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ANALYSIS AND MANAGEMENT OF A PIPELINE SAFETY INFORMATION SYSTEM

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FINAL REPORT

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DISCLAIMER

ANALYSIS AND MANAGEMENT OF A PIPELINE SAFETY INFORMATION SYSTEM

EXECUTIVE SUMMARY

Introduction

The Office of Pipeline Safety (OPS) and the Office of University Research of the Department of Transportation entered into a contract (DOT-OS-30110) with the University of Oklahoma in April, 1973 to continue operation of the existing OPS "Automated Leak and Test Failure Reporting System" and to analyze data available from the system. The initial contract period covered from April, 1973 through May, 1974 but this period was extended through November, 1974 to allow for the analysis of an additional year of data. Therefore, data was available for four years - 1970 through 1973.

The "Automated Leak and Test Failure Reporting System" is a data base developed from the collection of information from pipeline operators (both transmission and distribution operators) about the size and type of their system and the leaks which occur on the system. The data system actually consists of two components: (1) Individual Failure Reports - which provide comprehensive data concerning the cause and nature of certain "serious" leaks, and (2) Annual Reports - summary data provided by each operator on an annual basis that describe the size and characteristics of his system (e.g., miles of pipe by type) and the nature of leaks repaired during the year (e.g., number of corrosion caused leaks).

Objectives

The objectives to be achieved under this program of contract research were as follows:

1. Operation and maintenance of the existing OPS "Automated Leak and Test Failure Reporting System," including the production of periodic data summaries.
2. Statistical analysis of the data collected by OPS to draw appropriate inferences concerning any aspect of pipeline safety for which data had been reported.

3. Analysis of the data system to identify any problems with the data reporting forms and any data need not currently being met by the existing system.

The first objective was accomplished by the University of Oklahoma Office of Information Systems Program. The second objective was accomplished by the University of Oklahoma School of Industrial Engineering. Objective three was accomplished through the joint efforts of both groups in the University. The majority of the report, which is summarized here, deals with objectives two and three.

Results

OBJECTIVE 1:

The University of Oklahoma Office of Information Systems Program provided the keypunch/keytape and verification services necessary to enter data into the Automated Leak and Test Failure Reporting System as data forms were received from OPS. Standard summary reports were prepared and delivered to OPS quarterly or annually as required by the contract. A few examples of these summary reports are:

(a) Distribution Annual Report Delinquency List by State
(b) Comprehensive Annual Report by State
(c) Damages and Injuries Report by State
(d) Individual Leak Report - Major Item Report by Operator
(e) Corrosion Report by Operator and by State

etc. These reports are on file at OPS.

OBJECTIVES 2 AND 3:

The major effort of the research was aimed at a statistical analysis of the data in order to identify both the utility and weaknesses in the existing data system. The data system includes a large number of different data elements, and therefore, it was necessary to organize the assessment into a number of individual analyses centered around a particular parameter. For example, the following lists a few of the types of analyses that were performed:

(a) Individual Failure Reports - Analyses Related to Type of Material
(b) Individual Failure Reports - Analyses Related to Age of Pipeline

(c) Individual Failure Reports - Analyses of Leak Rates for Metallic vs. Plastic Pipe
(d) Annual Reports - Analyses Related to Cause of Pipeline System Leaks
(e) Analysis of Individual Operators' Safety Performance

A large number of statistically valid conclusions were drawn from this detailed analysis. Some of the more important conclusions are listed below:

1. The individually reported leak rate (from all causes) generally increases with the age of the system. However, in distribution mains the leak rate for systems installed in the 1970's is significantly higher than the leak rate for the previous two decades.

2. The individually reported leak rate caused by corrosion steadily increases with the age of the system. In distribution systems, the greatest effect of protection against corrosion is obtained by combining cathodic protection with coating.

3. Outside force is the cause of the greatest percentage of individually reported leaks, about 70 percent in distribution systems and 54 percent in transmission systems. Corrosion accounts for about 15 percent of individually reported leaks. In contrast, when analyzing all repaired leaks (from the annual reports), corrosion accounts for the majority of leaks, 45 percent in distribution systems and 77 percent in transmission systems. Outside force accounts for only 15 percent (distribution) and 3 percent (transmission) of all repaired leaks. Therefore, while outside force leaks are a relatively small portion of all repaired leaks, they tend to be the serious ones (i.e., those requiring individual reports).

4. The individually reported leak rate (leaks per mile of pipe) due to third party damage in distribution systems generally increases with age; however, for pipe installed in the 1970's, the third party damage leak rate shows a sudden increase.

5. Metallic pipe materials in aggregate show a significantly lower individually reported leak rate than do plastic pipe materials. Plastic pipe systems were also found to have a higher equipment caused leak rate than (a) steel and cast iron in distribution mains and (b) steel and copper in distribution services.

6. As noted above, more individual leak reports were filed on a per unit basis for plastic pipe than for metallic pipe in distribution systems. However, no statistically significant differences were found between plastic and metallic pipe on the basis of injuries, deaths, or property damage, primarily due to the wide variances which resulted from the limited amount of data.

7. The individual report rate for those accidents involving fire, explosion, death, or injury appears to be the best measure for evaluating the safety performance of individual operators. Unfortunately, at the current time this limits the analysis to only those operators with over 100,000 services. A procedure is presented for identifying operators that appear to have safety problems so that further investigation and possible corrective action may be undertaken.

Recommendations

The specific recommendations concerning the data system and data analysis are:

1. The exclusion of distribution operators with less than 100,000 services from the requirement to submit an individual failure report seriously limits the usefulness of the data system. Since the operators are currently required to file an annual report, it seems unwise to exclude them from the requirement to file individual failure reports. Therefore, it is recommended that individual failure reports be required of all pipeline operators who now file an annual report.

2. Significant problems of data accuracy exist for 1970 data, and to a lesser extent in the data for 1971, 1972 and 1973. A more extensive data review and audit procedure is necessary if accurate data is to be available for analysis. Therefore, it is recommended that a regular program of auditing should be implemented, using a statistically valid sampling procedure for selecting operators for audit.

3. Other methods of collecting pipeline safety data should be explored, especially the following two methods:

   (a) Data should be collected for more pipeline accidents by in-depth, multidisciplinary accident investigation teams similar to the team staffed by the NTSB for investigating a few selected pipeline accidents.

(b) The use of the "critical incident technique" by pipeline companies to collect data for use in improving pipeline safety should be encouraged by OPS through a demonstration program and a follow-up educational program in using the technique.

4. The individual failure report data should be utilized annually to compare the safety performance of individual operators, as described in Section 2.5.

5. Annual report data and the remaining individual report data should be analyzed at least every two years in a format similar to the one used for this report.

6. When approximately 7-10 years of data have been collected, consideration should be given to using a time-trend type of analysis on a yearly basis. It will be necessary to wait this period of time for most of the usual time-trend analysis methods to be successfully applied.

7. The installation of a computer terminal in the Office of Pipeline Safety for the purpose of performing data analyses does not appear to be justified because of the relatively low level of anticipated use over the entire year and because most of the analyses will require data for the entire report year. Thus, it is recommended that the analyses to be performed on an annual basis be completed each year as a batch-process operation.

8. The forms used for data collection were reviewed and it was found that changes were needed. New forms were developed and reviewed with OPS personnel.

Utilization of Results

The Office of Pipeline Safety will use the results of the data analysis to evaluate the relationship of several parameters to pipeline safety. These parameters include type of pipeline materials used, amount of corrosion of pipeline materials, etc. The Office of Pipeline Safety may then initiate rulesmaking activities as a result of this data evaluation that are intended to result in safer pipeline operations. The redesigned data forms will be of significant help to OPS by improving the quality of the data reported by pipeline operators and in turn the quality of future data analyses.

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CHAPTER 1.0

INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

The Office of Pipeline Safety (OPS) of the Department of Transportation entered into a contract (DOT-OS-30110) with the University of Oklahoma in April, 1973 to continue operation of the existing Automated Leak and Test Failure Reporting System and to analyze data which was already available in the system as well as data which would be reported during the course of the contract. The initial contract period covered from April, 1973 through May, 1974 but this period was extended through November, 1974 to allow the analysis of more data as it became available. This additional data was reported for the calendar year of 1973, and was not available for analysis until July, 1974.

Initial data reporting for pipeline operators began in 1970 so that data was available for the calendar years of 1970 through 1973.

The objectives to be achieved under this program of contract research were as follows:

1. Operation and maintenance of the existing OPS Automated Leak and Test Failure Reporting System, including the production of periodic data summaries.
2. Statistical analysis of the data collected by OPS to draw appropriate inferences concerning any aspect of pipeline safety for which data had been reported.
3. Analysis of the data system to identify any problems with the data reporting forms and any data need not currently being met by the existing system. In addition, the utility of the data currently being reported was to be evaluated in terms of improving pipeline safety.

The first objective was accomplished by the University of Oklahoma Office of Information Systems Program. The second objective was accomplished by the University of Oklahoma School of Industrial Engineering. Objective three was accomplished through the joint efforts of both groups in the University.

1.2 DATA COLLECTION FORMS

The original structure of the data system was based on the use of four different forms as listed and briefly explained below. A copy of each form and the related instructions for completion can be found in Appendix A of this report.

1. Leak Report - Distribution System - DOT F7100.1 (1-70)
2. Leak or Test Failure Report - Transmission and Gathering Systems - DOT F7100.2 (1-70)
3. Annual Report for Distribution System - DOT F7100.1-1 (10-70)
4. Annual Report for Gas Transmission and Gathering Systems - DOT F7100.2-1

Individual reports of leaks or test failures are required for leaks which are of "serious" nature (see 49 CFR, Part 191 for reporting requirements). These reports contain detailed information about the circumstances surrounding the leak occurrence. Distribution operators with fewer than 100,000 services are not required to file individual leak reports.

Annual reports are filed by all pipeline operators and contain data describing the size and nature of the operator's system, summary data about leaks repaired, data about the inspection of the pipeline for leaks, and other miscellaneous information. The annual report will be either for a distribution system or a gas transmission and gathering system, or both, as appropriate for the operator.

A number of changes have been proposed in the design of the four data collection forms as a result of the data maintenance and analysis activities performed during the course of completing this contract. These suggested changes were developed in conjunction with OPS personnel who also were aware of deficiencies in the design of the original data collection forms. The proposed designs for the four data collection forms have been reviewed by OPS personnel and rule-making activities will be initiated in the future by OPS to utilize the new forms. Thus, the proposed designs of the new data forms have not been presented in this contract report because of the possible confusion which might arise in presenting the new forms before official rule-making activities have been initiated.

1.3 DATA PROCESSING, MAINTENANCE AND REPORTING ACTIVITIES

The University of Oklahoma Office of Information Systems Program provided the keypunch/key tape and verification of services necessary to enter data into the Automated Leak and Test Failure Reporting System as data forms were received from OPS. Individual leak and test failure reports were processed quarterly, and annual reports were processed as received after the end of the prior reporting year.

The annual report was processed two times during the contract period. In June, 1973, the 1972 Annual History File updating was accomplished. In March, 1974, the 1973 annual reports from the operators were processed. The summary reports that were prepared and delivered to OPS were as follows:

1. Annual Edit List
2. Distribution Annual Report Delinquency List by State
3. Transmission Annual Report Delinquency List by State
4. Oil/Products Annual Report Delinquency List by State
5. Distribution Commercial Inspection Delinquency List
6. Transmission Commercial Inspection Delinquency List
7. Oil/Products Commercial Inspection Delinquency List
8. Comprehensive Annual Report by State
9. Damages and Injuries Report by State

Individual leak reports were processed five times during this contract period. Quarterly runs were completed in April, July, and October of 1973, and again in January, 1974. A fifth run was also made to update the 1973 Individual Leak Report History File. The summary reports that were furnished to OPS for the individual leak reports were as follows:

1. Individual Leak Report Edit List
2. Individual Leak Report - Major Item Report by Operator
3. Comprehensive Report - Operator Sequence
4. Comprehensive Report - State Sequence
5. Major Item Report (Year to Date) by Operator and by State
6. Corrosion Report by Operator and by State
7. Construction Defect and Material Failure Report by Operator and by State

8. Construction Defects by Manufacturer by Operator and by State
9. Month of Year versus Outside Forces Accident Report
10. Depth of Cover versus Outside Forces Accident Report by State

The name and address file was processed approximately once each month and the required output from these runs were as follows:

1. Name and Address Validation Listing in Operator I.D. Number Sequence
2. Name and Address Validation Listing in State of Operation Sequence
3. Selective Operator Name and Address Listing
4. Mailing Labels
5. Special Companies Listing (Distribution Companies over 100,000 Services)
6. Error Listing (Operator w/o Headquarters)

The inquiry program was run as requested by OPS professional personnel to answer specific questions.

The library of updated master file tapes was maintained for all the data collected since reporting was initiated in 1970. This master file was used by the School of Industrial Engineering for the statistical analysis of data which follows in the next chapter.

1.4 FOREWARD

The remainder of this report contains a statistical analysis of data, conclusions drawn from the data analysis and recommendations concerning future reporting and analysis of data.

CHAPTER 2.0

STATISTICAL ANALYSIS OF PIPELINE SAFETY DATA

2.1 INTRODUCTION

2.1.1 Purpose of Data Analysis

Data has been collected by the Office of Pipeline Safety for four years (1970 - 1973) since the initiation of reporting requirements for pipeline operators. During these four years, there was not an overall effort to statistically analyze the data available. As stated earlier in this report, one of the contract objectives was to perform an analysis of the data in order to determine what inferences could be drawn regarding the important parameters related to pipeline safety. Since the forms used for reporting data to the Office of Pipeline Safety include a relatively large number of different data elements, it was necessary to structure the overall analysis into a number of individual analyses centered around a particular parameter. This structure of the analyses is discussed in Section 2.1.2.

Since there were only four years of data to analyze, it was recognized that this would place a limitation on the type and number of statistical inferences that could be drawn. However, it was also recognized that an attempt to analyze the data available would be valuable in assessing the adequacy of the current information system in order to institute needed changes before too much more time has passed. Also, it was expected that sufficient data did exist to indicate areas where the information would be of value in improving pipeline safety.

2.1.2 Types of Analyses Performed

The different forms used for collecting data served as one of the bases of analyzing the data. The data forms used by the Office of Pipeline Safety for collecting data have been listed in Chapter 1.

It was noted in explaining the data forms in Chapter 1 that the individual reports contain more detailed information about the circumstances surrounding the leak occurrence than is available for leaks reported on the annual report forms. However, the individual reports do not contain information about the size of the pipeline system where the leak occurred or other measures of exposure of the pipeline system to a leak occurrence, which limits the analyses which can be done. Also, distribution operators with fewer than 100,000 services are not required to file individual reports for "serious" leaks. Since annual reports are filed by all pipeline operators and contain data describing the size of the operator's system, it was necessary in many instances to use data from the operator's annual report to normalize data being analyzed from the individual report.

Data analyzed from the individual leak reports is presented first in the following sections, followed by data analyzed from the annual reports.

A special analysis of both annual and individual report forms was completed for the purpose of comparing the safety records of individual operators and this analysis is presented in Section 2.5.

An analysis of test failure reports was attempted, but the absence of any source of normalizing data prevented this analysis from being completed.

2.1.3 Statistical Methods of Analysis

Given the type of data available for analysis, the statistical procedures appropriate for this application are either a test of hypothesis based on an F-statistic, or a test of means based on one of a number of similar tests available for this purpose. The choice of a particular test is predicated on whether it is more important to control the Alpha or Beta risk level in performing the analysis. One of the more widely used tests in this area is called the Duncan Multiple Range Test. This test does an adequate job of controlling the Alpha and Beta errors when analyzing the significant differences between items within a group of items. The usual way of presenting data analyzed with this test is as follows:

Assume a set of four mean values or averages are being compared for the leak rates of mains constructed with four different materials. The mean values are as follows:

Steel - 0.373 leaks/1,000 miles of main

Cast Iron - 1.280 leaks/1,000 miles of main

Plastic - 1.297 leaks/1,000 miles of main

Other - 1.050 leaks/1,000 miles of main

Using an Alpha error of 0.05, the analysis of the data can be presented as follows:

Plastic	Cast Iron	Other	Steel	
1.297	1.280	1.050	0.373	$\alpha = 0.05$

For an Alpha error of 0.01, the data analysis would be presented as follows:

Plastic	Cast Iron	Other	Steel	
1.297	1.280	1.050	0.373	$\alpha = 0.01$

A line drawn under any group of values indicates that these values do not differ significantly at the Alpha risk level given. Thus, the Alpha error is the probability that we have concluded that the mean values of the items in a group are different, when in fact they have come from the same set or population of data. The Beta error is the probability that we state that the items in a group are the same when in fact they are from different populations, given that a statement is made about the magnitude of the difference between the populations.

In practical terminology, the above analysis states that the leak rate for steel pipe is significantly lower than for plastic or cast iron, and that the probability of making an error in reaching this conclusion is 5 times out of 100. Thus, if we want to restrict our Alpha error to only one in 100, then we cannot state that there is any difference in any of the leak rates for the different materials.

The choice of an acceptable Alpha or Beta risk level must be based on the economic or other consequences of the action taken as a result of the data analysis, for instance the use of only steel pipe for mains.

It will be observed in the analyses which follow that two of the mean values for a given parameter being analyzed are shown as being not statistically different from one another, while two other means being analyzed for another parameter may differ algebraically by the same amount, but will be shown as statistically different from one another. Since this type of result is often confusing to a non-statistician, a brief explanation is in order.

If we examine the data for each year for a given parameter, such as for the data shown in Table 2.2 which follows in the next section, it will be seen that the leaks per 1,000 miles of steel mains have not varied more than 20 percent from the overall mean in any year. On the other hand, the yearly values for cast iron or plastic may vary more than 40 percent from the overall mean in any year. Thus, the ability to statistically differentiate between mean values being analyzed is a function of the variability of the data comprising the mean values.

The other aspect of statistical inference which is pertinent to the data analysis is the number of years of data available for analysis. In general, the greater the number of years of data available, the greater the ability to differentiate between the mean values for a given parameter. In statistical terms, this would be called increasing the degrees of freedom for the statistical analysis. Thus, the Office of Pipeline Safety will be able to improve the capability of performing statistical analyses of the data each year that more data becomes available.

2.2 ANALYSIS OF INDIVIDUAL FAILURE REPORTS

Table 2.1 presents a listing of all data tables prepared in the analysis of individual failure reports. This listing is presented for reference to the sections that follow covering the various leak rate parameters under discussion. The various types of analyses presented encompass all of the parameters available for analysis on the individual failure reports which were thought to have a relationship to leak rate and pipeline safety.

Each of the following sections includes the analyses of the transmission and distribution segments of the pipeline system for the particular parameter that is being evaluated for its effect on leak rate and pipeline safety.

The results of each analysis of data are presented as the individual parameters are considered, followed by a summary statement of conclusions. These conclusions are compared in Section 2.4 with those obtained from the analysis of data submitted on the annual report forms.

TABLE 2.1

Listing of Data Tables for All Analyses, Prepared from Individual Failure Report Forms (Forms DOT F 7100.1 and DOT F 7100.2)

1	2	3	4	5	6	7	8
No. of Table	Years of Data	Part of System Analyzed	Part which Leaked	Cause of Leak	Measure of Leaks/Safety	Analysis Parameter	Part of Individual Report where Data Obtained
2.2	70-73	Distribution Mains	Pipe	All types	Leaks/Year/ 1,000 miles of pipe	Type of Material	5.a, 6.a
2.3	70-73	Distribution Mains	All Except Pipe	All types	Leaks/Year/ 1,000 miles of Pipe	Type of Material	5.a, 6.a
2.4	70-73	Distribution Services	Pipe	All types	Leaks/Year/ 100,000 Services	Type of Material	5.a, 6.a
2.5	70-73	Distribution Services	All Except Pipe	All types	Leaks/Year/ 100,000 Services	Type of Material	5.a, 6.a
2.6	70-73	Distribution Mains	Pipe	All types	Leaks/Year/ 1,000 miles of Pipe	Nominal Diameter	5.a, 8.a
2.7	70-73	Distribution Services	Pipe	All types	Leaks/Year/ 100,000 Services	Nominal Diameter	5.a, 8.a

TABLE 2.1 Listing of Data Tables for All Analyses
Tables 8 thru 14
Continued

1	2	3	4	5	6	7	8
No. of Table	Years of Data	Part of System Analyzed	Part which Leaked	Cause of Leak	Measure of Leaks/Safety	Analysis Parameter	Part of Individual Report where Data Obtained
2.8	70-73	Transmission	Body of Pipe	All types	Leaks/Year/ 1,000 miles of Pipe	Nominal Diameter	6.a, 8.a
2.9	70-73	Distribution Mains	All parts	All types	Leaks/Year/ 1,000 miles of Pipe	Region	
2.10	70-73	Distribution Services	All parts	All types	Leaks/Year/ 100,000 Services	Region	
2.11	70-73	Transmission	All parts	All types	Leaks/Year/ 1,000 miles of Pipe	Region	
2.12	70-73	Distribution Mains	All parts	All types	Leaks/Year/ 1,000 miles of Pipe	Decade of Construction	5.b
2.13	70-73	Distribution Services	All parts	All types	Leaks/Year/ 100,000 Services	Decade of Construction	5.b
2.14	70-73	Transmission	All parts	All types	Leaks/Year/ 1,000 miles of Pipe	Decade of Construction	5.b

TABLE 2.1 Listing of Data Tables for All Analyses
Tables 15 thru 24
Continued

1 No. of Table	2 Years of Data	3 Part of System Analyzed	4 Part which Leaked	5 Cause of Leak	6 Measure of Leaks/Safety	7 Analysis Parameter	8 Part of Individual Report where Data Obtained
2.15	70-73	Distribution Mains	All parts	Corrosion	Leaks/Year/ 1,000 miles of Pipe	Decade of Construction	5.b
2.16	70-73	Distribution Services	All parts	Corrosion	Leaks/Year/ 100,000 Services	Decade of Construction	5.b
2.17	70-73	Transmission	All parts	Corrosion	Leaks/Year/ 1,000 miles of Pipe	Decade of Construction	5.b
2.18	70-73	Distribution Mains	Pipe	Corrosion	Leaks/Year/ 1,000 miles of Pipe	Internal Corrosion vs. External Corrosion	Part-A: 1.a
2.19	70-73	Distribution Services	Pipe	Corrosion	Leaks/Year/ 100,000 Services	Internal Corrosion vs. External Corrosion	Part-A: 1.a
2.20	70-73	Transmission	Pipe	Corrosion	Leaks/Year 1,000 miles of Pipe	Internal Corrosion vs. External Corrosion	Part-A: 1.a
2.21	70-73	Distribution Mains	Pipe	Corrosion	Leaks/Year/ 1,000 miles of Pipe	Cathodic vs. Non-Cathodic Protection and Bare vs. Coated	5.a, Part-A: 2.a, 4.a
2.22	70-73	Transmission	All parts	Corrosion	Leaks/Year/ 1,000 miles of Pipe	Cathodic vs. Non-Cathodic Protection and Bare vs. Coated	Part-A: 2.a, 4.a
2.23	70-73	Distribution Mains	---	All types	Percent of Leaks	Part which Leaked	5.a
2.24	70-73	Distribution Services	---	All types	Percent of Leaks	Part which Leaked	5.a

TABLE 2.1 Listing of Data Tables for All Analyses
Tables 25 thru 33
Continued

1 No. of Table	2 Years of Data	3 Part of System Analyzed	4 Part which Leaked	5 Cause of Leak	6 Measure of Leaks/Safety	7 Analysis Parameter	8 Part of Individual Report where Data Obtained
2.25	70- 73	Transmission	---	All types	Percent of Leaks	Origin of Leak or Failure	6
2.26	70- 73	Distribution Mains	All parts	---	Percent of Leaks	Cause of Leak and Decade of Construction	5.b
2.27	70- 73	Distribution Services	All parts	---	Percent of Leaks	Cause of Leak and Decade of Construction	5.b
2.28	70- 73	Transmission	All parts	---	Percent of Leaks	Cause of Leak and Decade of Construction	5.b
2.29	70- 73	Distribution Mains and Services	All parts	---	Percent of Leaks	Cause of Leak and Decade of Construction	Combination of Tables 2.26 & 2.27
2.30	70- 73	Distribution Mains	All parts	Third Party Damage	Leaks/Year/ 1,000 miles of Pipe	Decade of Construction	5.b, Part-B: 1.b
2.31	70- 73	Distribution Services	All parts	Third Party Damage	Leaks/Year/ 100,000 Services	Decade of Construction	5.b, Part-B: 1.b
2.32	70- 73	Distribution Mains	Pipe and Fitting	All types	Leaks/Year/ 1,000 miles of Pipe	Metallic vs. Plastic	5.a, 6.a
2.33	70- 73	Distribution Services	Pipe, Fitting and Tap Connection	All types	Leaks/Year/ 100,000 Services	Metallic vs. Plastic	5.a, 6.a

TABLE 2.1 Listing of Data Tables for All Analyses
Tables 34 thru 39
Continued

1	2	3	4	5	6	7	8
No. of Table	Years of Data	Part of System Analyzed	Part which Leaked	Cause of Leak	Measure of Leaks/Safety	Analysis Parameter	Part of Individual Report where Data Obtained
2.34	70- 73	Distribution Mains	All parts	Equipment-caused	Leaks/Year/ 1,000 miles of pipe	Material Type	6.a Part B: 1.a, 1.b
2.35	70- 73	Distribution Services	All parts	Equipment-caused	Leaks/Year/ 100,000 Services	Material Type	6.a Part-B: 1.a, 1.b
2.36	73	Distribution Mains	All parts	All types	Distribution of Stoppage Time	Metallic vs. Plastic	2.c, 6.a
2.37	73	Distribution Services	All parts	All types	Distribution of Stoppage Time	Metallic vs. Plastic	2.c, 6.a
2.38	70- 73	Distribution Mains	All parts	All types	No's of Reports, Deaths, Injuries and Prop. Damages over $500. (Basis: Pr. yr/ 1,000 miles of Pipe)	Metallic vs. Plastic	6.a, 10.a, 10.b, 10.g
2.39	70- 73	Distribution Services	All parts	All types	No's of Reports, Deaths, Injuries and Prop. Damages over $500. (Basis: Pr.yr/ 100,000 Services)	Metallic vs. Plastic	6.a, 10.a, 10.b, 10.g

TABLE 2.1 Listing of Data Tables for All Analyses
Tables 40 thru 41
Continued

1 No. of Table	2 Years of Data	3 Part of System Analyzed	4 Part which Leaked	5 Cause of Leak	6 Measure of Leaks/Safety	7 Analysis Parameter	8 Part of Individual Report where Data Obtained
2.40	70- 73	Distribution Mains and Services Transmission	All parts	Outside Party	Percent of Total Number of Reports	Prior Notification, Marking and Statute Requirement	Part-B: 1.a, 2.a, 2.b, 2.c
2.41	70- 73	Distribution and Transmission	All parts	All types	Percent of Total Number of Reports	Percent Ranges of Maximum Allowable Operating Pressure	Distr.: 2.d, 2.e Trans.: 3.f, 3.g

2.2.1 Individual Failure Reports--Analyses Related to Type of Material

The analyses of leak rates which were performed as a function of the type of material used in construction of the pipeline are presented in this section.

Table 2.2 presents the analysis of the annual leak rates (all causes) for distribution mains by material type. This data includes only leaks on the body of the pipe. For example, the data shows that in 1971 there were 1.51 leaks per 1,000 miles of cast iron mains. The column labeled "other" includes all additional materials for which data are collected, such as copper, ductile iron, and wrought iron for which the amount of data available is insufficient for analysis as a separate category. One should notice the large variability for the data in the "other" column from one year to the next. The purpose of this analysis was to determine--considering all causes--whether there are significant differences in leak rates in the three major types of materials used and also between these types of materials and those grouped in the "other" category.

The Duncan Multiple Range Test was used to determine whether there were statistically significant differences in these four categories of materials. The results of the test are presented at the bottom of Table 2.2 for $\alpha = 0.05$ and $\alpha = 0.01$. At the $\alpha = 0.05$ level, the test indicates that the leak rate for steel is significantly less than for all other materials. At the $\alpha = 0.01$ level of significance, none of the materials are found to be different in leak rate. Thus, for an α-level of 0.05, the material type used does affect the leak rate on mains. In some of the following tables this effect will be analyzed in more detail by also considering the cause of the leak.

Table 2.3 gives a similar analysis to that in Table 2.2, but Table 2.3 is for the leaks on the parts of the system other than the pipe in the distribution system. The purpose of this analysis is to determine whether the leak rate of the parts is dependent upon the material type. The "other" material type includes ductile iron, copper, aluminum, etc.

The result of the analysis using the Duncan Multiple Range Test is shown below the table. It indicates that the leak rate is much higher for

TABLE 2.2

Leak Rate of Pipe by Material Type

Distribution Mains

Individual Failure Report Data

Measure: Leaks per year per 1,000 miles of pipe

Year	Type of Material			
	1 STEEL	2 CAST IRON	3 PLASTIC	4 OTHER
1970	0.33	0.99	0.91	0.94
1971	0.40	1.51	1.36	0.51
1972	0.37	1.29	1.52	1.38
1973	0.40	1.26	1.41	0.79
MEAN	0.37	1.26	1.30	0.90

Standard Error of Mean = 0.125

Degrees of Freedom = 12

Duncan Multiple Range Analysis

3	2	4	1	α = .05
<u>1.30</u>	<u>1.26</u>	<u>0.90</u>	0.37	

3	2	4	1	α = .01
<u>1.30</u>	<u>1.26</u>	<u>0.90</u>	<u>0.37</u>	

TABLE 2.3

Leak Rate of Parts other than Pipe by Material Type

Distribution Mains

Individual Failure Report Data

Measure: Leaks per year per 1,000 miles of pipe

Year	Type of Material			
	1 STEEL	2 CAST IRON	3 PLASTIC	4 OTHER
1970	0.09	0.22	0.05	2.99
1971	0.07	0.23	0.0	1.94
1972	0.08	0.12	0.12	1.60
1973	0.09	0.14	0.10	1.40
MEAN	0.08	0.18	0.07	1.98

Standard Error of Mean = 0.178

Degrees of Freedom = 12

Duncan Multiple Range Analysis

4	2	1	3	$\alpha = .05$
1.98	0.18	0.08	0.07	

4	2	1	3	$\alpha = .01$
1.98	0.18	0.08	0.07	

the materials lumped together as "other." For steel, cast iron and plastic, no statistically significant differences are observed. Although the test shows no differences among the leak rates for steel, cast iron and plastic, it is noted that the number of reported leaks on which the leak rates are based is small for the material types other than steel. This makes the variance for this data relatively large and considerably weakens the power of the statistical test.

Table 2.4 shows the leak rate data years (all causes) for distribution services by material type. The data include the leaks reported on body of the pipe and were computed by using the ratio of the number of leaks in the individual report over the number of services in the annual report. The purpose of this analysis is to determine whether the material types make any difference in leak rates in the pipe used for services. The table and analysis are similar to Table 2.2.

In the table the average leak rates for plastic and "other" materials are significantly ($\alpha = 0.05$) higher than those for steel and copper. The leak rate does not differ significantly for steel and copper pipe or for plastic and "other" pipe.

Table 2.5 presents the data for distribution services and is similar to Table 2.4 in the analysis performed, except that Table 2.5 is for the leaks in the parts of the system other than the body of pipe. It is also similar to Table 2.3 except that the analysis in Table 2.3 is for mains. It is obvious from the data the leak rate for "other" materials is significantly higher; no explanation for this large differential is available. Because the leak rate for "other" materials is so large and the variance is so large, the "other" material is not included in the Duncan Multiple Range Test. The Duncan Multiple Range Test is used to compare steel, copper, and plastic, and it shows there is no statistically significant difference.

Even though the analysis shows a significantly different leak rate for "other" material types, one can suspect that the rate given in leaks per service per year may not be an appropriate measure. This is due to the fact that the proportion of time a particular type of material is used for parts other than the body of the pipe is unknown.

TABLE 2.4

Leak Rate of Pipe by Material Type

Distribution Services

Individual Failure Report Data

Measure: Leaks per year per 100,000 services

Year	Type of Material			
	1 STEEL	2 COPPER	3 PLASTIC	4 OTHER
1970	0.46	0.45	1.72	0.74
1971	0.45	0.53	1.87	2.87
1972	0.57	0.74	1.90	2.39
1973	0.46	0.61	1.88	0.57
MEAN	0.48	0.58	1.84	1.64

Standard Error of Mean = 0.293

Degrees of Freedom = 12

Duncan Multiple Range Analysis

3	4	2	1	α = .05
1.84	1.64	0.58	0.48	

3	4	2	1	α = .01
1.84	1.64	0.58	0.48	

TABLE 2.5

Leak Rate of Parts other than Pipe by Material Type

Distribution Services

Individual Failure Report Data

Measure: Leaks per year per 100,000 services

Year	Type of Material			
	1 STEEL	2 COPPER	3 PLASTIC	4 OTHER
1970	0.18	0.13	0.15	15.10
1971	0.32	0.35	0.59	25.80
1972	0.33	0.48	0.44	29.30
1973	0.24	0.39	0.25	9.25
MEAN	0.27	0.34	0.36	19.86

Note: Statistical Analysis for Steel, Copper and Plastic Only

Standard Error of Mean = 0.073

Degrees of Freedom = 9

Duncan Multiple Range Analysis
for Steel, Copper and Plastic

3	2	1	$\alpha = .05$
0.36	0.34	0.27	

3	2	1	$\alpha = .01$
0.36	0.34	0.27	

2.2.2 Individual Failure Reports--Analyses Related to Nominal Diameter of Pipeline

The analyses which were performed to examine the leak rate as a function of nominal pipe diameter are presented in this section.

Table 2.6 presents a breakdown of the mean annual leak rates of distribution mains by size of the pipe. The leaks originate from the body of pipe and are the result of all causes. The leak rates are obtained by dividing the total number of leaks in one range of diameter by the corresponding number of miles of pipe of the same diameter range. The former values are obtained from the individual reports and the latter values from the annual report.

The range test shown beneath the table indicates that at the $\alpha = 0.01$ level, the pipes of large diameter (8 inches or greater) have significantly higher leak rates than the pipes of a size smaller than 8 inches. At the $\alpha = 0.05$ level, the difference in leak rates of 8-inch pipe and of pipe greater than 10 inches in diameter is also significant. Also, the pipe of less than one inch diameter has a leak rate which is not significantly different from the leak rate for 4 through 6-inch diameter pipe at the $\alpha = 0.05$ level. These results show that the large diameter mains (8 inches or more) cause proportionately more leaks than the mains of intermediate size when the leaks are counted strictly on a per-mile basis. Of course, the larger diameter pipe has a greater surface area per mile which is subject to corrosion leaks. However, the leak rate for pipe of less than one inch diameter does not follow this expected pattern since the leak rate for this category does not differ significantly at the $\alpha = 0.05$ level from mains of pipe 4 through 6 inches in diameter.

Table 2.7 gives the individually reported leak rates on the body of the pipe used in distribution services for four different ranges of diameter. The table and analysis are similar to Table 2.6 except that Table 2.6 is for distribution mains. Using an α-level of 0.05, the leak rate for pipe greater than two inches in diameter is significantly higher than for pipe of size less than one-half inch, and pipe of less than one-half inch has a significantly higher leak rate than pipe of size 0.5-2.0 inches in diameter.

TABLE 2.6

Leak Rate of Pipe by Nominal Diameter

Distribution Mains

Individual Failure Report Data

Measure: Leaks per year per 1,000 miles of pipe

YEAR	Nominal Diameter in Inches					
	1 LE 1	2 1-2	3 2-4	4 4-6	5 8	6 GE 10
1970	0.58	0.33	0.52	0.52	0.83	1.10
1971	0.62	0.53	0.49	0.76	0.92	1.25
1972	0.80	0.43	0.48	0.69	1.31	1.47
1973	0.84	0.45	0.51	0.65	1.14	1.36
MEAN	0.71	0.43	0.50	0.65	1.05	1.29

Standard Error of Mean = 0.066

Degrees of Freedom = 18

Duncan Multiple Range Analysis

6	5	1	4	3	2	α = .05
1.29	1.05	0.71	0.65	0.50	0.43	

6	5	1	4	3	2	α = .01
1.29	1.05	0.71	0.65	0.50	0.43	

TABLE 2.7

Leak Rate of Pipe by Nominal Diameter

Distribution Services

Individual Failure Report Data

Measure: Leaks per year per 100,000 services

Year	Nominal Diameter in Inches			
	1 LE .5	2 .5-1	3 1-2	4 GT 2
1970	1.01	0.62	0.55	1.35
1971	1.81	0.55	0.49	3.47
1972	1.81	0.62	0.43	1.97
1973	1.46	0.59	0.49	2.62
MEAN	1.52	0.59	0.49	2.35

Standard Error of Mean = 0.246

Degrees of Freedom = 12

Duncan Multiple Range Analysis

4	1	2	3	α = .05
2.35	1.52	0.59	0.49	

4	1	2	3	α = .01
2.35	1.52	0.59	0.49	

Table 2.8 follows a similar analysis performed in Tables 2.6 and 2.7, but the data is for the transmission system. A general pattern is evident in this data of a decreasing leak rate per 1,000 miles of transmission line as the nominal diameter of the pipe increases.

Even at the $\alpha = 0.01$ confidence level, the pipe of diameter less than two inches has a significantly higher leak rate than other sizes. At the $\alpha = 0.05$ level, no significant difference exists between pipe in any three adjacent size ranges from 2-22 inches. Similarly, no significant difference in leak rate exists for pipe 24 inches or more in diameter. Perhaps the lower leak rate for larger diameter pipe reflects the greater care which is characteristic of the installation of large diameter lines as compared to those of smaller diameters.

TABLE 2.8

Leak Rate of Pipe by Nominal Diameter

Transmission Systems

Individual Failure Report Data

Measure: Leaks per year per 1,000 miles of pipe

	Nominal Diameter in Inches									
	1	2	3	4	5	6	7	8	9	10
Year	LE 2	2-4	4-6	8,10	12,14	16,18	20,22	24,26	28,30	GE 32
1970	2.74	1.19	1.68	1.28	1.18	1.11	0.62	0.72	0.34	0.21
1971	3.38	1.76	1.73	1.43	1.18	1.15	1.47	0.20	0.24	0.33
1972	2.77	1.76	1.68	1.87	1.59	1.49	1.24	0.53	0.12	0.05
1973	2.25	2.23	1.62	1.75	0.92	1.20	0.60	0.34	0.21	0.04
MEAN	2.78	1.73	1.68	1.58	1.22	1.24	0.98	0.45	0.23	0.16

Standard Error of Mean = 0.146

Degrees of Freedom = 30

Duncan Multiple Range Analysis

1	2	3	4	6	5	7	8	9	10	α = .05
2.78	1.73	1.68	1.58	1.24	1.22	0.98	0.45	0.23	0.16	

1	2	3	4	6	5	7	8	9	10	α = .01
2.78	1.73	1.68	1.58	1.24	1.22	0.98	0.45	0.23	0.16	

2.2.3 Individual Failure Reports--Analyses Related to OPS Administrative Region within the U.S.A.

Comparisons of leak rate for pipeline systems in the five different OPS administrative regions of the U.S.A. are presented in the following section.

The data presented in Table 2.9 is the result of an analysis to determine if a regional difference exists in reported individual leaks for distribution mains. The entries in the table were obtained by dividing the total number of leaks shown on the individual reports in one region, by the miles of pipe of that region. A scale factor of 1,000 miles is used as in the other tables.

The statistical test indicates that at α = 0.01 confidence level, the leak rate is significantly higher for Region 5 (Western states, including Alaska) and significantly lower for Region 2 (Southeastern states). The rates of reported leaks are not different in Regions 1, 3, and 4.

The reasons for the high leak rate in Region 5 are not known. But for Region 2 the lower leak rate could possibly be explained by the fact that a large number of smaller operators--as found in Region 2--are not required to individually report leaks.

Table 2.10, similar to Table 2.9, contains the leak rates for the five regions, but for distribution services rather than mains. The rates were determined by dividing the total number of leaks reported in a region by the number of services in that region. A scale factor of 100,000 services is used in this table.

The test shows that at the α = 0.05 level, the rate of reporting individual leaks was significantly higher in Region 5, as was the case in distribution mains. The leak rates of the other four regions do not differ significantly.

The analysis given in Table 2.11 is the result of an analysis of the regional difference in rate of reporting leaks in transmission systems (not including gathering systems). The values are in number of leaks per year per 1,000 miles of pipe. The highest leak rate is for Region 1 (North-eastern states) which is significantly different from the other regions at the α = 0.01 level. At the α = 0.05 level, Regions 2, 4 and 5 are not significantly different in leak rate, and Regions 3 and 4 are also not significantly different in leak rate.

TABLE 2.9

Leak Rate by Region

Distribution Mains

Individual Failure Report Data

Measure: Leaks per year per 1,000 miles of pipe

Year	Region				
	1	2	3	4	5
	REG 1	REG 2	REG 3	REG 4	REG 5
1970	0.54	0.31	0.51	0.69	0.81
1971	0.83	0.34	0.55	0.69	1.04
1972	0.82	0.34	0.59	0.63	0.91
1973	0.55	0.40	0.66	0.66	1.17
MEAN	0.68	0.35	0.58	0.67	0.98

Standard Error of Mean = 0.053

Degrees of Freedom = 15

Duncan Multiple Range Analysis

5	1	4	3	2	$\alpha = .05$
0.98	0.68	0.67	0.58	0.35	

5	1	4	3	2	$\alpha = .01$
0.98	0.68	0.67	0.58	0.35	

TABLE 2.10

Leak Rate by Region

Distribution Services

Individual Failure Report Data

Measure: Leaks per year per 100,000 services

Year	Region				
	1	2	3	4	5
	REG 1	REG 2	REG 3	REG 4	REG 5
1970	0.83	0.56	0.68	0.71	0.92
1971	0.91	1.11	1.05	0.48	1.50
1972	1.08	1.30	0.97	0.85	1.70
1973	0.86	1.34	0.94	0.98	1.69
MEAN	0.92	1.08	0.91	0.75	1.45

Standard Error of Mean = 0.132

Degrees of Freedom = 15

Duncan Multiple Range Analysis

5	2	1	3	4	$\alpha = .05$
1.45	1.08	0.92	0.91	0.75	

5	2	1	3	4	$\alpha = .01$
1.45	1.08	0.92	0.91	0.75	

TABLE 2.11

Leak Rate by Region

Transmission Systems

Individual Failure Report Data

Measure: Leaks per year per 1,000 miles of pipe

Year	Region				
	1	2	3	4	5
	REG 1	REG 2	REG 3	REG 4	REG 5
1970	2.52	1.73	1.06	1.16	1.14
1971	2.46	1.89	1.32	1.26	1.77
1972	2.98	1.57	0.95	1.49	2.39
1973	2.33	1.48	0.91	2.23	1.58
MEAN	2.57	1.67	1.06	1.53	1.72

Standard Error of Mean = 0.180

Degrees of Freedom = 15

Duncan Multiple Range Analysis

1	5	2	4	3	α = .05
2.57	1.72	1.67	1.53	1.06	

1	5	2	4	3	α = .01
2.57	1.72	1.67	1.53	1.06	

2.2.4 Individual Failure Reports--Analyses Related to Age of Pipeline

The analyses performed to determine the influence of age of the pipeline on the leak rate are presented in this section.

Table 2.12 presents the analysis for the effect of age of the pipe on the leak rates in distribution mains. The age of pipe is represented by the decade in which the pipe was constructed. The leak rate is calculated by dividing the number of reported leaks on the pipe system built in each decade by the corresponding number of miles built in that decade, all being taken from the annual report file. The pipe system whose construction decade is unknown is not considered in this analysis. This omission of pipe of unknown age probably would not change the general result very much, i.e., increasing leak rate with age as shown in the average leak rates in the table.

The Duncan Multiple Range Test shown with the table indicates that, at $\alpha = 0.05$ level, the pipe installed prior to 1940 had a significantly higher leak rate than pipe installed in the decades since 1940; and the decades of the 1930's, '40's, and '70's, as a group, have higher leak rates than the decades of the '50's and '60's. The apparently higher leak rate forecasted from the data for the '70's might be viewed with concern.

Table 2.13 presents the data for the age of pipe versus the leak rate for distribution services. The data were obtained in the same manner as the data in Table 2.12. Except for the services constructed in the most recent years, the leak rates appear to be higher for older pipe.

The Range test shows that the services constructed prior to 1930 have a leak rate significantly higher than the rest of the decades and at the $\alpha = 0.05$ level the decades of the 1930's, '40's, and '70's, as a group, have higher leak rates than the '50's and '60's. The apparently higher leak rate in the decade of the '70's is cause for concern.

Table 2.14 shows the increasing leak rate with the age of pipe in transmission systems. The analysis is similar to those in Tables 2.12 and 2.13. The increase in leak rate with age is very drastic in the 1920's and '30's. As in the distribution systems, the leak rate in the 1970's deviates from the general trend.

Statistically, the leak rates for pipe installed in both the 1920's and '30's are distinctly different from those of the following decades at the $\alpha = 0.05$ level. Thus, proportionately more leaks requiring individual reports occur in old pipe than in new pipe.

Again, although the result is statistically significant in this case, the data does indicate that the 1970's decade pipe has a higher leak rate than might be expected. This might be explained by the fact that new systems require time to "get the bugs out," i.e., to detect and repair problems created in construction. If this is true, then possibly more tests should be required of new installations.

TABLE 2.12

Leak Rate by Decade of Construction

Distribution Mains

Measure: Leaks per year per 1,000 miles of pipe

Individual Failure Report Data

	Decade of Construction					
	1	2	3	4	5	6
Year	---29	30-39	40-49	50-59	60-69	70---
1970	1.64	1.41	0.85	0.64	0.31	0.83
1971	1.51	1.36	1.22	0.71	0.37	1.62
1972	1.71	1.65	1.27	0.63	0.30	1.16
1973	1.66	1.42	1.48	0.57	0.34	1.15
MEAN	1.63	1.46	1.20	0.64	0.33	1.19

Standard Error of Mean = 0.092

Degrees of Freedom = 18

Duncan Multiple Range Analysis

1	2	3	6	4	5	$\alpha = 0.05$
1.63	1.46	1.20	1.19	0.64	0.33	

1	2	3	6	4	5	$\alpha = 0.01$
1.63	1.46	1.20	1.19	0.64	0.33	

TABLE 2.13

Leak Rate by Decade of Construction

Distribution Services

Measure: Leaks per year per 100,000 services

Individual Failure Report Data

	Decade of Construction					
	1	2	3	4	5	6
Year	---29	30-39	40-49	50-59	60-69	70---
1970	2.23	0.83	0.97	0.54	0.80	1.01
1971	2.53	1.52	1.38	0.88	1.03	1.69
1972	2.43	1.93	0.96	1.23	1.16	1.98
1973	3.32	1.00	1.19	0.78	0.89	1.75
MEAN	2.63	1.32	1.12	0.86	0.97	1.61

Standard Error of Mean = 0.183

Degrees of Freedom = 18

Duncan Multiple Range Analysis

1	6	2	3	5	4	$\alpha = 0.05$
2.63	1.61	1.32	1.12	0.97	0.86	

1	6	2	3	5	4	$\alpha = 0.01$
2.63	1.61	1.32	1.12	0.97	0.86	

TABLE 2.14

Leak Rate by Decade of Construction

Transmission Systems

Measure: Leaks per year per 1,000 miles of pipe

Individual Failure Report Data

	Decade of Construction					
	1	2	3	4	5	6
Year	---29	30-39	40-49	50-59	60-69	70---
1970	9.92	2.14	1.14	0.83	0.54	1.81
1971	7.91	3.08	1.65	0.95	0.82	1.04
1972	9.41	3.24	1.81	0.94	0.71	1.01
1973	11.38	3.18	1.45	1.36	0.93	1.22
MEAN	9.65	2.91	1.51	1.02	0.75	1.27

Standard Error of Mean = 0.331

Degrees of Freedom = 18

Duncan Multiple Range Analysis

1	2	3	6	4	5	$\alpha = 0.05$
9.65	2.91	1.51	1.27	1.02	0.75	

1	2	3	6	4	5	$\alpha = 0.01$
9.65	2.91	1.51	1.27	1.02	0.75	

2.2.5 Individual Failure Reports--Analyses Related to Leak Rate as a Function of Corrosion of Pipeline Materials

The analyses presented in this section are subdivided into three areas, all related to leak rate as a function of pipeline corrosion. The areas to be covered are:

(1) Leak rates due to corrosion as a function of age of pipeline;

(2) Leak rates which are produced by external versus internal corrosion of the pipeline;

(3) Leak rates which result as a function of the type of corrosion protection employed.

2.2.5.1 Leak Rates Due to Corrosion as a Function of Age of Pipeline

Table 2.15 gives the corrosion-caused leak rate for distribution mains broken down by the decade of construction. For example, in 1971 the individually reported leaks caused by corrosion on components constructed in the 1940's yields a leak rate of 0.34 leaks per 1,000 miles of main. Notice that in 1970 there were no reported corrosion leaks for systems constructed in 1970.

Table 2.15 is different from Table 2.12 in that Table 2.12 is for leaks of all causes, while Table 2.15 is only for corrosion-caused leaks. An inspection of the data indicates an increasing leak rate for older pipe, which confirms the notion that older pipe is more likely to be corroded and thus will leak more often than pipe constructed in the latter decades. Notice that the pipe of "unknown" age which leaks is not included in the tabulation. Omission of this data can significantly bias all of the test results presented here, especially since the "unknown" category tends to be older pipe for which records of installation date are not available. For this reason, in the future it will be necessary to attempt to classify as little of the data as possible in the "unknown" category, moving it into one of the age categories shown.

The Duncan Multiple Range Test was utilized to statistically analyze this data. A glance at the data indicates a general trend of increasing leak rate with age, and indeed the test verifies this result. At the $\alpha = 0.05$ level, the corrosion-caused leak rate for pipelines constructed

TABLE 2.15

Corrosion Leak Rate by Decade of Construction

Distribution Mains

Measure: Leaks per year per 1,000 miles of pipe

Individual Failure Report Data

	Decade of Construction					
	1	2	3	4	5	6
Year	---29	30-39	40-49	50-59	60-69	70---
1970	0.32	0.30	0.24	0.13	0.04	0.0
1971	0.21	0.45	0.34	0.11	0.05	0.05
1972	0.27	0.37	0.37	0.12	0.03	0.04
1973	0.35	0.37	0.38	0.13	0.04	0.01
MEAN	0.29	0.37	0.33	0.12	0.04	0.02

Standard Error of Mean = 0.023

Degrees of Freedom = 18

Duncan Multiple Range Analysis

2	3	1	4	5	6	$\alpha = 0.05$
0.37	0.33	0.29	0.12	0.04	0.02	

2	3	1	4	5	6	$\alpha = 0.01$
0.37	0.33	0.29	0.12	0.04	0.02	

in the 1950's is significantly lower than for pipelines constructed prior to this time, but higher than for those constructed after this time. In addition, at the $\alpha = 0.05$ level, the decade of the 1920's has a significantly lower leak rate than the decade of the '30's, but not lower than the decade of the '40's. At the $\alpha = 0.01$ level, no significant differences exist among the leak rates of the decades prior to 1950.

In summary, the corrosion-caused leaks do have a higher probability of occurrence in older systems.

Table 2.16 gives a similar analysis of corrosion leaks for distribution services as Table 2.15 does for mains. The leak rate in this table again generally follows the expected pattern.

The ranges shown at the $\alpha = 0.05$ level essentially verify the expectation that old pipe causes proportionately more corrosion leaks in distribution services.

Table 2.17 shows the increasing corrosion leak rate with the age of the pipe in transmission systems (excluding gathering). The table is similar to Tables 2.15 and 2.16.

The statistical test ($\alpha = 0.05$) indicates that the leak rate does significantly increase with age except in the decades of the 1940's, '50's, and '60's where the differences in the observed values are not significant. The difference between the 1930's and '40's is insignificant at the $\alpha = 0.05$ level.

2.2.5.2 Leak Rates Due to Internal versus External Corrosion of Pipeline

Tables 2.18, 2.19, and 2.20 show the comparison, in leak rate, between the internal and the external corrosion in mains, services, and transmission lines, respectively. This data is obtained from the individual leak reports. In each of the three tables, external corrosion shows a much higher leak rate than internal corrosion.

The significance of the difference was analyzed for each of the three tables, using the Student's "t"-test of hypothesis. In each of the three tests, the difference was found to be significant at the $\alpha = 0.01$ level.

In summary, for mains, services, and transmission, the internal corrosion leak rate is significantly lower than the external corrosion leak rate.

TABLE 2.16

Corrosion Leak Rate by Decade of Construction

Distribution Services

Measure: Leaks per year per 100,000 services

Individual Failure Report Data

	Decade of Construction					
	1	2	3	4	5	6
Year	---29	30-39	40-49	50-59	60-69	70---
1970	0.45	0.35	0.13	0.10	0.04	0.06
1971	0.39	0.66	0.39	0.09	0.04	0.08
1972	0.36	0.48	0.22	0.24	0.07	0.03
1973	0.36	0.36	0.26	0.15	0.11	0.04
MEAN	0.39	0.46	0.25	0.14	0.06	0.05

Standard Error of Mean = 0.041

Degrees of Freedom = 18

Duncan Multiple Range Analysis

2	1	3	4	5	6	$\alpha = 0.05$
0.46	0.39	0.25	0.14	0.06	0.05	

2	1	3	4	5	6	$\alpha = 0.01$
0.46	0.39	0.25	0.14	0.06	0.05	

TABLE 2.17

Corrosion Leak Rate by Decade of Construction

Transmission Systems

Measure: Leaks per year per 1,000 miles of pipe

Individual Failure Report Data

	Decade of Construction					
	1	2	3	4	5	6
Year	---29	30-39	40-49	50-59	60-69	70---
1970	1.34	0.71	0.32	0.06	0.04	0.14
1971	0.93	0.58	0.41	0.10	1.01	0.0
1972	1.18	0.81	0.41	0.17	0.14	0.0
1973	1.55	0.88	0.10	0.22	0.05	0.0
MEAN	1.25	0.74	0.31	0.14	0.08	0.03

Standard Error of Mean = 0.070

Degrees of Freedom = 18

Duncan Multiple Range Analysis

1	2	3	4	5	6	$\alpha = 0.05$
1.25	0.74	0.31	0.14	0.08	0.03	

1	2	3	4	5	6	$\alpha = 0.01$
1.25	0.74	0.31	0.14	0.08	0.03	

TABLE 2.18

Internal vs. External Corrosion in Distribution Mains

Measure: Leaks per year per 1,000 miles of pipe

Individual Failure Report Data

Year	Internal	External
1970	0.000	0.105
1971	0.003	0.102
1972	0.002	0.107
1973	0.002	0.115

TABLE 2.19

Internal vs. External Corrosion in Distribution Services

Measure: Leaks per year per 100,000 services

Individual Failure Report Data

Year	Internal	External
1970	0.006	0.102
1971	0.003	0.136
1972	0.003	0.140
1973	0.003	0.135

TABLE 2.20

Internal vs. External Corrosion in Transmission Systems

Measure: Leaks per year per 1,000 miles of pipe

Individual Failure Report Data

Year	Internal	External
1970	0.012	0.167
1971	0.031	0.157
1972	0.039	0.216
1973	0.055	0.168

2.2.5.3 Leak Rates for Pipelines as a Function of the Type of Corrosion Protection Employed

Table 2.21 gives the leak rates due to corrosion in distribution mains for the various combinations of protective methods. The data are from the individual reports. Without any statistical analysis, it appears obvious that pipelines that are both coated and cathodically protected offer substantially lower corrosion leak rates than any of the other three categories. In addition, it appears that there is no appreciable difference in the leak rates among the other three categories.

In order to test this observation statistically, a two way analysis of variance was performed on the data in Table 2.21. This statistical analysis showed that (1) the leak rates of the coated pipe were significantly lower than those of the bare pipe, and (2) the interaction between the coating and the cathodic protection was significant. The latter result verifies the effectiveness of the coating when combined with cathodic protection in the prevention of corrosion. The above conclusions were drawn at $\alpha = 0.01$ confidence level.

In summary, the analysis says that cathodic protection by itself has no significant effect; coating pipe does have a significant effect, but the greatest effect is obtained by combining cathodic protection with coating.

Table 2.22 gives the rates of leaks caused by corrosion in transmission lines classified into two separate factors. One factor is the coating of the pipelines and the other the cathodical protection. The reason for not giving combined effects of the two factors is that the miles of pipelines which are not both coated and cathodically protected account for only about 20 percent of all pipelines. Thus, the leak rates based on these mileage figures were subject to considerable experimental errors.

The separate one-way analysis of variance performed on the two sets of data showed that both the coating and the cathodic protection had significant effects on the leak rate of the corrosion-caused leaks. These conclusions should be interpreted with care since the lower leak rates for the coated or cathodically protected pipelines may well be the result of the interaction between the two protective methods.

TABLE 2.21

Effect of Coating and Cathodic Protection on Corrosion Leaks

Distribution Mains

Measure: Leaks per year per 1,000 miles of pipe
Individual Failure Report Data

	Year	Cathodic Protection	
		Yes	No
Coated	1970	0.03	0.12
	1971	0.02	0.15
	1972	0.03	0.15
	1973	0.02	0.37
Bare	1970	0.41	0.14
	1971	0.13	0.14
	1972	0.23	0.13
	1973	0.56	0.24

TABLE 2.22

Effect of Coating and Cathodic Protection on Corrosion Leaks

Transmission Systems

Measure: Leaks per year per 1,000 miles of pipe

Individual Failure Report Data

	COATING		CATHODIC PROTECTION	
Year	Coated	Bare	Yes	No
1970	0.11	0.64	0.11	0.74
1971	0.11	0.53	0.09	0.71
1972	0.18	0.77	0.17	0.79
1973	0.16	0.65	0.19	0.63

2.2.6 Individual Failure Reports--Analyses of Parts of Pipeline System Where Leak Occurred

The analyses which were performed to determine the relative frequencies of leaks as a function of the part of the pipeline where the leak occurred are presented in this section.

Table 2.23 is a breakdown of leaks reported individually by the part which leaked in distribution mains. The table shows that leaks on pipe account for between 76 percent and 83 percent of total reported leaks. Because the leak data on the parts which leaked--other than pipe--are sparse, the variance is quite large. Note that this data cannot be put on a leak "rate" basis because of the lack of normalizing data; that is, no information is available on the relative numbers of each part. The conclusions that can be drawn about such percentage data are severely limited. For example, the fact that valves account for about three percent of the leaks and fitting seven percent, does not imply that a fitting is more likely to leak than a valve. This would depend on the relative number of valves and fittings.

Table 2.24 gives the percentage of leaks by parts in distribution services, and is similar to Table 2.23 except that Table 2.23 was for distribution mains. It shows that in distribution services, leaks on pipe account for over 50 percent of the reported leaks, and fittings account for over 18 percent. Again, any conclusions that can be drawn from this data are limited.

Table 2.25 gives a percentage breakdown of individually reported leaks by origin for transmission lines, gathering lines, and transmission lines of the distribution system. In the transmission lines, about 54 percent of the leaks originated on the body of the pipe, 13 percent of the leaks originated in a fitting, and each of the other parts produced a small percentage of the total number of leaks. In both the gathering lines and the transmission lines of the distribution system, the body of the pipe was the origin of the highest percentage of leaks, with the fittings being the second highest percentage of leaks. However, for gathering lines, the percentage of leaks originating on the body of the pipe ranged from 45 percent to 82 percent over the four years, and the percentage of leaks originating on the fittings

TABLE 2.23

Part which Leaked as Percentage of Total Leaks

Distribution Mains

Individual Failure Report Data

Year	Part Which Leaked							
	Pipe	Valve	Fitting	Drip	Regulator	Tap Connection	Other	
1970	76.2	3.4	7.9	1.5	0.0	5.2	5.8	100%
1971	83.4	3.5	6.0	0.5	0.0	2.0	4.6	100%
1972	83.0	1.40	9.4	0.9	0.9	2.1	2.3	100%
1973	82.8	2.5	8.0	0.5	2.4	1.8	2.0	100%

TABLE 2.24

Part which Leaked as Percentage of Total Leaks

Distribution Services

Individual Failure Report Data

Year	Part Which Leaked							
	Pipe	Valve	Fitting	Drip	Regulator	Tap Connection	Other	
1970	63.4	4.6	20.2	0.0	1.5	6.9	3.4	100%
1971	50.6	5.2	23.4	0.0	2.60	5.2	13.0	100%
1972	52.0	4.3	21.2	0.0	5.70	4.3	12.5	100%
1973	54.4	3.1	18.7	0.2	7.5	4.2	11.9	100%

TABLE 2.25

Individual Failure Report Data

Part which Leaked as Percentage of Total Leaks

Transmission/Gathering Systems

Origin of Leak

System	Year	Body of Pipe	Girth Weld	Longi-tudinal Weld	Other Welds	Com-pressor	Valve	Scraper Trap	Tap Connec-tion	Fitting	Gas Cooler	Other	
Trans-mission	1970	52.0	4.9	4.9	1.2	0.6	2.2	0.3	8.1	14.3	0.0	11.5	100%
	1971	47.0	7.6	7.9	0.6	0.3	2.5	0.0	5.9	16.0	0.6	11.6	100%
	1972	59.1	5.7	6.7	0.0	0.8	2.7	0.5	3.5	11.0	0.0	10.0	100%
	1973	58.6	7.2	5.6	0.7	0.7	1.6	0.2	4.9	12.1	0.0	8.4	100%
Gather-ing	1970	71.4	7.1	0.0	0.0	0.0	0.0	0.0	0.0	14.3	0.0	7.2	100%
	1971	45.4	13.6	0.0	4.6	0.0	9.1	0.0	0.0	18.2	0.0	9.1	100%
	1972	81.8	0.0	0.0	0.0	9.1	0.0	0.0	0.0	0.0	0.0	9.1	100%
	1973	57.1	0.0	0.0	0.0	0.0	14.3	0.0	14.3	0.0	0.0	14.3	100%
Trans-mission line of Distribu-tion Sys-tem	1970	62.5	0.0	0.0	0.0	0.0	12.5	0.0	0.0	12.5	0.0	12.5	100%
	1971	41.6	0.0	4.2	0.0	0.0	4.2	0.0	0.0	25.0	0.0	25.0	100%
	1972	60.9	4.4	0.0	4.3	0.0	0.0	0.0	8.7	13.0	0.0	8.7	100%
	1973	56.3	6.2	3.1	0.0	0.0	0.0	0.0	0.0	34.4	0.0	0.0	100%

ranged from zero percent to 18 percent. On the transmission line of the distribution system, the percentage of leaks originating on the body of the pipe ranged from 42 percent to 63 percent and the percentage originating on the fittings ranged from 13 percent to 34 percent.

Again, the fact that the data are expressed in percentages limits the conclusions that can be drawn. To say that in 1971 the girth weld (where 7.6 percent of leaks on the transmission line originated) and the longitudinal weld (where 7.9 percent of leaks on the transmission line originated) were equally likely to leak, is incorrect. One would have to consider the relative number of welds in each category. Also, there was a small number of total reports, causing a high variance in the percentage data. For example, in the year 1970, for transmission lines of distribution systems, only four categories were reported as the origins of leaks.

In summary, for these three major divisions of the transmission system, at least half of the leaks originate on the body of the pipe, about 15 percent of the leaks originate on the fitting, and a small percentage of leaks originate on each of the other parts.

2.2.7 Individual Failure Reports--Analyses of Leak Rates Produced by Various Causes

The analyses of leak rate as a function of all of the various causes reported to have produced the leak are reported in this section.

Table 2.26 gives a breakdown of leaks for distribution mains by cause for each decade of construction and an overall total for the years 1970-1973. These figures are based on data from the individual reports of those corresponding years. Overall, about 65 percent of all leaks are caused by outside force, while corrosion accounts for about 17 percent of the leaks, and about 12 percent are attributed to material failure. For pipe installed during a specific decade, such as in the 1960's, outside force accounted for about 78 percent (from 72.8 percent to 82.6 percent) of the leaks; corrosion, about 12 percent (from 9.5 percent to 13.9 percent) of leaks; and material failure, about 5 percent (from 3.2 percent to 6.3 percent) of all leaks.

Although the observation can be made that the percentage of leaks due to outside force during almost all decades decreases steadily with age, the fact that the data are expressed in percentages severely limits any statistical analysis. First of all, the leak rate (not percentage) for pipe in each age category should be referred to before concluding that a leak due to outside force is more likely to occur in a new, rather than an old, pipe. Also, the corrosion leak rate is known to increase with age; hence, corrosion accounts for a higher percentage of leaks installed before 1950. Since, in a given decade, the percentage must add up to 100, a rise in the percentage of leaks due to corrosion because of an increasing corrosion leak rate, will necessitate a decrease in the percentage of leaks due to all other causes. Hence, the decrease in percentage of leaks due to outside force with age could have been caused by the increasing corrosion leak rate.

In summary, outside force accounts for the majority of leaks (about 65 percent) in the individual reports. Corrosion accounts for about 17 percent of the leaks, and material failure accounts for about 12 percent. Construction defect and all other causes account for a very small percentage of the leaks.

Table 2.27 gives a breakdown of the percentage of leaks by cause for decade of construction and an overall total for service distributions

TABLE 2.26

Percentage of Leaks by Cause and by Decade of Construction

Distribution Mains

Individual Failure Report Data

Cause	Year	Unknown	--29	30-39	40-49	50-59	60-69	70--	Total
		Decade of Construction							
Corrosion	1970	18.0	21.4	21.2	28.6	20.0	11.9	0.0	18.6
	1971	9.1	16.2	33.3	28.0	15.1	13.9	0.0	15.9
	1972	6.7	21.3	22.7	28.9	19.0	9.5	0.0	15.7
	1973	10.0	30.2	26.3	25.8	23.7	12.2	1.3	17.7
Outside Force	1970	68.0	62.5	69.7	71.4	61.4	77.9	78.6	68.4
	1971	63.6	44.6	44.5	56.0	59.1	79.8	80.4	61.8
	1972	77.8	52.0	59.1	61.5	64.3	82.5	87.9	68.6
	1973	66.0	52.3	42.1	53.2	56.6	72.8	86.0	63.3
Construction Defect	1970	0.0	0.0	0.0	0.0	1.3	3.4	0.0	.9
	1971	0.0	4.1	0.0	0.0	3.2	0.0	3.9	1.9
	1972	2.2	0.0	0.0	0.0	2.4	3.2	3.5	1.7
	1973	4.0	1.6	5.3	1.6	5.3	2.7	3.8	3.4
Material Failure	1970	8.0	16.1	3.0	0.0	16.0	3.4	0.0	8.7
	1971	27.3	31.1	22.2	12.0	20.4	6.3	5.9	17.5
	1972	4.4	22.7	15.9	9.6	13.1	3.2	5.2	11.2
	1973	14.0	11.1	18.4	14.5	9.2	5.5	5.1	10.2

(Table continued on following page)

TABLE 2.26 continued

Percentage of Leaks by Cause and by Decade of Construction

Distribution Mains

		Decade of Construction							
Cause	Year	Unknown	--29	30-39	40-49	50-59	60-69	70--	Total
Other	1970	6.0	0.0	6.1	0.0	1.3	3.4	21.4	3.4
	1971	0.0	4.0	0.0	4.0	2.2	0.0	9.8	2.9
	1972	8.9	4.0	2.3	0.0	1.2	1.6	3.4	2.8
	1973	6.0	4.8	7.9	4.9	5.2	6.8	3.8	5.4
Total		100%	100%	100%	100%	100%	100%	100%	100%

TABLE 2.27

Percentage of Leaks by Cause and Decade of Construction

Distribution Services
Individual Failure Report Data

		Decade of Construction							
Cause	Year	Unknown	--29	30-39	40-49	50-59	60-69	70--	Total
Corrosion	1970	13.8	38.1	41.7	12.9	19.0	5.1	0.0	14.2
	1971	16.4	13.1	43.5	27.9	10.5	3.8	0.0	12.8
	1972	11.6	25.0	25.0	23.3	19.1	5.7	1.3	12.1
	1973	4.4	32.1	35.7	21.6	19.2	12.4	2.4	12.7
Outside Force	1970	74.1	57.1	33.3	83.9	66.7	89.9	88.2	76.5
	1971	72.6	52.2	47.8	67.4	77.6	81.7	77.5	73.3
	1972	71.0	60.0	67.8	70.1	73.4	78.9	88.0	75.8
	1973	79.1	53.6	64.3	64.9	61.6	76.2	82.3	72.7
Construction Defect	1970	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.4
	1971	1.4	0.0	4.4	0.0	2.6	2.9	5.0	2.4
	1972	0.0	0.0	0.0	0.0	0.0	0.8	4.0	0.9
	1973	0.0	0.0	0.0	2.7	2.7	2.1	2.4	1.7
Material Failure	1970	3.5	0.0	16.7	0.0	0.0	2.5	0.0	2.4
	1971	2.7	21.7	0.0	4.7	1.4	5.8	10.0	5.2
	1972	2.9	10.0	3.6	3.3	4.3	7.3	2.7	4.8
	1973	7.7	7.2	0.0	2.7	4.2	5.2	3.5	4.9
Other	1970	8.6	4.8	8.3	3.2	11.9	2.5	11.8	6.5
	1971	6.9	13.0	4.3	0.0	7.9	5.8	7.5	6.3
	1972	14.5	5.0	3.6	3.3	3.2	7.3	4.0	6.4
	1973	8.8	7.1	0.0	8.1	12.3	4.1	9.4	8.0
Total		100%	100%	100%	100%	100%	100%	100%	100%

based on data from the individual reports. Overall, outside force accounts for about 75 percent of the leaks, and corrosion accounts for about 13 percent of the leaks. In the case of pipe installed in the 1940's corrosion accounts for about 21 percent of the leaks (12.9 percent to 27.9 percent) and outside force accounts for about 72 percent of the leaks (64.9 percent to 83.9 percent).

Again, the fact that the data in the table are expressed in percentages limits the type of conclusions that can be drawn. The conclusion that the percentage of leaks due to outside force decreases with age may have been influenced by the corrosion leak rate's increasing with age. Hence, in older pipe the higher leak rate due to corrosion means a higher percentage of leaks caused by corrosion. Since, for any given year and a particular decade of construction, the sum of the percentages of leaks by the various causes must equal 100, a higher percentage of corrosion leaks means a lower percentage of leaks due to all other causes. Thus, leak rates (not percentages) must be examined before any conclusions concerning trends in causes of leaks can be made.

In summary, for service distributions, outside force accounts for 75 percent of all leaks; corrosion, 13 percent of all leaks; material failure, about 4 percent of all leaks; construction defects, about 1 percent of all leaks; and all other causes account for only about 7 percent of all leaks.

Table 2.28 gives a breakdown of percentage of leaks by cause for decade of construction and an overall total for transmission systems, based on data from the individual reports. Overall, outside force accounts for about 54 percent of the leaks. About 19 percent of the leaks are due to material failure, and another 15 percent of the leaks are due to corrosion. However, a given decade of construction may have a different breakdown of percentages. For example, for pipe installed in the 1950's, outside force accounts for about 42 percent of the leaks (from 35.5 percent to 45.5 percent) while material failure accounts for about 30 percent of the leaks (from 23.7 percent to 36.4 percent) and leaks due to corrosion comprise about 13 percent (from 7.6 percent to 18.4 percent) of all leaks.

Conclusions that can be drawn from the table are limited. For instance, the percentages of leaks due to outside force for the 1950's are

TABLE 2.28

Percentage of Leaks by Cause and Decade of Construction

Transmission Systems
Individual Failure Report Data

Cause	Year	Decade of Construction: Unknown	--29	30-39	40-49	50-59	60-69	70--	Total
Corrosion	1970	12.7	15.1	35.1	29.0	7.6	7.3	0.0	15.3
	1971	2.3	16.4	19.2	25.0	10.5	11.6	0.0	13.6
	1972	0.0	22.2	25.0	22.6	18.4	20.7	0.0	17.8
	1973	9.0	18.5	27.8	7.1	16.5	5.5	0.0	13.3
Outside Force	1970	57.8	62.2	51.4	48.4	45.4	53.7	66.7	53.9
	1971	63.6	63.6	63.5	54.2	35.5	49.3	11.1	52.1
	1972	75.5	66.7	51.8	39.6	44.7	46.5	37.5	52.8
	1973	73.0	60.0	53.7	52.4	44.7	60.3	60.0	56.9
Construction Defect	1970	7.0	1.9	8.1	6.5	6.1	12.2	11.1	6.8
	1971	2.3	3.6	5.8	0.0	15.8	1.5	11.1	5.7
	1972	0.0	3.2	3.6	5.7	9.2	3.5	0.0	4.3
	1973	4.5	3.1	3.7	2.4	7.8	4.1	4.0	4.7
Material Failure	1970	16.9	15.1	0.0	16.1	36.4	12.2	0.0	17.5
	1971	15.9	5.5	9.6	18.7	34.2	27.5	55.6	21.0
	1972	6.1	3.2	10.7	28.3	23.7	22.4	25.0	16.5
	1973	9.0	16.9	11.1	28.6	26.2	27.4	28.0	20.7
Other	1970	5.6	5.7	5.4	0.0	4.5	14.6	22.2	6.5
	1971	15.9	10.9	1.9	2.1	4.0	10.1	22.2	7.6
	1972	18.4	4.7	8.9	3.8	4.0	6.9	37.5	8.6
	1973	4.5	1.5	3.7	9.5	4.8	2.7	8.0	4.4
Total		100%	100%	100%	100%	100%	100%	100%	100%

lower than for other decades. It would then be an improper interpretation of the data to conclude that leaks due to outside forces are less likely to occur in pipes installed in the 1950's than for pipes installed in other decades. This limitation should be kept in mind when analyzing the percentage breakdown of cases of leaks for pipe installed in the 1970's, since in some cases there are dramatic variations in the data from one year's report to the next. In particular, the fact that no corrosion leaks were reported for pipe installed in the 1970's means that, for any given year, the sum of the percentages of leaks by all non-corrosion causes for pipe installed in the 1970's would be 100 percent. Hence, these other causes would have higher percentage values.

In summary, for transmission pipelines, 54 percent of the leaks are due to outside force, 19 percent are due to material failure, 15 percent are due to corrosion, about 5 percent of the leaks are accounted for by construction defects, and "other" causes account for 7 percent of all leaks.

Table 2.29 combines Table 2.26 (mains) and Table 2.27 (services) to give an overall analysis of distribution systems with a breakdown of leaks by cause in each decade of construction. The purpose of this combined analysis is to allow a direct comparison between the data based on individual reports (Table 2.29) and the data based on annual reports (Table 2.47). These two tables have comparable formats.

The percentages in Table 2.29 are not drastically different from the values in Tables 2.26 and 2.27. Therefore, we can say that Table 2.29 is similar to both Tables 2.26 and 2.27.

The four-year averages of various causes under "Total" are approximately 15.0 percent for corrosion, about 70 percent for outside force, 1.6 percent for construction defects, 8.2 percent for material failures, and 5 percent for other causes.

TABLE 2.29

Percentage of Leaks by Cause and Decade of Construction

Distribution Mains and Services
Individual Failure Report Data

			Decade of Construction						
Cause	Year	Unknown	--29	30-39	40-49	50-59	60-69	70--	Total
Corrosion	1970	15.7	26.0	26.6	21.2	19.7	8.0	0.0	16.7
	1971	14.2	15.5	37.3	28.0	13.0	8.2	0.0	14.4
	1972	9.6	22.1	23.6	26.8	19.1	7.0	0.7	13.8
	1973	6.4	30.8	28.8	24.2	21.5	12.3	1.8	15.2
Outside Force	1970	71.3	61.0	60.0	77.3	63.2	84.8	83.8	72.0
	1971	69.8	46.3	45.7	61.3	67.5	80.9	79.1	67.3
	1972	73.7	53.7	62.5	64.6	69.1	80.1	88.0	72.3
	1973	74.5	52.7	48.1	57.6	59.1	74.9	84.1	67.9
Construction Defect	1970	0.0	0.0	0.0	0.0	1.7	1.4	0.0	0.7
	1971	0.9	3.1	1.7	0.0	3.0	1.6	4.4	2.1
	1972	0.9	0.0	0.0	0.0	1.1	1.6	3.8	1.3
	1973	1.4	1.1	3.8	2.0	4.0	2.3	3.1	2.5
Material Failure	1970	5.6	11.7	6.7	0.0	10.3	2.9	0.0	5.8
	1971	10.4	28.9	13.6	8.6	11.8	6.0	7.7	11.7
	1972	3.5	20.0	11.1	7.3	8.4	5.9	3.8	7.9
	1973	9.9	9.9	13.5	10.1	6.7	5.3	4.3	7.7
Other	1970	7.4	1.3	6.7	1.5	5.1	2.9	16.2	4.8
	1971	4.7	6.2	1.7	2.1	4.7	3.3	8.8	4.5
	1972	12.3	4.2	2.8	1.3	2.3	5.4	3.7	4.7
	1973	7.8	5.5	5.8	6.1	8.7	5.2	6.7	6.7
Total		100%	100%	100%	100%	100%	100%	100%	100%

2.2.8 Individual Failure Reports--Analyses of Leak Rate due to Third Party Damage versus Age of Pipeline

The analyses of leak rate due to third party damage versus age of the pipeline are presented in this section.

Table 2.30 gives leak rates caused by third party damage on distribution mains, broken down by the decade of construction. For example, during 1972, for mains constructed in the 1950's, there were 0.27 individually reported leaks per 1,000 miles of main caused by third party damage. The purpose of this table is to examine whether there is some correlation between the age of the pipe and the third party damage leak rate.

Again, the Duncan Multiple Range Test proved useful in determining whether age has a significant effect. The data shows a general increase in the leak rate with age, except for the 1970's. Indeed, at the $\alpha = 0.05$ level, the test shows that, as a group, the systems installed in the 1950's and '60's have significantly lower leak rates than those constructed in the 1920's, '30's, '40's, and '70's.

There are several possible explanations for this sudden increase in leak rate in the 1970's. It may be that recently installed mains tend to be in new construction areas and densely populated areas, and are more likely, therefore, to be damaged by outside force. Another explanation might be that recently installed mains are more often made of plastic material which appears to be more susceptible to damage by outside force. The higher leak rates for the 1920's, '30's, and '40's might be explained by the fact that the older the line, the more likely it is to be poorly marked and/or unmapped.

In summary, there is some relationship between the age of the pipe and the third party damage leak rate.

Table 2.31 gives the third party damage leak rates on distribution services broken down by the decade of construction. The purpose of the data, like the data in Table 2.30, is to find how the age of the system is related to the occurrence of third party damage.

In this system, the leak rates of the pipe constructed during 1930 are higher than those during 1970 but there is no statistically significant difference at the $\alpha = 0.05$ level. However, the test confirms that the '30's and '70's' leak rates are higher than those of the other decades.

TABLE 2.30

Leak Rate Due to Third Party Damage by Decade of Construction

Distribution Mains

Individual Failure Report Data

Measure: Leaks per year per 1,000 miles of pipe

	Decade of Construction					
	1	2	3	4	5	6
Year	---29	30-39	40-49	50-59	60-69	70---
1970	0.68	0.73	0.46	0.32	0.22	0.51
1971	0.36	0.45	0.49	0.31	0.25	0.84
1972	0.60	0.56	0.49	0.27	0.17	0.68
1973	0.64	0.34	0.55	0.22	0.19	0.66
MEAN	0.57	0.52	0.50	0.28	0.21	0.67

Standard Error of Mean = 0.054

Degrees of Freedom = 18

Duncan Multiple Range Analysis

6	1	2	3	4	5	α = .05
0.67	0.57	0.52	0.50	0.28	0.21	

6	1	2	3	4	5	α = .01
0.67	0.57	0.52	0.50	0.28	0.21	

TABLE 2.31

Leak Rate Due to Third Party Damage by Decade of Construction

Distribution Services

Individual Failure Report Data

Measure: Leaks per year per 100,000 services

	Decade of Construction					
	1	2	3	4	5	6
Year	---29	30-39	40-49	50-59	60-69	70---
1970	1.06	0.14	0.69	0.26	0.49	0.73
1971	0.86	0.46	0.58	0.43	0.35	0.59
1972	0.79	0.83	0.35	0.44	0.36	0.87
1973	0.95	0.36	0.39	0.27	0.27	0.82
MEAN	0.91	0.45	0.50	0.35	0.37	0.75

Standard Error of Mean = 0.080

Degrees of Freedom = 18

Duncan Multiple Range Analysis

1	6	3	2	5	4	$\alpha = .05$
0.91	0.75	0.50	0.45	0.37	0.35	

1	6	3	2	5	4	$\alpha = .01$
0.91	0.75	0.50	0.45	0.37	0.35	

2.2.9 Individual Failure Reports--Analyses of Leak Rates for Metallic versus Plastic Pipe

This section presents four different areas of analyses as related to the overall comparison of leak rate and safety for metallic versus plastic pipe. These four areas of leak rate analyses are as follows:

1. Overall leak rates for metallic versus plastic pipe
2. Equipment-caused (usually excavation) leak rates for metallic versus plastic pipe
3. Time required to stop the flow of gas after a leak in metallic versus plastic pipe
4. Injuries, deaths, and property damage over $500 for leaks in metallic versus plastic pipe

2.2.9.1 Comparison of Overall Leak Rates for Metallic versus Plastic Pipe

Table 2.32 gives a leak rate comparison for metallic and plastic pipe in distribution mains. The leak data comes for the individual report and the mileage figures for metallic and plastic pipe come from the annual report. A similar comparison is done for fittings even though the unit of leak rate (leaks per 1,000 miles of pipe per year) may not be appropriate for parts other than pipe itself.

Metallic materials consist of steel, cast iron, ductile iron, wrought iron and copper. It is obvious in the table that the metallic type has a lower leak rate than the plastic type in the leaks on pipe. For fittings, little can be said about the comparison because the reported numbers are so small.

For a statistical test, a simple test of two means from normal distributions ("t"-test) was used. The test showed that a significant difference exists in the leak rates of metallic and plastic pipe at the $\alpha = 0.05$ level. It is noted that, although the metallic materials in aggregate give significantly lower leak rates than the plastic material, this does not necessarily mean that any particular metallic pipe (copper pipe, for example) yields lower leak rates than the plastic.

TABLE 2.32

Comparison in Leak Rate Between Metallic and Plastic Systems

Distribution Mains

Individual Failure Report Data

Measure: Leaks per 1,000 miles of pipe

Year	Part	No. and Rate	Metallic	Plastic
1970	Pipe	No. Leaks Leak Rate	230 0.421	19 0.91
	Fitting	No. Leaks Leak Rate	21 0.038	1 0.05
1971	Pipe	No. Leaks Leak Rate	324 0.537	38 1.36
	Fitting	No. Leaks Leak Rate	23 0.038	0 0.0
1972	Pipe	No. Leaks Leak Rate	304 0.493	50 1.52
	Fitting	No. Leaks Leak Rate	31 0.050	4 0.12
1973	Pipe	No. Leaks Leak Rate	313 0.501	58 1.41
	Fitting	No. Leaks Leak Rate	28 0.045	3 0.07

Table 2.33 shows the leak rates for metallic and plastic pipes and fittings in distribution services. As with distribution mains, plastic pipe shows higher leak rates than metallic pipe. The existence of a significant difference was indicated by the "t-test" performed on this data. For fittings, there does not appear to be any significant difference in leak rates and because of the small number of reported leaks, a statistical test was not performed.

2.2.9.2 Comparison of Equipment-Caused Leak Rates for Metallic versus Plastic Pipe

Table 2.34 compares the equipment-caused (usually excavation) leak rates (leaks per 1,000 miles of pipe per year) for three material types used for distribution mains. The leak data is based on reported leaks caused by equipment operated by the company operator or by an outside party. The data associated with several metals--such as copper, wrought iron, and ductile iron--were so sparse that it was ignored in this analysis.

The table shows that the plastic parts had more leaks on a per 1,000 mile basis in all three years. On the other hand, steel and cast iron do not show any appreciable difference in their leak rates. The Duncan Multiple Range Test supports this observation. It shows, at both the α = 0.05 and α = 0.01 levels, that there is a significant difference in leak rates between plastic and metals (steel and cast iron). But, steel and cast iron do not differ significantly from each other.

In summary, plastic systems appear to be more susceptible to equipment-caused damage than metallic systems.

Table 2.35 is similar to Table 2.34, but is for distribution services. For this table, the data for cast iron, wrought iron, and ductile iron were ignored because of its sparseness.

As was also observed in Table 2.34, plastic systems have higher leak rates from equipment-caused damage. The Range test verifies this at both α levels. Also, based on the available data, one cannot detect any difference in leak rates between steel and copper.

In conclusion, plastic systems have a higher equipment-caused leak rate than metallic systems.

TABLE 2.33

Comparison in Leak Rate Between Metallic and Plastic Systems

Distribution Services

Individual Failure Report Data

Measure: Leaks per 100,000 services

Year	Part	No. and Rate	Metallic	Plastic
1970	Pipe	No. Leaks Leak Rate	141 0.458	23 1.72
	Fitting	No. Leaks Leak Rate	39 0.127	1 0.08
1971	Pipe	No. Leaks Leak Rate	160 0.475	35 1.87
	Fitting	No. Leaks Leak Rate	71 0.211	7 0.37
1972	Pipe	No. Leaks Leak Rate	183 0.609	43 1.90
	Fitting	No. Leaks Leak Rate	80 0.266	5 0.22
1973	Pipe	No. Leaks Leak Rate	170 0.479	60 1.88
	Fitting	No. Leaks Leak Rate	59 0.166	4 0.13

TABLE 2.34

Equipment-Caused Leaks by Material Type

Distribution Mains

Individual Failure Report Data

Measure: Leaks per year per 1,000 miles of pipe

	Material		
	1	2	3
Year	Steel	Plastic	Cast Iron
1970	0.27	0.86	0.29
1971	0.28	0.96	0.25
1972	0.25	1.36	0.22
1973	0.26	1.07	0.30
MEAN	0.26	1.06	0.26

Standard Error of Mean = 0.063

Degrees of Freedom = 9

Duncan Multiple Range Analysis

2	3	1	$\alpha = .05$
1.06	<u>0.26</u>	<u>0.26</u>	

2	3	1	$\alpha = .01$
1.06	<u>0.26</u>	<u>0.26</u>	

TABLE 2.35

Equipment-Caused Leaks by Material Type

Distribution Services

Individual Failure Report Data

Measure: Leaks per year per 100,000 services

	Material		
	1	2	3
Year	Steel	Plastic	Copper
1970	0.38	1.27	0.27
1971	0.34	0.91	0.22
1972	0.39	1.50	0.35
1973	0.28	1.19	0.26
MEAN	0.35	1.22	0.27

Standard Error of Mean = 0.073

Degrees of Freedom = 9

Duncan Multiple Range Analysis

2	1	3	$\alpha = .05$
1.22	0.35	0.27	

2	1	3	$\alpha = .01$
1.22	0.35	0.27	

2.2.9.3 Comparison of Time to Stop a Leak in Metallic versus Plastic Pipe

Table 2.36 gives the distribution of stoppage times for metallic and plastic distribution mains. Stoppage time is defined, in this analysis, as the time from the detection of a leak until it is stopped.

In this table, the stoppage times come from the 1973 individual reports. The distributions in 1970, 1971, and 1972 reports are not significantly different from the distribution in 1973 reports, and therefore, examining 1973 data alone serves our purpose.

The table gives both percentage of total leaks for each time interval and its cumulative value, for both plastic and metallic. Comparing the two materials indicates that plastic system leaks are, in most cases, stopped more quickly than metallic systems. For plastic systems, 77 percent of all leaks are stopped in less than two hours, and all but a small percentage are stopped in less than four hours. In metallic systems, only about 47 percent of the leaks are stopped in less than two hours, and about 77 percent of the leaks are stopped in less than five hours. Approximately 6 percent of the leaks are not stopped for over twelve hours from the time of being reported. The mean and standard deviation of the metallic system leaks are relatively large. This is because a few of the leaks had very long stoppage times.

In summary, one can conclude that leaks in plastic mains are generally shut off quicker.

Table 2.37 gives an analysis similar to Table 2.36 on stoppage times of metallic and plastic pipe systems in distribution services. When this table is compared to Table 2.36, it is found that less time is taken to stop the leaks in services than the leaks in mains. This is true for both material types.

A comparison of the times for plastic and metallic systems indicates that leaks in plastic systems are stopped faster than leaks in metallic systems, as was the case in distribution mains. Almost 84 percent of the plastic system leaks were stopped within 2 hours. For metallic systems, approximately 74 percent of the leaks were stopped in 2 hours, and 3.6 percent of the leaks were not repaired for over 8 hours.

In summary, plastic systems in distribution services compare favorably to metallic systems in terms of leak stoppage time.

TABLE 2.36

Analysis of Times to Stop Leaks

Distribution Mains

Individual Failure Report Data

Stoppage Time	Metallic		Plastic	
Range (Hours)	% Total	% Cumulative	% Total	% Cumulative
Less than 1	20.1	20.1	38.7	38.7
1 - 2	27.1	47.2	32.3	71.0
2 - 3	15.7	62.9	16.1	87.1
3 - 4	10.8	73.7	6.5	93.6
4 - 5	5.1	78.8	1.6	95.2
5 - 6	4.1	82.9	(Over 5)- 4.8%	100.0%
6 - 7	4.1	87.0		
7 - 8	2.4	89.4		
8 - 9	1.6	91.0		
9 - 10	0.8	91.8		
10 - 11	1.1	92.9		
11 - 12	1.4	94.3		
Over 12	5.7%	100.0%		

	Metallic	Plastic
Number of Leaks	369	62
Mean Time	4.64 hrs.	1.56 hrs.
Standard Deviation	11.8 hrs.	1.37 hrs.

TABLE 2.37

Analysis of Times to Stop Leaks

Distribution Services

Individual Failure Report Data

Stoppage Time	Metallic		Plastic	
Range (Hours)	% Total	% Cumulative	% Total	% Cumulative
Less than 1	47.1	47.1	55.9	55.9
1 - 2	27.2	74.3	27.9	83.8
2 - 3	11.0	85.3	8.8	92.6
3 - 4	2.6	87.9	(Over 3)- 7.4%	100.0%
4 - 5	4.8	92.7		
5 - 6	1.5	94.2		
6 - 7	1.1	95.3		
7 - 8	1.1	96.4		
Over 8	3.6%	100.0%		

	Metallic	Plastic
Number of Leaks	272	68
Mean Time	1.87 hrs.	1.11 hrs.
Standard Deviation	3.15 hrs.	0.96 hrs.

2.2.9.4 Comparison of Individual Failure Reports, Injuries, Deaths, and Property Damage Over $500 for Metallic versus Plastic Pipe

Table 2.38 compares metallic and plastic pipe in distribution mains on the basis of four measures: (1) number of reported leaks, (2) number of injuries, (3) number of deaths, and (4) number of incidences involving property damage over $500. Each of these measures is normalized to a common base, per 1,000 miles of pipe per year.

In examining the number of reported leaks, it appears clear that plastic systems in mains always have a greater number of leaks on a rate basis than do metallic systems. A statistical test of means ("t"-test) verifies this observation at the $\alpha = 0.05$ level. Based on the data that are available now, plastic systems generally appear to have a higher rate of reported leaks than metallic systems.

The other three measures involving injuries, deaths, and property damage have a wide variation compared to the average values, so that no differences between metallic and plastic can be seen.

The analysis in Table 2.39 concerns distribution services, but otherwise, it is similar to that in Table 2.38. Here the four measures are normalized to a base of per 100,000 services. As in Table 2.38, the measures involving injuries, deaths, and property damage have such a large variance in relation to their means that no differences between metallic and plastic can be seen.

In examining the individually reported leak rate (or number of reports per 100,000 services per year), it appears that plastic systems have a higher leak rate, and indeed a statistical test of means indicates a significant difference at the $\alpha = 0.05$ level.

Thus, in terms of the number of leaks reported individually on a per unit basis, plastic systems cause more problems than metallic systems.

TABLE 2.38

Comparison of Individual Reports, Injuries, Deaths, and Operator's Property Damage Over $500

Metallic vs. Plastic Materials

Distribution Mains

Measure: Number reported per 1,000 miles of pipe

Classification	Year	Metallic	Plastic
Individual Reports	1970 1971 1972 1973	0.53 0.63 0.59 0.59	0.96 1.36 1.64 1.51
Injuries	1970 1971 1972 1973	0.14 0.26 0.20 0.25	0.19 0.29 0.24 0.63
Deaths	1970 1971 1972 1973	0.01 0.03 0.01 0.03	0.0 0.0 0.0 0.05
Property Damage Over $500	1970 1971 1972 1973	0.10 0.11 0.15 0.20	0.05 0.11 0.15 0.41

TABLE 2.39

Comparison of Individual Reports, Injuries, Deaths,

and Operator's Property Damage Over $500

Metallic vs. Plastic Materials

Distribution Services

Measure: Number reported per 100,000 services

Classification	Year	Metallic	Plastic
Individual Reports	1970	0.67	1.87
	1971	0.84	2.45
	1972	1.06	2.34
	1973	0.80	2.13
Injuries	1970	0.16	0.23
	1971	0.26	0.69
	1972	0.39	0.13
	1973	0.22	0.50
Deaths	1970	0.01	0.0
	1971	0.02	0.0
	1972	0.06	0.0
	1973	0.01	0.09
Incidents Involving Property Damage Over $500	1970	0.02	0.15
	1971	0.03	0.11
	1972	0.05	0.0
	1973	0.06	0.13

2.2.10 Individual Failure Reports--Analysis of the Circumstances Under Which Leaks Were Caused by Equipment Operated by an Outside Party

Table 2.40 shows the tabulation of the information concerning the circumstances under which leaks were caused by equipment operated by an outside party. The data are taken from Part B, Item 2, of the individual leak reports.

The first column--"Prior Notification"--indicates whether the operator received prior notification from the equipment operator that the area would be excavated. The second column--"Marking"--shows whether the pipeline was marked or identified. The third column--"Statute Requirement"--asks whether the outside party was required by statute or ordinance to determine the location of the pipelines.

The entries in each column are given in percentage of the total number of leaks for that column. For example, the percentage of the leaks blamed on an outside party in mains in 1970, which correspond to "Yes" in all three classifications, is 10.4, or 16 of a total of 154 reported (Case 1). That is, 16 individually reported outside party leaks occurred on mains in 1970 when the outside party gave prior notification, the line was marked, and there was a statute in effect requiring the outside party to locate the line before excavation could begin. On the other hand, 27.3 percent (or 42) of the total leaks in mains correspond to "No" in all three classifications (Case 8). And, in 1970, 7.1 percent of the leaks occurred where there was prior notification but no marking or statute requirement (Case 4).

What one would like to determine from this table is the effect these three factors, working together or independently, have on outside party leak rates. Unfortunately, such an analysis cannot be done because the data cannot be "normalized." To illustrate, consider the data for 1973 mains. We know that 12.7 percent occurred with all three factors working (Case 1), and 28.2 percent occurred when none of the three factors were working (Case 8). However, we do not know how many excavations took place in these categories when no damage occurred. For example, suppose there were 10 times as many excavations by outside parties under Case 8 conditions as compared to Case 1 conditions. If this were true, it would

TABLE 2.40

Three-Way Classification of Leaks Resulting from the Damage by Outside Party

Measure: Percentage of Leaks
Individual Failure Report Data

				System											
	Prior		Statute	Mains				Services				Transmission			
Case	Notification	Marking	Requirement	70	71	72	73	70	71	72	73	70	71	72	73
1	Yes	Yes	Yes	10.4	9.7	7.7	12.7	18.5	15.7	10.6	8.8	1.9	0.9	2.3	0.6
2	Yes	Yes	No	29.3	25.8	24.3	31.5	15.4	15.0	18.4	19.2	14.8	8.5	10.2	10.3
3	Yes	No	Yes	1.3	0.0	.6	1.1	1.5	1.6	0.7	4.0	.9	0.0	0.0	0.0
4	Yes	No	No	7.1	3.4	3.0	3.3	4.6	8.7	4.3	7.2	1.9	0.9	0.0	0.0
5	No	Yes	Yes	1.9	1.1	2.4	2.8	2.3	1.6	2.1	0.0	3.7	2.6	5.5	7.1
6	No	Yes	No	13.0	13.1	18.9	13.8	9.2	10.2	13.5	8.0	59.3	73.5	65.6	64.5
7	No	No	Yes	9.7	5.7	7.1	6.6	8.5	18.1	11.3	10.4	0.0	0.0	3.1	0.6
8	No	No	No	27.3	41.2	36.0	28.2	40.0	29.1	39.1	42.4	17.5	13.6	13.3	16.8
				100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Total Reported			154	175	169	181	130	127	141	125	108	117	128	155

indicate that proportionately fewer leaks occurred under Case 8 conditions than Case 1 conditions. Thus, for such data to be useful in determining the effect of these factors, one would need to know something about the number of incidences of "no leak" under each of the conditions. Unfortunately, such data is not currently available and might be difficult to collect in the future.

2.2.11 Individual Failure Reports--Analysis of Leaks as a Function of the Estimated Percentage of Maximum Allowable Pressure at Point and Time of Leak Incident

Table 2.41 shows the relative percentages of the different estimated pressure levels at the point and time of the leak incident as a percentage of maximum allowable operating pressure for the distribution and the transmission systems. The tabulation is based on the four years of individual leak reports. The purpose of this tabulation is to find the percentage of the incidents where the pressure level at the point and time of the leak, exceeded the maximum allowable level.

In distribution system leaks, the estimated pressure is shown to have exceeded the maximum pressure by less than 10 percent in 13.9 percent of the incidents. In transmission leaks, the figure is 2.4 percent. In only a very small number of incidents did the estimated pressure exceed the maximum by more than 10 percent.

TABLE 2.41

Analysis of the Estimated Pressure at Point and Time of Incident

as Percent of Maximum Allowable Operating Pressure

1970-1973 Leak Reports

Number of reports providing data on pressure levels:

Distribution = 3,223
Transmission = 1,590

Individual Failure Report Forms

Ratio of Estimated Pressure to Maximum--in Percent	Percent of Total Number of Reports: Distribution Leaks	Percent of Total Number of Reports: Transmission Leaks
0 - 20%	4.0%	2.3%
20 - 40	14.3	6.9
40 - 60	25.1	14.3
60 - 80	23.6	33.4
80 - 100	18.4	39.9
100 - 110	13.9	2.4
Over 110%	0.7	0.8
	100%	100%

Average Values of Estimated-Incident/Maximum Allowable:

Distribution = 63.7%
Transmission = 71.5%

2.3 ANALYSIS OF ANNUAL REPORTS

Table 2.42 presents a listing of all data tables prepared in the analysis of annual reports filed by pipeline operators. This listing is presented for reference to the sections that follow covering the various types of analyses which were performed, using annual report data. In many cases the analyses have a parallel to those performed for individual failure report data, as presented earlier in Section 2.2.

Each of the following sections includes the analyses of the transmission and distribution segments of the pipeline system for the particular parameter that is being evaluated for its effect on leak rate and pipeline safety.

The results of each analysis of data are presented as the individual parameters are considered, followed by a summary statement of conclusions. These conclusions are compared in Section 2.4 with those obtained from the analysis of data submitted on the individual failure report forms.

TABLE 2.42

Listing of Data Tables for All Analyses, Prepared from Annual Report Forms

(Forms DOT F 7100.1 -1 and DOT F 7100.2-1)

1	2	3	4	5	6	7	8
No. of Table	Years of Data	Part of System Analyzed	Part Which Leaked	Cause of Leak	Measure of Leaks	Analysis Parameter	Part of Annual Report where Data Obtained
2.43	70-73	Distribution Mains	Pipe	All Types	Leaks/Year/ 1,000 miles of Pipe	Decade of Construction	Part D: NR*
2.44	70-73	Distribution Services	Pipe	All Types	Leaks/Year/ 100,000 Services	Decade of Construction	Part E: NR
2.45	70-73	Transmission	Body of Pipe	All Types	Leaks/Year/ 1,000 miles of Pipe	Decade of Construction	Part D: NR
2.46	70-73	Transmission	Welds	All Types	Leaks/Year/ 1,000 miles of Pipe	Decade of Construction	Part D: NR
2.47	70-73	Gathering	Body of Pipe	All Types	Leaks/Year/ 1,000 miles of Pipe	Decade of Construction	Part E: NR
2.48	70-73	Distribution Mains and Services	All Parts	---	Percent of Total Leaks	Cause of Leak and Decade of Construction	Part F: R** & NR

* "NR" stands for the non-reported leaks.

** "R" stands for the reported leaks.

TABLE 2.42 Listing of Data Tables for All Analyses, Prepared from Annual Report Forms

Continued

1	2	3	4	5	6	7	8
No. of Table	Years of Data	Part of System Analyzed	Part Which Leaked	Cause of Leak	Measure of Leaks	Analysis Parameter	Part of Annual Report where Data Obtained
2.49	70-73	Transmission and Gathering	All Parts	---	Percent of Total Leaks	Cause of Leak and Year of Construction	Part F: R & NR
2.50	70-73	Distribution Mains	---	All types	Percent of Leaks	Part which Leaked and Decade of Construction	Part D: NR
2.51	70-73	Distribution Services	---	All Types	Percent of Leaks	Part which Leaked and Decade of Construction	Part E: NR
2.52	70-73	Transmission	---	All types	Percent of Leaks	Part which Leaked and Decade of Construction	Part D: NR

2.3.1 Annual Report--Analyses Related to Age of Pipeline System

The analyses of leaks and leak rates for various parts of the pipeline system as a function of age of the system are presented in this section.

The purpose of Table 2.43 is to present an analysis of the leaks for distribution mains as a function of the age of the pipe. These leaks were shown on the annual reports for which an individual report was not filed. Analysis of the "non-reported" leaks is important because they account for more than 99 percent of the total leaks reported on the annual report. It was observed in Table 2.12 that the leak rate of the individually reported leaks increases as the pipe becomes older. The same result is seen in this table.

The range test shows that, at the $\alpha = 0.05$ level, the leak rates of pipelines constructed before 1940 are higher than the leak rates for pipelines constructed in the 1940's, and this leak rate in turn is higher than for pipelines constructed in the '50's, '60's and '70's. This pattern of leak rates can partially be explained by the increase in leaks resulting from corrosion in older pipe, with only the leak rate for the '70's not fitting this pattern.

The leaks on pipe of unknown decade of construction are about 25-to-30 percent of the total leaks. However, for statistical analysis of age effect, they are ignored in this table. When such a large portion of data must be ignored in an analysis, it could seriously bias any meaningful statistical analysis. For example, if "unknown" tends to be old pipe, then actual leak rates for old pipe would be much higher than this analysis would show.

Table 2.44 presents an analysis of the non-reported leaks broken down by the decade of construction for distribution services in the same format that Table 2.43 presents for mains.

Again using the $\alpha = 0.05$ level of significance, it can be seen that the leak rate of services constructed in the 1930's is significantly higher than the other decades. The leak rates for services constructed before 1930 and the decade of the '40's do not differ significantly from each other. Likewise, the leak rates of the 1940's, '50's, and '70's do not differ significantly from each other. However, if we group the services constructed

TABLE 2.43

Leak Rate on Pipe by Decade of Construction

Distribution Mains

Annual Report Data

Measure: Leaks per year per 1,000 miles of pipe

	Decade of Construction					
	1	2	3	4	5	6
Year	---29	30-39	40-49	50-59	60-69	70---
1970	468.9	472.1	362.4	184.0	136.5	314.4
1971	929.1	724.7	474.8	219.8	71.2	151.5
1972	727.0	629.1	472.2	206.8	60.0	111.0
1973	810.9	755.7	500.8	218.8	64.2	120.0
MEAN	734.0	645.4	452.1	207.4	83.0	174.2

Standard Error of Mean = 53.5

Degrees of Freedom = 18

Duncan Multiple Range Analysis

1	2	3	4	6	5	$\alpha = 0.05$
734.0	645.4	452.1	207.4	174.2	83.0	

1	2	3	4	6	5	$\alpha = 0.01$
734.0	645.4	452.1	207.4	174.2	83.0	

TABLE 2.44

Leak Rate on Pipe by Decade of Construction

Distribution Services
Annual Report Data

Measure: Leaks per year per 100,000 services

	Decade of Construction					
	1	2	3	4	5	6
Year	---29	30-39	40-49	50-59	60-69	70---
1970	556.1	680.4	419.3	260.6	229.1	478.3
1971	848.0	1179.9	789.9	457.8	260.3	519.6
1972	972.2	1234.4	851.9	580.0	269.1	400.6
1973	997.9	1414.4	909.9	521.4	309.8	460.3
MEAN	843.6	1127.3	742.8	455.0	267.1	464.7

Standard Error of Mean = 93.9

Degrees of Freedom = 18

Duncan Multiple Range Analysis

2	1	3	6	4	5	$\alpha = 0.05$
1127.3	843.6	742.8	464.7	455.0	267.1	

2	1	3	6	4	5	$\alpha = 0.01$
1127.3	843.6	742.8	464.7	455.0	267.1	

in the 1920's, '30's, and '40's together (calling it "older" pipe) and group the services constructed in the 1950's, '60's, and '70's together (calling it "newer" pipe), then the leak rates for older pipe are significantly higher than for newer pipe.

Even though the observed differences in leak rates seem quite large, the lack of more statistically significant differences can be attributed to the large year-to-year variance in the data for some decades. This variance is caused primarily by the large differences in leak rates reported for the year of 1970 as compared to the three subsequent years.

Here again, leaks in services of unknown construction date, account for a large portion of the data--from 25-to-37 percent in various years.

Table 2.45 gives the breakdown of leak rate on the body of the pipe by decade of construction in transmission systems (excluding gathering). The average leak rates for pipelines constructed in the 1920's and the '30's appear much higher than the leak rates of pipelines constructed in the subsequent decades.

The range test for an $\alpha = 0.05$ significance level shows that pipelines constructed in the 1920's and the '30's have significantly higher leak rates than pipelines constructed in other decades, and that they are also different from each other. No significant differences exist in leak rate among the decades after 1940.

The analysis in Table 2.46 is presented to show whether the age of the pipe is related to the leaks originating from welds on the pipe in transmission systems. The range test shows that pipelines constructed in the '30's have a significantly higher leak rate on welds than pipelines constructed after 1940. The leak rate on welds for pipelines constructed in the '20's and '30's do not differ significantly.

Table 2.47 is similar to Table 2.45 except that the gathering system is considered instead of the transmission system. All of the non-reported leaks considered in this table originate from the body of the pipe. The average leak rate of pipelines constructed in each decade is found to increase as the pipeline gets older, except for the pipelines constructed in the 1970's, which have a higher than expected leak rate.

While the average leak rates do generally increase with age, the Duncan Multiple Range Test indicates that at the $\alpha = 0.05$ confidence level, pipe constructed prior to 1930 has a significantly higher leak rate than the other decades. The leak rates for the 1930's, '40's and '70's are not significantly different, and neither are the leak rates for the 1940's through the '70's as a group. This lack of statistical significance between the leak rates for each decade, even when there is an apparent trend in the data, is due to the large variance in the data for each of the four reporting years. For example, notice that for pipelines constructed in the 1970's, the leak rates vary from 485.9 to 14.4.

TABLE 2.45

Leak Rate on Body of Pipe by Decade of Construction

Transmission Systems

Measure: Leaks per year per 1,000 miles of pipe

Annual Report Data

	Decade of Construction					
	1	2	3	4	5	6
Year	---29	30-39	40-49	50-59	60-69	70---
1970	511.7	139.0	39.4	10.3	15.0	73.5
1971	364.0	126.7	54.6	15.2	10.4	62.9
1972	477.4	117.8	68.2	11.2	5.7	8.4
1973	478.6	127.7	45.9	14.6	5.9	7.9
MEAN	457.9	127.8	52.0	12.8	9.3	38.2

Standard Error of Mean = 15.3

Degrees of Freedom = 18

Duncan Multiple Range Analysis

1	2	3	6	4	5	$\alpha = 0.05$
457.9	127.8	52.0	38.2	12.8	9.3	

1	2	3	6	4	5	$\alpha = 0.01$
457.9	127.8	52.0	38.2	12.8	9.3	

TABLE 2.46

Leak Rate on Welds by Decade of Construction

Transmission Systems

Measure: Leaks per year per 1,000 miles of pipe

Annual Report Data

	Decade of Construction					
	1	2	3	4	5	6
Year	---29	30-39	40-49	50-59	60-69	70---
1970	4.2	8.1	4.9	1.9	2.6	4.0
1971	2.6	7.2	3.3	1.5	1.9	4.1
1972	6.1	3.3	3.5	1.9	1.7	2.3
1973	4.1	5.3	2.4	1.4	1.1	3.2
MEAN	4.3	6.0	3.5	1.7	1.8	3.4

Standard Error of Mean = 0.61

Degrees of Freedom = 18

Duncan Multiple Range Analysis

2	1	3	6	5	4	$\alpha = 0.05$
6.0	4.3	3.5	3.4	1.8	1.7	

2	1	3	6	5	4	$\alpha = 0.01$
6.0	4.3	3.5	3.4	1.8	1.7	

TABLE 2.47

Leak Rate on Body of Pipe by Decade of Construction

Gathering Systems

Measure: Leaks per year per 1,000 miles of pipe

Annual Report Data

	Decade of Construction					
	1	2	3	4	5	6
Year	---29	30-39	40-49	50-59	60-69	70---
1970	598.3	219.1	251.0	62.0	128.5	485.9
1971	509.4	177.0	149.7	83.4	33.4	311.7
1972	774.0	464.6	238.4	120.9	28.1	71.9
1973	597.4	366.6	285.3	114.4	43.4	14.4
MEAN	619.8	306.8	231.1	95.2	58.4	221.0

Standard Error of Mean = 59.2

Degrees of Freedom = 18

Duncan Multiple Range Analysis

1	2	3	6	4	5	$\alpha = 0.05$
619.8	306.8	231.1	221.0	95.2	58.4	

1	2	3	6	4	5	$\alpha = 0.01$
619.8	306.8	231.1	221.0	95.2	58.4	

2.3.2 Annual Report--Analyses Related to Cause of Pipeline System Leaks

The analyses of the causes of leaks reported for the distribution, transmission, and gathering portions of pipeline system operations, are presented in this section.

Table 2.48 classifies the leaks in distribution systems by cause for each decade of construction of the pipe. The data comes from Part F of the annual report for distribution systems. The numbers in each column indicate the relative frequency of leaks for four major causes of leaks, with the remaining data shown as "other" causes. For example, in the systems constructed in the 1960's, the leaks are caused by corrosion about 28 percent of the time, by outside forces about 23 percent of the time, and by construction defects and material failures about 10 percent and 14 percent of the time, respectively.

The annual report form does not separate mains and services in Part F, and mains are measured in miles, and services in number of services. For this reason only "percentages" can be calculated, not leak "rates." Thus, little can be said, in explicit terms, of the relative ranking among the decades.

Table 2.49 shows an analysis of the repaired leaks in transmission/gathering systems by cause for each time interval in which a pipe system was installed. Notice the difference in the size of time interval between Tables 2.48 and 2.49.

The data shows that corrosion is the most important cause of non-reported leaks in transmission pipelines, accounting for approximately 77 percent of the total leaks. The next most important cause of leaks is material failure which accounts for about 10 percent of total leaks. Leaks produced by outside forces are only 3 percent of total leaks. The comparison of this data with the corresponding data in the individual reports is a point of interest, and is taken up in the discussion found in Section 2.4 of this chapter. The same limitations in data analysis occur as with Table 2.48 in that no statistical tests can be performed on such percentage data.

TABLE 2.48

Classification of Leaks by Cause for Each Decade of Construction
Distribution Systems
Annual Report Data

			Decade of Construction						
	Year	Unknown	--29	30-39	40-49	50-59	60-69	70--	Total
Corrosion	1970	44.1	49.8	64.6	62.9	54.0	31.8	35.5	46.8
	1971	40.9	46.8	65.5	58.8	48.5	27.6	18.3	43.4
	1972	41.2	49.2	65.3	64.3	54.3	26.7	20.5	45.2
	1973	44.8	51.2	65.4	64.3	54.1	27.2	10.7	45.4
Outside Force	1970	15.9	7.2	5.8	7.2	11.9	23.9	23.3	14.5
	1971	15.0	9.7	7.2	8.4	11.8	23.6	37.0	15.2
	1972	14.2	6.2	7.0	7.2	9.3	19.2	37.9	13.2
	1973	13.8	6.3	8.3	7.2	9.5	19.1	41.1	13.9
Construction Defect	1970	3.1	1.2	1.4	2.5	4.4	8.3	10.1	4.3
	1971	6.4	1.6	2.1	3.4	5.5	8.2	9.5	5.3
	1972	4.2	1.8	3.1	4.4	6.5	12.4	10.8	5.9
	1973	6.1	1.8	3.4	4.2	6.3	11.6	10.2	6.2
Material Failure	1970	10.2	10.5	7.2	8.3	9.9	12.4	12.0	10.3
	1971	9.6	11.1	7.0	8.6	10.8	12.8	8.8	10.2
	1972	8.8	9.8	7.5	7.1	9.4	14.8	8.7	9.7
	1973	9.7	10.1	7.8	7.8	9.8	15.6	10.5	10.5

(Table continued on following page)

TABLE 2.48 Continued

Classification of Leaks by Cause for Each Decade of Construction

Distribution Systems

Decade of Construction

	Year	Unknown	--29	30-39	40-49	50-59	60-69	70--	Total
Other	1970	26.7	31.3	21.0	19.1	19.8	23.6	19.1	24.1
	1971	28.1	30.8	18.2	20.8	23.4	27.8	26.4	25.9
	1972	31.6	33.0	17.1	17.0	20.5	26.9	22.1	26.0
	1973	25.6	30.6	15.1	16.5	20.3	26.5	27.5	24.0
Total		100%	100%	100%	100%	100%	100%	100%	100%

TABLE 2.49

Classification of Leaks by Cause for Each Decade of Construction

Transmission/Gathering Systems
Annual Report Data

			Decade of Construction					
	Year	Unknown	--59	60-64	65-67	68-69	70--	Total
Corrosion	1970	76.4	80.0	50.9	65.3	84.4	76.6	78.4
	1971	65.7	80.2	56.2	58.4	65.3	78.7	73.7
	1972	79.4	81.6	56.9	56.3	28.6	58.8	78.8
	1973	80.5	80.1	62.4	59.5	42.6	39.2	78.1
Outside Force	1970	2.5	1.6	12.1	9.2	4.4	5.9	2.6
	1971	1.6	3.2	10.0	11.1	10.7	8.0	3.4
	1972	2.9	1.8	8.9	7.8	17.1	10.2	2.8
	1973	2.7	2.2	16.8	12.6	11.8	13.3	3.2
Construction Defect	1970	0.7	1.4	12.2	8.6	3.9	2.9	1.7
	1971	0.7	2.0	10.8	10.5	6.2	2.1	2.0
	1972	0.9	2.1	9.6	8.4	17.4	10.2	2.6
	1973	0.6	1.3	5.4	8.5	9.1	16.9	1.8
Material Failure	1970	0.2	10.1	17.1	11.8	3.9	8.0	7.6
	1971	19.4	10.3	10.6	13.8	12.3	5.8	13.4
	1972	7.6	8.4	15.7	11.4	10.1	11.8	8.6
	1973	12.7	7.2	7.5	6.2	13.3	11.9	8.6
Other	1970	18.2	6.9	7.7	5.1	3.4	6.6	9.7
	1971	12.6	4.3	12.4	6.2	5.5	5.4	7.5
	1972	9.2	6.1	8.9	16.1	26.8	9.0	7.2
	1973	3.5	9.2	7.9	13.3	23.2	18.7	8.3
Total		100%	100%	100%	100%	100%	100%	100%

2.3.3 Annual Report--Analyses of Part of Pipeline System Where Leaks Occurred

The analyses of the part of the pipeline system which failed and produced a leak are presented in this section.

Table 2.50 gives a breakdown of leaks for distribution mains by the part which failed for each decade of construction and an overall total. For example, the overall total shows that about 71 percent of all leaks are on the pipe itself, while about 11 percent of the leaks occur on fittings. However, looking only at systems installed in the 1940's, about 80 percent (from 79.0 to 84.3 percent) of the leaks are on the pipe and only 8 percent (from 5.8 to 9.9 percent) occur on the fittings. Although it is not indicated in this table, the column labeled "unknown" accounts for 24 percent of the data reported. That is, 24 percent of the repaired leaks are made on pipeline components that are of unknown age.

Because this data is expressed as percentages rather than as leak rates, the conclusions that can be drawn are quite limited. For example, the percentage of leaks on valves decreases with age, but this does not say that new valves are more likely to leak than old ones. To say something about this would require one to know the number of valves in each age category and to normalize the data; however, this information is not available. In fact, notice that each column must add up to 100 percent. Thus, if in a given decade the percentage of leaks in one part increases, then the percentage of leaks in all the remaining parts would have to decrease.

Similarly, the data indicates that, overall, valves account for about 6 percent of the repaired leaks, and fittings account for about 11 percent. One cannot conclude from this that the probability of a fitting's leaking is twice that for a valve. To make a statement of this nature, one would need to know the relative number of valves and fittings that are in the system.

In summary, this table shows that the pipe itself accounts for a great majority of the leaks (approximately 71 percent), that fittings account for approximately 11 percent, and valves account for about 6 percent. Of the remainder of the parts, each accounts for a very small percentage of all repaired leaks.

TABLE 2.50

Classification of Leaks by Part Which Leaked for Each Decade of Construction
Distribution Mains
Annual Report Data

Part Repaired	Year	Unknown	Decade of Construction --29	30-39	40-49	50-59	60-69	70--	Total
Pipe	1970	85.4	82.6	78.6	84.3	83.0	81.0	70.2	73.9
	1971	83.5	85.9	78.6	79.8	77.8	65.4	62.5	72.3
	1972	74.1	72.9	77.7	79.0	73.1	61.0	70.4	70.3
	1973	72.4	70.2	75.3	75.6	69.3	54.3	66.6	66.6
Valve	1970	2.8	1.7	3.5	3.6	5.5	5.7	8.6	4.8
	1971	3.4	1.5	3.7	4.5	7.1	11.6	11.0	5.3
	1972	5.6	1.9	4.0	5.8	11.3	15.9	9.2	6.4
	1973	5.4	2.5	5.9	7.3	14.2	20.6	10.1	8.8
Fitting	1970	4.8	7.8	9.0	5.8	6.5	7.2	10.5	9.0
	1971	6.2	6.0	9.6	9.0	9.1	12.6	12.4	11.4
	1972	10.6	10.2	10.4	8.4	9.0	12.6	9.9	11.4
	1973	9.9	13.3	10.3	9.9	9.6	14.4	12.4	11.9
Drip	1970	1.1	1.7	1.6	1.1	0.8	0.9	0.9	1.2
	1971	1.1	1.3	1.3	1.3	1.2	1.6	1.1	1.2
	1972	1.1	1.5	1.4	1.0	1.1	1.3	0.9	1.2
	1973	1.2	1.4	1.4	1.7	1.5	1.7	1.3	1.4
Regulator	1970	0.9	0.2	0.6	0.5	0.8	1.1	2.5	0.7
	1971	0.7	0.1	0.3	0.3	0.6	1.3	2.1	0.5
	1972	0.6	0.1	0.2	0.3	0.5	1.6	1.7	0.5
	1973	0.6	0.1	0.2	0.3	0.6	1.5	1.5	0.5

(Table continued on next page)

TABLE 2.50 continued

Classification of Leaks by Part Which Leaked for Each Decade of Construction

Distribution Mains

		Decade of Construction							
Part Repaired	Year	Unknown	--29	30-39	40-49	50-59	60-69	70--	Total
Tap Connection	1970	0.8	1.1	2.2	2.0	1.8	2.0	2.8	1.4
	1971	1.2	0.7	1.3	1.6	1.6	3.8	5.7	1.6
	1972	1.2	0.8	1.0	1.4	1.8	3.1	3.0	1.4
	1973	1.5	1.0	1.1	1.5	1.6	2.8	3.9	1.5
Other	1970	4.2	4.9	4.5	2.7	1.6	2.1	4.5	9.0
	1971	3.9	4.5	5.2	3.5	2.6	3.7	5.2	7.7
	1972	6.8	12.6	5.4	4.1	3.2	4.5	4.9	8.8
	1973	9.0	11.5	5.8	3.7	3.2	4.7	4.2	9.3
Total		100%	100%	100%	100%	100%	100%	100%	100%

Table 2.51 is the summary of leaks for distribution services, showing the relative magnitude of leaks for each part within each decade of construction. The table is similar to Table 2.50 which is for distribution mains. The column under "total" shows that, on the average, the percentages comprising the total leaks in the annual report are approximately 56 percent for pipe, 20 percent for fittings, 8 percent for valves, 4 percent for regulators, and 3 percent for tap connections.

One can state from this data that the probability of a leak on the 1970's decade pipe coming from a valve is about 8 percent, while the probability of a leak on the '30's decade pipe coming from a valve is only about 5 percent. However, one must be very careful in understanding this statement: It does <u>not</u> say that a 1970's valve is more likely to leak than a 1930's valve.

In summary, because the data are in percentages, the data have limited value in analyzing the leak rates of the pipe components. Only limited conclusions can be drawn in this table, as was discussed in more detail in Table 2.50.

Table 2.52 gives a breakdown of leaks in the transmission systems by parts for each decade of construction. The leaks in the gathering systems are not included in the table. A discussion of the limited usefulness of this type of data is given in Tables 2.50 and 2.51. The data provide the frequency of leaks on a particular part, relative to the frequencies of leaks on the rest of the parts within each decade.

It is seen in the column under "total" that the overall percentages of contributions to the total number of leaks are approximately 73 percent by body of pipe, 12 percent by fittings, 3 percent by welds, 3 percent by valves, and 1 percent by tap connections. Thus the leaks on the body of pipe are by far the most important cause.

TABLE 2.51

Classification of Leaks by Part Which Leaked for Each Decade of Construction
Distribution Services
Annual Report Data

		Decade of Construction							
Part Repaired	Year	Unknown	--29	30-39	40-49	50-59	60-69	70--	Total
Pipe	1970	80.3	86.7	75.4	76.2	67.9	61.2	50.9	61.9
	1971	71.2	83.1	73.6	71.0	67.8	55.2	53.2	59.5
	1972	56.0	80.6	67.9	64.3	56.9	43.7	46.9	52.0
	1973	56.0	80.6	65.2	64.4	55.9	43.7	48.5	52.2
Valve	1970	4.6	2.6	4.4	5.3	6.8	7.9	9.6	7.6
	1971	7.0	3.4	5.1	6.7	7.8	9.5	8.1	8.4
	1972	9.7	3.8	5.4	7.1	8.0	11.1	7.1	7.8
	1973	9.7	3.9	5.6	6.2	8.6	10.6	8.1	8.0
Fitting	1970	7.2	5.9	11.4	10.7	15.1	15.5	20.0	14.7
	1971	10.2	7.2	11.9	11.9	12.8	17.5	19.4	17.1
	1972	16.9	8.8	17.6	18.9	22.4	27.2	25.7	22.7
	1973	16.1	9.6	18.7	17.9	22.6	30.3	23.7	24.5
Drip	1970	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2
	1971	0.4	0.3	0.5	0.2	0.2	0.4	0.2	0.3
	1972	0.3	0.2	0.1	0.1	0.2	0.2	0.3	0.2
	1973	0.3	0.2	0.2	0.2	0.1	0.2	0.2	0.2
Tap Connection	1970	1.6	0.9	2.0	1.8	3.2	4.2	8.1	3.9
	1971	3.3	0.9	2.1	2.7	3.5	5.1	6.3	3.7
	1972	4.6	0.4	1.7	2.6	3.8	4.5	5.9	3.5
	1973	4.7	0.5	2.7	3.2	3.8	3.5	7.5	3.8

(Table continued on Following Page)

TABLE 2.51 continued

Classification of Leaks by Part Which Leaked for Each Decade of Construction

Distribution Services

		Decade of Construction							
Part Repaired	Year	Unknown	--29	30-39	40-49	50-59	60-69	70--	Total
Tap Connection	1970	2.6	2.1	4.5	3.3	4.0	5.8	4.1	3.9
	1971	2.9	2.1	2.9	3.4	3.5	5.3	6.0	3.4
	1972	3.5	1.4	2.4	2.6	2.8	4.1	3.8	2.8
	1973	2.9	1.9	2.9	2.8	3.0	3.6	4.0	2.8
Other	1970	3.5	1.6	2.1	2.5	2.8	5.2	7.0	7.8
	1971	5.0	3.0	3.9	4.1	4.4	7.0	6.8	7.6
	1972	9.0	4.8	4.9	4.4	5.9	9.2	10.3	11.0
	1973	10.3	3.3	4.7	5.4	6.0	8.1	8.0	8.5
Total		100%	100%	100%	100%	100%	100%	100%	100%

TABLE 2.52

Classification of Leaks by Part Which Leaked for Each Decade of Construction
Transmission Systems
Annual Report Data

Part Repaired	Year	Decade of Construction: Unknown	--29	30-39	40-49	50-59	60-69	70--	Total
Body of Pipe	1970	74.0	84.6	83.4	72.8	64.0	67.7	79.4	72.8
	1971	82.8	83.1	81.9	84.1	76.8	69.2	82.8	75.0
	1972	85.9	84.6	82.0	90.0	65.4	47.5	55.5	70.3
	1973	88.9	85.3	84.5	85.9	73.8	59.0	41.9	75.4
Girth Weld	1970	1.0	0.4	2.7	6.5	6.3	6.7	2.5	2.1
	1971	0.3	0.5	2.8	3.7	4.2	6.8	2.9	2.0
	1972	0.9	0.7	1.6	2.3	7.2	7.8	8.1	1.9
	1973	0.3	0.6	3.0	3.0	3.8	6.8	10.1	1.7
Longitudinal Weld	1970	0.2	0.0	1.7	1.7	5.1	3.3	1.8	1.1
	1971	0.1	0.1	1.5	1.1	2.6	3.1	1.7	1.0
	1972	0.1	0.2	0.6	1.8	3.1	5.0	3.0	0.9
	1973	0.0	0.1	0.4	0.8	3.1	2.0	2.1	0.5
Other Field Weld	1970	0.1	0.3	0.4	0.8	0.7	1.6	0.0	0.4
	1971	0.1	0.1	0.4	0.2	0.9	3.0	0.9	0.9
	1972	0.1	0.2	0.1	0.5	0.9	1.5	1.2	0.3
	1973	0.1	0.1	0.1	0.6	0.3	1.8	4.8	0.3
Compressor	1970	0.2	0.0	0.0	0.5	2.4	1.6	0.2	0.4
	1971	1.6	0.1	0.0	0.3	0.2	1.4	0.1	0.5
	1972	0.0	0.1	0.0	0.2	0.9	4.6	2.7	0.9
	1973	0.0	0.2	0.1	0.6	1.3	1.5	4.8	0.4
Valve	1970	4.1	0.5	0.4	1.5	3.1	4.3	4.8	1.9
	1971	2.5	0.2	0.6	0.7	4.3	3.8	2.5	2.2
	1972	2.0	1.2	2.1	1.4	5.0	8.3	6.0	8.0
	1973	2.1	1.2	0.7	1.8	3.9	5.1	4.8	1.7

(Table continued on following page)

TABLE 2.52 continued

Classification of Leaks by Part Which Leaked for Each Decade of Construction

Transmission Systems

Part Repaired	Year	Unknown	--29	30-39	40-49	50-59	60-69	70--	Total
		Decade of Construction							
Scraper Trap	1970	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
	1971	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
	1972	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	1973	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Tap Connection	1970	2.6	1.5	0.9	1.6	4.4	4.1	2.1	1.9
	1971	2.3	0.7	1.3	0.9	1.9	0.9	0.8	1.4
	1972	2.0	0.2	0.7	0.4	1.4	3.9	3.6	0.9
	1973	1.2	0.5	0.6	1.0	2.0	1.0	2.4	0.8
Fitting	1970	11.5	9.3	4.7	3.7	5.2	7.0	4.6	12.6
	1971	7.0	11.0	8.3	6.8	5.8	7.5	6.4	13.0
	1972	6.9	8.6	6.6	2.2	10.7	8.0	12.8	11.5
	1973	5.6	9.2	5.0	3.9	5.7	17.0	23.0	12.3
Gas Cooler	1970	0.0	0.0	0.0	0.3	0.2	0.1	0.4	0.1
	1971	0.2	0.0	0.0	0.0	0.1	0.7	0.0	0.1
	1972	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.0
	1973	0.0	0.0	0.0	0.1	0.3	0.3	0.2	0.1
Other	1970	6.3	3.4	5.8	10.6	8.6	3.5	4.2	6.7
	1971	3.1	4.2	3.2	2.2	3.2	3.4	1.9	3.9
	1972	2.1	4.2	6.3	0.0	5.1	3.3	7.1	5.3
	1973	1.8	2.8	5.6	2.3	5.8	5.5	5.7	6.8
Total		100%	100%	100%	100%	100%	100%	100%	100%

2.4 COMPARISON OF CONCLUSIONS FROM INDIVIDUAL AND ANNUAL REPORTS

This section consists of comparisons of the conclusions drawn from the analyses of "reported" leak data (individual reports) with analyses of "non-reported" leak data (annual reports).

The number of comparisons that can be made is limited by the fact that of the 50 tables (excluding Tables 2.1 and 2.42) presented in the previous section, only ten (Tables 2.43 through 2.52) analyze non-reported leak data obtained from the annual reports; of these ten tables, only eight contain data that can be directly compared with data from the individual reports. The reason for this relatively small number of direct comparisons is that the individual reports contain much more detailed information about leaks, the same level of detail not being available from the annual reports. Of course, much of the information in the annual reports is mileage data that is used as a normalizing factor for leak data from the individual reports.

2.4.1 Leak Rates by Age

2.4.1.1 Distribution Mains (Table 2.12 vs. 2.43)

Leak rate data for distribution mains (all causes) as a function of the decade of construction are presented in Tables 2.12 and 2.43. The differences in these two tables are: (1) Table 2.12 presents data for individually reported leaks, whereas Table 2.43 presents data for all non-reported leaks (from the annual report form); and (2) Table 2.12 includes leaks on all parts of the pipeline, but Table 2.43 includes only leaks on the body of the pipe.

Comparing these two tables, it can be seen that both analyses confirm the general notion that the total leak rate increases with age of the system. The chief difference between the tables is in the relative ranking of the leak rate for the 1970's. In Table 2.43, the leak rates for the 1950's, '60's, and '70's are significantly lower than for the other decades; but, in Table 2.12, the '70's leak rate is significantly higher than that for the '50's and '60's. Hence, pipeline installed in the 1970's shows a significantly higher rate of serious leaks (the type requiring individual reports) than pipelines installed during the '50's and '60's. However, there is no significant difference among the leak rates of non-reported leaks in the 1950's, '60's, and '70's.

2.4.1.2 Distribution Services (Tables 2.13 vs. 2.44)

These tables contain data similar to that found in Tables 2.12 and 2.43 except that the data is for distribution "services" rather than "mains." Again, the differences are: (1) Table 2.13 presents data for individually reported leaks while Table 2.44 presents data for all non-reported leaks; and (2) Table 2.13 includes data for leaks on all parts of the system, while Table 2.44 presents only data for leaks on the body of the pipe.

Comparisons between these tables yield conclusions similar to those drawn in the comparison of Tables 2.12 and 2.43. Both generally show a trend of increasing leak rates with age of the system. Also, in Table 2.44, the leak rate for the 1950's, '60's, and '70's is significantly lower than those for other decades, but in Table 2.13, the only significant conclusion is that the leak rate for the 1920's is significantly higher than that for the other decades. As was the case for distribution mains previously, it appears that there is a general trend of increasing leak rates with age, except the 1970's pipe has a significantly higher rate for individually reported leaks.

2.4.1.3 Transmission Systems (Tables 2.14 vs. 2.45)

These two tables present data similar to the previous sets of tables (2.12, 2.13, 2.43, and 2.44) except in this case, the leak rates as a function of pipe age are analyzed for transmission systems. The basic differences in Tables 2.14 and 2.45 are: (1) Table 2.14 presents data for all individually reported leaks whereas Table 2.45 presents data for all non-reported leaks; and (2) Table 2.14 includes leaks on all parts of the system, but Table 2.45 includes only leaks on the body of the pipe.

Once more, the tables indicate that the leak rates increase with age of the system. In this comparison, the two statistical analyses yield identical results: namely, that the leak rate for the 1920's is significantly higher than all others, and the 1930's leak rate is higher than the 1940's, '50's, '60's, and '70's. The leak rates for the latter four decades do not significantly differ from each other.

2.4.2 Leak Rates by Cause

2.4.2.1 Distribution Systems (Tables 2.29 vs. 2.48)

Tables 2.29 and 2.48 both present a percentage of leaks, by cause, for each decade of construction for distribution mains and services. However, Table 2.29 concerns only individually reported leaks, and Table 2.48 includes all leaks (reported and non-reported) from the annual report. In the annual report the number of reported leaks, as compared to the number of non-reported leaks, is small. Therefore, Table 2.48 gives a good approximation of the non-reported leaks for purposes of comparison with reported leaks in Table 2.29.

In making the comparison, the age breakdown is of minor importance, and conclusions will be drawn from the overall percentages by cause. In comparing the two tables, there are two major differences: (1) corrosion leaks account for approximately 45 percent of all leaks in Table 2.48 but for only about 15 percent of the leaks in Table 2.29; and (2) outside force accounts for only 14 percent of the leaks in Table 2.48, but in Table 2.29, approximately 70 percent of the leaks are caused by outside force. Hence, the comparison indicates that leaks caused by outside force generally tend to be the "dangerous" ones, in that they require individual reports. Corrosion-caused leaks develop gradually and accumulation of escaped gas is slow, if it happens at all. Leaks caused by outside force usually involve a rupture of the pipe and are more frequently followed by explosion. This indicates that if one wished to use leak data in the annual reports as a basis of some safety measure, it would require the use of some weighting factors in order to make the annual report data comparable to the data in the individual reports.

One way of doing this is to divide the percents in Table 2.29 by the corresponding percents in Table 2.48 and use the resulting quotients as the weights. Such weights are calculated below:

Cause	Percentages of Total Leaks: Individual	Annual	Weighting Factor
Corrosion	15.0%	45.2%	0.33
Outside force	69.9	14.2	4.92
Construction defect	1.7	5.4	0.31
Material failure	8.3	10.2	0.81
Other	5.2	25.0	0.21

From the weights assigned to corrosion and outside force, we can see that one outside force leak is equivalent to approximately 15 (4.92/0.33) corrosion-caused leaks in terms of potential danger.

2.4.2.2 Transmission Systems (Tables 2.28 vs. 2.49)

Tables 2.28 and 2.49 each present percentages of leaks by cause, broken down by decade of construction for transmission systems. Table 2.28 includes data for individually reported leaks, while Table 2.49 includes data for both reported and non-reported leaks from the annual report. Note that the age breakdowns for the tables are different.

The comparisons that can be made are very similar to the comparisons made for Tables 2.29 and 2.48. In the annual reports (Table 2.49), corrosion accounts for about 77 percent of the leaks, and outside force accounts for about 3.0 percent, whereas Table 2.28 indicates that corrosion accounts for only about 15 percent of the leaks and outside force, for almost 54 percent. Hence, the same conclusion about outside force causing the more serious leaks, can be made.

Applying the weighting factors to the data in the annual reports as a safety measure, we get the following calculations:

	Percentages of Total Leaks		
Cause	Individual	Annual	Weighting Factor
Corrosion	15.0%	77.3%	0.19
Outside force	53.9	3.0	18.0
Construction defect	5.4	2.0	2.7
Material failure	18.9	9.6	2.2
Other	6.8	8.2	0.83

From the weights assigned to corrosion and outside force, we see that in the transmission system, one outside force leak is equivalent to approximately 95 (18.0/0.19) corrosion leaks in terms of potential danger.

2.4.3 Leak Rate by Part

2.4.3.1 Distribution Mains (Table 2.23 vs. 2.50)

Tables 2.23 and 2.50 give the percentage breakdown of leaks by the part which leaked, for distribution mains. Table 2.23 is for individual reports, while Table 2.50 is for non-reported leaks from the annual report form. Table 2.50 also gives a further breakdown by age.

In comparing the two tables, their results are quite similar. The primary differences are: (1) Pipes account for about 71 percent of the leaks in the annual report (Table 2.50), but the percentage is a little higher (from 76-to-83 percent of the leaks) in the individual reports; and (2) the "other" category accounts for almost 9 percent of the leaks in Table 2.50, while it accounts for 2.0 to 5.8 percent of the leaks in Table 2.23. However, both tables yield the same conclusion: namely, that almost 75 percent of the leaks originate on the pipe with approximately 10 percent of the leaks originating on the fitting.

2.4.3.2 Distribution Services (Table 2.24 vs. 2.51)

The comparison between Tables 2.24 and 2.51 is very similar to the previous comparison, except that these tables are for distribution services. Again, the differences between the tables are: (1) Table 2.24 presents data from the individual leak reports, while Table 2.51 presents data from non-reported leaks; and (2) Table 2.51 gives a further percentage breakdown by age.

In the comparison of the "total" category of Table 2.24 with Table 2.51, there is considerable similarity in the data. In both cases the pipe accounts for over half of the total leaks, and the fittings account for the second greatest percentage of leaks.

2.4.3.3 Transmission Systems (Table 2.25 vs. 2.52)

These tables give leak percentages by part which failed for transmission systems. Table 2.25 presents this data from the individual leak reports, while Table 2.52 presents data for non-reported leaks. Also, Table 2.52 gives a further percentage breakdown by age. Table 2.25 contains information for not only the transmission lines, but also gathering systems and transmission lines that are part of a distribution system.

Hence, the comparison is made between the first four lines of Table 2.25 and the "total" column of Table 2.52.

In comparing the tables, we note (as we did in the comparisons between Tables 2.23 and 2.50, and Tables 2.24 and 2.51) that the pipe and the fittings are the origins of the largest and second largest number of leaks, respectively. However, there are several differences: (1) The body of the pipe accounts for about 74 percent of the non-reported leaks (annual report), but it accounts for only 47-to-50 percent of the individiually reported leaks; and (2) tap connections account for 1-to-2 percent of non-reported leaks, but they account for 3.5-to-8.1 percent of individually reported leaks.

2.5 ANALYSIS OF INDIVIDUAL OPERATORS

The purpose of the analysis in this section is to determine measures and to develop statistical procedures which can be used to evaluate and compare the performance of individual operators. Using the data submitted in the annual and individual leak reports, the goal is to identify those operators whose performance indicates a possible safety problem so that further investigation and possible corrective action may be undertaken.

This section is organized into two major parts. First, a description will be given of alternative measures which might be used to assess the safety performance of individual operators, and a specific measure is recommended. Secondly, using the recommended measure, a procedure is explained for analyzing individual operators and "flagging" those that appear to have potential safety problems as compared to average operators.

Most of the specific analyses referred to in this section were based on the distribution system data, but the general procedures should apply equally to transmission operators.

2.5.1 Measures of Safety

2.5.1.1 Death and Injury Rate

One of the initial measures of an operator's safety performance examined was the death and injury rate resulting from accidents involving the operator's system. The death and injury rate is determined by dividing the total of deaths and injuries as reported on the annual report by the number of miles of pipe in the operator's system. The total miles of pipe is determined by adding miles of mains to miles of services, using a conversion factor of 50.5 feet per service, as has been described in several other places in the report.

One obvious reason for choosing death and injury rate is that it is a direct measure of safety, i.e., safety means the prevention of human and/or property damage. To demonstrate that death and injury can indeed be used to assess safety, an analysis was performed to show there is a correlation between death and injury rate and operator size, a result that seems correct on an intuitive basis. This data is presented in Table 2.53. It can be observed that the mean value of deaths and injuries per 1,000 miles of pipeline is inversely related to the size of the system (as measured by the number of services of the operator). From this analysis, it might be concluded that the smaller operators should receive more attention from OPS enforcement personnel than large operators, since they generally have a higher death and injury rate. However, if the data is viewed from another perspective, then the opposite conclusion may be drawn. It can be seen that the 83 operators with over 100,000 services (representing only 9 percent of all gas distribution operators) account for 68 percent of total injuries and deaths. On the other hand, the 341 operators with less than 1,000 services (representing 38 percent of all operators) only accounted for 2.7 percent of the injuries and deaths. It might therefore be predicted that efforts to improve the safety performance of the operators with over 100,000 services would have a greater impact in reducing deaths and injuries than effort spent working with the large number of smaller operators. In summary, the data in Table 2.53 shows that death and injury rate measures can be useful when assessing the safety of groups of operators.

On the other hand, there are several disadvantages with attempting to use death and injury rate to assess individual operators. To explain,

TABLE 2.53

Injuries and Deaths for Different Operator Sizes

Distribution Systems

Class by Number of Services

		less than 1,000	1,000 to 10,000	10,000 to 100,000	Over 100,000	Total or Overall
No. of Operators		341	343	119	83	886
No. of Miles*	1970	13,300	39,700	133,200	788,500	974,700
	1971	8,800	41,600	134,800	764,400	949,600
	1972	8,500	46,700	151,800	751,100	958,200
No. of Injuries or Deaths	1970	11	51	46	260	368
	1971	12	34	133	295	474
	1972	12	48	70	321	451
Injuries and Death per 1,000 Miles	1970	0.83	1.28	0.35	0.33	0.38
	1971	1.36	0.82	0.99	0.39	0.50
	1972	1.41	1.03	0.46	0.43	0.47
Mean Value 1970-1972		1.20	1.04	0.60	0.38	0.45

*Miles of mains plus number of services converted into equivalent miles by 50.5 ft/service.

suppose two operators of similar size each have an accident, with one accident resulting in a single injury or death and the other accident resulting in seven injuries or deaths. In this instance, based on death and injury rate, one operator would appear seven times worse than the other. Or, an operator who is obviously unsafe by most standards may be fortunate enough not to be the cause of any serious accidents during a particular year, while on the other hand, a safe operator may have an outside party cause an accident that kills or injures several people. In statistical terms we can say that the random occurrence of deaths and injuries has an irregular distribution, i.e., incidences involving deaths and injuries generally occur infrequently, but when they do, they can easily involve anywhere from one to ten injuries. This causes the death and injury rate for operators to either be zero (no deaths or injuries) or relatively large (one, five or ten deaths or injuries).

To illustrate this point an analysis of the death and injury rate for distribution operators was performed to obtain some indication of the range of this measure for individual operators in different size groups. This data is presented in Table 2.54. To explain the data in Table 2.54, consider the operators with less than 1,000 services (column 1). For each operator, the death and injury rate for each of three years (1970-1972) was calculated and then the range of this rate determined by subtracting the smallest rate from the largest rate. The percentage frequency distribution of these 341 ranges is then given in column 1. The data says that 97.95 percent of the operators with less than 1,000 services had a range of zero, which in all likelihood means that their death and injury rate was zero for all three years. One operator (.29 percent of 341 operators) had a range of between 1.0-1.2 deaths and injuries per mile, which in all likelihood means that for two years this operator had zero deaths and injuries, and in one year had a death and injury rate of 1.0-1.2 per mile. Note that the units are different on each column, e.g., column 4 for operators over 100,000 services is based on deaths and injuries per 1,000 miles.

The irregularity of the death and injury rate data is easily observed in Table 2.54, especially for the smaller operators. The death and injury rates are quite high for a small percentage of the operators with less than 10,000 services, while most operators in this size range had no injuries or

TABLE 2.54

Frequency Distributions of the Three Year Range of Death and Injury Rate for Each Operator

Class by Number of Services

	less than 1,000	1,000 to 10,000	10,000 to 100,000	Over 100,000
No. of Operators	341	343	119	83
Rate Basis	per 1 mile	per 10 miles	per100 miles	per 1,000 miles
Interval	Percent Frequency of Range			
0.0	97.95	87.17	57.14	13.25
0.0 - 0.2	1.47	9.33	25.21	18.07
0.2 - 0.4	0.29	1.46	10.92	15.66
0.4 - 0.6	0	0.87	1.68	15.66
0.6 - 0.8	0	0.29	1.68	9.64
0.8 - 1.0	0	0.29	0.84	3.61
1.0 - 1.2	0.29	0.29	0.84	9.64
1.2 - 1.4		0	0.84	0
1.4 - 1.6		0.29		3.61
1.6 - 1.8				1.21
1.8 - 2.0				2.41
2.0 - 4.0				2.41
over 4.0				4.81
Average Range	0.00492	0.0297	0.122	0.831

deaths during the three year period.

Another way to see this general problem is shown by the data in Table 2.55. This table lists distribution system operators who filed at least one individual report during 1972; that is, this listing is for operators who appeared on the individual report file. For each operator, Table 2.55 lists the following information for 1972:[1]

Column No.	Total of Column
1.	Name of Company (left blank in this report to preserve confidentiality of individual operator reports)
2.	Operator Number
3.	Total Number of Individual Reports
4.	Total Number of Deaths (from the individual leak reports)
5.	Total Number of Injuries (from the individual leak reports)
6.	Total Property Damage to the Operator (dollars)
7.	Number of Individual Reports per 1,000 Miles of Pipe
8.	Number of Deaths per 1,000 Miles of Pipe
9.	Number of Injuries per 1,000 Miles of Pipe
10.	Property Damage (dollars) per 1,000 Miles of Pipe
11.	1972 Repaired Leaks (annual report) per Mile of Pipe
12.	1972 Outside Force Leaks (annual report) per Mile of Pipe

In order to explain the data, notice that during 1972, Operator 4 filed 18 individual leak reports, reporting one death, 16 injuries, and $6,789 in property damage; and, based on all leaks from the annual report form, the company had a total leak rate of 0.59 leaks per mile and an outside force leak rate of 0.11 leaks per mile. Notice that by adding deaths and injuries together, the number of deaths and injuries ranges from zero for some operators to 23 for one operator.

Even though one can think of death or injury rate as a direct measure of an operator's safety performance, as previously discussed--and as Table 2.55 indicates--the data is too irregular for the limited data sample available to be utilized in ranking or comparing individual operators during any year.

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[1]Following the analysis procedure used elsewhere in this report, a distribution operator's total number of miles of pipe was obtained by converting the number of services to miles, using the conversion factor of 50.5 feet per service and adding this mileage to the miles of mains.

Table 2.55 Comparison of Distribution Operators Who Filed Leak Reports During 1972

1	2	3	4	5	6	7	8	9	10	11	12
NAME OF COMPANY	ID NO	REPORTS	DEATHS	INJ.	PROP. DAM.	REPORT RATE	DEATH RATE	INJURY RATE	PROP. DAM. RATE	LEAK RATE TOTAL	OUT. FOR.
						----------(PER 1000 MILES)----------				---(PER MILE)---	
(Left blank in this report to preserve confidentiality of Data)	1	29	0	0	2085.	3.699	0.0	0.0	266.0	1.8560	.1447
	2	29	0	2	6950	3.293	0.0	0.227	789.3	0.5845	.2562
	3	17	0	1	2750	0.989	0.0	0.058	159.9	0.8976	.1328
	4	18	1	16	6789	0.977	0.054	0.868	368.3	0.5860	.1086
	5	3	0	3	200	0.400	0.0	0.400	26.7	0.5824	.1005
	6	12	0	4	600	1.945	0.0	0.648	97.2	0.3371	.0726
	7	16	1	7	131	1.873	0.117	0.819	15.3	2.3654	.1810
	8	1	0	0	100	0.247	0.0	0.0	24.7	0.4365	.0745
	9	5	0	0	0	1.350	0.0	0.0	0.0	0.2829	.0124
	10	1	0	0	150	0.317	0.0	0.0	47.5	1.0883	.0640
	11	2	0	1	1200	0.712	0.0	0.356	427.2	0.3072	.0527
	12	7	1	2	5505	1.207	0.172	0.345	949.1	1.1968	.0210
	13	7	0	2	6250	1.397	0.0	0.399	1247.6	0.2799	.1082
	14	4	0	0	82	0.752	0.0	0.0	15.4	0.5046	.0759
	15	14	0	2	46360	0.656	0.0	0.094	2172.3	0.6949	.0593
	16	9	0	2	2453	0.990	0.0	0.220	269.7	1.4321	.0479
	17	3	0	0	525	0.541	0.0	0.0	94.7	0.7386	.0454
	18	1	0	2	0	0.384	0.0	0.767	0.0	0.1335	.0828
	19	26	0	22	4010	3.428	0.0	2.901	528.8	2.8115	.0314
	20	4	0	1	3905	1.372	0.0	0.343	1339.0	0.7167	.0096
	21	51	0	7	2114	2.085	0.0	0.286	85.4	0.4970	.1882
	22	6	0	1	0	0.959	0.0	0.160	0.0	0.4592	.0530
	23	3	0	1	125	0.144	0.0	0.048	6.0	0.7244	.0184
	24	7	0	1	1010	1.264	0.0	0.181	182.4	0.8475	.0282
	25	14	0	4	33440	16.209	0.0	0.220	36717.1	0.9447	.0859
	26	4	0	2	475	0.424	0.0	0.212	50.4	1.4230	.0667
	27	16	0	5	4970	1.905	0.0	0.595	591.7	0.8335	.0906
	28	2	0	3	250	0.439	0.0	0.559	54.9	1.7663	.0310

Table 2.55 (Continued)

1 NAME OF COMPANY	2 ID NO	3 REPORTS	4 DEATHS	5 INJ.	6 PROP. DAM.	7 REPORT RATE	8 DEATH RATE	9 INJURY RATE	10 PROP. DAM. RATE	11 LEAK RATE TOTAL	12 LEAK RATE OUT. FOR.
						----------(PER 1000 MILES)----------				---(PER MILE)---	
(Left blank in this report to preserve confidentiality of data)	29	2	0	2	325	0.702	0.0	0.702	114.1	0.4862	.0270
	30	2	0	0	80	0.439	0.0	0.0	17.6	0.3686	.0434
	31	3	0	2	3100	1.094	0.0	0.729	1130.0	0.3299	.0521
	32	6	0	2	4550	1.888	0.0	0.629	1431.5	0.4087	.1262
	33	1	0	0	50	0.346	0.0	0.0	17.3	0.7140	.0551
	34	39	0	13	5314	1.390	0.0	0.475	194.4	1.2173	.1375
	35	12	0	0	950	1.336	0.0	0.0	105.8	0.3842	.0715
	36	6	0	2	450	1.319	0.0	0.440	98.9	0.5586	.2799
	37	3	0	4	0	0.626	0.0	0.834	0.0	0.3551	.0450
	38	2	0	2	0	0.478	0.0	0.478	0.0	0.6314	.0327
	39	3	0	0	1225	1.183	0.0	0.0	483.2	0.5577	.0935
	40	45	0	6	28185	2.332	0.0	0.304	1428.7	0.6542	.1085
	41	14	0	19	6560	2.635	0.0	3.577	1234.9	0.6737	.3308
	42	6	0	1	1498	1.157	0.0	0.193	288.8	0.6157	.0816
	43	2	0	0	12000	0.560	0.0	0.0	3362.9	0.1169	.0132
	44	4	0	1	1076	0.596	0.0	0.149	160.2	0.4585	.1314
	45	5	0	5	1203	0.804	0.0	0.804	193.3	0.9093	.1434
	46	2	0	0	50	0.749	0.0	0.0	18.7	0.3365	.0880
	47	1	0	0	500	0.305	0.0	0.0	152.3	0.4748	.0417
	48	6	2	5	1250	0.680	0.227	0.567	141.7	0.6209	.0939
	49	21	0	1	9390	0.695	0.0	0.033	310.7	0.2928	.0595
	50	6	1	1	1815	0.500	0.083	0.083	151.2	0.3856	.0216
	51	8	6	13	2225	1.692	1.269	2.749	470.5	0.5158	.2276
	52	2	0	0	207	0.229	0.0	0.0	23.7	0.3736	.0967
	53	5	0	3	2695	0.383	0.0	0.230	206.6	0.2010	.0564
	54	42	1	3	15105	0.983	0.023	0.070	353.6	0.3935	.0318
	55	1	0	0	0	0.335	0.0	0.0	0.0	0.5492	.0479
	56	4	1	22	400	1.291	0.323	7.099	129.1	4.4403	.0303
	57	3	0	0	5450	0.328	0.0	0.0	595.1	0.8499	.1141

Table 2.55 (Continued)

1 NAME OF COMPANY	2 ID NO	3 REPORTS	4 DEATHS	5 INJ.	6 PROP. DAM.	7 REPORT RATE	8 DEATH RATE	9 INJURY RATE	10 PROP. DAM. RATE	11 LEAK RATE TOTAL	12 LEAK RATE OUT. FOR.
						----------(PER	1000 MILES)	----------		---(PER	MILE)---
(Left blank in this report to preserve confidentiality of data)	58	13	0	2	2198.	1.832	0.0	0.282	309.8	1.2582	.0130
	59	3	0	0	200	0.274	0.0	0.0	18.3	0.3601	.0256
	60	8	0	1	1050	1.237	0.0	0.155	162.3	1.4067	.0691
	61	5	0	3	500	0.635	0.0	0.381	63.5	0.8188	.0184
	62	6	0	1	4750	1.026	0.0	0.171	812.1	0.1968	.0468
	63	10	0	0	4450	0.789	0.0	0.0	351.1	0.3719	.0116
	64	1	0	12	200	0.399	0.0	4.784	79.7	0.4680	.1874
	65	6	0	0	10625	0.568	0.0	0.0	1006.7	1.2232	.1483
	66	2	0	0	80	0.500	0.0	0.0	20.0	0.7858	.0795
	67	16	0	11	9490	0.766	0.0	0.526	454.2	0.3571	.0501
	68	2	2	0	5500	0.430	0.430	0.0	1181.7	0.7966	.0294
	69	7	0	3	4350	0.953	0.0	0.409	592.4	0.2578	.0477
	70	7	0	0	465	1.425	0.0	0.0	94.7	0.3659	.1641
	71	2	0	0	1613	0.459	0.0	0.0	370.2	0.6672	.1680
	72	92	1	16	31179	1.690	0.018	0.294	572.7	0.2980	.0429
	73	3	2	1	2930	1.124	0.749	0.375	1096.4	0.4934	.1304
	74	23	2	13	30228	1.671	0.145	0.944	2195.7	0.7392	.0989
	75	6	0	0	100	1.384	0.0	0.0	23.1	0.5039	.2583
	76	5	0	0	0	1.533	0.0	0.0	0.0	0.2695	.0797
	77	13	0	10	3480	2.445	0.0	1.881	654.4	1.4909	.0046
	78	19	0	3	922	0.976	0.0	0.154	47.4	0.6175	.1053
	79	1	0	0	0	0.275	0.0	0.0	0.0	0.2699	.0183
	80	5	0	1	750	1.594	0.0	0.319	239.1	1.2699	.1731
	81	41	3	9	19075	3.881	0.284	0.852	1805.6	1.2443	.2878
	82	8	2	1	200375	1.104	0.276	0.138	27655.9	0.3380	.1340
	83	3	[illegible]	3	84	0.933	0.622	0.933	26.1	[illegible]	.0352
	84	2	0	1	775	0.248	0.0	0.124	96.3	0.3101	.0605
	85	2	0	0	[illegible]	0.468	0.0	0.0	55.0	0.5782	.0374

2.5.1.2 Individual Failure Report Rate

Another measure examined for use in comparing individual operators was based on the individual report rate--determined by taking the total number of reports filed by an operator during a year and dividing by his total system mileage. This appears to be a reasonable measure since individual reports are filed only for "serious" leaks, as defined in 49 CFR, Part 191. In practice, a variety of slightly different measures based on individual reports can be used:

(a) total individual report rate

or (b) report rate based only on reports involving fire, explosion, death or injury

or (c) report rate based only on reports involving deaths or injuries

etc.

Notice that (c) eliminates the irregular character of the death and injury rate measure discussed previously, i.e., in this measure two accidents are counted equally even though one may cause one death or injury and the other cause five deaths or injuries.

Of course, the disadvantage of this measure is that it can only be used to evaluate operators with more than 100,000 services, since smaller operators are currently not required to file individual reports.

2.5.1.3 Repaired Leak Rate

Another of the "indirect" measures of safety examined on an individual operator basis was the total repaired leak rate, as calculated from each operator's annual report. In this analysis, the annual leak rates for 1970, '71, and '72 were determined for each operator, and operators were then ranked according to their average over these three years. Transmission and distribution operators were treated separately; also, the rankings were done separately for each region.[2] An examination of this printout indicated that there were several deficiencies in the data. For example, in Region 2 there were 95 operators whose average leak rate was zero, either because they had submitted no information or reported no leaks whatsoever. On the other hand, one operator's data indicated an average leak rate of 26.67 leaks per mile. Such obvious

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[2] This computer listing was submitted to OPS as part of Monthly Report No. 7, November 1, 1973, and should be labeled as Output 7.1.

errors in the data would make any ranking of operators highly misleading.

However, even if the data were completely accurate, the major problem with trying to use repaired leak rate as a measure of safety is that a high leak rate might not indicate that an operator is unsafe; and, in fact, there could be an inverse relationship. Some "safe" operators may have good record keeping systems and also may be regularly searching for and repairing all leaks, regardless of how small, and, therefore, will show a relatively high repaired leak rate.

2.5.1.4 Outside Force Leak Rate

According to Tables 2.28 and 2.29, the individually reported leaks caused by outside force account for approximately 70 percent and 52 percent of all individually reported leaks in distribution and transmission systems, respectively. (See also the discussion in Section 2.4.2) If, indeed, the individually reported leaks are the "serious" ones, then it follows that outside force leak rates are of major concern. An analysis of the data indicated that in distribution systems over the period from 1970 through 1972, 44 percent of the deaths and injuries were the result of outside force leaks, while the next highest contributors were material failures and construction defects, totaling 22 percent.

However, there are obvious problems in trying to use outside force leak rate to evaluate safety. In the first place, in many instances an operator has no control over the occurrence of an outside force accident, since--although the line may be marked and outside parties required to notify the operator before digging--outside parties may, nevertheless, ignore these warnings and accidents may occur. Also, the occurrence of outside force leaks is highly dependent on the environment; for instance, such leaks are generally more likely to occur in heavily than in sparsely populated areas since factors are involved in densely populated areas over which the operator does not have full control. In addition, although leaks represent a potential danger, the actual danger is highly dependent upon how the operator responds to the accident; two operators may have the same outside force leak rate and yet one may be much safer in his response to repairing the leak than the other.

2.5.1.5 Conclusions Concerning Measures of Safety

A number of potential measures of safety performance for individual operators have been examined, and all were found to be lacking in some respect. However, it appears that the best measure available is one based on individual report rate. Its disadvantage is that operators with fewer than 100,000 services are not required to file individual reports. (As discussed in the section on Recommendations, it is suggested that this exclusion be eliminated.) The particular measure used for the analysis in the following section is "individual report rate involving fires, explosions, deaths, or injuries." These incidents seem to be the most serious ones, and an analysis showed that 80 percent of all individually reported leaks fall into this category.

2.5.2 Procedure for Identifying "Potentially Unsafe" Operators

In this section we first give the basic statistical theory underlying the recommended procedure, and then show the results of applying the procedure to distribution operators with over 100,000 services for the years 1971-1973. The data for 1970 was not used in the analysis because it does not seem to be as reliable as the succeeding years' data. Throughout this section, the terms "leaks" or "reports" will mean individual reports involving fires, explosions, deaths, or injuries.

2.5.2.1 Development of the Procedure

The probability of a serious leak occurring on a given length of pipeline for an "average" operator can be estimated by dividing the total number of serious leaks reported for all operators by the total miles of pipeline of these operators' distribution systems. An analysis of individual operator performance can then be accomplished by predicting the expected number of serious leaks for the operator based on his total system mileage and then comparing this with the operator's actual number of serious leaks. The calculation of this probability is based on the binomial distribution. In general terms, this distribution has two parameters: (1) the probability of an event occurring, called "p", and (2) the number of trials over which this expected event may occur, called "n". For this application, the value of p is the average number of serious leaks per mile and n is the number of miles of pipe for a given operator.

The use of this type of analysis then results in a comparison of the expected versus actual number of serious leaks and a statement of the probability of a given number of serious leaks occurring in relation to the expected number. The probabilities are very cumbersome to compute for this analysis by using the binomial distribution directly, so a good approximation based on either the normal or Poisson distributions was used as appropriate for each case.

It was necessary in performing the analysis to choose a probability level for separating the "potentially unsafe" operators from the remainder of the group. If the probability of an actual number of serious leaks in relation to the expected number of serious leaks was less than 0.05 or 5 times in 100, then this operator was declared a "potentially unsafe" operator.

2.5.2.2 Results of the Procedure

An analysis of all 82 operators having more than 100,000 services was performed for the years of 1971-1973, and operators were flagged that appeared "potentially unsafe" in any one of the three years. Table 2.56 presents a listing of these 12 operators with the actual versus expected number of serious leaks.

To explain the table, in 1971 operator 1 reported 25 serious leaks. However, based on his mileage and the average leaks per mile on the entire system, the expected number of leaks for operator 1 was only 5.3. Using the binomial distribution (or actually the Poisson as an approximation to the binomial), it was determined that the probability of having 25 leaks when the expected value was only 5.3 has a probability of occurring that is less than 0.05. Therefore, in 1971 operator 1 is identified as being "potentially unsafe." This operator would then be assessed in more detail to determine whether any further action is required on the part of OPS.

It can be seen that two operators had such a large number of serious leaks in only one given year (Operators 10 and 11) that they also appear in the "potentially unsafe" category when the cumulative data is analyzed for the entire three-year period. It is also noteworthy that eight operators were identified as "potentially unsafe" in two or more of the three years. <u>This result tends to indicate that it is possible to use this approach to identify operators who should be the target of OPS enforcement efforts</u>. Viewed from another perspective, this approach would provide a high probability that the operators targeted for additional enforcement in any given year would be those operators whose safety records were poor over two or more years and should produce a maximum payoff for the enforcement effort expended.

TABLE 2.56

Listing of Distribution Operators Who Reported a Higher Than Expected Incidence of Fires, Explosions, Injuries or Deaths for Period 1971-73

Operator Identification Number	Reported (R) Versus Expected (E) Number of Leaks											
	R_{71}	E_{71}	R_{72}	E_{72}	R_{73}	E_{73}	R_{71-73}	E_{71-73}	1971	1972	1973	1971-1973
180	25	5.3	24	5.7	28	5.5	77	16.5	X[1]	X	X	X[2]
594	34	5.8	20	6.3	26	6.4	80	18.5	X	X	X	X
1640	8	3.8	4	4.4	5	4.3	17	12.5	X			
1800	10	5.9	16	6.2	14	5.9	40	17.9		X	X	X
2704	33	5.2	23	5.5	19	5.2	75	15.9	X	X	X	X
11680	20	18.3	30	19.7	32	19.2	82	57.2		X	X	X
12408	19	13.4	32	14.2	26	13.8	77	41.4		X	X	X
13780	5	3.2	7	3.4	7	3.4	19	9.9		X	X	X
18532	4	9.7	21	9.9	12	10.2	37	29.8		X		
18536	0	2.8	6	3.1	16	3.2	22	9.1			X	X
21350	7	2.1	4	2.3	2	2.2	13	6.6	X			X
22182	28	7.1	24	7.6	7	7.3	59	22.0	X	X		X

(1) An (X) indicates this operator reported a number of "serious" leaks for this year greater than would be expected only 5 times in 100 for an "average" operator.

(2) An (X) indicates this operator reported a cumulative number of "serious" leaks greater than would be expected only 5 times in 100 for an "average" operator during this period.

CHAPTER 3.0

CONCLUSIONS AND RECOMMENDATIONS

3.1 INTRODUCTION

This chapter contains a number of specific conclusions drawn from the analysis of pipeline safety data, followed by additional conclusions of a more general nature regarding the adequacy of the data system. Recommendations are then presented for improving the pipeline safety data system, followed by recommendations dealing with other approaches for improving pipeline safety.

The statistical analyses of data presented earlier in this report often included the results for two α-risk levels for purposes of comparison. In the following sections the specific statements of conclusions are based on an α-risk level of 0.05, since this appears to be the most acceptable level for this analysis.

3.2 CONCLUSIONS DRAWN FROM STATISTICAL ANALYSIS OF INDIVIDUAL LEAK REPORTS

In Section 2.2 of this report an extensive analysis of the data from individually reported leaks was presented. This data covered both distribution systems (usually subdivided into mains and services) and transmission systems. The following list summarizes the major conclusions drawn from this analysis.

1. Type of Material: (See Section 2.2.1)
   For leaks on the body of the pipe, steel (and in certain cases other metals like copper, ductile iron, and wrought iron) shows a lower leak rate than the other materials used for pipeline construction. (Note: The type of material effect is also analyzed in the section on metallic vs. plastic pipe.)
2. Nominal Diameter: (See Section 2.2.2)
   In distribution mains and services, the larger diameters of pipe show a higher leak rate than pipe of smaller and intermediate diameters. In transmission systems there is an opposite trend, with the smallest diameters of pipe showing a higher leak rate, while pipe having the greatest diameters show the lowest leak rate.
3. Region: (See Section 2.2.3)
   In distribution mains and services, Region 5 shows a significantly higher leak rate than the other regions. However, for transmission systems, Region 1 shows a significantly higher leak rate than the other regions, and the remaining four regions do not differ significantly.
4. Age: (See Section 2.2.4)
   Considering all types of leaks on all parts of the system, this analysis showed a generally increasing leak rate with the age of the system. The significantly higher leak rates are found in the older systems, particularly those installed before 1929. However, in distribution mains the leak rate for systems installed in the 1970's is significantly higher than the leak rate for the previous two decades.

5. Corrosion: (See Section 2.2.5)

Several analyses were made on the relation of corrosion to the leak rate in pipeline: (1) The corrosion leak rate showed a steady increase with the age of the system. The highest corrosion leak rates invariably were found in systems installed before 1939. (2) In both distribution and transmission systems, the external corrosion leak rate was shown to be definitely higher than the internal corrosion leak rate. (3) In distribution systems, the greatest effect of protection against corrosion is obtained by combining cathodic protection with coating. Although not tested statistically, the combination of the two methods provides the best protection to the transmission systems also.

6. Parts Which Leaked: (See Section 2.2.6)

In both distribution and transmission systems, the majority of individually reported leaks originate on the body of pipe. A smaller percentage, about 10 to 20 percent, of all leaks originate on the fittings. The percentage of leaks originating on the other parts of the pipe is small.

7. Cause: (See Section 2.2.7)

Considering all distribution systems and transmission systems, outside force is the cause of the greatest percentage of individually reported leaks, about 70 percent in distribution systems and 54 percent in transmission systems. Corrosion-caused leaks are the second highest percentage (about 15 percent) in distribution systems. In transmission systems, material failure accounts for about 19 percent of all leaks and corrosion slightly less, with about 15 percent.

8. Third Party Damage versus Age: (See Section 2.2.8)

The leak rate due to third party damage in distribution systems generally increases with age; however, for pipe installed in the 1970's, the third party damage leak rate shows a sudden increase. Pipe installed during the decades of the 1950's and the 1960's shows the lowest leak rates.

9. Metallic versus Plastic Pipe: (See Section 2.2.9)

   a. Overall Leak Rates

      Metallic pipe materials in aggregate show a significantly lower leak rate than the materials used for plastic pipe in distribution systems.

b. Equipment-Caused Leak Rates

Plastic pipe systems were found to have higher equipment-caused leak rates than: (a) the steel and the cast iron pipe in distribution mains and (b) the steel and copper pipe in distribution services.

c. Stoppage Time after a Leak is Detected

Based on the 1973 leak reports, it was concluded that it took less time to stop the leaks in plastic pipe than in metallic pipe. This is true for both distribution mains and services.

d. Injuries, Deaths and Property Damage Resulting from Leaks

More leak reports were filed on a per unit basis for plastic pipe than for metallic pipe in distribution systems. No significant differences were found between plastic and metallic pipe on the basis of injuries, deaths, or property damage, primarily due to the wide variances which resulted from the limited amount of data.

10. Outside Party-Caused Leaks: (See Section 2.2.10)

The leaks produced by outside parties were analyzed by calculating the percentage of leaks that occurred under each combination of three conditions: (1) "prior notification", (2) "marking", and (3) "statute requirement." For example, in distribution mains the largest percentage of leaks (about 28 percent) occur when there has been prior notification, there is a marking and there is no statute requirement. However, no conclusions could be drawn from the data about how these factors affect safety because of the lack of normalizing or exposure data.

11. Estimated Pressure at Time of Incident: (See Section 2.2.11)

The pressure levels at the point and time of the incident show that 14.6 percent of the leaks in distribution systems occurred while the pressure exceeded the maximum allowable pressure. In transmission systems, only 3.2 percent of the individually reported leaks exceeded the maximum allowable pressure.

3.3 CONCLUSIONS DRAWN FROM THE STATISTICAL ANALYSIS OF ANNUAL REPORTS

This section summarizes the major conclusions drawn from the analysis of data from the annual reports, as presented in Section 2.3.

1. Age: (See Section 2.3.1)
   The repaired leak rate generally increases with the age of the pipe. This is true for both distribution and transmission systems. In distribution systems the leak rate of the pipe constructed before 1950 was significantly higher than the leak rate of the systems constructed after 1950. In transmission systems, the leak rate was higher for the systems constructed before 1940. No significant differences were shown for the pipelines constructed since 1940. It was also shown in the analyses of the transmission systems that the welds on the pipe laid before 1930 had higher leak rates. In gathering systems, only the systems constructed before 1930 showed significantly higher leak rates on pipe.
2. Cause: (See Section 2.3.2)
   The majority of repaired leaks are caused by corrosion. These corrosion leaks account for approximately 45 percent of the leaks in distribution systems and 77 percent in transmission systems. When the leaks are classified by the age of the system as well as by the cause, it was again found that corrosion is the major cause in every decade of construction.
3. Parts Which Leaked: (See Section 2.3.3)
   The body of the pipe accounts for 65-75 percent of the repaired leaks in distribution mains and transmission systems, while it accounts for approximately 56 percent in distribution services. The analysis of the data presented in Section 2.3.3 is quite limited because of the lack of normalizing factors.

3.4 CONCLUSIONS CONCERNING INDIVIDUAL OPERATOR ANALYSIS

From the analyses of individual operators presented in Section 2.5, the following conclusions have been drawn:

1. The individual report rate for those accidents involving fire, explosion, death, or injury appears to be the best measure for evaluating the safety performance of individual operators. Unfortunately, at the current time this limits the analysis to only those operators with over 100,000 services. A procedure is presented for identifying operators that appear to have safety problems so that further investigation and possible corrective action may be undertaken.
2. Death and injury rate alone are not sufficiently stable indicators of safety performance to be used exclusively for evaluating individual operators.

3.5 RECOMMENDATIONS

3.5.1 The Data System

1. The exclusion of distribution operators with less than 100,000 services from the requirement to submit an individual failure report seriously limits the usefulness of the data system. Since the operators are currently required to file an annual report, it seems unwise to exclude them from the requirement to file individual failure reports. Therefore, it is recommended that individual failure reports be required of all pipeline operators who now file an annual report.

2. Significant problems of data accuracy exist for 1970 data, and to a lesser extent in the data for 1971, 1972 and 1973. A more extensive data review and audit procedure is necessary if accurate data is to be available for analysis. Therefore, it is recommended that a regular program of auditing should be implemented, using a statistically valid sampling procedure for selecting operators for audit.

3. Other methods of collecting pipeline safety data should be explored, especially the following two methods:

   (a) Data should be collected for more pipeline accidents by in-depth, multidisciplinary accident investigation teams similar to the team staffed by the NTSB for investigating a few selected pipeline accidents.

   (b) The use of the "critical incident technique" by pipeline companies to collect data for use in improving pipeline safety should be encouraged by OPS through a demonstration program and a follow-up educational program in using the technique.

3.5.2 Periodic Data Analysis and Report Generation

1. The individual failure report data should be utilized annually to compare the safety performance of individual operators, as described in Section 2.5.

2. Annual report data and the remaining individual report data should be analyzed at least every two years in a format similar to the one used for this report.

3. When approximately 7-10 years of data have been collected, consideration should be given to using a time-trend type of analysis on a yearly basis. It will be necessary to wait this period of time for most of the usual time-trend analysis methods to be successfully applied.

4. The installation of a computer terminal in the Office of Pipeline Safety for the purpose of performing data analyses does not appear to be justified because of the relatively low level of anticipated use over the entire year and because most of the analyses will require data for the entire report year. Thus, it is recommended that the analyses to be performed on an annual basis be completed each year as a batch-process operation.

APPENDIX A

Contents:

Form Approved: Budget Bureau No. 04-R0...

DEPARTMENT OF TRANSPORTATION

LEAK REPORT—DISTRIBUTION SYSTEM

REPORT DATE

INSTRUCTIONS: Complete this side of this form for each incident regardless of cause. Check appropriate box for specific cause of leak or failure and complete the pertinent part(s) on the reverse side.

☐ CORROSION PART A ☐ DAMAGE BY OUTSIDE FORCES—PART B ☐ CONSTRUCTION DEFECT OR MATERIAL FAILURE—PART C ☐ OTHER *(Describe incident in detail in writing and attach to this form where parts are not applicable.)*

If material to answer an applicable question is not available this should be stated. Only such portions of the form as apply to the particular leak are to be completed. In all parts of the form which are not applicable, the letters "NA" should be inserted so that every item is completed. If additional instruction is needed to complete this form, the operator may telephone the Department of Transportation, Office of Pipeline Safety, Area Code 202, 962-6000, Monday through Friday, 8:30 A.M. to 5:00 P.M. Eastern Time.

GENERAL

1. OPERATOR INFORMATION

NAME OF OPERATOR

NUMBER & STREET

CITY & COUNTY

STATE & ZIP CODE

REPORTING OFFICIAL'S TELEPHONE NUMBER *(Include Area Code)*

2. LOCATION AND TIME OF LEAK OR FAILURE

a. NUMBER & STREET

CITY & COUNTY

STATE & ZIP CODE

b. TIME OF DETECTION (1) DATE (2) HOUR

c. HOURS & MINUTES BETWEEN TIME OF DETECTION & TIME ESCAPE OF GAS WAS STOPPED

d. ESTIMATED PRESSURE AT POINT AND TIME OF INCIDENT (PSIG) ______

e. MAXIMUM ALLOWABLE OPERATING PRESSURE (PSIG) ______

3. METHOD OF LEAK OR FAILURE DETECTION

a. Method: (1) ☐ Routine Maintenance survey (2) ☐ Outside party

b. Reported by: (1) ☐ Operator personnel (2) ☐ Agency causing damage (3) ☐ Customer (4) ☐ Police (5) ☐ Public (6) ☐ Other *(Specify)* ______

4. PART OF SYSTEM WHERE LEAK OR FAILURE OCCURRED

a. ☐ Main b. ☐ Service c. ☐ Other *(Specify)* ______

5. PART OF SYSTEM WHICH LEAKED OR FAILED

a. Part (1) ☐ Pipe (2) ☐ Valve (3) ☐ Fitting (4) ☐ Drip (5) ☐ Regulator (6) ☐ Tap connection (7) ☐ Other *(Specify)* ______

b. Date installed ______

6. MATERIAL WHICH LEAKED OR FAILED

a. Material (1) ☐ Steel (2) ☐ Plastic (3) ☐ Cast iron (4) ☐ Copper (5) ☐ Ductile iron (6) ☐ Wrought iron (7) ☐ Other *(Specify)* ______

b. Was the material that leaked or failed the same material as adjoining pipe or component? (1) ☐ Yes (2) ☐ No
(If "No," describe material in the adjoining component or parts)

c. Is a metallurgical analysis planned? (1) ☐ Yes (2) ☐ No

7. ORIGIN OF LEAK OR FAILURE

a. ☐ Base material fracture b. ☐ Longitudinal weld c. ☐ Girth weld d. ☐ Other field weld e. ☐ Corrosion f. ☐ Other *(Specify)* ______

8. PIPE DESCRIPTION *(If here applicable)*

a. Nominal Diameter *(Inches)*	b. Nominal wall thickness *(Inches)*
c. Specification and grade	d. Grade

9. TYPE OF REPAIR

a. Pipe (1) ☐ Weld over sleeve (2) ☐ Patch-welded (3) ☐ Clamp (4) ☐ Replace pipe *(Length)* ______ feet (5) ☐ Other repair or disposition *(Specify)* ______

b. Component (1) ☐ Replaced (2) ☐ Reconditioned (3) ☐ Other *(Specify)* ______

10. PERSONAL INJURY OR PROPERTY DAMAGE RESULTING FROM ESCAPE OF GAS

a. Number of employee(s) ______
(1) Fatalities ______
(2) Suffering lost-time injuries ______

b. Number of non-employee(s)
(1) Fatalities ______
(2) Injured and requiring medical treatment other than on-site first aid ______

	Yes	No
c. Rupture occurred	(1) ☐	(2) ☐
d. Gas ignited	(1) ☐	(2) ☐
e. Explosion occurred	(1) ☐	(2) ☐
f. Incident induced any secondary explosions or fires	(1) ☐	(2) ☐

g. Estimated value of operator's property damage $ ______

11. ENVIRONMENTAL DESCRIPTION

a. Predominant type of area (1) ☐ Commercial (2) ☐ Industrial (3) ☐ Residential (4) ☐ Rural (5) ☐ Unknown (6) ☐ Other *(Specify)* ______

b. Predominant above-ground structure adjacent to leak

	Multi-story	Single-story
(1) Commercial	a ☐	b ☐
(2) Industrial	a ☐	b ☐
(3) Residential	a ☐	b ☐
(4) Other *(Specify)* ______	a ☐	b ☐

c. Approximate distance to nearest above ground structure *(Within 1 mile of leak)* ______ feet

d. Did other underground facility(ies) contribute to occurrence of leak in any manner? ☐ Yes ☐ No

e. If so, what was effect of existence of other facility(ies)? ______

f. Was other utility(ies) imperiled by the leak? (1) ☐ Yes (2) ☐ No

g. Distance of other facility(ies) or utility(ies) from leak or failure location

Other facility(ies) contributing to			Other utility(ies) impaired
______ Ft.	(1) ☐	Other gas	(8) ☐ ______ Ft.
______ Ft.	(2) ☐	Telephone	(9) ☐ ______ Ft.
______ Ft.	(3) ☐	Electric	(10) ☐ ______ Ft.
______ Ft.	(4) ☐	Sewers *(Storm)*	(11) ☐ ______ Ft.
______ Ft.	(5) ☐	Sewers *(Other)*	(12) ☐ ______ Ft.
______ Ft.	(6) ☐	Water	(13) ☐ ______ Ft.
______ Ft.	(7) ☐	Other *(Specify)*	(14) ☐ ______ Ft.

h. Location of leak or failure (1) ☐ Within building (2) ☐ Above ground (3) ☐ Below ground (4) ☐ Below water (5) ☐ Below other paved area *(Specify)* ______ (6) ☐ Below walkway (7) ☐ Below road — a ☐ Paved b ☐ Median or unpaved

i. Depth of cover ______ inches

j. Soil information at pipe depth (1) ☐ Soil (2) ☐ Rock
(3) Estimated soil temperature at point of leak ______ °F

12. ADDITIONAL DESCRIPTION OF INCIDENT OR FOR CONTINUATION OF EXPLANATION OF ITEMS ABOVE

NAME AND TITLE OF REPORTING OFFICIAL	SIGNATURE OF REPORTING OFFICIAL

Form DOT F 7100.1 (1-70)

PART—A CORROSION

1 GENERAL CORROSION INFORMATION

a. Location
(1) ☐ Internal corrosion
(2) ☐ External corrosion

b. Description
(1) ☐ Pitting
(2) ☐ General

c. Cause
(1) ☐ Galvanic
(2) Bacterial
(3) ☐ Stray current
(4) ☐ Other (Specify) ______

2 PIPE COATING INFORMATION

a. Coating
(1) ☐ Bare
(2) ☐ Coated
(3) ☐ Wrapped

b. Year installed

c. Method of application
(1) ☐ Mill coated
(2) ☐ Yard coated
(3) ☐ Field coated
(4) ☐ Unknown

d. Material
(1) ☐ Coal tar
(2) ☐ Asphalt
(3) ☐ Wax
(4) ☐ Prefabricated film
(5) ☐ Thin-film coatings
(6) ☐ Other (Specify) ______

3 CAUSE OF COATING FAILURE
a. ☐ Damage
b. ☐ Defective material
c. ☐ Defective application
d. ☐ Decomposition
e. ☐ Other (Specify) ______

4 CATHODIC PROTECTION
a. ☐ Yes
b. ☐ No
c. Year started
d. Type
(1) ☐ Impressed
(2) ☐ Galvanic
(3) ☐ Other (Specify) ______

5 pH OF SOIL NEAR LEAK

6 SOIL RESISTIVITY
a. Last soil resistivity measurement in the area of the leak ______ (ohm-cm)
b. Date of measurement
c. Distance from leak (feet)

7 PIPE TO SOIL POTENTIAL
a. Last pipe-to-soil potential measurement at nearest points on each side of the leak ______ (volts) and ______ (volts)
b. Distances from leak to each measurement point ______ (feet) and ______ (feet)
c. Date of measurement

PART—B DAMAGE BY OUTSIDE FORCES

1 PRIMARY CAUSE OF LEAK
a. ☐ Damage by equipment operated by or for operator
b. ☐ Damage by equipment operated by outside party
c. ☐ Damage by earth movement
d. ☐ Other (Specify) ______

2 LOCATING INFORMATION FOR EXCAVATING AND BLASTING INCIDENTS

a. When leak resulted from damage by outside party's equipment, did the operator get prior notification that the equipment would be used in the area?
(1) ☐ Yes (3) Date (4) Time
(2) ☐ No

b. Was the pipeline marked or identified? (1) ☐ Yes (2) ☐ No
(3) If "Yes," what type of marking or identification was used to advise outside party of location of pipeline.
a. ☐ Permanent markers
b. ☐ Map furnished
c. ☐ Temporary stakes
d. ☐ Paint
e. ☐ Excavation
f. ☐ On site observation
g. ☐ Other (Specify) ______

c. Does statute or ordinance require the outside party to determine the location of pipelines
(1) ☐ Yes (2) ☐ No

3. DAMAGE BY EARTH MOVEMENT
a. ☐ Subsidence
b. ☐ Earthquake
c. ☐ Land slide
d. ☐ Washout
e. ☐ Other (Specify) ______

f. Was the earth movement caused by direct or indirect action by others? (1) ☐ Yes (2) ☐ No (If "Yes," explain below)

PART—C CONSTRUCTION DEFECT OR MATERIAL FAILURE

1 PRIMARY CAUSE OF LEAK
a. ☐ Construction defect
b. ☐ Material failure

2. PIPE CLASS (If applicable)

a. Steel
(1) ☐ Seamless
(2) ☐ Electric-resistance welded
(3) ☐ Submerged-arc welded
(4) ☐ Butt welded
(5) ☐ Furnace-lap welded

b. Plastic
(1) ☐ Thermoplastic (2) ☐ Thermosetting
Reinforced ((1) or (2))
a ☐ Yes b ☐ No

c. Cast Iron
(1) ☐ Centrifugally-cast
(2) ☐ Pit cast

d ☐ Other pipe material (Specify)

3 INITIAL TEST DATA
Was this facility strength proofed or leak tested at the time of installation?
a. ☐ Yes b. ☐ No c. ☐ Not known
If "Yes" was test medium:
(1) ☐ Air
(2) ☐ Gas
(3) ☐ Water
(4) ☐ Other (Specify) ______

(5) Date of test
(6) Minimum test pressure (psig)
(7) Time held at test pressure (Hours)
(8) Estimated test pressure at point of leak (psig)

4 SUBSEQUENT TEST DATA
Have there been later strength proof or leak test made? a. ☐ Yes b. ☐ No c. ☐ Not known
If "Yes," Was test medium:
(1) ☐ Air
(2) ☐ Gas
(3) ☐ Water
(4) ☐ Other (Specify) ______

(5) Date of test
(6) Minimum test pressure (psig)
(7) Time held at test pressure (Hours)
(8) Estimated test pressure at point of leak (psig)

Form Approved: Budget Bureau No. 04-R...

DEPARTMENT OF TRANSPORTATION

LEAK OR TEST FAILURE REPORT—TRANSMISSION & GATHERING SYSTEMS

REPORT DATE

☐ LEAK REPORT ☐ TEST FAILURE REPORT ☐ NEW CONSTRUCTION ☐ EXISTING FACILITY *(Specify reason for test)*

INSTRUCTIONS: Complete this side of this form for each incident regardless of cause.
Check appropriate box for specific cause of leak or failure and complete the pertinent part(s) on the reverse side.

☐ CORROSION PART—A ☐ DAMAGE BY OUTSIDE FORCES—PART—B ☐ CONSTRUCTION DEFECT OR MATERIAL FAILURE—PART—C ☐ OTHER *(Describe incident in detail in writing and attach to this form where parts are not applicable.)*

If material to answer an applicable question is not available this should be stated. Only such portions of the form as apply to the particular leak are to be completed. In all parts of the form which are not applicable, the letters "NA" should be inserted so that every item is completed. If additional instruction is needed to complete this form, the operator may telephone the Department of Transportation, Office of Pipeline Safety, Area Code 202, 96-26000, Monday through Friday, 8:30 AM to 5:00 PM Eastern Time.

GENERAL

1. OPERATOR INFORMATION
NAME OF OPERATOR
NUMBER & STREET
CITY & COUNTY
STATE & ZIP CODE
REPORTING OFFICIAL'S TELEPHONE NUMBER *(Include Area Code)*

2. LEAK WITH RUPTURE
a. Shear fracture *(feet)* b. Cleavage fracture *(feet)*
c. Has a fracture toughness test been made on the material that failed? (1) ☐ Yes (2) ☐ No
d. Is a metallurgical analysis planned? (1) ☐ Yes (2) ☐ No

3. LOCATION AND TIME OF LEAK OR FAILURE
a. Number & Street
City & County
State & ZIP Code b. Mile Post c. Survey Station No.
d. Time of Detection (1) Date (2) Hour
e. HOURS & MINUTES BETWEEN TIME OF DETECTION AND TIME ESCAPE OF GAS WAS STOPPED
f. Estimated pressure at point and time of incident *(PSIG)*
g. Maximum allowable operating pressure *(PSIG)*

4. LEAK OR FAILURE OCCURRED ON
a. ☐ Transmission system c. ☐ Gathering system
b. ☐ Transmission line of distribution system

5. PART OF SYSTEM WHICH LEAKED OR FAILED
a. Part
(1) ☐ Pipeline
(2) ☐ Compressor station
(3) ☐ Dehydration plant
(4) ☐ Regulator station
(5) ☐ Meter station
(6) ☐ Other *(Specify)*
b. Date installed

6. ORIGIN OF LEAK OR FAILURE
a. ☐ Body of pipe
b. ☐ Girth weld
c. ☐ Longitudinal weld
d. ☐ Other field weld
e. ☐ Compressor
f. ☐ Valve
g. ☐ Scraper trap
h. ☐ Tap connection
i. ☐ Fitting *(Type)*
j. ☐ Gas cooler
k. ☐ Other *(Specify)*

7. MATERIAL WHICH LEAKED OR FAILED
a. ☐ Steel b. ☐ Plastic c. ☐ Other *(Specify)*

8. PIPE DESCRIPTION
a. Nominal diameter *(Inches)* b. Nominal wall thickness *(Inches)*
c. Pipe specification d. Grade

9. TYPE OF REPAIR
a. Pipe
(1) ☐ Weld over-sleeve
(2) ☐ Patch-welded
(3) ☐ Clamp
(4) ☐ Replace pipe *(length)* ______ feet
(5) ☐ Other repair or disposition *(Specify)*
b. Component
(1) ☐ Replaced
(2) ☐ Reconditioned
(3) ☐ Other *(Specify)*

10. PERSONAL INJURY OR PROPERTY DAMAGE RESULTING FROM ESCAPE OF GAS
a. Number of employee(s)
(1) Fatalities
(2) Suffering lost-time injuries
b. Number of non-employee(s)
(1) Fatalities
(2) Injured and requiring medical treatment other than on-site first aid

	Yes	No
c. Rupture occurred	(1) ☐	(2) ☐
d. Gas ignited	(1) ☐	(2) ☐
e. Explosion occurred	(1) ☐	(2) ☐
f. Incident induced any secondary explosions or fires	(1) ☐	(2) ☐

g. Estimated value of operator's property damage $

11. ENVIRONMENTAL DESCRIPTION
a. Predominant type of area

(1) At time of construction	(2) At time of incident
a ☐ Commercial	a ☐ Commercial
b ☐ Industrial	b ☐ Industrial
c ☐ Residential	c ☐ Residential
d ☐ Rural	d ☐ Rural
e ☐ Undeveloped	e ☐ Undeveloped
f ☐ Unknown	f ☐ Other *(Specify)*
g ☐ Other *(Specify)*	

b. Predominant above-ground structure adjacent to leak

	Multi-story	Single-story
(1) Commercial	a ☐	b ☐
(2) Industrial	a ☐	b ☐
(3) Residential	a ☐	b ☐
(4) None ☐		
(5) Other *(Specify)*	a ☐	b ☐

c. Approximate distance to nearest above-ground structure *(Within 1 mile of leak)* .... feet
d. Did other underground facility(ies) contribute to occurrence of leak in any manner? (1) ☐ Yes (2) ☐ No
e. If so, what was effect on existence of other facility(ies)?
f. Was other utility(ies) imperiled by the leak? (1) ☐ Yes (2) ☐ No
g. Distance of other facility(ies) or utility(ies) from leak or failure location

Other facility(ies) contributing to			Other utility(ies) Impaired
____ Ft. (1) ☐	Other gas	(8) ☐	____ Ft.
____ Ft. (2) ☐	Telephone	(9) ☐	____ Ft.
____ Ft. (3) ☐	Electric	(10) ☐	____ Ft.
____ Ft. (4) ☐	Sewers *(Storm)*	(11) ☐	____ Ft.
____ Ft. (5) ☐	Sewers *(Other)*	(12) ☐	____ Ft.
____ Ft. (6) ☐	Water	(13) ☐	____ Ft.
____ Ft. (7) ☐	Other *(Specify)*	(14) ☐	____ Ft.

h. Location of leak or failure
(1) ☐ Within building
(2) ☐ Above ground
(3) ☐ Below ground
(4) ☐ Below water
(5) ☐ Below walkway
(6) ☐ Below road → a ☐ Paved b ☐ Median or unpaved
(7) ☐ Below other paved area *(Specify)*

(i) Depth of cover ______ *inches*
(j) Soil information at pipe depth (1) ☐ Soil (2) ☐ Rock
(3) Estimated soil temperature at point of leak ______°F

12. ADDITIONAL DESCRIPTION OF INCIDENT OR FOR CONTINUATION OF EXPLANATION OF ITEMS ABOVE

NAME AND TITLE OF REPORTING OFFICIAL | SIGNATURE OF REPORTING OFFICIAL

Form DOT F 7100.2 (-70)

PART—A CORROSION

1. GENERAL CORROSION INFORMATION

a. Location
(1) ☐ Internal corrosion
(2) ☐ External corrosion

b. Description
(1) ☐ Pitting
(2) ☐ General

c. Cause
(1) ☐ Galvanic
(2) ☐ Bacterial
(3) ☐ Stray current
(4) ☐ Other (Specify) ________

2. PIPE COATING INFORMATION

a. Coating
(1) ☐ Bare
(2) ☐ Coated
(3) ☐ Wrapped

b. Year installed ________

c. Method of application
(1) ☐ Mill coated
(2) ☐ Yard coated
(3) ☐ Field coated
(4) ☐ Unknown

d. Material
(1) ☐ Coal tar
(2) ☐ Asphalt
(3) ☐ Wax
(4) ☐ Prefabricated film
(5) ☐ Thin-film coatings
(6) ☐ Other (Specify) ________

3. CAUSE OF COATING FAILURE

a. ☐ Damage
b. ☐ Defective material
c. ☐ Defective application
d. ☐ Decomposition
e. ☐ Other (Specify) ________

4. CATHODIC PROTECTION

a. ☐ Yes
b. ☐ No
c. Year started ________
d. Type
(1) ☐ Impressed
(2) ☐ Galvanic
(3) Other (Specify) ________

5. pH OF SOIL NEAR LEAK

6. SOIL RESISTIVITY

a. Last soil resistivity measurement in the area of the leak ________ (ohm-cm)

b. Date of measurement

c. Distance from leak (Feet)

7. PIPE-TO-SOIL POTENTIAL

a. Last pipe-to-soil potential measurement at nearest points on each side of the leak ____(Volts) and ____(Volts)

b. Distances from leak to each measurement point ____(Feet) and ____(Feet)

c. Date of measurement

PART—B DAMAGE BY OUTSIDE FORCES

1. PRIMARY CAUSE OF LEAK

a. ☐ Damage by equipment operated by or for operator
b. ☐ Damage by equipment operated by outside party
c. ☐ Damage by earth movement
d. ☐ Other (Specify) ________

2. LOCATING INFORMATION FOR EXCAVATING AND BLASTING INCIDENTS

a. When leak resulted from damage by outside party's equipment, did the operator get prior notification that the equipment would be used in the area?
(1) ☐ Yes
(2) ☐ No
(3) Date
(4) Time

b. Was the pipeline marked or identified? (1) ☐ Yes (2) ☐ No
(1) If "Yes," what type of marking or identification was used to advise outside party of location of pipeline?
a ☐ Permanent markers
b ☐ Map furnished
c ☐ Temporary stakes
d ☐ Paint
e ☐ Excavation
f ☐ On-site observation
g ☐ Other (Specify) ________

c. Does statute or ordinance require the outside party to determine the location of pipelines
(1) ☐ Yes (2) ☐ No

3. DAMAGE BY EARTH MOVEMENT

a. ☐ Subsidence
b. ☐ Earthquake
c. ☐ Landslide
d. ☐ Washout
e. ☐ Other (Specify) ________

f. Was the earth movement caused by direct or indirect action of others? (1) ☐ Yes (2) ☐ No (If Yes, explain)

PART—C CONSTRUCTION DEFECT OR MATERIAL FAILURE

1. PRIMARY CAUSE OF LEAK a ☐ Construction defect b ☐ Material failure

2. DESCRIPTION OF PIPE

a. Manufacturer

b. Where was pipe manufactured

c. Year manufactured ________
(1) ☐ Expanded (2) ☐ Nonexpanded

d. Method of transportation
(1) ☐ Truck (2) ☐ Rail (3) ☐ Ship (4) ☐ Other (Specify) ________ (5) ☐ Unknown

3. PIPE CLASS

a. Steel
(1) ☐ Seamless
(2) ☐ Electric-resistance welded
(3) ☐ Submerged-arc welded
(4) ☐ Butt welded
(5) ☐ Furnace-lap welded

b. Plastic
(1) ☐ Thermoplastic
(2) ☐ Thermosetting
Reinforced ((1) or (2))
a. ☐ Yes b. ☐ No

c. Cast Iron
(1) ☐ Centrifugally cast
(2) ☐ Pit cast

d. Other pipe material (Specify) ________

4. CONSTRUCTION TYPE AT TIME OF LEAK OR FAILURE AS DEFINED IN USAS B31.8-1968 CODE: ☐ A ☐ B ☐ C ☐ D

5. INITIAL TEST DATA

Was the line strength proof tested at the time of installation?
a. ☐ Yes b. ☐ No c. ☐ Not known

If "Yes," what was test medium
(1) ☐ Air
(2) ☐ Gas
(3) ☐ Water
(4) ☐ Other (Specify) ________
(5) Date of test
(6) Minimum test pressure (psig)
(7) Time held at test pressure (Hours)
(8) Estimated test pressure at point of leak (psig)

6. SUBSEQUENT TEST DATA

Have there been later strength proof tests made? a. ☐ Yes b. ☐ No c. ☐ Not known

If "Yes," Was test medium:
(1) ☐ Air
(2) ☐ Gas
(3) ☐ Water
(4) ☐ Other (Specify) ________
(5) Date of test
(6) Minimum test pressure (psig)
(7) Time held at test pressure (Hours)
(8) Estimated test pressure at point of leak (psig)

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DECEMBER 1972

DEPARTMENT OF TRANSPORTATION
Office of Pipeline Safety
Washington, D.C. 20590

INSTRUCTIONS FOR COMPLETING FORM DOT-F-7100.1-1
"ANNUAL REPORT FOR CALENDAR YEAR 19____,
DISTRIBUTION SYSTEM"

NOTE: These instructions supersede all previous instructions.

General Instructions: Each operator of a gathering system in a nonrural area, of a transmission system, or of a distribution system is required to file an annual report. Section 192.3, 49 CFR defines the following:

1. "Distribution line" means a pipeline other than a gathering or transmission line.

* 2. "Gathering line" means a pipeline that transports gas from a current production facility to a transmission line or main.

* 3. "Transmission line" means a pipeline other than a gathering line that -

   a. Transports gas from a gathering line or storage facility to a distribution center or storage facility;

   b. Operates at a hoop stress of 20 percent or more of SMYS: or

   c. Transports gas within a storage field.

The reporting requirements are contained in Part 191 of Title 49 of the Code of Federal Regulations "Transportation of Natural and Other Gas by Pipeline: Reports of Leaks." Each operator of a distribution system, except petroleum gas systems which serve less than 100 customers from a single source, must submit an annual report Form DOT-F-7100.1-1 for the preceding calendar year not later than February 15. If an operator has more than one type of system, he must file an appropriate report for each type.

The annual report must be submitted to the Director, Office of Pipeline Safety, Department of Transportation, Washington, D.C. 20590. If the regulations of a State agency require submission of duplicate copies of the annual report through that agency, the operator should comply with that requirement. In doing so, the operator should give the State agency sufficient time to submit the report to the Office of Pipeline Safety by February 15.

The annual reporting period is on a calendar basis, beginning January 1 and ending on December 31 of each year.

Each independent subsidiary operation must report separately. The address of the operator should be that address where information regarding this report can be obtained.

Section 191.5 sets forth the regulation concerning telephonic notice of certain leaks. The new telephone number for reporting these leaks, as amended April 16, 1971, is area code 202 426-0700. Disregard the telephone number on Form DOT-F-7100.1-1.

If you have any questions concerning this report, please write or call the Office of Pipeline Safety, Department of Transportation, Washington, D.C. 20590, telephone number 202 426-2082.

*If the operator determines that he has facilities that fall under either of these definitions, he should refer to the instructions for completing Form DOT-F-7100.2-1 for gathering and transmission lines.

Form Approved OMB No. 04-R5008

DEPARTMENT OF TRANSPORTATION

ANNUAL REPORT FOR CALENDAR YEAR 19
DISTRIBUTION SYSTEM

When data are readily available, such data should be reported. Current year reporting should be actual data. When back data are not obtainable without a major effort to reconstruct prior years, estimates may be reported and so noted. A brief explanation of the procedures used in deriving estimates should be attached. Each operator shall submit separate reports for each of his corporate subsidiaries that transports gas. If additional instruction is needed to complete this form, the operator may telephone the Department of Transportation, Office of Pipeline Safety, Area Code 202 962-6000, Monday through Friday, 8:30 a.m. to 5:00 p.m. Eastern Time.

PART A—OPERATOR INFORMATION

NAME OF OPERATOR	NUMBER & STREET	REPORTING OFFICIAL'S TELEPHONE NUMBER (Include Area Code)
CITY & COUNTY	STATE & ZIP CODE	

TR	TP	YEAR	OPR I.D.	← OPS USE ONLY

	ITEM			UNKNOWN	PRIOR TO 1930	1930 THRU 1939	1940 THRU 1949	1950 THRU 1959	1960 THRU 1969	1/1/70 TO 12/31 OF REPORTING YEAR	SYSTEM TOTAL
PART B — DESCRIPTION OF PIPE IN SYSTEM AT END OF YEAR	Pipe by Construction Date	MILES OF MAINS									
		NUMBER OF SERVICES									
	Coated A Pipe by Coating Date	MILES OF MAINS									
		NUMBER OF SERVICES									
PART C — CATHODICALLY PROTECTED SYSTEM	Coated A Pipe by Protection Date	MILES OF MAINS									
		NUMBER OF SERVICES									
	Bare B Pipe by Protection Date	MILES OF MAINS									
		NUMBER OF SERVICES									
PART D — LEAKS ON MAINS REPAIRED DURING YEAR (By year installed) (R = Leaks reported and NR = leaks not reported under Section 191.9)	PIPE		R								
			NR								
	VALVE		R								
			NR								
	FITTING		R								
			NR								
	DRIP		R								
			NR								
	REGULATOR		R								
			NR								
	TAP CONNECTION		R								
			NR								
	OTHER		R								
			NR								
PART E — LEAKS ON SERVICES REPAIRED DURING YEAR (By year installed) (R = Leaks reported and NR = leaks not reported under Section 191.9)	PIPE		R								
			NR								
	VALVE		R								
			NR								
	FITTING		R								
			NR								
	DRIP		R								
			NR								
	REGULATOR		R								
			NR								
	TAP CONNECTION		R								
			NR								
	OTHER		R								
			NR								
PART F — TOTAL LEAKS REPAIRED DURING YEAR BY CAUSE (Number by year installed)	CORROSION										
	DAMAGE BY OUTSIDE FORCE										
	CONSTRUCTION DEFECT										
	MATERIAL FAILURE										
	OTHER										

A Pipe coated with any hot or cold applied coating or wrapper

B Pipe without any type of hot or cold applied coating or wrapper

PART G

MILES OF MAINS IN SYSTEM AT END OF YEAR

MAINS		1" OR LESS	OVER 1" THRU 2	OVER 2" THRU 4	OVER 4" THRU 6	8	10	12	OVER 12	TOTAL
BY MATERIAL	STEEL									
	WROUGHT IRON									
	CAST IRON									
	DUCTILE IRON									
	COPPER									
	PLASTIC									
	OTHER (Specify) ________									
	TOTAL SYSTEM									

PART H

NUMBER OF SERVICES IN SYSTEM AT END OF YEAR

SERVICES		NOMINAL SIZE							
		UNKNOWN	1/2" OR LESS	OVER 1/2 THRU 1"	OVER 1 THRU 2	OVER 2 THRU 4"	OVER 4" THRU 6	OVER 6	TOTAL
BY MATERIAL	STEEL								
	CAST IRON								
	COPPER								
	PLASTIC								
	OTHER (Specify) ________								
	TOTAL SYSTEM								

PART I

MAINS AND SERVICES INSTALLED DURING YEAR		EXPANSION	REPLACEMENT
	MILES OF MAINS		
	NUMBER OF SERVICES		

PART J

MAINS AND SERVICES RETIRED DURING YEAR		
	MILES OF MAINS	
	NUMBER OF SERVICES	

PART K

MILES OF MAINS CATHODICALLY PROTECTED

PART L

CATHODICALLY PROTECTED SYSTEM: FREQUENCY OF INSPECTION

LOCATION [C]	FREQUENCY [D] OF INSPECTION BY TYPE: P/S POTENTIAL	CURRENT OUTPUT	INDICATING METER (Warning system)
COMMERCIAL			
INDUSTRIAL			
RESIDENTIAL			
RURAL			

PART M

LEAK SURVEYS DURING YEAR: % OF SYSTEM COVERED BY TYPE AND FREQUENCY OF SURVEY

LOCATION [C]	% OF SYSTEM COVERED: FLAME IONIZATION	VEGETATION	AVAILABLE OPENING (Combustible gas indicator)	BAR HOLE (Combustible gas indicator)	INFRARED	OTHER (Specify)	FREQUENCY [D]
COMMERCIAL							
INDUSTRIAL							
RESIDENTIAL							
RURAL							

PART N

UNACCOUNTED FOR GAS FOR LAST 5 YEARS BASED ON % OF TOTAL INPUT FOR 12 MONTHS ENDING JUNE 30 EXCLUDING CURRENT YEAR (*The system for which these figures apply may include transmission*)

YEARS AGO	%
5	
4	
3	
2	
1	

PART O

UNACCOUNTED FOR GAS DURING PAST 12 MONTHS ENDING LAST JUNE 30	%

PART P

NUMBER OF KNOWN SYSTEM LEAKS AT END OF YEAR SCHEDULED FOR REPAIR	MAINS	
	SERVICES	

PART Q

TOTAL PERSONAL INJURIES OR PROPERTY DAMAGE RESULTING FROM ESCAPE OF GAS DURING YEAR

NUMBER OF EMPLOYEE(S) OF OPERATOR	FATALITIES	
	SUFFERING LOST TIME INJURIES	
NUMBER OF EMPLOYEE(S) OF CONTRACTORS	FATALITIES	
	SUFFERING LOST TIME INJURIES	
NUMBER OF NON-EMPLOYEE(S)	FATALITIES	
	INJURED & REQUIRING MEDICAL TREATMENT OTHER THAN ON-SITE FIRST AID	

NUMBER OF FIRES		
NUMBER OF EXPLOSIONS		
NUMBER OF INDUCED SECONDARY EXPLOSIONS OR FIRES		
ESTIMATED AGGREGATE VALUE OF PROPERTY DAMAGE TO	OPERATOR	$
	OTHERS — FOR ALL CASES SETTLED DURING THE REPORTING YEAR	$

C *Definitions of locations should be in accord with operator's customary practice*

D *Frequency codes: 1 Weekly, 2 Bi-weekly, 3 Monthly, 4 Quarterly, 5 Semiannually, 6 Annually, 7 Other, 0 No inspection or survey*

NAME AND TITLE OF REPORTING OFFICIAL	SIGNATURE OF REPORTING OFFICIAL

U.S. GOVERNMENT PRINTING OFFICE

DEPARTMENT OF TRANSPORTATION
Office of Pipeline Safety
Washington, D.C. 20590

INSTRUCTIONS FOR COMPLETING FORM DOT-F-7100.2-1
"ANNUAL REPORT FOR CALENDAR YEAR 19____, GAS
TRANSMISSION & GATHERING SYSTEMS"

NOTE: These instructions supersede all previous instructions.

General Instructions: Each operator of a gathering system in a nonrural area, of a transmission system, or of a distribution system is required to file an annual report. Section 192.3, 49 CFR defines the following:

1. "Gathering line" means a pipeline that transports gas from a current production facility to a transmission line or main;

2. "Transmission line" means a pipeline other than a gathering line, that -

    a. Transports gas from a gathering line or storage facility to a distribution center or storage facility;

    b. Operates at a hoop stress of 20 percent or more of SMYS; or

    c. Transports gas within a storage field.

*3. "Distribution line" means a pipeline other than a gathering or transmission line.

The reporting requirements are contained in Part 191 of Title 49 of the Code of Federal Regulations "Transportation of Natural and Other Gas by Pipeline: Reports of Leaks." Each operator of a nonrural gathering system or of a transmission system must submit an annual report Form DOT-F-7100.2-1 for the preceding calendar year not later than February 15. If an operator has more than one type of system, he must file an appropriate report for each type.

The annual report must be submitted to the Director, Office of Pipeline Safety, Department of Transportation, Washington, D.C. 20590. If the regulations of a State agency require submission of duplicate copies of the annual report through that agency, the operator should comply with that requirement. In doing so, the operator should give the State agency sufficient time to submit the report to the Office of Pipeline Safety by February 15.

The annual reporting period is on a calendar basis, beginning January 1 and ending on December 31 of each year.

Each independent subsidiary operation must report separately. The address of the operator should be that address where information regarding the report can be obtained.

Section 191.5 sets forth the regulation concerning telephonic notice of certain leaks. The new telephone number for reporting these leaks, as amended April 16, 1971, is area code 202 426-0700. Disregard the telephone number on Form DOT-F-7100.2-1.

If you have any questions concerning this report, please write or call the Office of Pipeline Safety, Department of Transportation, Washington, D.C. 20590, telephone number 202 426-2082.

*If the operator determines that he has facilities that fall under this definition, he should refer to the instructions for completing Form DOT-F-7100.1-1 for distribution lines.

14873

Form Approved OMB No. 04-R5606

DEPARTMENT OF TRANSPORTATION

ANNUAL REPORT FOR CALENDAR YEAR 19 ___
GAS TRANSMISSION & GATHERING SYSTEMS

When data are readily available, such data should be reported. Current year reporting should be actual data. When back data are not obtainable without a major effort to reconstruct prior years, estimates may be reported and so noted. A brief explanation of the procedures used in deriving estimates should be attached. Each operator shall submit separate reports for each of his corporate subsidiaries that transports gas. If additional instruction is needed to complete this form, the operator may telephone the Department of Transportation, Office Of Pipeline Safety, Area Code 202 962-6000, Monday through Friday, 8:30 a.m. to 5:00 p.m. Eastern Time.

PART A—OPERATOR INFORMATION

NAME OF OPERATOR	NUMBER & STREET	REPORTING OFFICIAL'S TELEPHONE NUMBER (Include Area Code)
CITY AND COUNTY	STATE & ZIP CODE	

TR	TP	YEAR	OPR I D	← OPS USE ONLY

Part	ITEM			UNKNOWN	PRIOR TO 1930	1930 THRU 1939	1940 THRU 1949	1950 THRU 1959	1960 THRU 1969	1/1/70 TO 12/31 OF REPORTING YEAR	SYSTEM TOTAL
PART B DESCRIPTION OF PIPE IN SYSTEM AT END OF YEAR	Miles of Pipe by Construction Date	TRANS-MISSION									
		GATHER-ING									
	Miles of Coated [A] Pipe by Coating Date	TRANS-MISSION									
		GATHER-ING									
PART C CATHODICALLY PROTECTED SYSTEM	Miles of Coated [A] Pipe by Protection Date	TRANS-MISSION									
		GATHER-ING									
	Miles of Bare [B] Pipe by Protection Date	TRANS-MISSION									
		GATHER-ING									
PART D TRANSMISSION SYSTEM LEAKS REPAIRED DURING YEAR (By Year Installed) ("R" = Leaks reported and "NR" = Leaks not reported under Sec. 191.15)	BODY OF PIPE		R								
			NR								
	GIRTH WELD		R								
			NR								
	LONGITUDINAL WELD		R								
			NR								
	OTHER WELDS		R								
			NR								
	COMPRESSOR [C]		R								
			NR								
	VALVE		R								
			NR								
	SCRAPER TRAP		R								
			NR								
	TAP CONNECTION		R								
			NR								
	FITTING		R								
			NR								
	GAS COOLER		R								
			NR								
	OTHER		R								
			NR								
PART E GATHERING SYSTEM LEAKS REPAIRED DURING YEAR (By Year Installed) ("R" = Leaks reported and "NR" = Leaks not reported under Sec. 191.15)	BODY OF PIPE		R								
			NR								
	GIRTH WELD		R								
			NR								
	LONGITUDINAL WELD		R								
			NR								
	OTHER WELDS		R								
			NR								
	COMPRESSOR [C]		R								
			NR								
	VALVE		R								
			NR								
	SCRAPER TRAP		R								
			NR								
	TAP CONNECTION		R								
			NR								
	FITTING		R								
			NR								
	GAS COOLER		R								
			NR								
	OTHER		R								
			NR								

[A] Pipe coated with any hot or cold applied coating or wrapper
[B] Pipe without any type of hot or cold applied coating or wrapper
[C] Compressor includes the main body of the unit and appurtenances thereto that are not listed separately on the left above

Form DOT F 7100.2-1 (10-70)

PART F

TOTAL LEAKS REPAIRED DURING YEAR BY CAUSE (NUMBER BY YEAR INSTALLED)

CAUSE OF LEAK	UNKNOWN	PRIOR TO 1960	1960 THRU 1964	1965 THRU 1967	1968 THRU 1969	1/1/70 TO 12/31 OF REPORTING YEAR	SYSTEM TOTAL
CORROSION							
DAMAGE BY OUTSIDE FORCE							
CONSTRUCTION DEFECT							
MATERIAL FAILURE							
OTHER							

PART G

MILES OF PIPE IN SYSTEM AT END OF YEAR

BY MATERIAL

SYSTEM	STEEL	PLASTIC	OTHER (Specify)	SYSTEM TOTAL
TRANSMISSION →				
GATHERING →				

BY NOMINAL SIZE

MILES

SYSTEM	1" OR LESS	OVER 1" THRU 2"	OVER 2" THRU 4"	OVER 4" THRU 6"	8"	10"	12"	14"
TRANSMISSION								
GATHERING								
SYSTEM TOTAL								

SYSTEM	16"	18"	20"	22"	24"	26"	28"	30"
TRANSMISSION								
GATHERING								
SYSTEM TOTAL								

SYSTEM	32"	34"	36"	38"	40"	42"	ABOVE 42"
TRANSMISSION							
GATHERING							
SYSTEM TOTAL							

PART H

MILES INSTALLED DURING YEAR

SYSTEM	EXPANSION	REPLACEMENT
TRANSMISSION		
GATHERING		

PART I

MILES RETIRED DURING YEAR

SYSTEM	
TRANSMISSION	
GATHERING	

PART J

MILES OF TOTAL SYSTEM CATHODICALLY PROTECTED

PART K

CATHODICALLY PROTECTED SYSTEM: FREQUENCY OF INSPECTION

LOCATION ᴰ	FREQUENCY ᴱ OF INSPECTION BY TYPE: P/S POTENTIAL	CURRENT OUTPUT	INDICATING METER (Warning system)
COMMERCIAL			
INDUSTRIAL			
RESIDENTIAL			
RURAL			

PART L

FREQUENCY AND METHOD OF LEAK SURVEYS DURING YEAR

LOCATION ᴰ	FREQUENCY ᴱ OF SURVEY BY METHOD: AERIAL	FLAME IONIZATION	COMBUSTIBLE GAS INDICATOR	INFRARED	VEGETATION	OTHER
COMMERCIAL						
INDUSTRIAL						
RESIDENTIAL						
RURAL						

PART M

NUMBER OF KNOWN SYSTEM LEAKS AT END OF YEAR SCHEDULED FOR REPAIR →	TRANSMISSION	
	GATHERING	

PART N

TOTAL PERSONAL INJURIES OR PROPERTY DAMAGE RESULTING FROM ESCAPE OF GAS DURING YEAR

NUMBER OF EMPLOYEE(S) OF OPERATOR	FATALITIES	
	SUFFERING LOST TIME INJURIES	
NUMBER OF EMPLOYEE(S) OF CONTRACTORS	FATALITIES	
	SUFFERING LOST TIME INJURIES	
NUMBER OF NON-EMPLOYEE(S)	FATALITIES	
	INJURED & REQUIRING MEDICAL TREATMENT OTHER THAN ON-SITE FIRST AID	

NUMBER OF FIRES	
NUMBER OF EXPLOSIONS	
NUMBER OF INDUCED SECONDARY EXPLOSIONS OR FIRES	

ESTIMATED AGGREGATE VALUE OF PROPERTY DAMAGE TO	OPERATOR	$
	OTHERS — FOR ALL CASES SETTLED DURING THE REPORTING YEAR	$

REMARKS

ᴰ Definitions of location should be in accord with company's customary practice.

ᴱ Frequency Code: 1 Weekly, 2 Biweekly, 3 Monthly, 4 Quarterly, 5 Semiannually, 6 Annually, 7 Other, 0 No inspection or survey

NAME AND TITLE OF REPORTING OFFICIAL	SIGNATURE OF REPORTING OFFICIAL

U.S. GOVERNMENT PRINTING OFFICE : 1970 [illegible]

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OFFICE OF THE SECRETARY
Washington, D.C. 20590

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