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STUDY ON CURRENT PRACTICES, TECHNOLOGIES, PROBLEMS, AND RECOMMENDATIONS RELATING TO THE OVERALL SAFETY OF GAS PIPELINE DISTRIBUTION SYSTEMS

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16. Abstract

This study provides an overall assessment of the safety of natural gas distribution systems and the measures being promoted or in use to increase safety. The report summarizes data collected by the Office of Pipeline Safety Operations (OPSO) and the results of OPSO sponsored studies and other research intended to improve the safety of specific gas distribution problems. The report focuses on several problem areas identified as important from a safety standpoint and formulates conclusions and recommendations basec. on previous work and research currently underway. Techniques employed included a wide literature survey, review of leakage data, and fault tree analysis. The main topics in the report relate to gas distribution pipeline system inspection and assessment, corrosion, outside force damage, odorization, plastic pipe usage, emergency plans, valving and rapid shutdown, and master metering. Results include findings, conclusions, and recommendations for increasing gas system safety for each topic.

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SECTION 1

INTRODUCTION

This study was conducted for the Office of Pipeline Safety Operations (OPSO) to provide an overall assessment of safety of gas distribution systems. These systems deliver natural gas to over 44 million customers in this country each day through a million-mile piping network, most of which is buried underground. This is a form of transportation that is usually unseen and unheard by the public it serves. However, since the product carried is a flammable gas and is present where people live, work, shop, and play, the safety of these systems cannot be overlooked.

The need for an overall study stems from the multiplicity of independent and sometimes uncoordinated activities going on that bear on safety, and the relative recency of the creation of a regulatory unit at the federal level for applying uniform safety standards countrywide. Prior to 1968 the gas distribution systems' safety requirements first evolved as a matter of self-regulation and were then further shaped by the formation of various municipal and state regulatory agencies. In 1968, the Natural Gas Pipeline Act set up the OPSO to regulate safety in .gas utilities. By this act the OPSO inherited jurisdiction over a vast segment of pipelines of which in some cases little was known. Further, a great number of companies with various ways of dealing with problems came under OPSO regulations. The method chosen to initiate this gas safety program was to incorporate into regulations standards previously used by gas companies. These regulations would then be amended in future years to provide increased safety.

Recognizing the complexity of safety problems in distribution systems, OPSO initiated this study to provide an overview and appraisal of the overall situation. To be included in this review were:

a. Four years of reports to OPSO of distribution system leakage data.
b. Three OPSO-sponsored studies of specific distribution system safety aspects.

c. Applicable research conducted or sponsored by the gas industry and others.

1.1 PURPOSE

The purpose of this report is to present a summary of overall safety problems of gas distribution systems and the current practices and technologies in use or available for controlling them. It includes an identification of safety problems together with an examination of methods for containment or reduction of these problems. These methods include procedures and equipment in use at the present time, those under development or recently introduced to the gas industry, and those which require improvement or further research.

1.2 PROGRAM OBJECTIVES

The objective of this work is to present a cohesive summary of current practices, technologies and problems related to the overall safety of gas distribution systems and includes:

- Definition of safety problems through analysis of leakage and failure reports, and results of conducted surveys.
- Consolidation of results of research initiated by OPSO to indicate the progress accomplished to-date and impact for the future.
- Investigation and evaluation of research and work performed by OPSO and others for an overall assessment of present day practices, technologies, solutions, and unresolved safety problems of the gas industry.

1.3 SCOPE

At the outset of the program the only boundary placed on the scope of this report was to limit it to natural gas distribution systems. This allowed a broad approach to be assumed such that all or any safety problems of the gas distribution systems could be included. The criteria used to determine the topics detailed in this report were that only the major problems identified by leakage or failure reports or those where sufficient data was available for a quantified definition would be studied in depth. Other problem areas not meeting the noted criteria but developed in this report, are identified as topics for future consideration.

1.4 APPROACH

The approach used was to initially review failure and leakage data and literature from as many sources as possible to identify safety problem areas and possible solutions. From these sources, specific problems were identified as important either by their frequent mention in many reports or by the high percentages of occurrences. After these problems were so identified, the rest of the study concentrated on them.

The program approach is shown in Figure 1-1. Of primary importance are the analyses and surveys of leakage data, gas operators, OPSO reports, equipment manufacturers and service companies and literature and research. Each of these is discussed to indicate the information obtained and how it was used to define the safety problems such that current and proposed solutions could be evaluated.

1.4.1 Analysis of Leakage Data

Leakage data and failure reports were analyzed to determine both primary and contributory causes of failures and reportable incidents. The primary causes centered on the frequency and magnitude of the various types of leaks experienced in gas distribution systems. The contributing causes included items which allowed the leak to occur (i.e., a coating holiday allowed corrosion) or allowed the leak to attain hazardous proportions (personnel errors or slow emergency response). This data included:

OPSO Annual Reports

OPSO Leak Report Summaries

National Transportation Safety Board Reports

Special Reports and Analyses (American Gas Association & University of Oklahoma)

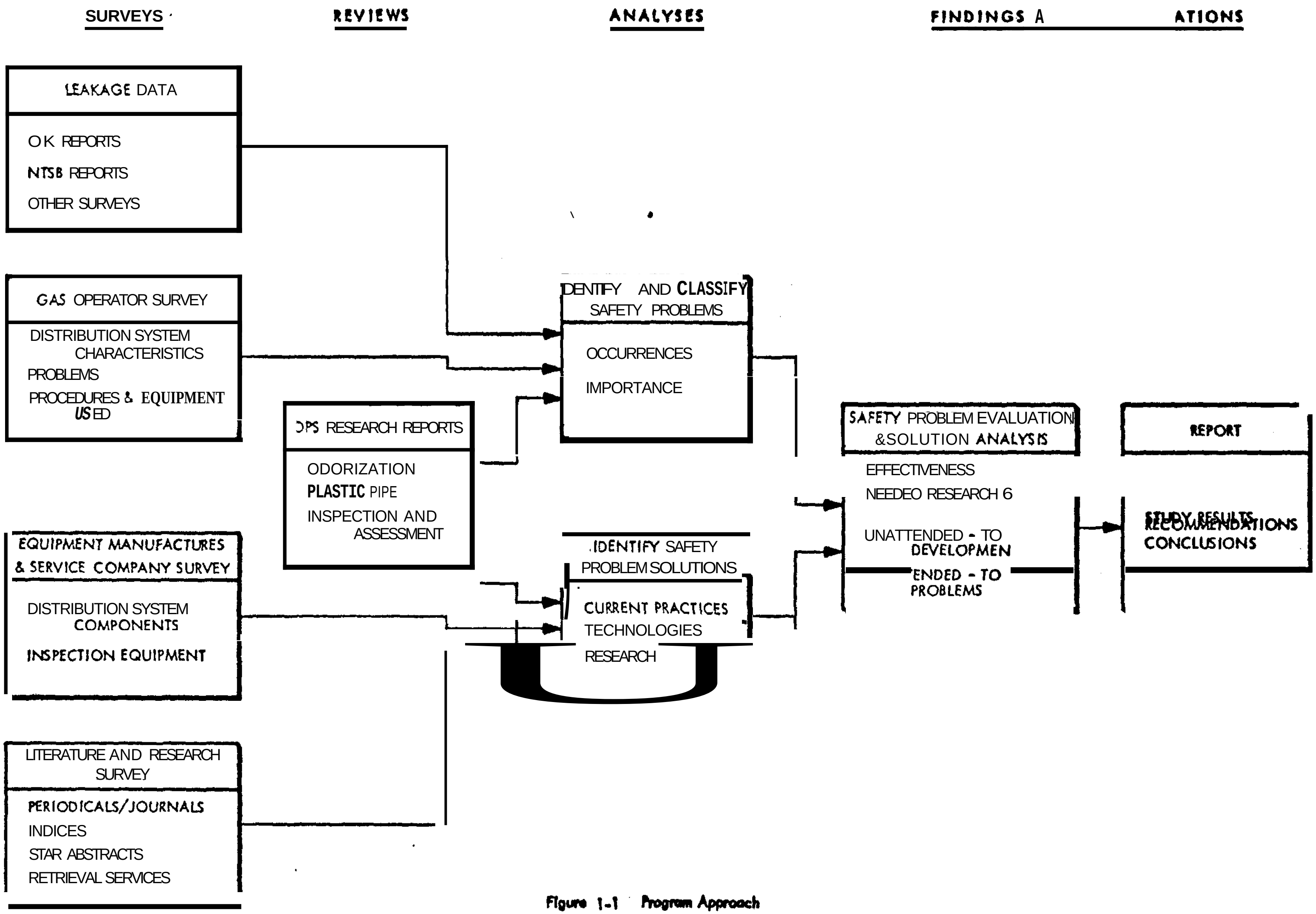

Figure 1-1 Program Approach

This formed the study data base for identification of safety problems, analysis of occurrences, and importance for classification purposes.

1.4.2 Gas Distribution Operator Survey

A number of gas utility operators were surveyed to identify the safety problems faced by the pipeline industry and to determine their more effective or desired solutions. It was also possible to obtain a descriptive characterization of various distribution systems and an assessment of the interfaces between maintenance, operation and management problems encountered in running these systems. Both personal visits and telephone contacts were used to obtain a representative cross section of the gas utility industry with regard to company size, age, geographical location and climate. Additionally, attendance at OPSO conducted meetings and AGA Conferences broadened the gas operator survey base.

1.4.3 OPSO Research Reports

The results of research studies initiated by OPSO were obtained and analyzed, for inclusion in this report. The specific reports of major importance completed in 1975 were:

- Pipeline Industry's Practices Using Plastic Pipe in Gas Pipeline Facilities and the Resulting Safety Factors.
- Study of the Properties of the Numerous Odorants and of Their Effectiveness in Various Environmental Conditions to Alert People to the Presence of Natural Gas.
- Study to Evaluate the Tools and Procedures for Assessing the Safety of Existing Gas Distribution Systems.

Additionally, prior OPSO reports on rapid shutdown of failed pipeline systems and on pipeline corrosion processes, detection and mitigation were reviewed. Incorporation of OPSO research into this report was important for consolidation purposes and because of its relevance to increased safety.

1.4.4 Manufacturers and Service Company Surveys

Information from over 100 companies was requested and received during the program on actual distribution components, pipeline inspection equipment, and services performed for utilities. Equipment specifications and brochures, instruction manuals, and application reports were obtained and reviewed to determine the procedures and equipment used and the extent of their application to safety problems.

1.4.5 Literature and Research Survey

An extensive literature survey was conducted with emphasis on articles published in the past five years, in order to obtain state-of-the-art information concerning new developments and applications of technology. The resources of four major libraries were used to cover the Applied Science and Technology Index, Engineering Index and gas and pipeline journals and periodicals. Government sources and the gas industry itself (through AGA publications) were investigated. Data search services of the Institute of Gas Technology (MASTIR) and the Smithsonian Science Information Exchange Research system were employed.

SECTION 2

SUMMARY

Although gas distribution systems are relatively mature in a technological sense, dating back almost a century, their regulation for safety from the federal level is recent. During this period of their existence, these systems have successively been expanding, consolidating, repairing, and then upgrading to meet the problems associated with terrain, weather, soil conditions, and urban complexity. The resultant picture today is a system of some 1700 companies of diverse age, size, materials and components.

In looking at their safety problems, it becomes evident that while there are some problems which are attendant to specific utilities or local conditions, others are common to a majority of gas utilities. These are either manifested in leakage and failure reports or are somewhat obvious based upon the utilities' make-up, purpose, and desire to maintain safe systems. Most problems relate back to unintentional leakages of gas from numerous possible causes in a manner or location where it becomes a potential hazard. As such, the overall problem or solutions are related to accurate location of actual or potential leaks, warnings that leakage is occurring, prevention of the major leak causes, and the handling of leaks after occurrence. The topics which bear directly on these overall safety problems include assessment of pipelines, corrosion, outside forces, odorization, plastic pipe, emergency plans, valving and rapid shutdown and master metering.

With respect to these topics, it should be noted that they are acknowledged throughout the industry and considerable work and research has been and is being performed. Individual gas companies and the American Gas Association (AGA) have sponsored research into these fields in the natural course of their operations. The American Society of Mechanical Engineers (ASME) and the

National Association of Corrosion Engineers (NACE) have supplied guidelines and specifications to assist in solving some of these pipeline problems. These organizations and others have been relied on to provide the investigations and direction for maintaining safe systems. More recently the Federal Government has sponsored research and enacted regulations to provide minimum requirements for uniformity in action and control of these problems and others. Overall, while controls and improvements have been made, some problems still remain to be solved or mitigated.

The methods now used by gas utilities to determine the physical condition and integrity of their pipelines are largely based on detecting and locating leaks. This procedure is essentially after-the-fact and largely precludes preventative maintenance. Efforts should be promoted to develop methods for identifying and locating deteriorating conditions before failure occurs and leakage ensues. Two techniques of nondestructive testing - acoustic emission and ultrasonics - appear to hold promise for such application.

Corrosion accounts for the largest number of repaired leaks each year. Improvements are needed in the overall understanding of the corrosion process and methods for better determination of active corrosion and assessment of applied cathodic protection.

Outside forces are the cause of a large percentage of reportable leak incidents. The effectiveness of programs to reduce pipeline damage are difficult to assess but improvements are noted with better communication between operators and excavators, better pipeline markings, and education of excavators.

Odorization acts as a warning of the presence of natural gas and allows the public at large to assist in leak detection. Expanded education programs for the public on recognition of gas odors and reporting methods are needed, as well as improvements in the odorants themselves to preclude fading, particularly through soil contact.

Plastic pipe has recently enjoyed a large increase in use in distribution systems. Its performance should be monitored to identify potential problems with specific compounds, ages and components to resolve some unknowns. Items needing improvements include better quality control, compounds usable up to 140°F, testing instruments for field inspection of joints, and testing methods for fittings and plastic pipe compounds.

Emergency plans tailored to particular distribution systems and training of gas employees have been shown to be beneficial in control of hazardous conditions. Improvements needed here are investigations which allow better guidelines for emergency plan content and requirements for training programs of employees.

Valving and rapid shutdown methods are difficult to specify for distribution systems or justify by cost/benefit analysis. Automatic service shut-off valves should be installed in special situations and their performance monitored for reliability and effectiveness.

Master metering exists and it should be addressed by investigation to determine the scope and integrity of the system and means to determine compliance to regulations.

SECTION 3
DISTRIBUTION SYSTEMS

This section describes the general characteristics of the systems under study, the various approaches available to evaluate safety, and the relation of management functions to a gas company's goals.

3.1 GENERAL DESCRIPTION

Distribution pipelines are generally defined as any lines which are **not** gathering or transmission lines. Gathering lines are used to transport gas from a well head to interim storage or a transmission line. Transmission lines convey gas generally at high pressures and for long distances from a storage facility or a gathering network to a locale where *it* will be used. Distribution lines provide the final piping network to take the gas from a transmission line and deliver it to the ultimate consumer.

Gas distribution systems then are the terminal part of an overall pipeline network by which gas is delivered to the user. The systems can be large, supplying complete major cities, or be very small, supplying only a few customers or small towns in rural areas. Some systems have been in existence for more than 100 years while others are relatively new. Their growth and new construction activities have resulted in systems which have been revised, modified and added to over the period *of* years such that they consist of a vast mixture of pipe materials, components, coatings, sizes and interconnections of lines. It becomes extremely difficult to define these systems in typical terms because of the way in which they evolved and grew and because they were tailored to suit the particular geographical location, terrain, soil, and climate in which they were located, and the product and customers supplied. One ramification of this mixture is that the developed practices of the gas distribution systems are varied with regard to operation, maintenance, and management in order to meet the needs of variations within the system.

Basically, distribution systems consist largely of pipe (both welded and jointed) and have a large number of bends, connections, joints and fittings as well as mixes of material in the pipeline segments. The size range is wide since existing systems may have within their own network pipes ranging from 1/2" diameter in service piping to over 12" diameter in main supply lines. Further, these size ranges must be correlated to other distribution components such as valves, risers, drip pots, meters and pressure regulating and control devices. Of course all of the piping and components can and do vary in material, age, coatings, protection, etc.

The distribution system is a link between high pressure transmission lines (700 to 1100 psi) and the customer's plumbing (generally 1/3 to 1/4 psi) so a large range of pressures is involved. Distribution supply mains may operate at pressures over 200 psi while the majority of feeder mains operate at pressure somewhere below 60 psi. Ultimately, the pressure must be reduced to about 1/4 psi. In many cases this is done at the end of a service line at the connection between the distribution company line and customer plumbing, but there are existing mains and service lines operating at this low pressure. A conceptual view of a gas distribution system is shown in Figure 3-1.

3.2 SAFETY CONSIDERATIONS

The safety of a gas distribution system is directly tied to gas leakage and the potential loss of control of a system due to the leakage. This is not to say all leaks are hazardous, for the gas industry handles leaks in a routine manner with only a few (less than 0.2%) attaining proportions requiring OPSO Leak Reporting and even fewer involving extensive property damage or fatalities. The few major gas failure incidents, however, do receive rather widespread publicity because of their catastrophic nature in that often several fatalities or destruction of structures occur.

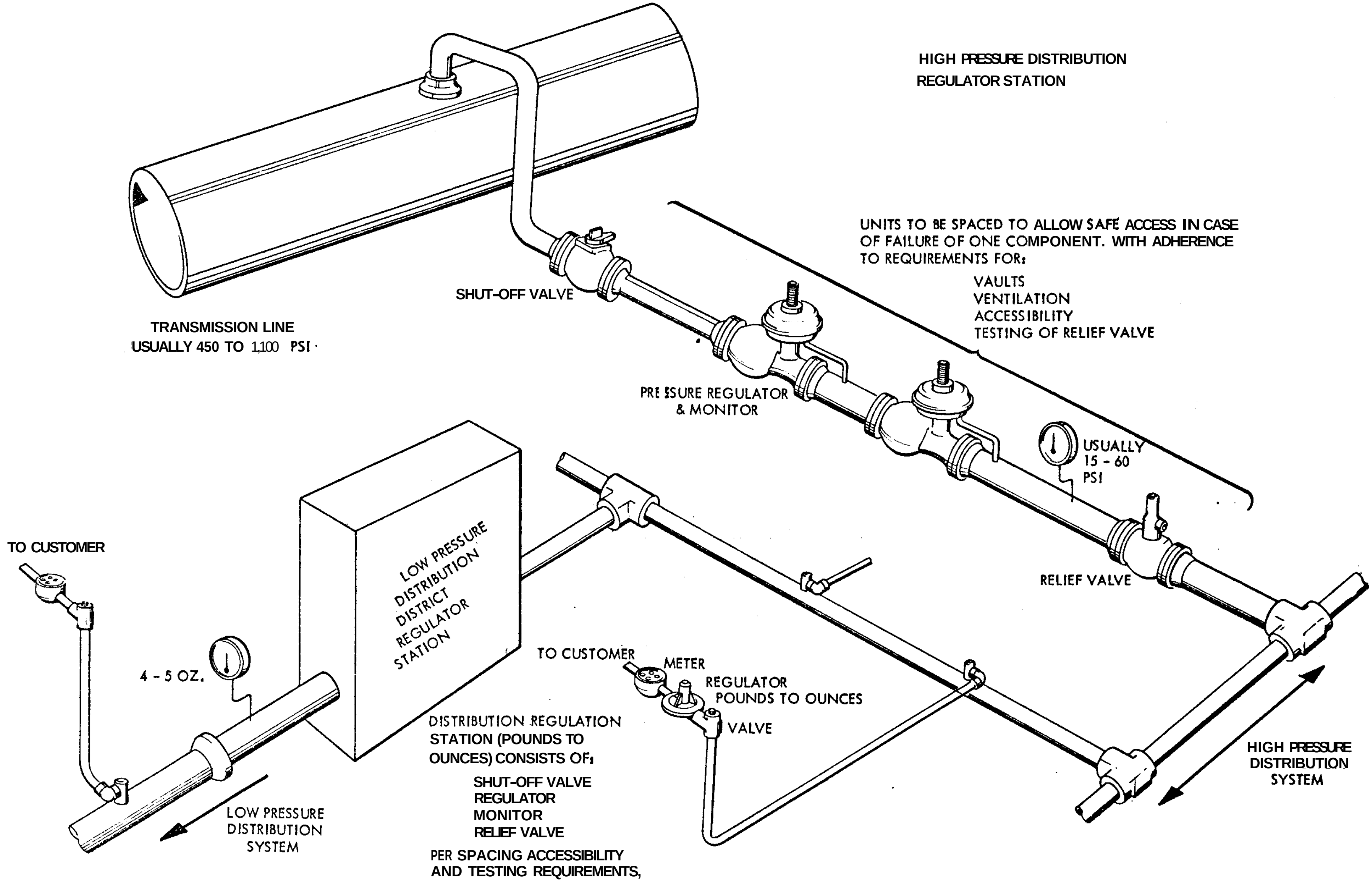

Figure 3-1 Distribution System

Therefore, the prime safety consideration of gas systems is to maintain control of the gas and minimize leakage effects through actions for preventing, identifying, and proper handling of leakage. Gas leakage can be caused by a multitude of events which may or may not be under the control of gas operators. Time-dependent deterioration of the underground plant, induced stray electrical currents on piping, natural events such as earthquakes or soil heaves, or damage by dig-ins of the piping are all examples of leak causes to be considered by the gas company. Accordingly, maintenance, operation and management functions must all be interrelated to provide solutions to the safety problem.

While a great number of preventative measures can be taken (cathodic protection, pipeline marking, etc.) and be proved beneficial, leakage will still occur and it becomes important to provide means to identify and locate leaks and potential leaks, methodologies for classification of the leaks, and procedures for proper handling of both minor and major leaks.

In order to place the question of overall safety in perspective it is useful to look at it from several different vantage points.

One of these is time-oriented and divides the activities associated with the life cycle of a distribution system into four successive phases:

1. Design
2. Construction
3. Operation and Maintenance
4. Replacement/Retirement

Since Phase 3, the operating lifetime, is very long compared to the other phases it is natural to expect that most safety problem areas are connected to activities of that period. The correspondence of problems examined in this report with phase activities is shown in Table 3-1.

A somewhat different approach to overall safety is provided by the methodology of system safety analysis. This analytic method, originally developed to meet the needs of aerospace and nuclear power programs, provides formalized procedures for evaluating the ways that malfunctions can occur,

Table 3-1. Safety Topics as Related to Life Cycle

	Coverage herein
1. **DESIGN**	
System design	Partial - safety analysis techniques; valving: rapid shutdown
Specification of materials and construction	Partial - plastic piping
2. CONSTRUCTION	
Installation, Testing, Start-up — Mains & Services	None
3. OPERATION & MAINTENANCE	
Protection against damage by others	Yes
Response to emergencies	Yes
Change of operating pressure	No
Odorization	Yes
Assessment of conditions; surveys	Yes
Component inspection & maintenance	No
Leak Repair	No
Accident analysis	Yes
4. RETIREMENT / REPLACEMENT	None
5. OTHER	
Jurisdictional matters	One - master metering

the probabilities of subsequent failure modes, and their expected effects. This approach has been recommended by NTSB (Ref. 5-1) and has been developed in some detail for the gas industry by the AGA (Ref. 5-3).

One variant of this general approach is a safety rating system developed for consumer and similar products (Ref. 5-2). Its thesis is that safety is the perfection of all controls necessary to prevent the injurious or damaging effects of energy. The analysis, which also uses a fault-tree technique, yields a Hazard Index number that predicts the likelihood of injuries and their severity before the fact. It would appear that application of this rating method to systems as large, extensive and complicated as gas distribution systems might be tedious and cumbersome, but in principle quite possible.

A third approach is the traditional statistical method of compiling historical data, establishing failure rates, and extrapolating this to future time periods. This method of measuring safety performance suffers from two sources of weakness:

1. Insuring that the historical data measures or represents typical performance, and
2. Assuming "steady state" conditions from past to future, i.e., neither the system nor its environment changes substantially with time.

Still another way of improving safety is the pragmatic application of experience; correcting or avoiding mistakes of the past. A prime example of this approach is the procedure followed by NTSB in which catastrophic accidents are investigated, causes ascertained, and recommendations made for prevention of similar conditions.

In recent years considerable attention has been paid to the economic aspects of safety. These studies indicate that the oft-stated goal of perfect safety (zero accident rate) is unrealistic and impractical What should be sought is an "optimum" level of safety - - - a low accident rate and an investiment in safety that will protect the company against dangerous financial losses. The financial risk to the company can be reduced in two ways: 1) increased funding for in-house safety improvements, and 2) transfer of risk through commercial insurance or self-insurance.

Safety is not solely a matter of economics however. Humanitarian and other considerations have led to legislation and government regulation that have served to establish minimum acceptable safety levels.

In aerospace systems there has been extensive research done in the study of human error analysis and human reliability. The results indicate that 50 to 70 percent of failures of major aerospace systems are due to human errors. The five most predominant types are classified as follows (from Human Error Analysis, Second System Safety Conference, 1975).

		% of Total
1.	Failure to follow procedures	40
2.	Incorrect diagnosis of particular situations	20
3.	Misinterpretation of communications (written or verbal)	10
4.	Inadequate tools, equipment, environment	10
5.	Insufficient attention or caution	20
		100%

The first type "Failure to follow procedures" is often caused by poorly written procedures (procedures that are incorrect). The second type "Incorrect diagnosis of particular situations" is usually caused by poor engineering design. The third type "Misinterpretation of communications" is generally the result of the "I didn't listen" syndrome. Poorly written communications can also result in misinterpretations, hence, "mistakes." The fourth type, "Inadequate tools, equipment, physical environment" often contribute to human error. The fifth type "Insufficient attention or caution" is just plain carelessness. These pure goofs account for approximately 20% of the human errors made. This figure has been established repeatedly no matter what type of industry, or job being done.

3.3 OPERATION AND MANAGEMENT FACTORS

The management and operation of distribution systems involves procedures and practices which allow attainment of the goals of the organization. Since these systems handle an explosive form of energy, safety and a good public image are important considerations in the running of a utility. Considerable emphasis is placed on maintaining the system for proper operation and control. Regulations imposed on the utilities are implemented to provide legal requirement compliance. Many regulations are enacted to insure standardized operations and safety to the general public. Finally, each distribution company has a fixed investment in pipeline systems and equipment and a profit must be made to provide a return on the investment. This requires that the public be served such that customer satisfaction is achieved while the resources available for operation of the company are conserved.

These management considerations are implemented so that specific needs of the distribution companies are met. In many cases this can depend strongly on the size and location of the utility and the age and characteristics of the piping systems. The results are procedures and techniques for system assessment, maintenance and operational practices. Decisions are made on system expansion and engineering and system up-dating and repairs. Emergency planning for control of actual or potential hazardous situations is performed to facilitate rapid recovery from loss of control of the system. Figure 3-2 graphically presents the above mentioned goals and implementation methods.

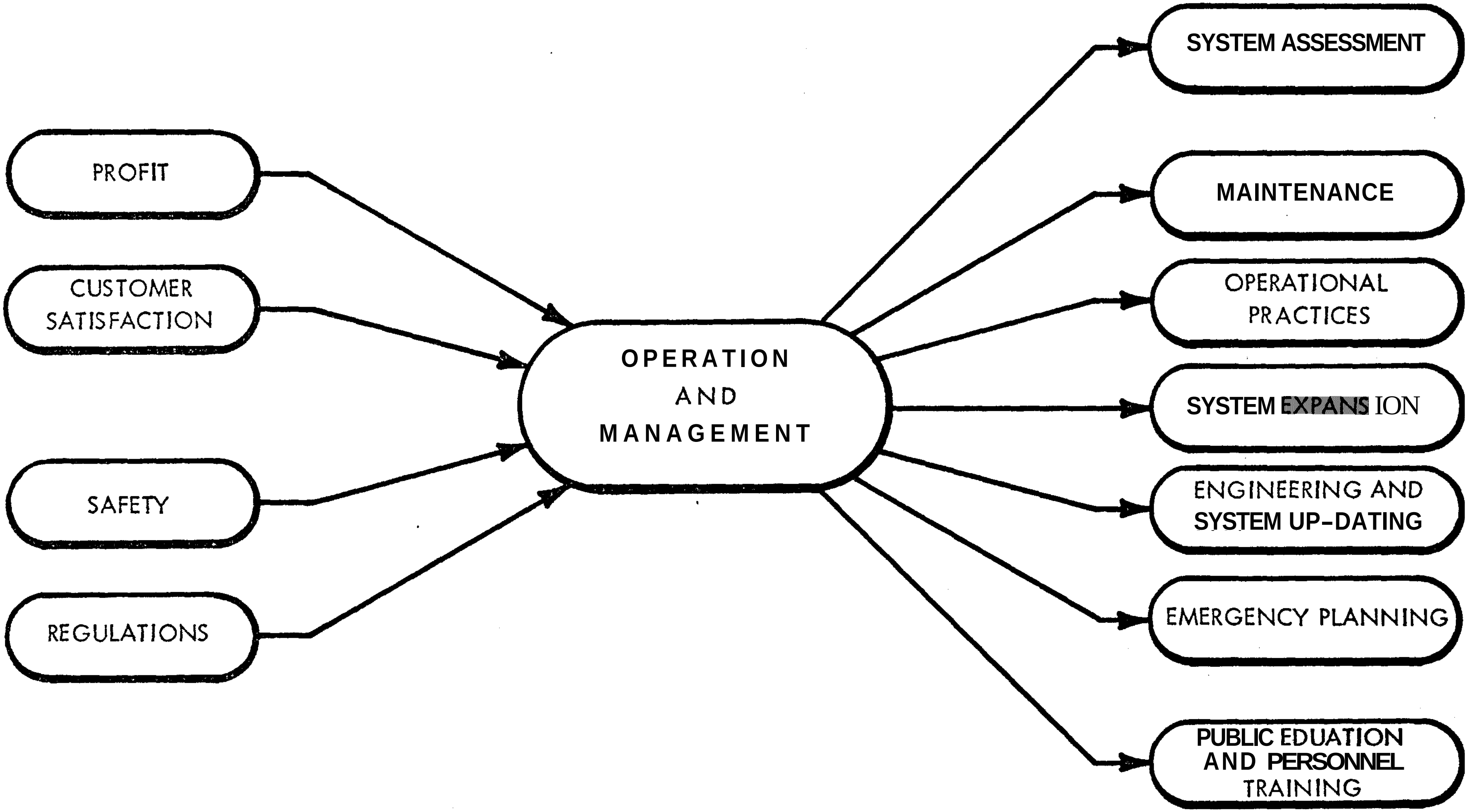

Figure 3-2 Distribution Considerations

SECTION 4
ANALYSIS OF LEAKAGE DATA

As a first step in determining the overall safety problems of the gas distribution industry, a review was made of leakage and failure data. A wide range of data is available in various record systems which have different purposes and consequently collect specific types of data and organize them for various end uses. Since gas leakage, whether from operational errors, equipment malfunctioning, deterioration or outside forces, is one key to identifying safety problems, the data sources most applicable to this study were those that reported system characteristics and the primary and secondary causes of failures in those systems.

It was found that the OPSO Annual Report and Leak Report Data and the NTSB Reports were most applicable. Also, previous analyses of OPSO data by Battelle and the University of Oklahoma were found to be useful. The OPS Annual Reports present many characteristics and a good overview of the magnitude of the distribution system leak causes, while the Leak Reports provide somewhat more detailed information on serious leaks. NTSB Reports are in-depth investigations of specific pipeline failures. This section presents selected information, data, and extracted results from all of the above.

4.1 OPSO DATA AND ANALYSIS

The OPSO annual report form (DOT-F-7100.1-1) is submitted to the OPS by approximately 1,700 companies operating about 660,000 miles of mains and 44,000,000 services (or about 440,000 miles of services). Over the past several decades, most gas distribution systems were in an expansion phase, but this has now been slowed. During 1973, there were about 18,000 miles of main and 1,300,000 services installed. New growth, however, amounted to only about 2% due to the amount of pipe that was replaced or retired. In fact, of new pipe installed, 23% of the mains and 30% of the services were replacements rather than additions. In 1974, the rate of system expansion slowed even more.

In 1973, 769,260 leaks were repaired of which only 1393 or less than 0.2% attained proportions requiring a telephonic or individual leak report (Form DOT-F-7100.1). Of the 769,260 leaks, 292,261 were on mains and 476,999 on services. The pipe leaks, correlated to overall pipeline mileage, accounted for 291 repaired leaks per 1000 miles of mains and 636 repaired leaks per 1000 miles of services. Piping accounted for the majority of leaks, with fittings second, as shown in Table 4-1 below.

Table 4-1. Repaired Leak Relationships
1973 Annual Report

Item	Percent of Total Repaired Main Leaks	Percent of Total Repaired Service Leaks
Pipe	66.6%	52.2%
Valve	8.8	8.0
Fitting	11.8	24.5
Drip	1.4	0.2
Regulator	0.5	3.8
Tap Connection	1.5	2.8
Other	9.4	8.5

The causes of leaks are shown in Table 4-2. Corrosion was the leading cause and it should be noted that outside forces played a rather small part.

Table 4-2. Causes of Repaired Leaks, Mains and Services - 1973 Annual Report

Cause	Percent of Total Leaks
Corrosion	46
Outside Forces	13
Construction Defect	6
Material Defect	10
Other	25

The characteristics of distribution piping in terms of material and size was determined. Table 4-3, which shows a material breakdown of installed pipe, reveals that steel, cast iron and plastic are the primary materials in use. Recent developments in material use show that cast iron is not being used in new installation while plastic is becoming increasingly popular. The sizes of pipe as shown in Figures 4-1 and 4-2 indicate that pipe sizes of 2" or less include about 50% of the mains and 98% of the services.

Table 4-3. Pipe by Material - 1973 Annual Report

Material		Percent of Mains	Percent of Services
Steel		81.7%	83.6%
Wrought Iron		1.1	
Cast Iron		10.4	0.1
Ductile Iron		0.2	---
Copper		0.1	5.7
Plastic		6.2	8.1
Other		0.3	2.5
	Total	100 %	100 %

The OPS Leak Report Summaries provide some detailed information on hazardous leaks and operational procedures of gas companies. Although the summary sheets do not provide enough information to explicitly define leaks in terms of material, age, location, etc, some general trends and conclusions can be determined.

The response time of gas operators to reportable leaks from both 1971 and 1972 data shows that over 50% had an elapsed time of less than 2 hours between leak detection and stoppage of escaping gas. This time may include reaction or travel time of company personnel, the time to perform some work such as valve location and closing or digging up the line, plus a reaction time not controlled by the gas utility. As noted in Table 4-4

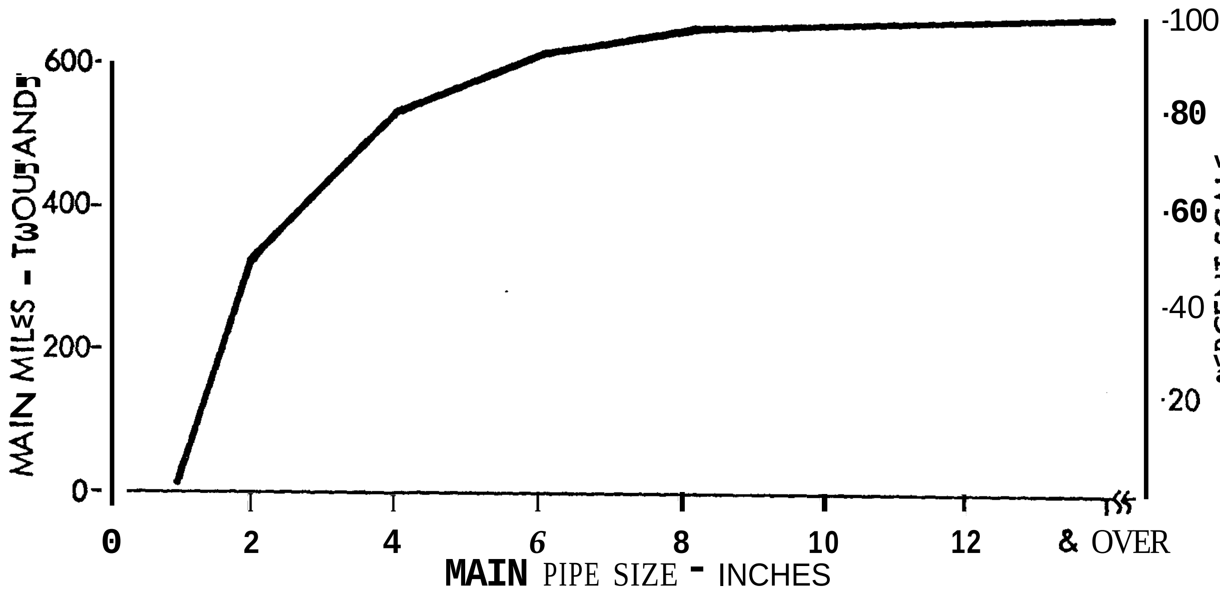

Figure 4-1 Cumulative Main Miles vs Pipe Size

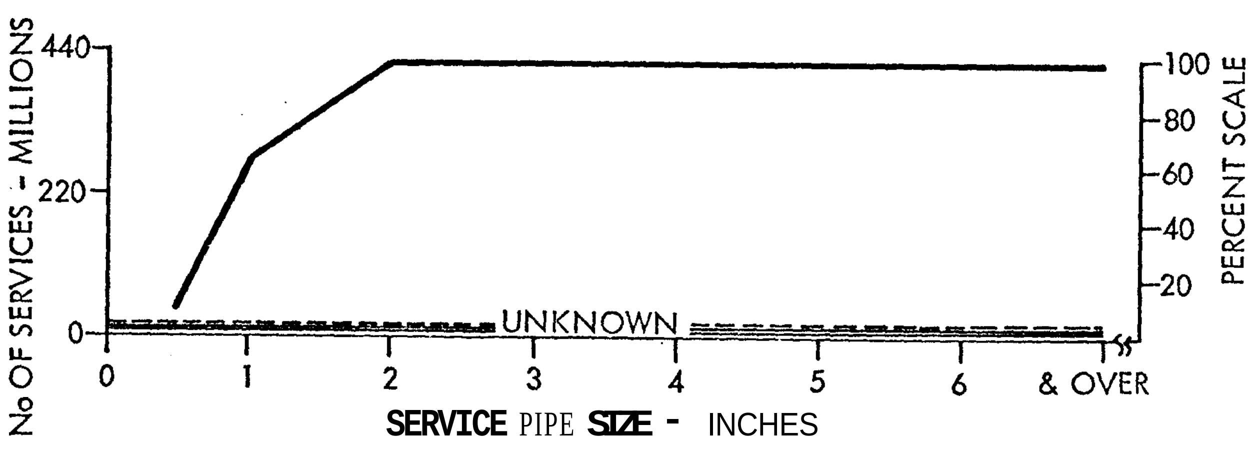

Figure 4-2 Cumulative Number of Services vs Pipe Size

gas operators detected only 9% of the leaks reported. The public and customer either directly or in conjunction with or through police, fire departments or other organizations, detect most reportable leaks. This points to the need for good coordination of these organizations and the gas utility, and the importance of gas odorization and education of the public as to the best response after detecting the smell of gas.

Table 4-4. Method of Leak Detection - 1973 Individual Leak Reports

Item	Percent of Reports
Operator Personnel	9%
Agency Causing Damage	28
Customer	19
Police	11
Public	7
Utility Company	2
Fire Department	23
General and N.A.	1
	100%

In 1973, the leaks requiring Individual Leak Report Forms totaled 893 of which 450 were on mains, 428 on services and 15 were denoted as "other". Pipe and fittings accounted for a majority of the incidents, as shown in Table 4-5 below. This correlates fairly close with the results of the annual report data previously noted in Table 4-1.

Table 4-5. Component Leak Relationship - 1973 Individual Leak Reports

Item	Percent of Leak
Pipe	68.2%
Valve	2.9
Fitting	13.2
Drip	0.5
Regulator	4.9
Tap Connection	2.9
Meter	4.2
Other	3.2
	100 %

The cause of the 893 leaks are shown in Table 4-6 below. It will be noted that outside force was the cause of the largest percentage of **leaks,** while corrosion was a somewhat minor one. This is nearly the reverse of the Annual Report results shown in Table 4-2.

Table 4-6. Causes of Leaks - 1973 Individual Leak Reports

Cause	Percent of Leaks
Corrosion	15%
Outside Force	68
Construction Defects	2
Material Defects	8
Other	7
	100%

The locations of leaks in terms of areas is shown in Table 4-7 below.

Table 4-7. Type of Area' - 1973 Individual Leak Reports

Area	Percent of Leaks
Commercial	20.0%
Industrial	3.8
Residential	69.8
Rural	5.8
Other	0.6
	100 %

Residential areas stand out as an important area of investigation. It should be noted however, that gas companies have remarked that in terms of degree of hazard, commercial areas concern them more. These areas with their greater population density, and paved areas that make detection and repair more difficult, are considered more hazardous. The location of leaks regarding pipeline cover is shown in Table 4-8.

Table 4-8. Location of Leaks - 1973 Individual Leak Reports

Location	Percent of Leaks
Under Soft Cover (Soil and unpaved areas)	50.2%
Under Hard Cover (Paved Areas)	30.0
Assessible (Above ground or in buildings)	19.8

It has been previously remarked that the leak reports show that outside forces are most significant, with corrosion a far distant second. The leak report summary sheets have additional data as to causes. A breakdown of the outside forces, shown in Table 4-9, reveals that the majority were caused by an outside party not directly controlled by the gas company.

Table 4-9. Outside Forces - Primary Causes of Leaks

Cause	Percent of Outside Force Leaks
Operator	3.3%
Outside Party	57.8
Earth Movement	13.0
Willful Damage	1.2
Weather	5.8
Vehicle	7.6
General	11.3
	100 %

For corrosion faults, a number of accompanying conditions are noted. The most prevalent descriptors of corrosion leaks were found to be external corrosion of the pipe, no cathodic protection on the pipe, galvanic action, pitting type of corrosion, and bare pipe.

4.2 NTSB DATA

The NTSB Pipeline Accident Reports convey results from detailed investigations conducted by the National Transportation Safety Board. An important reason for these investigations is that many of the contributory or secondary causes of failures are brought to light. A brief summary of several NTSB Reports showing primary and secondary causes is presented in Table 4-10. Note that outside forces, corrosion, construction and material defects, the factors attendant to most leaks, also prevail as causes on the NTSB reports reviewed. Note also that a number of the preventative measures that could have been taken are noted along with an assessment of the actions and procedures taken or not taken to eliminate the hazards. In many cases, the findings are related to the inadequate follow-through of emergency procedures which allowed a leakage situation to ignite or assume catastrophic proportions. In many cases while gas leakage is the crux of the problem, it is a breakdown in the preventative measures or leak handling which is a contributing factor and therefore an identified safety problem area.

Table 4-10. Summary of Pipeline Failure Causes - NTSB Reports

NTSB REPORT	PRIMARY FAILURE CAUSE	SECONDARY OR CONTRIBUTING CAUSE
Gary, Indiana June 3, 1969	Overpressuring a system caused by inadvertent opening of a separation valve between a medium and low pressure distribution system.	Failure of regulator caused by the pressure and inaccessibility of the shutoff valve for the regulator. Lack of relief valves. No written plan for pressure conversion.
NTSB-PAR-70-1 Burlington, Iowa November 6, 1969	Bulldozer damaged a gas regulator pit which allowed higher than normal gas pressure in the distribution system.	Monitoring regulator failed to operate to limit gas pressure. Lack of knowledge of construction personnel on regulator location. Failure to privide construction plans indicating that the regulator was in the construction area. Failure to recognize significance of damage and the delayed reporting. Lack of overpressure relief devices on the low pressure system.
NTSB-PAR-72-3 North Richland Hills, Texas October 4, 1971	A service line to main connection was broken by soil stress and hydrogen embrittlement of the service pipe. Gas migrated and accumulated under the concrete slabs of houses.	Lack of liaison and communications between gas employees and firemen and delay in evacuating houses. Failure to close three valves on the gas main to isolate the affected section and reduce the amount of gas released. The length of time required to locate the leak.
NTSB-PAR-72-2 Pittsburgh, PA November 17, 1971	Asphyxiation of gas employees attempting to change a valve in a vault without first stopping the gas.	Company safety practices were not followed. Equipment required to comply with the safety practices such as masks and ventilators were not available. No written procedures were prepared for the planned operation. Inadequate personnel training procedures.

Table 4-10. Summary of Pipeline Failure Causes - NTSB Reports (Continued. ..)

NTSB REPORT	PRIMARY FAILURE CAUSE	SECONDARY OR CONTRIBUTING CAUSE
NTSB-PAR-72-5 Fort-Worth, Texas October 4, 1971	Failure of a plastic service saddle-tapping nipple which allowed gas to escape and migrate.	Improper installation and inspection during construction of the plastic system. Insufficient detail of construction specifications. Loads and stress imposed on the pipe by heavy equipment operated above the pipe. Stresses induced in the pipe by rain-soaked heaving soil.
NTSB-PAR-73-3 Atlanta, GA August 31, 1975	Gas leaked from a cast iron main cracked by a bending force applied to the pipe by uneven soil settlement in an area on the pipe weakened by graphitization.	Lack of written emergency procedures. Buildings not checked for gas. Failure to shut off the flow of gas. Failure to notify the police and fire departments. Lack of historical records on frequency and causes of failures of cast iron mains for problem assessment.
NTSB-PAR-72-4 Annandale, VA March 24, 1972	Gas leakage from a main damaged by a contractor's backhoe.	Delay by the gas company in shutting of the flow of gas. Failure to check for gas in buildings. Failure of residents to report the odor of gas in their houses. Failure of the county to supply the contractor with the accurate gas main location provided by the company.
NTSB-PAR-73-1 Lake City, MN October 30, 1972	Gas leaked from an unmarked service line struck by a bulldozer	Failure to realize that the displacement of the pipe indicated a break other than at the visible spot. Use of a wooden plug inserted in the broken pipe sealed the escape route for the gas and allowing it to migrate to buildings.

(Continued.. ..)

Table 4-10. Summary of Pipeline Failure Causes - NTSB Reports (Continued...)

NTSB REPORT	PRIMARY FAILURE CAUSE	SECONDARY OR CONTRIBUTING CAUSE
		Failure to check buildings for gas and evacuate buildings. Unavailability of special valve key delayed shutting off the gas flow because the buried valve had to be excavated and exposed before it could be shut off.
NTSB-PAR-74-3 Clinton, Missouri December 9, 1972	Cast iron main cracked by a combination of soil stresses and railroad vibration which applied a bending force to the pipe in an area weakened by graphitization.	Delay in shutting off the gas flow due to trying to use valves other than designated emergency valves. Emergency procedures were incomplete. Gas was detected in the building but efforts to prevent ignition were inadequate. Information contained on the recording chart at the town border-station was not telemetered to the central office to assist in determining the magnitude of the break.
NTSB-PAR-74-1 Coopersburg, PA February 21, 1973	Gas leaked from an acelylene weld in an 8" pipeline after the weld had been cracked by the detonation of dynamite charges.	Warnings of excessive dynamite charges and the proximity to the gas main were not heeded. Improper dynamite weight charges were being used. Lack of preplanned emergency procedures for leaks. Delay in isolating rapidly the failed section of pipe.
NTSB-PAR-74-2 El Paso, Texas April 22, 1973	Gas leaked from a broken cast-iron reducer and two corrosion leaks in a gas main.	Lack of adequate support below the cast iron reducer and shock loading delivered by heavy traffic. Improper follow-up on the report that a leak could not be located. Failure of gas personnel to absolutely determine the location or absence of a leak before leaving the scene. Failure of residents to report the odor of gas.

Table 4-10. Summary of Pipeline Failure Causes - NTSB Reports (Continued.. .)

NTSB REPORT	PRIMARY FAILURE CAUSE	SECONDARY OR CONTRIBUTING CAUSE
NTSB-PAR-74-5 Bowie, Maryland June 23, 1973	Gas leaked from a crack in a plastic service line.	An occluded particle in the plastic pipe created a stress point. The soil and ground cover allowed the formation of a gas reservoir. The odorant in the gas had been absorbed by the soil so the gas was not detectable by odor.
NTSB-PAR-74-4 Charleston, West Virginia December 2, 1973	Corrosion leaks allowed gas to migrate through soil under concrete and collected in enclosed spaces in the house.	Gas odors detected were not reported to the gas company. The company's warnings on gas odor and hazards by educational material were submerged and unheeded by customers.

4.3 SUMMARY

In summary, a few important points can be extracted from the annual and individual leak report and failure data. The annual reports show that corrosion is the leading cause of all repaired leaks. Steel is the predominant material in the underground plant, most leaks are associated with pipes and fittings, and small diameter pipe accounts for the greatest percentage of installed pipes. The leak reports show that 1) outside forces are the leading cause of reportable leaks, 2) individuals (public, customer or through police or fire departments) report a number of incidents, and 3) confirm the annual report conclusion that more leaks occur on pipe than anywhere else. The NTSB reports concur on primary causes of failures but their depth of detail make their secondary or contributory causes important. A few of these are related to emergency handling such as procedures, failure to locate leak or check buildings, or stop the flow of gas. Others show failure of individuals to report gas odors or that the gas odorization had faded. Also, insufficient communication between utility and construction workers was noted in several cases. By reviewing this data, some of the more important problems of gas distribution systems surface due to being repeated in several reports or by quantity or percentage of leaks reported. From this data, corrosion, outside forces, odorization, emergency plans and lack of rapid shutdown all appear as distribution system safety problems.

SYSTEM 5
FAULT TREE ANALYSIS

One systematic approach to pipeline safety is to analyze the systems and their operation to identify hazards before they occur. By so doing, a number of steps can be taken to reduce the possibility of a failure. These steps include 1) designing for minimum hazards, 2) revising operations, 3) adding safety or warning devices, and 4) developing special procedures. An analysis is most useful in terms of direct recommendations or results when tailored to a particular system. In these cases, the events or inputs can be identified down to actual components or parameters for comprehensive evaluation. For the purposes of this report, a general fault tree diagram was prepared to introduce many items for use in discerning interrelationships of overall safety problems of the gas industry.

A fault tree is a graphic method of tracing the potential of a number of events to produce an undesirable event. Some events require a contributing item to provide a condition which can progress to the top level condition while other events can of themselves progress to interim conditions and eventually the top level event. Graphically, the events, inputs, and logic gates are represented on the fault trees by the symbols shown in Figure 5-1. The fault trees are developed down from some top level undesired event and subsequently branch downward to lower level conditions and events, and ultimately terminate in a large number of the lowest level items, events, or cause factors. When applied to a specific system, statistical analysis can be conducted by establishing values for probability of occurrence of each event.

The top level event shown on Figure 5-2 is a pipeline failure which results in casualties and property destruction. The lower level conditions are identified and continued through on Figures 5-3 through 5-7 as referenced on Figure 5-2. Probably *of* most interest on these diagrams is the degree to

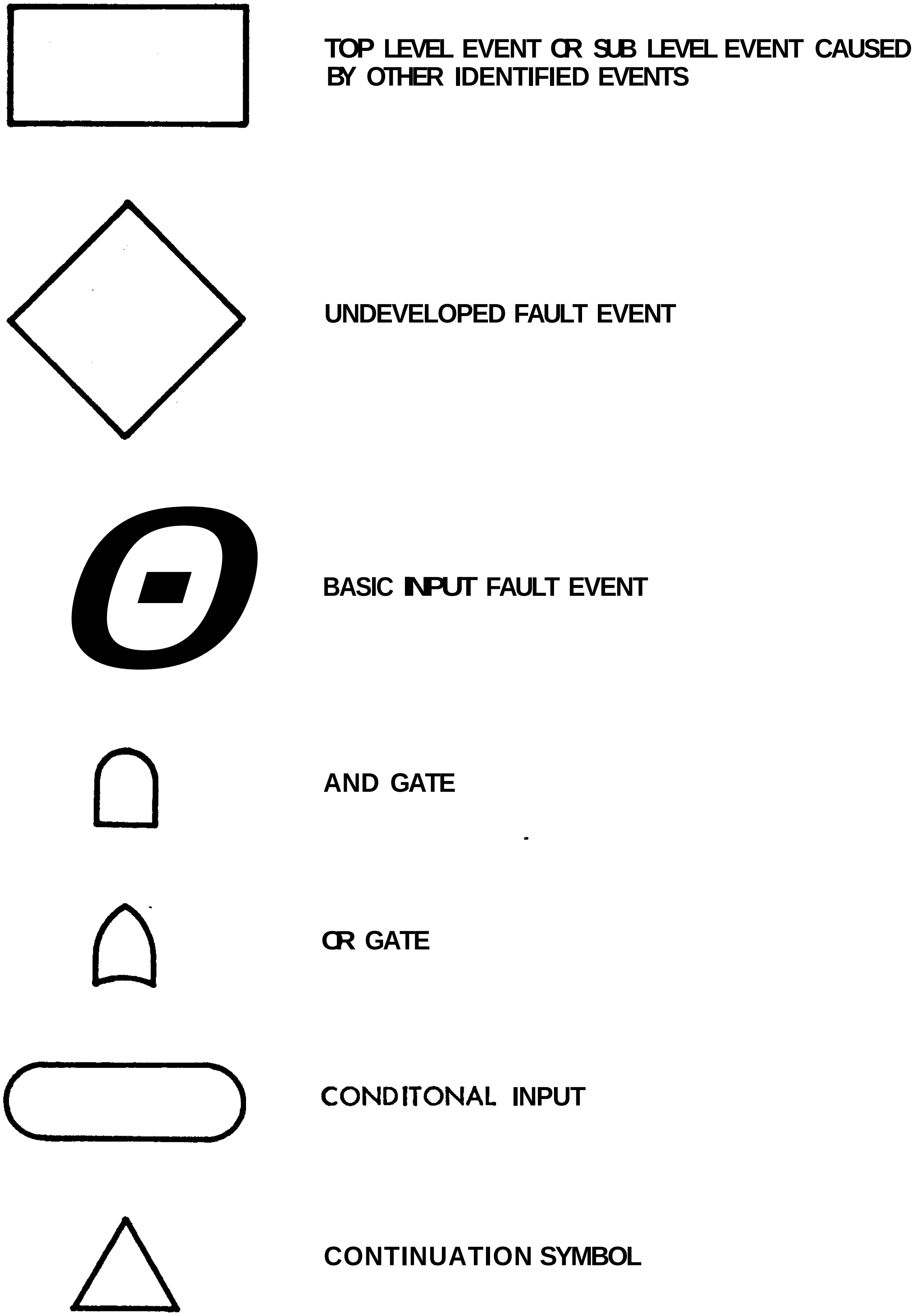

Figure 5-1 Fault Free Symbols

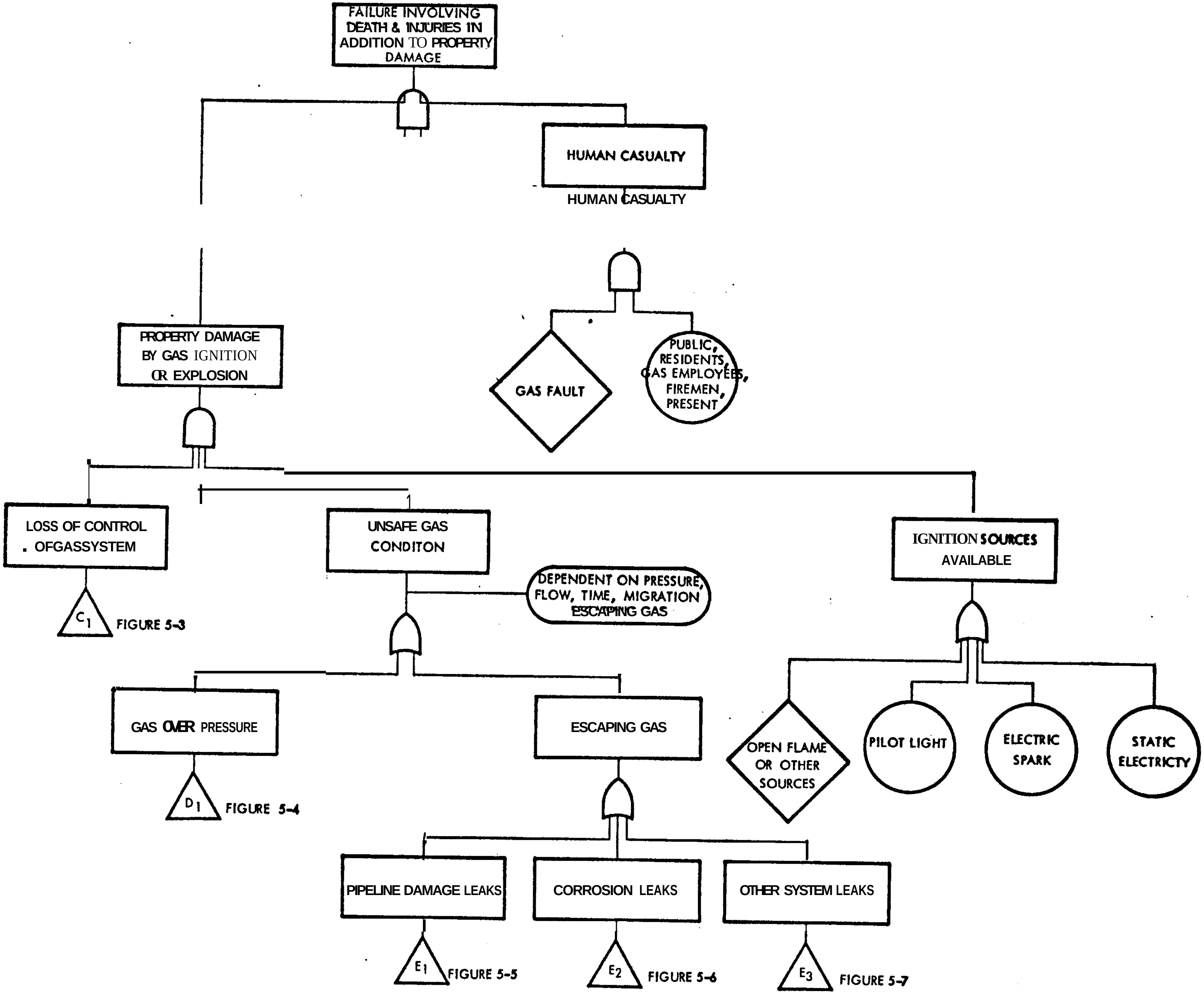

Figure 5-2 Fault Free - Top Level

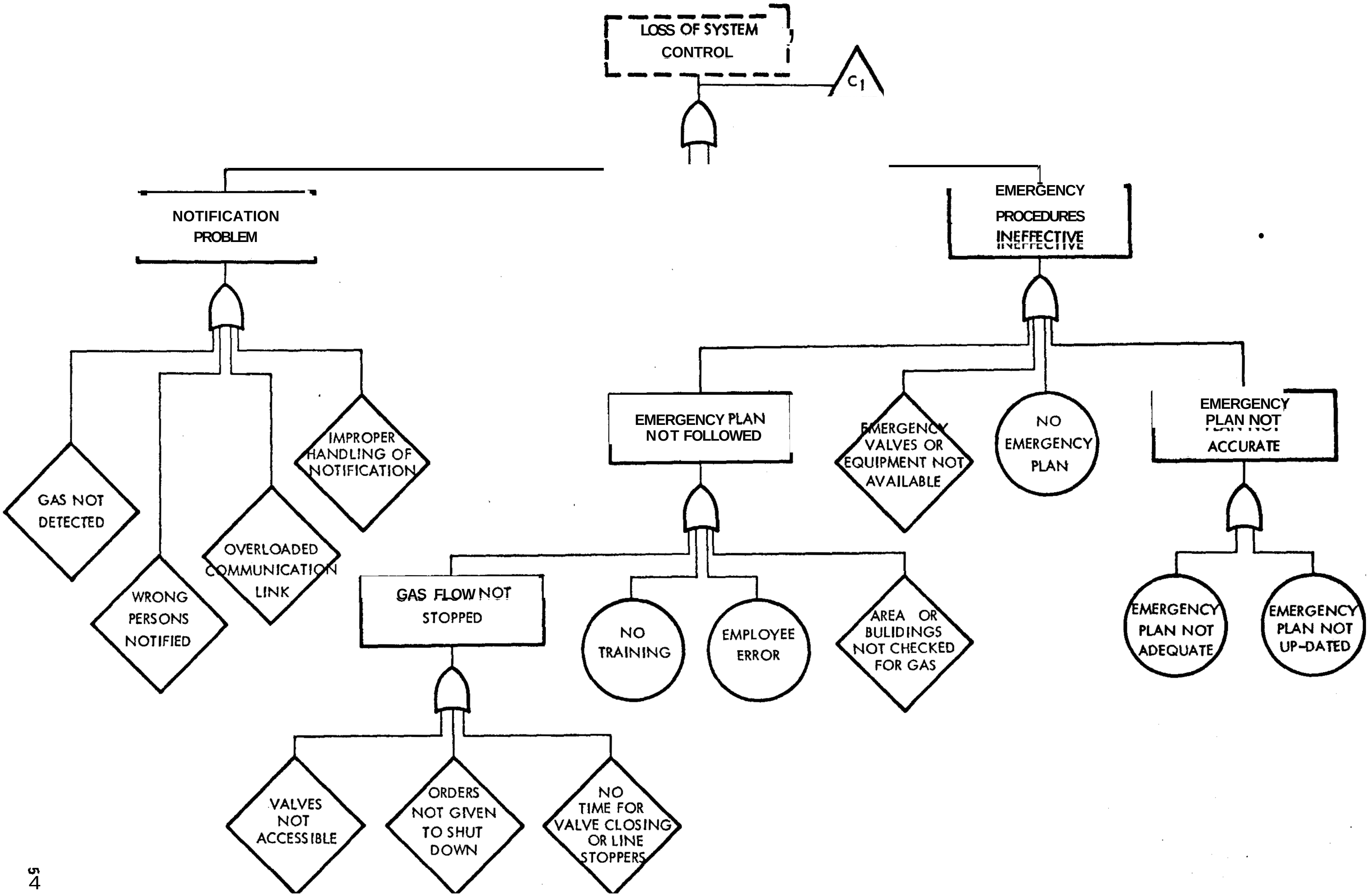

Figure 5-3 Fault Free - Loss of Control of Gas System

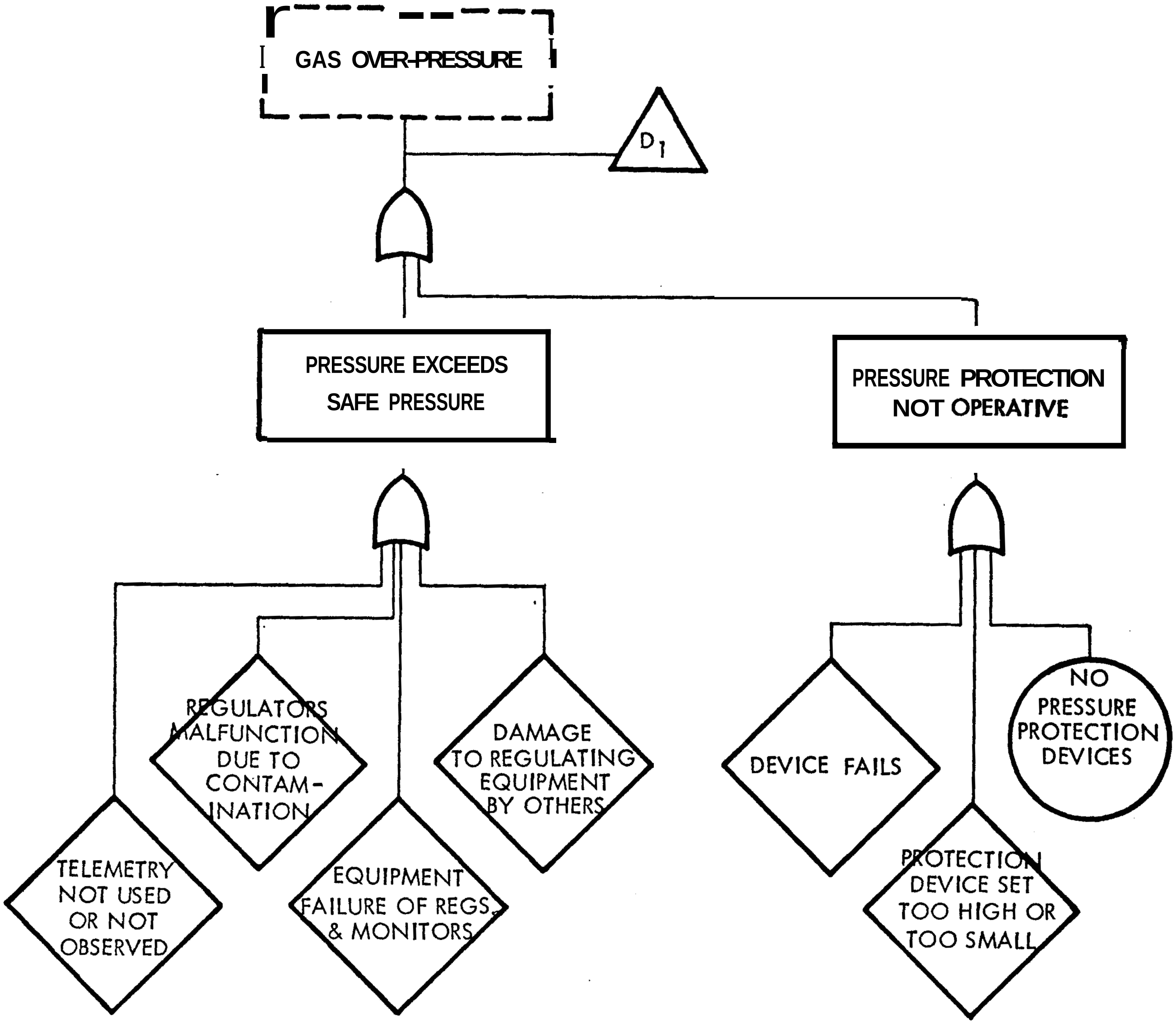

Figure 5-4 Fault Free - Gas Over Pressure

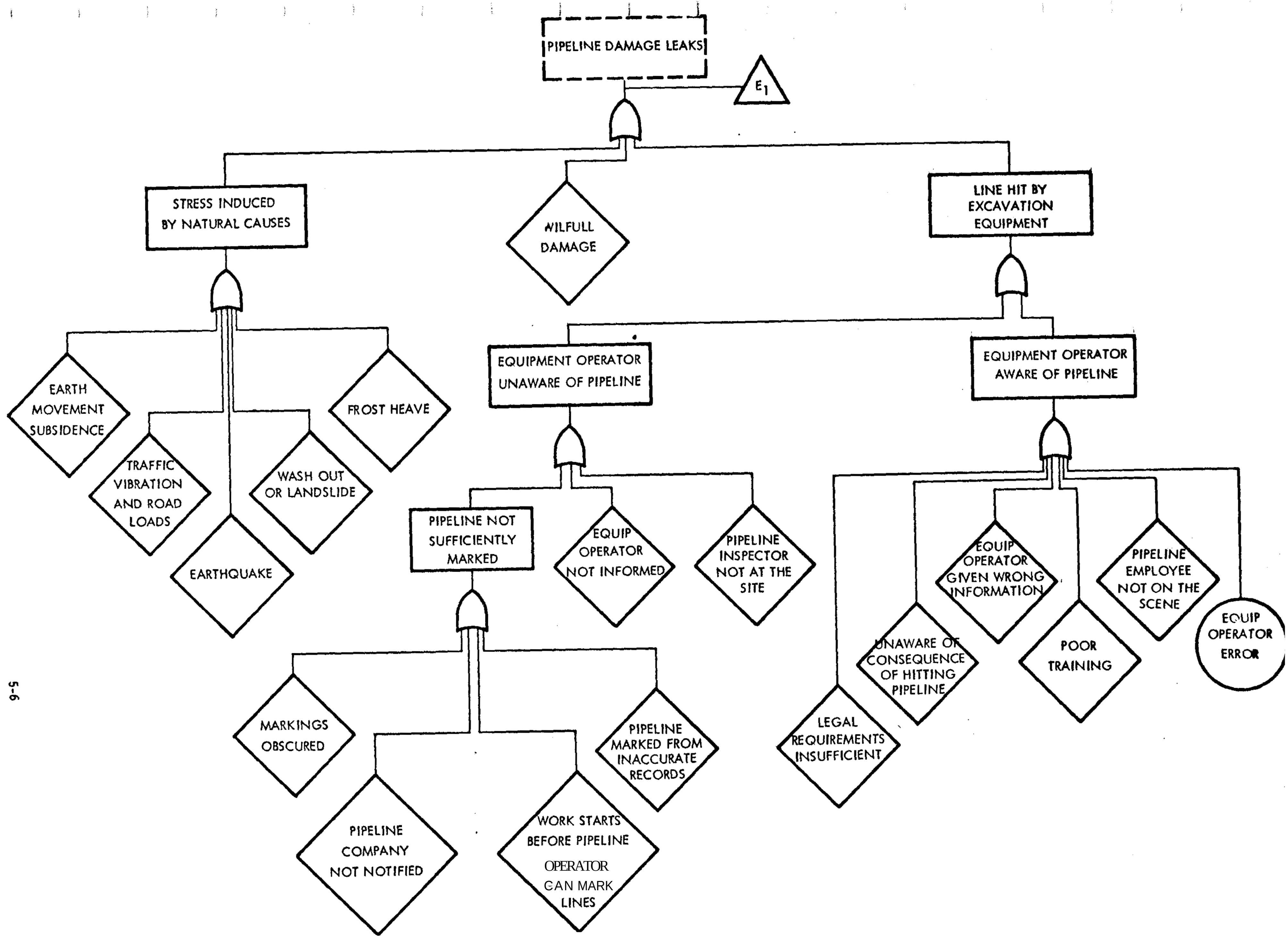

Figure. 5-5 fault Free - Pipeline Damage Leaks

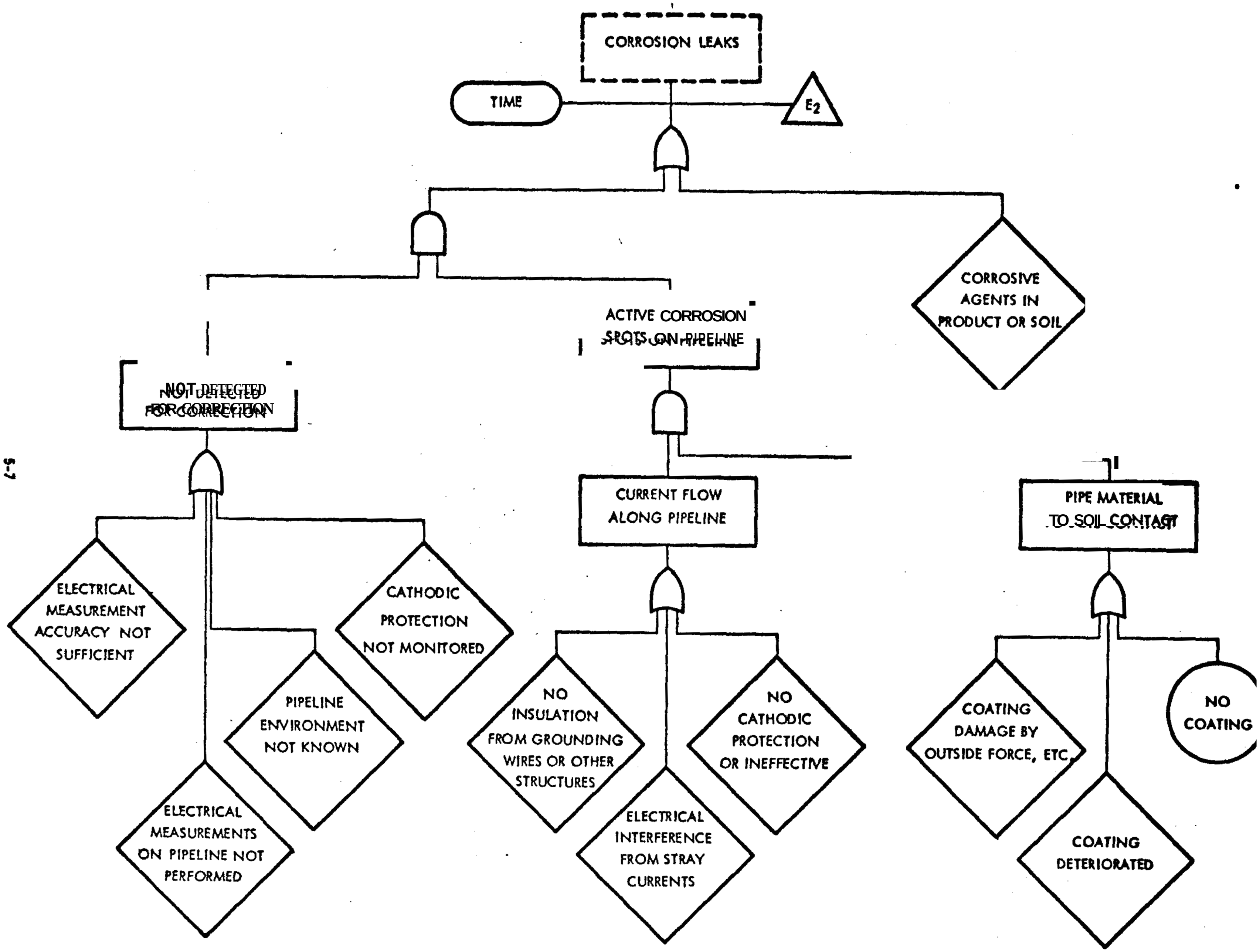

Figure 5-6 Fault Tree - Corrosion Leaks

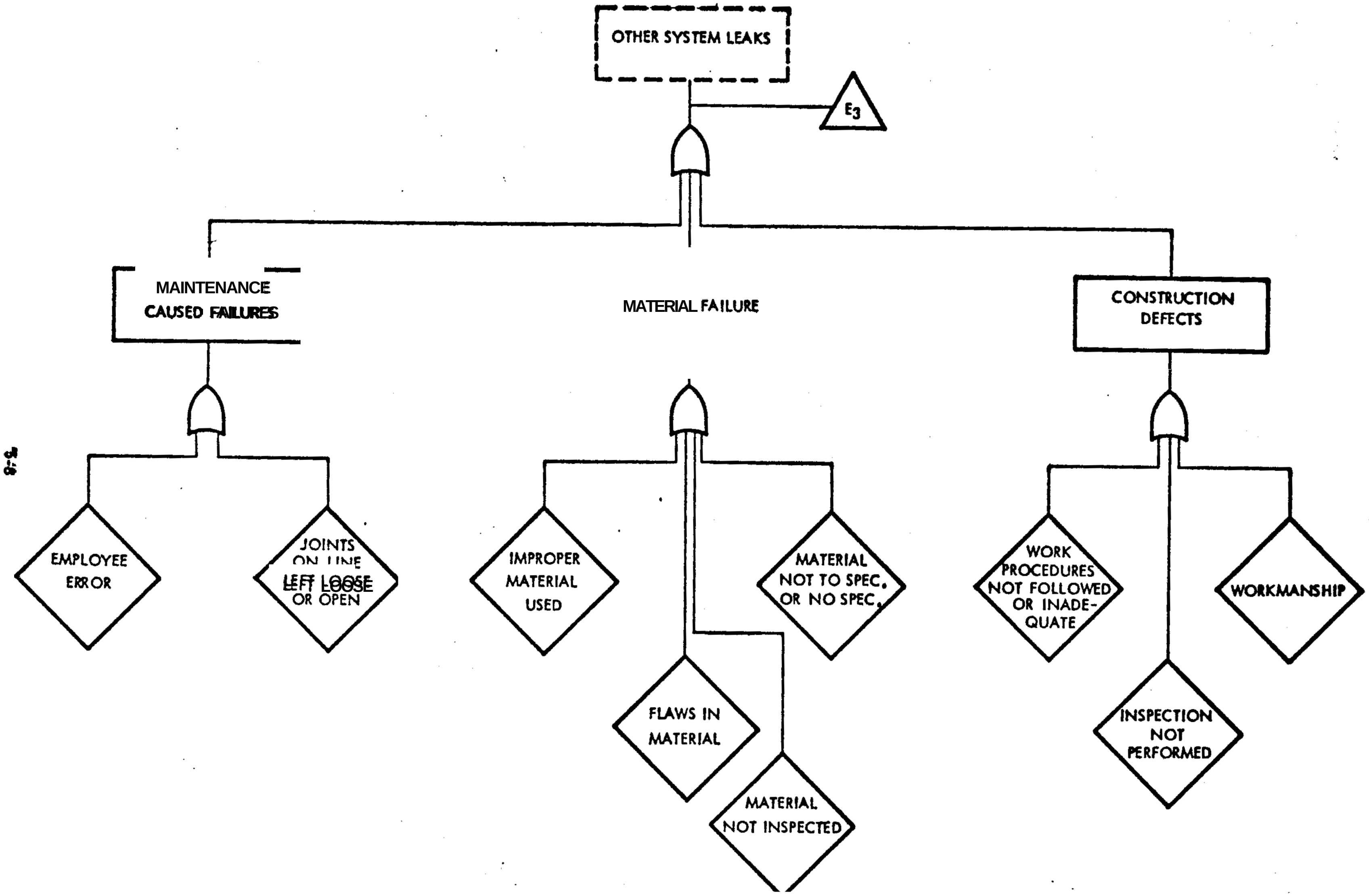

Figure 5-7 Fault Tree-Other System Leak

which procedural methods of reduction are represented and the high level of their representation. For example, human casualties result when the public, residents, gas employees, or firemen are involved with a gas fault. The importance of education of the public, extensive training of gas employees, and good coordination with governmental agencies are pointed out here.

Also, the loss of control of the gas system which is primarily controlled by procedures and the actions of persons is closely equatable to the overall cause of an event as an unsafe gas condition. In other words, the progression of an unsafe gas condition to a serious event requires the loss of control of the system, which can range from simply being unaware of the gas conditions to a breakdown of emergency procedures. Overall then, these diagrams indicate that the two major areas of interest are maintaining control of the system and eliminating unsafe gas conditions. Beyond this, a number of general fault inputs have been included but cannot be construed to apply to any one specific distribution system. It does point out the importance of several needs such as good leak notification methods and emergency procedures and a few problematic leak causes including outside forces, corrosion, and other system leaks.

The fault tree diagrams present a graphic picture of a number of the inputs or events which can ultimately result in a major pipeline failure. As a visible method of illustrating the potential hazards of rather minor events or all the factors that can be involved in a failure, this analytic method appears to be excellent. Further it serves as a tool for reports of this nature, since many of the topics in this report can be identified diagramatically and an assessment can be made of their relative importance.

However, the fault tree may not be too applicable for predicting failures or usable in conjunction with probability factors. It should be remembered that the major part of a distribution system is simply piping.

Piping has no moving parts but simply degrades with time or succumbs to outside disturbances. Here the failures are often due to human beings and their actions or, in the case of corrosion, due to time as related to a number of environmental conditions. Also, two identical size leaks in pipes cannot be equated as equal in hazardousness unless a host of other conditions such as soil types, nearness to buildings, ground cover and others are included. It seems then that failure prediction or numerical evaluations of failure probability by fault tree analysis cannot be performed with a high degree of confidence. It can be used for educational programs and for illustrating all the various leak causes and events which can and do result in distribution pipeline failures.