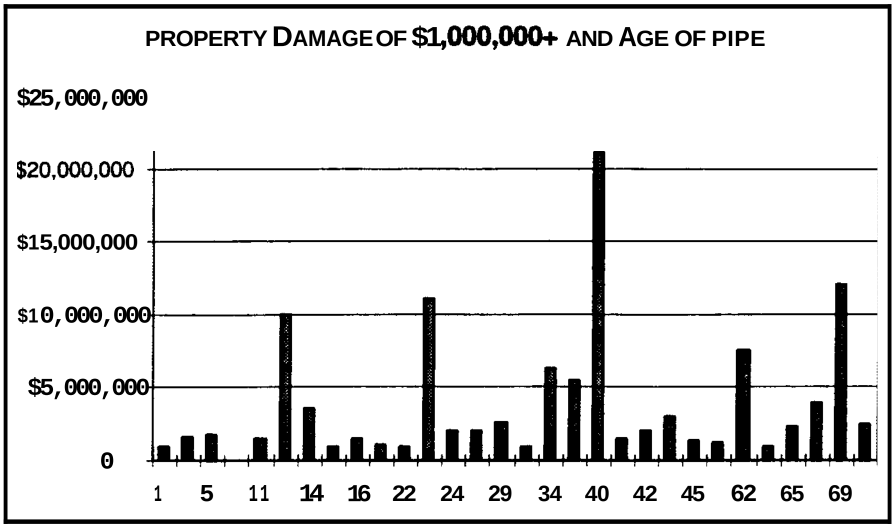
The above figure shows that significant property damages occur in pipelines between 20 and 25 years of age. This could be explained by the large number of pipe in service at that age. Total mileage by age information on the hazardous liquid industry (if it was available) could have been used to verify this hypothesis. However, it is interesting to note that the age group with the largest property damage in LIQLCK is about 40 years old. The largest in LIQUID was 25. These age groups correspond to each other because the average time shift between accidents reported in these databases is about 15 years. This may indicate that high figures of property damages at certain age groups is related to the mileage of pipelines in service.

10.3 ANALYSIS OF ACCIDENTS WITH PROPERTY DAMAGES OF $1,000,000 OR MORE.

CAUSE	PROPERTY DAMAGE
1	$23,760,743
2	$27,259,000
3	$1,000,000
4	$24,000,000
5	$27,759,634
6	$1,000,000
7	$9,252,165







No special pattern can be observed from the $1 million plus property damage data. The spikes that appear in the above figures are due mostly to an individual accident that caused a very large property damage.

The top 10 property damage accidents in LIQLCK are:

CAUSE		YEAR INSTALLED	AGE	PROPERTY DAMAGE
FAILED PIPE	(4)	1949	40	$20,000,000
FAILED WELD	(2)	1925	69	$12,000,000
CORROSION	(1)	1969	23	$11,000,000
OUTSIDE FORCE	(5)	1980	13	$10,000,000
FAILED WELD)	(2)	1929	62	$7,500,000
CORROSION	(1)	1950	37	$4,000,000
OUTSIDE FORCE	(5)	1957	34	$4,000,000
FAILED WELD	(2)	1950	43	$3,000,000
FAILED PIPE	(4)	1923	67	$3,000,000
FAILED WELD	(2)	1929	65	$2,359,000

In the top 10 most costly accidents, there are six accidents caused by either failed weld **(4** accidents) or failed pipe (2 accidents). **Also,** four accidents occurred on pipe installed in the **1920s,** all of them caused by the previously mentioned failures. **A** corollary of these findings is that in spite of efforts by the industry to protect the pipe from potential failures caused by corrosion and outside forces, an old pipe is at higher risk to fail and cause considerable property damage.

PROPERTY DAMAGE AND WALL THICKNESS OF THE PIPE

PROPERTY DAMAGE	< STANDARD	= STANDARD	> STANDARD
$1,000,000+	30	4	3
TOP 10	9	1	0

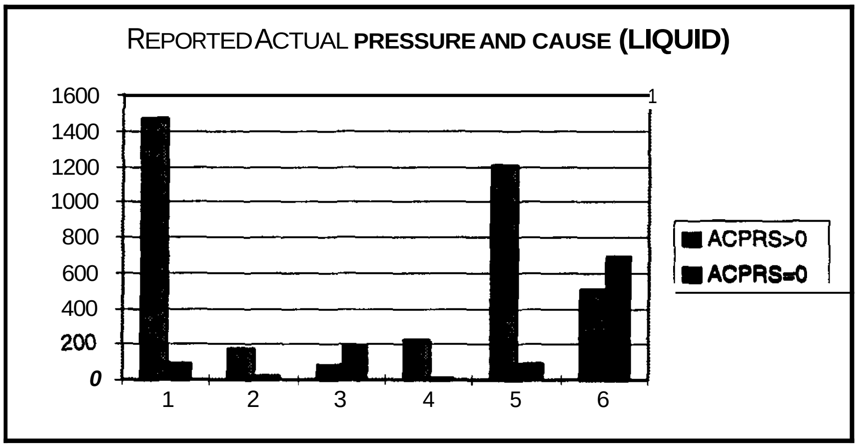
The above table confirms a previous observation that a minimum of standard wall thickness must be required for all pipe.

11.0 OPERATING PRESSURE AND THE CAUSE OF ACCIDENTS

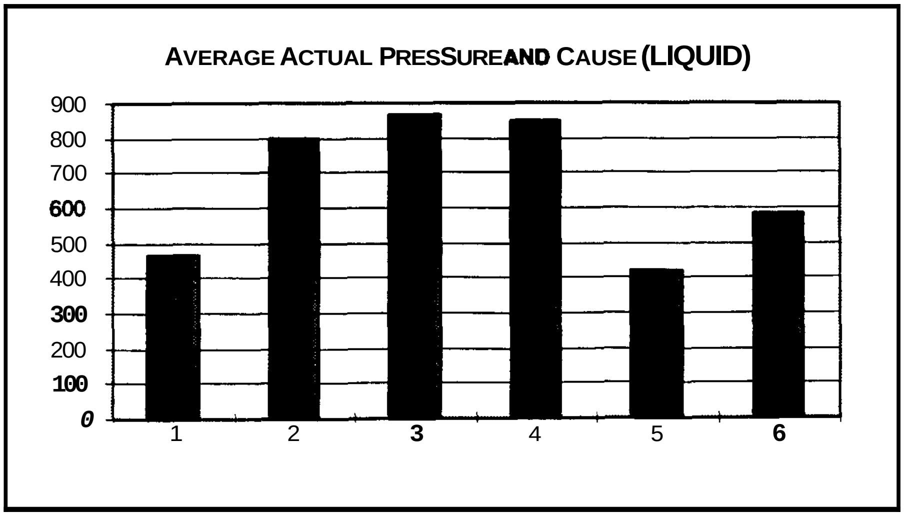
The actual pressure in the pipe at the time of an accident is another important factor that can be linked to pipeline failure. Actual pressure (APRS) by itself is less important than its relationship to the maximum operating pressure (MOP) (49 CFI Part 195.406).

11.1 ANALYSIS OF LIQUID DATABASE

The following figure indicates whether a need to request the value for the actual pressure (APRS) of an accident was found in the database. One can see that the majority of accident reports with cause categorized as "incorrect operation by carrier personnel"(3) and "other"(6), do not have APRS information. It would seem that in these categories in which the operator committed errors or a component of the pipe system failed, the actual pressure at the time of the accident would be of utmost importance. Not reporting this information makes it very difficult to accurately determine the actual cause of the accident. It leaves unresolved a fundamental question: "Was the pressure a contributing factor to the failure?"



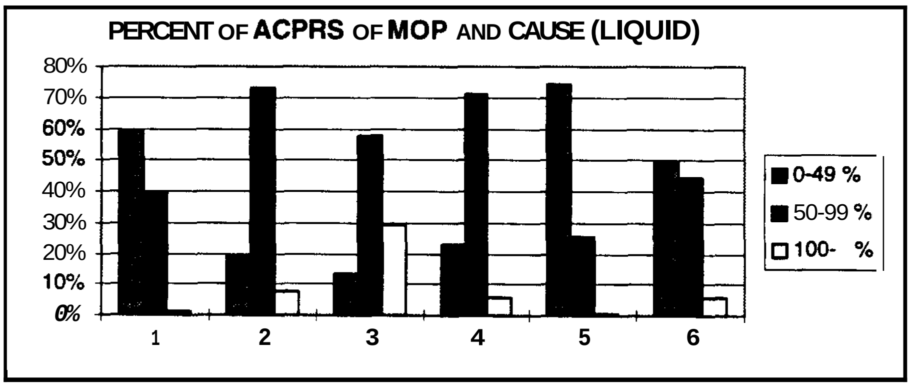
The importance of recording the actual pressure becomes evident from the following figure where we find that the cause with the largest average pressure is due to "incorrect operation by carrier personnel"(3).



Provided below is a comparison between the actual pressure at the time of the accident and the maximum operating pressure. The analysis is carried out by computing the percentage of APRS with respect to MOP.

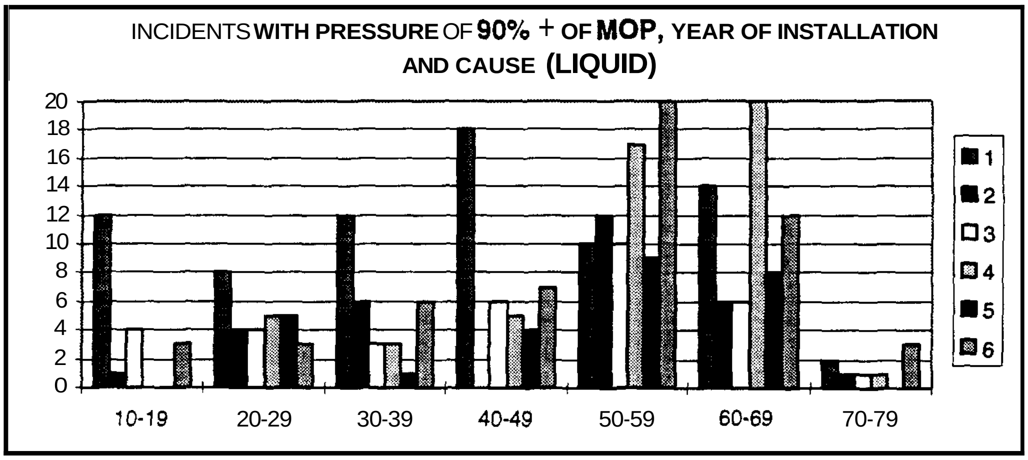
CAUSE

% of MOP	1	2	3	4	5	6
0-9 %	9%	2%	2%	1%	16%	11%
10-19 %	11%	5%	2%	4%	15%	10%
20-29 %	13%	4%	4%	2%	14%	11%
30-39%	11%	2%	0%	6%	15%	7%
40-49%	14%	6%	5%	10%	14%	10%
50-59%	12%	13%	6%	6%	10%	8%
60-69 %	8%	13%	13%	13%	7%	11%
70-79 %	8%	15%	8%	14%	4%	9%
80-89 %	7%	19%	13%	19%	3%	10%
90-99 %	4%	12%	17%	19%	2%	6%
100 %	1%	4%	8%	5%	1%	2%
100- %	1%	4%	20%	1%	0%	3%

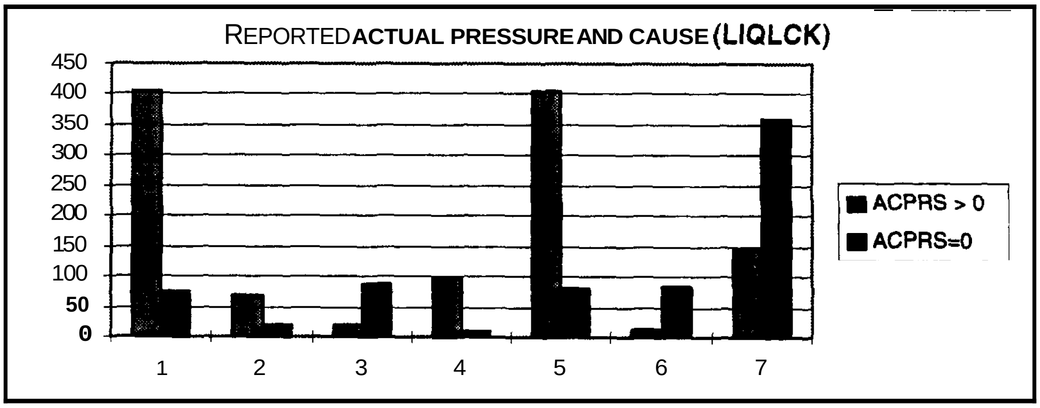


The above table and figure show that there were relatively more accidents caused by "corrosion," "other," and especially "line ruptured by equipment" in pipe with operating pressures of less than 50% of their MOP. Pipe and weld failures are more likely to occur as the actual pressure increases above 50% of MOP (about 80% of the accidents in these categories fall in the 50%+ range). Thus, a stricter definition of the maximum operating pressure might have prevented some of these costly (see top 10 property damage analysis) accidents. Finally, about 90% of the accidents caused by "incorrect operation by carrier personnel" are due to actual operating pressures near or above the MOP.

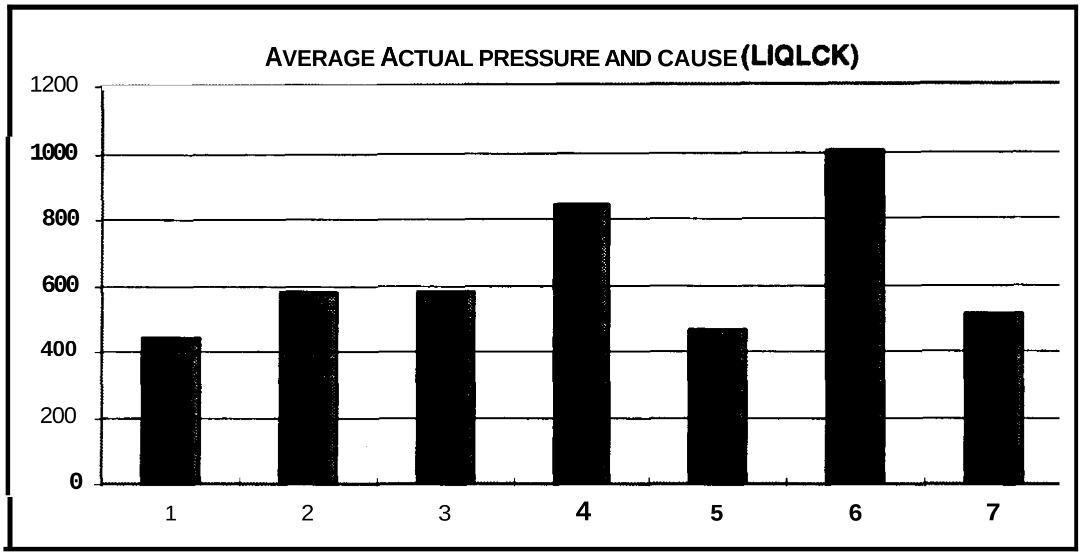
The correlation between the year of installation of pipe which operates at actual pressures of ***90%*** or greater of MOP and the cause is another interesting aspect of pipeline accidents. The amount of data available to relate these factors is rather small. However, the analysis is performed although no statistically significant conclusions can be drawn. The next figure shows that corrosion is the dominant cause of failure for older pipe in the above category. Most of the accidents in pipe installed in the **1950s** or later, however, are due to pipe failure or failure of relief/control components.



11.2 ANALYSIS OF LIQLCK DATABASE



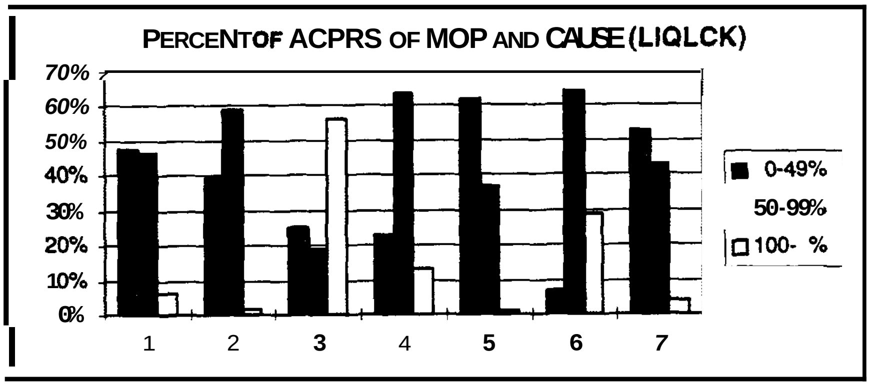
As in the case of LIQUID, reporting of the actual pressure at the time of the accident is more complete for "corrosion"(1) and "outside force"(5) than for "operator error"(3) or "failure of components of the pipe system" (2, 4, 6, 7). As mentioned earlier, availability of the operating pressure at the time of the accident and its relationship to MOP is very important for a better understanding of pipeline failures. It would be desirable to have more data on the pressure for all cause categories to see whether there is a correlation between the cause and higher operating pressures. The next table shows that the "corrosion"(1) and "outside force"(5) have the lowest average pressure at the time of the accidents. As expected, the cause with the highest average pressure is malfunction of control or relief equipment. It also indicates, perhaps, that the current MOP may be too high for these devices.



The following table summarizes the percent of accidents in each cause category according to the percent of the actual pressure of the maximum (allowable) operating pressure (MOP).

CAUSE

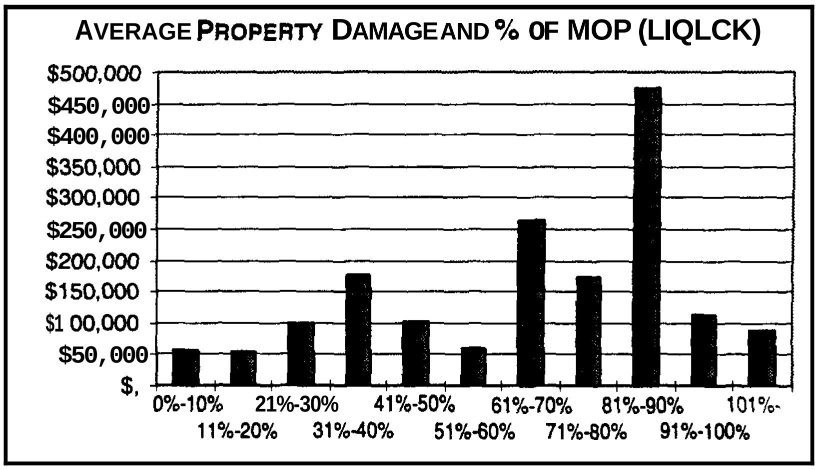
% of MOP	1	2	3	4	5	6	7
0-9 %	9%	7%	13%	3%	12%	0%	7%
10-19 %	13%	9%	6%	5%	13%	0%	12%
20-29 %	8%	7%	0%	3%	11%	0%	15%
30-39 %	10%	7%	6%	2%	14%	0%	7%
40-49 %	8%	9%	0%	9%	13%	7%	12%
50-59 %	11%	9%	0%	7%	12%	0%	7%
60-69 %	10%	10%	0%	8%	7%	0%	13%
70-79 %	8%	10%	6%	11%	6%	0%	8%
80-89 %	9%	16%	6%	12%	6%	14%	6%
90-99 %	9%	13%	6%	25%	7%	50%	9%
100 %	4%	0%	13%	10%	1%	21%	3%
100- %	2%	1%	44%	3%	1%	7%	1%



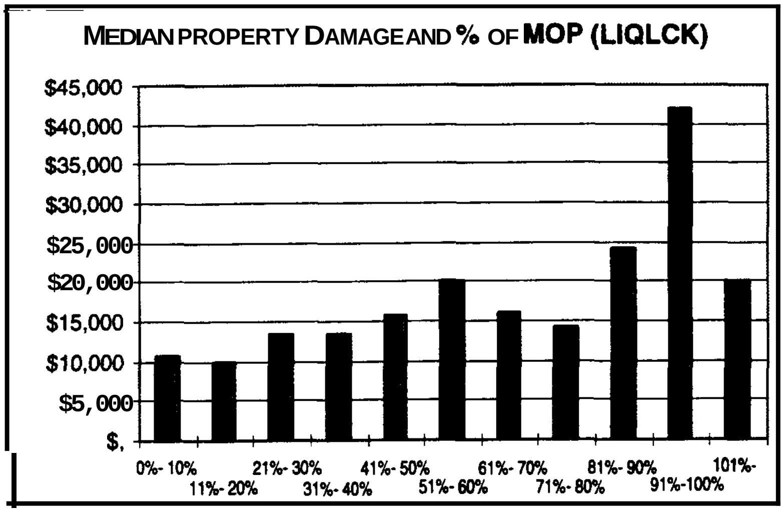
The above figure shows that most accidents caused by operator error occurred when the actual pressure was at 100% or more of the maximum operating pressure. Other indications from this figure are similar to those previously mentioned, namely, outside force accidents occur mostly in low operating pressure pipe, and pipe failures occur mostly at high operating pressures.

11.3 OPERATING PRESSURE AND PROPERTY DAMAGE

The actual operating pressure (or its percent of MOP) is examined against the severity of the property damage. The next figure presents the average property damage at various levels of pressure (in % of MOP). The largest average property damage is at operations between 80%-90% of MOP. Since the average is being used, the normalization of what percent of the industry operates at this level of capacity is somewhat less important. However, the average is a measure that is sensitive to large fluctuations. A few accidents with very high or very low property damage could have a major impact on the value of the average.



An estimate that is less sensitive to fluctuation is the median. The next figure shows the median property damage as a function of the percent of MOP. It is clear from both of these figures that relatively high operating pressures (i.e., near 100% of MOP) causes larger property damage.



12.0 PREVENTION PROGRAMS

There are several prevention programs in OPS databases for which data exists. The following is a summary of what data on prevention programs exists and in what database:

PREVENTION PROGRAM	DATABASE
DISTANCE TO THE NEAREST LINE MARKER	LIQUID
FREQUENCY OF RIGHT-OF-WAY PATROL	LIQUID
ONE CALL SYSTEM	LIQLCK

LIQUID database does not have information on the one-call systems because they did not exist at the time during which the data was compiled (before 1984). However, it is unfortunate that the information on the distance from the location of the accident to the nearest line marker was not required in LIQLCK. This data could be useful for evaluating the effectiveness of the line marking system. The omission of the frequency of right-of-way patrol is less important because operators generally comply with the regulation in 49 **CFR** Part 195.412.

The analysis on prevention programs will start with an examination of the information contained in LIQUID, followed by an analysis of the one-call system data from LIQLCK.

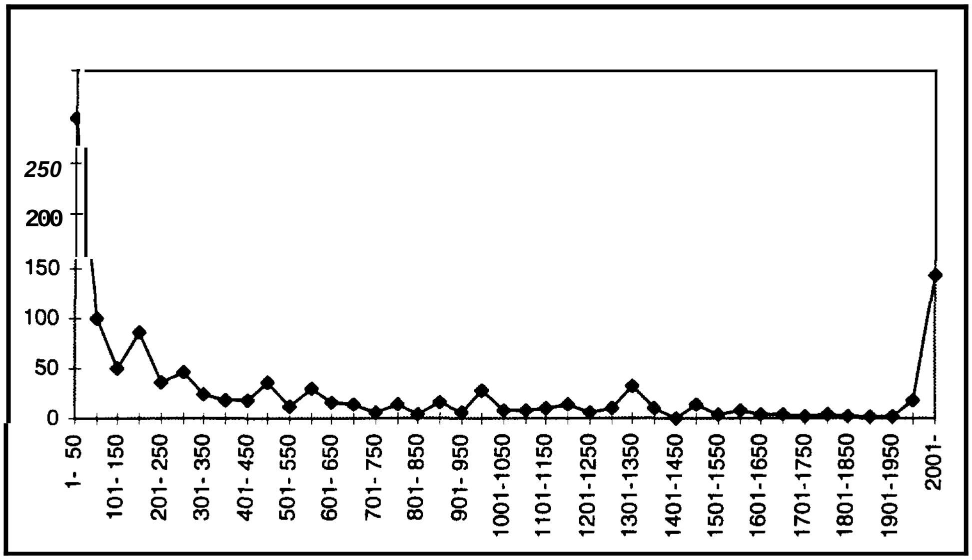
12.1 LINE MARKING AND THE CAUSE OF ACCIDENTS

Line markers do not have a direct contribution to pipeline related accidents. Their purpose is rather to prevent accidents by making the pipeline more visible. Effective line markers are those that send a clear message to whomever is working in the vicinity of the pipeline that it is dangerous to work nearby. A line marker that is not visible or does not convey this message is an ineffective prevention tool.

As mentioned earlier, the LIQUID database has information on how far each accident occurs from the nearest line marker. The database contains distances to line markers for accidents with various cause categories. Obviously, line markers will have very limited preventive effects on accidents with cause categories such as "corrosion" or "failed pipe". The main cause category for which this distance is relevant is "equipment rupture line." Nevertheless, redundant data is always better than missing data. The following table and figure summarizes the "distance to the nearest line marking" data from the LIQUID database:

NUMBER OF ACCIDENTS AND DISTANCE TO THE NEAREST LINE MARKER

CAUSE	100 FT.	200 FT.	500 FT.	1000 FT.	2000 FT.	>2000 FT.
1	21	9	8	13	16	9
2	1	1	1	2	1	2
3		1	1	1	0	0
4	7	1	2	2	2	1
5	401	138	182	154	170	142
6	25	7	20	13	15	19



The above table and figure are very interesting. One can see that 25% of the accidents caused by "equipment ruptured line" occurred within 50 feet of the closest line marker and 33% occurred within 100 feet. This means that one third of the accidents occurred very close to the line marker.

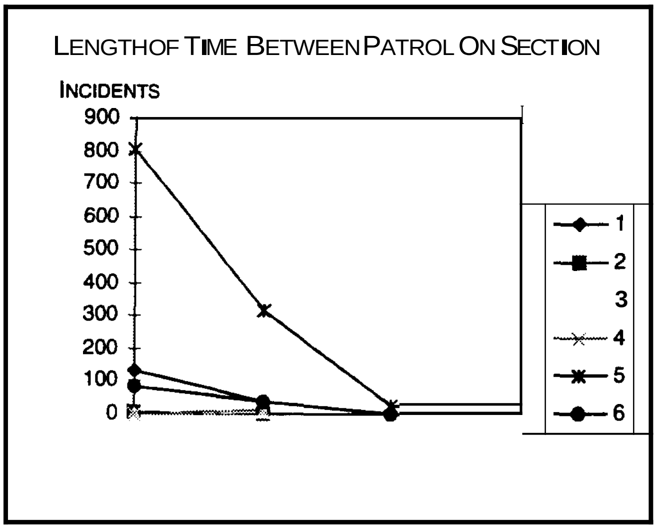
The spike in the graph for accidents that occurred 2000 feet or more from the nearest line marker indicates that many accidents occur in unmarked areas. In other words, for all practical purposes, if a marker is more than 2000 feet away from where an activity takes place, it is not visible.

12.2 FREQUENCY OF RIGHT-OF-WAY PATROLS AND THE CAUSE OF ACCIDENTS

As with line markers, the data on the frequency of right-of-way patrols is relevant mostly for third party damage (Cause *5).* Nevertheless, all information is summarized in the following table and figure:

PATROL FREQUENCY INTERVAL **(WEEKS)**

CAUSE	1	2	4	>4
1	135	36	3	9
2	9	3	0	0
3	3	5	0	0
4	2	12	0	0
5	801	314	24	37
6	84	34	2	7



Analyzing the "equipment rupture line" data *(5)* confirms findings similar to those for line marking. Since the latest right-of-way inspection occurred within one week prior to the accident it seems that the procedure is lacking robustness. Usually before excavation takes place there are preparatory activities (**e.g.**, a survey) to mark the location of the excavation. A well designed and executed patrolling procedure should be able to detect an upcoming danger to the integrity of the pipeline.

12.3 ONE CALL SYSTEM AND CAUSE OF DAMAGE

The **LIQLCK** database has a four stage data input scheme that deals with damage prevention and the one-call system. These stages are:

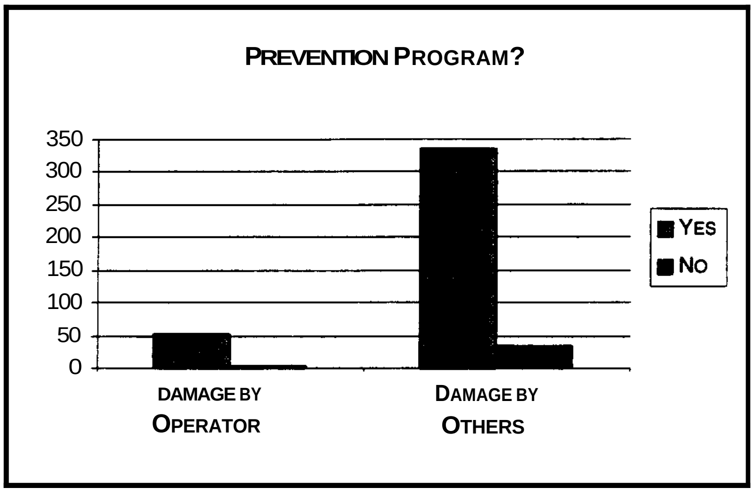
1. Was a damage prevention program in effect? (Y/N)

2. If yes, was the program "one-call"? (Y/Other)
3. Did the excavator call? (Y/N)
4. Was the pipeline location temporarily marked for excavation? (Not analyzed).

To analyze the response to these questions, the data was divided into two categories. The first is damage by the operator or its contractor and the other is damage by others (true 3rd party). The rationale for this division is that one would expect the operator to have a tight control on its employees or contractors to prevent damage to the pipeline. The public may not be familiar with the location of the pipeline or with the need to call for information before excavating. However, one would expect that the operator would take all the necessary precautions to prevent damage to its own pipeline. The results of the analysis are:

1. WAS A DAMAGE PREVENTION PROGRAM IN EFFECT? (Y/N)

	DAMAGE BY OPERATOR	DAMAGE BY OTHERS	TOTAL
Yes	52 (12%)	335 (79%)	387 (92%)
No	3 (1%)	32 (8%)	35 (8%)

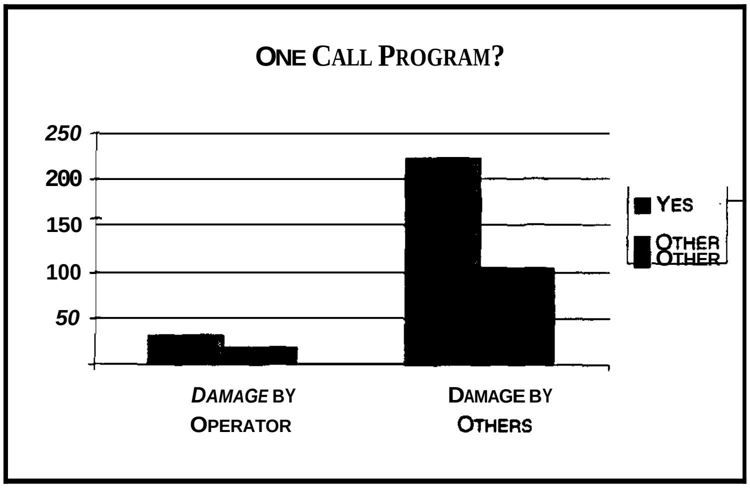


The above data indicates that there were prevention programs in place at the time of almost all of the accidents. The number of accidents where damage was caused by others is significantly larger than those caused by operators. Additional data on the utilization of the prevention programs would have been very helpful in this analysis. It would help in clarifying the question of how many accidents were prevented versus the number of accidents that have occurred. It would also be interesting to know how much work around the pipeline was performed by the operator or its contractor versus work performed by a third party. Fifty two **(52)** accidents (or 12%) caused by the operator or its contractor is rather a large number. But if most of the activities around the pipeline are performed by this group, and still their record on accidents is one to seven and a half better than third party, this means that they are much more aware of preventive measures.

2. IF YES, WAS THE PROGRAM "ONE-CALL"? (Y/OTHER)

The next question is was there a one-call system. The table and figure below show that about 2/3 of the accidents occurred in an area where a one-call system was in place. An unreasonable conclusion that one can draw is that we should not have a one-call system because there are more accidents where this system exists. The appropriate analysis should take into consideration the percentage of the pipeline system that is covered by the one-call system. For example: if 90% of the system is under the one-call program then 2/3 of the total number of accidents show that there is some prevention and vice versa. Thus, unless the data is normalized, conclusions reached can be faulty.

	DAMAGE BY OPERATOR	DAMAGE BY OTHERS	TOTAL
Yes	30 (%8)	221 (%59)	251 67%
Other	18 (%5)	104 (%28)	122 33%



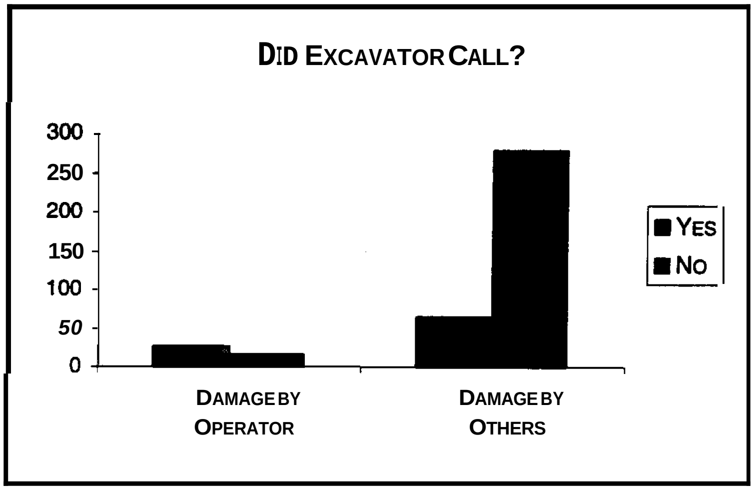
3. DID THE EXCAVATOR CALL? (Y/N)

Here again, the operator or its contractor seems to have better control in preventing damages. Is it because they are more aware of the need to call in? Additional information that could have been helpful in determining the effectiveness of the one-call system is how many people have actually used the one-call system (assuming each call is a successful damage prevention situation) compared to those who did not and caused an accident?

The high number of excavators that did not call for information indicates that perhaps the system is not very effective. It is difficult to explain why **73%** of the excavators (damage by others) did not call in for information. Is this because these people (and the public) are not aware of the one-call system? Is it because there was no proper line marking with information on the need to call in or whom to call? It is difficult to assume that these excavators knew that a pipeline existed in the area, knew about the one-call system (and in some places about the law which requires them to call in) and decided to take a chance and endanger their lives or violate the law.

A conclusion that can be drawn here is that public education is lacking.

	DAMAGE BY OPERATOR	DAMAGE BY T	L
Yes	26 (7%)	63 (16%)	89 (23%)
No	16 (4%)	277 (73%)	293 (77%)
	No Data	1358	



13.0 SUMMARY AND CONCLUSIONS

The summary and the conclusions of this report are given in Chapter 1.