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AN EVALUATION OF JOINT REPAIR METHODS FOR CAST IRON
NATURAL GAS DISTRIBUTION MAINS AND THE PRELIMINARY
DEVELOPMENT OF AN ALTERNATIVE JOINT SEAL

by

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ABSTRACT

Approximately 10 percent of the natural gas pumped into distribution
systems is unaccounted for. A significant portion of this amount is
leakage from joints in 50 to 100 year old cast iron main. Because of the
cumulative effects of many small leaks, these leaks must be repaired even
though the repair expense is not always justified by the value of the
gas conserved.

Part One identifies and evaluates leak sealing techniques of the
past and present by compiling available test data. A major task was to
review all documented test results in journals and technical reports.
This study followed-up on published articles by contacting all the individ-
uals and organizations concerned. Recommendations for future development
of an alternate sealing system are made.

Part Two discusses preliminary criteria for the design of an alterna-
tive system to seal main joints from within the main without service inter-
ruption. Experiments were performed showing that very soft elastomers
pressed against the rough pipe wall could prohibit leakage. Potential
cleaning methods were tested. Wire and abrasive wheels, and water-jets
were recommended for further development. Based on time-dependent charac-
teristics and resistance to aging and to chemicals found in mains, fluoro-
carbon was recommended for use as the seal material. Preliminary design
of the seal verified its feasibility. Several innovative concepts for
the seal are presented. Considerations for the cleaning and sealing
device and for the overall system are discussed.

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1.0 INTRODUCTION

Low pressure cast iron natural gas distribution mains are beneath most streets in older sections of most cities. The pieces of pipe are joined together with lead and jute bell-and-spigot joints similar in construction to water mains and sewer stacks. (See Figure 1.) The mains which were initially constructed to carry manufactured gas began to carry natural gas with the completion of the transmission lines in the 1950's. The conversion to drier natural gas exacerbated the existing problem of joint leakage. A major portion of the maintenance budgets of all natural gas utilities operating in older cities is the cost of repairing leaks from old cast iron low pressure mains. Because of the cumulative effects of many small leaks, most leaks must be repaired even though the cost of stopping the leak is not balanced by the value of the gas that is conserved. The cost of the repair includes the costs of excavation, resurfacing and overhead labor costs, as well as the direct labor and material costs.

In an attempt to reduce maintenance costs, the Consolidated Edison Company of New York has funded research at the Massachusetts Institute of Technology to develop a main sealing method that is more effective and economical than currently available systems. Phase I of this research program was to evaluate all existing and previously-attempted leak sealing methods and to determine those factors that are critical in a method's success or failure. As a result of Phase I, Phase II will develop a mechanical seal capable of being emplaced on the inside of the main while still maintaining a flow of gas in the main. A critical task of Phase II is to identify cleaning methods that are appropriate for specific seal designs. The task of Phase III is to design and develop the machines necessary to clean the joint area and install the seal. Finally, Phase IV development will be to design the support systems for the alternative sealing method to include safe access into live cast iron mains.

This thesis is divided into two parts. Part One describes the work done under Phase I including the results of a laboratory experiment on

ethylene glycol gas conditioning. Part Two of this thesis describes the
preliminary work done in the development of the mechanical seal. It
develops design criteria and tests the feasibility of several novel
approaches to joint sealing and cleaning.

Part One of this thesis is a summary of all Phase I research. It
identifies all leak sealing methods and evaluates their effectiveness
based on published reports, documented field and laboratory tests, and
experience of the gas industry. Part One attempts to substantiate claims
of contractors and manufacturers and opinions of gas utilities by collecting
all available test data. It identifies those factors that may influence
leaks from joints, and that may influence the effectiveness of sealing
methods. Finally, Part One makes recommendations for the direction of
future phases of this research.

During Phase I, all major organizations, manufacturers, and contractors
in the United States and in the United Kingdom were contacted for informa-
tion. A complete and detailed survey of available literature has been
concluded, having checked over 400 journal articles with 195 articles
containing pertinent information. More importantly, extensive effort was
made to follow-up on all methods referenced by journal articles to determine
the methods' extent of development, commercialization and history since
the publication of the articles. No other similar effort has been found
documented by any published report.

Part Two of this thesis describes the first steps of the continuing
research under Phase II of the ConEdison-MIT program. This part presents
a series of design criteria needed for continued development. It also
tests the feasibility of the overall system and the feasibility of several
design concepts. It contains a list of preliminary design criteria based
on what was learned during Phase I of this research. Part Two attempts,
by performing several experiments, to find a relationship between the
surface roughness of the cast iron pipe, the hardness of the rubber gasket,
and the compressive stress of the gasket material required to stop leaking
gas. Several different cleaning methods are investigated, and recommenda-
tions for further development are made.

Recommendations for the type of elastomer to be used are made based
upon an analysis of the pipe deposits and the results of a literature
survey. Consideration is given to the time-dependent characteristics of

elastomers such as creep and stress relaxation.

The design considerations of providing adequate support and gasket stress are discussed. Several possible concepts for providing the stress are considered, and the feasibility of a few such as the use of foam and heat shrinkable plastics is discussed. The overall system design is discussed and preliminary calculations check the feasibility or advisability of certain components. Finally, recommendations are made for the continuing work on the development of an internal mechanical seal as part of Phase II.

Several other organizations are conducting similar research into the sealing of cast iron mains. Both efforts are funded by the Gas Research Institute. Work at Battelle Columbus Laboratories began in 1980 and has concentrated on the design of an internal epoxy-spraying device for use in live mains, an external repair clamp that can be used on steel pipe as well as cast iron, and a flexible heater blanket as a replacement for the propane torch used to shrink heat shrink sleeves. A separate study of cleaning methods was conducted in 1982. More recently, Arthur D. Little, Inc., began work to develop concepts for new repair techniques, and the criteria with which to properly evaluate them. The initial direction was to develop external methods similar to what was attempted at the Institute of Gas Technology in the early 1960's, but with new technology. Examples of concepts are the development of a jelly grout to seal the main, and use of the ground as a mold for a foaming urethane sealant. The current direction for the internal repair of mains is to adapt existing systems for use in live mains. Engineers at A. D. Little have expressed knowledge of the critical problem of adequately cleaning the area to be sealed. Neither organization is considering the use of a mechanical seal as in the research at M.I.T.

Lead Backing

Cast Iron Bell
Piece

Jute Ring

Cast Iron Spigot
Piece
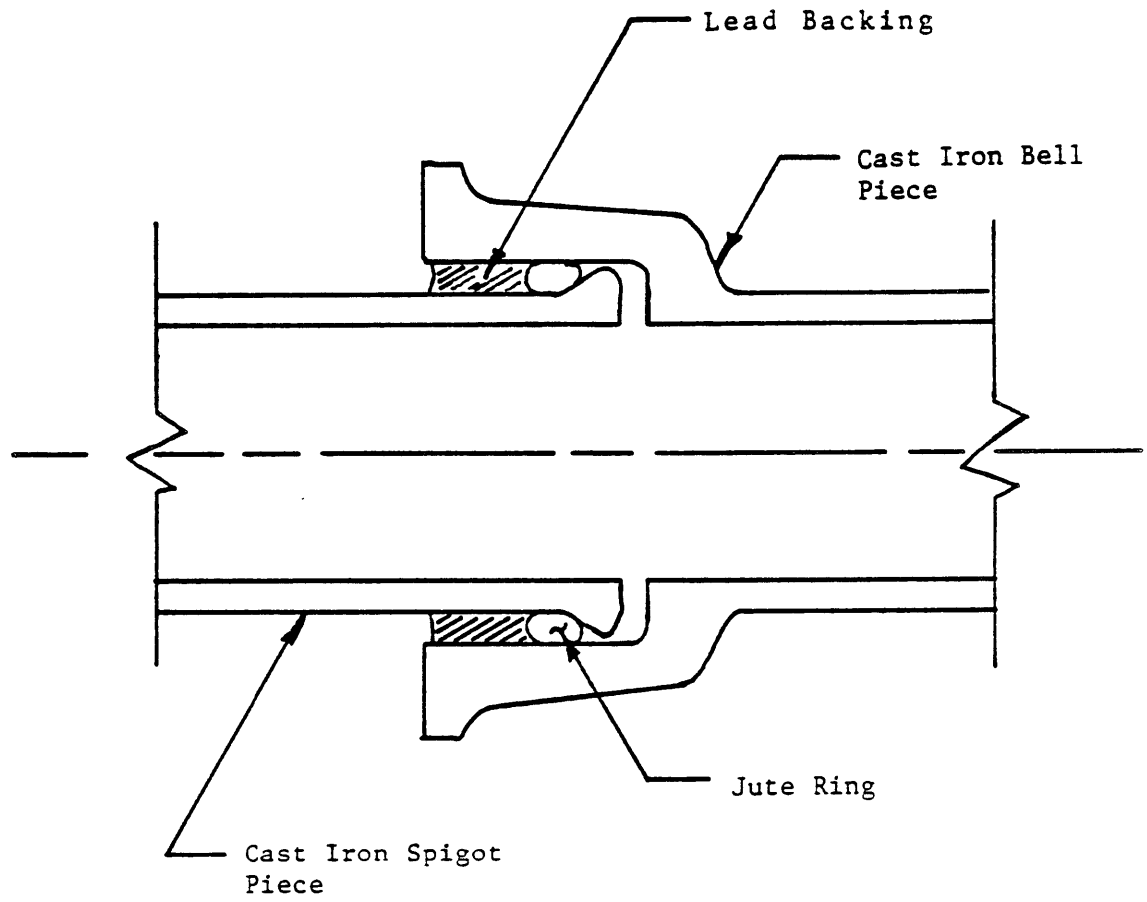
FIGURE 1   Cast Iron Bell and Spigot Joint

PART ONE

AN EVALUATION OF JOINT REPAIR METHODS FOR

CAST IRON NATURAL GAS DISTRIBUTION MAINS

2.0 RECOMMENDATIONS

Succeeding phases of research in developing an alternative method of sealing leaking cast iron gas mains should include the following design areas, listed in order of priority. It is recommended that the design procedure should develop these areas into an integrated system, keeping in mind the interrelationships of these areas as the development continues.

(a) A seal on the inside surface of the pipe that does not require extensive cleaning and that seals the joint by mechanical means.

(b) The cleaning procedures required by the seal and the preliminary design of the device to clean the pipe wall without interruption of service.

(c) The device that cleans and seals the joint without service interference. The device must be able to pass through "tees," branches and around bends.

(d) Safe access to the live main without service interruption.

(e) Quality control by television both in the preparation of the joint area and in the installation of the seal.

(f) Overall system design and estimated cost of application.

3.0 METHODS AND ASSUMPTIONS

3.1 Assumptions

3.1.1 This study identifies sealing techniques to repair leaking bell and spigot joints in cast iron gas distribution mains. Only low to medium main pressure (less than 25 psig) sealing techniques are considered. This study is not concerned with leak repair methods for high pressures, in service lines, in transmission pipelines, or in distribution mains with mechanical joints. However, if a repair technique has applicability beyond concrete- or lead-backed bell and spigot joints, it is discussed in Section 4.0, RESULTS.

3.1.2 ConEdison's Environment. To better evaluate the effectiveness of different sealing methods, an attempt was made to characterize Con-Edison's distribution system. The following characterization is very generalized and does not fully describe the variation of conditions found. However, these comments do provide for an understanding of the distribution system and for a determination of the worst case conditions when attempting to repair a leaking main.

The distribution system is comprised of cast iron pipe with nominal sizes ranging from 4 inches to 36 inches in diameter. Most main diameters are between 4 and 8 inches in diameter. Main pressures vary from 4 inches, w.c. to 25 psig.

The condition of the jute packing is unknown and can be expected to vary considerably from like-new to completely deteriorated. The packing may be relatively clean, or heavily contaminated with manufactured gas

deposits. The jute may have been dipped in tar prior to construction. Most joints are backed with lead, but some may be concrete-backed. In most joints, the backing can be expected to have separated from the pipe material. ConEdison converted to natural gas from manufactured gas from 1951 to 1958.

Service lines are close together and may supply gas to large buildings with many separate consumers, each of which may have several appliances. Buildings may have only one meter, or many meters, one for each consumer.

The distribution mains generally follow the streets and can have branches, "tees," reducers, or bends in any one block. It is expected that long straight sections of main of one diameter, and without branches or "tees," are rare in the system.

To externally seal a joint requires that the pavement be cut, the hole excavated and backfilled, and the hole resurfaced. The existence of other utility lines underground can complicate the excavation or increase costs if damage occurs. Traffic disruption results in high social costs.

Removing a main from service can result in very high labor costs. Service lines must be disconnected and the main purged. Upon restoring service, the pilot flame for each appliance must be relit consuming large amounts of maintenance crew time, even if every appliance is readily accessible. In other cases, alternative sources of fuel must be provided if the interruption of service will be for an extended period of time. Any interruption of service will result in high social costs.

Other sealing techniques may have been attempted. These sealants, such as Carbo-seal or fogging oil, may still be present in the main. The material may be found along the bottom of the main interior as a liquid or

absorbed by the rust and dirt. It may also be found in the jute packing.

Water may be present in the mains in the joint recess or along
the bottom of the interior of the pipe. The pipe interior can be heavily
coated with dried tars and gums that vary with the history of the distribu-
tion system.

3.2 Sources of Information.

3.2.1 Numerous contacts were made with key individuals involved in
the sealing of leaking gas mains to gather complete and current infor-
mation. These contacts were made by telephone, by telex, by mail, and in
person. The individuals were identified from conversations with other
individuals and from published articles read during the course of the
literature survey. The individuals and organizations contacted include
public utilities, contractors, manufacturers, inventors, and governmental
agencies. A complete list of organizations and individuals contacted is in
Appendix B.

3.2.2 Literature Search. Four major sources were used to acquire
relevant literature citations. The articles referenced in these citations
were found in the libraries at M.I.T., and in the libraries of the Boston
Library Consortium, or were borrowed or copied from other libraries by the
M.I.T. Libraries Interlibrary Borrowing Section. The first source of cita-
tions was the bibliography prepared in 1979 and updated in 1981 by the
Consolidated Edison Company Technical Library Staff. The second source of
citations was the publications catalogues and libraries of the following
organizations:

a. American Gas Association

b. Institute of Gas Technology

c. British Gas Corporation (U.K.)

d. International Gas Union (Paris, France)

e. Institution of Gas Engineers (U.K.)

f. U.S. Commissioner of Patents and Trademarks.

g. Atlantic Gas Research Exchange

The third source of citations was the computerized and manual search through available indices. The following indices were searched by the M.I.T. Computerized Literature Search Service:

a. U.S. Government Reports Announcements (NTIS)

b. Engineering Index

c. Science Citation Index

d. Energy Abstracts (DOE)

e. Energy Bibliography and Index (Texas A & M)

f. Transportation Information Service (DOT)

g. Gas Abstracts (surveyed by ConEdison).

The following indices were searched manually:

a. Applied Science and Engineering Index (1960-1981).

b. British Technology Index (1962-1980).

The fourth source of citations was the reference listings in major publications and references recommended by individuals in utilities, governmental agencies, contractors, or manufacturers. Ap'.endix A is an annotated bibliography of references used in this report, and Appendix C is a list of publications and journals containing relevant publications. Over 400 articles were checked, with 219 articles of interest listed in Appendix A, Annotated Bibliography.

3.3 Criteria for Evaluation

Three general classes of criteria were assumed in making qualitative evaluations of the different sealing methods. The first class of criteria used in the evaluation is the direct costs of the sealing operation. These costs are not quantified but remain as qualitative approximations relative to other sealing methods. The direct costs include the cost of excavation and resurfacing; the cost of the sealing material; the cost of specialized support equipment; the labor costs, both skilled and semi-skilled; and the overhead costs of the specific procedure. The second class of criteria is the technical characteristics of the method. These charateristics include the reliability and life-span of the seal, the amount of cleaning required, the material used, the ease of application or installation under field conditions, the sensitivity to errors in procedure or application, and the safety and potential side effects of the method. The third class of criteria include the social costs of interrupting service to consumers by removing a main from service and the social costs of disrupting traffic flow because of extensive excavation. Both of these costs are not reflected in the direct evaluation of a sealing method, but are included to better understand all factors at work.

4.0 RESULTS

The results of the literature search and subsequent communications with individuals and organizations in the gas industry are presented according to general classes of information. The causes of joint leakage and common characteristics of typical tests performed on leak sealing methods are discussed separately from the sealing methods. The discussions of the sealing methods are grouped according to the general subdivisions of gas conditioning, jute swellants, fill and drain methods, internal methods, external methods, and replacement by insertion techniques.

4.1 Leak Mechanism

Before analyzing the leak sealing techniques, it was necessary to understand the leak mechanisms in lead - or concrete-backed cast iron bell joints. Based on the test results found in the literature, it is not possible to draw any definite conclusions on the reasons why joints leak. It is, however, possible to conclude that the backing does not provide a seal over the life of the main. The jute packing is able to hold a seal if the interstices are blocked. Moisture may block the leak paths by swelling the jute fibers or gummy manufactured gas deposits may fill jute interstices. When dry gas replaced manufactured gas, the jute probably shrank and the deposits probably became hard and brittle, no longer able to seal the joints.

Upon conversion from the wet manufactured gas to the dry natural gas, utilities in the United States and more recently in the United Kingdom

experienced rapid increases in main leakage rates. Many articles appeared
in the American and British technical press discussing what was happening
and what should be done to combat the increasing main leakage. A common
assumption was that the jute packing in the joints dried out upon conver-
sion and shrunk causing the joint to leak at greater rates. A survey of
American gas companies, conducted in the late 1950's, showed that most uti-
lities thought that dehydrating jute was the most important reason for the
increasing leakage rates.[25*] These beliefs were based on experience and not
upon quantitative testing. The same survey found that other factors such
as main flexing, traffic vibration, and the drying out of manufactured gas
deposits in the jute were assumed to be influential as well.[25] Few studies
were performed attempting to determine quantitatively the exact mechanisms
for leakage. Not surprisingly, the results were not conclusive because of
the extreme number of variables that can effect in-situ gas mains. What
may be an important factor for one joint may be insignificant for another.
To date, it is impossible to predict when a joint will leak or to
understand why it leaks when it does. However, the results from reports
studying the causes of leakage are valuable for a better understanding of
how the joint may act.

The 1962 Institute of Gas Technology (IGT) Technical Report Number 5
records the results of an analysis of sixty bell joints removed from
service by fifteen participating utilities. Most of those joints backed by
concrete did not leak before removal from service, and most of those backed

by lead leaked before removal. The IGT report concluded that the backing provided a seal only until the backing separated from the cast iron pipe. Apparently the concrete bonded to the cast iron and did not crack or deform in response to external loads because of the concrete's high compressive strength. On the other hand, the lead backing did not bond to the pipe and would deform when the main flexed, vibrated, expanded or contracted. Because there was no relationship between the age of the pipe and whether or not it leaked, the IGT report concluded that the lead backing of the joint must have separated from the cast iron pipe soon after construction.[27] Furthermore, this report concluded that once the seal provided by the backing had broken, the joint would leak unless there was sufficient extraneous material in the jute to block the interstices. In laboratory tests, new dry jute was unable to provide a seal against gas pressure as low as 10 inches, w.c.[27] In a follow-on project to the one documented in IGT Report Number 5, succeeding tests show that leakage from joints made up with fresh jute could not be stopped even with unrealistically high compaction. The leakage rate approached an asymptote for high compaction values.[91] No measurements of the moisture content of the jute under compaction were apparently made. These test results led to the conclusion of the report that the joint leaks when the backing seal has broken.

In the IGT Report No. 5, the packing material of each excavated joint was analyzed but there was no apparent relationship between the condition of the packing material and whether or not the joint leaked before removal from service. Packing taken from lead-backed joints had low pH values, presumably from the manufactured gas deposits; and packing from

concrete-backed joints had high pH values, from the alkali constituents of the concrete. Packing that had heavy deposits were deteriorated more than lightly deposited packing. The deposits were found to consist of aliphatic oils, heavy aromatics, oxidized gums, rust and dirt. It was thought that the interstices of the jute could have been blocked by these deposits sealing the joint even after the backing was broken, and that too many deposits could deteriorate the packing to a point where it could not hold a seal.[27] No further laboratory or field tests were conducted to verify this conclusion.

Earlier in a 1938 study, Skeen reported that the backing would separate from the spigot soon after the main was constructed. He concluded that the jute provided the actual joint seal if the jute had been properly installed and as long as it was not permitted to dry out. In laboratory tests, Skeen showed that the jute will swell 41 percent by volume in the presence of water and that it will swell and shrink as a unit. When deposits are present, the drying out of the jute results in shrinkage and the hardening of the gums and tars. These deposits cement the fibers together and the packing decreases in volume irregularly, leaving leakage paths too large to be blocked by liquids.[79] No discussion of Skeen's test procedure is in the Gas article, but may be contained in the American Gas Association (A.G.A.) Proceedings of which the article is only part. Unfortunately, the only information available from the A.G.A. is the abstract of Skeen's original paper.

In a testing program reported by Commer[4] in 1930 and Mix[14] in 1932, the A.G.A. conducted tests beginning in 1915 on the construction of new pipe joints.[14] Twenty-five joints were removed from service and tested by

the A.G.A. Most of the leaking joints were lead-backed and had obvious separations between the spigot and the lead at the top and the bottom of the pipe. These gaps were reported as indications that ground movement normal to the horizontal plane of the pipe caused deformations of the lead backing.[4] As a result of these tests and others, cast lead was not recommended for backing in new joints.[14] It was also concluded that it was impossible to make a gas-tight seal with dry jute alone against 5 psig of gas pressure.[14]

More recent tests conducted in the U.K. provide results similar to Skeen's. Laboratory tests showed that water-saturated jute would swell 40 percent, and that passing dry gas through a water-saturated test joint would result in a fivefold increase in leakage. From these two tests, it was concluded that the increase in leakage upon conversion is due to the shrinkage of the jute.[32] Specific laboratory procedures and results are not included in the referenced article. These tests and other tests and experiences lead to the common belief in the U.K. that moist jute provides an adequate seal which may leak upon drying out. British engineers generally do not concur with the conclusion of the IGT Technical Report Number 5 that the lead was intended to be the original seal that leaked soon after construction.

4.2 Gas Conditioning

Upon conversion from manufactured gas to the drier natural gas, utilities reported an immediate problem of the dust of dried manufactured gas deposits being carried along by the gas. The utilities also reported

an increase in leakage within one to two years after conversion.[52] The

leakage increase was thought to be the result of the jute drying out and

shrinking and the deposits becoming hard and no longer pliable. Leakage

was also thought to be the result of the shrinking of the rubber gaskets in

mechanical joints as the aromatic hydrocarbons of manufactured gas were

desorbed by the gasket. In response to their own experience, or that of

others, several utilities added water vapor to the natural gas to keep the

jute moist, and a variety of oils to keep the tars and gums soft and

pliable, and the gaskets swollen. The intent was to keep the joint packing

and the rubber gaskets in as near a pre-conversion condition as possible.

The conditioning of natural gas was consistent with procedures during the

distribution of manufactured gas where the gas had to be dehumidified. In

both cases, the gas was conditioned to have the properties necessary for

proper distribution and combustion.[29] Gas conditioning was intended as an

interim measure to keep the leakage problem from getting worse until some

other leak sealing technique became available. There was a consensus that

the conditioning must begin before or immediately upon conversion to

prevent the packing from deteriorating beyond rehabilitation. A secondary

purpose of conditioning was to fix the dust in the bottom of the main and to

lubricate portions of the system that previously were lubricated by the

heavy hydrocarbons in the manufactured gas.

Gas conditioning is reported to be effective at minimizing leakage if

it was initiated upon conversion to natural gas. Conditioning is not

considered to be effective at completely and permanently sealing leaking

bell joints, but it is effective in fixing the main dust. Conditioning was

considered to be cheaper than other repair methods even though it had to be

applied continuously. It does have the advantages of being able to be applied to the gas without interruption of service or cleaning of the main interior. A combination of humidification and oil fogging was used to preclude the difficulties resulting from oversaturation and condensation. Nothing has been written recently about gas conditioning using humidification or oil fogging. Several utilities continue to humidify and fog, but have little quantitative evidence that the methods are effective. There are also no references describing what happened when those utilities that were conditioning stopped, and few tests and documentation of the effects were made within companies. Gas conditioning is thought to have little effect upon the leakage rates from old mains, and what effect it does have, probably does not warrant the large number of journal articles.

4.2.1 Humidification. Humidification is an attempt to keep the jute moist in its pre-conversion condition, and to preclude the drying-out and deterioration of the jute.[17,19,29,48] It was recommended to be initiated before conversion,[29] and was only used to keep the leakage problem from getting any worse until another technique could be applied to seal the joints.[13,17,24,45] Once begun, humidification had to be maintained indefinitely or risk losing all previously derived benefits of the process.[13] Once the jute had dried out, humidification could not be initiated with any success,[52] apparently because the jute had begun to deteriorate.

Humidification was primarily by steam injection into the gas stream.[25] Great effort was expended at keeping the relative humidity at 85 percent at the lowest gas temperature in the system to approximate the pre-conversion manufactured gas conditions.[25] The difficulty in keeping a constant humidity is the subject of most articles written on humidifica-

tion. If the gas temperature or pressure at any point in the distribution system were different from the temperature and pressure of the point of application, then fluctuations in the relative humidity would result.[25,48] Automatic control systems were found to be required.[29,73]

Oversaturation could cause condensation and its resulting problems, and the cyclical oversaturation and partial drying of the jute was potentially detrimental to the jute.[29] For these reasons a reference recommended that an alternative to complete saturation was partial saturation combined with oil fogging. The jute was allowed to slowly dry out as it was being slowly saturated by the oil.[29,78]

Completely saturated new jute was found to swell to a maximum of 41 percent in volume. Skeen found that one half of the swelling occurred when the relative humidity increased from 75 to 100 percent. The volume of the jute decreased almost 15 percent when the relative humidity decreased from 100 to 75 percent.[25] Humidification affects leaks due to drying and shrinking jute, but not to hardening manufactured gas deposits.[25] Keeping the deposits moist may limit the concentration of acidic or alkaline deposits in the jute and may slow the deterioration of the jute.[27]

To prepare for conversion to natural gas in the U.K. in the early 1970's, British engineers conducted laboratory and field tests to study the effect of humidification upon leakage rates.[56] A field joint tested in the laboratory showed that the moisture content of the gas does affect the leakage rate, and other laboratory tests showed that old jute will not absorb moisture as readily as will new jute. This latter effect is especially true in ranges of high humidity, where most of the swelling would be expected to occur. Field tests were not as optimistic. One section of

main was isolated for a pressure decay test after seven weeks of treatment with over 70 percent relative humidity but with no reduction in leakage. A second section and a control section were tested with incomplete results at the time of publication. This second section showed a 55 percent decrase in the humidified section and a 45 percent decrease in the non-humidified control section.[56] The final test results apparently were considered successful because most area boards of the British Gas Corporation were humidifying before conversion to glycol vaporization described in section 4.2.3.

Although much was written about the procedures of humidification, little was found on the effectiveness of the method over the long term. Kollock reported in 1935 that after 5 years of humidification, half of Atlanta's distribution system responded to treatment, while the other half did not.[64] Articles announced the initiation of humidification, but none announced its discontinuation. No references were found discussing why the procedure was discontinued, or what happened upon its cessation.

Upon contacting several utilities that still humidify or have stopped humidifying, none were able to provide any data to support the decision to continue or to cease humidifying. There is a great amount of managerial inertia acting to continue doing what has been done in the past. Few managers would wish to stop humidifying if there was a chance that the leakage rate would increase. Those utilities that stopped gave the reason that the water vapor was not reaching the joints throughout their systems and therefore humidification was a waste of money and effort. Humidification is not thought to be worth the amount of money and effort that must be spent to properly control the amount of steam injected into the gas main.

4.2.2 Oil Fogging. Oil Fogging was performed to seal leaking joints, to fix the main dust, and to lubricate equipment of the distribution system such as seals and meter diaphragms. The oil was intended to keep the jute moist,[30] or to block leakage paths through the packing by filling the interstices.[44,45] It was recommended that utilities begin oil fogging first and then try other sealing methods if the fogging did not work.[46] Oil fogging was primarily intended to keep rubber-gasketed joints tight by swelling the rubber of the gasket, or to keep the dust fixed to the sides of the pipe wall.

Fogging oil was either atomized or vaporized to get the fuel gas to carry the oil as far downstream as possible.[67] Hybrid vaporizers and foggers were used to combine the advantages of both methods.[45] Controlling the amount of oil added to the main and measuring the distance the fog travelled in the system were very great difficulties for the utilities. A persisent fog rather than a vapor system was recommended by several references because the oil would be deposited on anything in the main that the fog particles touched.[57,92] If the oil was carried by the gas as a vapor, the jute would be saturated by the condensation of the oil, which would be very difficult to control. Considerable numbers of articles have been written about the fogging mechanisms, the measurement techniques, and the distances that the fog would travel, and several of the best are included as references.[25,83] Mineral oils, gas oil, kerosene, WO8 and Carnea 21 were the primary oils used.[45]

There were some operational difficulties that resulted when a utility employed fogging. Industrial and residential users complained of pilot outages and soot,[29,30,64] the oil clogged dust filters,[86] and perhaps most

importantly, the oils may have prohibited the successful use of another sealing technique attempted after fogging was discontinued.[25]

Tests showed that with low pressure mains, use of oil reduced leakage in joints with heavy deposits by 41 percent, whereas a commercial jute swellant reduced leakage by only 3 percent. It was also found that the oil would rise further up into contaminated jute joints than would the swellant.[45] Other tests concluded that the oil must be continuously applied to be effective.[32] A comprehensive study in 1959 of available literature and a utility questionnaire concluded that oil fogging was effective in laying the dust but had no significant effect to reduce or prevent joint leakage. The study also concluded that spot cold fogging was effective in increasing the odorant level by slowing down the absorption of the odorant by rust in the main.[25] Only one utility contacted in the U.S. still fogs kerosene into the distribution system, but no tests of the method's effectiveness have been made.[274]

In the U.K., a commercially available system that seemed to have more publicity and testing than other systems was WO8, a Shell International product. The oil was atomized by propane. The method required that the jute be in good condition and the effects were expected to last three years.[39] The Tokyo Gas Company experienced leak reductions with WO8, but has discontinued extensive use because of the difficulties in evaluation.[70,229] Because of insignificant sales, the product was discontinued by Shell in pre-1977 years.[77]

Oil fogging is not thought to be effective at reducing leaks from bell-and-spigot joints but it may still be used because of organizational inertia. It probably does little to affect the distribution system in

either a beneficial, or detrimental way.

4.2.3 Monoethylene Glycol Vaporization. As a result of experimentation and development in the British Gas Corporation, ALH Systems, Ltd., markets a method of gas conditioning by injecting monoethylene glycol (MEG) vapors into the gas stream. MEG is absorbed by the jute fibers, swelling them and reducing the amount of gas passing through the packing. Previous attempts at fogging diethylene glycol have not been very successful because of the limited distances the aerosol particles would travel through the distribution system. Vaporizing MEG into the gas allows the swellant to travel further through the system, but, because of the relatively high vapor pressure of the MEG, the treatment must be continuous.[6] ALH Systems, Ltd., sells two types of vaporizing units. The first is a hot fogger which vaporizes the MEG directly by a thermal unit. The second unit atomizes glycol particles which vaporize in the gas stream.[47] The effectiveness of this method depends upon the condition and compaction of the packing, the glycol vapor saturation level in the gas, the temperatures of the gas in the system and the leak rate of the joint before treatment.[47] Almost all the distribution system in the U. K. is conditioned with MEG; several utilities in the U. S. are still evaluating the process; and the Osaka Gas Co., Ltd., of Osaka, Japan, uses the system.

Consolidated Edison has been evaluating MEG vaporizing since December 1978 when a hot fogging unit was installed on a main in an isolated section of Astoria, Queens. A second hot fogger was installed in the Bronx in May 1979, and a cold fogger was installed on a low pressure main in Astoria in August 1981. The hot foggers are installed on a 10 psig main at a gate station from the 175-275 psig Transfer System. The drop in pressure and

the resulting drop in gas temperature restricts the amount of glycol to be carried by the gas. The pressure is decreased once again to about 6 in., w.c. in the low pressure mains. Because of the pressure drop and the low injection temperature, the gas at the jute to be treated is usually less than about 20 percent saturated. There have also been mechanical problems with operating the fogging units.[54] Individual leaking joints were encapsulated in treated and untreated areas to measure changes in leakage rates, but a series of difficulties in the preparation of the test joints may have invalidated any resulting data. The leakage rates from the joints have been very erratic, showing no trends. Laboratory analysis of the jute from four excavated encapsulated joints have shown that only one had absorbed glycol to ten percent by weight. Three others had absorbed less than 2 percent. No trends could be identified by this result. Repair activity has also been monitored in treated and untreated areas, but repair activity is very sensitive to other factors such as the weather or the decisions of supervisors. Both treated and untreated areas show a decrease in the number of repairs per mile as a moving average of the previous twelve months. If MEG vaporization could reduce the leakage rate by 10 percent, the savings in maintenance costs would pay for the required capital equipment. A decision was made to shut down the two hot foggers in January 1982 to try to identify an increase in leakage and to establish a base-line leakage rate.[92]

Brooklyn Union Gas Company began conditioning an isolated two block square section of the distribution system. Like ConEdison, Brooklyn Union fogs at a gate station from the Transfer System and experiences the same low MEG injection rate because of low temperature and a pressure drop to the low pressure system. It is estimated that the gas at the low pressure

joints would be about 60 percent saturated. Brooklyn Union has experienced mechanical breakdowns with the equipment which is undersized to fully saturate winter demand flows. The leakage rate is computed by the difference between the amount of gas measured entering the system and the amount used by the customers. This method will measure all leakage and not just joint leakage, but could provide information from any changes. No tests have been performed to see if the glycol is actually reaching the joints, but analysis of two joints did identify a trace of MEG present in the jute. The test is continuing and the use of gas heaters at the gate station is planned to increase the gas temperature and the glycol saturation levels.[74]

Peoples Gas of Chicago began conditioning 15-20 percent of the sendout in early 1981. The vapor is injected into 22 psig mains and it has been computed that the gas is approximately 40 percent saturated at the low pressure mains. Controls are being installed to proportion the amount of glycol injected to the amount of gas carried by the main. Leak surveys are considered by People Gas to be valid data sources. This year will be the first year that the city has completed its five-year survey cycle, and comparisons of before and after leak rates are expected to show a decrease in leakage. However, leak surveys are very sensitive to factors such as the speed of the vehicle and the wind conditions, and realistically should not be expected to provide much useful data. 24 joints have been encapsulated, 17 have stopped leaking, and 7 continue to leak. No joints in untreated sections of the system were encapsulated as test controls. The summer of 1982 will be the first time that the encapsulated joints will be checked to insure that the seals have not broken on the encapsulations. ConEdison

discovered that several of their encapsulated joints had become cracked and the measured leak rate was actually the difference between the amount of gas leaking out of the joint and the amount of gas leaking between the encapsulation material and the pipe.[92] Peoples' Gas used a Phil-lastic material similar to the epoxy Epi-Seal used by ConEdison. The epoxy cracks at cold temperatures and, based on ConEdison's experience, it is expected that some of Peoples' data from the joints will be invalidated by cracked encapsulation. The utility has also scheduled laboratory analysis of the jute from treated joints to be performed in the summer of 1982.[68]

Baltimore Gas and Electric Company began treating about one-half of their system during January 1981. The fogger is placed on a 17 psig main downstream of a regulator reducing the pressure from 300 psig. However, the pressure reduction occurs in three steps and one-half mile of exposed pipe separates the regulators from the fogger so that the temperature drop is not as sevire as in New York. The system had been humidified and oil fogged since conversion to natural gas in 1950,[85] and the company had poured glycol down the inside of mains up until 1979. The leakage rate began increasing in early 1981 and the company began pouring diethylene glycol again at the same time that they began conditioning with MEG. The 10-15 percent per year leak rate increase has slowed since then. The company has a belief in glycol's ability to reduce leakage, but was concerned that the glycol would not travel throughout the system. MEG vapors at about 20-30 percent saturation have been measured twelve miles from the fogger whereas humidification and oil fogging were effective for only one and one quarter miles downstream. The company is well satisfied that the glycol is reaching the low pressure joints. The utility uses a computer

program to compile leak survey results and repair activity between treated and untreated areas, but have no results to date. The company did not encapsulate joints after learning of the difficulties experienced by ConEdison and Peoples' Gas. They have calculated that an 8 percent leak reduction would pay off the capital costs of the MEG equipment.[36]

Northern Utilities of Portland, Maine, has been treating a 9000 foot-long section of 24 inch diameter main since 1979, and the utility is convinced of the method's effectiveness. For the first one and one-half years, they monitored leak rates by bar hole surveys, a method attempted and abandoned by most of the other utilities mentioned in this section of this report. The company began treating the remainder of their system in 1980. They assume that they are treating the low pressure system in downtown Portland, but have not measured MEG quantities in the gas and have no idea how far downstream the vapor actually travels. The major source of data that the company uses is the report of repair activity that is required by the U.S. Department of Transportation.[5/]

The most comprehensive tests of the method were performed by the British Gas Corporation's Engineering Research Station. At the completion of preliminary laboratory tests, full scale joint tests were conducted in 1975 with new jute, and in 1977, old joints removed from service were tested. In the 1975 tests, twelve joints made up with new jute experienced an 84 percent reduction in leakage after being treated with gas with MEG vapors at 55 percent saturation for 400 days. In another test, joints humidified at 70 percent relative humidity were tested and the leakage rate decreased by 40 percent. Upon conversion to MEG conditioning, the leakage

rate rapidly increased but after 100 days had reduced below the 40 percent level.[4/]

In the 1977 tests, 48 joints were removed from service and treated, showing a 70 percent reduction in leakage after 600 days, but the scatter of the test results was greater than before. British engineers were particularly interested in reducing the number of Publicly Reported Escapes (PRE) because these leaks must be repaired immediately and cannot be deferred. Even though the quantity of gas leaking was reduced significantly in these tests, the number of PRE's that would have occurred was estimated to be reduced by only 30 percent. The threshold for a customer smelling the gas is about one liter per minute and MEG treatment affects more readily those leaks at rates of about 1 to 5 liters per minute. Therefore, even though the method may reduce the large leaks, the customers may still be detecting about the same number of leaks.[4/]

Field tests at five locations in the U.K. showed significant reductions in leakage rates ranging from 54 percent in four months to 85 percent in two years. Several locations had been fogging with DEG before switching to MEG. The leakage reductions were estimates based on a varying combination of measured parameters, such as pressure decay tests, muffed joint tests, PRE's, repair activity and leak surveys.[4/]

Before the method is introduced into a section of main, a yarn sample is taken for each 100 to 200 miles of main. One and one-half grams of jute are removed from a hole drilled in the back of the bell and sent to the London Research Station where it is tested for tar content and swelling ability. The swelling pressure test involves placing a pre-dried sample in a test holder and compacting it. The jute is then saturated with liquid

MEG and the swelling pressure measured by a transducer.[71] It is not known how the jute is mechanically worked prior to testing or if the results of swelling pressure tests have ever been correlated with the effectiveness of the method in the actual mains treated. In the laboratory analysis of jute from mains to be treated in Con Edison's system, the recommendation to treat or not treat a section was based upon only one jute sample for each section of main.[82] It is thought that the variation in jute condition in a main may require more samples being taken before a proper recommendation can be made. However, extracting jute from a buried joint probably would cost about as much as the cost of clamping, and the resulting refining of data probably could not justify the increased cost.

Gollob Analytic Services performed laboratory analysis for Con-Edison. The jute from two joints were mixed and mechanically crushed into eight 1/2 inch diameter tubes. Nitrogen saturated with MEG vapors was circulated through the tubes. The leakage rate was periodically measured with a constant pressure drop across each tube of about 15 in., w.c. After 10 weeks, the tubes showed a reduction of 9.5 percent and three tubes had absorbed 0.7, 3.0, and 2.0 percent glycol by weight respectively. After nine months, the average leak reduction was 17 percent and the average glycol absorbed was about 5.8 percent by weight.[54]

In the IGT study in the early 1960's new jute was tested with liquid diethylene glycol. New jute was cut with a special cutter and packed into 1/2 X 2 inch tubes. The test sample was soaked for two hours, drained for three days and the jute did swell enough to form a seal against 2 psig pressure.[27] This test is not considered applicable because it used diethylene glycol rather than MEG.

Osaka Gas Company has reportedly conducted sufficient tests to convince themselves that the method will work for their system. The Osaka Gas system began treatment with MEG when it converted from manufactured gas to LNG.[92] However, they will not provide any information because of proprietary agreements with ALH Systems, Ltd.[81]

A test is being conducted at the Massachusetts Institute of Technology that will simulate as closely as possible in the laboratory those conditions found in actual distribution sytems.

Previous lab tests were conducted on new jute, or old jute that had been mechanically reworked after removal from the field joints. Several tests used liquid glycol to swell the test jute rather than MEG vapors as would be found in the actual system. In the M.I.T. test, jute samples were removed from joints from the ConEdison system and were confined in holders designed to be geometrically similar to the original joints. The jute is treated with nitrogen partially saturated with ethylene glycol vapors. Under normal test conditions, the nitrogen test gas is recirculated through the samples at approximately 50 percent of saturation with the glycol vapors at a concentration of 4.47 mg/ft.^{3} This concentration is approximately seven times higher than the 0.69 mg/ft.^{3} estimated to be found in the natural gas during ConEdison's field tests. Nine test samples are treated with the nitrogen-glycol mixture and two with dry nitrogen as the test controls. A more detailed description of the test procedure and equipment is contained in Appendix E.

Before constructing all sample holders and test equipment, two samples were tested with liquid ethylene glycol to test for any reduction in

leakage. If the jute removed from the ConEdison system had not significantly responded to liquid glycol, then it would not respond to glycol vapors. Because the liquid glycol-saturated test samples did show significant reductions in leakage, the glycol vapor test was initiated.

As a final check before initiating the glycol vapor test, the jute in all samples was found to respond to a change in ambient moisture concentrations. By passing dry nitrogen through each sample for ten days, the leakage rates increased and the weights decreased. Because the jute could desorb water vapor inferred that it should also absorb glycol vapor.

The glycol vapor test was initiated and there was a general downward trend in the leakage rates of the nine samples treated with glycol. After 63 days, the average leakage rate for all nine samples decreased by 12.2 percent. However, Samples 3 and 4 had decreases of 36.2 and 22.2 percent respectively. The average leakage rate for the remaining samples (No. 5 through 11) decreased by only 7.3 percent. Concurrently, the leakage from the test control (No. 12) decreased by 4.5 percent. The leakage rate from sample No. 2 (which had previously been saturated with liquid glycol) increased by 44.0 percent, presumably as glycol is desorbed. The data for all samples are contained in Table 20 and Figures 36 and 37 in Appendix E.

On the basis of the results to date, the leakage rates in this test are not decreasing as rapidly as those in the tests conducted in the British Gas Corporation.[4] In the British tests, leakage rates from joints made up with new jute decreased 63 percent in only 40 and 100 days. In test on joints removed from actual service, the leakage rates reduced 70 percent in 600 days. Assuming an exponential decrease with time, this reduction corresponds to a 63 percent reduction in about 500 days. If the

leakage rates in the tests at M.I.T. are also assumed to decrease exponentially, a 63 percent reduction can be expected in 800 days. A more detailed discussion of the results to date are contained in Appendix E. The test at M.I.T. will continue to determine the long term effects of glycol treatment on jute samples.

The results from laboratory and field tests in the U. K. show that this method of gas conditioning may work for the distribution system in the U.K., but do not insure that it will work in the U.S. British systems have been conditioned by humidification and oil fogging since conversion to natural gas in the early 1970's. Most U.S. utilities converted to natural gas at least thirty years ago and very few have humidified their system since that time. As a result, American distribution systems can be expected to have drier and probably more deteriorated jute than British systems. It has yet to be shown either by laboratory tests or in field tests that MEG vaporization will significantly reduce leakage rates in American systems. The test at MIT described above and in Appendix E should add more information to better understand how this method will work for American utilities.

4.3 Jute Swellants

Concurrently with the original efforts to condition the gas, several materials were developed to condition the jute packing in the joints without interrupting service. These materials were designed to swell the jute to block the interstices and to seal the joint. Most of the materials contained ethylene glycol, which reacts chemically to swell the jute fibers

by more than 40 percent. Diethylene glycol was preferred over monoethylene glycol because its lower vapor pressure enabled it to remain in the main for a longer time. Carbo-seal was the most prevalently used swellant in the U.S., and Weasal was the most prevalently used swellant in the U.K. There were other swellants, such as Havoseal and Sealall, mentioned in the literature, but no substantive information was found concerning their effectiveness or extent of use. ."Saturseal" was announced in a journal article but no further comments were found. During an American Gas Association sponsored project, the Institute of Gas Technology developed a two-part jute swelling sealant that cures forming a permanent seal. Jute swellants provide, at best, a means of inexpensively reducing leak rates without service interruption. Glycol will swell jute fibers, but only if the fibers are not glued together with deposits, and only if the glycol reaches the jute. These two problems remain as major limitations of jute swellants.

4.3.1 Carbo-seal. Carbo-seal was developed by the United Gas Improvement Company and marketed by the Union Carbide and Chemical Company to seal joints in low pressure mains by swelling the jute packing without interrupting service. Carbo-seal was also used to lay the dust in the main.[62] Carbo-seal was approximately 70 percent diethylene glycol, and was designed to dissolve manufactured gas deposits, to climb through the jute by capillary action to swell the fiber along its entire length, to keep the fiber rigid after swelling, and to be hygroscopic and miscible with water.[9]

Several methods of application were employed. Initially Carbo-seal was manually poured from high points of the system along the bottom of the

main to the drip pots at the low points.[62] Approximately 15 to 20 percent of the amount necessary to saturate the packing was retained in the joint recess at the bottom of the main necessitating several treatments. In the Auto-seal process, the Carbo-seal was automatically poured into the main at a very slow rate and recycled until all the joints were saturated.[25] Alternately, the Carbo-seal was sprayed onto the pipe walls by pulling a spray head through the main 150-200 feet in each direction from one excavation. Two or three treatments were normally necessary.[25,63] No documented tests were found that verified that the sprayed swellant actually traveled through the joint recess into the jute. Another application method considered was to inject the swellant directly into the packing through two holes drilled in the bell of the joint. This method which would necessitate excavating each joint was never tested in the field.[15]

The effectiveness of applying Carbo-seal depended upon the condition of the jute in the packing. Carbo-seal did not seal joints in which the jute was deteriorated or soaked in cement prior to installation, and it would not seal joints that were improperly constructed. This conclusion was verified by examining leaking joints after Carbo-seal treatments.[1/,2/,50] Smaller diameter mains responded to treatment better than did larger diameter mains, because of limits to capillary action. Additionally, more than one application was required, and it was usually necessary to clamp some joints that would not respond to treatment.[50] Estimates of the life-span of Carbo-seal ranged from 20 years in the U. S.[33] to 3-4 years in Holland.[1/] Carbo-seal treatment complicated future sealing techniques because the glycol had to be removed before adequate adhesion to the pipe wall was possible.[25]

The most comprehensive tests were conducted by J. R. Skeen in 1938.[79] In the these tests, he tested numerous substances for jute swelling, capillary climbing, ability to wet metals and vapor pressures. He also tested the ability of substances to climb through tarred jute. Other comprehensive tests were conducted by the Institute of Gas Technology in 1962. In these tests it was shown that Carbo-seal failed to climb and swell the jute when the jute was tarred or gummed. The commercial pretreatment to dissolve these deposits did not work in the laboratory. These tests concluded that Carbo-seal application should be limited to mains with diameters less than 8 inches.[27]

Many utilities in the U.S. used Carbo-seal beginning in the late 1930's. ConEdison used the Auto-seal method of application until 1973 when examination of excavated joints showed that the material did not climb throught the jute material.[80] This conclusion was verified by the British Gas Corporation in 1978. In preparation for the test program described in Section 4.2.3, the London Research Station analyzed several joints treated by the Auto-Seal method and found insignificant amounts of Carbo-seal present.[82] Due to a lack of a strong market, Union Carbide no longer makes Carbo-seal.[84]

Carbo-seal required jute to be in good condition to be effective. Utilities experienced difficulties in insuring that the liquid reached the joint, much less the jute. After its initial acceptance, utilities apparently realized its limitations, and its manufacture was discontinued.

4.3.2 Weasal. Weasal was the jute swellant most commonly used in the United Kingdom because of cost and availability. It consisted of 75 percent diethylene glycol. Like Carbo-seal, Weasal could be poured or sprayed

with the latter method being the most popular. The effectiveness of applying jute swellants was tested in England in 1969-71[34] and Scotland in 1971-74.[6] The leakage rate was measured before and six weeks after treatment by leak surveys, overnight pressure variation tests, and recording publically reported leaks. Over 1900 kilometers of main were treated and surveyed with a 73 percent drop in leakage by direct measurement, a 61 percent reduction in reported leaks, and a 68 pecent reduction in leakage by leak surveys.[6] It is not known if the method is continued in the U.K.

4.3.3 Saturseal. One 1939 reference briefly announced "Saturseal," a liquid polymer that cured after saturating the joint packing. It was claimed that Saturseal would revive contaminated jute and seal the porous concrete backing. The sealant would leave a plastic film over everything inside the main, permanently fixing the scale and dust in place. The sealant was supposedly elastic to expand and contract with the pipe. The journal article mentions that a test resulted in a 78-92 percent leakage reduction in 30 days. Nothing is given in the article about the formulation of the polymer, how it is cured, or its history. It was probably fogged into the gas stream, but no mention is made of the potentially deleterious effects upon meters, regulators, or appliances. It probably did not work because positive control could not be maintained over the liquid or its polymerization with 1930's technology.[5]

4.3.4 IGT 2-part Sealant. A two-part sealant was developed in the early 1960's by the Institute of Gas Technology (IGT) for the American Gas Association. This sealant was designed to be introduced into the main as a liquid to saturate and swell the jute packing without service interruption. After a predetermined time, the sealant would cure to a

solid forming a higher pressure seal than other swellants such as Carbo-seal.[60] The liquid phase sealant contained a solvent for the manufactured gas deposits, was designed to change viscosity when required and would exhibit minimum shrinkage upon curing.[60] The sealant was designed to be poured into the main, rising into the packing by capillary action; to be sprayed into the joint by a machine; or to be forced into the joint packing by a specially designed fill and drain machine that would allow gas to pass through it.[60] Three different sealants and curing mechanisms were presented. The first sealant was liquid epoxy resins with an amine curing agent. The mixture would be introduced into the packing in the winter and would cure in the summer with rising ambient temperatures. The second sealant was either silicone or polyester resins that would be introduced without curing agents. After the resins had impregnated the packing, water vapor would be added to the gas stream curing the resins. The final sealant was a styrene monomer that would polymerize with time.[59]

Field tests of a two-part sealant were conducted with eight utilities treating approximately 10,000 feet of main. The sealant was poured down the invert of gas mains and was recirculated. The results were inconsistent with the reasons not completely known. Excavated joints showed that the sealant did not rise into the packing by capillary action. The success of the sealant application depended on the condition of the jute and upon the presence of manufactured gas deposits. Accumulations of gum and rust along the bottom of the inside of the main absorbed the sealant, interfering in its distribution to the joints. It was concluded that the gum dissolving capabilities of the sealant needed additional development, and that the presence of Carbo-seal may interfere with the curing times.

As a result of these tests, application by the pour method was not recommended if the jute were deteriorated, gummed, or missing; if the main was larger than 8 inches in diameter; or if the main had a negligible gradient.[91]

Different formulations of the ,ealant were required to adjust the curing mechanism and time for applying the sealant by either spraying or by a fill-and-drain machine. The sealant curing process would be very sensitive to changes in formulation and it is concluded that accurate quality control of larger-scale sealant applications would be difficult to achieve, resulting in potentially ineffective results. It is also thought that accurate planning would be necessary to prevent the sealant from accumulating and hardening in low points or drip pots. At worst, a sealant accumulation could restrict or block the flow of gas in the main. J. R. Skeen in 1938 considered a one-phase sealant to be a benefit for these same reasons.[9] Even though the hardened sealant would seal a higher pressure, it is questioned whether the liquid-phase sealant would not be blown out of the joint by the gas pressure before it had a chance to cure in the packing. Finally, use of this sealant technique may preclude applications of succeeding leak sealing techniques.

The development work on this sealant was never completed before the end of the A.G.A. sponsored project. Its success depends upon clean jute in good condition, and the sealant could theoretically be applied without service interruption.

The results of the field tests at the Northern Illinois Gas Company, of Aurora, Illinois (NIGas), were published in a 1966 Gas article. In this article, the author discusses successful tests of the 2-part sealant poured

into three main sections.[69] These test results are included in the draft

report for A.G.A. Project PB-37a[91] and are the test results mentioned in

previous paragraphs. Upon contacting NIGas, the director of research said

that it had been very difficult to properly locate the high points of the

main and too expensive to verify relative elevations of the main. In a

field test conducted after those described above, the liquid did not travel

to where it had been predicted. The company was never sure why it did not

reach the predicted "low point," but assumed that the liquid had gone the

other way. For this reason, it was decided that the pour method was not

worth pursuing. The director said that a device to spray the sealant

directly into the joint was never tested at NIGas.[66] No further

documentation was available.

Another individual who had worked in the maintenance sections was

contacted at NIGas, and he remembered another test in which the sealant was

sprayed into the joint area by a television-guided device. Before sealant

application the main was removed from service and was cleaned by scrapers

and a vacuum system. In this test, the material did not adhere to the pipe

wall as well as it did in laboratory tests. After a short time, thin films

of the material drooped down across the pipe opening, perhaps caused by

clearing service lines of the liquid by compressed air.[160] The individual

remembered no further testing of this method at NIGas, and no documentation

was readily available.

This method could probably be best applied as a fill and drain tech-

nique where the sealant is mixed and forced into the joint recess by a

device similar to that patented by the inventor of this method. Proper

control of the liquid, control of the polymerization of the sealant and

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good quality control throughout are essential for this method to be effective. Even if these problems were overcome, the required level of cleaning would have to be determined and the means for attaining it developed. It is thought that this method may hold promise, but full development is far off.

4.3.5 Jerto. Jerto is a method of spraying a jute swellant inside of 500 foot sections of main without removing the main from service. The swellant is an oil-based material manufactured by Shell that reportedly has similar characteristics as Carbo-seal, but without the dangers of eye- and skin-irritation that made Carbo-seal difficult to handle. The swellant is a light weight oil that was designed as a cutting oil for non-ferrous metals.[42] A key component of the system is a special Y-fitting that allows for retreatment without additional excavation. The fitting is attached to the main through a 1 1/4 inch tap and extends up to grade when the excavation is backfilled and resurfaced. The method is claimed to be 70-80 percent effective and retreatment must be scheduled every 5 to 6 years. Several utilities have used the Jerto method and it continues to be marketed.[49,61] This method reduces the cost of retreatment with jute swellants. If a utility were to consider continuing to use swellants, this technique would probably save some money. There is a large question, however, on how effective this liquid is at reducing leaks.

4.4 Fill-and-Drain Methods

Partially as a response to the lack of a complete and permanent sealing of leaks using gas conditioning and jute swellants, fill-and-drain procedures were developed. In these procedures, the utility fills a section of main with the sealant, pressurizes it to force the material into all of the interstices of the packing and other leak paths, and then drains out the excess for reuse. Several materials were developed with Con-Seal as the only remaining method with full commercialization.

Because the main must be removed from service, the fill-and-drain method is limited to certain areas where the economics allow. The cost of disconnecting and reconnecting services and relighting pilot lights in appliances is high and becomes astronomical in densely inhabited urban areas. If the service is removed for any length of time, the utility must also provide an alternate source of fuel such as bottled propane. Because of these costs, the fill-and-drain method is limited usually to rural and suburban areas.

4.4.1 Con-Seal. The "Never-leak" method using Con-Seal was developed by Consolidated Edison in the late 1950's. The process is currently marketed by Ford, Bacon and Davis with the material manufactured by the West Chester Chemical Company. The main to be treated is removed from service, purged, cleaned and filled with the sealant. Con-Seal is an acqeous emulsion of neoprene rubber particles. The water will swell the jute, and the neoprene particles will block the interstices of joints or service lines. The sealant is pressurized at 70-80 psig for 3-4 hours to insure that all leak paths have been impregnated and sealed. Sections of mains

from 500 to 2000 feet in length are treated after first removing excessive deposits of rust or dirt[21],[122] and after removing other liquid sealants still present in the main.[159] The main is pressurized with air to locate any very large leaks and to provide a standard against which the results of the treatment can be measured. All services are disconnected and capped. The sealant is pumped into the section of main at the lowest point and air is vented at the highest. After pressurizing the main, the excess Con-Seal is pumped out, filtered and checked for pH prior to reuse. The main will supposedly be out of service for only 8-10 hours. However, the main pressure must be limited to 1 psig for 6-8 weeks to allow the neoprene to cure. After curing, the main pressure may be increased to 5-10 psig.[121],[136],[162],[163]

It had been originally claimed that no cleaning was required prior to treatment,[136] but now it is generally agreed that excess deposits of dirt, rust and other contaminants must be removed. To insure the stability of the Con-Seal emulsion, rust, diethylene glycol, or anything else that would absorb water out of the emulsion must be removed from the main.[159] To remove all chemical contaminants, such as glycols, the main must be removed from service and is filled with a mixture of water and a solvent, NOX 968. The solvent and water mixture unfortunately swells the jute in the packing and treatment with Con-Seal must be delayed for at least four months to allow the jute to shrink back to its original size. West Chester Chemical analyzes a sample of main deposits to insure that the main can be treated successfuly but no formulation changes are made.[122]

Con-Seal does not require the jute packing in the joints to be in good condition, or even to be present, but will seal all leak paths in the main

and services.[121,163] The method does not require extensive excavation and according to the literature costs about one-third to one-half that of clamping.[148,159]

The "Never Leak" method requires extensive planning and preparation of the section to be treated. All customers must be notified of the imminent service interruption and a survey of the section must be made to identify all those pieces of equipment or sections of main or services that may not be able to withstand the high hydrostatic pressures.[148,159] All services must be disconnected and capped and reconnected and the appliance pilot lights relighted, all of which can cause excessive amounts of labor costs. The high pressure air test may rupture either the main or service lines increasing costs.[150] Finally, if the implementation plan of the utility in applying Con-Seal is either faulty or does not go according to plan, the resulting delays can be costly.

The only documented laboratory test of Con-Seal is published in the IGT Technical Report No. 5. In these tests in which Con-Seal is not mentioned by name, Con-Seal was found to be the most effective of the fill-and-drain sealants. Con-Seal was found to seal most leakage paths even in the small annular space between the backing and the cast iron. However, fogging oil was found to impede the formation of a good seal in this area, and the experiments did not test how manufactured gas deposits would affect the Con-Seal. These tests also determined that an emulsion with a higher solids content would reduce the shrinkage upon curing. However, when an emulsion with a higher solids content was tested, the larger particles were found to settle out of suspension and begin to agglomerate on the bottom.[27]

The West Chester Chemical Company has provided copies of eight

utilities' responses to a 1979 letter from Ford, Bacon and Davis requesting

information on their expericences with Con Seal. All utilities reported

that the sections treated with Con-Seal remained almost completely leak

free. The mains had been treated anywhere from 5 to 20 years before the

date of the responses. Several companies mentioned that the method was

economically restricted to sections of main with few services because of

the cost of disconnecting, reconnecting or replacing service lines. The

utilities reported that the preparation time and labor, the large amounts

of support by maintenance crews that must be diverted from other tasks, the

requirement to replace portions of the system to prepare for the high

hydrostatic impregnation pressures, the difficulties in contacting all

customers, the expense of using the solvent, "NOX," and the pressure

restrictions waiting for the neoprene to cure limited the applicability of

the method to less than general use. The costs of application varied from

40 percent to more than 80 percent of the cost of clamping each joint

depending on how the costs were computed.[159] It is not known exactly how

these costs were computed or if the costs included all preparation and

labor overhead. According to Ford, Bacon and Davis publications, only 532

miles of 2 inch to 24 inch diameter mains were treated with Con-Seal from

1957 to 1976.[152]

The city of Richmond, which has treated about 60 miles of main with

Con-Seal,[2/5] considers the "Never-leak" method to be a relatively inexpen-

sive main replacement method, costing about half that of relaying the main.

A study in Richmond in 1971 compared "Never-Leak" with other methods and

found that "Never-Leak" was the best use of their funds. Unfortunately,

the study is no longer available.[2/6]

The "Never-Leak" method is thought to provide a relatively reliable seal for existing leaks and allows for an upgrading of an entire section of the distribution system. However, because of the problems enumerated in the previous paragraph it is thought that the method has become too expensive for general use once all those costs associated with service interruption are included. For example, in New York City, the total cost of treating a section of main with the "Never-Leak" method is estimated to be about four and a half times more expensive than the "rule of thumb" used by Ford, Bacon, and Davis.[275] The cost per joint is still about half that of clamping all the joints in the section of main.[277] About 40 percent of all joints have already been clamped. If the cost of treatment is computed for the unclamped joints only, the cost of "Never-Leak" approaches the cost of clamping. In New York, a main must be tested to 90 psi every time it is removed from service, even if the main is normally used for low pressure service. The "Never-Leak" method therefore necessitates the costly removal of all components not designed to hold 90 psi, even if these components are not to be treated with Con-Seal. There may still be some doubt as to how long the seal will remain intact, even though the method has been available for twenty-five years. This doubt may eliminate any remaining cost advantage. The relative availability of funds allocated for capital and maintenance expenses and whether or not "Never-leak" costs can be capitalized may affect the attractiveness of the method.

4.4.2 CFI6. CFI6 was marketed in Europe by Shell International from 1968 to 1972.[153] The fill-and-drain method required that the main be taken out of service and the service lines disconnected. The sealant was an aqueous emulsion of bitumen that would dry within eight days and remain

flexible. The water of the emulsion was designed to swell the jute fibers and the bitumen was designed to block all the interstices within the joint, and to coat the walls of the pipe fixing the dust in place. The jute must be in good condition except for shrinkage due to dehydration. The emulsion was pressurized for two hours with a pressure head of 2-4 meters. The emulsion would seal all small leaks in the main and the service lines. The sealant was drained for reuse and the service lines were blown clear. If no aromatic hydrocarbons were present in the gas, the resulting seal was expected to last more than ten years. However, if aromatics were in the gas, the lifespan was expected to be shorter, especially if the aromatics condensed to a liquid along the bottom of the pipe.[101] No mention is made of how the CF16 reacted in the presence of fogging oils and glycols, or of the curing time during which the main pressure was restricted.

In a later reference, it was stated that the pressure of a treated main must be limited for several weeks while waiting for the sealant to cure.[6] This same reference states that CF16 did not provide a permanent seal and that the method was no longer used[6]. Shell International states that the material was designed for use in mains with pressures less than 5 psig. When it was used in mains with higher operating pressures, the resulting failures gave the material a bad reputation and it was withdrawn from the market in 1972.[153] The British Gas Corporation conducted field tests on mains treated with CF16, and the leakage rate increased shortly after treatment. Laboratory analysis showed that the bitument sealant was unlikely to seal because of the ionic character of the emulsion, its low viscosity and its tendency to shrink and creep on drying.[1]

4.4.3 Gutentite. This fill-and-drain method was used by the Milwaukee Gas Light Company in the late 1950's. The sealant was a plastic colloidal solution in the form of a latex,[156] that would impregnate the packing of bell and spigot joints. Initially, a water test was used to locate major leaks to be sealed by other means.[15/] However, the water test was discontinued because the water would saturate the packing, prohibiting impregnation with the sealant.[25] In the original procedure the main was filled with the first part of the sealant, and pressurized at 25 psig for one hour. The main was drained, flushed with water and refilled with the second part at a pressure of 25 psig for 1 hour. It was during this second filling that the compounding occurred.[15/] The main was then drained and air was introduced at 25 psig to force the rubber compound into the joints. This procedure was replaced with a single application of a one-part sealant that was pressurized at 25 psig for 1 hour.[25]

The main was cleaned before treatment by using an auger cutting tool to loosen the deposits and scale, and a vacuum system to remove and store all the debris. Pea gravel was introduced into the main and pulled through by the vacuum, burnishing the main interior.[156] It was estimated that a block long section of main must be out of service for 4-6 hours. None of the literature mentions the required cure time for the plastic, or if the pressure in the main had to be limited for any period after treatment. Because this method required that the main be removed from service, it incurred high overhead labor costs to disconnect and reconnect services. After a year from treatment, it was found that sections of treated mains began to leak again, and the utility deferred use using the method until additional tests could be made.[25] No record of further testing is available.

4.4.4 Gas Phase Sealant. This fill-and-drain method, marketed by the A.D.I. Corporation, requires that the main be taken out of service and purged. No cleaning is reportedly required. The sealant consists of two gas-phase chemicals, a metal alkyl compound and an organosilane compound,[95] at a concentration of 25,000 ppm[9] in a nitrogen carrier. The sealant chemicals react to form a porous plug blocking all leakage paths. The chemicals react in the presence of water vapor, forming a solid rivet-like matrix in the soil surrounding the pipe or in the jute packing of bell-and-spigot joints.[9] The plug is allowed to grow back into the main to "lock-in" the seal on both sides of the pipe wall. The porosity of the solid plug limits the effectiveness of the seal to about 80 percent,[9] although complete effectiveness has been claimed.

The company literature claimed that 4000 feet of main could be treated in four hours.[10] The inventor claimed in a 1972 journal article that 12,000 foot long mains with pressures up to 100 psig and leakage rates up to 800 cubic feet per hour could be sealed in about four hours. The time depends on the soil- moisture content, soil pH, and soil permeability.[96] However, in discussions with the inventor, the actual sealing time depends upon the condition of the soil surrounding the main. If the main is undermined, the sealant will fill in the entire cavern under the main before all leaks can be sealed. The total sealing time may therefore take more than four hours and the main may require large amounts of the expensive sealant chemicals.[9]

The sealant will react with water, glycols, or any other chemical having a hydroxyl radical. If water is standing in the bottom of the main the sealant will form a skin on the surface of the water. The skin probably would not block the main but would waste a lot of sealant. The sealant reacts with

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water quicker than with glycol. During tests of the method, air was blown through the main to dry it out.[93]

Laboratory tests were conducted at the Anderson Development Company for seal mechanical properties, aging, and effects upon component materials of distribution systems. A test of a joint sealed by the method withstood a 1000 lb. tension force and holes sealed by the method were finally forced out by 20,000 psig. The aging test consisted of subjecting a treated buried main to eight months of 1/2 inch of simulated daily rain. The main was pressurized to 100 psig and only one of 32 holes had failed, but because of structural reasons. Seals were tested in weak solutions of acids and alkalis (3 to 11 pH) for six months with no deterioration. Materials commonly found in distribution systems were exposed to the gaseous chemicals for 24 weeks. Metals were not effected but porous plastics such as ABS, polyethylene, polyvinyl chloride, and elastomers, such as urethane, neoprene, and nitrile rubber, experienced slight embrittlement. Polysulfide and acrylic caulking compounds completely disintegrated within 24 weeks. Meters, regulators and other system components showed no effects to the gaseous chemicals after six months of exposure. The sealants were reportedly not significantly affected by the presence of olefins, water, oils, Carbo-seal, alcohol, odorants, rust or tar. The only observed problems could be eliminated by treating the line before sealing.[96] Presumably, the problems were that the sealant would react with standing water and glycols present in the main. In summation, the sealant would not be significantly affected by any previously attempted sealing technique. It may, however, eliminate any previous seals made with polysulfide rubber such as by the Fuelling or Spring Band method.

Two references from Europe describe the method as one that could be used in a live main.[13,17] However, the inventor designed the method as a fill-and-drain procedure.[93] The sealant may seal all orifices such as pilot flame openings and the sealant may be environmentally detrimental if it entered individual dwellings. In October, 1981, the method was tested by the British Gas Corporation on a live main in England with unsuccessful results. It was mentioned that a potential reason for failure was that the soil surrounding the main was not moist enough for the sealant to work.[38] However, the inventor stated that the method was successfully tested in Ohio, Pennsylvania, Missouri, Texas, and Florida; locations with greatly differing soil-moisture levels.[93] In the British tests, attempts were made to humidify the gas to wet the soil before injecting the gas sealants, but apparently with little success.[38] The Tokyo Gas Company has conducted some tests using this method,[38] but would not provide any information because of proprietary agreements.[229]

If this system could be made to work with a live main, it would present a significant advantage over other internal sealing methods, because there would be no service interruption. However, it is thought that the environmental problems of exhausting or burning the chemicals in homes would greatly limit its acceptability. More laboratory and field tests must be performed to determine the long-term safety of this method on live mains. If this system were used on mains removed from service, it would still present an advantage over Con-Seal because the main pressure need not be restricted for two months after treatment. The gaseous chemicals may be cheaper than Con-Seal, but cannot be reused. The gas-phase sealant method does not require high impregnation pressures, nor does it require that the sealant be blown back into the main in clearing service lines. On the

other hand, this method does not necessitate the identification and replacing of weak portions of the system as required by Con-Seal. The cost of support labor may be less than with Con-Seal for this reason, but upon completion, the utility is not sure that the main section has been completely rehabilitated. The gas-phase sealant method seals only those leaks that exist at the time of treatment, and not those that occur at a later date due to external loading or temperature effects. This method is not thought to be fully developed for widespread application,[145] and may have only a marginal cost advantage over Con-Seal if it is ever developed further.

4.4.5 Other Fill-and-Drain Methods. Several other fill-and-drain methods were mentioned in the literature.[1] The first method was called "Limpetite," and was a rubber solution in a mixture of toluene and xylene. It was a solution in an organic solvent, rather than the water based emulsions of Con-Seal and CF16.[15] However, there were significant problems that had to be overcome such as the safe handling of the flammable and toxic substance, the safe venting of the evaporating solvent, and the restrictions on when the main could be returned to service because of toxic vapors. The British Gas Corporation conducted tests of solvent based emulsions, but nothing further was in the literature.

The second method in the U. K. used the 3M - produced EC776 (nitrile rubber in methyl isobutyl ketone)[15] to seal mains. This product is designed to seal fuel tanks by the fill-and drain method, and a representative of the company in this country did not know that it had been used to seal gas mains.[129] However, the proper application of the sealant required the surface to be clean, dry and free of oil or grease which presumably

would include fogging oil and glycol.[129] These stringent requirements pro-
bably preclude application in gas mains. Also there would be the same
handling and use difficulties as for "Limpetite." No further references
are found in the literature although the British Gas Corporation conducted
tests on its applicability.[1/]

After the failure of the bitumen emulsion, CF16, the British Gas
Corporation conducted research into developing an alternative. Two sealants
were developed, one for low pressure, and one for medium pressure mains.
The low pressure sealant, Evostik 9612, was applied as a fill and drain
sealant and could be easily removed from service lines. The medium
pressure sealant, Evostik 9611, was applied between captive pigs on mains
with no service lines. Two field trials were conducted but were unsuccess-
ful because of inadequate cleaning of the mains.[1,111] No further work
was documented. A result of this research was the development of a fill-
and-drain sealant for sealing leaks in service piping in buildings.[1,111]
This sealant is now marketed by Press Leakage Control Services, Ltd.[155]

Perhaps one reason for discontinuing field testing on mains was the almost
universal reluctance to remove a main from service.

The developers of the Gas Phase Sealant of Section 4.4.4 are currently
testing a water-based urethane co-polymer as a fill-and-drain material.
The material reportedly cures within 24 hours. The results of the tests
will determine if development of the product will continue.[93]

4.5 Bridge-the-Gap Methods.

Several methods were developed that sealed each joint from inside the
main by bridging the gap between the spigot and bell sections of pipe. The

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"bridge" was usually a flexible material that was either held in place mechanically, or by an adhesive bond to the cast iron. The sealing material either was introduced into the main in its final composition, or polymerized while bonding to the pipe. All methods were developed with a specific procedure for preparing the main interior and joint area for sealing. Bridge-the-gap methods require that each joint be sealed individually, rather than the blanket approach of gas conditioning or jute swellants. Because the section of main to be sealed must be removed from service, utilities have used these methods in scheduled maintenance programs to renovate sections of main as an alternative to replacement. Because of their costs, bridge-the-gap methods were never designed or used to make emergency repairs to individually leaking joints. Utilities have been reluctant to expend the funds to seal non-leaking joints, but bridge-the-gap methods offer the advantage of sealing all joints, even those that may begin to leak in the future. Bridge-the-gap methods include manually - and machine-installed mechanical and adhesive-bonding seals, and only a few are still available for use. A few methods have been considered for use in live mains, but none have been seriously attempted. There are no commercially available bridge-the-gap methods for use in mains that have have not been removed from service. For this reason, bridge-the-gap methods incur all the costs and problems associated with service interruption for extended periods of time.

4.5.1 Manual methods. For many years, utilities have sealed large diameter mains from the inside when it was impossible or impractical to externally seal the joints. In early situations, the main was removed from service and purged, and workmen sealed the joints with a variety of synthe-

tic rubbers or epoxies.[99,123,142] No references were found describing the long-term effectiveness of these early methods and it is felt that these efforts were individual utilities' responses to necessity. To make the internal repair of mains more efficient and less labor-intensive, several methods were developed that used pre-prepared sealing materials for installation into the pipe. The Weko-Seal replaced most earlier methods and is the only manually installed internal seal currently available with wide-spread marketing. Because men must install the seals while working inside the main, the main must necessarily be removed from service and ventilation must be provided.

(a) Weko-Seal.

The Weko-Seal was developed in West Germany in 1966 and is marketed outside of Germany, France and Hungary by ALH Systems, Ltd. The Weko-Seal is manually installed inside the mains with diameters greater than 20 inches. Mains can be internally sealed at a rate of one mile per month.[119] The joint area is cleaned to bare metal by a pneumatically driven grinding stone machine that exerts a uniform pressure around the circumference of the joint. A bitumen-based liquid lubricant is hand-brushed around the joint to reduce friction when the seal is installed and to hold the seal in place until the retaining bands can be installed. The seal is a wide nitrile rubber (Acrylonitrile Butadiene Rubber, NBR, Buna-N) strip with molded lips that are pressed against the pipe surface by two retaining bands, one on the bell and one on the spigot side of the joint. The retaining bands are coated to protect against corrosion. After installation, the section bridging the recess between the two bands is inflated and

the seal is checked for leaks by a soap test. The seal is flexible enough to allow for joint movement and will hold main pressures of up to 30 psig.[7,119,166] The Weko-Seal superceded the Strip-Seal and Dresser clamps in the U. K.[6] and the internal spring band in the U.S., and is probably the best designed for ease of installation with small chance of error. The mechanical seal is thought to be more reliable than an adhesive bond. Weko-seal, however, does require service interruption in large mains, a particularly expensive requirement for utilities.

(b) Spring-band.

The internal spring band method of sealing was developed by Consolidated Edison of New York, and was used on mains between 24 and 48 inches in diameter. After the main was removed from service and was purged, workmen cleaned the joint area four inches on either side of the joint recess. Cleaning to bare metal was done by mechanically operated power grinders with rotating discs and cutter wheels. The steel spring band, covered by a strip of aluminum and coated with Thiokol polysulfide liquid polymers, was inserted into the main by collapsing the band into a "U." At the joint to be sealed the spring band was expanded holding the polymerizing rubber against the cast iron to which it bonded after curing in about 24 hours. The steel band was then removed for reuse.[21,164] The section of main was then checked for leaks by direct metering.[25]

This method was labor-intensive and did not lend itself readily to mass production. Quality control was essential to insure proper installation.[21] Mercaptan odorants react with the polymer reversing the polymerization back to a liquid state.[158] Even though the aluminum strip

was assumed to protect the Thiokol rubber from the mercaptans, the strips of rubber sagged from the top after a few years, presumably because of the reaction with the odorant. Upon examination, the rubber was found to be very soft and incusions of air in the material indicated improper preparation of the material upon installation. This method is ro longer used probably because it was unreliable and has been replaced by Weko-Seal.

(c) Strip-Seal.

The Strip-Seal was marketed by Avon Lippiatt and Hobb, Lts., in the U.K. to seal mains with diameters greater than 18 inches.[106] The main was removed from service and workmen cleaned the joint area to bare metal using a power driven wire brushing machine. The joint recess was filled with an expanding mortar and the joint area was coated with a butyl adhesive. A sandwich of butyl rubber, metal shim plates and rubber was built in place, and held against the pipe ;by a steel retaining band. The band was not removed and reportedly kept a 1.4 psig constant pressure on the seal. The rubber was a bitumen-filled polyisobutylene that was soft enough to flow into the irregularities of the pipe surface under the pressure of the gas. Butyl rubber has an extremely low gas permeability. The seal reportedly allowed a joint movement of one inch and was adequate for gas pressures of up to 35 psig. The literature does not mention how long the main must be out of service.[106]

The Strip-Seal was replaced by the Weko-Seal which is also marketed by ALH Systems, Ltd. The Strip-Seal was found to sag from the top of the main, even after the steel shim plates were reinforced. The Weko-Seal is a less labor-intensive product and is more reliable.[38]

(d) Dresser Internal Clamp

Dresser Manufacturing Company marketed a clamp for internally sealing the joint area of mains from 30 to 48 inches in diameter. The main was taken out of service and workmen cleaned the joint area by wire brushing to bare metal. The clamp consisted of a gasket and an intricate series of followers, compression rings and hardware, and could be installed in one half hour per clamp.[108] A polypropylene shield at the bottom protected the gasket from drip oils.[21]

Dresser still makes an internal clamp but with a lower profile and an easier installation procedure. The clamp still consists of a segmented metal follower ring that forces a Buna-N rubber (Acrylonitrile Butadiene Rubber, NBR, nitrile rubber) gasket against the joint area. The clamp is a special order item. The clamp is reportedly comparable with the Weko-seal in cost because of importation fees.[100]

(e) Press Leakage Control Services, Ltd. (PLCS)

A new manually-installed internal seal is currently being tested in the U.K. by the Scottish Gas Board. At the conclusion of the test, PLCS will begin to market the method, and the company will send information on the method.[155]

4.5.2 Machine Methods. Because workmen must be able to move freely within the main, manually installed sealing methods are restricted to mains with diameters greater than 18 inches. However, the majority of low pressure mains in any distribution system will have much smaller diameters. Machines were developed to seal joints internally in these smaller diameter mains. Only two methods, Interseal and Gasloc, are currently available for

use. Several other methods have been attempted but were not effective, and others have been patented but not fully developed and marketed. An electrically driven device to clean, inspect and coat welds in the interior of steel transmission pipelines has been developed by the Nippon Kokan Kabushiki Kaisha (NKK) of Tokyo. It has not been used to seal joints in cast iron mains.[9/,120] A device to seal welds of transmission pipelines is currently being tested by Raychem, Inc., for use in live cast iron mains. The seal consists of a mesh of betalloy, a memory metal alloy of copper.[151]

All of these methods require the joint area be adequately prepared before and during installation of the seal. Adhesive bonding seals require more intensive surface preparation than do mechanical seals. Both of the currently available methods pay strict attention to the level of cleaning actually performed. Those methods that were unsuccesfully attempted in the past, failed because the surface was not properly cleaned, or the sealant reacted with a chemical found within the main. All of the following methods are limited because they require the main to be removed from service.

(a) Interseal.

Interseal is the trade name of the process known as Joint Interne in Europe and is currently marketed by Gas Energy, Inc. The method seals joints from the inside of 4-20 inch diameter mains that have been taken out of service and pu·ged. Up to 360 feet of main can be treated in any section as long as the main is all of the same diameter and without any offsets or bends. The services are disconnected and the main is leak tested with air at a pressure of 12 inches, w.c. before cleaning begins.[138,139]

The main is cleaned by pulling through the main a cleaning train

consisting of prong scrapers, blade scrapers and wire brushes.[126] A vacuum

is used to pull the cable through and to remove debris loosened by the

cleaning train. The cleaning continues until the condition of the cleaning

equipment indicates that the main is clean and until the main looks clean.

Water and glycols are removed by vacuuming a dessicant through the main.

This process is continued until the dessicant comes out of the main as dry

as it went in.[116]

A mandrel is used to seal each joint, after locating it with an

electromagnetic sensor. The seal for each joint is wrapped around the

mandrel, which is inserted into the main and presses the seal against the

inside of the pipe. The mandrel must be withdrawn and reloaded for each

joint to be sealed. The seal consists of layers of aluminum, urethane

adhesive, burlap, aluminum, and urethane adhesive wrapped around the

mandrel and overlapping by a third.[126] The mandrel inflates from the

center towards the ends of the mandrel to force the seal against the pipe

without air pockets. The burlap prevents the adhesive from being forced

out from under the aluminum by the pressure of the mandrel. The completed

seal has a low profile and its smooth surface does not impede the flow.[138]

After the section of main has been sealed, it is tested with a

pressure test. The mandrel locates any remaining leak by adjusting its

location by increasingly smaller increments until the leak is accurately

located. The leak is then repaired by this method or by some other

applicable method. It is possible to pressurize the main to 1 psig

immediately, but 48 hours are necessary to insure adequate bonding before

increasing the pressure to 30 psig.[116]

Interseal is restricted to straight sections of main that can be removed from service. The cleaning is the most important aspect of the operation and also the most subject to errors. It is felt that the use of scrapers, wire brushes and dessicants may at some time be inadequate because of a lack of proper supervision. The loading of the mandrel with only one joint seal must be tedious, but it simplifies the design of the mandrel, and reduces the chance of malfunction.

(b) Gasloc

The Gasloc system, marketed by the Gasline Renovators, Inc., was initially marketed by the C.O.E. Corporation. The device slings a 12-part epoxy at the pipe interior from a head rotating at 4000 rpm and with a pressure of 80 psig. The epoxy fills in the joint recess and coats both sides of the joint to a thickness of about 1/4 inch. The contractor calls the sealant an "epoxy" that is based on "Thiokol LP."[115] Apparently the polysulfides and the epoxies are co-polymers. Thiokol LP is the same material that was the base polymer for the Fuelling method and the Internal Spring Band method. The additives apparently have overcome the earlier problem of using Thiokol, because the contractor claims that it has passed all environmental aging tests with excellent results. The operator controls the system by a television camera, and an annotated video tape completely maps the section of main for future use by the utility. The main is removed from service and is cleaned by a 6000 psig water jet, after tar, rust and dirt are loosened with a separate cleaning tool.[115] Excess water and debris are removed from the main by polyurethane pigs. The device can pass through "tees," branches, and mild bends, but not around 90

degree bends. A pressure test before and after shows the improvement the method has made on the leakage rate. It is possible to seal 400 to 500 feet of main in one night minimizing the disruption to customers and traffic. After 24 hours, the seal will withstand 100 psig. The method was used in Pensacola, Florida in the early 1970's, and the utility expressed continuing satisfaction in a 1979 letter to the contractor. Another contract is continuing in Holyoke, Massachusetts.[114,115]

If the claims of the contractor are true, this system may be an improvement over the Interseal. The mandrel can travel around bends and through branches, and can seal all joints in a section of main on one sealant cannister. The cleaning method, it is felt, leaves little to chance. The most serious drawback of the system is that the main must be taken from service.

(c) Fuelling

The Fuelling method was designed in the late 1950's to seal small diameter mains from the inside by using a remotely controlled machine. The machine could travel 350 feet in any single main section, pass through "tees", but not around bends. The section of main had to be of one diameter and greater than 8 inches in diameter. The main was removed from service and purged. Joints were located by an electro-magnetic sensor and sealed with a two-part polysulfide rubber using Thiokol liquid polymers. It was possible to sea' all joints in the section of main without reloading the machine. The liquid components of the rubber were stored in separate compartments in the machine and were mixed during application. Rotating paddles forced the rubber into the joint recess and on the pipe interior

three inches on either side of the recess. The main could be used immediately for low pressure gas, and upgraded to medium pressure after allowing 12-16 hours for the material to cure.[135] The main would be out of service for 36-48 hours.[141]

When the method was first developed, each joint was cleaned by flailing the area with toothed wheels on chains that rotated around the axis of the machine. Compressed air blasts removed the debris away from the joint area.[2,25] No attempt was made to remove water or residual sealants.[25] Each joint was cleaned and then sealed before moving on to the next joint.

In later models, a more advanced cleaning system was used to insure a clean, dry bonding surface. A squeegee removed the water and other liquid contaminants that were standing in the bottom of the main. Wire brushes removed loose material and finally the interior of the main was sand-blasted down to bare metal.[12/] The entire section of main was cleaned at one time. A vacuum system removed all debris loosened in the cleaning operation. Absorbent diatomaceous earth was moved through the main by the squeegee to absorb the remaining water and other contaminants.[12/,135] This process reportedly resulted in a clean, dry surface for bonding. A final blast of air removed all dust from the joint area immediately before sealing. The polysulfide rubber would bond to the cast iron only if the surfaces were clean and dry. The material would sag from the top if the surface were contaminatrd, if the rubber did not have the proper consistency, or if the rubber was applied too thin.[25]

Using this machine without removing the main from service had been considered at one time,[25] but it was never attempted.[104]

The polysulfide rubber would un-polymerize in the presence of the mer-captan odorant. The manufacturers of the liquid polymers limited the odorant to .007% by weight, but local conditions could apparently exceed this limit resulting in failure of the sealant. The sensitivity to mercaptans is believed to be one reason the process is no longer used[25,104] and service interruption is believed to be another.

Use of the process in Glasgow, Scotland was documented and biannual checks of the seal were to be made by excavating a joint for examination.[99] No documentation of these follow-on checks has been received. Press Leakage Control Services, Ltd.(PLCS), had purchased the rights to use the device, but British utilities expressed no interest. To the knowledge of an individual contacted at PLCS, the device was never used in England,[155] even though several tests were mentioned in the literature.[15,108] In 1978, the Fuelling company sold the process rights to H. P. Linck of Essen, West Germany.[104]

(d) Trace

The Trace process was designed and tested in England to seal the interior of main joints of 6 to 8 inches in diameter. A remotely controlled machine applied a single-part silicone rubber to joints in straight sections of main with maximum lengths of 100 to 200 yards. The joints were located by an electromagnetic sensor.[144]

The main was taken out of service, purged and lightly cleaned with an abrasive not described in the literature. The debris was blown out of the main. The machine would locate a joint, clean it with carbide-tipped flails and blow the dust and debris away with a blast of compressed air. A

primer was fogged onto the joint area and forced dried with compressed air.
The silicone rubber was forced into and across the recess by a rotating
trowel head. The machine then moved to the next joint and the process was
repeated. The main section would be removed from service for less than 24
hours, and 24 hours after application the main pressure could be increased
to 50 psig.

The Company brochure specified that the main to be treated must be
reasonably dry.   In field tests, the presence of water and glycols in
the bottom of the main fouled the cleaned joint area interfering with the
bonding of the rubber to the cast iron.[118] The process was originally
designed for use with a heavily filled hypalon rubber (chlorosulfonated
polyethylene) but the sealant could not meet the material criteria.
Silicone rubber was the second choice, and necessitated the primer and its
associated application systems. However, the silicone rubber was weak in
bonding, especially in the presence of water or glycols. The cleaning
process did not adequately clean and dry the area nor could the process
keep the area clean until after bonding. Inexperienced operators
compounded the problem resulting in unsuccessful field tests.[118] The method
also incurred the high social costs of removing a main from service which
added to its technical problems.

(e) Internal Pipe Sealing Device

A device was patented in 1972 to seal the inside of mains with a
mechanical seal. The seal is an elastic material with ridges that compress
against the pipe interior when held in place by a single steel retaining
band. The retaining band and seal material are expanded by a mandrel until

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the retaining band is extended enough for the latching devices on the ends

to catch. More than one seal can be loaded on the mandrel at any one

time.[113] Presumably the main must be removed from service, and the interior

cleaned, but neither factor is mentioned in the patent. The patent

assignees, Northern Illinois Gas Company, (NIGas) sold the patent rights to

the Press-Seal Gasket Manufacturing Company, however, the patent rights are

currently in litigation.[154] Field tests with NIGas identified a problem

with accurately centering the seal on the joint,[160] and currently available

fill-and-drain and external repair methods were found to be preferable.[133]

The inventor patented this method after his experience with

attempting to develop a seal that required an adhesive bond to the pipe

wall.[160] It is thought that the single retaining band will not be adequate

to provide uniform pressure for the gasket if the pipes are badly skewed.

The gasket is not confined, and may creep over time losing gasket pressure.

(f) Apparatus for Internally Sealing Pipes

This device was patented in 1971 by the Institute of Gas Technology

(IGT) and was designed for use in live mains to apply the IGT Two-part

Sealant more accurately and with more intensity. Particular applications

include large diameter mains or mains in which the jute will not allow

successful capillary climbing of the sealant if applied along the bottom of

the main. The device is collapsible for introduction into the live main.

Even though the device is equipped with a local drain to collect excess

sealant, there still remains the chance for excess sealant to form solid

puddles at low points resulting in flow restrictions. In the patent,

another embodiment for the device is a fill-and-drain machine where the

sealant fills an annular region between the device and the pipe and between two inflatable end seals. In both cases, gas passes through the center of the device.[165] The device was never tested in the field, or marketed.[28]

The device contains several interesting design features, but does not insure that the sealant actually travels into the joint recess to the jute. The fill-and-drain machine is thought to provide more positive control of the sealant. As mentioned before, control of the polymerization and proper quality control is essential.

4.6 External Methods

Methods that seal leaking joints from the outside are the oldest repair method used in the gas industry. Early mechanical clamps were found to have limited life-spans and were relatively expensive. The development of plastics resulted in the experimentation with several methods that did not provide a cost advantage over the traditional clamps. The past twenty years have seen several new types of external sealing methods including the Avonseal, encapsulation and sleeves using heat shrinkable material. These methods can easily seal leaks from non-standard fittings and from joints that are off center.[1,193] Clamps could not seal leaks in similar locations. Externally installed methods require that the joint be excavated resulting in approximately 80 percent of the overall cost of the repair.[189] Although excavation is expensive and inconvenient, external methods allow leaking joints to be permanently sealed without removing the main from service. Several methods required that the main pressure be reduced before repair, but recent developments allow the main to remain at

full operating pressure. External repairs can be made as part of a scheduled maintenance program, or in emergencies. Several of the methods are designed with all required equipment and materials contained in the same package and are intended to be carried on maintenance trucks for use on individual emergency repairs.

4.6.1 Manual External Methods. Several methods in the literature are described where the face of the bell was manually covered with a sealing material. These methods were apparently attempts to find a cheaper method to seal joint leaks than by using the currently available mechanical clamps which were expensive and had expected lifespans of less than twenty years. These manual methods were cheaper in material costs, but were more expensive in labor costs due to the methods of application and because of extended curing time.

The joint could be repacked with Thiokol polysulfide rubber,[25] recaulked with epoxy,[25,191] or sealed by applying thin coats of epoxy to avoid pin holes.[179] In another example, holes were drilled into the bell and Thiokol rubber was injected into the packing,[25] or a bell joint clamp was modified with holes drilled through the gasket and Thiokol was injected under the gasket.[2] A final method replaced the backing and packing with self-sealing rings that were forced against the cast iron when replacing the backing.[221] These methods seem to have been responses by utilities to reduce the cost of externally clamping leaking joints and evidence of extensive marketing was not discovered in the literature.

Epi-Seal is a currently available material for manually sealing cast iron joints, and was first announced in a 1959 Gas article.[210] This product is an epoxy compound that is packaged as a unit with a gas vent and plug,

catalyst, brush and stirrers. The joint area must be sandblasted and caulked or the gas vented with the wrap-around vent tube. The mixed compound is brushed into the pores of the metal as with a primer and the compound is applied at the face of the bell in a fillet. The vent can be capped when the material has hardened, presumably in about one half hour.[169] This product has been used to encapsulate leaking joints to measure the leakage rate. In these leakage tests the material has been found to crack at low temperatures and to separate from the cast iron.[92]

4.6.2 Concrete Repair Methods. Several methods were attempted that made use of concrete's ability to bond to cast iron. Two methods were developed in the 1930's and one more recently in the early 1960's. Repair methods using concrete experienced two significant problems. The first is that the repair could not be backfilled until the concrete has cured. The second problem was that the weight of the concrete casing around the joint could cause the cast iron main to break because of differential settlement. The concrete casing would tend to settle more than adjacent sections of pipe forcing the main to act as a beam perhaps resulting in breakage.

(a) "Antileke" (1933) - "Lek-Pruf" (1936).

In both of these methods a perforated copper tube was wrapped around the bell face of an excavated and cleaned bell joint. The joint was encased in concrete with the copper tube venting leaking gases so as not to disturb the curing concrete. After the concrete has cured, either an emulsion with Alemite gum ("Antileke") or a jelly made with Ivory flakes ("Lek-Pruf") was injected into the copper tube. The injected substances were to react with substances in the concrete forming solids and gums that would block all leakage paths.[173,206]

(b) Concrete External Joint Sealant.

This method resulted from research conducted at the Institute of Gas Technology (IGT) under A.G.A. Project 37a, which attempted to find an external sealing technique that required minimal excavation and .cleaning. A leaking joint was excavated and most of the bulk deposits of dirt, rust and scale were removed. It was reportedly not necessary to remove completely all the scale from the pipe. The sealant was principally concrete with wetting agents and constituents to control shrinkage and accelerate curing. The concrete would bond to the cast iron after penetrating the residual scale. Main pressure was restricted to 1 psig for 3 days to allow the concrete to cure.[196,197] Joints sealed in the laboratory could hold 2 psig without leaking, and the results of the field tests that were mentioned in the literature are undocumented. However, in discussions an individual with the Northern Illinois Gas Company, the field tests identified problems with shrinkage, and different coefficients of thermal expansion. The Keyhole method was thought to be more cost effective.[160]

In preliminary work on A.G.A. Project PB-37a, attempts were made to inject soil additives around joints to seal any leaks. These attempts failed because sandy soils would not hold the sealant long enough near the main, clay soils were impermeable to the sealant, and because it was difficult to accurately pinpoint the location of the joints from the street surface.[196] No published report describes the results of this study. Monthly and quarterly reports are available on microfilm from the IGT.[208]

4.6.3 Mechanical Clamps. Mechanical clamps have been used to repair leaking joints since the time of installation of cast iron mains and varied little between use on gas or water mains.[220] Early clamps were made of

cast iron to hold a gasket against the face of the bell. The clamp was held together by steel bolts, and the gasket was compressed to higher pressures than the main pressure. The cast iron clamp material was sometimes cracked upon installation either because of damage or because of overtightening the bolts. The clamps were also susceptible to damage during excavation or backfilling of adjacent utility lines. Unless the gasket were totally confined, it would creep with time, lose internal pressure and allow the gas to leak. Early attempts to place lead tips on the gaskets failed because the lead would plastically deform, extruding into the annulus between the spigot and the backing. The rubber of the gasket would also react with components of the manufactured gas or its residual deposits.[212] Dresser Manufacturing Company produced a new clamp in 1934 by analyzing gasket pressures and by designing an armored gasket, confined and protected by a helical spring at the tip.[212] Steel bolts had to be either protected against corrosion by cathodic protection and coated, or replaced within 20 years. The bolts are now made of corrosion resistant alloys.[224] One utility experimented in 1960 with applying Thiokol rubber under the clamp gasket.[191] Mechanical clamps are used to seal leaking joints in emergency repairs as well as in scheduled repair programs.

Dresser Manufacturing Division currently manufactures two styles of mechanical repair clamps. The style 60 consists of a bell ring and a segmented spigot follower ring that forces a split flat rubber gasket against the bell face. Corrosion resistant bolts are tightened to around 50 ft-lbs.[21] The gasket that is made of Buna-S rubber (Styrene Butadiene Rubber, SBR) is not armored, but it is completely confined by the design of the follower ring.[224] The Style 160 uses the same gasket but is easier to

install because the follower ring is hinged. For both clamp styles, the joint surface is cleaned almost to bare metal, and the bell face is caulked and finished to insure a flat surface for the gasket.[21]

4.6.4 Encapsulation. In an effort to externally repair leaking joints without the expense or corrosion problems of mechanical clamps, several manufacturers have developed techniques for encapsulating the joint. These techniques have the common characteristic of using a reusable mold or disposable muff to contain a polymer sealant until it cures and bonds to the cast iron with a gas-tight, flexible and chemically resistant seal. Encapsulation has an advantage over clamping because the muff can be easily made to fit unusual fittings or joints in which the pipe ends are badly skewed or off center. The sealant is usually injected under pressure to stop the joint from leaking and collapse escaping bubbles of gas to prevent the formation of voids and leak paths. Medium pressure mains are sealed without pressure reduction with molds than can withstand sealant pressures 5-10 psig greater than the main pressure. Muffs are either supported against the pressure by metal shells, or by internal stiffeners. All encapsulation methods require that the surface of the cast iron be thoroughly cleaned, usually by shot- or grit-blasting.

Development work began in the United States in the early 1960's and in the U.K. by the British Gas Corporation in the early 1970's. Development work has continued in the U.K. with the available kits having undergone changes to make the systems easier to use in the field with minimal chances of error. The individual methods have been designed for use by emergency repair crews and are packaged in kits containing all materials and specialized equipment necessary to repair one joint. Because these methods

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repair the joint externally, approximately 80 percent of the cost of repair is still the cost of excavation and resurfacing. Improvements in the sealing methods and materials do not substantially change the overall cost of externally sealing leaking joints.

Encapsulation methods have been standardized in the U.K. by the British Gas Engineering Standard BGC/PS/LC8 which clearly defines testing standards and procedures. Encapsulation methods cannot be purchased by the British Gas Corporation until they have satisfied the vigorous requirements of this standard.[1/1] Test results are confidential, but ALH Systems, Ltd., publishes portions as technical data for promotional use.[16/] All existing encapsulation systems have converged to similar designs. They all seem to be well engineered in an attempt to make them insensitive to errors in use. These systems are popular because there is no interruption of service.

(a) Avon Series IV.

The Avon Series IV is an encapsulation method marketed by ALH Systems, Ltd., that can seal low pressure mains. The joint area is shot blasted and primed and is covered by a disposable fabric muff. The two-part urethane encapsulant is poured into the muff and is pressurized by twisting down the filler neck as with a tube of toothpaste. The muff is tested for leaks and the repair can be backfilled within 30 minutes. When fully cured the repair will seal up to 2 bar (30 psig).[166]

A similar muff is used to seal medium pressure mains up to 2.5 bar (35 psig). A light steel shell is fitted over the muff providing the support to the muff during pressurization. The shell is not required to hold the encapsulant inside, and it does not have to be cleaned after reuse

resulting in significant labor cost savings. The "Series Four M.P." urethane encapsulant is poured into the filler neck and pressure is applied to 10 psig above main pressure. The fabric neck is squeezed off at the base and the repair cures in four hours. At the end of four hours, the steel shells are easily detached and the excavation backfilled.[166] The Avon Series IV is the only medium pressure encapsulating system to pass the BGC/PS/LC8 interim requirements for testing.[38] As a result of BGC/PS/LC8, the sealant has been modified to be more flexible and not sensitive to moisture on the joint area.[192]

In the U.S., the Series IV shells have been modified for use without the disposable muff. In this regard, the method is similar to the Encapress. (See Section 4.6.4(d)) Several American utility companies apparently feel that the muff costs more than the labor costs incurred in trying to get the mold shells to fit and to clean the shells prior to reuse. The sealant is repressurized after 15 minutes to counter any shrinkage that may have occurred.[38]

Avon Series III is the same as Series IV, except with an epoxy sealant. The Series III was never introduced into the U.S. because the low American winter temperatures would cause the epoxy to crack. The Series III is currently being used in Spain on inflexible joints.[38]

The Avon BGA method was developed to seal medium pressure mains without having to reduce line pressure as had been required by previous methods.[177] The joint area was grit blasted and primed and the two piece polyurethane mold is strapped to the pipe. The epoxy pitch sealing material is injected into the mold allowing escaping gas to bubble out the top. The final sealant amount is applied under pressure at 5 psig above

the main pressure. A rubber mold was thought to be appropriate because it could continue to exert pressure on the sealant even when it shrank upon curing. The pressure cylinder used to pressurize the sealant must be cleaned after use, but was designed to be readily disassembled. The mold has to be pulled off the cured sealant after about three hours before back-filling. Special molds had to be fabricated for each size and type of main joint.[1//] The BGA was designed to seal leaks in medium pressure mains with mechanical joints in the U.K. The BGA became obsolete because the leaking was controlled by fogging oils swelling the joint gaskets.[38]

(b) Keyhole

This technique is marketed by Ford, Bacon and Davis and was developed by the Philadelphia Electric Company.[216] The Keyhole procedure is named because of the small 4" X 18" hole that is cut in the pavement over each joint. The joint is uncovered by an air lance to loosen the soil and a vacuum system to remove the soil for reuse in backfilling. The Keyhole procedure is designed to reduce costs because the resulting hole is excavated by machine and is smaller than those manually dug. Resurfacing costs are also less because the pavement area to be replaced is smaller and because patches can be made by the utility, rather than large scale resurfacing required and performed by municipalities. Sandblasting and all sealing operations are supposedly conducted from the surface of the roadway. A disposable neoprene fiber mold is strapped around the joint and filled with coal-tar epoxy[195] called "Phil-lastic" at 40 psig.[21,18/] The excavation can be immediately backfilled.[21] For this technique to be economical, each joint must be accurately located.[216] The Keyhole

technique was tested in the U.K. but was not accepted because of the need for specialized excavation equipment and because the mold is designed for use with only bell and spigot joints.[13] Another reference mentioned that, in the British tests of the Keyhole methods, the tools were found to be unsuitable for use in clayey soils. There was difficulty in accurately finding the joint location, the cost of excavation was comparable to that of conventional means, and the cost of the elastomer was very high.[15] There is also some domestic criticism of the method because of the difficulty in cleaning and inspecting the joint and installing the mold from the roadway. The method has been used extensively and the specialized skills and equipment necessitate the use of a contractor. The seal itself has been reliable; and the excavation method has reduced resurfacing costs. Similar excavation methods have been used by several utilities for different sealing techniques.

(c) BTR "Silverkit"

The family of BTR "Silverkits" are manufactured by BTR Silvertown, Ltd., and are designed for low pressure (0-2 psig), partial medium presure (2-10 psig) and full medium presure (35 psig). The "Silverkit" is the result of ten years of development at BTR Silvertown and the Engineering Research Station of the British Gas Corporation (BGC).[18] In the "Silverkit" used for low pressure mains, a disposabl: fabric mold is zipped together and strapped to the main, minimizing the sealant required. Everything in the kit is disposable with other equipment such as grit blasters and banding tools present on the repair trucks as common equipment. This

feature makes the "Silverkit" attractive for use as an emergency repair method that can be stored on repair trucks until needed. The joint area must be grit blasted and air dried with a blower to provide a standard pipewall condition. The two part polyurethane sealant, S41, requires no primer and is pressurized in the muff by winding down the filler neck. Trapped air is relieved by inserting a hypodermic needle at the high points of the muff as the sealant is being pressurized. Backfilling can begin from 15 minutes to 2 hours depending upon the ambient temperature.[1/2] The "Silverkit" for only low pressures has been approved for use by the BGC according to Standard PS/LC8, and this approval was acquired only after modifying the sealant to make it more flexible and less susceptible to moisture on the area to be repaired.[35,192]

Partial medium pressure (a British Gas Corporation designation for less than 10 psi) mains are sealed using the same kit except that a sealant check value in the riser tube allows the sealant pressure to be maintained at higher pressures.[1/2]

The "Silverkit" for full medium pressures uses a disposable muff that supports the high pressure sealant without needing metal supports and without reducing the main pressure. The muff has two layers between which a fast curing compound, M35, is injected and pressurized using a winddown filler neck. After the M35 in the muff annulus has hardened. S41 sealant is injected into the muff under pressure. A removable and disposable pressure cylinder liner and connecting hoses allows the sealant to be pressurized while minimizing cost and equipment to be cleaned. All materials except the pressure cylinder and gauge are disposable. Backfilling can begin from 15 minutes to 2 hours after injecting the sealant into the muff.[1/2]

A sealing method no longer marketed by BTR was the "Readyseal." This encapsulation method was designed to be installed with little training and with little chance of error. It was intended to be carried by repair crews as part of their basic equipment. The pipe joint area was cleaned to bare metal by grit blasting and a primer was applied.[1],[11] The polyurethane sealant was mixed in the bag to impregnate a strip of polypropylene felt.[1] The felt was wrapped around the joint with the vent hole in the felt allowing gas to escape while the repair cures. The entire joint repair was wrapped in polyurethane film. When the resin had cured, the vent was then plugged. Company literature does not say how long the resin takes to cure.[1/2] This method apparently is no longer marketed because the isocyanates in the sealant can cause severe skin irritation.[38]

The Engineering Research Station of BGC began developing the encapsulation method as early as 1970.[214] In early configurations, the wrap-around muff was filled with either estercrete, a rigid cement-filled polyester resin, or a more flexible and more expensive epoxy resin.[15] The sealant was injected and pressured by an external pressure cylinder. Main pressures were limited to 3 psig during encapsulation and without limit 3-4 hours after application.[186] The same basic sealant material and procedure was being used in 1974. Backfilling could not begin for at least four hours, and the maximum main pressure was limited to 30 psig after curing.[1/8] BTR Silvertown, Ltd. began calling the kit the "LP2" and the epoxy sealant was pressurized using a reusuable top plate and hand pump on the end of the filler tube. Cure time was accelerated so that backfilling could begin in less than 30 minutes. During encapsulation, the main pressure was limited to 2 psig and after two hours to 30 psig.[1//] The name

of the kit was changed to the "Silverkit" when the sealant was changed to the urethane, S41, in response to BGC/PS/LC8.[192,222]

(d) Encapress

The Encapress systems are manufactured by the Press Leakage Control Services, Ltd., (PLCS) and are designed to repair low, partial medium and medium pressure mains. In the low pressure Encapress "Zip-Kit," a disposable fabric mold is wrapped around the joint with ends connected together with a zipper. The mold is strapped to the main and filled with either of two sealants, one of which requires no primer. The sealant is pressurized by winding down the filler neck, and the repair may be backfilled from 30 minutes to 2 1/2 hours after injecting the sealant into the mold. The joint area must be cleaned by shot-blasting before sealing can begin. The "Zip-Kit" is sold in packages containing all the material necessary to make one repair.[213] Other necessary equipment, such as cleaning and banding equipment, is normally already found on maintenance trucks.[182] The "Zip-Kit" is very similar to the BTR "Silverkit." Partial medium pressure mains may be repaired by modifications to the fabric mold used in the "Zip-Kit."[226]

The medium pressure Encapress "MP80" can seal mains up to 35 psig. The joint area must be cleaned by shot-blasting and then primed. A reusable steel mold is placed around the joint and a two-part polyurethane sealant is injected into the mold from a side filling cylinder. The sealant is then pressurized to 8 bar (116.0 psig) by a top mounted pressure piston. The mold can be removed in 45 to 80 minutes and the repaired joint backfilled.[213]

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A previous low pressure method marketed by PLCS was "LC80," and it was superceded by the "Zip-Kit." The joint area was shot blasted and primed. A translucent PVC mold was wrapped around the joint, strapped down around the pipe, and filled with a two-part polyurethane polymer. The filler neck was then wound down to pressurize the sealant, and the translucent mold allowed the operator to ensure that no gas bubbles were trapped resulting in the formation of leak paths. The sealant allowed for adequate adhesion and flexibility. The hole was backfilled after waiting 1 to 1-1/2 hours for the sealant to cure.[213]

(e) Denso-Tape.

One American utility uses a product called "Denso-Tape" to seal leaks in low pressure mains.[212] The product is manufactured by Winn and Coates, Ltd., in England and is usually used to protect pipes against corrosion and to make emergency temporary leak repairs. The tape is a petrolatum-based material that never hardens and is applied after a primer has impregnated the scale on the pipe, filling voids and limiting corrosion. The pipe must be cleaned by wire brushing.[185] Using this product as a permanent seal is not accepted by other utilities, perhaps because of the chance of damage from backfilling or nearby excavation.

(f) Denso-Foam.

An attempt at encapsulation in 1971 injected a foaming polyurethane into a polyethylene sheet mold. The joint was cleaned, primed and wrapped with Denso-Tape before attaching the mold.[185] The method was not successful because of potential health hazards from the release of toxic isocyanate gases during mixing.[170]

4.6.5　Avonseal. The Avonseal was developed in 1971 to seal bell-
jointed mains with up to 30 psig pressure without temporary pressure reduc-
tion. The bell face and first three inches of the spigot are grit blasted
and two primers are hand applied with each coat being dried by a blower and
cowling. A strip of polychloroprene rubber (neoprene) is softened at 150°C
in an oven and molded against the bell face by a specifically designed mold
plate and hydraulic harness. After 30 minutes of cooling, the harness and
mold plates are removed; the joint is soap-tested for leaks; and the exca-
vation immediately backfilled.[7,15,166,211,223] The Avonseal is thought to
be more appropriate for use on scheduled repairs rather than for emergency
repairs because of the specialized equipment necessary to install the
seal.[13] An early reference described the seal as a butyl elastomer with
aluminum powder fillers.[15] Avonseal was changed from a butyl rubber to
neoprene within the first six months of development when it was found that
neoprene could provide a better seal at higher main pressures.[198]

The Avonseal Two is an improvement over the original Avonseal,
requiring only 30 minutes from cleaning to backfilling. It is designed
principally for pressures up to 2 psig for 3 inch to 12 inch diameter
mains. The polychloroprene rubber has a lower softening temperature, and
is heated in a vacuum sealed plastic packet in boiling water. The rubber
is molded to the bell face by a simple bolt-tightened harness. The cure
and cooling time is only 5 minutes.[166] Avonseal Two is the only method to
have full BGC approval,[192] the results of which are published by ALH
Systems, Ltd., as technical reports.[16/] Avonseal Two provided a quick easy
repair that required limited amounts of specialized equipment. The rapid
cure time increases crew efficiency.

4.6.6 Gas Repair Sleeve. The Gas Repair Sleeve (GRS) is a heat-shrinkable sleeve repair method manufactured by Raychem Corporation. The sleeve is made of radiation cross-linked polyolefins that will shrink to its original shape when elevated to a temperature of about 180°F. The shrinkage ratio is approximately 2.5 to 1. The sleeve will repair leaks in mains with pressures up to 5 psig.[219] The manufacturer and a utility in the U.K. recommend that the pipe and joint be cleaned with a pneumatic triple-head scaler because sand blasting is not required to successfully repair the main.[199,215] The required cleaning is not as intensive as for encapsulation, but is more extensive extending the entire length of the pipe to be covered by the sleeve.[215] The bell face is caulked to stop the leak long enough for the sleeve to be properly installed. Before proceeding, the excavation is checked by gas detectors to insure that no residual gas remains in the soil surrounding the excavation. A triangular strip of mastic is wrapped around the spigot at the bell face to provide mechanical support to the sleeve.[215] When the gas in the soil and excavation has dissipated, an open-flame propane torch is used to preheat the main to 140 F, hot enough to start the mastic to flow.[215] In the U.K. a catalytic heater is used rather than the open flame.[199] Preheating also removes moisture and accelerates the sleeve shrinking time by eliminating the heat sink effect of a cold pipe.[219] The sleeve is coated on the inside with mastic and is composed of segments of sleeve fastened together with a stainless steel closure channel.[219] The modular construction of the sleeve allows the method to be used on 3 inch to 48 inch in diameter mains by connecting together a series of 6 inch wide sleeve segments.[174] After the sleeve surrounds the joint, it is shrunk using the propane torch or

catalytic heater from the center to the outside. It takes approximately 10 minutes to shrink most sleeves. The mastic flows out both ends of the sleeve showing that the seal is complete.[219]

The Gas Repair Sleeve is reportedly easier to install than mechanical clamps and without their inherent problems. The method also allows for simpler inventories, stocking only one type of sleeve segment rather than many different sizes and styles of clamps or encapsulation kits.[219] The system is considered to be more applicable to emergency repairs rather than to large-scale scheduled repair programs.[215] The resulting repair is reportedly flexible under varying climatic conditions and is not adversely affected by traffic vibrations. The GRS was successfully tested by 10 utilities in field applications, and in the laboratory in high pressure, deflection, axial extension, and disbonding tests.[188] It has also been tested to resist earthquake damage as required by the Tokyo Gas Company.[183,228]

The British Gas Corporation has reportedly dug up a joint repaired by the GRS and found that after five years in use, it was still intact.[215] A U. S. utility company has experienced no repair failures since it began to use the GRS in 1973. It digs up an intact repaired joint each year to check on the condition of the sleeves and has observed no problems with deterioration.[217] Heat shrink sleeves are the only external repair methods used by Tokyo Gas[229] and are methods approved for main repairs in the ConEdison system.[189]

4.7 Insertion and Relining

Several techniques have been developed to provide cheaper alternatives to replacing or renovating an existing main by excavating a trench and relaying a new pipe. These methods include inserting the replacement main inside the existing main, thereby minimizing excavation. Other methods are to reline the existing main with nylon tubes, resin impregnated felt tubes, or with a coating material applied by a specially designed pig. All of the methods described except one incur the high cost of removing a main from service. The total cost remains cheaper than total replacement. Even though most of these methods are not intended as a means to repair leaking joints, it may be cost effective to use one of these methods to avoid excavating at each joint every 12 feet.

4.7.1. Insertion. Replacing an existing main by inserting a new smaller diameter main inside of the older main has been an accepted practice for at least twenty years in the U. S. and the U. K.[6,251] This procedure has also been used to replace service lines. Insertion is usually used as a method to replace a badly deteriorated section of main, or to replace an older low or medium pressure main with a new higher pressure pipe in response to increases in demand. It is usually not intended as a method to seal joint leaks in otherwise sound pipe. Insertion is usually cheaper than new construction or replacement with a new main in a parallel trench. These cost savings include not only the material and labor costs, but also the costs of excavation and resurfacing and the social costs of traffic disruption. Both steel and polyethylene (PE) pipe have been inserted into existing mains.[235,239,246] It is

necessary that steel inserted mains be coated and cathodically protected
from corrosion. Sections of steel pipe must be welded together and the
welds coated and inspected before insertion into the existing main.[246]
Polyethylene pipes made of material such as "Aldyl" (Dupont's PE2306), have
several advantages over steel. Because of its flexibility, continous runs
of PE pipe can be constructed by fusing sections of pipe together above
ground rather than in excavations as necessary with steel pipe.[11] The
plastic pipe is easy to transport, handle and insert because of its low
weight. The plastic pipe is also corrosion resistant, flexible and
resistant to adverse effects of traffic vibration.[11] If plastic service
lines are also used, the services can be quickly fused to the main without
concern for the problems of joining dissimilar materials.[6]

Extensive use of inserting new pipe in old mains has been made,
and the predominant method has been to remove the existing main from ser-
vice before attempting to insert the new main. Service is not restored to
all users until all service lines have been reconnected to the newly
inserted main. The cost of relighting appliance pilots and providing
alternate fuel sources can be substantial.

One insertion technique of interest has been developed and was
marketed in the U.S. by the Kerotest Manufacturing Corporation of
Pittsburgh, PA. This method has been discontinued in the U.S., but
continues to be used in the U.K. where it is called the "Blackburn
Method."[271] In this process a smaller diameter polyethylene pipe is pulled
through the existing main without taking the existing main out of service.
A stiff fiberglass rod is pushed through the live main and pulls back a
cable that will pull the plastic pipe through the main. Access to the live

main is made through specially designed gate boxes attached to each end of the section of main to be inserted. The gas is fed into the main by lateral connections. The inserted plastic pipe must be small enough to allow sufficient gas to flow through the annulus between the plastic and the cast iron main. The plastic pipe must also be of a higher pressure than the existing main because it must have the same capacity but with a smaller cross-sectional area. The inserted pipe must also be able to meet projected increases in demand. The plastic main may be pressurized as soon as it is inserted. Service lines may then be connected to the plastic main, one at a time, while all other customers are supplied by the existing main. Services are shut off only once to connect to the new main and are off for only a short period of time. This procedure has a strong advantage in that the work of reconnecting service lines can proceed at a rate convenient to the customer and efficient for the utility. Each service connection is excavated at the main and the low pressure gas in the annulus between mains is blocked by injecting a two-part polyurethane foam on each side of the connection. The old main is then cut away and the service connection made.[250,255,256,25/, 263,266,26/]

A maximum of about 600-700 feet of main may be renewed by this method in one section.[255,26/] However, there is an economic break-even point where the cost of replacing the main equals the costs of insertion and excavating and reconnecting each service. If the services are too close together, then the method may be more expensive and more time consuming than laying a replacement main in a trench parallel to the existing main.[248,266,26/] The section of main to be inserted must be straight and contain no branches or "tees." If the plastic pipe were to rupture during

insertion and subsequent work, high pressure gas would pass into the low

pressure distribution network resulting in possible loss of life and

property. If the inserted plastic pipe passes through a "tee", the high

pressure gas could pass into adjacent low pressure mains, extending the

damage.[266]

The Kerotest method requires considerable amounts of specialized

equipment and skilled labor to complete the complicated procedure

successfully. Utilities by necessity would have to contract to have the

work done efficiently. Because of the small chance of finding a long sec-

tion of straight main with no branches and wide service spacing, this

method is thought not to be applicable for the ConEdison System.

4.7.2 Insituform Method. The Insituform process lines the inside of

mains with a temperature cured felt and resin liner. The resin impregnated

felt tube that is coated with resin on the inside and covered with

polyurethane on the outside is turned inside out and forced through the

main so that the polyurethane is on the inside and the resin impregnated

felt is in contact with the pipe wall. Up to 500 feet of main can be lined

after the main section has been removed from service and purged.[240]

In the original design the felt tube was Terylene needle felt with a

polyester resin. To prohibit the manufactured gas deposits from reacting

with the resin, a polyethylene preliminary lining was turned inside out

into the main by air at a pressure of 12 inches, w.c. Cold water at a

pressure of 12 feet was used to force the felt liner into the pipe. Hot

water at 50°C cured the felt in about two hours. In effect, the felt

liner cured and bonded to the polyethylene leaving an annular space between

the pipe wall and the new lining.[240] The initial field tests failed in

England in 1974 because the resin reacted with the main deposits and because the lining shrunk upon curing, allowing gas to pass along the annular space. For these reasons the Insituform method was not accepted for use in gas mains by the British Gas Corporation.[258] In the initial configuration, the main was purged and pigged, but presumably no additional cleaning was performed.[240]

Since the initial trials, Insituform (Pipes and Structures) Ltd. has developed an epoxy resin which reportedly solves the problem of reacting with deposits and shrinkage. In this new configuration, the liner will actually bond to the pipe, and the strength of the bond depends upon the cleaning of the main.[268] This new process while awaiting approval for use in the U. K. has sealed gas mains in Europe. Service lines are reconnected by cutting a hole in the lining by a television controlled device. The company claims that the process is very cost effective in cities where bends in mains occur. The process has been used in North America, mostly in sewer and water mains. The local licensee is greatly interested in applying the method to gas mains.[236]

The Tokyo Gas Company has used a similar process in which a polyester and nylon fiber tube with a polyester elastomer lining is drawn into the main and turned inside out using a belt and caterpillar feed control. A heat curing epoxy resin impregnates the tube fibers. Steam cures the resin at 60°C in 20 minutes. The main is then pigged to remove condensed water. The main is cleaned using a sequence of swabs, scrapers, wire brushes and squeegees.[237] This system is usually used in medium pressure mains where there are no service lines. Service lines cannot easily be reconnected. Insituform, Ltd., claims that Tokyo Gas Company has copied their system and that it is not viable for general work.[268]

4.7.3 Lining by Nylon Membrane. This method was first tested under field conditions in England in 1975 and is currently marketed by Howson-Durion, Ltd. In this process, an .004 inch thick nylon membrane is bonded to the inside of a clean and dry main that has been removed from service. The main section must be straight with a maximum length of 800 feet with one diameter from 4 inches to 18 inches. All scale, rust, moisture and liquid contaminants must be removed to allow for a proper bond between the cast iron and the nylon. A pig with four rotary cutting wheels is pushed through the main by 50 psig air pressure which also powers the cutting head. Ketone under pressure scrubs the surface removing all water and liquid contaminants. The main is air dried. The collapsed nylon membrane is inserted into the main on a trolley that gives it a U-shape. The membrane slides into the main on a nylon-polyester underlay which pro-tects the membrane during insertion. A two-part polyurethane adhesive is poured into the U-shaped collapsed membrane when it enters the main. Once inside, the nylon membrane is inflated forcing itself against the pipe wall. The adhesive is designed to flow down from the top of the membrane around the sides to the bottom, supposedly completely coating the pipe circumference.[241,264]

4.7.4 Internal Coating by Using Pigs. In the literature, there were several references in which pipelines, mains, and services were coated internally by using pigs in tandem with a slug of coating material in be-tween. The speed of the pigs, the stiffness of the pig seals and the viscosity of the coating material all must be considered in controlling the thickness of the coating. The pipeline must necessarily be removed from service, purged and cleaned sufficiently to allow adhesion to the pipe sur-

face. Wire brushes, scrapers, sand blasting, detergents, solvents and acids can all be used to remove dirt, dust, deposits, moisture and other chemical contaminants.[254] This method of coating is usually used in steel pipelines to prevent corrosion and to increase through-put. The requirements for long straight sections of pipe and for intense cleaning makes this method not appropriate for distribution systems.[25,243,252,253,254,260] The Seiku Gas Company in Japan coats mains with a material called "SG-K Sealcoat" with a TV-controlled pig.[249]

4.8 Comments on Tests Performed on Leak Sealing Methods

Documentation of tests performed on leak sealing methods is generally unavailable. Those tests that yielded substantive results have already been discussed in previous paragraphs. However, it is felt to be desirable to make some general comments on the types of tests usually made and the different perspectives of the individuals or organizations performing them.

Laboratory tests are designed to check the material characteristics and behavior and are performed in special test rigs and on cast iron joints that have been removed from distribution systems. Field tests are usually the final trial of a method that has successfully passed all the laboratory tests. Both laboratory and field tests are performed by utilities, manufacturers, R & D organizations and governmental agencies.

4.8.1 Laboratory Tests. Certain tests performed in the laboratory investigate the properties of the material used to make the seal. For sealing methods using a mechanical seal or an adhesive bonding polymer, the cured material can be tested in tension, compression, shear impact, and fatigue over time and with temperature changes. Adhesion tests are conducted on techniques requiring an adhesive bond to a cleaned surface. For sealing methods that rely upon interaction with the jute packing several other tests have been performed. Measurements of the absorption rates of the sealant, the permeability of the treated jute, the ability of the sealant to climb in the jute by capillary action, the dissolving of contaminants, and the swelling of jute fibers have been made. Additional tests of the ability of the sealant to seal the interstices in the jute and the crevice between the lead backing and the spigot have been performed.

For all sealing methods, the material is tested to determine if it will react with any chemical found in or on the main, and to determine its aging properties. Care must be taken in extrapolating laboratory tests to successful application under field conditions. Critical parameters are identified only after field experimentation.

Sealing techniques are also tested on cast iron joints removed from distribution systems. The sealed joint can be tested for its ability to withstand the conditions found in actual usage. These tests can include pulling the two pieces apart, bending one piece with respect to another, and vibrating to induce fatigue failure. These tests are designed to simulate the effects of differential soil settlement, thermal contraction or expansion, traffic vibration and earthquake loading. Other tests are performed on joints that were sealed while in use and that were removed for examination. These tests attempt to determine why a sealing method was successful or why it was not. Common parameters observed are the amount of contaminants present, the condition of the packing and backing, the amount of cleaning actually achieved and most importantly the failure mechanism.

The British Gas Corporation (BGC) has published Standard PS/LC8 which specifies the performance and material specifications for external methods of sealing leaking joints. This standard specifies the rigorous testing procedure and results that must be obtained before a method can be purchased by the BGC. Interim acceptance of a particular method is possible after testing in the laboratory and full acceptance is granted only after the manufacturer can extrapolate aging tests to a 50-year life span.

4.8.2 Field Tests. Many tests of sealing methods are performed on sections of mains that have been isolated from the distribution system because of obsolescence or on dead-end sections of mains currently in use. Several other tests have been conducted on a more random basis throughout a system. The choice of location is determined by the parameters that the test attempts to measure and control, or by the availablilty of an accessible section of main.

Frequently, a section of main is tested for leaks immediately before and after sealing the joints to compare and evaluate the results of the sealing operation and to attempt to quantify the amount of gas saved. If the services have been disconnected, the main is pressurized with gas or air and a record of the pressure decay gives an approximation of the leakage rate. A similar result is obtained by direct metering the amount of air required to be added to the main to keep a constant pressure. A second method tests for leakage rates after the main has been restored to service. At times of low constant demand, usually at night during the summer, the main pressure may be increased while directly metering the amount of gas added to the main section. The amount of leaking gas is computed by estimating the amount of gas consumed by the appliance pilot flames. Both of these methods do not differentiate joint leaks from leaks from service lines or cracks in the pipe, but they do provide quantitative approximations of the amount of gas lost to leaks.

Follow-on tests are occasionally performed to determine how the sealing methods perform over time. To provide a direct quantitative measurement of leaking gas, joints are encapsulated to capture and measure the amount of gas escaping through the sealed joint. However, this method

may affect the amount of leaking gas because the joints are isolated from the soil and the soil around the joint must be disturbed to apply the muff. This last criticism is valid only if the repair method is applied long before the joint is encapsulated with the test muff.

A second method used to measure long-term seal performance is by leak detection surveys. These surveys record the amount of natural gas in the air and in bar holes, and are usually intended to identify hazardous leaks rather than measuring long-term repair performance. Leak survey equipment measures the amount of leaked gas present, and not the actual amount of gas leaking from any one source. Gas may travel from other sections of main along utility corridors, along the underside of the pavement, or along the caverns under mains caused by undermining. Leak surveys using a survey vehicle are usually not of much value because of the very large number of variables in the test. The operator, calibration of the detection meter, velocity of the vehicle and atmospheric conditions all work to limit the reliability of the method. Bar hole surveys are difficult to use because of the problems with keeping the holes clear of debris and dirt, and because of the previously mentioned problems of gas migration.

A third method of checking the long-term effects of a sealing method is to compare the numbers of leak repairs performed. This method probably does not provide reliable results because the leak repair rate may be greatly affected by the decisions of supervisors and managers, the weather, and other factors such as a street that is scheduled to be repaved and all the joints under it are clamped. Additionally, repair records do not differentiate repairs on joints that were leaking from repairs on joints that were not leaking. When a joint is uncovered for any reason, it is

usually sealed externally whether or not it is leaking. If the joint is leaking, no record of the cause of leakage or the failure mechanism of the repair technique is made or kept. A record of each repair must be kept and periodically reported to the Department of Transportation. No report of the type of failure or the type of repair is required to be made, so no record is kept.

A fourth method for testing the long-term effects of a seal is to use the low demand pressure rise test as described in the previous section. This method provides relatively repeatable results.

A fifth method of checking the long-term effects of a sealing method is by comparing numbers of reports of leaking gas called in by the public. This method is usually not valid because most publically reported leaks occur in service lines, and not from main joints. What the customer would smell would be gas that travelled along an unspecified path to provide sufficient concentrations of the odorant to be detectable. Changes in odorant concentrations, or changes in the weather would be additional variables adding to the uncertainty.

In general, it is very difficult to identify and measure parameters that may influence field tests. It is impossible to determine the forces acting on the main and to know the condition of the joint recess and packing without first excavating and disturbing the joint. It is also difficult to measure the amount of contaminants and moisture present on the inside or outside of the pipe. Even if they were identifiable and could be measured, it would be extremely difficult to try to control the critical parameters because of the difficult experimental conditions of the test. Experimental conditions are virtually impossible to duplicate between

joints much less between distribution systems. Before and after tests are usually made on the same site because of the difficulty of comparing one test site against a control site.

4.8.3 Acceptance Tests. Acceptance tests in the field and laboratory are conducted by utilities to insure that a sealing method works as well as claimed, and to determine the direct and indirect costs of installation or application. These tests are usually performed on sections of the distribution system before they are accepted for full scale use. In effect, utilities' testing programs are to verify manufacturer claims and to insure applicability for the specific distribution systems. There is no economic incentive for a utility to conduct costly extensive scientific experiments over a long period of time. If the sealing method performs well in tests, and if the method provides an economic advantage over existing methods, the utility will use it. If the method fails, technically or economically, the utility will not use it, and will not spend a lot of time on isolating the exact reasons for failure. In the acceptance tests, few measurements are made of any parameter except the obvious ones such as pressure or leakage rate. Little documentation is kept of the test results and what is kept may be inaccessible or proprietary in nature.

Few follow-up tests are scheduled to check if the sealing method performs well over time. If routine leak surveys identify that a specific type of sealing method consistently fails, the method will be discontinued as an acceptable leak repair option. No detailed leak repair records are kept for reasons described above.

Leak surveys are performed to identify potentially hazardous leaks for repair, not to collect quantitative data on the effectiveness of leak

sealing methods. This latter type of data may be able to be compiled from survey records, but is it is usually not done because of the expense and because there is little use for the information. The incentive for the utility is to find hazardous leaks, not to conduct scientific experiments.

4.8.4 Contractors Tests. Contractors rarely perform laboratory or field tests on leak sealing methods unless it is in conjunction with a manufacturer or a utility. Field applications of the method may be analyzed with a view toward making the crews more efficient. However, these field applications are usually performed as part of a contract for a utility.

4.8.5 Manufacturers Tests. Manufacturers perform many tests to develop a product into a marketable system. These tests are probably relatively scientific in nature and provide the data necessary for redesign or reformulation. Laboratory tests on the material are performed first, followed by tests on field joints and field tests. If a problem is discovered in any of these types of tests, the manufacturer begins the process from the beginning after modifying the design to overcome the identified problem. These tests may continue over a long period of time building upon one another as the project matures through development. Records of these tests are usually unpublished in notebook and file form. These records are relatively inaccessible and the manufacturers are reluctant to allow access to them because of their proprietary nature. If the results of tests are published in trade journals, the conclusions are usually general in nature with little mention of ancillary conditions that may have affected the tests. The results of unsuccessful tests are usually not published. To meet the conditions of the BGC Standard PS/LC8,

manufacturers must submit a detailed confidential report to the BGC requesting approval. ALH Systems, Ltd., and other companies have published portions of these reports as technical reports in promotional folders.

4.8.6 R and D Organizations Tests. Research and Development organizations are usually government owned as are the Research Stations of the BGC, or are consulting organizations for government as is the Institute of Gas Technology. These organizations, in responding to a clearly defined need, have evaluated existing techniques or have developed new methods. The work performed includes laboratory and field tests but also surveys of utilities' experiences and analysis of government statistical data. The results of tests are usually contained in files and notebooks and are usually not published. To meet the conditions of the BGC Standard PS/LC8, manufacturers must submit a detailed confidential report to the BGC requesting approval. ALH Systems, Ltd., and other companies have published portions of these reports as technical reports in promotional folders.

4.8.7 Published Test Results. Published test results found in journal articles are usually limited to those tests that were successful or were encouraging. The discussion of the testing procedures and results is usually in general terms and seems to be intended to notify the readers that the test was completed, and not to provide information for critical analysis. Very rarely have unsuccessful results been published.

5.0 CONCLUSIONS

5.1 Factors Affecting Joint Leakage

It is extremely difficult to identify all factors affecting joint leakage that act on a joint that that was buried under three or four feet of soil over fifty years ago. It is even more difficult to define the relative strengths of certain factors and to identify their time-variant behavior. The few joints that have been encapsulated to study leakage rates have exhibited random leakage rates, sometimes stopping or starting, or cyclically varying. Even though little actual data is available, it is possible to present possible factors leading to a qualitative appreciation. This section will identify and discuss those factors potentially affecting leak initiation and continuation.

5.1.1 Leak Initiation. Section 4.1 of this report concludes that cast iron lead- or concrete-backed joints will probably leak when the backing separates from the cast iron pipe. The backing will separate from the cast iron for one of three basic reasons: (1) the joint was improperly constructed, (2) external loadings induce large stresses in the joint, and (3) temperature changes in the pipe induce large stresses in the joint.

Obviously, if the joint was initially constructed improperly, it did not perform as intended. The jute may have been improperly inserted prohibiting the proper placement of the backing. The lead backing may not have been properly compacted, or the concrete may not have been properly mixed or cured. If a large temperature change occurred during curing, or if the concrete dried out during curing, the backing may have separated very soon

after construction. A 1928 study in Halifax, Nova Scotia showed that 25 of 30 leaking joints failed because of poor construction.[5]

External loads on the main can cause large enough stress to break the pipe, or to separate the packing from the cast iron. Except for the damage from digging equipment or tools hitting the main, most external loads are associated with the differential settlement or movement of the soil surrounding the main, resulting in induced bending and shear stresses. Upon the initial construction of the main, the soil may settle at different rates and amounts because of varying soil conditions and different amounts of compaction. If the main passes under a roadway, the ground will settle more above and below the main in sections under the roadway than in sections under unpaved areas. This is especially true if the road has begun to pass heavy commercial trucks since construction. Excavation for joint repairs, or for other utilities will result in the newly backfilled soil settling faster than the soil placed around the main during the original construction. Frost heaves can result in very large soil movement. A particularly dangerous situation occurs when the soil supporting the main is undermined, leaving a cavern running under the main. Lead-backed joints are particularly susceptible to failure caused by external loading. In compression, the lead deforms plastically leaving a leak path upon relaxation of the load. Of 25 leaking joints analyzed in the 1928 A.G.A. Pipe Joint Research Program, most were found to have separations of the lead at the top and bottom of the pipe, indicating motion normal to the horizontal plane of the pipe. Because the lead would so easily deform, this same program recommended in 1930 that cast lead joints not be used in new construction.[4,14]

Large temperature changes in the pipe result in large axial stresses in the joints because of the expansion or contraction of the cast iron. In the A.G.A. Pipe Joint Research Program, joints were loaded in the laboratory to the amount of stress that the joint would experience with an annual 60°F temperature variation. Most of the construction methods of the period failed before 25 reversals. Cement-backed joints gave particularly unsatisfactory results; even the specially designed A.G.A. No. 2 bell joint failed. In lead-backed joints, it was found that the pipe roughness would score the lead axially, opening up leak paths.[4,14]

5.1.2 Leak Continuation. Once the backing had broken, the joint would probably begin to leak. Several factors influence whether the leak would continue, and the rate at which gas would escape. All of the factors described in section 5.1.1 also influence the leak rate. Ground movement and thermal expansion or contraction may continue to affect the leak rate.

As section 4.1 describes, the jute may slow or stop the leak rate if the jute's interstices are blocked by deposits, liquid contaminants, or water. Upon conversion to dry natural gas, the leak rates may have accelerated because the jute dried out and shrank, or completely deteriorated.

If the soil surrounding the joint has a high clay content and is relatively moist, the soil may inhibit the leak rate. As the dry natural gas passes through this soil, the leak rate can be expected to increase because the gas will dry out the soil. Dry or free-draining soils can be expected to offer little resistance to leakage.

For relatively low leakage rates (those normally found in low pressure distribution systems), the soil particles affect the flow of leaking gas such that the escaping mass flow is linearly proportional to the main

pressure. If the soil particles did not interfere with the flow, the mass flow would be proportional to the square root of the main pressure. Experimental correlations of flow through packed beds show that the flow is linearly proportional to the pressure difference.[2/3] In a 1928 study, the leakage rate from sections of an operating distribution system was found to be linearly proportional to the pressure difference,[9] which may confirm that the soil particles affect the leakage rate. For larger leakage flows at higher pressures, the soil particles would be expected to have less influence on the leakage flow and the leaking pipe may act as an orifice.

Finally, it may be difficult to determine the actual leak rate from an individual joint. The gas will travel along the path of least resistance, perhaps along the undermined cavern under the pipe, along other utility pipes, or along the underside of the pavement exhausting into the atmosphere through a crack.

5.2 Factors Influencing Repair Methods.

After analysis of the existing and previously used sealing methods, it is concluded that certain common factors influence whether or not a particular method will be accepted by the gas industry. It can be assumed that a method probably would not gain wide acceptance if it did not prove to be reliable and cost effective. The common factors are divided into several groups that will be discussed in succeeding sections: cost, operational, environmental and material factors.

5.2.1 Cost Factors. A sealing technique will not gain general acceptance unless it provides a significant long-range cost advantage over

existing successful methods. The perceived cost to the utility includes direct and indirect social costs and the expected future maintenance expenses. These costs are weighted according to the needs and experiences of the utility and the community. Specifically, removing a main from service incurs high overhead costs and social costs. In a densely populated urban distribution system, these costs become excessive. To seal all joints externally in a section of main requires an excavation every 12 feet. The excavation and resurfacing costs and the social costs of traffic disruption are very high, but are probably not as high as those incurred by taking a main out of service. Other sealing methods may require specialized skills or specialized equipment. The cost of these factors may prohibit or restrict the use of the methods to limited applications.

5.2.2 Operational Factors. Many factors involved with the application or installation can influence the reliability or cost of a particular sealing method and therefore influence its success. Perhaps the most important of these factors is the ease with which the method can be used. If the installation procedure is complex, and the reliability of the seal depends upon the procedure being followed in detail, then this sealing method will probably not gain wide acceptance. The reliability of the seal would be too sensitive to variations in procedure and the chance of error would be very high. Closely tied to this concept is the need for accurate quality control and the cost in time and labor of the necessary level of supervision. The availability of specialized sk\.lls and equipment and their cost can also greatly affect the success of a sealing method.

If the main pressure must be restricted during sealing and if the pressure must be limited for extended periods of time to allow the sealant

to cure, then the sealing method will probably not become widely used. The sealing method may become immediately ineffective if the pressure is increased beyond the curing pressure limit.

Sealing methods that require an adhesive bond are very susceptible to failure if the bonding surface is not cleaned and dried and kept clean and dry until bonding occurs. Those methods that allowed for inadequate cleaning because of poor quality control or methodology are no longer used. Only those methods that pay adequate attention to cleaning have been successful. Similarly, those methods that did not provide for the complete removal of water, jute swelling glycols and fogging oils were not successful. Mechanical sealing methods do not require as much cleaning but success still depends upon the adequate surface preparation before sealing. Surface preparation includes the filling in of large pits and holes as well as removing the scale and casting burrs from the pipe surface.

Sealing methods that rely upon the jute packing require that the jute be in good condition. The jute cannot have been tarred upon construction, and it cannot be overly contaminated with manufactured gas deposits.

A sealing method will not gain acceptance if its own use depends on narrow specific restrictions on its location. An example of a restriction is for the need for straight sections of pipe with the same diameter and with no branches or "tees." Obviously, if a distribution system has few sections of main that meet these requirements, then the sealing method will have limited use. A sealing method would be of greater value if its use were more flexible.

The sealing method must be safe to use. If there are large chances in the installation procedure of loss of life or damage to property, the

utilities will not use the method. Similarly, sealing materials that are hazardous to handle during installation, or present dangers during curing will probably not be allowed for general use by regulatory agencies or by the utilities themselves.

5.2.3 Environmental Factors. Once the sealing method has been installed on a main, many factors in the environment of the distribution system will determine the success of the method. When the main was originally laid or during subsequent construction, the excavated and backfilled earth will settle at different rates and to different extents. Differential settlement of the soil under or over a main can cause large forces to be exerted on the main and its repaired joints. Undermining of the main can cause the main to act as a beam and the repaired joints to take significant loads and the pipe sections to displace relative to each other. If the soil is frost susceptible, frost heaves may push the main up exerting similar loads on the joints. Temperature differences can cause the pipe material to expand and contract resulting in forces and relative displacement of the pipe sections. Vibrations from street traffic may cause cyclical loading on joints and potential fatigue failure of the sealing material. Traffic vibrations also contribute to different soil settlement rates between sections directly under the pavement and sections not under the pavement.

5.2.4 Material Factors. Characteristics of the seal material significantly affect the effectiveness of the sealing method. The material cannot react with natural gas or its mercaptan odorant, manufactured gas deposits, additives such as jute swellants or fogging oils, or oil from compression equipment. The material should be corrosion resistant and

should remain flexible and not become brittle with time or at low temperatures. If appropriate, the seal material should have an adequately short cure time even at low temperatures and should provide adequate adhesion under field conditions.

5.3   Generalization of Applicability and Limitations by Sealing Method Type

From the results of the literature search and from discussions with individuals involved in the sealing of leaking mains, conclusions are drawn about the applicability of the general types of sealing methods and about the constraints under which successful use of the methods are limited. The general types of joint sealing methods are grouped as gas conditioning, jute swellants, fill-and-drain, bridge-the-gap, external and insertion techniques. This discussion of the conclusions will also include comments describing the sealing methods' applicability to the ConEdison distribution system. Appendix D is a summary table of all sealing techniques discussed in this report.

5.3.1 Gas Conditioning. Gas Conditioning describes the treatment of gas in the distribution system by humidification, oil fogging, or monoethylene glycol (MEG) vaporization. In general, gas conditioning is intended to keep the jute packing in the joints from deteriorating until other joint repair methods can permanently seal the joints. Gas conditioning is meant to be a relatively inexpensive method of controlling joint leaks without interruption of service; it is not meant to be a means of permanently sealing all leaking joints.

Gas conditioning is more effective if initiated before the changeover

from manufactured gas to natural gas. Because of variations in gas temperature and pressure between the points of application and other points in the distribution system, and because of demand changes, gas conditioning presents a significant control problem to insure that the vapor or droplets travel to all the joints in the system as planned. Once begun by a utility, the method must be continued or allow an increase in joint leakage. Gas conditioning must be continuous, or at least periodic, because the effects of the conditioning agent in the main are temporary. However gas conditioning will attempt to seal all leaks as they occur.

Humidification is intended to keep the jute packing as moist as it was before the changeover to natural gas, and presents significant problems of condensation and freezing during the winter. Oil fogging does not substantially affect joint leakage and is primarily intended to keep main dust from travelling in the gas stream. MEG vaporization is intended to swell jute fibers even after the main has carried natural gas for a long time.

The ConEdison system changed over to natural gas from 1950 to 1958 and the joints were allowed to dry out. Humidification would probably not be able to renovate the jute in the joints. MEG vaporization may be able to reduce joint leakage in those sections where the jute will swell in the presence of MEG.

5.3.2 Jute Swellants. Mixtures of glycols are poured along the bottom of the pipe, or sprayed through a section of the main to seal joints without interruption of service. Little excavation is required to treat sections of main. The material is intended to dissolve manufactured gas deposits, climb throughout the jute packing by capillary action, saturate

the jute, and swell it, blocking leak paths.

In practice, effectiveness was limited to small diameter mains in which the joints contained clean jute in relatively good condition. If the jute was tarred during construction, or had been impregnated with deposited tars and gums, the swellants would not adequately penetrate through the contaminants to climb, saturate, or swell the jute. Multiple treatments were needed initially to seal joints. The seals were likely to deteriorate with time requiring retreatment within a few years.

The Auto-Seal method using Carbo-seal was discontinued at ConEdison after the examination of excavated joints showed that the swellant had failed to fully climb to saturate the jute at the top of the pipe.

5.3.3 Fill-and-Drain. Emulsions such as Con-Seal, CF16 and Gutentite fill isolated sections of main and are pressurized to fill and block the leak paths for the gas. The remaining emulsion is then drained for reuse. Treatment by this method require that the main be removed from service for at least a day and operated at reduced pressures for a few months afterwards. Little excavation is necessary and cleaning prior to treatment usually involves removing loose deposits, fogging oils and glycol.

Fill and drain methods incur extremely high overhead costs because of the detailed prepartion and planning required by the gas utility. The requirement to restrict the main pressure for up to two months limits the method's applicability to only cer'ain sections of main or to times of low demand. Fill and drain methods seal only those leaks that exist at the time of treatment. The method may not seal leaks that may develop at a later date.

In the ConEdison system, fill and drain methods are considered to be too expensive for general use. The costs of removing a section of main from service, the labor overhead, and the pressure limitations after treatment severely restrict the use of fill and drain methods.

5.3.4 Bridge-the-Gap. In these methods used inside the main, a manually- or machine-emplaced seal bridges the recess between the bell and spigot sections of the joint. The main must be removed from service, but bridge-the-gap methods require little excavation. These methods take advantage of the long life-span of the cast iron pipe by renovating the seals between sections of pipe. These methods seal all joints in the main, rather than just those joints that are leaking at the time of treatment.

Bridge-the-Gap methods incur all those costs and limitations associated with removing a main from service. If the main to be sealed has a diameter less than 18 inches, it must be sealed by a machine. However, if a machine is used to seal the joints, the section of main must be straight, be of one diameter, and may not be able to contain any branches or "tees." If the seal requires a chemical bond to the cast iron, the joint area must be thoroughly cleaned, dried and all contaminants such as Carbo-seal must be removed. Successful internal sealing machine methods have used either sandblasting, specially designed scaper pigs, or high pressure water jets. All successful methods require that the joint area be dry and free of contaminants. For mechanical seals the joint area must be cleaned but not as intensively as for adhesive seals. All casting burrs must be ground down and all low spots filled in. The seal material must be chemically inert to constituents of gas, manufactured gas deposits, or other sealants that might be present. At this time there is no

commercially available internal sealing method that does not require that the main be removed from service.

Bridge-the-Gap methods are appropriate for use in the ConEdison system only where the benefits of sealing the joints exceed the cost of repair and removing the main from service. For the machine-emplaced seals, the chances are low of finding straight sections of pipe without branches and "tees" in the low pressure distribution system.

5.3.5 External Methods. Repairing cast iron joints from the outside is the most traditional and has been the most common method of sealing leaks in mains. Leaks can be repaired without service interruption or pressure reduction in low to medium pressure gas mains. Repairs by these methods can be made on a scheduled or on an emergency basis. Because the joints are accessible, quality control of the sealing operation is possible.

To seal every joint in a section of main, excavations must be made at least every 12 feet. Depending upon the ordinances of the municipality, a strip of pavement may have to be removed and replaced down along the sections of main, rather than patching the existing pavement. The costs of excavation and resurfacing far exceed the costs of actually sealing the pipe. Excavating at each joint along a section of main can cause traffic disruption and incur high social costs. The joint area must be cleaned and prepared adequately to allow bonding in the case of adhesive seals or to provide a relatively uniform surface for mechanical seals. Most successful adhesive bonding seals require grit blasting of the joint area whereas mechanical seals require that the area be cleaned with a pneumatic scaler and the bell be refaced.

The traditional mechanical clamps have been complemented by encapsulation which may quickly seal odd shaped joints and fittings,[192] and by heat-shrink sleeves.

Although the cost of excavation is high in the ConEdison system, external sealing methods remain the preferred means of sealing bell joint leaks because the main does not have to be removed from service. It is assumed that when an external repair has been made, the joint leak has been sealed because of the relative ease of quality control. Internal sealing methods have not proved to be as reliable as have the external methods.

5.3.6 Insertion. It may be cheaper to insert a new main inside of the existing main than to excavate and replace the old main with a new one. Insertion is usually performed only when the main is to be replaced because of pipe deterioration or increased demand, rather than when the joints leak in otherwise good pipe. The main must be removed from service and the plastic or steel replacement is pushed into the existing cast iron main.

This method is expensive but costs less than replacing the main by new construction. Insertion incurs the cost of removing the main from service. Insertion is restricted to almost straight sections of pipe in which there are no branches or "tees" to interfere with the pushing of the new pipe. Because of the costs and the need for few interconnections, this method has been predominantly used to replace medium pressure mains with few service taps.

A method has been developed that inserts a polyethylene pipe into an existing main without interruption of service. There are economic and safety constraints that limit this method to more rural or suburban areas.

5.4 Characteristics of an Alternate Sealing System.

Based on the generalizations of the limitations contained in section 5.3, it is concluded that an alternate sealing system should have the following characteristics:

(a) Internally seals the joints without relying on an adhesive bond to the cast iron.

(b) Requires a minimum of cleaning and surface preparation.

(c) Seals joints without taking the main out of service.

(d) Requires a minimum of excavations.

(e) Can be used in sections of mains with "tees," branches, bends, and service taps.

(f) Is simple to install and is not labor intensive.

(g) Seal remains flexible and compliant, expanding and contracting with pipe movement. Gas pressure aids the seal rather than forcing against it. Seal does not react with any chemical found in the pipe interior.

(h) Allows for quality control by TV.

(i) Overall system costs (operational and social) are less than existing systems.

PART TWO

THE PRELIMINARY DEVELOPMENT OF AN

ALTERNATIVE JOINT SEAL

6.0 PRELIMINARY DESIGN CRITERIA

6.1 General Discussion

As an initial step, it was advantageous to define a series of preliminary design criteria to provide the broad direction for successive development of an alternative sealing method. These criteria follow directly from the recommendations of Part I of this thesis and are based upon the extensive literature and industrial survey conducted in its preparation.

The most significant of these preliminary criteria are that the alternative sealing method should provide a positive mechanical seal at the joint on the inside of the pipe, all without interruption or disruption of service. During the discussion of these and other design criteria, specific examples of existing and previously attempted sealing methods will be used to illustrate why these criteria are considered important.

A major portion of this discussion will explain why a mechanical seal is preferred over adhesive-bonding or liquid sealant methods. That the seal be applied internally to a main still carrying natural gas has long been recognized as essential for any repair methods wishing to avoid the high cost of excavation and service disruption. Currently, other efforts are being made to develop adhesive-bonding sealing methods for internal use. It is strongly felt that only a mechanical seal will provide a reliable long-term repair to a leaking cast iron joint under the rigorous conditions found in any distribution system.

Before beginning the discussion of the preliminary criteria, it is appropriate to discuss those rigorous conditions found in natural gas distribution systems. These comments are based on information obtained in Phase I and from the examination of pipe joints removed from three different distribution systems. Deposited condensates from the distribution of manufactured gas still remain on the inside of the distribution mains. These deposits have been found to vary significantly between distribution systems, and even between sections of the same distribution system. Hard adherent deposits and soft crusty coatings that could be easily

flaked off were both found. Thick deposits of tar were also found. Ground water may intrude into the main and diethyelene glycol, oil, and other substances from failed sealing attempts may still be present in the main. The recess between the pipe ends was consistently found to be filled with debris at the bottom of the main. The pipe ends were found to be separated by as much as five-eighths of an inch and were offset by as much as a half inch. Significant concentrations of the tertiary butyl mercaptan odorant may be present in the gas, and condensation of this substance may result in liquid deposits along the pipe bottom. In the ConEdison system, the natural gas purchased from the transmission company already contains a design concentration of odorant of 0.7 lbm/MCF.[52*] This low concentration will never result in condensation of mercaptan in the distribution system. Finally, casting burrs may be present, sometimes acting as nucleation sites for large deposits of gummy manufactured gas deposits.

6.2 Sealing Without Se·vice Disruption of Interruption

It is important to insure that the customer downstream of the sealing operation is not affected in any way. The sealing of the main should obviously be done without shutting off the gas supply. It also should be performed without introducing anything into the gas stream that will be hazardous, annoying, or an inconvenience to the downstream customer.

6.2.1 Interruption.

Shutting off the service to customers incurs the costs of relighting appliance pilot flames or of providing alternative service. It also incurs the loss of customer goodwill because of the inconvenience. Whenever a utility must shut off service, it must make extensive effort to properly plan the work. It must notify each customer that the service will be shut off and to arrange for access to the dwelling to relight the pilot flames of all appliances.

*Superscripts refer to references in Appendix F.

Of course, not all customers will be at home to allow access by the work crew, and return visits will be very costly. In New York, where the service spacing can be as little as 10 feet and where there may be as many as five customer meters for each service line, the labor costs associated with taking a main out of service quickly become excessive. In those locations where the service cannot be shut off, alternative methods of supplying gas must be used. These methods include the use of gas bottles, compressed natural gas trucks, or temporary mains laid in shallow trenches along the curb.

Because of customer inconvenience and cost, repair methods that can be employed without service interruption are preferred in most distribution systems. Because all currently available internal methods can only be used after the main has been removed from service, external repair methods requiring extensive excavation, are usually preferred.

6.2.2 Disruption. A sealing method should not introduce anything into the gas stream t at may become hazardous or an annoyance to the customer. Because a large portion of domestic gas use is for cooking, with unvented flames, no toxic chemicals, whether or not they are combustible, can be allowed to enter the homes of customers. Solvents and other volatile organic chemicals released during sealing or after curing over time cannot be used. Similarly, soot-forming substances should be avoided because of obvious esthetic reasons but also because the soot will foul furnaces and other larger appliances.

The sealing method should not allow dry condensate deposits to be carried downstream by the gas. Moving a mandrel through an uncleaned main may cause large amounts of dust to be carried by the gas stream, extinguishing pilot flames.

As described in Part One, experiments with solvent-based fill-and-drain materials showed that the difficulties with safe handling and venting were intractable. As a result of these experiments, most fill-and-drain procedures included water-based emulsions of synthetic rubber. No solvent-based material was ever seriously considered. The ADI method

was originally designed to be used in mains removed from service. Experiments in England attempted to use the method on live mains. No information is available on the effect of these chemicals in dwellings, but it is expected that there may be some concern about health effects. During the initial attempts at gas conditioning, diethylene glycol was fogged into the gas stream. If the concentration was too high, the burning glycol would cause soot to form or would extinguish pilot flames.

6.3 Seals from Within the Main

The alternative sealing method should repair the leaking joint from inside of the main to minimize excavation costs and traffic disruption. External repair necessitates that an excavation be made at each joint, at most 12 feet apart. Under most conditions, the cost of the actual repair to the main comprises only 20 percent of the total cost. The remaining 80 percent is the cost of excavation, backfilling and resurfacing. In the ConEdison sy tem, the average cost of an external repair is $1000 per joint.[52] This cost does not include the detrimental effects on public and municipal relations of extensive excavation and numerous pavement patches.

Over the past twenty-five years, development work in the U.S. and the U.K. have attempted to reduce the cost of sealing and the cost of excavation. The Keyhold method in the U.S. was the first encapsulation system, and it attempted to remove the soil by an air lance and vacuum system. Further development of encapsulating systems was conducted in the U.K. resulting in the well-engineered ALH, BTR Silvertown, and PLCS methods. Concurrently, heat shrink sleeves were introduced. At this time, the Gas Research Institute is sponsoring research in machine excavation systems. This research includes the development of a soft excavation method that uses an air lance and an improved vacuum excavator. GRI also sponsors research into improved backfill and paving materials, proximity devices to warn backhoe operators, and a device to locate buried pipe.[21]

6.4 Seals With a Mechanical Seal.

The alternative method should seal the joint without relying on an adhesive bond to the pipe by placing a gasket-like structure across the joint recess. Using such a seal provides the confidence that if the seal is in place, it will provide a positive seal to the gas. It will minimize the cleaning of the pipe surface and eliminate the chance cf material failure that was so prevalent in early internal sealing attempts.

6.4.1 Provides a Positive Seal.

The alternative sealing method should place an impermeable barrier across the joint gap. This method provides for the confidence that if the seal is in place properly, then it should not fail. The placement of a positive seal minimizes the chance of something going wrong with a polymerizing adhesive or liquid sealant, both of which are very susceptible to contamination or to errors in preparation of the material. A positive seal allows the utility to know that after it has paid for expensive joint repairs, it has solved the problem. A positive seal will stop all existing leaks but also those that may occur in the future.

Gas conditioning and jute swellants were inexpensive attempts at leak mitigation that never provided a reliable solution to the problem. Gas conditioning methods were intended as an interim measure to keep leakage rates at the pre-conversion levels. Utilities could never prove that these methods had any positive effects on leakage. Jute swellants, while inexpensive and easy to introduce into the mains, were too dependent for success on uncontrollable factors, such as the condition of the jute. The IGT Two-part sealant relied upon a difficult-to-control polymerization, and upon the condition of the jute. None of these methods are currently in widespread use because they could not guarantee that the problem would be solved after application.

Fill-and-drain methods sealed all leak paths, but it has not been proven whether these methods would provide a competent seal over the remaining life of the main. The fill-and-drain materials polymerize with the breaking down of an emulsion. Nothing in the process can guarantee

that contaminants in the main will not interfere with the adhesion to the pipe wall, or cohesion within the cured sealant. With time, main displacement, vibration, or reaction with contaminants may cause the sealed joints to begin leaking again.

Liquid sealants used for gasket material in flanged joints are not effective if the flanges are contaminated or coated.[3] It is recommended that liquid sealants be used with caution if the joint is subjected to temperature and pressure differences or to vibration.[3] These recommendations are based on experience with joints being constructed with quality control readily available. These reasons for concern are exacerbated when the sealant is to be used inside of a main that has heavy wall deposits.

Internal and external repair clamps, Avonseals, heat shrink sleeves, and encapsulation have all been effective because they physically block leak paths with little chance for error. An alternative leak sealing method must provide at least the same reliability.

6.4.2 Allows for a Minimum of Cleaning. A major advantage of a mechanical seal over an adhesive bonding seal is that the surface of the pipe need be cleaned only to provide a good gasket surface, and not to bare metal necessary for good bonding. It is much easier to reach that standard of cleaning necessary to remove loose deposits to prepare for a good gasket surface. This is particularly true when the cleaning must be done on the inside of a small diameter main. More importantly, however, the success of a mechanical seal is not as sensitive to cleaning as is a method relying upon an adhesive bond. Water, glycols, oil and other liquid contaminants do not have to be removed, eliminating the need for solvents or dessicants. Finally, because a mechanical seal minimizes the amount of debris to be removed, it also minimizes the chance that dust will be introduced into the gas stream disrupting downstream service. In summary, a mechanical seal allows more room for inevitable errors.

Cleaning has always been a major concern for internal repair methods. For those methods that required a good adhesive bond to the cast iron, the procedures were changed with experience to include some means of

cleaning the pipe wall down to bare cast iron. The Fuelling method initially used scrapers and carbide-tipped flails to clean a section of main to be repaired, but eventually added a mandrel to sandblast the pipe wall. A desiccant was used to remove all liquid contaminants. The Trace method failed because it assumed that the mains were dry. Glycols and water fouled the area to be sealed, interfering with adhesion. The Gasloc method uses high pressure water jets to clean down to bare metal, but the Interseal method relies upon a series of scrapers and dessicants to adequately prepare the surface. It is thought that eventually the Interseal method will have to include a more thorough cleaning method. At this time, the aluminum seal is being bonded to whatever deposits remain on the pipe wall. ConSeal was initially advertised as requiring no cleaning. After a few years the procedure was modified to include pretreatment by a solvent to remove the glycols that were interfering with the bonding of the neoprene to cast iron.

Proper surface preparation has also been important for external repair method . In trying to fight the utilities' reluctance to purchase portable sand blasting units, ALH Systems, Ltd. tested adhesion to surfaces cleaned by sandblasting and by pneumatic scalers.[45] This study found that sandblasting to bare metal was necessary to insure success for the Avonseal and for ALH's encapsulation systems. All external encapsulation systems require that the sealant adhere directly onto the cast iron pipe.

It is necessary to make one further comment about cleaning. If the surface of the pipe is not completely cleaned, then the sealant will bond to whatever remains on the pipe, and not to cast iron. Over time with the aging of the polymer, with vibration, and with the possibility of ground water intrusion, a repair relying upon a bond to pipe deposits will in all likelihood fail. To minimize the chance of future failure, a sealing method must either remove all deposits to allow for a good adhesive bond or must rely upon a good gasket design that is not as sensitive to the level of cleaning.

6.4.3 Minimizes Chance of Material Failure. Because a mechanical seal is emplaced as a finished product, it minimizes the chance that the sealing material may fail after installation. The material used as the impermeable barrier can be checked for compliance to the desired specifications well before it is to be emplaced. Use of a pre-inspected gasket material eliminates most of the chances for error inherent in .ured-in-place sealant systems. It eliminates the need for proper on-site quality control in handling and mixing of the components, and greatly simplifies the installation procedure. A gasket also obviates the difficulties in timing the polymerization. Knowing the characteristics of the polymer before installation also insures that it will be as resistant to chemicals in the main as was initially designed. In summary, a gasket-type seal minimizes the chances of something going wrong with the procedure or the polymerization.

Experiences with the cured-in-place sealants show that the difficulties in procedure can make the method effective. Both the Spring-band and the Fue. ling methods had difficulties because improper mixing of the components resulted in inclusions of air in the cured seal and its failure. The IGT Two-Part Sealant had elaborate schemes for polymerization that were difficult to control and predict performance. In fact, frustrations in testing this method led to the patenting of a primitive gasket seal concept that did not require polymerization inside the main.

6.5 Seal Components Should Have an Expected Life-Span of 50 Years.

To be successful, an alternate sealing method must remain gas-tight for a significant period of time, at least 50 years. Any time shorter than 50 years would probably not be acceptable to utilities because of the extremely high cost of replacement labor and materials. The material used in the alternative sealing method should be resistant to any chemicals found in the environment of the main, it should possess time-dependent characteristics adequate to at least 50 years, and it should remain flexible over time.

6.5.1 Chemical Resistance. The seal material should be resistant
to chemicals found in the pipe wall deposits such as residual aromatic
or aliphatic hydrocarbons, to liquid contaminants such as ethylene glycol,
water, mineral oils, and compressor oils, and to fuel gases, such as
natural gas, synthetic gas, and hydrogen. The material should not react
with the tertiary butyl mercaptan odorant, nor with the sulfur in the pipe
wall deposits. All metallic components must be protected against corrosion.

6.5.2 Adequate Time-Dependent Behavior. Elastomeric seal material
should be designed so that at normal system temperatures, the gasket
will retain sufficient compressive stress that it will not leak for at
least 50 years. Creep and stress relaxation will affect the material
by reducing the stress over time. The initial stress must account for
this natural reduction in stress. The material may be allowed to creep
into the surface asperities, but it should not be allowed to extrude away
from the sealing location.

6.5.3 Remains Flexible. Elastomeric seal material must remain
flexible to be able to be effective during displacement and vibration.
The seal must remain flexible at the low temperatures found in the winter.
It must not harden and crack with oxidation, and vulcanization cannot
continue with time, stiffening the elastomer.

6.6 General Considerations.

It is possible to mention a few considerations of a general nature
to aid in the continuing development of an alternative sealing method.
Total cost of the new method, the allowable temperature and pressure
operating ranges, the general design of the seal, quality control and
safety are areas of concern that should be considered for a successful
alternative system.

6.6.1 Cost. The total cost of the repair performed by the alterna-
tive method must be less than currently available repair methods. The

total cost should include the cost of material, labor and specialized equipment and support systems required to emplace the seal. Since a major cost of any repair is the labor cost for replacement should it fail,[3] the total cost of the alternative system should include any projected replacement expenses.

6.6.2 Operating Temperature Range. The seal material should remain effective for extended periods at temperatures up to 100°F and down to 0° F. These temperature limits represent the normal conditions found for buried pipe. For most times of the year, the pipe temperatures will remain between 40° and 65°F.

In certain areas of Manhattan, steam is used for space heating and buried steam pipes may pass close to gas mains. In these areas of Manhattan, the use of plastic pipe for gas mains and services has been discontinued because of the danger of the plastic melting if placed too close to a steam line.[52] On the other hand, external repair methods using elastomers have been used throughout this area, apparently without failure.

Preliminary calculations were made to estimate the temperature of the cast iron pipe near steam pipes under a variety of possible conditions. This temperature is of interest because it would be approximately the same as that of the gasket material. As a worst case approximation, the steady-state temperature of the cast iron would be 190°F with 425°F steam blowing directly on the bell joint. The pipe was modelled as a fin with an effective heat transfer coefficient combining the effects of convection on the inside of the gas main and conduction into the soil.[40] It is assumed that there are no internal temperature gradients in the pipe in a radial direction. The heat flow into the base of the fin is assumed to be half the heat supplied to the bell by convection. A more realistic estimate of the cast iron temperature is 130°F.

The cast iron temperatures are estimated for a gas main laid parallel to a steam pipe separated by only one foot of soil. The conduction heat transfer to the gas main[14] is balanced by the convective heat transfer

inside the gas main. Assuming that the gas temperature is 54.1°F, the average annual temperature for New York City, the cast iron temperature would be only 102°F. However, the gas temperature would rise as it received heat from the pipe wall. In just 10 feet, it is estimated that the gas temperature would rise to 200°F and the cast iron temperature to 230°F.

An approximation of the temperature of the cast iron was made for radiation heat transfer between the two pipes separated by one foot of air. The soil above and below the air spaces was assumed to act as refractory surfaces. The radiation heat transfer to the cast iron pipe was balanced by the convection by the flowing natural gas and by conduction into the soil touching the back side of the pipe. If the gas were assumed to be at 54.1°F, the cast iron wall temperature would be 236°F. If the gas were 100°F, the wall temperature would be 256°F. Under realistic conditions, the gas mains and steam mains would be parallel to each other laid along streets. They may also be close together separated by either soil o air if the excavation was not properly backfilled. Under both of these situations, the wall temperature of the cast iron pipe would exceed 250°F if the two mains were in proximity for more than a few feet. For this reason, the use of the elastomeric seal is not recommended near steam lines. The temperature operating range for further development of the alternative seal should be the ambient conditions of 0 to 100°F.

6.6.3 Seal Design. The emplaced seal should have a low profile to minimize losses in pumping the natural gas through the repaired main. The seal should be able to be easily installed by a machine inside a small diameter main. It should be of one piece to aid in installation. The seal should consist of a flexible, impermeable membrane placed across the gap between the bell and spigot pipe ends. This "bridge" across the joint gap should be secured to the pipe wall at each end of the membrane to allow each pipe to act independently of each other during joint deflection and vibration. Gasket material at each end of the "bridge" will provide the seal against gas leaking out between the "bridge" and the pipe wall. (See Figure 2.) A method of compressing the gasket material against the pipe wall must be provided. The seal must not allow leakage

throughout its lifespan, throughout its design temperature range, and for main gauge pressures of up to 25 psig. New York State Safety regulations require that if a main is removed from service for any reason (for a reason other than applying the alternative seal), it must be tested to hold 90 psig before being reinstated.[52] Therefore, the "bridge" material must have a burst strength of at least 90 psig.

6.6.4 Quality Control. A television camera inside of the main must be used to insure that the joint area is properly cleaned and that the seal is properly installed. A video recording of the work should be made for two reasons. As for the system, an accurate map of the main will aid in future maintenance efforts by the utility. Secondly, a video-tape of the repair will allow for after-the-fact supervision to detect errors in design or procedure. It will also provide the operator an incentive to do a complete and thorough job.

The alternative sealing system must be able to guarantee that the repaired section of main is, in fact, leak-free. It must check for all leaks in the main, locate and repair them before the equipment is removed from the site. In this way, when the work crew finishes, the utility is confident that all leaks have been repaired. The Interseal method is able to locate and repair individual leaks, but only after the main has been removed from service. The alternative system must be capable of finding and repairing leaks while the main is still in service.

6.6.5 Safety. The alternative system must be safe and not expose workmen or passers-by to undue risk. The system should not need to use toxic materials, and the equipment should be designed to minimize the chance of accidents. All electrical equipment used in the main, or near the excavation, must be designed to meet the Class I, Division I Standards of the National Electrical Code.[52, 30]
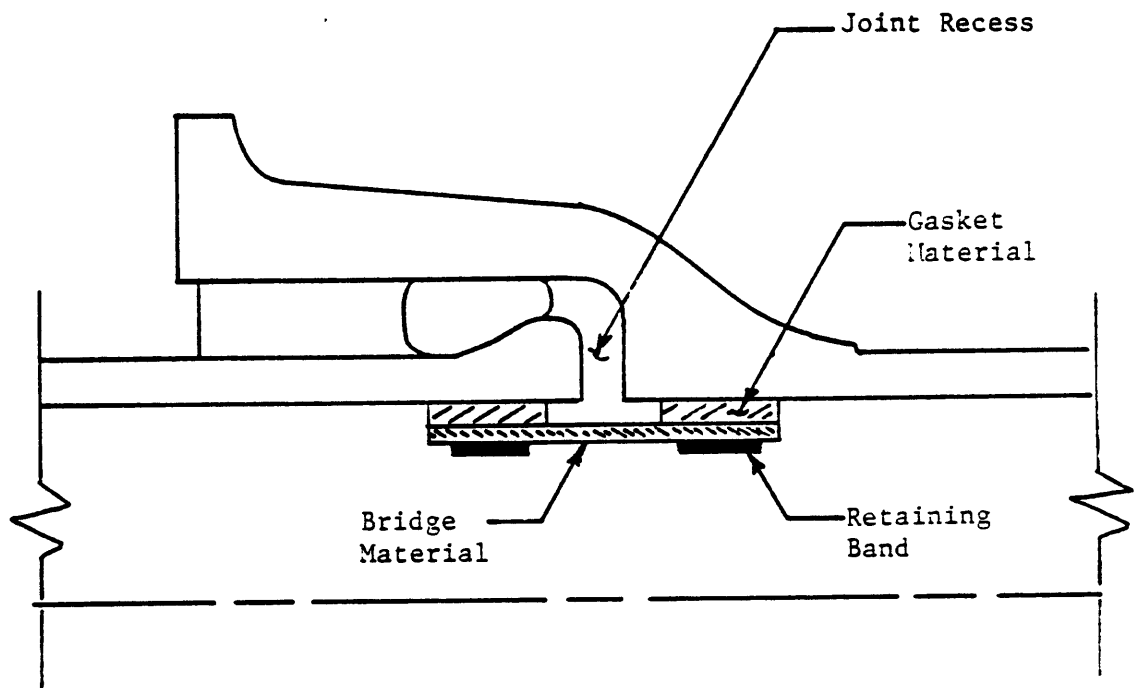
FIGURE 2   Idealized Design of the Alternative Seal

7.0 INTERFACE BETWEEN THE GASKET MATERIAL AND THE PIPE WALL.

The alternative mechanical seal must stop leaking gas by placing a gasket material against the cast iron pipe wall. Because this sytem cannot rely upon an adhesive bond, the gasket material must act as a physical barrier to the gas. Because the interface between the pipe wall and the gasket material is where the sealing occurs, it is convenient to study at one time important factors concerning that interface. This Chapter makes a first approximation of the effects of roughness and rubber hardness on the compressive gasket stress required to provide a seal against the gas. This Chapter discusses the method used to quantify roughness, the different cleaning methods studied and the sealability test used to relate cleaning to required gasket stress. This Chapter also describes the analysis of pipe wall deposits performed to identify substances that may cause the deterioration of gasket materials.

7.1 General

7.1.1 **Choice of Gasket Material.** It is necessary to study the interaction of the gasket and the pipe wall because of the unique nature of the sealing problem. In this application, a gasket at ambient temperature is pressed against a very rough surface to seal against low pressure (~ 1 psig) natural gas. In most other static sealing applications, the gasket is compressed between two relatively smooth ($\sim 60\,\mu$-in.) flanges to contain hot, high pressure fluids which may be highly corrosive. In other applications, dynamic seals are placed around rotating or reciprocating shafts to contain high pressure, high temperature fluids which may also be corrosive. Static seals may be made with fibrous, metallic, elastomeric, and plastic gasket materials and may be in sheet form, sealants applied as liquids, bellows, or O-rings.[3] Elastomers have the physical properties best suited for use as the alternative seal gasket material.

7.1.2 **General Gasket Properties.** In general, the elastomeric gasket material should have a plastic surface layer, an elastic internal

structure, low-time dependent properties and resistance to degradation while in contact with chemicals found in normal use.[3] Leakage past the gasket is stopped only if the surface layers of the gasket flow into all asperities of the pipe wall.[11] The elastic internal structure is necessary for the gasket to respond to joint deflection and vibration without leakage. Over time, the elastomeric material may creep or the gasket stress may relax, allowing leakage. Low time-dependent properties are necessary if the elastomeric seal will not leak for the life-span of 50 years.

    7.1.3 Zero Leakage. A perfect seal can never exist. Even if all flow between the gasket and the pipe wall is eliminated, there will still be fluid that diffuses through the gasket material.[12] Zero leakage has been defined by various organizations and companies, but no general rule exists.[11] Zero leakage is normally defined by what can be tolerated considering both the fluid and the application.[11] In the development of the alternative seal, leakage is assumed not to occur if it cannot be detected using a soap bubble test.

    7.1.4 ASTM Tests. In general, the standard test procedures of the American Society for Testing and Materials (ASTM) do not provide any information that may be used in the development of a new seal. However, once the design has been completed and the materials chosen to have desired properties, the ASTM tests can be used to quantify those properties. The results of these tests may be used to compare different materials of similar properties, or to insure that materials supplied by vendors meet design specifications. A list of ASTM tests that may be applicable is contained in Table 1.

7.2 Analysis of Pipe Wall Deposits

    7.2.1 General. A significant factor that makes a mechanical sealing method attractive is that it may not require that the pipe wall be completely cleaned. Because the elastomeric gasket material will be pressed against

the wall, it is necessary to insure that there is nothing in the pipe wall deposits that will excessively deteriorate the gasket material. Some deterioration is acceptable as long as the gasket material retains its sealing capability for its 50-year lifespan. Identification of reactive chemicals in the deposits will aid in the choice of elastomers to be used in further development. Of particular int rest, the amount and form of sulfur in the deposits will be a critical factor in the choice of gasket elastomer.

7.2.2 Sulfur Tests. There are two ways in which sulfur is expected to be present in the pipe wall deposits. Previous to the distribution of natural gas, hydrogen sulfide was present in small amounts in the manufactured gas. High-BTU Oil gas contained about 0.3 percent H_2S, and Coke Oven gas about 0.7 percent by mole concentrations.[50] Both types of manufactured gas contained traces of organic sulfur. The hydrogen sulfide probably reacted with the iron pipe to form ferric sulfide, still present in the main deposits. Secondly, the deposits may absorb or react with the mercaptan odorant present in natural gas.

To determine the total sulfur content, four samples of pipe wall deposits were analyzed by ion chromatography[26] at Galbraith Laboratories, Inc., of Knoxville, Tennessee. Two samples of deposits taken from different joints removed from the ConEdison system showed total sulfur contents of 0.83 and 1.82 percent respectively, by weight. The third sample was from the Commonwealth Gas system and it had a sulfur content of 0.5 percent. The fourth sample was from the Boston Gas system, and it had a sulfur content of 0.66 percent.

Further tests were made to determine the form of the sulfur in the ConEdison deposits containing 1.82 percent total sulfur. Ion chromatography was used to identify sulfates and the sulfide content was determined colormetrically.[26] Sulfides and sulfates were expected to be the most common forms of sulfur in the deposits.[23] Mercaptans would appear as sulfides in these tests.[23] The deposits were found to contain 0.015 percent by weight sulfides and 0.14 percent sulfates. Other forms of sulfur in the deposits are expected to be less reactive than sulfides.

Based on these limited tests, sulfur does not seem to be a significant constituent in the pipe deposits removed from three separate distribution systems. Because there was such a small amount of sulfides in deposits from the ConEdison system, minimum amounts of mercaptans are expected to be found in the pipe wall deposits. However, these conclusions result from the analysis of only one sample of deposits. The sulfide content of several other deposit samples should be measured to increase confidence in these conclusions.

Because the gasket must be in contact with the pipe wall for 50 years, long-term tests of the effects of trace amounts of sulfur on elastomers should be made. Chapter 11, Conclusions and Recommendations, continues this discussion.

7.2.3 Deposit Content Test. Deposits from one ConEdison joint were analyzed for their gross chemical content. The deposits were found to be 69.93 percent ash, 13.39 percent carbon, 2.32 percent hydrogen, 0.83 percent sulfur and 0.53 percent silicon. The carbon and hydrogen were identified by Galbraith Laboratories using a Perkin and Elmer C-H-N Analyzer; the ash, by heating to 800°C in a platinum crucible and weighing; the sulfur, by ion chromatography and the silicon, colormetrically.[26] The deposits were found to be predominantly inert ash.

7.2.4 Volatiles Test. A test was performed to estimate the molecular weights and therefore the volatility of components of the deposits. Three samples of deposits (one each from ConEdison, Commonwealth Gas and Boston Gas) were heated at 350°F for 15 minutes in an oxygen-free nitrogen environment.[15] Under these conditions, the volatiles evaporate and the remaining material could be assumed to have molecular weights of greater than 500.[15] The deposits from ConEdison, Commonwealth Gas, and Boston Gas had weight decreases and therefore volatiles contents of 3.44, 3.45, and 2.09 percent respectively. Such a small weight decrease indicates that over time since the conversion to natural gas, the manufactured gas condensates have polymerized and become heavier.[15]

7.3 Roughness Measurements

7.3.1 General. A method of quantifying the roughness of cast iron pipe was necessary to relate the required gasket compressive stress to elastomer hardness and cleaning method. The procedures and equipment described in this section provided a first approximation of surface roughness. The surface of the cleaned cast iron can be characterized by a small amplitude roughness superimposed over a general surface waviness. Leaks between a gasket material and the surface occur in the troughs between peaks of the waviness. The small amplitude roughness probably does not significantly affect leakage. Because the gasket material elastically follows the surface imperfections, the slopes of the asperities are as important as the amplitude of the peaks and troughs. However, in this first approximation of the roughness, only the root-mean-square deviation (rms) of peaks and troughs from a mean line was considered. For the cleaning methods described in the next section of this thesis, the rms deviations varied from 2500 to 6100 μ·inches. Typical values of roughness for flanged joints are from 70 to 250 μ·inches. The results of the measured roughnesses for different cleaning methods are discussed in Section 7.4.7 and are listed in Table 2.

7.3.2 Profilometer and Measurement Procedures. A simple stylus profilometer was used to record the profile of surfaces of cast iron pipe pieces that had been cleaned by different cleaning methods. One-inch long profiles were recorded of the surfaces where the gaskets would be placed during the sealability tests. Three profile measurements were made for each cast iron sample as shown in Figure 3. The profiles were in the axial direction, parallel to the path of leaking gas in both the sealability test and in the actual application. These profiles were perpendicular to grooves cut in the metal by the wire and abrasive wheels of the cleaning test.

The profilometer was a stylus supported at the end of a cantilevered strip of aluminum. Two strain gages mounted on the strip measured the displacement of the stylus. (See Photo 1.) The other end of the cantilever was supported by a block of aluminum fastened to the chuck of a milling machine. The cast iron pipe piece was fastened to the table of the machine and was moved away from the profilometer during the recording of the

profile. The two strain gages were two arms of a Wheatstone Bridge
circuit, the output from which was recorded on a strain gage strip
chart recorder. More detailed information about the profilometer is
contained in Appendix G, Equipment.

7.3.3 Profile Analysis. For each profile, a straight line was
drawn on the strip chart, approximating the mean surface profile for
the section. The distances from the mean line for all peaks and troughs
of the profile were recorded. The small amplitude roughness was dis-
regarded for reasons previously discussed. The rms deviation for the
peaks and troughs was calculated for each profile according to the
following equation:

$$d = \left[\frac{1}{m} \sum_{i=1}^{m} (d_i - d_m)^2 \right]^{1/2}$$

Where d_i is the deviation of the peak or trough from the mean line, and
d_m is the average deviation from the mean line of all peaks and troughs.
The rms deviation for each profile was converted to micro-inches. A
roughness number, $\bar{d}$, for each cast iron pipe piece was calculated as
the average of the rms deviations for each of the three profiles recorded.
The roughness numbers for the cast iron pieces tested are in Table 2,
and discussed in Section 7.4.7.

Another means of quantifying the surface profile is used in the
United Kingdom. In that method, two parameters are used to describe
both the amplitude and slope of the surface imperfection.[3] The first
parameter, R_a, is the arithmetic mean deviation from a mean line describ-
ing the general form of the surface. This parameter used to be known as
the centerline average or C.L.A.[3] In one study, the mean line was
computed by a least squares linear regression and the deviations of
peaks and troughs from that line were averaged.[13] The second parameter,
R_z, is the average distance between the five highest peaks and five deepest
troughs within the profile. The R_z values were usually found to be 4 to 7
times the R_a values.[3]

7.3.4 Comments. Most documented research into surface roughness and sealing is concerned with surfaces much smoother (~ 60 μ-in.) than those of cast iron gas mains (~ 6000 μ-in.). This research is also of an analytical nature, out of the scope of this thesis. However, several comments are included at this point to provide additional insight into the relationship between roughness and gasket sealing. In a study of O-ring sealing, it was found that lower slopes between peaks and troughs allowed for lower compressive stresses.[12] In another study, with similar results, rounded imperfections could be sealed at lower stresses than sharp imperfections.[31] In a study of compressive stresses between two rough cylindrical metallic surfaces, small amplitude roughness was found to extend the contact area further down peaks into the troughs.[28] In other words, small amplitude roughness acted to reduce the voids and therefore the leakage between two elastic surfaces.

7.4 Cleaning Studies

7.4.1 General. Several pieces of cast iron pipe were cleaned by different methods to determine the resulting surface roughnesses. The surface roughness and other factors such as power requirements, cleaning effectiveness, speed of cleaning and dust entrainment must be considered to properly evaluate cleaning methods for use in the alternative sealing system. Water jet, water jet with grit, wire wheel, abrasive wheel, air-abrasive and chemical cleaning methods were evaluated. Several pipe pieces were cleaned by hand to remove only the loose deposits. Table 3 lists the methods and results by sample and Table 4 by cleaning method. The results are described in detail in succeeding sections. Conclusions and recommendations contained in Section 7.4.7 are based upon results obtained in the cleaning studies and are not based upon the results of the sealability test. An attempt to identify the minimum amount of cleaning required to remove just the loose deposits to provide a good gasket surface was not successful. In most cases, the cleaning method cleaned down to the bare metal. Other methods easily removed the loose deposits leaving a thin black coating on the surface. Because the alterna-

tive sealing method depends on a good gasket surface, and not a completely clean surface, this final coating can probably remain for a successful seal. If the deposits are too hard to easily remove, then they are probably hard enough to provide a good gasket surface. Cleaning by hand-brushing was included in an attempt to simulate that minimum amount of cleaning necessary to remove only loose deposits. Tar was found to be the most challenging deposit to remove. Future experiments should be performed to determine if all tar should be removed to provide a good long-term gasket surface. This section does not address the problem of removing casting burrs, but concentrates on the cleaning of deposited condensates from relatively smooth pipe walls. Individual cleaning methods are discussed in the following sections.

7.4.2 Water Jet Cleaning. Several cast iron samples were cleaned by water jet and water and abrasive cleaning methods by the Norcom Company of Norwood, Massachusetts. The samples were cleaned with water, with and without grit at 2000 and 3000 psi pressure at 5 gallons per minute. Dry deposits and tar were both removed in a few seconds of cleaning. The results of the tests are listed in Table 4. Water jet cleaning with grit resulted in a rougher surface than did water alone. Water at 3000 psi left a rougher surface than did water at 2000 psi. The sample was cleaned to bare metal at 2000 psi with grit but a coating was left with 3000 psi water without grit. Loose deposits were removed with 2000 psi water without grit but tar was removed with 3000 psi with grit. Water with grit at 3000 psi at a one inch standoff cleaned to bare metal, but left a coating if at a five inch standoff (not possible in a four inch diameter main). The roughness numbers were the same for both standoff distances.

In general, water jet cleaning is a very well suited for surface cleaning, particularly for cleaning in spaces inaccessible to other cleaning methods.[49] The water at 2500 to 10,000 psi pressure removes hard, brittle deposits by breaking them away at the interface with under-lying metal.[22, 38] Softer material is eroded away at lower water pressures (2000-3000 psi).[22] There is also a tendency to push soft material around rather than to remove it.

As a cleaning method for use in the alternative sealing method, water has the advantage of entraining deposit debris which will keep dust from entering the gas stream,[49] and will aid in removing the debris from the joint area.[22] The joint area will be wet, but as discussed in Section 6.4.2, this should not limit the use of a gasket-type seal. There will be a reaction force resulting from the jet, but this can be balanced if an axisymetric nozzle arrangement is used. The high velocity jet will be deflected as it impacts on the wall and proper design of nozzle direction, speed and water flow rate should insure that the jet does not damage the machine. Flash oxidation occurred on the surfaces cleaned during this test, but it is not considered an impediment for a good seal. If necessary, rust inhibitors can be added to the water supply which could be filtered for reuse or disposal. Power requirements are expected to be within reasonable limits.

Water jet cleaning has been used to clean the inside of pipes, but not of gas mains unless the mains have been removed from service. The Gasloc system cleans pipe walls with a water jet at 6000 psi. The device with a rotating nozzle head is winched through the main. In another example, drain cleaning has been performed by a multi-nozzled head supplied by a 20 hp pump. A nozzle aimed forward breaks up any blockages and three directed backwards at a 45 degree angle propel the device forward. The device propels itself all the way through the main and is then pulled back cleaning and flushing debris in front of it as it goes.[49] Gooseneck piping at a coke plant was cleaned of condensate deposits by a device using 6000 psi water with a nozzle head rotating at 300 rpm. Power requirements were 0.65 hp.[8]

7.4.3 Wire Wheel. Pipe samples 1C and 3B were cleaned with a wire wheel and the resulting roughness number for Sample 1C was 2920 μ-in. as shown in Table 4. The samples were cleaned on a test stand that measured the radial and tangential forces exerted by the wire wheel. The test stand is described in Appendix G, Equipment, and is shown in Figure 5 and Photo 2. The radial, four-inch, O.D., wire wheel was one-half inch thick and the fill was medium density, 0.010 inch diameter, crimped wire. The wheel speed was a constant 723 rpm which did not decrease under load.

Sample 1C was cleaned to bare metal with little effort. The wheel exerted a radial force (normal to the pipe wall) of 9 lbf and a tangential force of 3 lbf. A power requirement of 0.068 hp was computed by the following equation:

$$P = \frac{FV}{550}$$

Where P is the power in horsepower, F is the tangential force and V = 12.62 fps (723 rpm for a 4-inch diameter wheel). When cleaning the samples, it was noticed that the exact placement of the wheel was not critical. The "give" of the wires allowed the sample to be cleaned with less concern for accurately controlling the normal force against the pipe surface. Because the wires bent as they struck the surface, a larger area was cleaned than just the dimensions of the wheel. The wire wheel removed a small amount of metal resulting in small grooves, but the amount removed did not significantly increase as the normal force increased.

Sample 3B was initially coated with a deposit of tar. The wire wheel did not completely remove the tar even though the normal force was increased to 15 lbf with a tangential force of 6 lbf, resulting in a 0.21 hp power requirement. The wheel was moved coaxially with the pipe against un-touched deposits of tar. At any one location, the tangential force decreased as the tar was removed, but the normal force remained constant. The remaining tar was hard and may provide a good gasket surface. However, the long-term effects of gasket pressure may cause the tar to creep, extrud-ing away from the gasket area.

It is possible to design the fill material to have the type of cleaning action desired.[18] Knot-type twisted wire wheels at higher speeds act like solid objects that can readily cut material. Crimped-wire wheels have a cushion effect that allows them to clean irregular surfaces.[18] It is the latter type that is probably more appropriate for cleaning the inside of gas mains.

Cleaning with a radial wire wheel was found to quickly remove deposits leaving a relatively smooth surface. The cleaning required very little power. An advantage of the flexible wire wheel was that it allowed room

for errors in controlling the wheel. The wheel did not remove all tar deposits, but a faster, stiffer wheel may do so. The wheel caused a lot of dust and debris to be thrown from the pipe piece. Water may have to be used to entrain the dust.

7.4.4 Abrasive Wheel. Samples 1D and 3B were cleaned with an abrasive wheel on the same test stand mentioned in the preceding section and described in Appendix G, Equipment. The resulting roughness number of Sample 1D was 2480μ-inches, as listed in Table 4. The test used a four-inch diameter, one-inch thick, aluminum oxide, general purpose grinding wheel at a speed of 723 rpm.

The grinding wheel cleaned a very small area, limited just to the contact area between the rigid pipe wall and the rigid wheel. The wheel exerted a cyclical loading on the pipe piece because of an eccentricity in the wheel. It was very difficult in the laboratory to evenly clean an area large enough for the gasket of the sealability test. A specifically designed device to exert a uniform force against the pipe wall would be needed in practice. Average normal and tangential forces of 34 and 10 lbf, respectively, were recorded. The power used was 0.23 hp.

Sample 3B was cleaned with the grinding wheel after it had been cleaned with the wire wheel. The grinding wheel removed all the tar and some metal creating a large amount of dust. The average normal and tangential forces were 25 lbf and 20 lbf, respectively. The power used was 0.46 hp.

The abrasive wheel removed all deposits, including tar, and left the smoothest surface of these tests. It requires more power than the wire wheel and will probably require a special device to accurately control the wheel to reduce the cyclical loading. The wheel caused a large amount of debris to be ejected from the pipe surface.

7.4.5 Air-Abrasive Cleaning. Sample 7 was cleaned by the Norcom Company with 80 psi air with a fine sand abrasive. The resulting roughness number of 3220 μ-inches was not as large as with water abrasive

cleaning, perhaps because the energy of the sand particles may have been less than that of the water and grit. No flash oxidation occurred in the absence of water. There were significant amounts of dust created by the removed deposits and the fractured sand particles.

Abrasive blasting is not usually effective in the removal of oils, tars, and other viscous deposi_s,[25] and this test did not attempt to clean tarry deposits with sand blasting. It is effective at removing dry scale[25] such as dried condensates. Abrasive cleaning should not be confused with shot peening which is used to increase the fatigue strength of metal components and not for cleaning.

7.4.6 Chemical Cleaning. Samples 8, 5A, and 5B were treated with an alkali, sodium hydroxide; a general purpose solvent, orthodichloro-benzene; and a mixture of hydrofluoric and phosphorous acids. The pipe pieces were treated with the chemicals overnight and flushed with 1000 psi water the next day. None of the chemical cleaners had a significant effect upon the deposits on the pipe.

Chemical cleaners should not be considered for future development. If they do work, they take too long to clean to an acceptable level. This conclusion is based on the extensive study of cleaning methods completed by the Battelle Columbus Laboratories. Those methods that did work took hours if not days, to complete the job.[42] This duration is thought to be too long to allow the overall system to be cost-effective. Too much equipment and manpower would be tied up waiting for the chemicals to work.

Even more critical than the long reaction time, the toxicity of these chemicals should prohibit their use. As mentioned in Section 6.6.5, no toxic chemicals may be allowed to enter the gas stream. There would also be significant problems in requiring workmen to handle the chemicals, to handle the equipment after it has been exposed to the chemicals, and to dispose of the chemicals properly after use.

7.4.7 Comparisons of Cleaning Methods. Comparisons of the cleaning methods are based on the resulting roughnesses and other considerations

such as ease of use or dust entrainment. These comments are not based
on the results of the sealability test, which will be discussed in
the next section.

Comparing the cleaning methods by roughness in Table 5 shows that
water jet with grit cleaning in general resulted in the roughest sur-
faces. Grinding resulted in the smoothest.

The previous sections and Table 4 describe the results of cleaning
different pieces of pipe by the same method. Detailed conclusions
for each cleaning method are also included in previous sections.   Hand
brushing Samples 1B and 4B show a difference in the roughness of deposits
after loose materials have been removed.

A comparison of different methods of cleaning pieces of the same
pipe joint can be made by referring to Table 3. The results of cleaning
all pieces of pipe taken from one six-inch diameter joint (Joint Sample
No. 1) show that cleaning with the wire wheel or the grinding wheel
results in smoother surfaces than by hand wire-brushing to remove only
the loose deposits. Cleaning with 2000 psi water resulted in a smoother
surface than by hand, but cleaning with 2000 psi water with grit resulted
in a rougher surface.

Analysis of the results of cleaning methods used on pieces from Joint
Sample No. 4 shows that cleaning with 3000 psi water results in a rougher
surface than cleaning by hand, even though the water cleaning did not
clean to bare metal.

Comparing the cleaning of Sample 3A, tar was removed with 3000 psi
water with medium grit, but the final coating was removed only if the
nozzle was placed one inch from the surface.

The results of cleaning with a wire and abrasive wheels showed that
both cleaned to bare metal in most cases. The wire wheel required less
power, but did not completely remove tarry deposits. The grinding wheel
removed tar, but will probably require a specialized device to uniformly
clean the surface. The wire brush will also require a device to control
the wheel, but the wire "gives" allowing larger tolerances and smaller
chances for errors. Both wheels create large amounts of dust, which
possibly may be controlled and removed by water. Because of its rigidity,

the grinding wheel will probably remove more material, both deposits and cast iron.

Table 6 shows the methods that cleaned down to bare metal and those that allowed a thin coating to remain. This comparison has minor implications for the gasket-like seal of the alternative system, but does show the futility of using scrapers to prepare the surface for an adhesive bond.

7.4.8 Recommendations. Based on the results of the cleaning tests performed, recommendations can be made for future development. These recommendations are not based on the results of the sealability test, which is described in the next section.

   a. The wire wheel has probably the best chance of success. It easily removes most deposits and provides flexibility and room for errors. It will also remove a minimum of metal along with the deposits.

   b. A water jet without grit may be acceptable because of the simplicity of design of the cleaning device. It provides a rougher surface which may be able to be sealed using higher stress or softer rubber. Because of its roughness, water jet cleaning is probably more suited for adhesive-bonding methods than for gasket methods.

   c. Water-jet cleaning with grit is probably not acceptable because of the difficulty in removing the grit from the main after cleaning.

   d. Sandblasting is not recommended because of the large amount of deposits and sand that would have to be removed from the cleaned area.

   e. The grinding wheel is probably limited by the rigidity of its surface. A specialized device would have to insure uniform grinding resulting in larger amounts of iron debris to be removed.

   f. Chemical cleaners are not recommended for the reasons already enumerated.

7.5 Sealability Test

   7.5.1 General. Because a reliable theoretical design analysis has yet to be developed for gasket sealing,[11] it is necessary to experiment to determine the important relationships of surface roughness, gasket material hardness, and gasket compressive stress. The unusually rough surface and

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low gas pressures of this sealing application make experimentation more of a necessity. This section describes a very simple test of pressing an elastomeric material against a cleaned surface of a piece of cast iron pipe. The results of this test provide a first approximation for the relationship between cleaning method, rubber hardness and the gasket stress required to stop leaking gas. This section discusses the test procedure and equipment, other testing methods, the test results and conclusions. Most importantly, it makes estimates of the gasket stresses needed to stop leaking gas for different rubber hardnesses and cleaning methods.

Forced against surface irregularities, the gasket must have more compressive stress than would be required if there were no irregularities. Once the seal has been made, it is possible to reduce the stress reaching a minimum stress to maintain the seal.[48] The gasket must also have sufficient flexibility and thickness to seal against surface asperities even when the pipe is out-of-round.[20] In the tests described in this section, it is conservatively assumed that the gasket stress required to seal against leaking gas is the minimum stress to maintain the seal. Once the sealing stress was reached, it was not reduced to find a smaller stress that would still maintain the seal. In these tests, one-quarter inch thick gaskets were found to be more than sufficient to conform to asperities and out-of-roundness. Future development should consider the use of thinner gaskets.

7.5.2 Test Procedures and Equipment. In these tests a rubber gasket was pressed between a curved shard of pipe and a support block with a curved surface. (See Figure 6 and Photos 3 and 4). There was a small chamber in the support block into which passed nitrogen. The test gas passed from the support block through a hole in the gasket and out between the gasket and the pipe wall. Leakage was indicated by a soap bubble test and an unsuccessful attempt was made to measure it as described in succeeding paragraphs.

The six pipe pieces that were used in this test had been cleaned as described in Section 7.4. The pipe pieces were cleaned with water jets, by sandblasting, with wire and abrasive wheels, and by hand with a wire brush. The gaskets were cut from 1/4 inch neoprene (because of cost)

sheet stock as shown in Figure 4. The gaskets had small areas of 1.64 square inches to try to maintain uniform stresses upon compression. The gaskets had durometer hardnesses of 15/20, 30, 40, and 60. Three edges of the rubber gaskets were coated with rubber cement before placing it on the piece of pipe. The gasket was placed at the balance point of the pipe piece and three sides sealed with rubber cement. (See Photos 5 and 6.) After testing, the gasket was checked to insure that no rubber cement had sealed any part of the leak path shown in Figure 4. The pipe piece and gasket were balanced on the support block so that the hole in the block was aligned with the hole in the gasket. Two blocks were used, one with a curved surface for 6-inch diameter pipes, and the other for 4-inch diameter pipe pieces. Photo 4 shows the pipe with gasket balanced on the support for 6-inch diameter pipes.

A Cleveland radial-arm drill press was used for support and to provide the compressive force. (See Photo 3.) A block of aluminum was fastened to the chuck of the press for stability during compression. A one-inch-thick soft rubber bushing provided uniform pressure on the back of the pipe sample. (See Figure 6 and Photo E.) A dynamometer under the support block measured the applied force. The output from the dynamometer was recorded on a Sanborn Model 321 Dual Channel Carrier Amplifier-Recorder. Both the dynamometer and the recorder were borrowed from the Materials Processing Laboratory at MIT. The calibration curve for the dynamometer is Figure 7.

The test began for all pipe samples with the softer 15/20 durometer material and a nominal gasket compressive stress of 25 psi. The nominal stress is defined as the total force applied divided by the area of the gasket, 1.64 in.^{2} Gas entered an accumulator (Photo 7) with a volume of 0.273 ft.^{3} until the desired pressure of 10 in., w.c. was reached. The test began when the valve from the accumulator to the test unit was opened and the pressure decrease was recorded. The volume change of the accumulator when the test valve was opened was less than 0.1 percent. After one minute, the interface between the gasket and pipe wall was tested with a commercial bubble test liquid. The test was repeated for 2 psig and 5 psig. The gasket was tested with 10 psig gas with the

bubble-test liquid alone. If the gasket did not leak at 10 psig, the
test for this particular rubber hardness was ended. If the gas did leak
at any pressure, the nominal gasket stress was increased to 50 psi and
retested. The compressive stress was increased to 75 and 100 psi until
the gasket would seal against 10 psig. This procedure was repeated for
durometer hardness values of 30, 40, and 60 and for all six pipe pieces.
The results of the test are shown in Figure 8.

The nitrogen was assumed to be an ideal gas and the leak rate was
computed from the pressure decrease by the following equation:

$$\dot{m} = \frac{V}{RT} \frac{dP}{dt} \approx \frac{V}{RT} \frac{\Delta P}{\Delta t}$$

Where V is the volume of the accumulator, T is the absolute ambient
temperature, P is the pressure, R is the gas constant for nitrogen,
and $\dot{m}$ is the mass flow rate of nitrogen.[24] During the tests, there
appeared to be a leakage from the piping system even when there were no
bubbles formed at the gasket. In several cases, the calculated flow rate
when no bubbles were present was higher than the calculated flow rate when
there were many bubbles forming at the gasket. Unsuccessful attempts were
made to find leaks from tubing connectors, value stems, and meter connectors.
Perhaps if there were leaks too small to be detected at the gasket,[12] then
the leaks from the tubing perhaps were also too small to be detected by
the bubble test. To try to quantify the piping system leakage, the test
unit was pressurized with the hole at the top of the support blocked.
The resulting leakage rates were not repeatable. A statistical analysis
was performed to identify the system leakage at each of the gas pressures
used. The results of the analysis were not consistent with the bubble test
and were based on too small a number of test points. Because of the
uncertainty of the leakage rate calculations, only the results of the
bubble test were used. If bubbles formed, the gasket was assumed to leak
and if they did not form, the gasket did not leak. This decision is
consistent with the leak test that will probably have to be used in
prototype testing, and almost certainly in field testing.

7.5.3 Other Testing Methods. Two basic methods for testing the
sealability of gasket materials were found discussed in the literature.
Both methods test material for flanged pipe joints, both test materials
at high fluid pressures, and both can measure the leakage of fluid past
the gasket into a sealed annulus. The leakage of the fluid can be
measured as it displaces water drawn up into a burette.[24, 37, 43, 44, 48]
The first method, similar to ASTM Test F37, uses a small 3-3/4 inch O.D.,
0.375-inch thick gasket between two flat flanges.[24, 44] The hollow top
flange is the pressure chamber. In this method, the pressure decrease is
converted to a leak flow rate.[24] ASTM F37 specifies a smaller 1.75 inch
O.D., 0.03 inch thick gasket material. The second method is specified
in ASTM F586 which requires the gasket to be compressed between two,
4-inch diameter welding flanges on schedule 80 steel pipe.[37] In both
methods, the compression is provided by either calibrated or strain-gage
bolts. Neither of these methods is suited for use in testing the seal-
ability of gasket material against cast iron pipe. The curved and rough
surfaces found on the inside of the pipes probably cannot be accurately
duplicated on a flat piece of metal.

7.5.4 Corrections to Nominal Gasket Stress. During the sealability
test, it was observed that the leak occurred at position 1, 3, or both, as
shown in Figure 6 and in Figure 9. These leak positions correspond to
profiles 1 and 3 in Figure 3. Because two curved surfaces with different
radii are forced together against a deformable gasket, a uniform gasket
pressure distribution will not result. The actual pressure distribution
can be approximated by a parabola as shown in Figure 9. Because the edges
of the gasket are sealed with rubber cement, positions 1 and 3 have the
lowest gasket stress for the unsealed leakage path. (See Figures 3 and 9.)

The following relationships can be made based upon the assumed para-
bolic pressure distribution, and projected onto a horizontal place. (See
Figure 9.)

$$\bar{\sigma} = \frac{F}{A}$$

$$\frac{\sigma_{L.P.}}{\overline{\sigma}} = 1.374$$

$$\frac{\sigma_2}{\overline{\sigma}} = 1.5, \text{ and}$$

$$\frac{\sigma_1}{\overline{\sigma}} = \frac{\sigma_3}{\overline{\sigma}} = 1.287$$

Where $\overline{\sigma}$ is the nominal stress; F is the applied force, A is the total gasket area, 1.64 in.^{2}; $\sigma_{L.P.}$ is the average stress over the leakage path; σ_1 and σ_3 are the stresses as positions 1 and 3 respectively; and σ_2 is the stress at the centerline, position 2. As shown, the gasket compressive stress at the most likely leak positions is 28.7 percent higher than the nominal stress. Values of gasket stress are adjusted by this factor in Section 7.5.6 and Table 7.

7.5.5 Results and Conclusions. Several conclusions can be made based on the results of the sealability test contained in Figure 8.

(a) Rubber with a durometer hardness of 15/20 provided a seal for all pipe pieces tested.

(b) Pipe pieces cleaned by wire or grinding wheels were sealed by only 25 psi gasket stress for rubber as stiff as 40 durometer.

(c) Water jet cleaning required higher gasket stresses to seal with 30 to 60 durometer rubber.

(d) Sandblasting required higher gasket stresses to seal with 40 to 60 durometer rubber.

(e) The roughness number, $\overline{d}$, was not the only factor to determine sealability of rubber gaskets on rough surfaces. For example, Samples 4A and 4B were cleaned with water jets and by hand respectively. Even though the water jet cleaning resulted in a rougher surface with a higher roughness number, Sample 4A was sealed with lower gasket stresses than was Sample 4B. As another example, Samples 1B and 4B were both cleaned by wire brushing by hand, resulting in similar roughness numbers. Yet, Sample 4B was sealed at a much higher stress than was Sample 1B. Clearly, another factor such as the slopes of the asperities (as described in Section 7.2) must influence the gasket stresses required to seal against gas.

By plotting the surface roughness numbers against the nominal gasket stress required to seal 10 psig gas, there appears to be a roughness number above which requires higher gasket stresses. Figure 10 shows that above a roughness number of about 3400μ-in., higher stresses are required for 30, 40 and 60 durometer hardnesses. By comparing cleaning methods and their resulting roughnesses in Table 5, it can be seen that wire and grinding wheels and sandblasting have roughnesses smaller than 3400μ-in. and that water jet and water jet with grit have roughnesses greater than 3400μ-in. For this reason, the former group will seal at lower gasket stresses.

A test was performed to see if a gasket could seal against an uncleaned surface. Sample 1B was tested for gasket sealability before disturbing the pipe wall deposits. It was then hand-brushed to remove only the loose deposits, and retested. As can easily be seen in Figure 11, the uncleaned pipe piece required significantly higher gasket stresses than did the cleaned pipe. On the basis of this test, it is concluded that at least the loose pipe wall deposits should be removed. This test was performed with relatively hard gasket material. The use of softer gasket material may reduce the difference in gasket compressive stress between cleaned and uncleaned pipe pieces.

7.5.6 Recommendations. Based upon the results of the cleaning and sealability tests, the following recommendations are made;

(a) Wire Wheel cleaning has the greatest chance of future development because of its low required gasket stress and relative ease of use.

(b) Grinding wheels have similar required stresses but with less ease of use.

(c) Sandblasting is not recommended because of the inherent dust problem.

(d) Water jet cleaning requires too high a compressive stress, and is thought to be more suited for adhesive-bonding sealing methods when it removes all deposit residues.

(e) Softer materials should be used for the gasket in the alternative seal.

From the results in Figure 10, Table 7 lists estimated minimum stresses for different cleaning methods and rubber hardnesses to seal 10 psig of gas. Values of gasket stress have been adjusted as described in Section 7.3.4.

TABLE 1

RELATED ASTM TESTS

C864   Standard Specification for Dense Elastomeric Compression
Seal Gaskets, Setting Blocks, and Spacers

D146   Standard Test Method for Fluid Resistance of Gasket Materials

D395   Standard Test Method for Rubber Property - Compression Set

D471   Standard Test Method for Rubber Property - Effect of Liquid

D573   Standard Test Method for Rubber Deterioration in an Air Oven

D575   Standard Test Method for Rubber Properties in Compression

D751   Standard Method of Testing Coated Fabrics

D865   Standard Test Method for Rubber Deterioration by Heating in
a Test Tube

D1149   Standard Test Method for Rubber Deterioration - Surface Ozone
Cracking in a Chamber (Flat Specimens)

D1349   Standard Recommended Practice for Rubber - Standard Temperature
and Atmospheres for Testing and Conditioning

D1390   Standard Test Method for Rubber Property - Stress Relaxation in
Compression

D1415   Standard Test Method for Rubber Property - International Hardness

D2240   Standard Test Method for Rubber Property - Durometer Hardness

D2934   Standard Method for Testing Rubber Seals - Compatibility with
Service Fluids

D3041   Standard Method of Testing Coated Fabrics - Ozone Cracking in a
Chamber

F37   Standard Test Method for Sealability of Gasket Materials

F38   Standard Test Method for Creep Relaxation of a Gasket Material

F118   Standard Definition of Terms Relating to Gaskets

F145   Standard Recommended Practice for Evaluating Flat-faced Gasketed
Joint Assemblies

F586   Standard Test Method for Leak Rates Versus y Stresses and m Factors
for Gaskets

TABLE 2

ROUGHNESS NUMBERS FOR DIFFERENT CAST IRON SAMPLES

SAMPLE	CLEANING METHOD	PROFILE rms DEVIATIONS ($\mu\cdot w.$)			ROUGHNESS NUMBER
		d_1	d_2	d_3	
1A (Left)	2000 psi water w/ med grit	3690	4970	5650	4760
1A (Right)	2000 psi water	3900	3550	3030	3500
1B	Hand brushing	3000	4830	4180	4010
1C	Wire Wheel	2620	3510	2620	2920
1D	Grinding wheel	2180	2340	2900	2480
2	3000 psi water w/ med. grit	4950	6820	6520	6100
3A (Top)	3000 psi water w/med. grit at 5 in. standoff	--	--	--	5880
3A (Bottom)	3000 psi water w/med grit at 1 in. standoff	--	--	--	5860
3B	wire wheel w/tar	--	--	--	--
3B	grinding wheel w/tar	--	--	--	--
4A	3000 psi water	4580	5570	4460	4870
4B	hand brushing	3400	4660	3390	3820
7	Air-Sand Blasting at 80 psi	3220	3390	3050	3220

TABLE 3

RESULTS OF CLEANING TESTS BY SAMPLE CLEANED

SAMPLE	JOINT FROM WHICH SAMPLE REMOVED	CLEANING METHOD	ROUGHNESS NO., $\overline{d}$ (μ-IN.)	RESULTS
1A (Left)	6 in. dia. ConEdison	2000 psi water	4760	residue remained
1A (Right)	6 in. dia. ConEdison	2000 psi water w/fine grit	3500	to bare metal flash oxidized
1B	6 in. dia. ConEdison	Hand brushing	4010	loose material removed
1C	6 in. dia. ConEdison	Wire Wheel	2920	to bare metal
1D	6 in. dia. ConEdison	Grinding wheel	2480	to bare metal
2	4 in. dia. ConEdison	3000 psi water w/med. grit	6100	to bare metal, oxidized
3A (Top)	4 in. dia. ConEdison w/tar	3000 psi water w/med. grit at 5 in. standoff from pipe	5880	tar removed, residue remained
3A (Bottom)	4 in. dia. ConEdison w/tar	1 in. standoff from pipe	5860	to bare metal, oxidized
3B	4 in. dia. ConEdison w/tar	Wire & Grinding wheels	--	tar removed by grinding wheel only
4A	4 in. dia. ConEdison	3000 psi water	4870	residue remained
4B	4 in. dia. ConEdison	Hand brushing	3820	loose material removed
7	4 in. dia. Boston Gas	Sand blasting	3220	to bare metal
5A	4 in. dia. Comm. Gas	Solvent overnight, 1000 psi water	--	removed oil film only
5B	4 in. dia. Comm. Gas	Strong acid overnight, 1000 psi water	--	no reaction
8	4 in. dia. Comm. Gas	Alkali overnight 1000 psi water	--	slight rust removal

TABLE 4

RESULTS OF CLEANING TESTS BY CLEANING METHOD

SAMPLE	CLEANING METHOD	ROUGHNESS NUMBER, $\bar{d}$ (μ-in.)	REMARKS
1. Water-Jet Cleaning.			
1A (Right)	2000 psi	3500	Residue Remained
4A	3000 psi	4880	Residue Remained
2. Water-Jet Cleaning.			
1A (Left)	2000 psi	4760	Bare metal
3A (Top)	3000 psi at 5 in.	5880	Residue Remained
3A (Bottom)	3000 psi at 1 in.	5860	Bare Metal
2	3000 psi	6100	Bare Metal
3. Radial Wire Wheel			
1C	0.07 hp; $F_n = 9$ lbf	2920	Bare Metal-cut grooves
3B	0.21 hp; $F_n = 15$ lbf	–	Tar not completely removed
4. Radial Grinding Wheel			
1D	0.23 hp; $F_n = 34$ lbf	2480	Removed metal
3B	0.46 hp; $F_n = 25$ lbf	–	Removed tar, metal

TABLE 4
(Cont'd.)

SAMPLE	CLEANING METHOD	ROUGHNESS NUMBER, $\bar{d}$ (μ-in.)	REMARKS
5. Sandblasting			
7	80 psi air w/fine sand	3220	Bare metal – no oxidation
6. Hand Brushing			
1B	hand wire brush	4010	loose deposits removed
4B	hand wire brush	3820	loose deposits removed

TABLE 5
COMPARATIVE ROUGHNESS BY CLEANING METHOD

METHOD	REPRESENTATIVE ROUGHNESS NO. $\bar{d}$, μ-in.	SAMPLES	DESCRIPTION
water w/grit	6000	3A, 2	3000 psi.
	4800	1A (L)	2000 psi.
water w/o grit	4880	4A	3000 psi.
	3500	1A (R)	2000 psi.
hand wire brushing	4000	4B, 1B	
sand blasting	3200	7	80 psi, 8 CFM
wire wheel	2920	1C	
grinding wheel	2480	1D	

TABLE 6

LEVEL OF CLEANING BY CLEANING METHOD

CLEANING METHOD	RESIDUE REMOVED	RESIDUE REMAINED
water at 3000 psi		X
at 2000 psi		X
water w/grit at 3000 psi	X	
at 2000 psi	X	
at 3000 psi at 1 in.	X	
at 5 in.		X
by hand		X
grinding wheel	X	
wire wheel	X	
sand blasting	X	

TABLE 7

ESTIMATES OF REQUIRED GASKET COMPRESSIVE STRESSES[*]

CLEANING METHOD	RUBBER DUROMETER HARDNESS			
	15/20	30	40	60
Wire Wheel	33*	33	33	65
Grinding Wheel	33	33	33	65
Water Jet at 3000 psi	33	65	65	97
Water Jet at 3000 psi w/grit	33	65	97**	130**
Sandblast	33	33	65	65

* Gasket Stresses are in psi that have been adjusted by a factor of 1.287 as described in Section 7.5.4.

** Conservatively estimated.

Axial Direction

Elastomeric
Material

Cast Iron Pipe Shard

Approximate
Leak Path

Cast Iron
Pipe Shard

$\frac{3}{8}$in. Dia Hole

1"

$1\frac{1}{4}$"

$1\frac{3}{4}$"

Approximate
Area Sealed
with Rubber
Cement

Gasket Area
=1.64 in^2
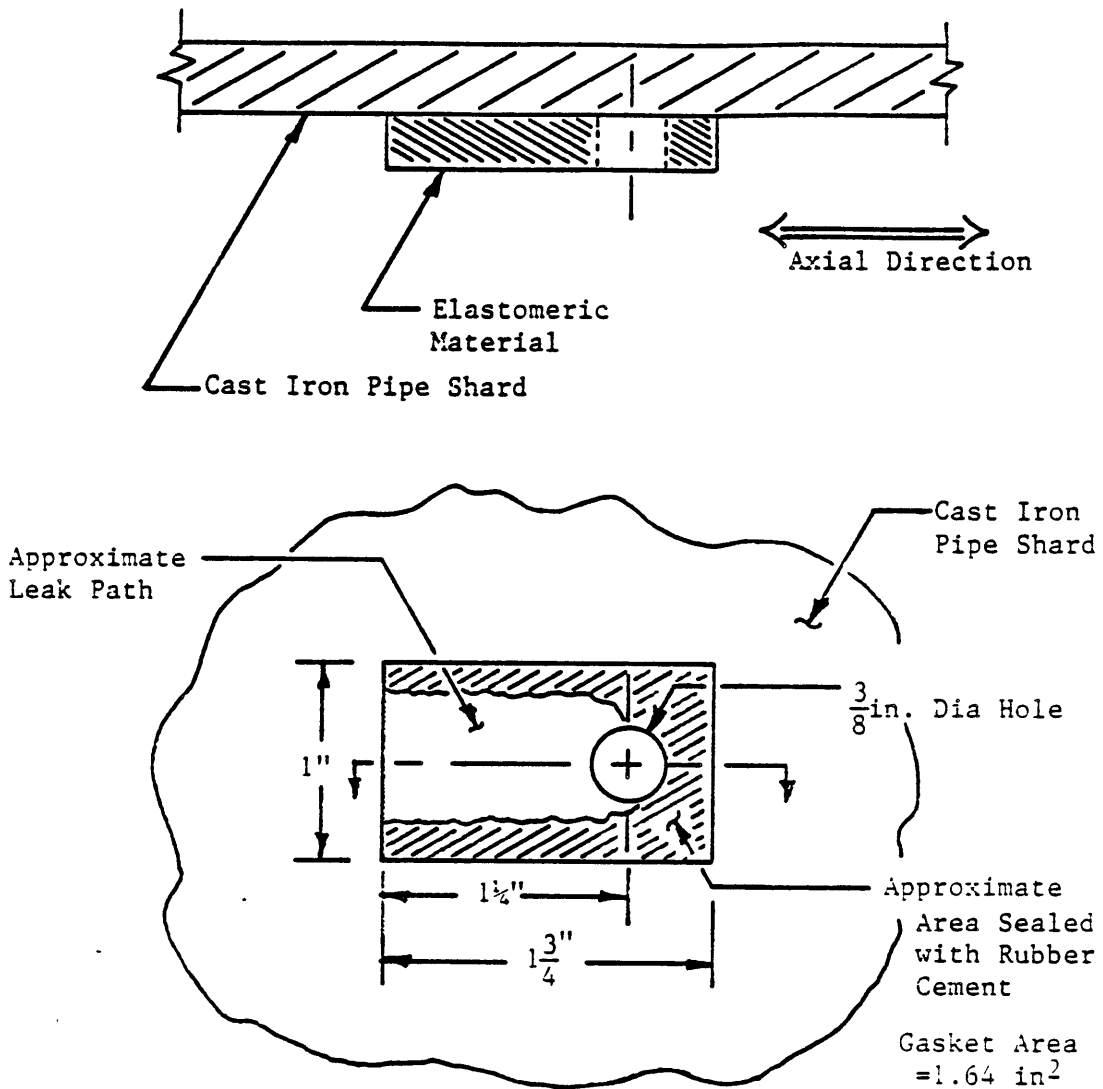
FIGURE 4   Gasket Used in Sealability Test

Profile #3
Profile #2

Outline of Gasket

$\frac{1}{4}$"

$\frac{1}{4}$"

Profile #1

1"

Note: Looking at
the Surface
of the Pipe
Shard
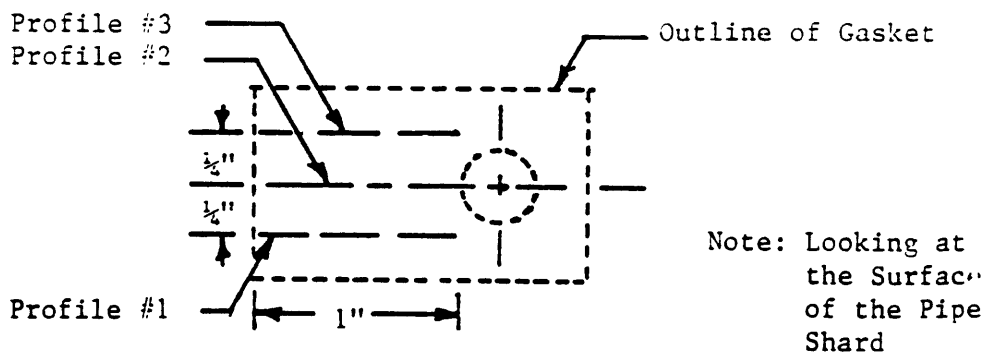
FIGURE 3   Surface Profile Location

Grindir.g or
Wire Wheel

End Support

Cast Iron
Pipe Shard

Side
Support

Steel
Base

Dynamometer

Dynamometer Support
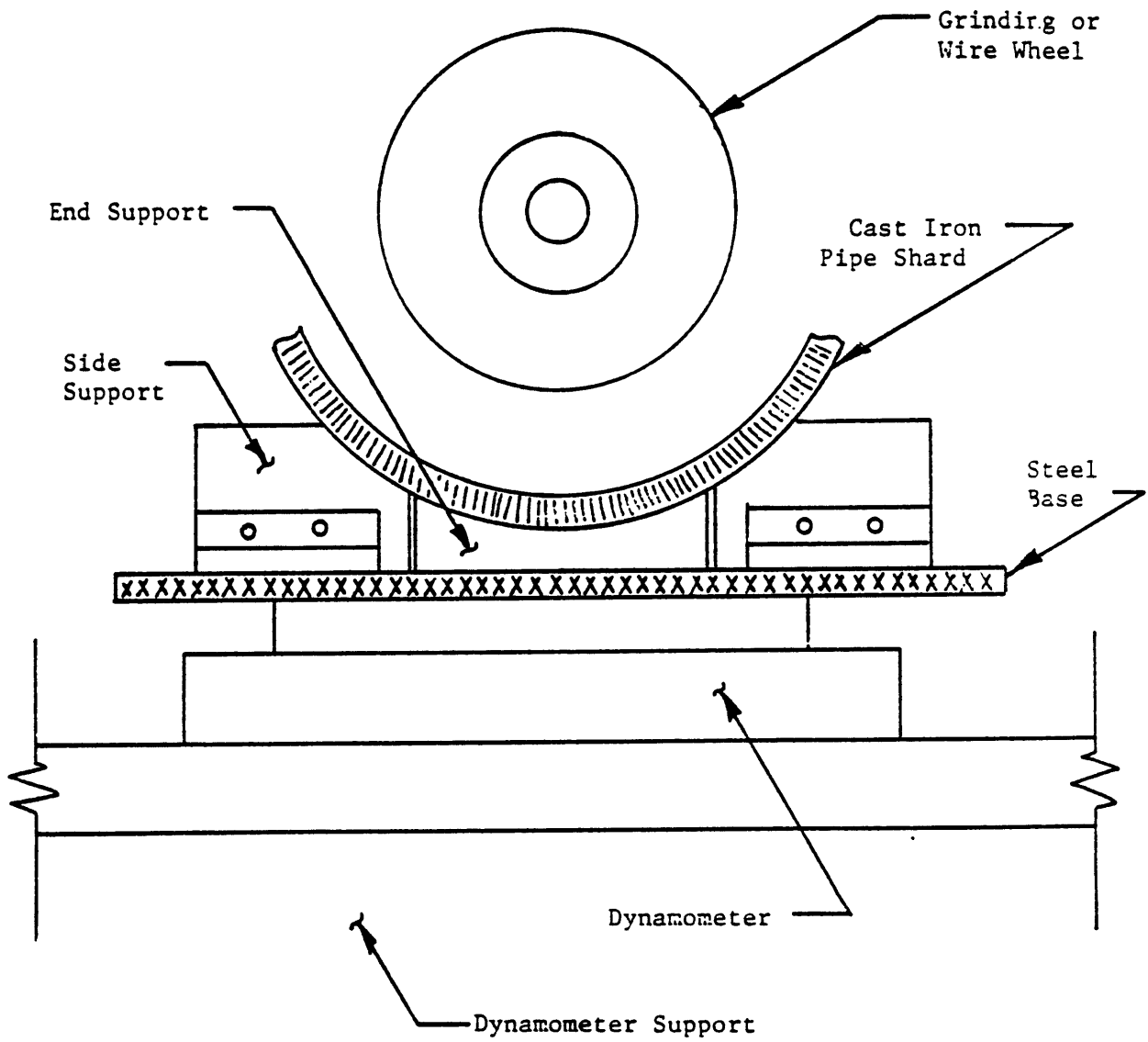
FIGURE   5 .   Cleaning Stand
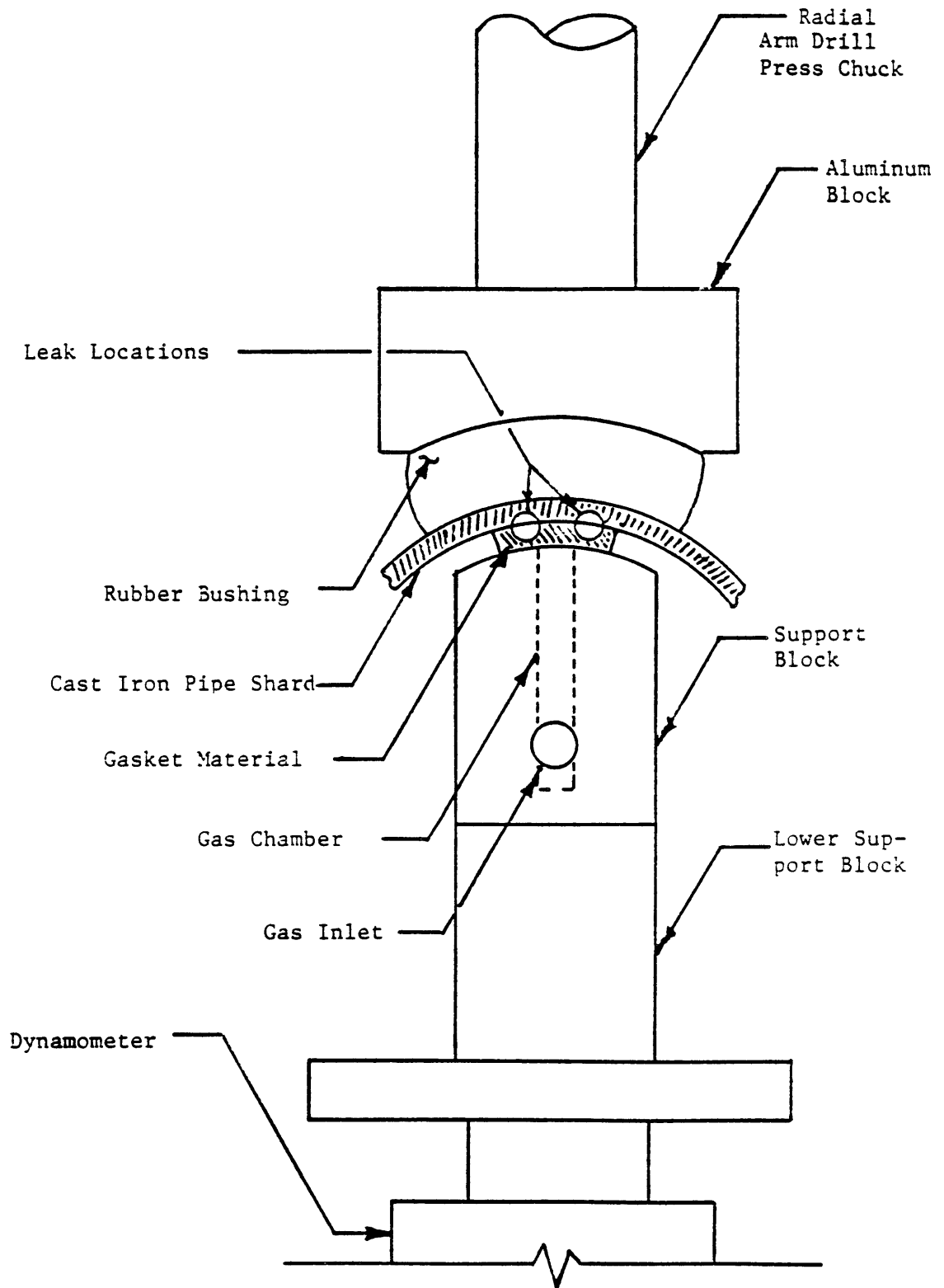
FIGURE 6   Equipment for Sealability Test

FIGURE 7   Dynamometer Calibration Curve - Vertical on No.5 Scale

The figure shows a plot of FORCE (lbf) on the y-axis (0 to 175) versus DIVISIONS ON NO. 5 SCALE on the x-axis (0 to 14).

Linear Regression
#Div=0.0767(lbf)+2.0971

Linear Regression
#Div=0.0887(lbf)+1.0923
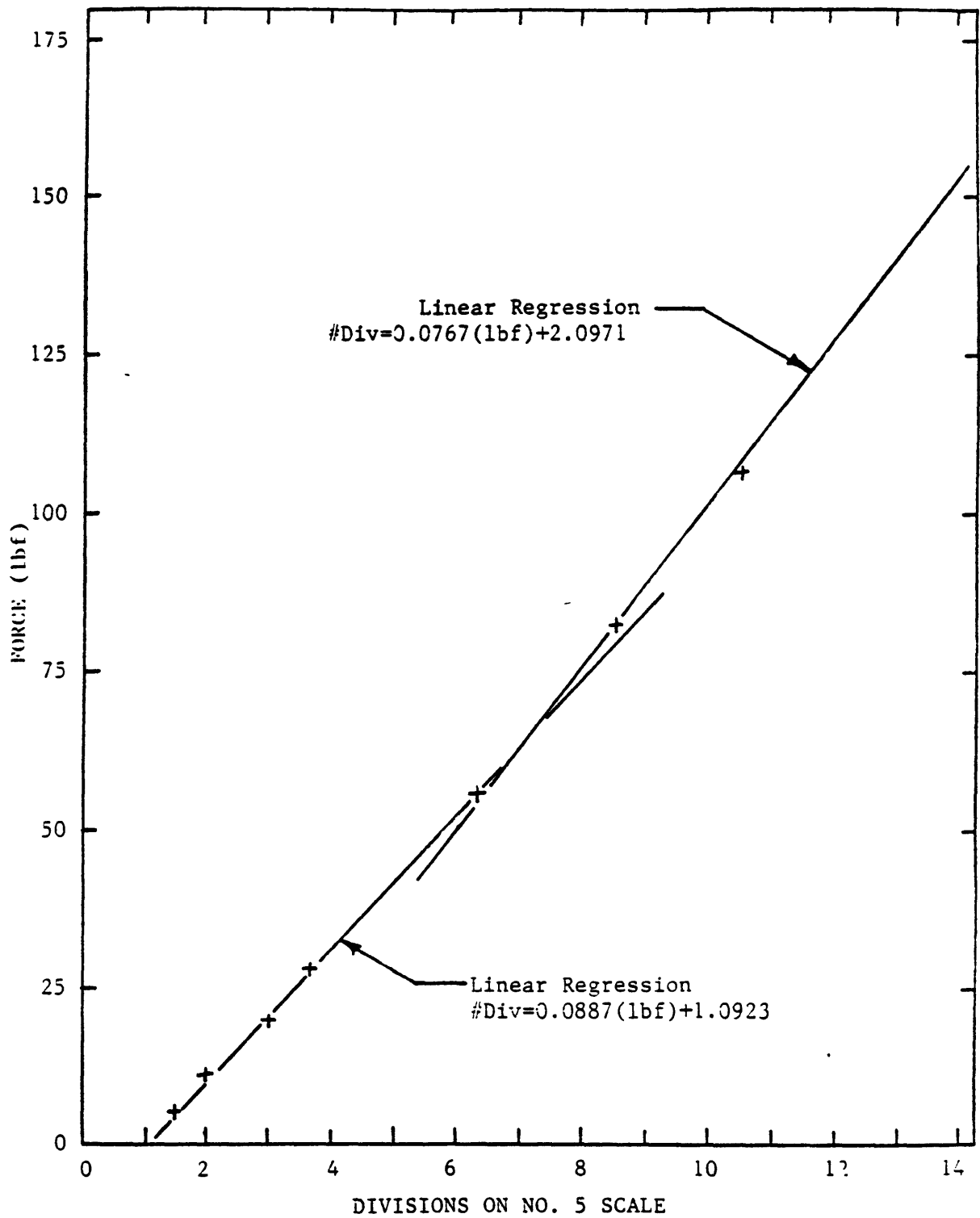
No. 5 Scale refers to the No.5
Attenuator Position of the Sanborn
Amplifier-Recorder

-168-
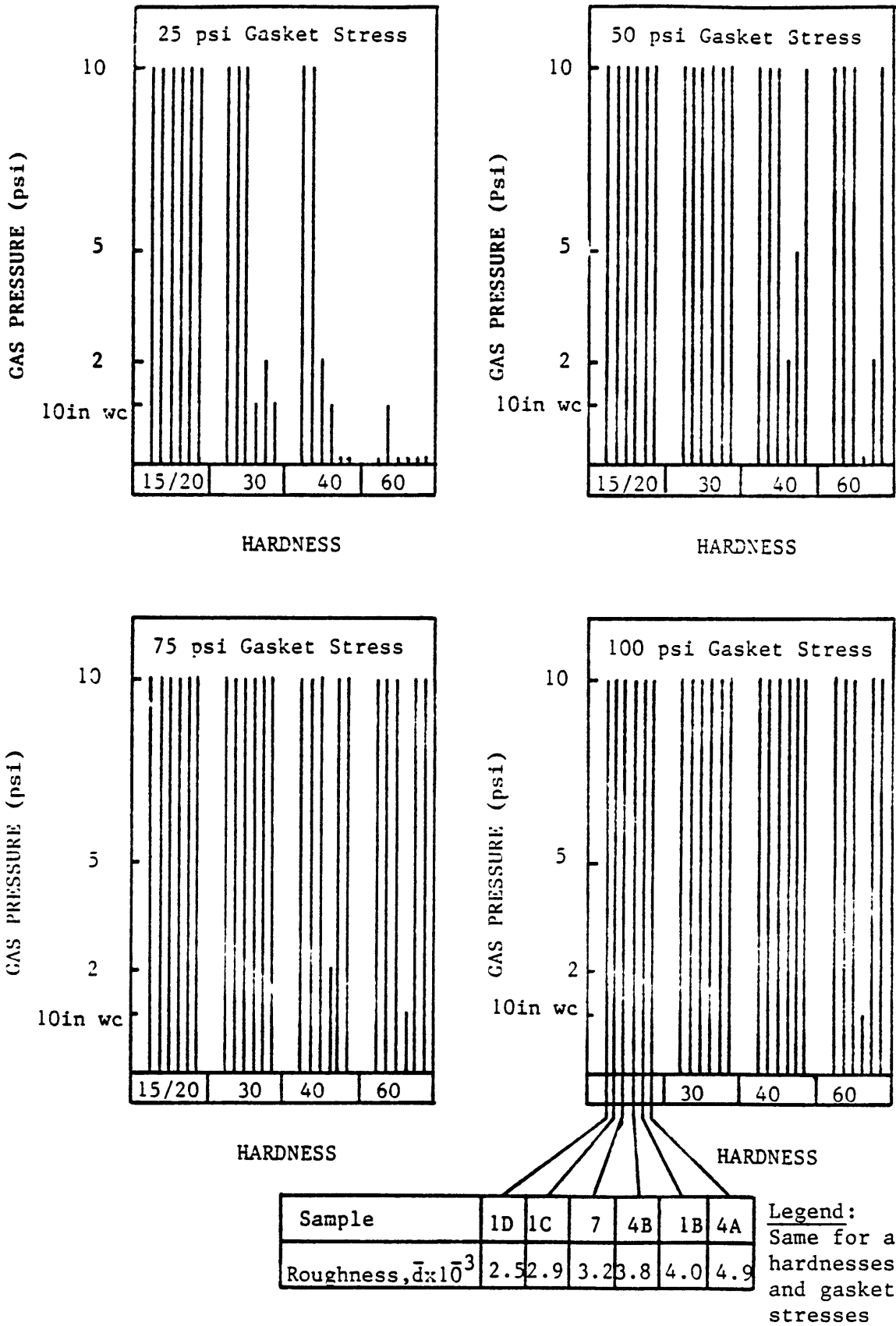
FIGURE 8   Results of Sealability Test

Gaskets of specified hardnesses and stresses prohibited leakage of gas at pressures shown in this Figure

-169-

FORCE, F

Cast Iron
Pipe Shard

Gasket, Cross-
Sectional Area,
A= 1.64 in^2

Assumed
Leak
Path

x'

x

Uniform Pres-
sure Distribu-
tion

$\bar{\sigma} = \dfrac{F}{A}$

$\sigma_1 = \sigma_3 = 1.278\,\bar{\sigma}$

$\sigma_2 = \sigma_4 = 1.5\,\bar{\sigma}$

Assumed
Parabolic
Pressure
Distribution

$\sigma(x)$

$\sigma_{\substack{leak\\path}} = 1.374\,\bar{\sigma}$

$\sigma(x) = \dfrac{3}{2}\,\bar{\sigma}\left(1 - \left(\dfrac{x}{x'}\right)^2\right)$
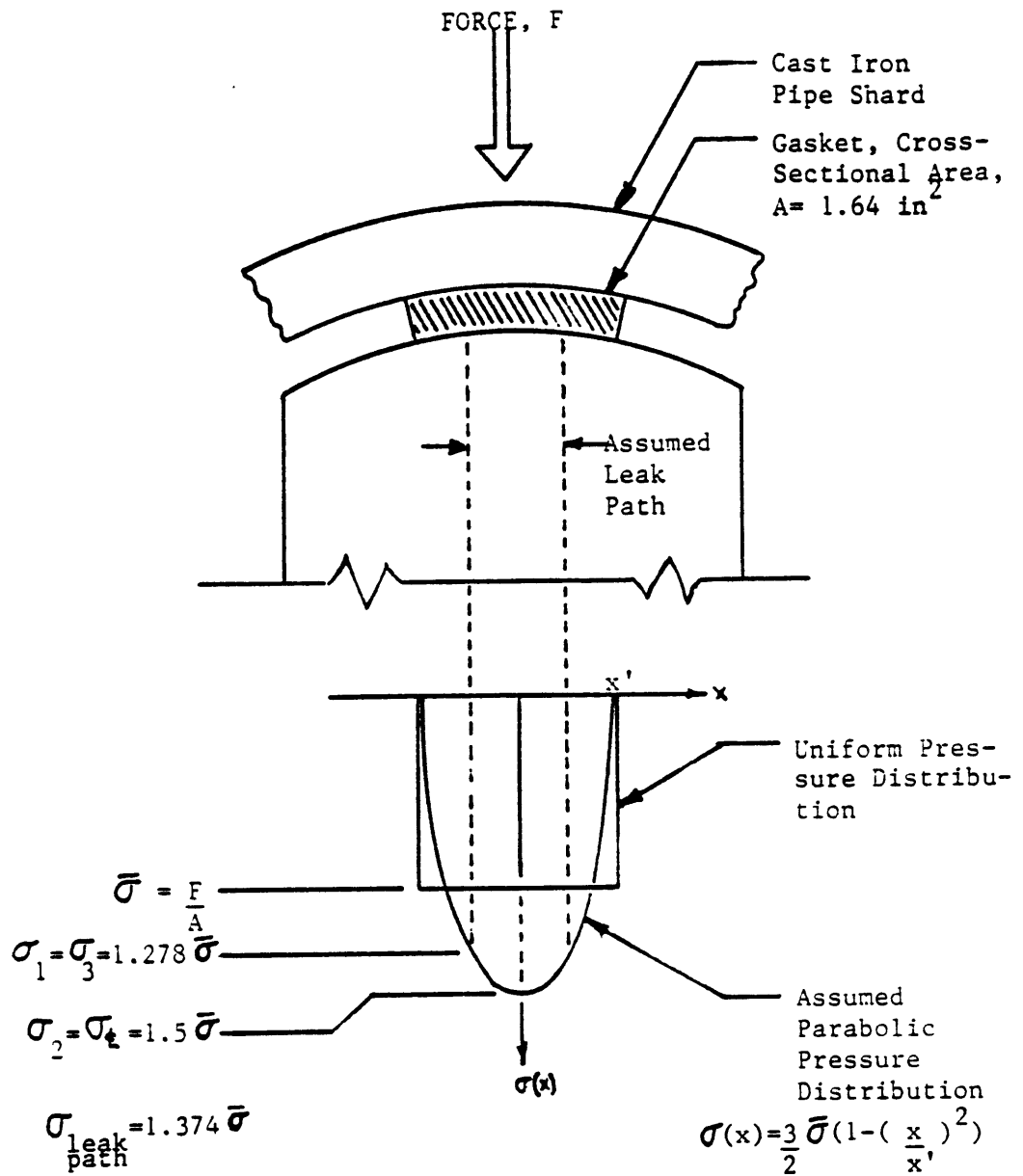
FIGURE   9   Assumed Gasket Pressure Distribution
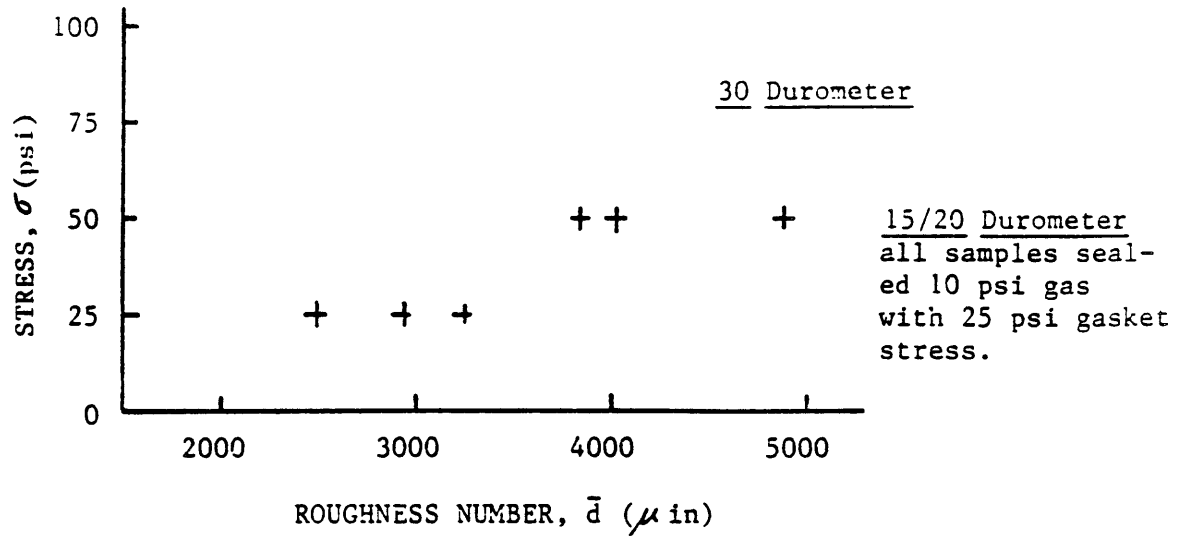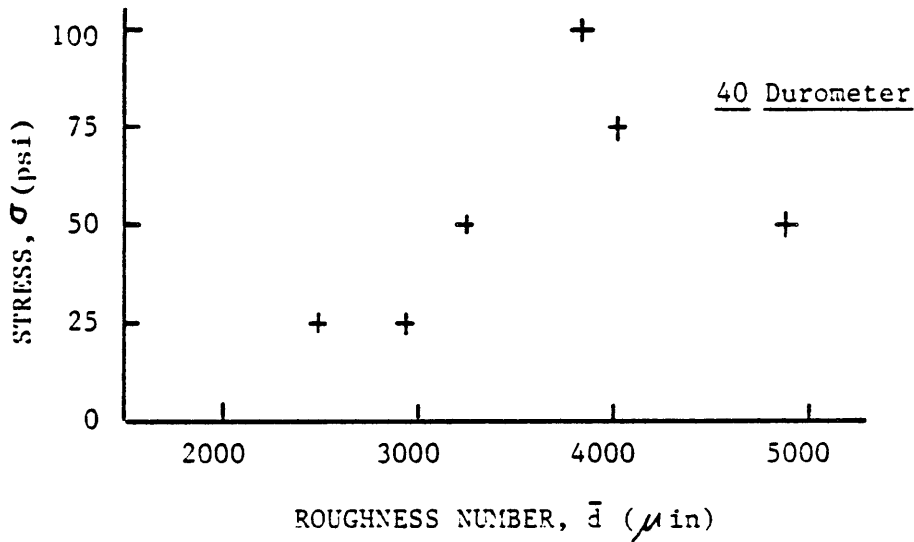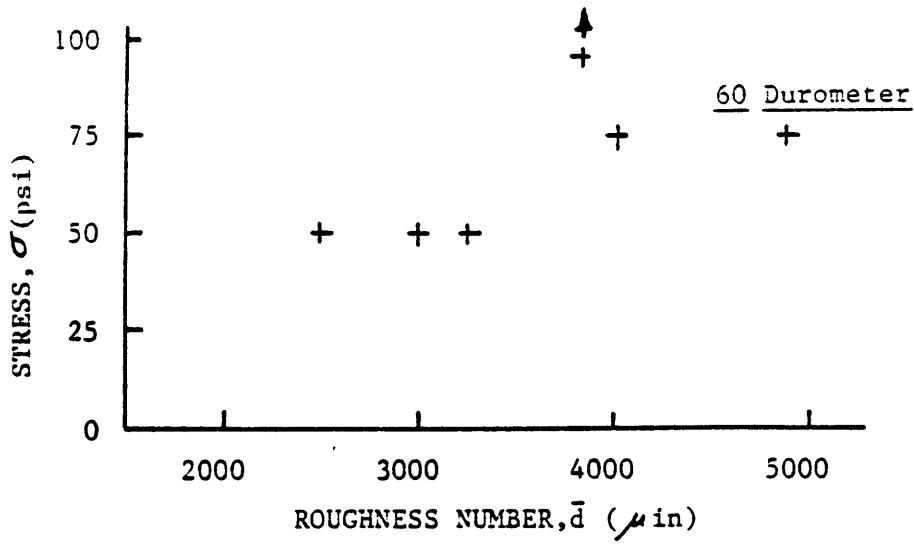
+ = Gasket Compressive Stress at which 10 psi gas is sealed

FIGURE 10   Gasket Compressive Stress vs. Roughness
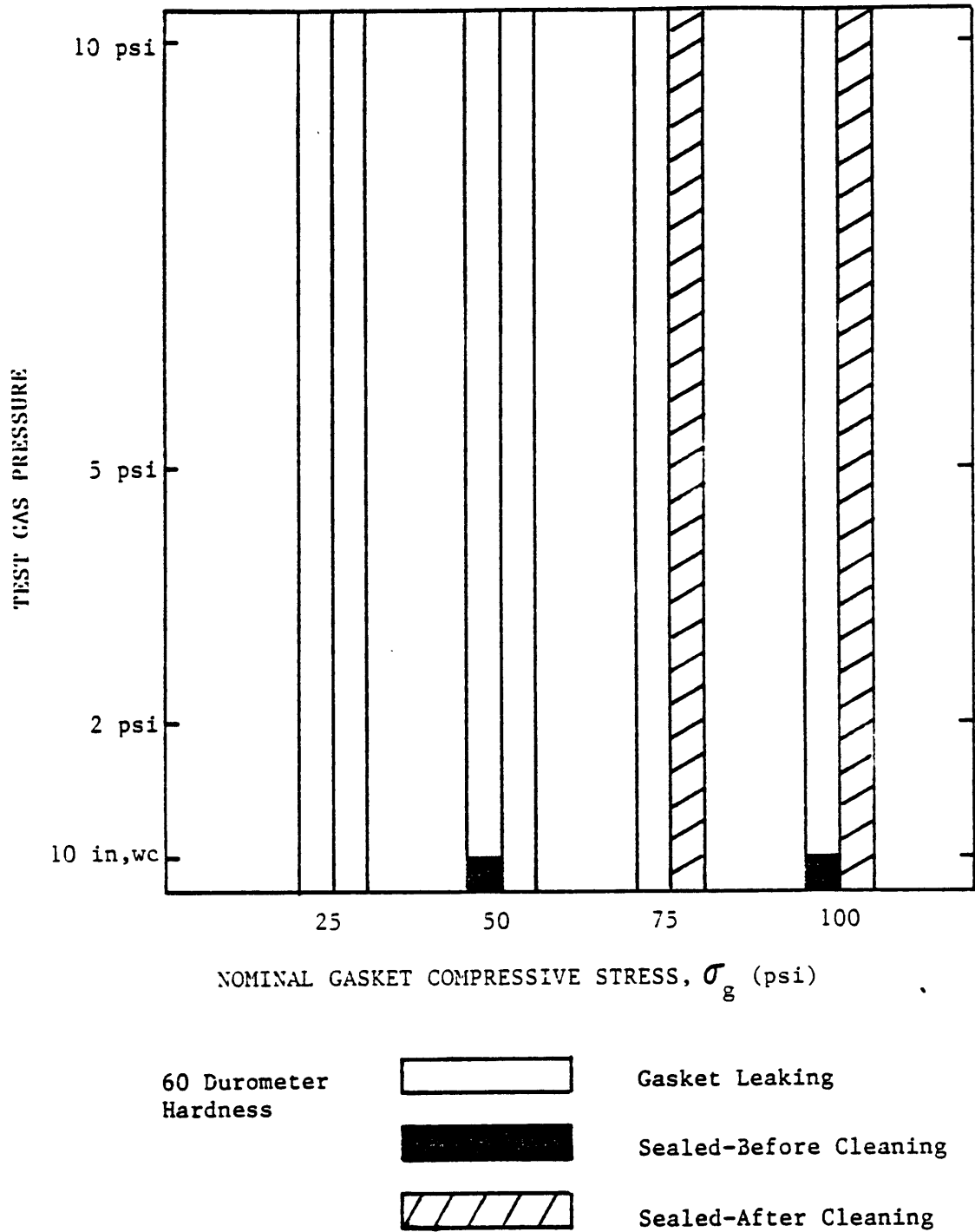
FIGURE 11   Sealability Test on Sample 1B - Before and After
            Cleaning
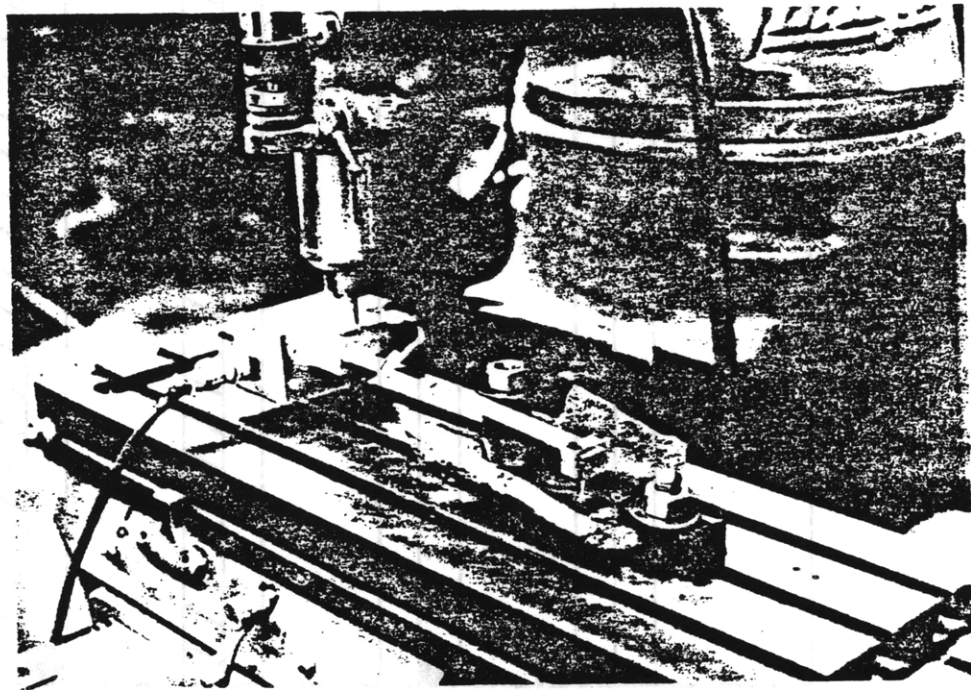
PHOTO 1   PROFILOMETER
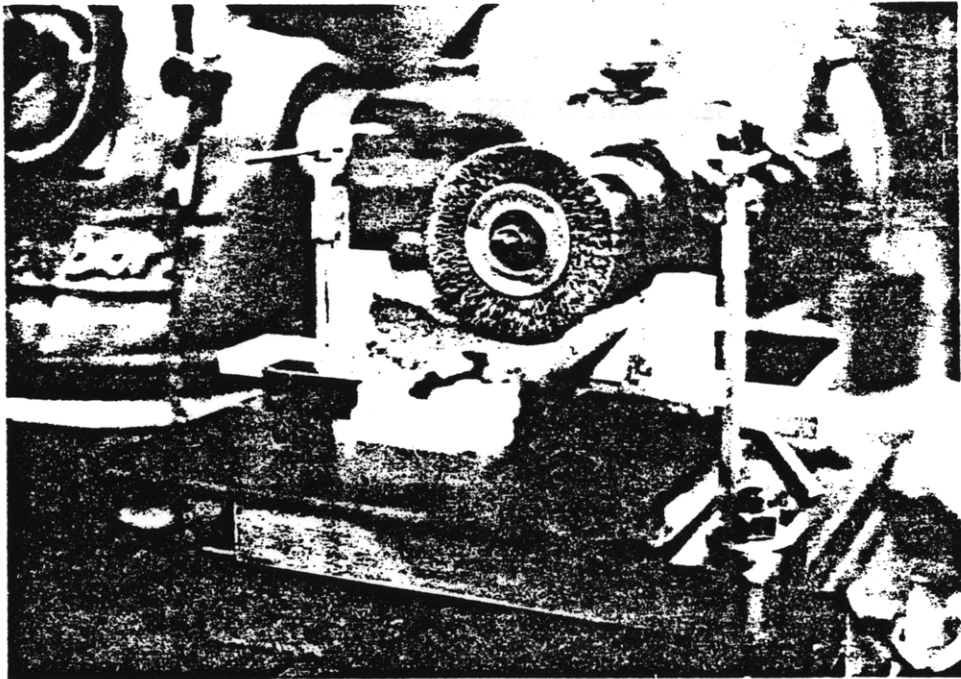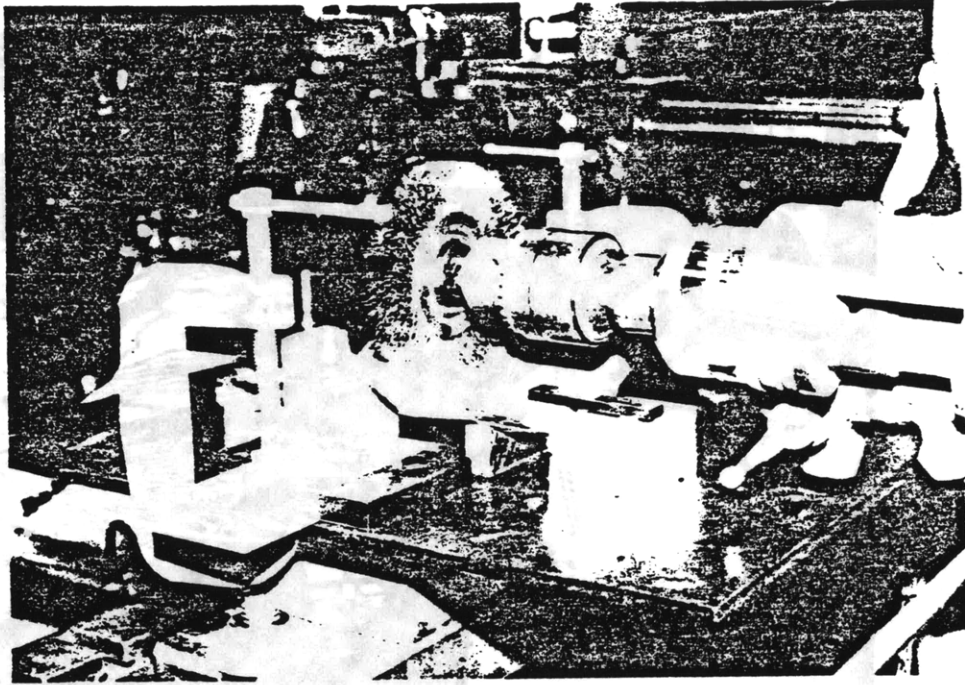
PHOTO 2   CLEANING STAND
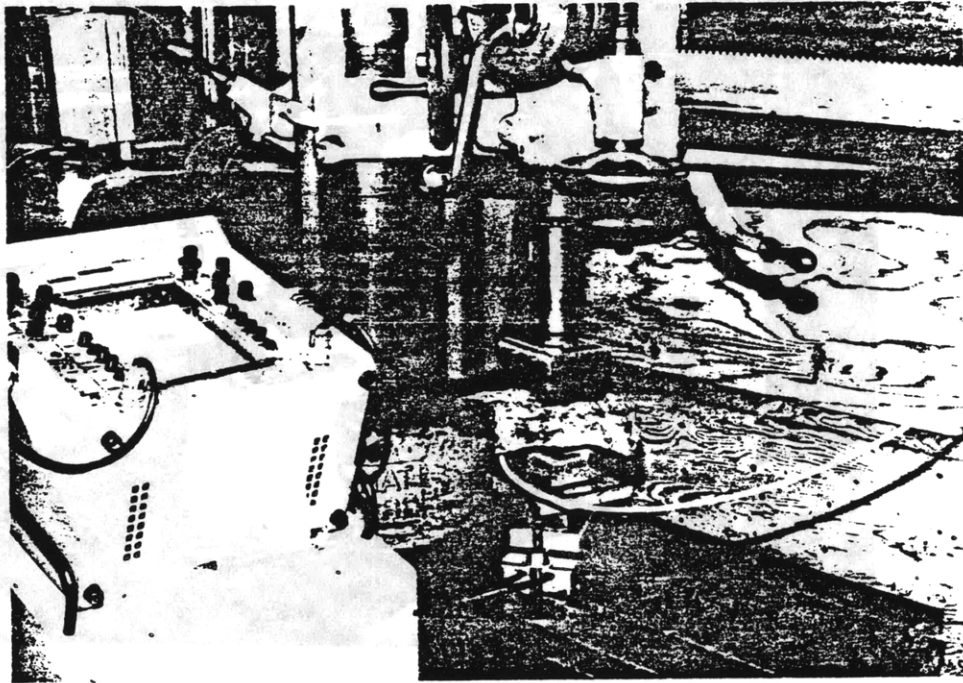
PHOTO 3   SEALABILITY TEST EQUIPMENT
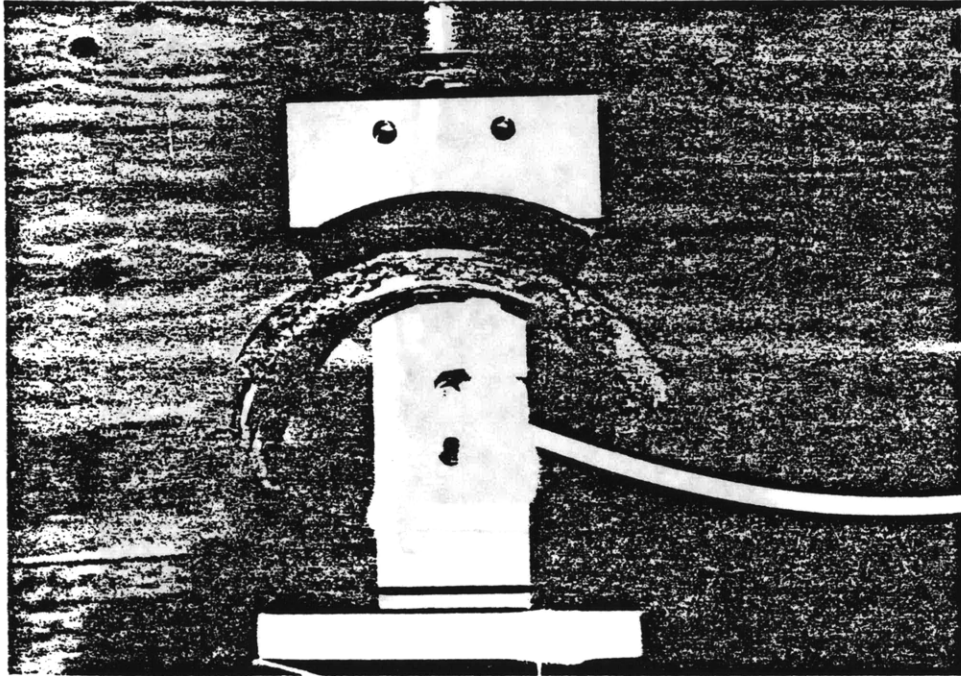
PHOTO 4   SEALABILITY TEST UNIT
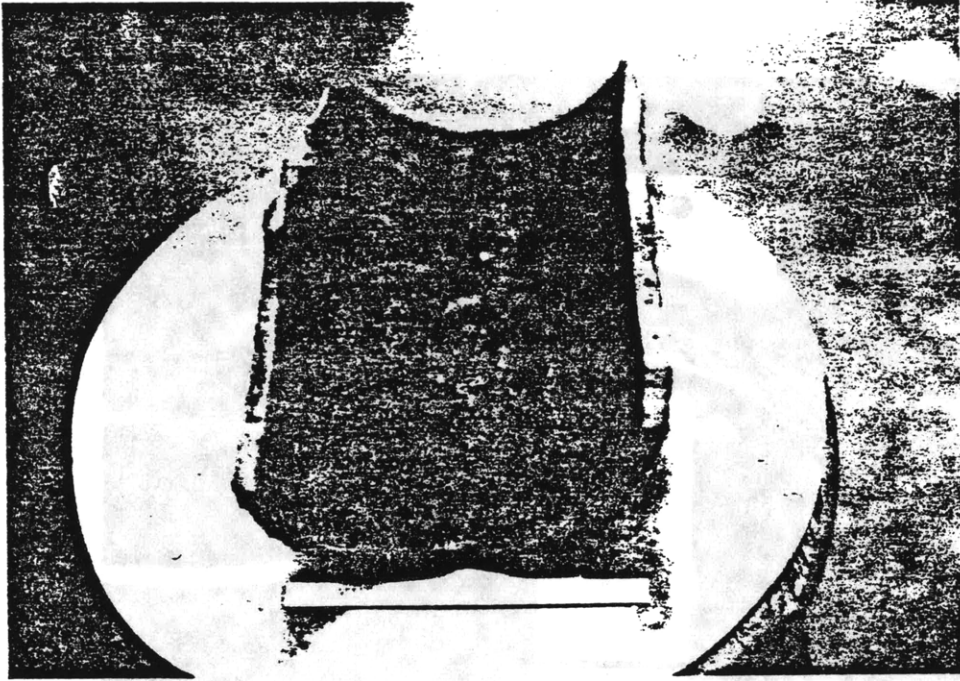
PHOTO 5 SAMPLE 4A WITHOUT GASKET
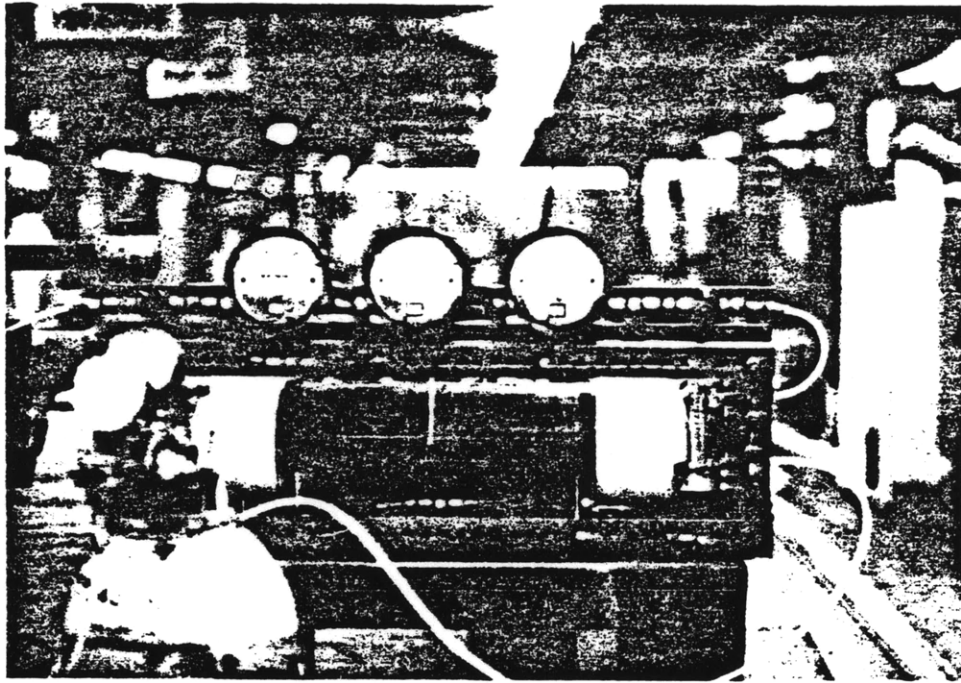
PHOTO 7   ACCUMULATOR

8.0 ELASTOMER DESIGN

8.1 General.

It is essential that the elastomeric gasket material maintain suffi-
cient compressive stress to seal against the gas pressure for its full
lifespan of at least 50 years. Therefore, to design a successful
seal, the long-term properties of elastomers must be considered to
properly choose the polymer. This Chapter discusses these long-term
properties of elastomers. Creep and stress relaxation, the aging of
the polymer, and resistance to chemicals found in the gas main are dis-
cussed. Additionally, the temperature-dependent behavior of elastomers,
a possible failure criteria, and gas permeability will be addressed.
A comparison of different elastomers and recommendations is made in
general terms. Specific recommendations are not possible because the
properties depend to a large extent on how the components are compounded.
Finally, several tests are recommended that should provide knowledge
about the behavior of elastomers.

8.2 Time-Dependent Behavior of Elastomers

8.2.1 General. The compressive stress in the gasket can be
expected to decrease over the lifespan because of physical and chemical
stress relaxation in the elastomer.[2] The gasket must be initially over-
stressed so that the compressive stress after 50 years is still more than
sufficient to seal against the gas. However, for the same physical reason
as the stress relaxation, the elastomer is expected to plastically flow
into surface asperities allowing sealing at a much lower compressive
stress. Creep and stress relaxation of the polymer are both due to
the viscoelastic behavior of its molecules. These effects occur when-
ever the material is stressed, not only at high temperatures and stresses
as with metals.[27] This section discusses the physics of viscoelastic
behavior, inter-relationships of properties, creep control measures
and procedures for extrapolating behavior to 50 years.

8.2.2 Creep and Stress Relaxation. Elastomers, like many polymers,
consist of a tangled mass of long linear molecules that are the result

of polymerization from monomer units.[27] With increasing temperature, the molecules are able to slide past each other in viscous flow because of weak intermolecular forces (Van der Waals forces).[36] Deformation of the molecules results in rotation rather than elongation of primary molecular bonds,[6] accounting for the low rigidity of most elastomers. The viscous flow is restrained from continuing by the physical entanglements of molecules and by the crosslinks between molecules as a result of vulcanization or curing.[36] With deformation, there is a tendency for the molecules to return to the equilibrium of an unstrained condition.[36] The physical entanglements may move, releasing molecules,[36] the chain molecules may break because of oxidation or ozonolysis, or further cross-linking between molecules may occur.[36] Over time, these effects result in an irreversible decrease in the capacity for an elastomeric gasket to seal.[2] These effects occur in a shorter time at higher temperatures. Creep is defined as an increase in strain for a constant stress, and stress relaxation as a decrease in stress for a constant strain. Both creep and stress relaxation describe the same behavior, and provide equivalent indicators of the physical properties of elastomers.[6]

8.2.3 Reinforcing Fillers. When an elastomer is vulcanized, the random crosslinking still allows movement of local segments of the molecule. To stiffen the material, reinforcing fillers, such as carbon black, are added to the mixture prior to polymerization to restrict the movement of these local segments. The resulting elastomer is harder and stiffer, but also more susceptible to creep and stress relaxation.[2, 36] (Refer to Figure 12.) In general, harder rubbers (more reinforcing filler) experience creep and stress relaxation more than softer rubbers,[2, 36] but harder rubbers can be compounded to be relatively resistant to those time-dependent effects.[36]

When fillers are added to a polymer mixture, agglomerations of filler and polymer are formed making the material relatively rigid. With a few deformations, this "structure" breaks down reducing stiff-ness.[36] If filled elastomers are used, it is important that the material be properly conditioned to destroy the "structure" before use.[36] If the

material were not conditioned and the stiffness was reduced soon after installation as the "structure" broke down, the seal may leak with the loss of compressive stress.

8.2.4 Compression Effects. Overstressing the gasket to insure sufficient stress to seal at 50 years will not accelerate the time dependent properties of the elastomer. The initial compression of the elastomer does not greatly influence creep or stress relaxation.[2, 48] As can be seen in Figure 13, the creep does not depend greatly on the amount of initial compression.[36]

8.2.5 Creep Control. The resistance of elastomers to creep can be augmented by confining the material, or by reinforcing it with chopped or woven fiber. Because elastomers deform without changing the primary molecular bonds of the polymer chain, elastomers can be considered to be incompressible.[36] If the incompressible material is not allowed to continue to deform because it has been confined, then any reduction of sealing stress due to viscous flow is eliminated. However, confinement will not prohibit stress relaxation due to crosslinking or polymer chain degradation. These effects remain free to occur, reducing the sealing stress. Mixing into the uncured elastomer short sections of latex covered fiberglas will act to internally confine the material from flowing. Whether or not it can reduce chemically caused stress relaxation is not known. Similar comments can be made for coating reinforcing fabric with the elastomer. Section 8.9 discusses tests that may be performed on fiber-reinforced elastomers to identify long-term performance in this application.

8.2.6 Tests for Time-Dependent Behavior. Tests must be performed on prospective gasket materials to determine their long-term properties. Tests for creep, stress relaxation and compression set are prescribed by the American Society for Testing and Materials (ASTM) as listed in Table 1. These tests may be at ambient or higher temperatures, and allow

short duration comparisons between materials rather than provide any information about longer term performance.

Most creep and stress relaxation effects occur within a short time of the initial compression. For plastics, these effects level off within the first six weeks,[29] and for non-metallic gasket materials, within 24 hours.[47, 48] It is suspected that in this latter case, the test was performed at temperatures much higher than ambient.

For most elastomers, it is expected that, after a short time, creep or the modulus of elasticity may become a linear function of the logarithm of time. Plotting this relationship on semi-log graph paper may allow an extrapolation to the 50-year life of the seal. A short-term experiment may easily test to the third decade of time (100 hours), and by continuing for an additional 37 days, may test to the fourth decade (10^3 hours). Continuing to the next decade (10^4 hours) at the end of 1 year, 52 days, may allow an extrapolation to less than two additional decades to 50 years (4.38×10^5 hours). Figure 14 contains a sketch of an idealized extrapolated curve.

To extrapolate almost two orders of magnitude may be risky except for the rather consistent behavior of elastomers. Without cross linking, the polymer would eventually experience viscous flow and lose all strength and elasticity.[36] However, because of crosslinked molecules, the visco-elastic region is extended indefinitely.[27] A sudden drop off in modulus or a sudden increase in creep is not expected with well cured elastomers. More current data should be acquired to determine if this assumption is still considered valid.

It was found that the lowest practical creep was 1.2 to 1.5 percent per decade of log (time) for a well-vulcanized soft rubber containing little or no filler.[36] Conversely, a hard elastomer containing a large proportion of filler may creep as much as 15-20 percent per decade.[36] Because creep was found to be log-linear, the modulus or any other property of the elastomer is expected to be log-linear.[36]

Several ASTM methods describe accelerated tests at elevated temperatures. In general, it is not advisable to infer long-term performance at ambient temperatures directly from short-term accelerated tests.

However, by using a "master curve," a generalized time-temperature relationship, it is possible to predict long-term performance at ambient temperature, from short-term results at higher temperatures.[6, 36]
Figure 15 shows an idealized "master curve." In this Figure, the ordinate is the relaxation modulus for time, t, and is defined as:

$$G(t) = \frac{\sigma(t)}{\epsilon} = \frac{\sigma}{\epsilon(t)}$$

Where σ and ϵ are the stress and strain respectively. The relaxation modulus is not to be confused with the "modulus" of the elastomer, defined as the stress required to stretch the material to 100 percent elongation. This definition of the relaxation modulus is valid for only small strains (1-2 percent). For strains greater than 2 percent, the relationship is no longer linear. It is not known what effects this non-linearity for large deformations will have on the accuracy of using the "master curve." Manufacturers should be contacted to determine if the concept of a "master curve" is still used in the industry, and if it is, to acquire curves for approximate elastomers.

Before full approval for use in the gas system, the British Gas Corporation requires life testing of external repair methods. The method requires that sections of pipe be held at elevated pressures for up to six months (21.0 X 10^5 minutes). The results are extrapolated to 50 years (1.5 X 10^7 minutes).[9] Although this procedure does not test properties relevant for elastomers, it does assume a log-linear performance decrease. For this reason, the procedure may be able to be adapted for use in testing elastomeric gasket materials.

8.3 Aging.

Properties of elastomers may change with exposure to oxygen, ozone, light or moisture. For this reason, the elastomers used in the alternative seal must be chosen so that there is no significant deterioration in sealing stress over the lifespan of the seal. Aging may occur when the seal is in storage,[31] as well as when it has been placed in the main. The effects of aging may be a softening of the material due to degradation

of the molecule chains.[6] The material may also harden as oxidation creates new crosslinks[6] or residual vulcanizing agents continue to cure the polymer.[3] In both cases, higher temperatures accelerate the aging.

Those polymers with unsaturated carbon bonds in the chain molecules (elastomers based on diene monomers)[27] are inherently more susceptible to aging than are polymers with saturated chain molecules. There is an analogy between vulcanization of these unsaturated polymers and degradation by oxidation or ozonolysis.[6] The vulcanizing agent attaches itself to molecules at carbon atoms where the reactive double bonds existed. Oxygen and ozone attack the same bonds, and ultraviolet light may cause the bond to react spontaneously.[6] The chain molecule may either break into sections,[32] or may form new crosslinks with neighboring molecules.[6]

Reaction by the unsaturated bonds may occur at any point along the chain molecule. The degradation or breaking of the molecule may occur randomly, or as part of a chain depolymerization of the elastomer. In the first case, the result of degradation will be a mixture of fragments of lesser molecular weight. In the latter, the "unzippering" of the molecule will result in unpolymerized monomer.[6]

The reactivity of the polymer to oxygen and ozone is limited by the diffusion of the gas into the material.[6] Antioxidants can usually be compounded into the elastomer to retard degradation,[4] but protection against ozonolysis is more difficult. Waxes or coating may be applied, but these are usually quickly removed by solvent action.[4] Protection against oxidation is required because the seal will be exposed to air during storage and the back of the seal may be exposed to air during use. The seal will be exposed to ozone during storage, but it is expected that most ozone will not reach a pipe buried under several feet of soil. However, since as little as 0.1 parts of ozone per million parts of air can cause ozone surface cracking,[36] it is probably wise to provide ozone protection for the elastomer.

Most tests recommended by the ASTM (see Table 1) require measurement of an elastomer property such as creep before and after treatment in an environment of air, oxygen, or ozone. The treatment usually occurs at a higher than ambient temperature. It is expected that the effects of aging

will have a log-linear relationship with time as did creep and stress relaxation.[36] Recommended tests for the aging of the seal material are discussed in Section 8.9.

8.4 Chemical Resistance.

To maintain a sealing pressure against the pipe wall the alternative seal material must be resistant to all chemicals found in service. It is not possible to find an elastomeric material that is completely resistant to all substances, nor would it be economical. The elastomer must be chosen and designed to resist those chemicals that will have the greatest chance of weakening the material.[31] This decision must be based on the amount of chemical expected to be present, the extended lifespan of this seal, and the service temperatures. The substances that are expected to be present in the gas main are manufactured gas condensates, water, glycols, aliphatic and aromatic hydrocarbons, odorant, and natural gas. The material should also be resistant to the products of coal gasification should the source of fuel gas switch from natural gas in the 50-year lifespan of the seal. The constituents of different processes of coal gasification are listed in Table 8 and the total list of probable substances is listed in Table 9.

Solvents act to swell the elastomer by slowly diffusing into the material. The rate of swelling depends on the diffusion rate.[6] The cross-links between the molecules keep elastomers from being totally dissolved by solvents. Swelling is expected to be the only effect,[6] but depending upon the application, a swell of 15 percent is usually unacceptable. In this application, the shrinking of the material upon desorbing the solvent will probably be more detrimental to the seal.[31]

The introduction of polar groups into the elastomer tends to decrease solubility because of the strong polymer-polymer bonds that can develop.[6] However, polar solvents such as acetone can quickly swell polar elastomers, such as nitrile.[31] No information was found quantifying the polarity of common elastomers and probable solvent substances found in gas mains.

Sulfur compounds may be present in the pipe wall deposits, in the gas stream as an odorant, or as a constituent of coal gasification. Sulfur reacts with the unsaturated carbon bonds of polymers in the same manner as does oxygen or ozone.[6] (Mercaptans and elemental sulfur are both used as vulcanizing agents.)[6] If the elastomer is exposed to sulfur compounds, the polymer may harden as vulcanization continues, or it may soften as it begins to degrade due to overcuring or "reversion."[6]

Presently, the gas used in the ConEdison system is odorized with tertiary butyl mercaptain (TBM) by the transmission company to a design concentration of 0.07 lbm per million cubic feet.[46] There is no chance of oversaturation and condensation within the distribution system. No information concerning aging of appliances and pipeline components with TBM was found, but nitrile rubber is used extensively throughout the ConEdison system.[52]

Future tests should test the susceptibility of elastomers to sulfur in the pipe wall deposits and in small concentrations in the gas stream. These tests should be extrapolated to the 50-year lifespan of the seal. It is expected that the degradation of the elastomer is a function of the diffusion of the sulfur compounds into the material. Recommended tests for sulfur susceptibility are discussed in Section 8.9.

8.5 Temperature Effects.

As mentioned in previous sections, increasing the temperature will accelerate the effects of creep, stress relxation, aging and chemical reaction. In most sealing applications of flanged joints at ambient conditions, bolt torque loss (stress relaxation) is not expected to occur.[33] However, because the alternative seal is placed against a comparatively rough surface for an exceptionally long time, this assumption cannot be made.

In this application, the seal will be exposed to ambient temperatures as described in Section 6.6.2. However, short duration temperature increases may be encountered in the lifespan of the seal. An example of a short-term temperature increase would occur if an exothermic reaction expanding foam were to be used to inflate the seal. (See

Chapter 9.0 for a more detailed discussion of this method.) Most changes
to elastomers at prolonged high temperatures are chemical in nature
and are irreversible.[31] However, if the exposure is intermittent, most
changes to properties reverse themselves in a short period of time.[31]

When the temperature increases, the sealing stress increases
because of two effects. The first is the Gough-Joule effect where the
modulus of elasticity of the rubber is directly proportional to the absolute
temperature.[2, 36] Secondly, the coefficient of linear expansion is much
greater for rubber than for cast iron or steel. For example, neoprene
expands at 3.6×10^{-4} inch/inch - °F [27] which is much greater than the
9.9×10^{-6} and 6.5×10^{-6} inch/inch - °F for steel and iron respective-
ly.[5] When the temperature decreases after being greater than ambient for
a short time, the gasket material will contract more than will the
adjacent metal. The seal will leak upon contraction unless the material
is able to quickly recover from the compression caused by the high tempera-
ture.[2] The elastomer can be compounded to have this capability which is
tested by methods similar to compression set.

8.6 Elastomer Fracture.

If the stress is very high or the duration is very long, the
elastomer may "fracture" with the oxidative degradation of the chain
molecules or by the failure of intermolecule crosslinks. When this
happens, the elastomer will begin to act like a viscous fluid, flowing
with significant loss of rigidity.[36] Figure 16 is an idealized sketch
of deflection vs. time when fracture occurs.

Under "normal" stress levels, polymer fracture seldom occurs.[36]
However, because of the very long life span of this seal design, the
point of fracture may occur at a much lower stress at a long time.
Because of the chance of fracture, extrapolating test data as described
in Section 8.2.6 must proceed with caution.

In actual applications, failure of the material may occur at times
much less than that of fracture. Because of design considerations,
the usefulness of a seal may be limited by a relatively small change
in modulus rather than fracture of the elastomer. Payne suggests a
10 percent decrease in modulus as a reasonable definition of failure.[36]

8.7 Permeability.

As discussed in Chapter 7.0, the gasket is defined to seal against gas if none is allowed to pass between the pipe wall and the gasket material. It was also mentioned that gas will continue to diffuse through the gasket material. To estimate the gas flow through the gasket, the very large permeability of oxygen through natural rubber of 17.7×10^{-8} cm^2 /sec - atm was chosen.[4] The total gas flow through a seal made with ¼-inch thick natural rubber was only 1.86 cc/hr. By using nitrile rubber (Hycar 102) the gas flow rate was estimated to be only 0.187 cc/hr. The nitrile rubber was a more realistic choice because of other considerations. From these estimated flow rates, permeability through the bridge and gasket materials of the seal is not expected to be a major parameter in choosing the elastomers to be used.

8.8 Elastomer Recommendation.

8.8.1 General. This section makes recommendations for the elastomers to be used as the gasket and bridge materials for the alternative seal. Because the physical properties depend upon the compounding of the elastomer's constituents and additives, it is not possible to make recommendations for the specific elastomer. It is possible, however, to choose between the common elastomer types, making recommendations based on information found in the literature.

For the purposes of discussion in this Section, the seal is assumed to consist of gasket material that presses against the pipe wall and of a membrane that bridges the joint recess. (See Figure 2.) Future development will consider designs more innovative than this simple design, but these designs must still employ gasket-like material to stop leaking gas and a membrane-like structure to connect the two pieces of cast iron pipe.

This Section discusses the physical properties and resistances to substances found in gas mains that were considered to significantly affect the performance of the seal. Comparisons of the common elastomer

types are included leading to separate recommendations for the gasket and bridge materials. The comparison leaves room for differences in properties from compounding which is out of the scope of this thesis. A discussion of the cost of the elastomer concludes this Section.

This Section does not discuss the properties of mixtures of different elastomer types, compounded to take advantage of properties of the component elastomers. This Section also does not discuss the properties of expanded elastomers, which may allow sealing against low pressure gas at much lower sealing stresses.

8.8.2 Discussion of Required Properties of Elastomers. As a first step, it was necessary to decide what it was that the elastomers were required to do. The relevant physical properties and the chemical substances most likely to be present were identified and relative priorities were assigned. Physical properties were more critical in the choice of the gasket material and the effects of reactive substances include changes to these properties as well as chemical degradation of the elastomer. It was assumed that the bridge material would probably be reinforced with fabric and therefore, the physical properties of the unreinforced elastomer were not as critical to the decision. The cost of the elastomers is described in Section 8.8.4.

Table 10 shows the properties and substances considered to be important. The chemical substances listed are taken from Table 9 and are consolidated. The priority rating of "1" indicates that the factor is most important to the decision. Priority 2 was assigned to those factors that may be important, and Priority 3 indicates those properties and substances that are probably not relevant, but are considered in the case they may be. Priority 4 was assigned to those factors not considered relevant. Different priorities were assigned to factors considered for use in the gasket and the bridge of the seal. Comments are included in Table 10 to provide information on the choice of priorities.

8.8.3 Comparisons and Recommendations. The comparisons of elastomers were made in three steps. The first step screened all elastomers for

resistance to fuel gases, water, ethylene glycol and aging. The second step screened for the physical properties relevant to the application. The final step compared resistances to substances and physical properties to choose the best elastomer for the gasket and for the bridge material. The data for the comparison came from references 4, 6, 27, 31, 33, and 36, are not intended to be a complete representation of available literature. The results of Step 1 and Step 2 are listed in Tables 11 and 12 respectively. Tables 13 and 14 contain the results of Step 3 for the gasket and bridge material respectively. As a result of these comparisons, it is recommended fluorocarbon elastomer (Viton) be chosen for both the gasket and the bridge. Other recommended elastomers are contained in Table 15.

To properly interpret the comparisons of elastomers several comments should be made. Several references do not recommend that particular elastomers be used with aliphatic hydrocarbons, such as methane or ethane. However, these same references recommended that the elastomers could be used with aliphatic liquids, such as hexane. By recognizing that the elastomers in question also had high gas permeabilities, it may be inferred that the elastomers were not recommended for methane because of permeability, not incompatibility. Similar comments can be made for hydrogen gas, except that in some cases, chemical incompatibility may be the reason for not recommending specific elastomers.

Aging includes both degradation and hardening from oxidation and ozonolysis as described in Section 8.3. Nitrile and neoprene are both based on diene monomers (two double carbon bonds) and are inherently susceptible to aging. Other polymers considered in Step 3 had saturated chain molecules and were inherently insensitive to aging.

Similar to aging, hydrogen sulfide gas (H_2S) and tertiary butyl mercaptan (TBM) react with unsaturated bonds. For reasons given above, nitrile and neoprene are inherently susceptible, whereas the other elastomers are not. Very small quantities of hydrogen and TBM are expected to be present, but the elastomers to be used should be tested to observe changes in physical properties. It is thought that the rating of chemical incompatibility of elastomers with TBM[31] is for liquid TBM,

and not for the odorant in very small concentrations in natural gas. Fluorocarbon is resistant to TBM even in the liquid phase.[31]

If the seal uses a foaming polyurethane to inflate the gasket materials, exothermic temperatures of 300°F can be encountered for a short time. Even though the physical properties are not expected to change with a short exposure to 300°F temperatures (see Section 8.2), elastomers should be chosen that will not suffer chemical deterioration at that temperature of however short a duration. To insure that there will not be any deterioration, elastomers should be chosen to be able to operate at 300°F continuously, not just for a short time. If the foam system is not used, there are no temperature restrictions on the material.

Because the gasket elastomer is compressed against the pipe wall, several additional comments can be made. Creep and stress relaxation are different descriptions of viscoelastic behavior. In practice, a convenient measure of an elastomer's resistance to creep and stress relaxation is compression set. Compression set tests measure the ability of elastomers to regain original dimensions after compression. The greater the compression set, the lower the resistance to creep and stress relaxation. Section 8.2 discusses several methods of extrapolating test data to 50 years. Figure 17[31] contains data of O-ring performance to 10^4 hours (1 year, 51 days). By extrapolating the data to 50 years, it can be seen that fluorocarbon, silicone, and ethylene-propylene elastomers probably have sufficient resistance to creep and stress relaxation, whereas neoprene, SBR and nitrile elastomers do not.

As discussed in Chapter 7.0, the elastomeric gasket will probably have to be relatively soft (40 durometer) to be able to seal against the rough pipe wall surface. As seen in Table 13, fluorocarbon and epichlorohydrin have minimum durometer hardnesses of 70 and 50 respectively. These data are taken from information provided by an O-ring manufacturer,[31] and may only refer to recommended hardnesses that maximize their product's performance. By properly compounding, the elastomers can probably be made softer, but care must be taken not to decrease the resistance to stress relaxation.

The comparisons in this Section depend on several assumptions and result in a few unanswered discrepancies in data. Tests should be performed and manufacturers contacted to verify these comparisons. Recommended tests are in Section 8.9.

8.8.4 Cost Comparisons. Table 16 lists current retail prices for most common elastomers studied in previous sections. It can be seen that the elastomer recommended for both the bridge and the gasket is almost 14 times more expensive than neoprene. However, for a 6-inch diameter joint seal with a 4-inch wide bridge with two, 1-inch wide gaskets, the cost of elastomers is estimated to be about $50 per seal for fluorocarbon. A seal made of epichlorohydrin is estimated to cost about $30 per joint.

The cost of elastomers is almost insigificant compared to the total cost of the repair. The cost of the machinery, labor and fabrication of the seal must all be considered in comparing relative costs of elastomers. More importantly, the total cost of a joint seal should include the cost of the repair should it fail. If a more expensive elastomer can reduce the probability of a seal failure, the additional cost is well justified.

8.9 Recommended Tests for Elastomeric Materials.

8.9.1 General. This Section describes several tests that may be performed to provide needed information on the behavior of elastomers used as gaskets. Other tests for different aspects of the alternative sealing system are included in Chapter 11.0. This Section recommends tests and equipment to extrapolate stress relaxation behavior to 50 years as described in Section 8.2.6. It also discusses aging tests for use in environments containing sulfur-bearing compounds. This section discusses a test for the stability of pipe deposit tar as a gasket surface, and makes recommendations for improving the leak measuring device used in Chapter 7.0. Finally, this Section describes a simple test to identify the minimum sealing stress after allowing the elastomer to flow into pipe wall surface asperities.

This Section describes tests designed to measure long-term changes in the physical properties of the elastomeric material. Stress relaxation is the most important property to be considered in the design of the gasket and is the property that should be measured in these tests. As shown in Figure 18, a test unit should be used to press a gasket against a pipe shard. The device should be easily transported and stored. Spacers maintain the constant strain that would be found in the actual system. A strain gage bolt measures the stress. An actual pipe shard is used rather than the flat flanges of most relaxation tests to simulate the conditions found in use. Fluorocarbon should be the gasket material tested. All samples should be cut from the same sheet of fluorocarbon, and they should be conditioned to break down the "structure" of filled elastomers.

Before beginning testing, an extensive effort should be made to search through the literature, and to contact elastomer compounders and polymer manufacturers. An attempt should be made to gather as much information as possible to obviate testing or to complement data from tests performed at M.I.T. Results of long-term tests should be correlated with the results of accelerated ASTM tests. Evidence should be sought for indications of unrestrained viscous flow at long durations.

8.9.2 Stress Relaxation Tests. Tests should be conducted for at least a year to provide data to attempt an extrapolation to 50 years, as described in Section 8.2.6 and in Figure 14. An attempt should be made to correlate this long-term test with shorter term ASTM tests. Table 1 contains applicable tests.

A simple device should be constructed, modelled on the device described in ASTM F37,[44] to attempt to identify a point of unrestrained viscous flow. Two samples of elastomer should be deformed to constant deflections for as long as possible. The stress decrease with time should be measured by strain gage bolts. The deflection should be chosen to be larger than that expected in application.

If necessary, at least two test units shown in Figure 18 should be used to test the long-term characteristics of fluorocarbon against cleaned pipe wall. The fluorocarbon gasket should be deflected to a

constant strain and the stress relaxation periodically measured by strain gage bolts.

8.9.3 Environmental Tests. If the information is not available from manufacturers, several units should be constructed as shown in Figure 18 to test the effect of sulfur in pipe wall deposits and in the environment on the stress relaxation properties of fluorocarbon. An attempt should be made to extrapolate data to 50 years, and to correlate long-term test results with the short-term ASTM tests.

The first test should test the relative long-term effects of sulfur in deposits and in the environment. This test requires two cleaned and two uncleaned shards of pipe. Four units, as shown in Figure 18, should be constructed and fluorocarbon gaskets compressed to a constant deflection. The stress should be measured periodically using strain gage bolts. The two units with cleaned pipe shards should be tested in environments of hydrogen sulfide gas and tertiary butyl mercaptan vapor respectively. The other two units, with uncleaned pipe, should be tested in environments of hydrogen sulfide and nitrogen, respectively. The nitrogen is preferred over air to preclude oxidation. Diffusion is expected to be the limiting factor in the speed with which sulfur-bearing gas effects the physical properties of fluorocarbon. Physical properties of fluorocarbon samples can be tested before and after exposure to hydrogen sulfide. The physical properties, such as compression set or hardness, can be tested by the appropriate ASTM tests. Exposure to hydrogen sulfide can be in the chamber used in the first test, or it may be in the device shown in Figure 19. In this device, the fluorocarbon acts as the gasket to keep the hydrogen sulfide gas from leaking from the chamber. The hydrogen sulfide diffuses through the fluorocarbon in much the same way it would diffuse through bridge material.

8.9.4 Tests on Pipe Deposit Tar. A test is necessary to insure that tar provides a stable gasket surface. There is a significant chance that under stress, the tar, a viscous fluid, may creep away from the gasket. Two pieces of pipe, one with and one without tar deposits,

should be mounted in the device in Figure 18. Fluorocarbon should be compressed against both surfaces to the same deflection and the strain measured by strain gage bolts. The differences between the two stress relaxation rates is a measure of the creep of the tar. This test should be continued for at least two months to record the rapid initial decrease in modulus of the fluorocarbon.

8.9.5 Leak Measuring Devices. Two methods of measuring the leakage rates from gaskets pressed against pipe walls are recommended as alternatives to the procedures in Chapter 7.0. The first method, shown in Figure 20, is an adaptation of the method in ASTM test F37. The test unit is a modification of the unit in Figure 18 and is enclosed in a large, sealed container that captures all gas escaping past the gasket. This method requires that a large leak-free container be constructed, but does not require leak-free valves.

The second method, also shown in Figure 20, is easier to build requiring no large container. It does require a leak-free valve to isolate the two legs of the manometer. As in the first test, the leakage rate is measured by recording the displacement of water as gas leaks past the gasket.

8.9.6 Minimum Sealing Stress. Using a modified test unit, the fluorocarbon gasket is pressed against the pipe wall to a constant deflection. The stress should be recorded for several months. At the end of a period sufficiently long to allow the elastomer to flow into the surface asperities, the stress is reduced until leakage occurs. The difference between the stress at constant strain and the stress at leakage provides a measure of how well the elastomer flows. Because the stress required to seal against gas may be less over time, the gasket may not have to be compressed initially as much as it would have to be if the material did not flow into surface asperities. A lower initial gasket stress may allow for a simpler design.

TABLE 8

COMPONENTS OF GAS PRODUCED BY COAL GASIFICATION[34]

% mole Component	Fixed Bed		Fluidized Bed				Entrained Bed
	LURGI/BGC	LURGI/DRY ASH	BATTELLE	HYGAS	WINKLER	WESTING-HOUSE	KOPPERS TOTZEK
H_2	28.05	39.4	58.8	30.2	14.0	14.4	36.0
CO	61.2	16.9	15.5	23.8	22.0	19.2	52.5
CO_2	2.55	31.5	9.1	24.5	7.0	9.3	10.0
CH_4	7.65	9.0	13.7	18.6 (C_2H_6)	1.0	2.7	-
C_NH_M	0.45	0.8	-	0.7	-	-	-
O_2	0.10	-	-	-	-	-	-
N_2	-	1.6	2.9	0.1	56.0	54.3	1.0
H_2S+COS	-	0.8	0.0	1.2	-	0.1	0.4
NH_3	-	-	-	0.5	-	-	-
BTX(light oils)	-	-	-	0.4	-	-	-

n.b. All values are after scrubbing and cooling and are from coal sources most accessible to ConEdison.

TABLE 9

POSSIBLE SUBSTANCES AFFECTING GAS MAIN SEALS[31, 36]

Substance	Remarks
Ammonia, Gas, NH_3	from Coal Gasification
Butane	
Carbon Dioxide	
Carbon Monoxide	
Coal Tar	in Pipe Wall Deposits
Coke Oven Gas	Condensates in Pipe Wall Deposits
Diethylene Glycol	From Carboseal
Ethane	
Ethylene Glycol	From ALH Method
Hydrogen Gas, H_2	
Hydrogen Sulfide	From Coal Gasification
Kerosene	As fogging oil
Lubricating Oils	From Compression Equipment
Methane	
Mineral Oil	As Fogging Oil
Natural Gas	
Nitrogen	
Oxygen	
Ozone	When in Storage
Producer Gas	
Propane	
Sulfur	in Pipe Wall Deposits
Tar, Bituminous	in Pipe Wall Deposits
Tertiary Butyl Mercaptan	As an Odorant
Water	in storage, ground water
Aromatic Hydrocarbons	in Pipe Wall Deposits
Aliphatic Hydrocarbons	in Pipe Wall Deposits

TABLE 10
RELATIVE IMPORTANCE OF ELASTOMER CHARACTERISTICS

A) CHEMICAL COMPATIBILITY SUBSTANCE	PRIORITY		COMMENTS
	GASKET	BRIDGE	
Natural Gas	1	1	
Aliphatic Hydrocarbon Gases (methane, ethane, and up)	2	2	Literature may consider as cryogenic liquids
Water	1	1	In Situ/In Storage
Ethylene Glycol	1	1	
Hydrogen, H_2	2	2	Literature ratings may include permeability
Oxygen, O_2	2	2	Coal Gasification Products
CO, CO_2	2	2	
Tar (Bituminous/Coal)	2	3	Pipe Deposits may be more inert than these examples
H_2S	2	3	Gasification Product
Tertiary Butyl Mercaptan	2	3	Small Diene Rubber Reactive
Kerosene	3	3	Fogging Oil in Boston Gas, Not in ConEd
Ammonia, Gas, NH_3	3	3	Gasification Product, HYGAS (Table 8)

Cont'd. on Next Page

Priority Rating

1 = Most Likely to be Present

2 = May Be Present

3 = Probably Not Present, But to be Safe, Consider Present

4 = Unlikely, Don't Consider

See Table 9 for Complete List of Chemical Substances

TABLE 10

(Cont'd.)

A) CHEMICAL COMPATIBILITY SUBSTANCE	PRIORITY		COMMENTS
	GASKET	BRIDGE	
Aliphatic H-C Liquids	3	3	Components of Pipe Wall Deposits
Aromatic H-C Liquids	3	3	
Producer/Coal Gas	4	4	Gasification Products will be scrubbed
Mineral oil	4	4	Fogging Oil - unlikely
Gasoline/Diesel Oil	4	4	- Aliph. H-C Liquids Unlikely
Elemental Sulfur	4	4	
Lubricating Oil	4	4	Compression Equipment - Unlikely

TABLE 10

(Cont'd.)

B) PHYSICAL PROPERTY	PRIORITY		COMMENTS
	GASKET	BRIDGE	
Hardness	2	3	Gasket Mat'l. must be soft enough to seal rough surface - compounding
Aging	2	2	Can be properly stored - aging's effect on other properties?
Compression Set Resistance	1	3	
High Temperature Resistance	1	1	If exothermic foam system used
Cost	3	3	Total Cost includes labor, equipment, future lifespan
Permeability	2	2	
Modulus	2	3	

TABLE 11

COMPARISON OF ELASTOMERS FOR FUEL, GASES, WATER
ETHYLENE GLYCOL ANG AGING
(Step 1)

Elastomer	On To Next Step	Not Recom.	Comments
Natural Rubber		C	Poor Fuel/Aliphatic Hydrocarbon Resistance
Butyl		C	Poor Fuel/Aliphatic Hydrocarbon Resistance
SBR (BUNA-S)		C	Poor Fuel/Aliphatic Hydrocarbon Resistance
Nitrile (NBR, BUNA-N)	A		Aging: Fair/Poor,[31]*High Resist[36]
Polychloroprene (Neoprene)	A		
Polysulfide	B(-)		Water: Poor,[31] Unaffected by Water,[4] Glycol: Poor,[31] Hydrogen: Poor[31]
Ethylene - Propylene Diene (EPDM)		C	Poor Fuel/Aliphatic Hydrocarbon Resistance
Silicone	B(-)		Natural Gas: Exc.,[31] but poor for aliphatic gas/liquids; poor for hydrogen
Fluorocarbon (Viton)	A(+)		
Polyacrylate	B		Poor Water/Glycol Resist.,[31] but not recom. for continuous hot water immersion[4]
Polyurethane		C	Poor for aliphatic gases, water, glycol; subject to hydrolysis[3, 7]
Fluorosilicon	B(+)		Exc. for Hydrocarbons, poor for NG, H_2 (High Permeability)
Epichlorohydrin (Hydrin)	A		
Chlorosulfonated Polyethylene (Hypalon)	A		

RATING

A = Adequate for Application
B = May be Adequate, More Data Necessary
C = Inadequate for Application

* Superscripts refer to references in Appendix F

TABLE 12

COMPARISON OF PHYSICAL PROPERTIES OF ELASTOMERS
(Step 2)

ELASTOMER	GASKET MATERIAL		BRIDGE MATERIAL		COMMENTS
	ON TO NEXT STEP	NOT RECOM.	ON TO NEXT STEP	NOT RECOM.	
Nitrile (NBR, Buna-N)	B		B		Low Temp./ High Permeability
Polychloroprene	B		B(+)		Low Temperature
Polysulfide		C	B(+)		Poor Compression Set/Low Temp.
Silicone	A		B		Highest Compr. Set[4]*/High Permeability
Fluorocarbon (Viton)	B		A		High Durometer ~70
Polyacrylate		C	A		Poor Compr. Set
Fluorosilicon	B		B		Physical Properties have improved/[4] high permeability
Epichlorohydrin	B(-)		B		Fair/Good Set Resist./Low Temp.
Chlorosulfonated Polyethylene (Hypalon)	B(-)		B		Fair/Poor Set Resist./Low Temp.

Rating

A = Adequate for Application
B = May Be Adequate, More Data Necessary
C = Inadequate for Application

*Supercripts refer to References in Appendix F.

TABLE 13

COMPARISON OF ELASTOMERS FOR USE AS THE GASKET[31]

FACTOR	NITRILE (NBR)	POLYCHLOROPRENE (NEOPRENE)	SILICONE	FLUOROCARBON (VITON)
CHEMICAL COMPATABILITY				
Natural Gas	1	1	1	1
Aliphatic H-C Gases	1	1	4	1
Hydrogen	1	1	3 (Permeab?)	1
Aging	3	2	1	1
(Ozone)	4	3	1	2
H_2S	4	2	3	2
T. Butyl Mercaptan	4	4	4	1
Tar (Bitum./ Coal)	2/1	2/3	2/4	1
Aliphatic H-C Liquids	1	2	4	1
Aromatic H-C Liquids	1	3	4	1
PHYSICAL PROPERTIES				
Set Resistance	1	2	1	1
Minimum Hardness	40	40	40	70
Temp. Resistance T Max, °F	260	250	430	390
RESULTS	Not Recom. Double Bonds Unstable	Not Recom. Double Bonds Unstable	Recommended if Aliphatic Gases did not reduce physical prop. -- Exc. Set Properties	Recommended 70 dur. too hard

1=Excellent; 2=Good; 3=Fair; 4=Poor

TABLE 13
(Cont'd.)

FACTOR	FLUOROSILICONE	EPICHLOROHYDRIN (HYDRIN)	CHLOROSULFONATED POLYETHYLENE (HYPALON)
CHEMICAL COMPATABILITY			
Natural Gas	3 (Permeab?)	1	1
Aliphatic H-C Gases	2	1	2
Hydrogen	3	1	1
Aging	1	1	1
(Ozone)	2	1	2
H_2S	3	2	2
T. Butyl Mercaptan	(-)	(-)	4
Tar (Bitum/Coal)	1	2/(-)	4
Aliphatic H-C Liquids	1	1	3
Aromatic H-C Liquids	1	1	3
PHYSICAL PROPERTIES			
Set Resistance	2[4]*	2	3
Minimum Hardness	40[4]	50	50
Temp. Resistance T_{Max}, °F	350	260	252
RESULTS			
	Recommended Ref. 4 - Outstanding Resist. to Fuel High Permeability Set Conditions Require Test	Recommended Too Hard Low Temp. use only Lowest Permeability	Not·Recom. Poor Set Good for Coated Fabrics[4]

*superscripts refer to References in Appendix F

TABLE 14

COMPARISONS OF ELASTOMERS FOR USE AS THE BRIDGE[31]
(Step 3)

FACTOR	NITRILE (NBR)	POLYCHLORO-PRENE (NEOPRENE)	POLYSUL-FIDE	SILICONE	FLUORO-CARBON (VITON)
CHEMICAL COMPATABILITY					
Natural Gas	1	1	2	1	1
Water	1	1	4 (Ref. 4-unaffected)	1	1
Ethylene glycol	1	1	3	1	1
Aliphatic H-C gases	1	1	1	4	1
Hydrogen	1	1	3	3	1
Aging	3	2	1	1	1
(Ozone)	4	3	2	1	2
H_2S	4	2	1	3	2
T. Butyl Mercaptan	4	4	4	4	1
Aliphatic H-C Liquids	1	2	1	4	1
Aromatic H-C Liquids	2	4	1	4	1
PHYSICAL PROPERTIES					
Permeability	2	2	1	4	1
Temp. Resistance T Max, °F	260	250	220	430	390
RESULTS	Not Recom. Unstable Double Bonds	Not Recom. Unstable Double Bonds	Not Recom. Glycol & Water Incom-patability	Not Reccm. Incompat. with H-C Hi-Perme-ability	Recommended Excellent Resistance Low Perm.
RATING	–	–	–	–	1

1=Excellent; 2=Good; 3=Fair; 4=Poor

TABLE 14
(Cont'd.)

FACTOR	POLYACRYLATE	FLUORO-SILICONE	EPICHLORO-HYDRIN	CHLOROSULFONATED POLYETHYLENE (HYPALON)
CHEMICAL COMPATABILITY				
Natural Gas	2	3	1	1
Water	4	1	1	1
Ethylene Glycol	3	1	1	1
Aliphatic H-C Gases	1	2	1	2
Hydrogen	2	3	(-)	1
Aging	1	1	1	1
(Ozone)	5	(-)	1	2
H_2S	4	3	2	2
T. Butyl Mercaptan	4	(-)	(-)	4
Aliphatic H-C Liquids	1	1	1	2
Aromatic H-C Liquids	4	1	1	3
PHYSICAL PROPERTIES				
Permeability	2	4	1	1
Temp. Resistance T Max, °F	330	350	260	252
RESULTS				
	Not Recom. Incomp. w/ Glycol & Water	Not Recom. Not Rel. for Nat. Gas. High Permeability	Recommended Low Temp. Exc. Ozone Resistance	Recommended Low Temp. Need to Test w/TBM
RATING	-	-	2	3

TABLE 15

RECOMMENDED ELASTOMER TYPES

Elastomer	Common Name	Comments
Gasket Material:		
Fluorocarbon	Viton	Hardness must be lowered by compounding, if possible
Fluorosilicone	-	Resistant to fuels, high permeability, set resistance must be tested
Epichlorohydrin	Hydrin	Lowest Permeability, low temperature use only (not with exothermic foam systems); set and hardness must be compounded/tested
Silicone		Good set resistance, poor permeability, must test effect of aliphatic gas/tar on properties
Bridge Material:		
Fluorocarbon	Viton	No Restrictions
Epichlorohydrin	Hydrin	Cannot Be Used with Foam System
Chlorosulfonated polyethylene	Hypalon	Cannot Be Used with Foam System, Need to Test effect of tertiary butyl mercaptan

TABLE 16

RELATIVE COSTS OF ELASTOMERS

ELASTOMER	COST/yd^2[*]	RELATIVE RATING[**]
Natural Rubber	68.40	-
Neoprene	63.55	Low/Moderate
Butyl	84.25	Moderate
Nitrile	70.55	Low
SBR	59.40	Low
EPDM	68.90	Low
Polyurethane	221.82	Moderate
Silicone	161.03	Moderate
Fluorocarbon (Viton)	871.65	Moderate/High
Polyacrylate	210.00[***]	Moderate
Epichlorohydrin	-	Moderate
Fluorosilicone	800.00 (est.)	High
Polysulfide	-	Moderate
Chlorosulfonated Polyethylene	-	Moderate

[*]Retail Prices quoted by Greene Rubber Company, Cambridge, MA for ¼ thick sheet stock

[**]Taken from reference 31 in Appendix F

[***]Estimated from reference 3 in Appendix F

CREEP, %

Nitrile(20-min. vulcanization)

Nitrile(40-min vulcanization)

Neoprene

Natural Rubber (bonding quality)

Natural Rubber (Resilient Quality)

CARBON BLACK*, PARTS PER 100 RUBBER
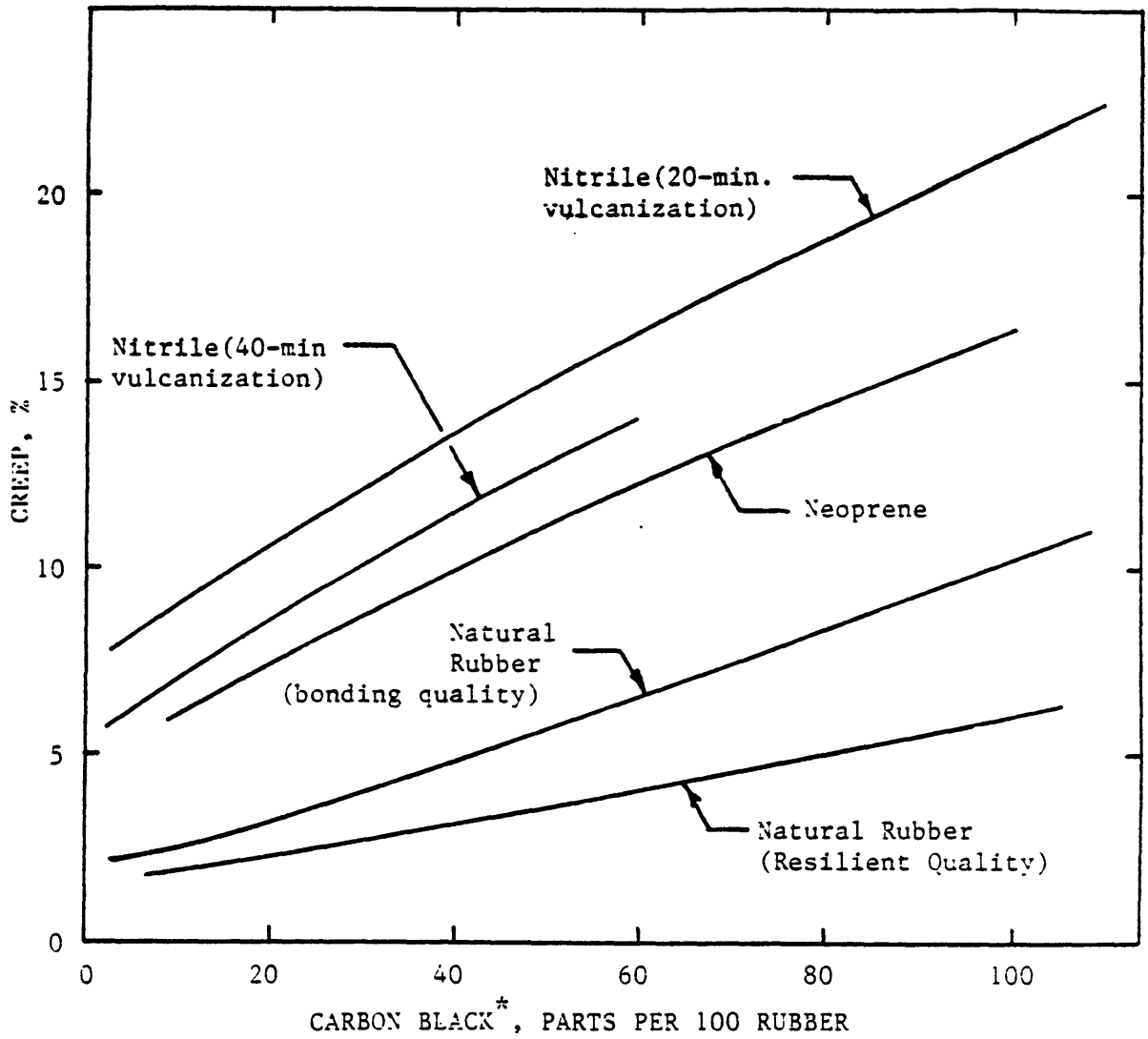
Taken from Payne and Scott, <u>Engineering Design</u> <u>with</u> <u>Rubber</u>, Reference 36.

* Carbon Black is a typical Reinforcing Filler

FIGURE 12   Creep Percentage vs. Carbon Black for Different Elastomers
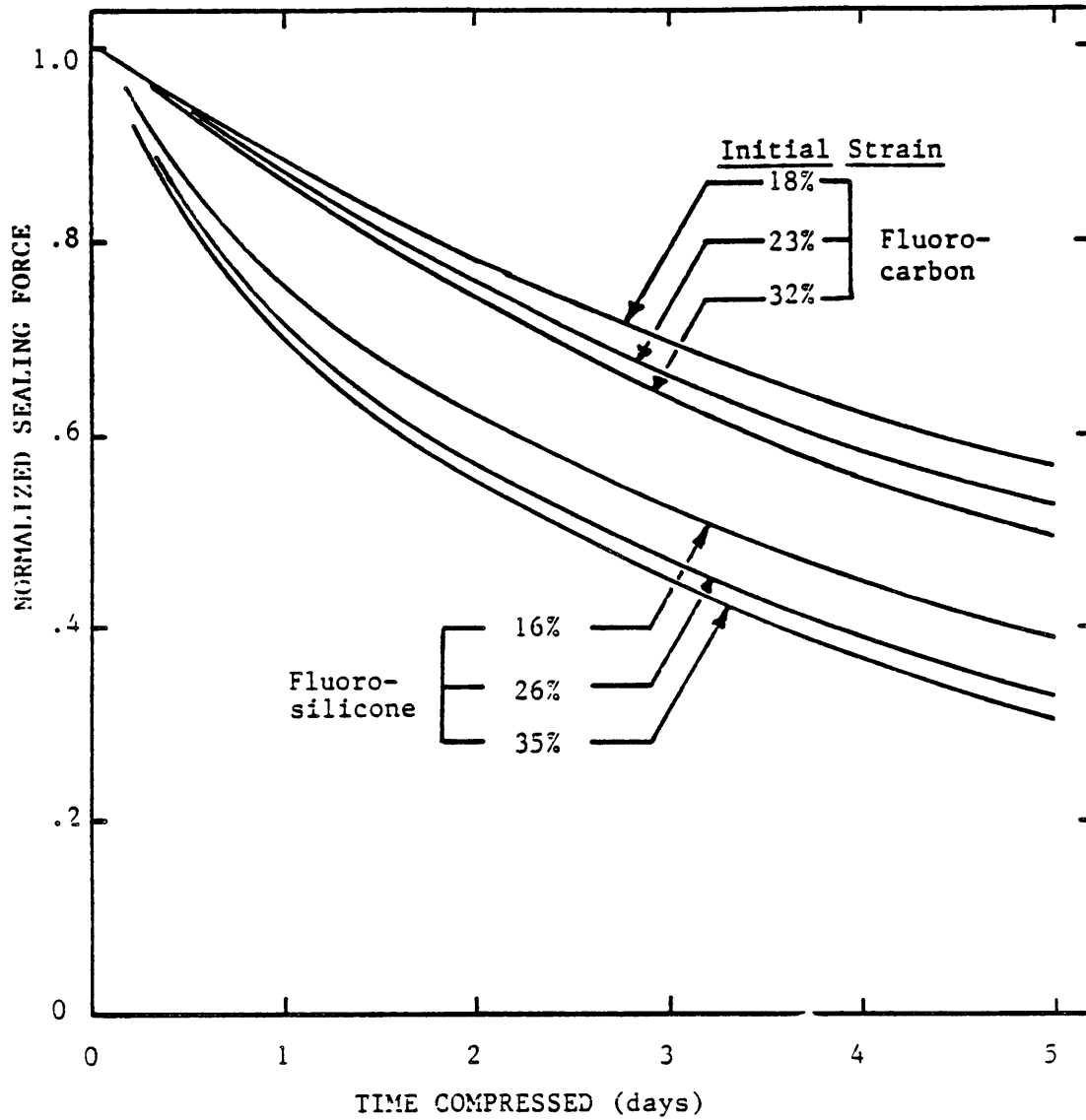
Taken from Aston,"Sealing Force of
Rubber Seals and its Measurement,"
Reference 2

FIGURE 13   Stress Relaxation vs. Time for Different
Initial Compressions
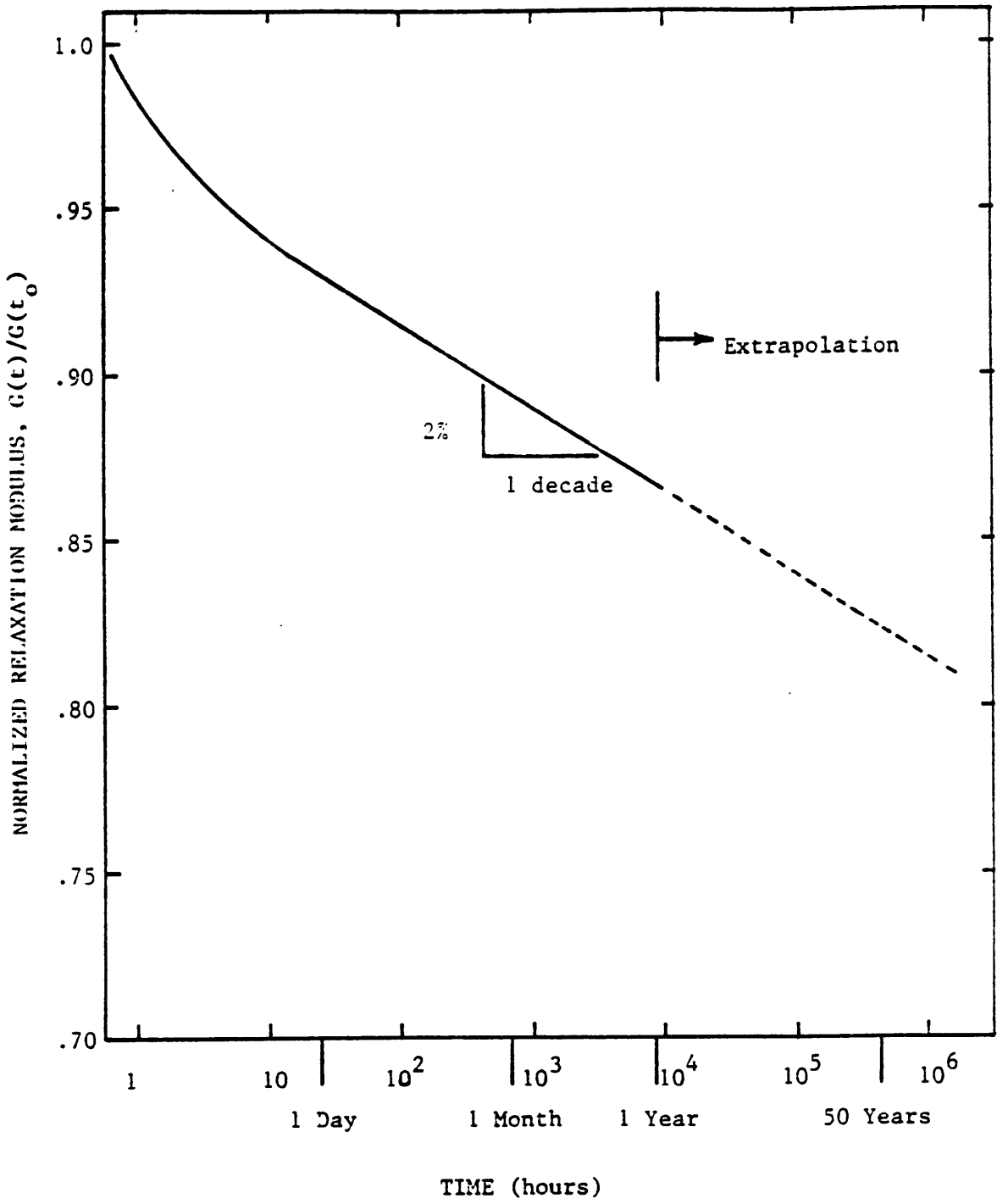
FIGURE 14   Idealized Curve of Modulus vs Log(time)

FIGURE 15   Stress Relaxation Master Curve

The graph axes and labels:

RELAXATION MODULUS, $G(t)$ (dynes/cm^2)

10^{12}, 10^{10}, 10^8, 10^6, 10^4, 10^2

Log($a_T t$) (hours)

-15, -10, -5, 0, 5

Crosslinked

Not Crosslinked

$$Log\ a_T = \frac{-17.44(T-T_g)}{51.6 + T - T_g}$$

where T_g = the glass transition temperature for the elastomer

Taken from Billmeyer, Textbook of Polymer Science, Reference 6

Behavior at very
high compressive
levels, or long
time

Fracture as viscous
flow begins

Behavior at normal
compressive levels

Does Elastomer
Eventually fail?

DEFLECTION, δ

10^2 10^4 10^6 10^8 10^{10}

TIME (hours)

Taken from Payne and Scott,
Engineering Design with Rubber,
Reference 36

FIGURE 16   Idealized Sketch of Elastomer at Fracture

-214-
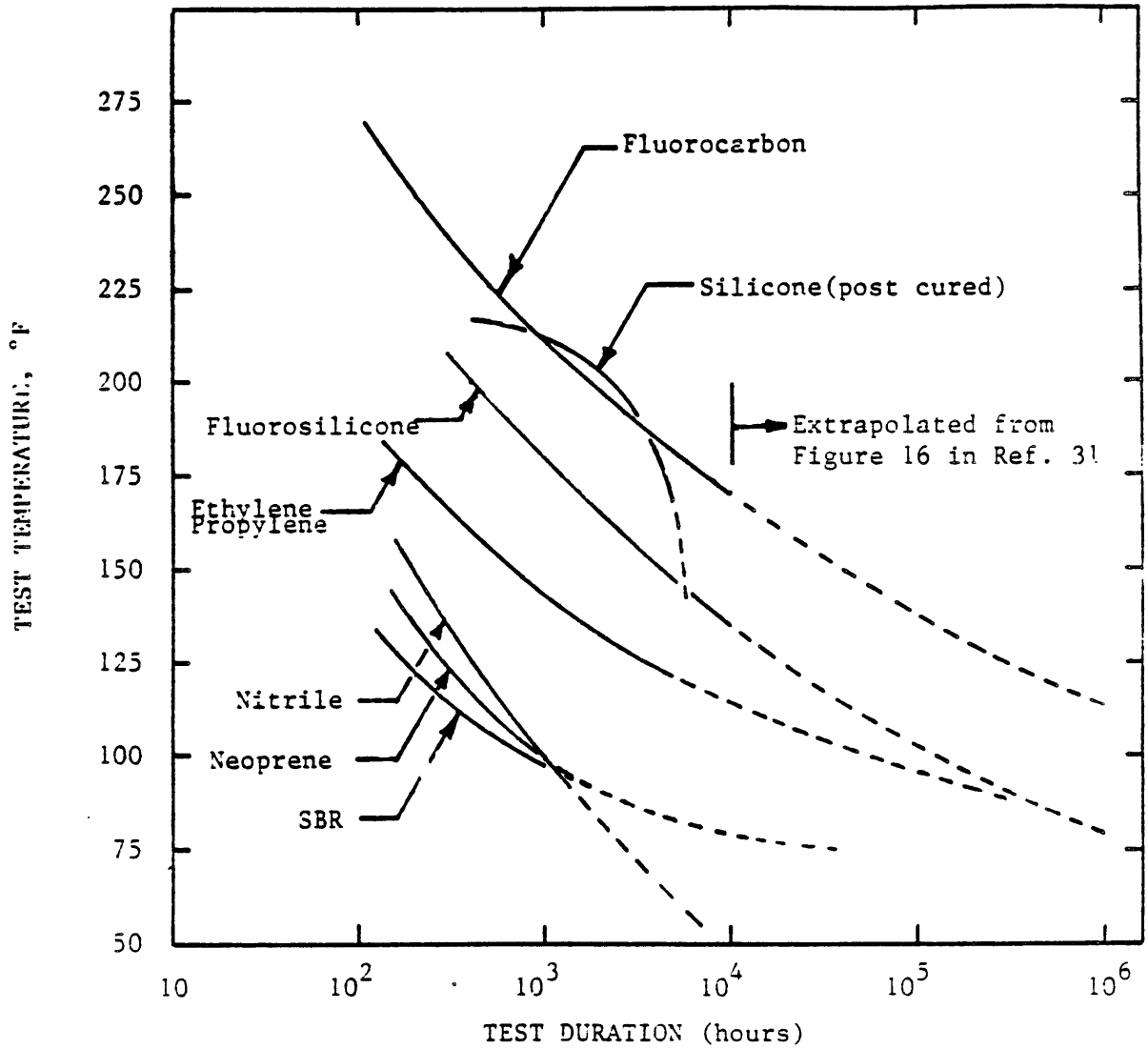
FIGURE 17   Test Temperature vs. Time to Reach
            90% Compression Set[*]

Frame

Strain Gage
Bolt

Custom-made
Compression
Block

Spacers
to insure
Constant
Deflection

Cast Iron Pipe
Shard

Support

Gasket
Material

FIGURE   18   Test Unit for Stress Relaxation Tests

Follower Ring

Elastomer
Material

Clamp

Diffusion

H_2S

H_2S at low
Pressure

FIGURE 19   Unit to Test Diffusion of H_2S Gas Through
Elastomer
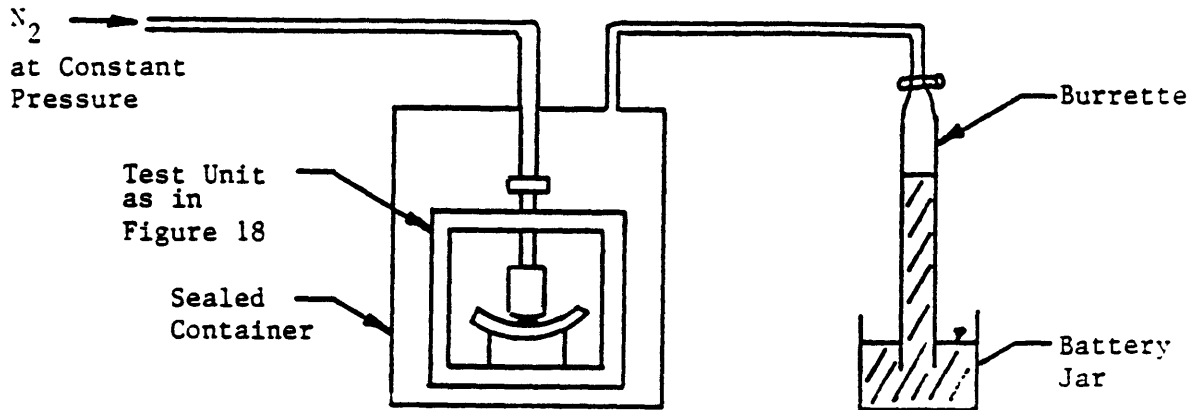
A)   Method as in ASTM F37

B)   Method Using Manometer

FIGURE 20   Alternative Leak Measuring Devices

9.0 SEAL DESIGN COMMENTS.

9.1 General. This Chapter discusses important factors and presents
innovative ideas that may aid in further development of the alterna-
tive sealing method. To seal against leaking gas, a seal must have
three components common to all seal configurations. Leak paths between
the seal and the pipe wall must be stopped by a gasket material soft
enough to conform to surface irregularities. As discussed in Chapter
6.0, each side of the pipe joint should be sealed with separate gasket
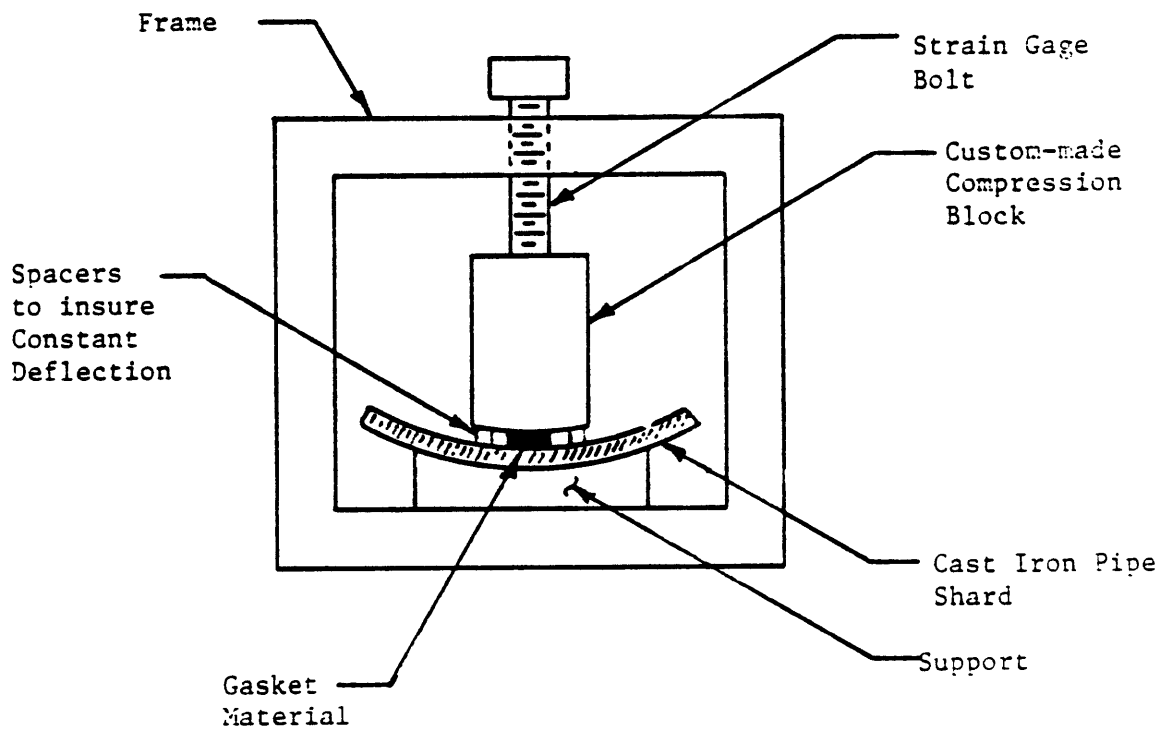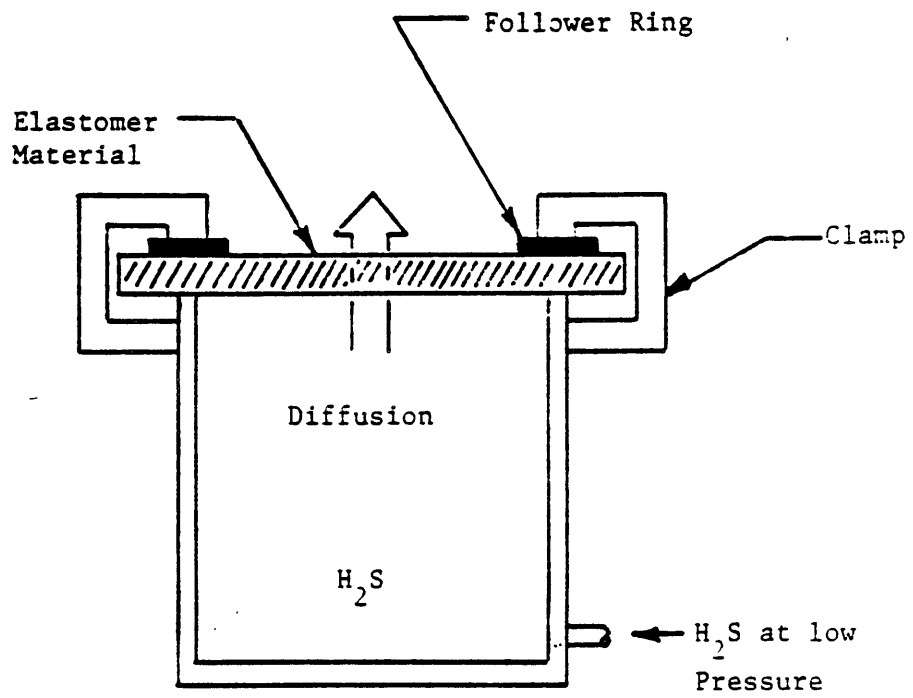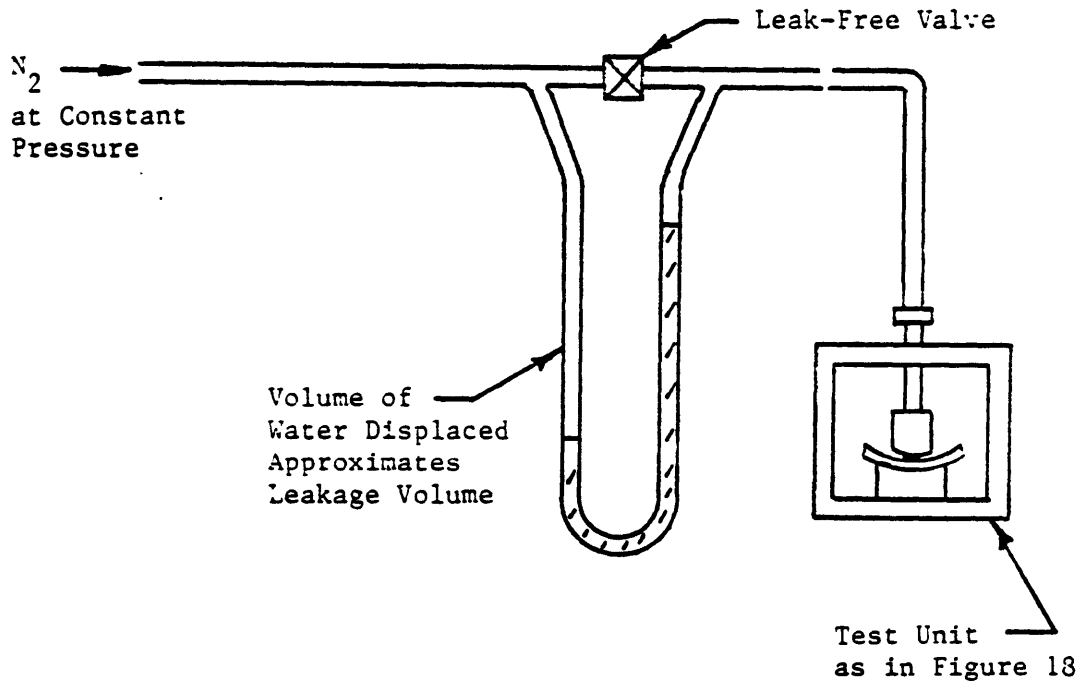surfaces. A diaphragm must "bridge" across the joint recess between
the two gaskets. Finally, some method is needed to compress the gasket
material against the pipe wall to stop the leak. The gaskets, bridge,
and retaining bands of this idealized seal design are shown in schematic
form in Figure 2. In practice, these functions may be performed by the
same structure. As mentioned in Chapter 6.0, the seal should be emplaced
as one piece to minimize the complexity of the installing device. This
Chapter tests the feasibility of the idealized des gn by calculating
for the component sizes and stresses required to seal the joint. It
also discusses design factors that may be useful in the design of each
of the seal components. Several design concepts are discussed that may
be developed further.

9.2 Design of the Idealized Seal.

As discussed in the previous paragraph, the feasibility of an
idealized seal is examined. It is expected that other seal configura-
tions will improve on this preliminary design. This section computes
the required gasket compressive stress, the gasket strain and the hoop
stress and dimensions of the retaining bands.

9.2.1 Estimated Gasket Compressive Stress. The initial gasket
stress must be sufficiently high to insure that the gasket will seal
against gas for its entire lifespan. The initial stress must account
for stress relaxation, normal variations in elastomer properties and
seasonal temperature variations. For the purposes of these calculations,
it was assumed that the gasket does not creep into the asperities reduc-
ing the stress level required to seal. The gasket was chosen to have a

durometer hardness of 30. It is possible that softer elastomers may be employed and this slightly stiffer material resulted in a conservative preliminary design. It was also assumed that the surface of the pipe had been cleaned with a wire wheel.

With an elastomer hardness of 30, it was found in Chapter 7.0 that a nominal compressive stress of 25 psi was required. This value was adjusted to 33 psi to account for the non-uniform pressure distribution. Because material properties of elastomers were found to vary by as much as 10-15 percent,[36] the required stress was increased 15 percent to 38 psi. As previously discussed, failure of an elastomer comes much sooner than total fracture of the material. For these calculations, it was assumed that the modulus can only decrease by 10 percent[36] in the lifetime of the seal. The initial stress must be 42.2 psi if, after a 10 percent decrease, the gasket still will have 38 psi at the end of its life.

If the seal is emplaced in the summer, the stress will decrease in the winter because of the Gough-Joule effect and because of the large thermal contraction of the elastomer. These preliminary calculations assumed that no foaming polyurethane system was used. (See Section 9.3.3.) As previously mentioned, the modulus of rigidity of the elastomer is proportional to the absolute temperature.[36] If the seal is installed in the summer, the modulus and therefore the stress of the gasket will decrease by a factor of 0.92 in the winter. This factor is the ratio of the average monthly air temperatures for New York City for January and July. Using these temperatures will provide a conservative estimate because the temperatures of the buried main are expected to be less extreme than those of the air. The coefficient of thermal expansion for typical elastomers is about 16 times that of steel or cast iron.[36] Assuming a constant Young's modulus, the stress is expected to decrease by about 0.7 psi when the seal cools from summer temperatures to winter. By combining both temperature effects, the initial gasket compressive stress was calculated to be 46.7 psi. This final estimate of the initial gasket stress combines the effects of temperature,

stress relaxation and variations in elastomers properties. In practice, it was found that gaskets in flanged joints are usually overtightened by 30-40 percent above what is theoretically sufficient to prevent leakage.[11] The calculated value of 46.7 psi represents a 42 percent increase over the stress measured in experiments described in Chapter 7.0.

9.2.2 Estimated Gasket Strain. The strain of the gasket was calculated from the following equation, which applies for common elastomers under simple compression with a static load:[36]

$$\sigma = -G \, (\lambda - \lambda^{-2}) \, S$$

Where G is the modulus of rigidity, λ is the ratio of strained to unstrained thickness ($\lambda = 1 - \epsilon$), and S is a shape factor accounting for the end conditions.[36] The modulus of rigidity was assumed to be equal to one-third of Young's modulus. This modulus of elasticity should not be confused with the modulus usually published with descriptions of elastomeric properties. This latter modulus is defined as the tensile stress at a specified elongation such as 300 percent.[36] Values of Young's modulus can be approximated for small deflections from the curve in Figure 21. From this curve, the elastomer with a durometer hardness of 30 has a Young's modulus of 146 psi. For an annular gasket, the shape factor, S, was calculated to be 1.59.[36] With a gasket stress of 46.7 psi, the strain, ϵ , was computed to be 0.165 in./in.

9.2.3 Estimated Retaining Band Dimensions and Stresses. The retaining bands were assumed to be made of spring steel (0.9-1.1% carbon) with a modulus of 28.6 X 10^6 psi.[39] The circumferential (hoop) stress in the band was calculated from the following equation:

$$\sigma = \frac{pR}{t}$$

Where σ is the stress, p is the gasket compressive stress, R is the mean radius of the band and t is the thickness of the band.[39] How-

ever, the limiting factor in the thickness of the band was its elastic
stability. The minimum thickness of the band was found by solving the
following equation for the thickness t:

$$P = \frac{3EI}{R^3}$$

Where p is the gasket compressive stress, R is the mean radius of
the band and I is the moment of inertia of the cross-section of the
band, $\frac{1}{12}$ bt^3. [39] Assuming a one-quarter inch thick gasket with a
strain of 0.167 in./in. for a six-inch diameter main, a one-inch wide
band must be at least 0.0625 inches thick (1/32") with a hoop stress
of 2,070 psi. A two-inch wide band would have to be at least .0469
inches thick (3/64") with a hoop stress of 2757 psi. Calculations for
4 and 8 inch diameter mains are contained in Table 17. These values of
thickness and hoop stress are considered to be reasonable. Therefore,
the idealized seal design is considered to be feasible. Any improve-
ments in design should show an expected reduction in hoop stress.

9.3 Discussion of the Gasket Design.

This Section presents a few general considerations for the detailed
design of the gasket material. This Section also presents design con-
cepts that are improvements on the idealized design of the previous
section.

9.3.1 General Considerations. In the idealized design a one-inch
wide, one-quarter inch thick gasket was assumed. These dimensions can
be varied to make the design more efficient. Using a narrower gasket
has the advantage of requiring less retaining band force to provide the
same gasket stress. However, a narrower gasket shortens the length of
potential leak paths, perhaps increasing the chance of leakage along
the very rough pipe wall.

Gaskets that were one-quarter-inch thick were used in the experi-
ments in Chapter 7.0, and in the preliminary calculations for the
idealized design. This dimension may be able to be reduced, but it

must be thick enough to respond to wide variations in surface profiles and to any out-of-roundness of the main. In surface profile measurements in Chapter 7.0, the largest displacement between an adjacent peak and trough was 0.0224 inches. Swick describes an approximate method of calculating the largest imperfection that a surface may have to allow a successful seal,[35] but this procedure is thought to be of limited use in this application.

If the gasket, bridge material and retaining bands are constructed in one piece before installation into the main, it is essential that proper design will eliminate stress concentrations at the interface between the metal and the gasket.[36] The gasket is the elastomer with the highest average stress, and therefore, the most susceptible to cracking or splitting. Stress concentrations should be eliminated by proper design to reduce the chance of failure of the elastomer.

9.3.2 Expanded Elastomers. It was shown in Chapter 7.0 that softer materials were better able to seal against a rough pipe wall at much lower stresses. In previous Chapters and experiments, it was assumed that the gasket material was made of relatively dense elastomer. Even though hardnesses of 15/20 were used in experiments, most literature specifies the minimum elastomer hardness to be around 30 to 40 on the Shore A durometer scale.[4, 31] The recommended material, fluorocarbon, was found to have a minimum hardness of 70. By introducing "blowing agents" into the elastomer mixture before polymerization, an expanded elastomer results. The sponge-like material is much softer, but with similar physical and chemical properties. Cellular elastomers have wide use in sealing against non-flat surfaces to stop low pressure gas.[11] The base elastomers used have been neoprene to seal against oils, silicone for higher temperatures,[11] and even PTFE (Teflon) which is not normally an elastomer.[33] Blends of elastomers have also been used.[4]

The expanded elastomer can be compounded to have either open or closed cells. Closed cells retain the gas used as the blowing agent, and have only fair compression set resistance.[4] Open cells do not retain the blowing agent, and absorb water,[4] and presumably glycol and

other liquid contaminants as well. It is possible, however, to mold
the expanded elastomer with a skin covering the open cells, but this
skin may be punctured by the surface roughness, eliminating the barrier
against liquids. Further readings and contacts with manufacturers are
necessary to properly evaluate the use of expanded elastomers for gasket
material in this application.

9.3.3 Foaming Polyurethane. Foaming polyurethane is considered
for two applications. In the first, the polyurethane foam inflates
a gasket between a one-piece retaining band and pipe wall to provide
the required sealing stress. This configuration would eliminate the
need for equipment to expand the retaining bands and the device to
connect the ends of the bands to maintain the stress. In the second
application, the foaming polyurethane would fill in the joint recess
under the bridge. The urethane would act as a labyrinth seal because
it probably would not adhere to the walls of the joint recess. The
gaskets surfaces would act as seals both for leaking gas and to confine
the expanding foam. Figure 22 shows sketches of both applications.

The foaming process would result in a rigid polymer with closed
cells containing the blowing agent, most likely freon. This foam would
have greatly different physical properties from the flexible expanded
elastomers of the previous section.

The foaming reaction is exothermic with a temperature of approxi-
mately 300°F. In either of the proposed applications, the duration of
the high temperature is expected to be relatively short. Even with a
short exposure, the elastomer of the seal must not chemically deteriorate.
The amount of initial foam pressure should be chosen so that upon cooling
and shrinking, the foam still maintains sufficient stress to seal against
the gas. Upon cooling from the higher reaction temperature, the gasket
elastomer will contract and the modulus will decrease as discussed in
Section 8.5. For this reason, the gasket must be chosen to be able to
rebound quickly from its initial contraction, or the seal will leak.[2]

Control of the pressure resulting from the expanding urethane foam
must be considered in the design. If too much pressure builds in the

small cavities shown in Figure 22, the elastomer may rupture. Similarly, too much pressure behind the bridge may bulge it out, buckling retaining bands, or bursting the bridge. If the foam in the small cavities in the inflatable gasket does not expand uniformly, the retaining bands may buckle. The pressure in the small cavities is expected to increase over time as natural gas diffuses through the elastomer into the freon-filled cells of the foam. This process can be limited by lining the small cavities with epichlorohydrin elastomer. If foam is used, hydrin cannot be used as the principal gasket or bridge elastomer because of its low temperature resistance. An increase in pressure from diffusion may aid the seal by increasing gasket stress as the modulus of the material decreases over time.

The speed of reaction requires that mixing of the two parts of the reaction must be done inside the main. An impingement-type mixing head is possible where the polyol and the isocyanate flow together head-on, mix, and then flow into the cavity. This sytem would require precise control of the quantities to be injected, a means of cutting and sealing the tube to the seal, and a means of cleaning the mixing head before reaction. As an alternative, small packets of the two parts of the mixture could be pre-positioned on the inside of the cavities within the gasket. To initiate the reaction once the seal was in place, a roller would pass over the seal, crushing the packets and mixing the components. This method would probably result in a non-uniform reaction with non-uniform pressures.[1] The reaction may continue longer than planned as unreacted components continued to mix and react.

The Mobay Chemical Company has been contacted for information on the use of foaming polyurethanes.[1] They have agreed to aid in the testing of either of the mixing methods discussed in the previous section.

9.3.4 Beaded Gasket. A gasket design that is used primarily in automotive applications should be considered for use in gas mains. In this design shown in Figure 23, an elastomeric gasket is selectively densified leaving soft, raised beads of less dense material.[35] The softer

material will provide a gas seal against the rougher surface and the denser material will constrain the soft material reducing creep. This design may allow the seal to require lower gasket stresses, resulting in lower retaining band stresses.

9.3.5 Gasket Coating. If the gasket material is coated with a viscous fluid, the required sealing stress may be reduced as the fluid flows quickly into the surface asperities. The fluid coating can remain a liquid, or it can cure over time molding itself to the rough surface. If the coating does not cure, the gasket must be designed to prohibit extrusion of the material away from the sealing area. Because using the liquid will result in a lower gasket stress, the tendency to extrude will be reduced. The liquid may be either applied directly to the pipe wall or it may be applied directly to the gasket before insertion into the main.

The curing fluid eliminates the problem of long-term extrusion. It may be applied to the outside of the gasket, and quickly conform to the surface irregularities of the pipe wall. The material will probably shrink upon curing, but will still be molded to the surface, resulting in a reduction in the required sealing stress. The fluid coating may adhere to the pipe wall for added assurance that the gasket will seal. However, the seal should be designed to be effective after the bond to the pipe wall fails. The fluid should bond to the gasket material whether or not it bonds to the cast iron.

9.3.6 V-Groove Gasket. This concept involves cutting a shallow V-shaped groove into the pipe wall to create a smooth gasket surface. A gasket with a small circumferential bump would be placed over the cut with the bump fitting into the groove. Figure 24 shows a sketch of this concept. Because of the small contact area between the V-shaped groove and the cylindrical gasket bump, high stresses could be achieved with only a moderate retaining band force. The relatively smooth surfaces of the groove would allow sealing at much lower stresses than those required by the rough pipe wall. This method would also require less material to be removed during surface preparation. Only the metal cut

from the groove would be removed rather than all the pipe deposits in the joint vicinity. The mandrel installing this seal must be designed to accurately seat the bead of the gasket into the V-shaped groove. Perhaps cutting another pair of grooves into the cast iron or adding another pair of sealing beads to the gasket may decrease the difficulty in properly positioning the seal.

9.3.7 Gasket Ridges. Raised ridges on the face of the gasket may be used to concentrate the stress into the relatively small area of the ridge. This concept is similar to the lips used in the Weko-seal as discussed in Chapter 4.0. A second application of ridges would be to confine softer material to prohibit creep or extrusion of the soft material. This concept would be required for the design described in Section 9.3.5. Sketches of both of these applications are shown in Figure 25.

9.4 Bridge Material.

The bridge acts as a diaphragm between the two gaskets across the joint recess. It is assumed that t.ie best choice of bridge material is elastomer coated fabric. Fabric reinforced elastomers will result in better physical properties being possible with less material. The bridge should be reinforced so that it will not sag down from the top of the main, but should not be so well-reinforced to inhibit joint deflection and translation. The burst strength of the bridge material should be 90 psi as described in Section 6.6.3.

9.5 Discussion of the Retaining Band Design.

This Section discusses the problem of elastic stability, connecting the ends together, and several design concepts for providing the support and force to the gasket to seal against leaking gas.

9.5.1 Elastic Stability. As previously shown in the preliminary calculations of the idealized design, elastic buckling is the limiting factor in the size of the retaining bands. Buckling can occur at lower stress levels if the pipe is out-of-round, or if a foaming system results in non-uniform gasket stresses. Stability of the retaining ring can

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be enhanced if reinforcing flanges can be added to give the cross-section a greater moment of inertia.

9.5.2 End Connectors. When installed by a mandrel, the seal must be expanded, compressing the gasket against the pipe wall. The two ends of the retaining band must be fastened together to give the ring stability and to maintain the gasket stress for the life of the seal. Two different concepts were considered for fastening the ends. Adhesives should be considered to join the ends of the retaining bands because of the ease of application. Manufacturers should be contacted to see if adhesives are appropriate for long-term shear stress levels of over 2000 psi (Table 17). The second concept is to use a mechanical latching device similar to the one patented by Dufour.[17] To be able to adjust to differences in the actual diameters of the pipe, the latching device must have several stops. The fastening of the ends of the retaining band may present significant challenges in further development.

9.5.3 LinaWeld. The Raychem Corporation developed the LinaWeld system to protect welds in steel pipelines against water and hot petroleum. The method is no longer used because the steel pipe coating was not adequate for this application and the pipes were replaced with stainless steel. A study was performed by Raychem in Belgium to determine if LinaWeld could be adapted for use in live low-pressure gas distribution mains. It was determined that the LinaWeld system was too expensive and Raychem plans no further development.[10]

The LinaWeld seal is a metal cage of a copper-based alloy, Betalloy N1040, that is covered with a membrane of polyvinylidiene fluoride. When heated to only 100°C, a martensitic transformation occurs in the Betalloy which has a four percent shape memory. The cage amplifies this shape memory. It was estimated that the seal cost $10 per diameter-inch.[10]

9.5.4 Heat Shrink Plastics. A design concept was proposed where a heat shrink plastic, similar to the Gas Repair Sleeve in Chapter 4.0, would be fastened to the outside of a coiled retaining band. This

coiled band would have a diameter a little smaller than the main in which it would be inserted. Upon heating to the release temperature, the heat shrink plastic would exert a moment on the retaining band, opening it up and compressing a gasket against the pipe wall. Upon performing preliminary calculations, the "bi-material" strip was not expected to open, much less exert a compressive stress on a gasket. This theoretical conclusion was verified by placing into an oven a ring of sheet metal with heat shrink plastic riveted to it. No change to the diameter of the ring was observed.

In performing the preliminary calculations to test how well the bi-material strip would perform, it was assumed that the heat shrink material was the same as used by the Raychem Corporation for WPC, a pipe protection wrap. This material is a radiation cross-linked polyethylene with a release temperature of 250°F. Upon reaching this temperature, the release force exerted by the material is given by the following equation:

$$F \text{ (lb/lin.in.)} = \frac{3}{5} M_{100} \, r_R \, (\lambda^3 - \lambda^{-2})$$

Where M_{100} is the modulus at 100 percent elongation ($M_{100} \cong 40$ psi), λ is the expansion ratio ($\lambda = 1.4$) and t_R is the thickness of the material upon recovery ($t_R = 0.40$ in.).[10] For the WPC material, the release stress was estimated to be 53.6 psi. Superimposed upon this release stress are the thermal stresses induced in the plastic upon cooling down to ambient. These stresses are approximately 2000 psi. The combined stresses would produce a moment of only 1.31 in-lbf in the retaining band. To expand the ring to the same dimension as the main would require a moment of approximately 22 in.-lbf or a stress of about 33,000 psi. For this reason, use of a heat shrink bi-material strip was considered to be infeasible.

9.5.5 Unsupported Inflated Tube. In this concept a gasket would be installed and inflated against the pipe wall. The gasket would be

reinforced such that it could provide adequate sealing stress without rupture and without any support from retaining bands. This concept is shown in Figure 26. The gasket would probably be inflated with polyurethane foam.

9.5.6 Single Piece Band. Use of a single piece retaining band would eliminate the problem of fastening the ends together. Two concepts were considered. The first is to use a piece of spring steel that is covered with an expanded elastomer. The unit is introduced into the main in a collapsed "U," much the same as the Springband method used by ConEdison (see Chapter 4.0). When in place, the band could be expanded against the pipe wall. Because the expanded elastomer would not require much stress to provide a gas seal, differences in diameters could be easily accounted for by using a thicker or stiffer foam. The second concept is to use a helical spring rather than a spring steel band. This spring method could be combined with the V-shaped groove concept in Section 9.3.6. The helical spring was first used by the Dresser Manufacturing Company in the 1930's to "armor" gaskets and by the Bal-Seal Engineering Company, but for a much smaller diameter.

9.6 Recommendations for Further Development of Design Concepts.

Based on the discussions of preceding sections, it is possible to recommend several concepts for further development. These concepts have the highest chance of successful development because of simplicity of design, ease of application, or fully developed technology.

The most promising concept is to use expanded elastomers (discussed in Section 9.3.2) on a single piece retaining band that can be inserted into the main as a collapsed - "U." (See Section 9.5.6.) This device may require minimum cleaning and small retaining band hoop stresses because of the conformability of the elastomer. It would not require any method to join the ends of the retaining bands.

The method of coating the gasket with a fluid is also recommended for further development. Coating the gasket material with a liquid

coating may allow it to seal without cleaning the pipe. For this reason, it may provide an advantage over methods that require that the main be cleaned.

The next most promising concepts are those that have smaller gasket areas than the idealized design. These concepts are the beaded gasket of Section 9.3.4. and the ridged gasket of Section 9.3.7. These concepts rely on a simple concept to seal against the gas. They may be able to be installed with a minimum of cleaning, but probably require a method to connect the ends of the retaining band.

The V-groove gasket (Section 9.3.6) may provide an advantage by minimizing the amount of material to be removed in cleaning, and by lowering the required gasket stress. The method may require a complex device to clean and remove the debris concurrently, reducing its chance of success.

The inflatable tube of Section 9.5.5 may be attractive because it would eliminate the need for retaining bands and a method to join their ends. The method would req ire the complex foaming polyurethane system described in Section 9.3.3. Using packets of foam, components prepositioned in the tube would be preferred to an impingement mixing system.

Using foaming polyurethane to fill the joint recess behind the bridge is not recommended because of the inherent problem of mixing and injecting the foam into the joint recess.

The LinaWeld method and Heat Shrink Plastics are not recommended for reasons described in Sections 9.5.3 and 9.5.4, respectively.

TABLE 17

RETAINING BAND HOOP STRESSES AND GASKET THICKNESSES FOR THE IDEALIZED DESIGN

DIAMETER OF MAIN (IN.)	RETAINING BAND		RETAINING BAND HOOP STRESS (ksi)	TOTAL GASKET THICKNESS (IN.)
	WIDTH (IN.)	THICKNESS (IN.)		
4.0	1	.0468	1.764	0.2556
	2	.03125	2.653	0.240
6.0	1	.0625	2.07	0.2713
	2	.0468	2.757	0.2556
8.0	1	.07813	2.24	0.2869
	2	.0625	2.809	0.2713

Assuming: ¼ in. thick gasket compressed to 16.7% strain
spring steel (0.9-1.1 C)
gasket pressure = 46.7 psi

FIGURE 21   Young's Modulus vs. Durometer Hardness
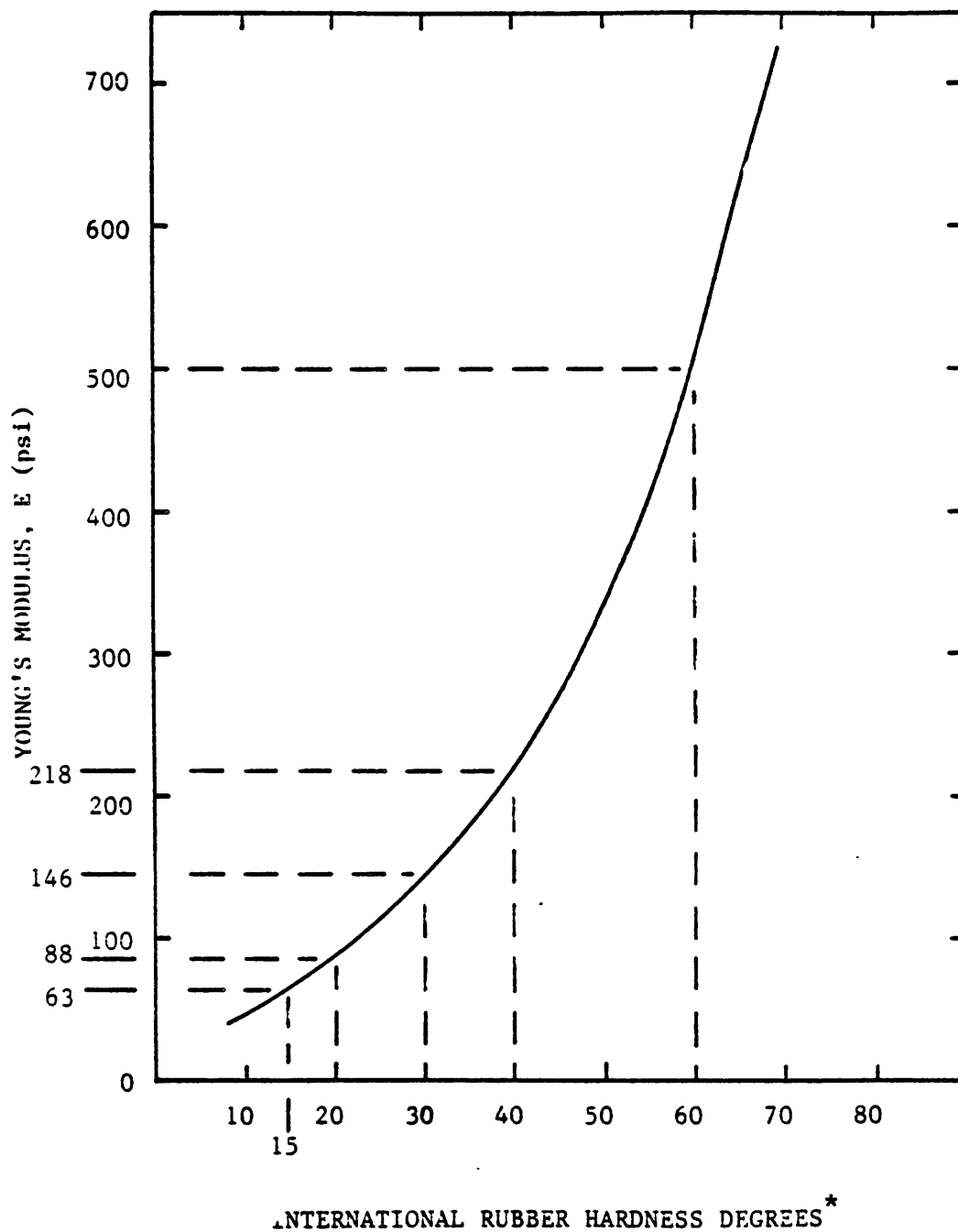
Information taken from ASTM D1415-
Standard Test Method for Rubber
Property- International Hardness

*International Rubber Hardness
Degrees equivalent to values of
Shore A Durometer

Gasket with
Uninflated
Compartments

Gasket with
Inflated
Compartments

A) Foam-Inflated Gasket

Cast Iron
Pipe

Foam in
Joint Recess

Retaining
Bands
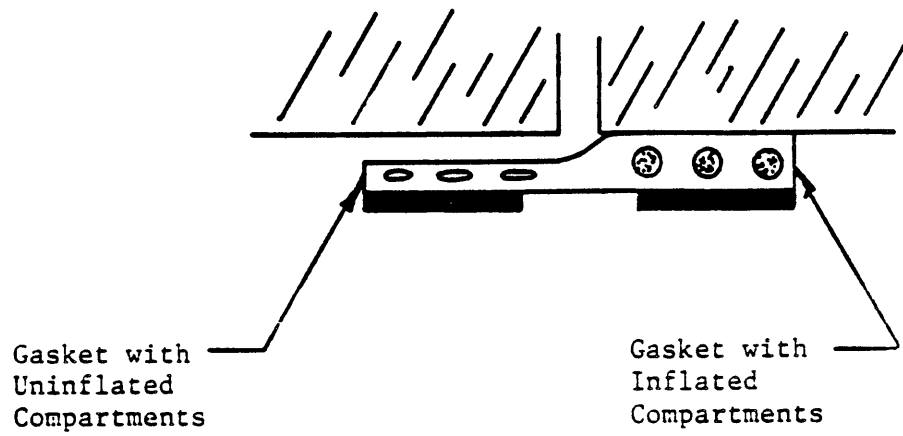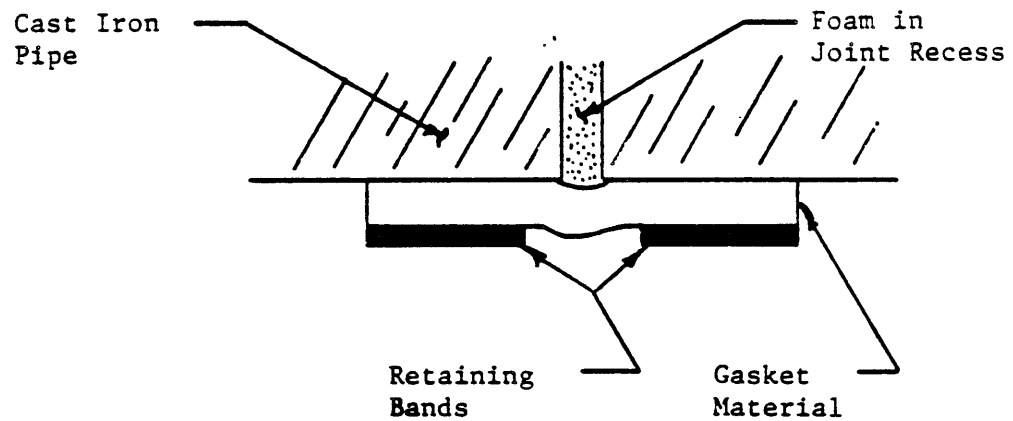
Gasket
Material

B) Foam in the Joint Recess

FIGURE 22   Applications of Foaming Polyurethane

Cast Iron Pipe

Undensified
Bead

Retaining
Band

Densified
Section

A) Before Installation

Densified
Section

Undensified
Bead
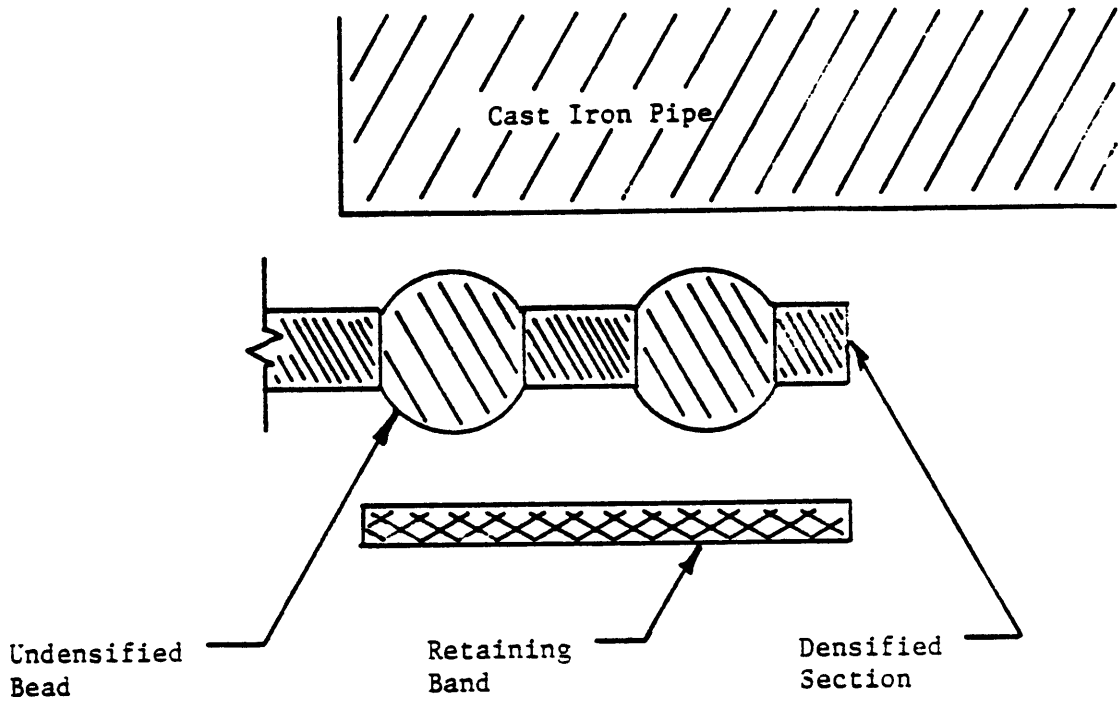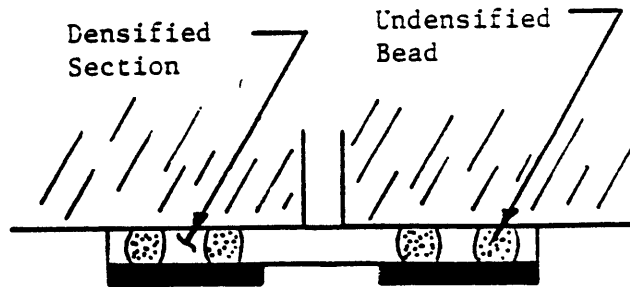
B) After Installation

FIGURE 23   Beaded Gasket

V-Shaped Groove Cut in Cast Iron

Cast Iron Pipe

Sealing Bead

Gasket &
Bridge

Retaining Band

A) Before Installation

Contact Area

Retaining Band
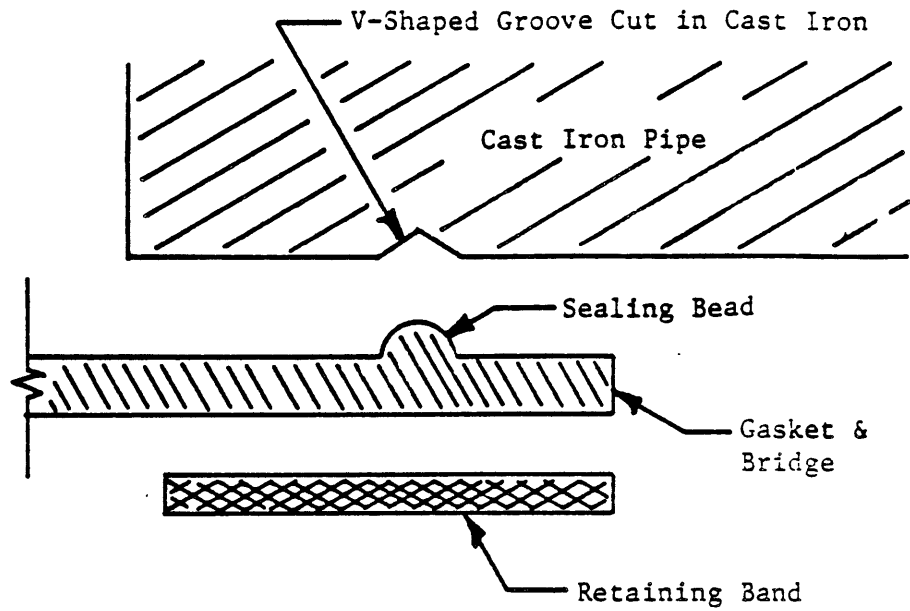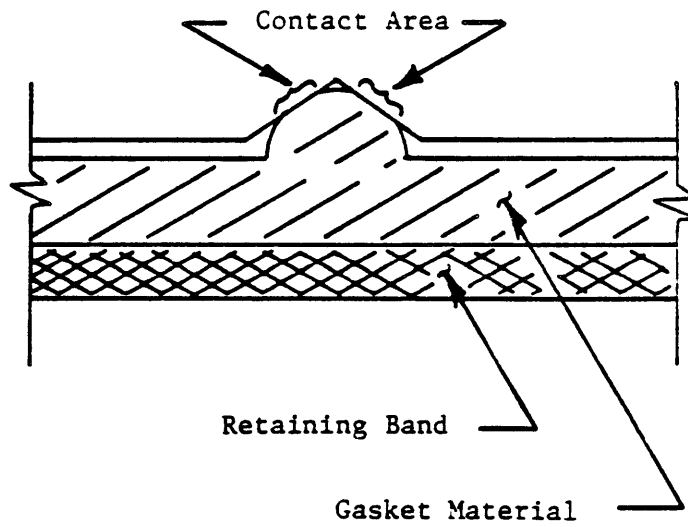
Gasket Material

B) After Installation

FIGURE 24   V-Groove Gasket

Cast Iron
Pipe

Retaining Band

Gasket Material

Molded
Ridges

A)   Gasket with Raised Ridges

Cast Iron
Pipe

Soft
Insert

Retaining Band
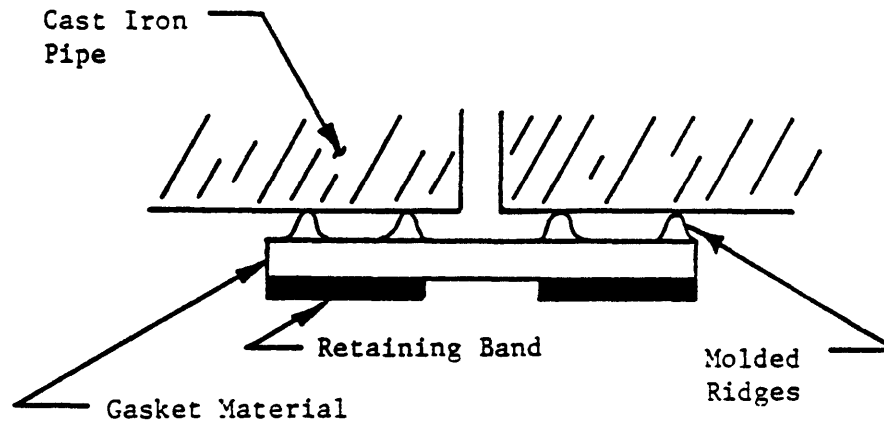
Gasket Material

Molded
Ridges
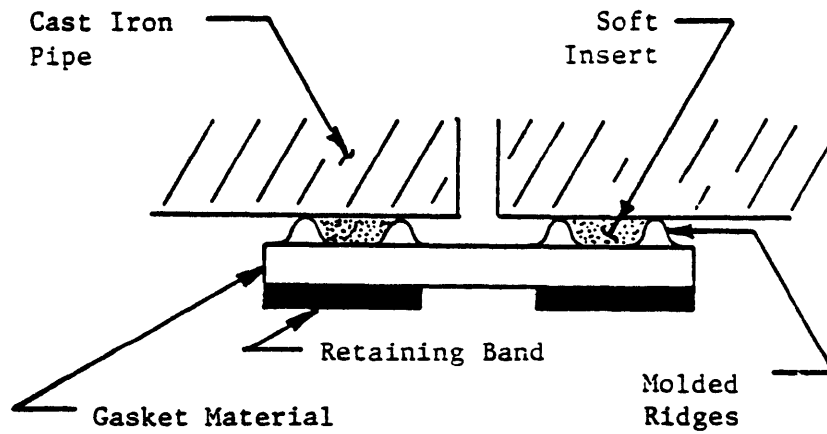
B)   Ridges with Soft Material Insert

FIGURE 25   Gasket with Raised Ridges

Cast Iron Pipe

Gasket — Material

Reinforced Elastomer Tube

Bridge Material

Polyurethane Foam

FIGURE 26   Unsupported Inflatable Gasket

10.0 SYSTEM DESIGN

10.1 General. This Chapter tests the feasibility of the alterna-
tive sealing system and provides information that may be useful in
further development. This Chapter provides comments that may be
useful in the Phase III development of this project in additioı to
the continuing work on Phase II. This Chapter discusses in general
terms the various systems that may be used to prepare the joint area,
the mandrel that must be used to clean or seal the joint, and addi-
tional comments on the design of the overall system.

10.2 Mandrel Design

10.2.1 General Comments. The general design of the device to
travel down the main to clean or seal the joint area is shown in
Figure 27. Because the pipe wall must be cleaned or sealed with gas
still passsing in the main, the work area of the mandrel must be an
annulus with a central core for gas to travel through. Both Yee[51]
and Battelle Columbus Laboratories[41] were forced by the nature of
the problem to the same basic configuration. To isolate the work
space from the gas stream, inflatable cuffs should be used at both
ends of the mandrel. These cuffs may not be required if dust is not
a problem, such as during sealing.

10.2.2 Pressure Drop Across the Mandrel. Preliminary estimates
of the pressure drop across a mandrel with a central core gas passage-
way indicated that such a device is feasible. Maximum measured gas
flow rates of 1892, 6266 and 11,413 SCFH for 4, 6, and 8 inch diameter
mains, respectively,[46] were used in this estimate. For all three
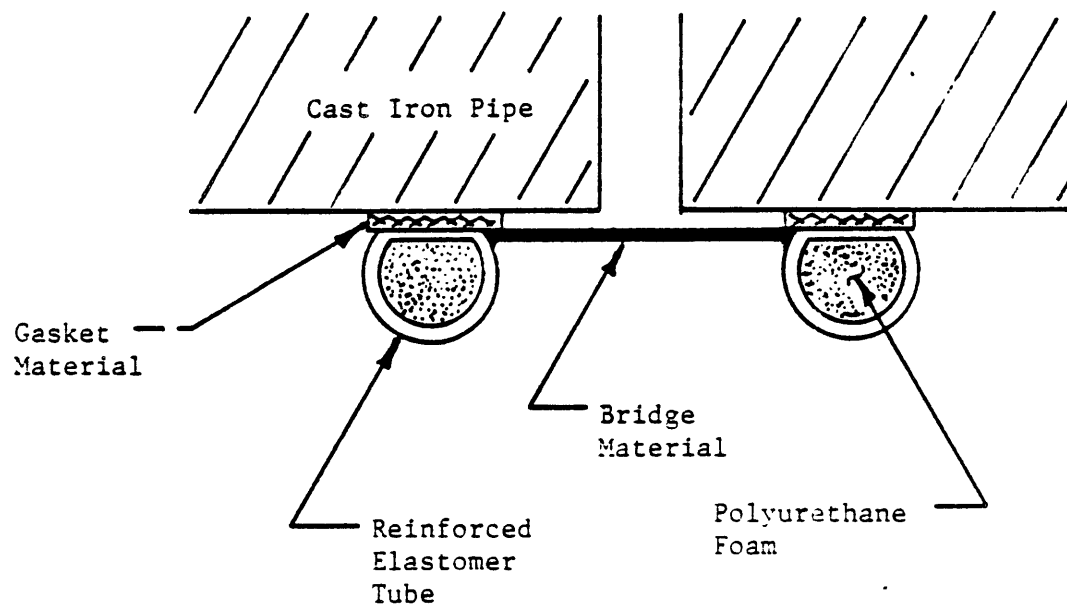diameters, a maximum of 1.5 inch, w.c., pressure drop resulted if the
core diameter to main diameter ratio, $\frac{d_1}{d}$ was 0.3. The ratio of
annulus thickness to diameter, tw/d, was accordingly 0.35, which should
be sufficient to clean and seal the joint area. The actual pressure
drop across the mandrel should be less than 1.5 in., w.c., of this
estimate because maximum flow rates are not expected to occur in the
summer when the repairs are likely to be made. The pressure drop across
the mandrel can be reduced further by streamlining the entrance and

exit of the gas passage.

10.2.3 Mandrel Length. As mentioned in Chapter 6.0, the device should be capable of passing through a 90 degree bend in the main. This requirement severely limits both the length and width of the mandrel. Figure 28 shows the results of a geometrical analysis of the length and width of a device to pass through 22, 45 and 90 degree bends. Given that the ratio of core to main diameters, d_1/d, was estimated at 0.3, another analysis was conducted to determine the space available for storing machinery as the mandrel passed through bends. Figure 29 is the result of this analysis. The most stringent conditions were for a mandrel to pass through a four inch diameter main with a 90 degree bend. Using Figures 28 and 29, a 6-inch long ($L/d = 1.5$) mandrel could pass through with a total width of 3.1 inches ($h/d = 0.77$). The annular space available for storing the machinery was 0.96 inches ($t_c/d = 0.24$) and the annular space available for work was 1.4 inches ($t_w/d = 0.5$). These dimensions are thought to present design challenges, but do not preclude in themselves further development. However, care must be taken in design to provide sufficient clearance so that the device cannot get stuck in a bend in the main.

10.2.4 Reducers and Other Components. The mandrel should be designed to pass through reducers in either direction and to negotiate "tees," and bifurcations without getting stuck or going down the wrong main. This requirement can be met for "tees," and branches by controlling the direction the mandrel may take. The requirement to pass through reducers will probably result in design changes to the support and roller systems. It should also result in modifications to the machinery used to clean and seal. In essence, the capability to pass through reducers requires than a main be sealed with a mandrel sized for a smaller diameter main.

10.3 Cleaning

10.3.1 General. Two major areas must be considered in designing

the method and device to prepare the joint area for sealing. The device must be powered to clean the pipe wall, and the debris must be removed from the joint area without adding dust to the gas stream. Both of these functions must be performed within a section of main that may easily be 500 feet in length. From the results of Chapter 7.0, only wire and abrasive wheels and water-jet cleaning without grit were considered. Water-jet cleaning with grit and air-sand blasting were not considered for reasons given in Chapter 7.0. The use of very small hydraulic and gas turbines were considered as engines to power the grinding wheels. Electric motors, if their use is possible, were found to provide an advantage.

10.3.2 Hydraulic Turbines. A concept to pump high pressure water to the cleaning area, pass the water across a small turbine, and use the water to remove debris was checked for feasibility. The shaft output of the turbine was initially conceived to provide the 0.25 hp needed to power the cleaning wheels. 0.25 was chosen as a conservative approxima-tion of the power needed to clean deposits with a grinding wheel or to clean tar with a wire wheel. The power requirements to clean deposits with a wire wheel were much less ($\sim$ .07 hp) and the choice of 0.25 hp is a conservative estimate. Because of space limitations within the main, a maximum of one-inch diameter (I.D.) hoses was assumed for both the water input and drain. Given the head loss in the hoses, it was estimated that 1.8 hp was needed to pump the water in both directions at the required flow rate of 27.7 gpm. To pump the water back out of the main would necessitate that a 1.8 hp pump must be attached to the shaft of the turbine, which would be increased to 2.05 hp.

This configuration was thought to be infeasible for several reasons. Because of the large flow rate necessary to power the turbine, it would take less than a second for the annular work area (see Section 10.3) to be filled should a blockage occur in the drain line. The pressure buildup would probably force water past the end cuffs of the mandrel into the main. Whereas water would not pose a serious problem in the main, the pressure

build-up in the annulus may cause the turbines and pump to malfunction and the operation to stop.

Another configuration of this concept would be to allow the annulus to be filled with water during the operation of the device. The return pump would be eliminated, relying on hydrostatic pressure to force the water and debris through the drain hose. However, the pressures required to overcome the frictional losses in the drain hose would be around 600 psig, much too high to be contained by the inflatable end cuffs. For this reason, this concept of the use of hydraulic turbine was considered infeasible.

More importantly, the size and complexity of the turbomachinery would probably preclude its use inside gas mains. The cost of designing and developing the equipment would make the system too expensive for use. The use of hydraulic turbines is not recommended for further consideration.

1 .3.3 Gas Turbine. This concept uses nitrogen rather than the water of the previous section. Approximately 9 hp was estimated to be required to push the gas through a one-inch hose to a turbine producing 0.25 hp to power a cleaning wheel. The dry debris from the cleaning wheel would be collected in a separate filter chamber. The nitrogen would pass through the filter into the natural gas stream. Nitrogen is preferred to air to prevent attaining an explosive mixture in the annular work area. To produce the gas velocities ($\sim$ 67 ft./sec.)[5] needed to convey the debris out of the cleaning area, the work area must be maintained at a pressure higher than the main gas pressure. With a positive pressure differential, dust could pass from the work area into the gas stream. If a separate gas pump were used to draw the debris into the filter bag, a negative pressure differential could be maintained reducing the chance of dust entering the gas stream. However, this pump would have to be run off of the shaft output of the turbine, increasing the required flow rate of nitrogen.

As with the hydraulic turbine, the gas turbine-pump would require specialized equipment that is probably not available, and must be

developed at large expense. The turbine and the pump may be too large
to place inside the main. For these reasons, use of a gas turbine
to power cleaning wheels is not recommended.

10.3.4 Electric Motors. If small electric motors can be found
that meet the safety code requirements, they should be able to be adapted
for use to clean mains. In addition to power the cleaning wheels, two
concepts were considered. An electric motor could power a small air
pump to draw dry cleaning debris into a filter bag, maintaining a nega-
tive pressure differential with the gas stream. Natural gas would leak
into the work area, entrain the dust, pass through the pump and the
filter, and return to the gas stream. Alternately, a small amount of
water could be sprayed near the cleaning wheel to entrain the dust.
The water would then be pumped out of the work area to a reservoir.
The water would be filtered and recycled. The reservoir could probably
be within the main, near the mandrel. An electric motor could easily
power the water pump. Several small motors, or one motor with several
power take-off units could be used, perhaps mounted in a separate
mandrel connected to the cleaning mandrel with a flexible cable.

If small explosion-proof electric motors are commercially avail-
able, their use is recommended to power the cleaning wheels and to
remove the debris from cleaning. Their size, flexibility of use, and
smaller umbilical cord requirements make them more attractive than
either gas or hydraulic turbines.

10.3.5 Water Jet Cleaning. Water-jet cleaning was not considered
in detail in this chapter. Experiments in Chapter 7.0 showed that 5
gallons per minute of water at 3000 psi quickly removed all tar and
loose deposits, but left a rougher surface than wire-and grinding-
wheel methods. This rougher surface may be acceptable considering
the great reduction in in-main machinery that is possible with water-
jet cleaning. Smaller flow rates may be possible to reduce the require-
ments to pump the expended water with debris from the work annulus.
Manufacturers of high pressure water cleaning equipment should be

contacted for information on feasibility and availability of equipment.

10.3.6 Other Comments. As the mandrel moves into the main, pipe deposits may be disturbed causing dust to travel downstream. Once the mandrel is in place, the strong eddies that result when the gas passes from the central core into the gas main may scour the pipe wall and carry dust downstream. Two methods of dust control are considered. The first method is to spray water onto the pipe wall as the mandrel moves into the main. The water would hold the dust until the mandrel was removed. Evaporation of the water would occur rapidly in natural gas and retreatment may be necessary as cleaning progressed. The water vapor would have no significant effect upon the combustion characteristics of the natural gas. Other substances to wet the deposits are not recommended for reasons discussed in Section 6.2.2 Use of a water wet-down prior to cleaning would preclude use of the dry debris removal methods as discussed in the previous sections.

The second dust control method would be to clean the entire main of most deposits as the mandrel moved into the main for the first time. The general main cleaning would be followed by cleaning each joint area at the time of sealing. This method would allow the mandrel to travel inside the main without causing dust to flow and would reduce the problem of dust control during the cleaning of each joint area.

In the discussion of cleaning methods in Chapter 7.0, the removal of casting burrs was not considered. It is thought to be more efficient to remove the burrs rather than to design the gasket to seal over them. Burrs are thought to be rare, and would have to occur within the joint area to present a problem. Burrs could be removed by a small grinding wheel mounted in a special mandrel. Casting burrs are not considered to be a serious problem at this time.

10.4 Design of the Overall System.

This section tests the feasibility of the completed seal and makes several comments about the cleaning and sealing device. Additional

comments for the support systems required are also included.

10.4.1 Effect of the Completed Seal. After the seal has been emplaced, there is expected to be a small increase in the power required to pump the gas to the customer. The seal placed at a joint every twelve feet is expected to increase the frictional losses in the pipe by at most 7.5 percent for a 4-inch diameter pipe. This estimate assumed that the seal is placed into a main constructed of new cast iron pipe. A more realistic assumption of the pipe wall conditions resulted in an estimate of a 7 percent increase in friction losses. Loss percentage increases for 6 and 8 inch diameter mains are less than those of 4-inch diameter mains.

Other factors such as bends, branches, and pipe rougher than that assumed above will reduce these approximations. Because the frictions loss increases are relatively small, the pumping power requirement is not expected to rise appreciably after installation of the seal.

10.4.2 Cleaning and Sealing Devices. From the discussion in Section 10.2.3, the length of the mandrel is limited by its ability to negotiate a bend in the main. If all functions cannot be performed by a single mandrel because of the truncated length, a train can be used by connecting together several mandrels of the proper length. Each mandrel of the train may be used for different functions, such as power, cleaning, or sealing.

The individual mandrel or train must be propelled through the main. Options are by towing with a winched cable from both ends of the main section, or by pulling through with an electrically powered tractor. The former method has been the method used by all other internal sealing devices.

10.4.3 Miscellaneous Comments. Efforts should be made in future development to use power sources and equipment that the utility already has in its inventory. Requiring purchase or development of specialized

equipment will severely limit the acceptability of the alternative sealing system.

In the design of all components of the cleaning and sealing devices, standard components or equipment should be used whenever possible. A reduction in performance may be easily justified if it resulted in being able to use off-the-shelf items.

Battelle Columbus Laboratories have already contacted the T. D. Williamson Company for assistance in developing a method to place mandrels into a live gas main.[41] Both of these organizations should be contacted for further information at a future, more appropriate, time.

Central Core for
Gas Passage

Maximum Width for
Cornering in a
90° Bend

A

A

Inflatable Cuffs

Annular Area
for Equipment

Central Core
for Gas Passage

Cast Iron Pipe

Annular Area
for Equipment

Inflatable Cuff
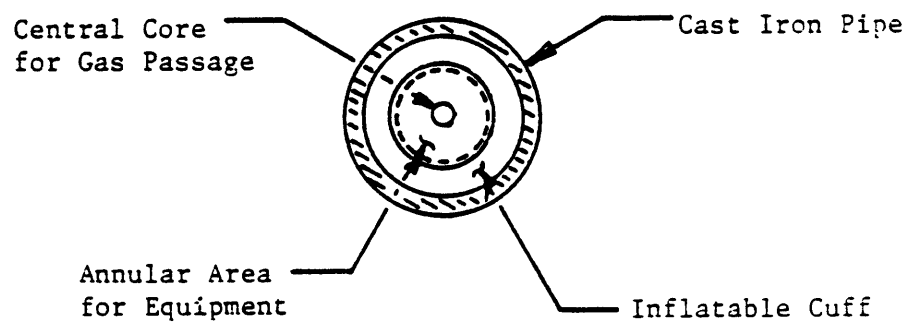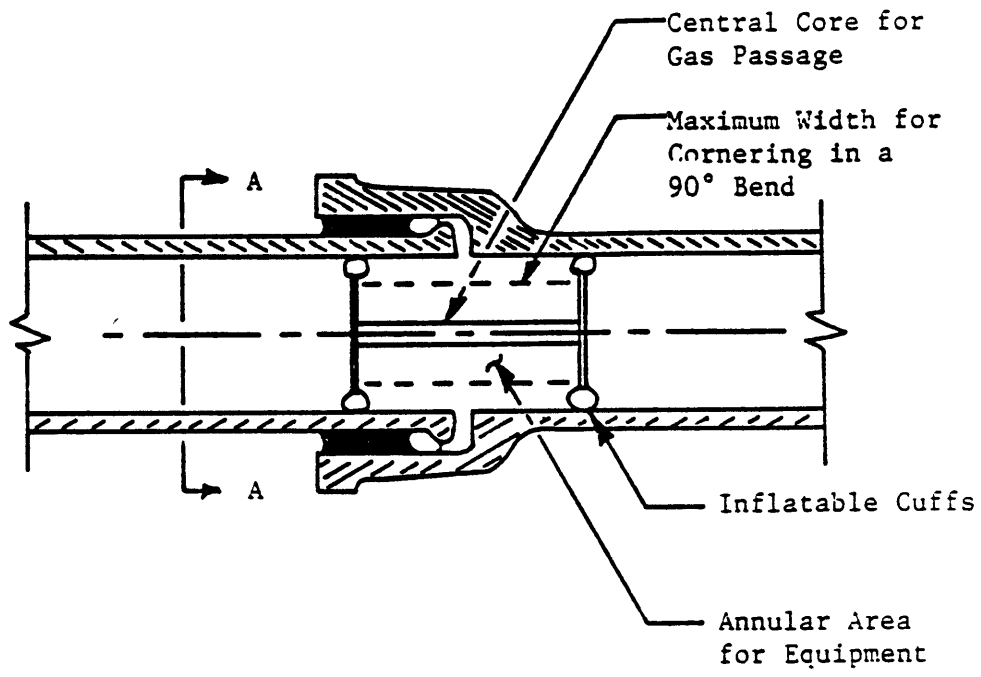
SECTION A-A

FIGURE 27   Mandrel Concept
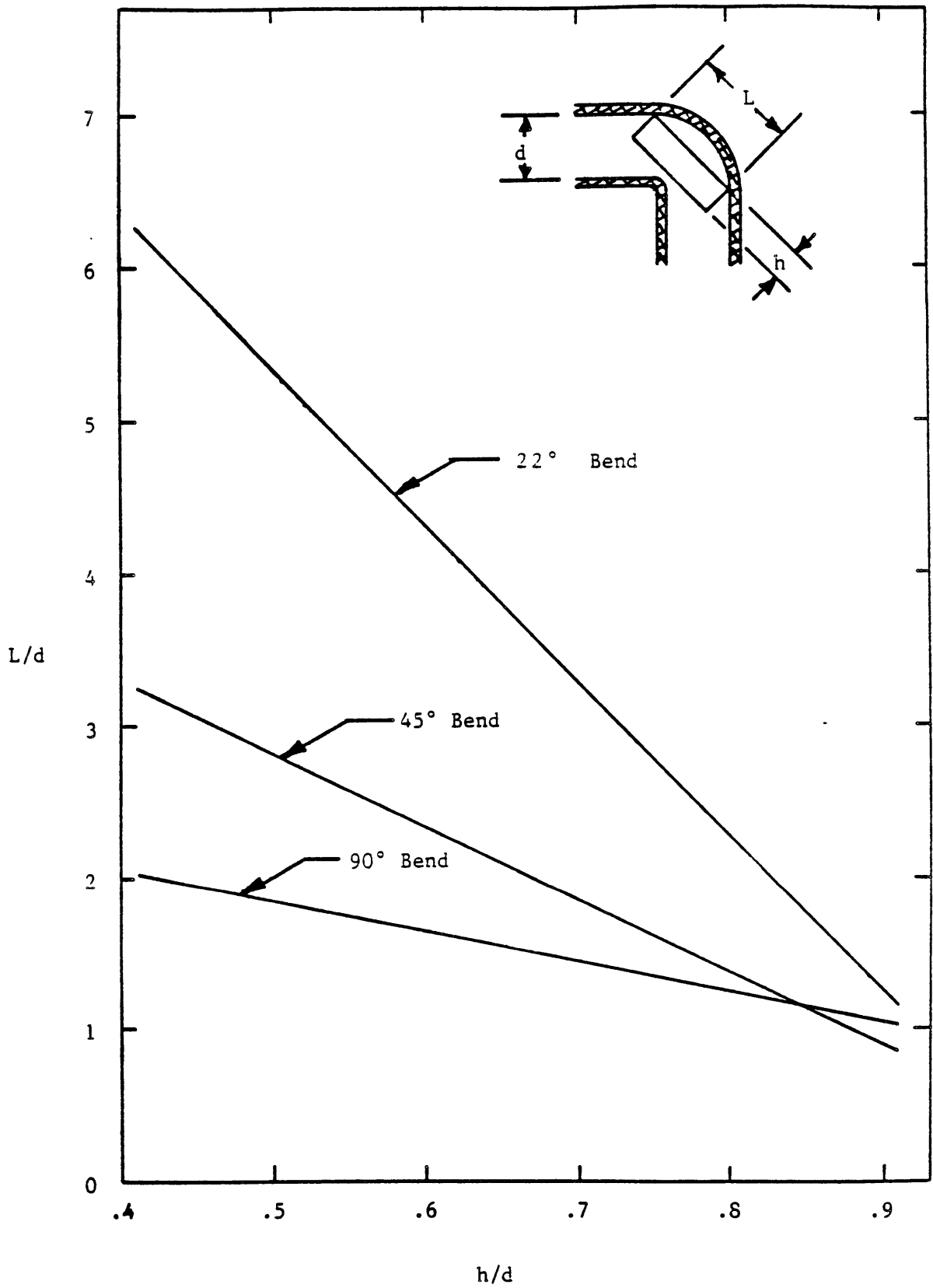
FIGURE 28   L/d vs. h/d for 22°, 45°, 90° Bends
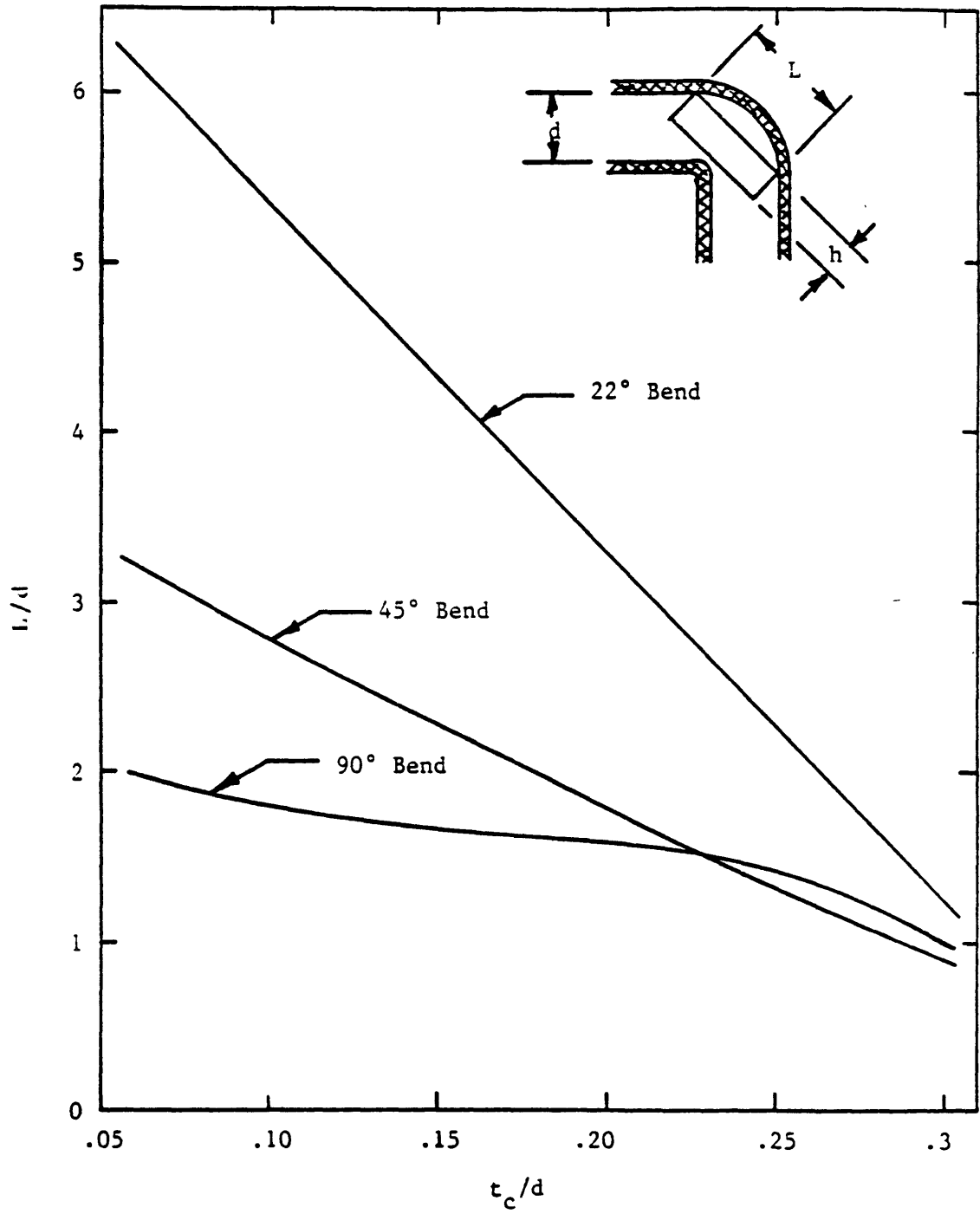
FIGURE 29   L/d vs. t_c/d for 22°, 45°, 90° Bends

11.0 CONCLUSIONS AND RECOMMENDATIONS FOR PART TWO.

This chapter discusses the conclusions and makes recommendations based on the experiments, the literature, and preliminary calculations of the previous five chapters of Part Two. Conclusions and recommendations for Part One of this thesis are contained in Chapters 5 and 2 respectively.

11.1 Conclusions.

It was found to be possible to seal against 10 psig gas pressure by pressing a soft rubber gasket against a very rough surface. The cast iron pipe surfaces were prepared by different cleaning methods with resulting roughnesses from 2500 to 5100 μ-inches (rms). An rms roughness of about 3400 μ-inches was found to be a limit above which greater gasket compressive stresses were required. Cleaning with a grinding wheel, a wire wheel and sandblasting resulted in roughnesses less than 3400 μ-in. Water-jet cleaning with or without abrasive grit resulted in roughnesses greater than 3400 μ-inches. Wire- and grinding-wheel cleaning were found to be feasible and the most attractive for further development. Water-jet cleaning without grit should be considered because of its expected ease of use, even though the cleaned surfaces will be rougher than with wheel cleaning. Water-jet cleaning with abrasive grit, sand blasting and chemicals were found to be infeasible or ineffective for this application.

Deposits were analyzed from pipe pieces removed from three different systems. The deposits were found to be mostly ash and large molecule hydrocarbons. In one sample taken from ConEdison, total sulfur content was about one percent and sulfides were about one-hundreth of the total sulfur found. Certain elastomeric materials are effected by sulfides, and the small percentage was expected to have a small effect upon most elastomers.

Based on the literature, fluorocarbon elastomer was recommended for use as the gasket material to be pressed against the pipe wall. It was

also recommended for use as the membrane material across the joint recess. This conclusion considered the time dependent characteristics of the material, resistance to chemicals found in the main, and resistance to aging and sulfur-bearing compounds.

Based on preliminary calculations for an idealized design of the seal, and the results of sealability tests, an internal seal was found to be feasible. The hoop stress of the retaining bands were estimated to be about 2000 psi. Alternative gasket design concepts were discussed. Further development of a seal should result in lower retaining band hoop stresses.

Preliminary calculations for a pipe mandrel to clean or seal concluded that a device can be used in the main without too large a pressure drop across the device. Estimates of the mandrel length and width were made to insure that the device could pass through a 90 degree bend and still have sufficient room for the equipment needed to clean or seal the joint. Electric motors, if they can be procured, provide a significant advantage over other schemes to power the device.

Finally, the added obstruction of the installed seal will increase .the pumping losses of main by less than seven percent. If other obstructions of the main were to be considered, this value would probably be much less.

11.2 Recommendations for Further Development.

This Section makes recommendations for the further development of an alternative internal joint seal, conducted under Phase II of this research. The cleaning of the main must be considered concurrently with the development of prototype seals. The two areas of design have strong interrelationships that must be recognized to develop an optimum system.

Manufacturers of water-jet cleaning equipment should be contacted to determine if their products can be adapted for use in live gas mains. The hydrodynamics of the water jet inside of the annular work space of the mandrel should be considered.

Methods of removing dry and wet cleaning debris should be studied. These methods may include vacuum cleaner-type devices to draw gas and the dry debris out of the annulus as soon as the debris is loosened. Another method that should be considered is the removal of a mixture of water and debris. This latter method would be applicable to water-jet cleaning and methods that used a water spray to entrain dust produced by wire or grinding wheels.

In experiments in Chapter 7.0, the wire wheel was not able to remove tar deposits. The test described in Section 8.9 should be conducted to determine the stability of tar as a gasket surface. If tar were found to be inadequate, it must be removed for a successful seal. Grinding wheels and water-jet cleaning removed the tar. Manufacturers of wire wheels should be contacted for recommendations on the cutting speed and wire fill of the wheel for removal of tar from the inside of gas mains. If no information is available, experiments should be conducted.

Manufacturers should be contacted to determine if small 0.25 hp explosion-proof electric motors are commercially available. If available, these motors would provide a significant advantage over other means of powering the devices for cleaning and sealing. If they are unavailable, nitrogen driven turbines are a possible alternative.

An extensive literature survey should be conducted and manufacturers contacted to obtain information on the long-term behavior of the elastomers recommended in Chapter 8.0. The 50-year lifespan mentioned throughout this thesis is intended to be a goal and not an inflexible standard. The expected lifespan of a seal should be a significant factor for comparison, and therefore open to compromise. If information about elastomer performance is not available, experiments as described in Section 8.9 should be performed to provide the missing data.

The experiments of Chapter 7.0 tested the sealability of elastomeric gaskets on rough surfaces. In these tests, the minimum nominal compressive stress was 25 psi and the maximum gas pressure was 10 psig. Any further testing of seals should include lower gasket stresses and gas pressures up to 25 psig. The test described in Section 8.9 should be performed to determine the minimum sealing stress after the gasket has crept into surface asperities.

The use of expanded elastomers should be considered as a means
of significantly lowering the required gasket stresses. Design
concepts that reduce the sealing force by limiting the contact area
of the gasket should be further developed.

Considering the expected difficulties in properly cleaning the
joint area without adding dust to the gas stream, design concepts
that eliminate or reduce the amount of cleaning should be emphasized.
Examples are the V-groove gasket and the soft gasket coating described
in Chapter 9.0.

APPENDICES

APPENDIX A - ANNOTATED BIBLIOGRAPHY

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47. Crompton, H., P. Hunter and D. E. Keene. Leakage Control by Gas Conditioning with Monoethylene Glycol. The Institution of Gas Engineers Communication 1128, London, 1980.

   Best overall reference on MEG vaporization. Discusses in detail the laboratory and field tests performed in England.

48. deWinton, Charles. "Emgas Pioneers Gas Conditioning by Humidification," Gas World, 180:141, 144-5, 147, 181, March 1975.

   Used humidifcation as a first solution to keep jute from deteriorating; statement of problems of humidification.

49. Dimura, Jerry. Jerto, Inc., Dunellen, NJ. Personal Conversation of June 10, 1982.

   Discussed Jerto, a system to spray a jute swelling oil inside mains.

50. Eaheart, E.A., H.G. Howell, "Memphis Carbosealing Experience," Gas Age, 101:22-23; 40, 43-44, April 15, 1948.

   65% reduction in leakage from 1938 to 1943 with treatment with Carbo-seal. Oil fogged from 1929 to 1931, but had difficulties with controlling the unit.

51. Elliott, F.G.H. "Experiences with Carboseal," American Gas Journal, 150:25-27, April 1939.

   Mentions pilot outages resulting from the fogging of Carboseal.

52. Erwin, J.H. "Gas Conditioning," Gas Age, 102:14-15, 52, 1948.

53. Gas Conditioning Technical Data. ALH Systems, Ltd.

   Provided by Miller Pipeline Corporation. Contains general promotional information.

54. Gollob Analytical Service Memoranda. Gollob Analytic Service, Berkeley Heights, NJ. (3/7/80, 6/24/80, 10/15/80, 4/1/82).

   Describes the laboratory testing performed for ConEdison to test the effectiveness of monoethylene glycol vaporization.

55. Hall, E.L. "Internal Treatment of Mains as Leakage Deterrent," American Gas Journal, 145:53-6, 112, October, 1936.

   Use of Carboseal.

56. Handrihan, J.W., A.H. Kelly, A. Rivers, "Humidification," Northern Junior Gas Association, 1971.

   Results of original tests performed in the U.K. to check effectiveness of humidification in preventing leaks.

57. Hendricks, Bill. Northern Utilities, Portland, Me. Personal conversation of March 22, 1982.

   Discussed experience with Monoethylene glycol vaporization.

58. Hitz, G. E. "Experiences in Leak Proofing Bell and Spigot Joints; Use of Carbo-seal," American Gas Journal, 144:20-3, April 1936.

   Discusses original development work of Carbo-seal by the United Gas Improvement Co. and the Central Hudson Gas and Electric Corporation.

59. Hylak, P.J., G.G. Wilson. Process for Repairing Gas Main Joints. U.S. Patent No. 3,507,725. April 1970.

   IGT Two-Part Sealant.

60. Hylak, Peter J. and Gene G. Yie. "Novel Two-Part Bell Joint Sealant," American Gas Association Proceedings, 1966, Paper 66-D-556.

   Discusses a two-part sealant that climbs into the jute, saturates it and solidifies sealing leaks. Result of A.G.A. Project PB-37a. (IGT Two-Part Sealant).

61. "Internal Spray Seals Leaks and Dust," Gas Age, pp. 15-18, March 1969.

   Reprint supplied by J. DiMura describing Jerto.

62. Keelan, J.P. "Correcting Dust Problems and Joint Leakage by Application of Carboseal," Gas Age, 110:35-6, 87-8, 1952.

   51% drop in leakage after treatment with Carbo-seal in Harrisburg, PA; Treated through 1 ft. square excavations in the street.

63. Knoblock, K.D. "Streamlining Treatment of Mains with Anti-Leak," Gas Age, 107:48-50, March 15, 1951.

   Spraying Carbo-seal; contractor's view toward making the treatment more cost effective. Used a gland stuffing box for treatment of live mains.

64. Kollock, E.C. "Humidifying and Oil Fogging Natural Gas," Gas Age Record, 75:161-164, February 1935.

   Excellent article containing data on a system five years after initiating oil fogging and humidification. Results are compared with a system that was not treated. Contains the composition of several fogging oils.

65. Kooke, C.A. "Effects of Gas Conditioning on the Distribution System," American Gas Association Proceedings, 1952, pp. 280-4.

   Results of conditioning two years after conversion to natural gas. Consolidated Gas and Electric Light and Power Co., Baltimore, MD.

66. Long, George. Northern Illinois Gas Co., Aurora, Illinois. Personal conversation of July 6, 1982.

   Discussed field tests performed on IGT Two-Part Sealant.

67. Mathias, H.R. "Fogging Oils," Western Gas, 9:36, 1933.

   Discussed the specifications for fogging oils, such as the need to limit the gum forming ability of the oil, rather than the olefin content.

68. McDonald, Bill. Peoples' Gas Company, Chicago, Illinois. Personal conversation of March 26, 1982.

   Discussed experience with monoethylene glycol vaporization.

69. Nelson, O.F. "Field Tests of Capillary Climb Sealant System," Gas, 42:50-1, April 1966.

   Field tests of the IGT Two-part Sealant at Northern Illinois Gas Co.

70. Nishio, N., et al. "Development of Internal Repair Techniques by Fogging Method," Report from the Research Laboratory. Tokyo: Tokyo Gas Co., Ltd., December, 1974.

   Discusses fogging with WO8.

71. Procedure for Yarn Sampling. ALH Systems, Ltd.

Provided by Miller Pipeline Corporation, and describes the procedure to take a jute sample for the swelling pressure test. This test is used to tell if a section of main will respond to treatment with monoethylene glycol.

72. "Review" Gas World, 169: suppl. pp. 8-12, June 28, 1969.

Describes how one contractor sprays Carbo-seal inside mains. Refers to muffed joints used to measure long-term effects.

73. Robinson, D.M. "Humidification in Gas Mains," Gas Engineering Management, 16:55-68, February 1976.

Procedure described well. Includes discussions of the controls and the calculations required.

74. Rossback, Erwin. Brooklyn Union Gas Company, Brooklyn, NY. Personal conversation of May 26, 1982.

Discussed experiences with monoethylene glycol vaporization.

75. "Saturseal, Joint Leakage Prevention Introduced," Gas Age, 83:48, April 13, 1939.

Introduces a jute swellant that polymerizes with time. Contains no further information.

76. Scott, G.B., D.F. Balfour, and K.F. Cairns. Experience with Yarn Swellants in Scotland. The Institution of Gas Engineers Communication 939, London, 1974.

Results from field tests using different criteria; discusses development of different spraying techniques.

77. Shell International Petroleum Company, London. Telex of December 22, 1981.

WO8 was withdrawn from the market before 1977 because of insufficient sales.

78. Shively, W. L. "Report of Subcommittee on Oil Fog Lubrication and Rehydration," American Gas Association Proceedings, 1930, pp. 789-97.

Early qualitative results of oil fogging and humidification.

79. Skeen, J.R. "Carboseal. The Development of its Physical and Chemical Properties," Gas, 14:33-37, 47, Oct. 1938.

   The first comprehensive test results on Carbo-seal. Includes comments on leak mechanisms.

80. Slack, Daniel D. Auto-Seal Method-Treatment for Bell and Spigot Joints. New York: Consolidated Edison Company of New York, 1973.

   Auto-Seal (Carbo-seal) treatment stopped in ConEdison after this report's recommendations.

81. Suetoshi, Tetsui. Oksaka Gas Company, Osaka, Japan. Correspondence of July 10, 1982.

   Concerning monoethylene glycol vaporization.

82. Tanner, M.W.G. Examination of Yarn Samples from Consolidated Edison, New York. Report of the London Research Station. London: British Gas Corporation, February 23, 1978.

   Swelling pressure test results of jute samples removed from ConEdison system prior to monoethylene glycol treatment.

83. Tuttle, L.W. "Gas Conditioning," Journal of the Western Society of Engineers, pp. 142-53, June, 1933.

   Discussion of equipment and calculations for humidification and oil fogging.

84. Union Carbide Corporation, Hackensack, NJ. Personal conversation of January 5, 1982.

   Carbo-seal discontinued because of lack of demand.

85. Utermohle, C.E. "Changeover Gas Conditioning," American Gas Association Monthly, 33:26, September, 1951.

   Described conditioning efforts at Baltimore during the changeover to natural gas in 1950.

86. VanVliet, R. "Has Oil Fogging and Humidifying Accomplished What We Wished?, " Gas Age, 109:69, March 27, 1952.

   Results of efforts on Staten Island, NY of oil fogging and humidification. Article mostly concerned with dust control and how far downstream the oil can travel.

87. Wilkerson, G. "Leakage Control and Gas Treatment in the North West," Gas Journal, 348:289, December 22, 1971.

Not too valuable overview of what was done in the Northwest Gas Board of England. Contains mostly information on oil fogging.

88. Williams, D.B. "Use of Carboseal Anti-Leak," American Gas Journal, pp. 31-33, June 1939.

Promotional article from the Carbide and Carbon Chemicals Corporation, NY.

89. "Use of Carboseal to Reduce Gas Main Leakage," American Gas Journal, 143:34, December, 1935.

90. Yie, G.G. Method for Internally Sealing Gas Main Joints. U.S. Patent No. 3,563,823. February 1971.

IGT Two-Part Sealant.

91. Yie, G.G., P.J. Hylak, Sealing of Bell and Spigot Joints. A Report Prepared by the Institute of Gas Technology. New York: American Gas Association, 1966. (Unpublished Final Draft Report of A.G.A. Project PB-37a).

Contains detailed discussion of the development of the IGT Two-Part Sealant. Discusses field tests and suggested future development.

92. Zlokovitz, Robert J. Consolidated Edison Company of New York. Meeting of March 24, 1982 to discuss monoethylene glycol vaporization.

III. Internal Manual and Machine Methods

93. Anderson, Amos R. Anderson Development Co., Adrian, MI. Personal
    conversations of November 24, 1981, May 26, 1982 and July 21,
    1982.

    Discussed the development and current status of the Gas Phase
    Sealant, marketed by A.D.I. Corporation.

94. Anderson, Amos R. Anderson Development Co. "Gas Phase Sealants for
    Leak Correction," Gas, 48:58-60, July 1972.

95. Anderson, Amos R. Method for Sealing Leaks in Vessels. U.S. Patent
    No. 3,608,000 September 21, 1971.

    Describes the chemical composition of the Gas Phase Sealant.

96. Anderson, Amos R. "Sealing Process Combats Pipeline Leaks," Oil and
    Gas Journal, 70:62-64, July 3, 1972.

    Detailed discussion of the procedure for the Gas Phase Sealant.
    Describes the testing procedure during the product development.

97. "Automated System Inspects, Cleans, and Coats Pipe Interior, "Iron and
    Steel Engineer, 50:77-8, March 1973.

    Describes the Nippon Kokan Kabushiki Kaisha (NKK) method to
    clean and coat welds in long-distance transmission pipelines.

98. Blain, H. M. "New Orleans: Joints Coated from Interior," American
    Gas Journal, 184:17-19, July 1957.

    Describes the New Orleans Public Service's experience with
    manually applying glass-reinforced epoxy to the inside of
    30-inch diameter mains.

99. Cairns, K. F. and J. D. White. "The Fuelling System in Practice,"
    Gas World, 170:95-6, August 2, 1969.

    Describes the use of the Fuelling method in Glascow, Scotland
    before conversion to natural gas. Bi-annual checks of exca-
    vated joints were to be made. Rough costs are included.

100. Chester, Tom. Dresser Manufacturing Division, Bradford, PA. Personal
     conversation of January 28, 1982.

     Discussed the Dresser internal joint clamp.

101. Clayton, R. S. "Sealants," <u>Gas World</u>, 166:6-9, August 26, 1967.

Discussed two products marketed by the Shell International Petroleum Company: CF16 and WO8.

102. "ConSeal Speeds up Sealing of Gas Leaks," <u>Gas Journal</u>, 332:239-40, November 15, 1967.

103. <u>Construction Manual of Leakage Repair, Linear Internal Repair.</u> Translated by Masaaki Sakagami. Tokyo: Tokyo Gas Co., November 1975.

Procedure for using Con-Seal and inserting polyethylene pipe inside of existing cast iron mains.

104. Cook, R. W. C. W. Fuelling, Inc., Decatur, IN. Personal conversation of December 24, 1981.

Discussed the history of use of the Fuelling method.

105. Delaruelle, J. and J. LeCorre. <u>Method of Filling or Sealing Joints Between Pipe Sections.</u> U. S. Patent No. 3,363,301. January 16, 1968.

Patent for "Joint Interne," renamed "Interseal" in the U. S.

106. deWinton, C. "The Field of Joint Sealing Surveyed," <u>Gas World</u>, 178:199, September 22, 1973.

General discussion of many different sealing techniques. Contains the most detailed description of the Strip-Seal manually installed internal seal.

107. deWinton, C. "Gas Main Repairs in Hyde Park (Weco-Seal: Avon Lippiatt Hobbs, Ltd.)," <u>Gas World</u>, 181:106, February 1976.

108. deWinton, C. "Internal Sealing of Cast Iron Gas Mains," <u>Gas Journal</u>, 341:69-73, January 21, 1970.

Discusses the Dresser Internal Clamp. Mentions a trowel-headed machine used by William Press, Ltd.

109. deWinton, C. "Reconstituting Joints in Cast Iron Mains," <u>Gas World</u>, 178:295-8, October 27, 1973.

Discussion of the Trace method and insertion with polyethylene pipe.

110. Diller, Robert L. "Ohio Utility Prepares Cast Iron Gas Main for 'Never Leak'," Pipeline Industry, 25:33-4, July 1966.

General information on use of Con-Seal.

111. Douglas, A. F. British Gas Corporation, London, England. Personal correspondence of July 29, 1982.

Updated history of the fill-and-drain products Evostik 9611 and 9612.

112. Doulemes, G. "Progress Report on New Liquid Sealant," Gas, 38:74-6, April 1962.

Description of Con-Seal use in Lowell, MA.

113. Dufour, R. J. Internal Pipe Sealing Device. U. S. Patent No. 3,700,265. October 24, 1972.

Machine emplaced mechanical sealing device.

114. Dunn, Carl. Gas Line Renovators, Inc., Sanford, Fl. Personal conversation of March 11, 1982.

Discussed the details of the Gasloc method.

115. Dunn, Carl. "20th Century Technology Renews 19th Century Lines," Pipeline and Gas Journal, 209:19-21, March, 1982.

Detailed description of procedure and equipment for the Gasloc method.

116. Feinberg, Ira J. Gas Energy, Inc., Brooklyn, NY. Personal conversation of December 22, 1981.

Discussed in detail the Interseal method.

117. Gaulin, R. C. Consolidated Edison Company of New York, New York, NY. Correspondence of November 6, 1981 and personal conversation of January 12, 1982.

Discussion of history of use in the ConEdison system of polysulfide-based sealing methods.

118. Grace, J. C. Tate Pipe Lining Processes, Ltd., Manchester, England. Personal correspondence of November 25, 1981.

Answered detailed questions concerning use and design of Trace method.

119. Harper, Robert A. "Weko-Seal for Cast Iron Joint Repair," A. G. A. Proceedings, 1976, Paper 76-D-52.

     Detailed description of the procedure for installing the Weko-Seal. Contained an excellent description of the effort required to support the actual installation.

120. Hasegawa, A. "NKK Develops Pipe Equipment for Cleaning, Coating, Inspecting," Pipeline and Gas Journal, 199:32, October 1972.

     Description of the remotely-controlled device to treat the welds of transmission pipeline developed by the Nippon Kokan Kabushiki Kaisha (NKK) of Tokyo, Japan.

121. Hilbush, E. O. "New Liquid Seal May End Leaking Joints," Gas, 36:46, July, 1960.

     Good description of how Con-Seal works and how it is applied.

122. Hilbush, Edward O., III. West Chester Chemical Company, West Chester, PA. Personal conversations of October 29, 1981 and March 23, 1982.

     Discussion of Con-Seal.

123. Hoppe, H. M. "How Joint Leaks on Cast Iron Mains Were Repaired Internally," Gas, 25:38-41, May 1949.

     Description of use of Thiokol manually applied to the joint area from inside of the main.

124. Hoppe, H. M. "Repairing Joint Leaks by Internal Application," Gas Age, 103:49-53, April 28, 1949.

     Description of use of Thiokol manually applied to the joint area from inside of the main.

125. "How One Small Utility Solves its Leakage Problems," Gas, August 1966.

     Con-Seal use in Greenville, NC.

126. Internal Joint Sealing System. Gas Energy, Inc., Brooklyn, NY.

     Promotional description of the Interseal method.

127. "In-Situ Maintenance of Buried Pipelines (U. K. Construction and Engineering Co., Ltd.)," Pipes and Pipelines, 14:20; May 1970.

     Good general reference on the Fuelling method.

128. "Joint Interne Fills a Gap," Gas World and Gas Journal, 182:637-8, 651, December 1977.

   Description of the Interseal method used in the U. K.

129. Kiffin, George G. 3M Company, Bristol, PA. Personal conversation of December 14, 1981.

   Discussed the use of EC776 as a fill-and-drain sealing material.

130. Kooke, Charles A. "Ingenious Internal Clamp Upgrades 43-Year-Old Baltimore 42-Inch Main," American Gas Journal, 190:20-5, February 1963.

   Discussion of use of the Dresser internal clamp.

131. Kridner, Ken. "Rehabilitating Old Gas Lines," Gas, 49:38-40, September 1973.

   Con-Seal used in Richmond, VA.

132. "Large Gas Mains Sealed Without Open Trench," Pipeline News, 47:23-4, August/September 1975.

   Promotional article describing the use of Weko-Seal by Peoples Gas Co., Chicago.

133. Long, George. Northern Illinois Gas Company, Aurora, Illinois. Personal conversation of June 14, 1982.

   Discussed the "Apparatus for Internally Sealing Pipes."

134. Long, G., R. J. Dufour. "Northern Illinois Gas Evaluates Con-Seal," Gas Age, 133: 23-7, August 1966.

   Good discussion of the tests performed by the utility on Con-Seal.

135. Mains Cleaning and Joint Sealing by the Fuelling Method. C. W. Fuelling, Inc., Decatur, IL.

   Promotional brochure.

136. Miles, O. L. "Internal Sealing Progress Report," American Gas Journal, 190:23-29, August 1963.

   Promotional discussion of history of use of Con-Seal.

137. "New Internal Method to Seal Leaking Joints in Gas Supply Mains," Gas Journal, 344:26, December 16, 1970.

   Announcement of the Trace method.

138. Osterberg, Eric L., I. J. Feinberg. "New Sealing Process Solves Leak Problems in Old Mains," Pipeline Industry, December 1980.

   Description of the Interseal method.

139. Osterberg, Eric. "The Real Inside Approach to Cast Iron Joint Sealing," A. G. A. Proceedings, 1980, D45-54.

   Description of the Interseal method.

140. "Peoples Gas Sealing 2.5 Miles of 24-Inch Main Internally," Pipeline and Gas Journal, 202:78, September 1975.

   Description of Weko-Seal method. Same article as "Large Gas Mains Sealed Without Open Trench," Pipeline News, vol. 47, Aug./Sept. 1975.

141. Peters, J. L. "Philadelphia Story: Internal Sealing Proves Itself as Effective Control Method," American Gas Journal, 186:39, May 1959.

   Discusses the Fuelling method.

142. "Pipe Joints Repaired from Inside the Main," Gas Age, September 1949.

   Discussed the manual sealing of a 30-inch main. The sealant was an undescribed liquid rubber compound.

143. Problems Stop Here, Trace Process. Eric Johnson, Stubbs, and Co., Ltd., Cheshire, England.

   Promotional brochure of the Trace method.

144. "Process (Trace)", Gas World, 172:7, October 1970.

   Announcement of the Trace method.

145. Radice, Robert C. ADI Corporation, Ft. Lauderdale, FL. Personal conversation of November 24, 1981.

146. "Renovation," Gas World, 167:14-5, June 29, 1968.

   Announcement of the Fuelling method.

147. "Repair Sealing Bell & Spigot Joints with Rubber Base Sealants," Gas, 34:59-61, February 1958.

Announcement of the Fuelling method.

148. Robinson, E. L. "Don't Replace, Rehabilitate," Pipeline and Gas Journal, 198:37-9, October 1971.

Description of use of Con-Seal in Lowell, MA.

149. Roegiers, J. V. "Fuelling Method of Bell Joint Sealing," Gas, 40:59-67, July 1964.

Discussion includes good cost breakdown.

150. Rousseau, R. A. "ConSeal Proves Effective, Economical at New Bedford Gas," American Gas Journal, August 1967.

General description of experiences with Con-Seal.

151. Schleef, Rick. Raychem Corporation, Roselyn, N. J. Personal conversation of July 22, 1982.

Discussion of the "Line of Weld" sealing method using betalloy.

152. "The Sealants People" Notebook. Ford, Bacon and Davis, Inc., Monroe, LA.

Promotional notebook containing information on Con-Seal and Keyhole methods.

153. Shell International Petroleum Company, London, England. Response of December 22, 1981 to telex.

Current status of CF16 and W08.

154. Skinner, Hank. Press-Seal Gasket Manufacturing Co., Ft. Wayne, IN. Personal conversation of December 14, 1981 and correspondence of January 21, 1982.

Discussed the "Internal Pipe Sealing Device."

155. Taylor, Bob. Press Leakage Control Services, Ltd., Gibbsboro, NJ. Personal conversation of July 6, 1982.

Discussed PLCS's experiences with Fuelling and a new fill-and-drain material.

156. Ungetheum, Ellsworth. "Here's How to Stretch the Main Maintenance Dollar," Gas Age, 120, 13-16, 59, September 5, 1957.

Describes the Gutentite method.

157. Ungetheum, Ellsworth. "Milwaukee: Mains Sealed Internally Under Pressure," American Gas Journal, pp. 15-6, July 1957.

Describes the Gutentite method.

158. Wazujian, Armen. Thiokol Corporation, Specialty Chemicals Division, Trenton, NJ. Personal conversations of January 18, 1982 and January 22, 1982.

Discussed the use of Thiokol polysulfide rubber in the presence of mercaptans.

159. West Chester Chemical Company, West Chester, PA. General information.

Collection of information on Con-Seal to include the experiences of eight utilities., the use of NOX 968, and data on the stability of the emulsion.

160. Wiedo, Ray. Northern Illinois Gas Company, Aurora, IL. Personal conversation of June 7, 1982.

Discussed the "Internal Pipe Sealing Device."

161. Xenis, C. P. "Experience with Bell and Spigot Joints Sealed by the Fuelling Method," American Gas Journal, pp. 22-4, August, 1958.

Discussion of the Fuelling method.

162. Xenis, C. P. "Internal Sealing of Gas Mains by the 'Never Leak' Method," A.G.A. Monthly, May 1958.

Description of use of Con-Seal.

163. Xenis, C. P. "The 'Never Leak' Method for Internal Sealing of Gas Mains," American Gas Journal, pp. 18-22, June 1959.

Description of the Con-Seal method.

164. Xenis, C. P. "Sealing Pipe Joints by the Internal Spring Band Method," American Gas Journal, pp. 17-19, December 1958.

Description of the Spring Band method.

165. Yie, G. G. Apparatus for Internally Sealing Pipes. U. S. Patent No.
       3,609,913. September 21, 1971.

       Collapsible device for spraying the Two-Phase Sealant without
       service interruption.

IV. External Repair Methods

166. ALH Systems, Ltd., Westbury, Wiltshire, England.

A collection of promotional brochures entitled Joint Repair Systems, Avonseal, Avonseal Two, Avon Series Four Encapsulation, Series Four Medium Pressure, and Weko Seal Internal Sealing System

167. ALH Systems, Ltd., Westbury, Wiltshire, England.

Technical Reports for the Avonseal Two, and Avon Series Four.

168. "Avonseal: A New Method of Gas Pipe Joint Repair," Gas Journal, 348:289-291, December 22, 1971

Announcement of Avonseal

169. Bonded Products Technical Data Sheet 102: Epi-Seal X/L 2000 Bell and Flange Joint Compound. Bonded Products, Inc., West Chester, PA.

170. Bowden, W. H. Winn and Coales (Denso) Ltd., London, England. Personal correspondence of March 4, 1982.

Discussed the history of Denso-Foam encapsulation.

171. British Gas Engineering Standard BGC/PS/LC8. Performance and Materials Specification for Methods of Repairing Leaking Gas Mains. Part 1 - External Systems (Excluding Clamps). London: British Gas Corporation, March 1981.

Detailed requirements for material and product testing. Long-term testing is of particular interest. All external repair methods must meet these criteria before they can be used in the British Gas system.

172. BTR Silvertown, Ltd., Burton-on-Trent, Staffordshire, England. A collection of promotional brochures entitled LP2 Encapsulation, Ready Seal, BTR Silverkit System, and BTR Silverkit Medium Pressure.

173. Carr, H. F. "Maintenance of Cast Iron Mains," Gas Age Record, 78:391-4, October 10, 1936.

Describes the use of external clamps and "Lek-Pruf," a method of encapsulating the joint with concrete.

174. Customer Evaluation of Raychem GRS for Low Pressure Gas Distribution Systems. Raychem Corporation, Redwood City, CA, March, 1976.

175. Denso Anti-Corrosion Products. Winn and Coales (Denso) Ltd., London, England.

   Promotional notebook.

176. deWinton, C.J.P. "Encapress Encapsulation Leak-Sealing System," Gas World, 181:152, March 1976.

   Describes the Press Leakage Control Service LC80 and Encapress.

177. deWinton, C.J.P. "Encapsulation Without Pressure Reduction," Gas World, 179:475, Sept. 1974.

   Describes the Avon BGA method of encapsulation. Previous methods required that the line pressure be reduced to preclude void formation caused by leaking gas.

178. deWinton, C.J.P. "ERS & BTR = Encapsulation," Gas World, 179:193-194, 196, 198, April, 1974.

   Discussion of the early BTR kits, probably renamed "LP2."

179. Detlefsen, Robert J. "Chicago: External Repairs Made with Epoxy Resins," American Gas Journal, pp. 12-4, July, 1957.

   Describes the manual application of epoxy to the face of the bell.

180. Dresser Bell Joint Clamps, Styles 60 and 160. Dresser Manufacturing Company, Bradford, PA.

   Promotional data sheet.

181. "Economical Method of Upgrading Cast Iron Gas Mains," Gas Journal, 346:165-166, May 26, 1971.

   Announcement of Denso-foam.

182. "Encapsulation," Gas World, 174:168-9, Sept. 11, 1971.

   Describes the BTR kit.

183. External Sealing System of Repairing Leaking Cast Iron Joints - Repair of Cast Iron Pipe (Waterpipe - Type) Joints by Heat Shrinkable Tubes. Tokyo Gas Company, Tokyo, Japan, Feb. 1973.

   Provided by Raychem Corp. and describes testing required by Tokyo Gas Co.

184. "External Sealing Technique Used to Repair Joints on Dual Cast-Iron Mains," Gas Digest, pp. 32-3, Sept./Oct. 1978.

   Overview of Avonseal and Weko-seal

185. "Foam (Denso-Foam: Winn and Coales, London)," Gas World, 173:7-9, May 1971.

   Announcement of Denso foam encapsulation.

186. Ford, E. "New Approach to the Repair of Leaking Joints," Gas Journal, 348:29-31, October 13, 1971.

   Description of the early BTR kit.

187. "Gas Industry Uses Cast Iron Joint Repair Service," Part 1 of "Sealing Techniques for Cast Iron Gas Distribution Mains, Joints, and Fittings," Gas Digest (reprint supplied by Ford, Bacon and Davis, Inc.)

   Description of Keyhole method.

188. Gas Repair Sleeve Systems Performance. Laboratory Report No. 5080. Raychem Corporation, Redwood City, CA, January, 1975.

   Describes tests performed during final product development.

189. Gaulin, Richard C. Consolidated Edison Company of New York, New York, NY. Personal conversation of November 6, 1981.

   Discussed ConEdison's experiences with the Gas Repair Sleeve.

190. Geldard, W. P. "Repairs of Breaks in Cast Iron Mains," A.G.A. Proceedings, 1936, pp. 602-5.

   Discussion of variety of clamps, sleeves, and concrete repairs available in 1936. Included comment that weight of the repair may cause the main to break elsewhere.

191. Hansen, R. A. "Cutting the Cost of Cast-Iron Clamping," Pacific Coast Gas Association Proceedings, 1960, 51:77-80.

   Application of Thiokol under the gasket of a standard clamp, and under a mold in locations where a clamp will not fit.

192. Hayre, John. Miller Pipeline Corporation, Indianapolis, IN. Personal conversation of March 10, 1982.

Discussed certain aspects of encapsulation, in particular the differences that resulted in all encapsulation methods because of Standard BGC/PS/LC8.

193. Hayre, John. "Encapsulation Seals Leaking Main, Eliminates Shutdown," Pipeline and Gas Journal, 209:17-18, March 1982.

Discusses the use of an Avon Series Four without the muff to seal a 20-inch main with a leaking tapping sleeve. Example of how encapsulation is not limited to standard fittings and joints.

194. Hickle, W. G. "Keyhole Technique for Externally Sealing Bell and Spigot Joints," American Gas Journal, 196:44-47, 1965.

195. Hilbush, Edward O., III. West Chester Chemical Company, West Chester, PA. Personal conversation of July 16, 1982.

Discussed composition of Phil-lastic material.

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205. Laskey, John. Mil-Mar Associates, Woburn, MA. Personal conversation of December 14, 1981.

   Discussion of Denso-tape as a leak sealing method.

206. "Leaks Sealed and Stopped with New Method," Gas Age Record, 71:76, January 21, 1933.

   Description of the "Antileke" method of concrete encapsulation.

207. Martin, Don. Miller Pipeline Corporation, Indianapolis, IN. Personal conversation of September 4, 1981 and November 13, 1981.

   Discussed all products marketed by ALH Systems, Ltd., to include Avonseal, Weko-Seal and glycol gas conditioning.

208. Mensch, Harold L. Institute of Gas Technology, Chicago, IL.
Personal conversation of December 3, 1981 and correspondence
of February 4, 1982.

Correspondence included a few copies of monthly status reports
of A.G.A. Project PB-37a. These reports were concerned with
external sealing without excavation. No final documentation
exists except for the unpublished final draft received from the
A.G.A.

209. Method of Repairing Internal Surface of Large Tubes (Weko Seal
Method). Translated by Masaaki Sakagami. Tokyo: Tokyo Gas
Company, June 1981.

210. "New Gas Pipe Repair 'Package' Demonstrated," Gas, 35:82-3, July,
1959.

Announcement of Epi-Seal repair kit.

211. "A New Way to Seal Gas Main Joint Leaks," Pipe Line Industry, 41:45,
July, 1974.

General description of Avonseal.

212. Pfefferle, George H. "Distribution of Gasket Pressure in Pipe Joints
and Clamps," Gas Age Record, 73:379-81, 386-8, 393-4, April
21, 1934.

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Dresser Manufacturing Co. Results of tests considering minimum
pressures, gasket cold flow, and chemical resistance. Resulted
in "armored gasket" design.

213. Press Leakage Control Services, Ltd., Brierly Hill, West Midlands,
England.

Promotional brochures entitled LC80, Encapress, MP80 Medium
Pressure Encapsulation System, Encapress Zip-Kit.

214. Richards, K.W.S. "Repair," Gas World, 172:6-10, September 26, 1970.

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and encapsulation development. Recommends reusable molds
rather than Keyhole method. Questioned the corclusion of IGT
Technical Report No. 5.

215. Robinson, Hugh. Raychem Corporation, Menlo Park, CA.
          Personal conversations of October 21, 1981 and October 23,
          1981.

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216. Rosengarten, W.E.J. "Experimental Development of an External Leak
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          discussion of the relative merits of disposable and reusable
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          General description of the Gas Repair Sleeve.

219. Schmidt, C. Larry. "Heat Shrinkable Sleeve for Repairing Cast Iron
          Bell Joints," Pipeline and Gas Journal, 201:40-44, August
          1974.

220. "Sealing Clamp for Leaking Gas or Water Mains," Engineering, 142:268,
          September 4, 1936.

          Describes a segmented external clamp holding a gasket against
          the bell face.

221. "'Self-Healing' Joints for Gas Main," Gas Engineer, 46:206-7,
          September 1929.

          Describes a method to remake joints with rubber gaskets backed
          with lead or cement.

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          England. Correspondence of December 16, 1981.

          Discussed detailed aspects of BTR Silverkits.

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          Pipeline and Gas Journal, 201:60-2, 1974.

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224. Snow, Ken. Dresser Manufacturing Company, Bradford, PA.
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225. Sparks, D.H. "How to Muff it, and Yet Succeed...," Gas World,
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     NJ. Personal conversation of February 2, 1982, and
     correspondence of February 2, 1982, and February 5, 1982.

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228. Vibration Testing of Raychem GRS. Laboratory Report No. 114. Raychem
     Corporation, Redwood City, CA. July 1972.

229. Uzawa, Koji. Tokyo Gas Company, Tokyo, Japan. Personal correspondence
     of April 22, 1982. Translated by Masaaki Sakagami.

     Discussed the various leak-sealing methods used by the Tokyo
     Gas Company.

230. Wilby, F. V. "External Sealing of Bell and Spigot Joints on Cast
     Iron Mains," Gas, 28:69-72, April 1952.

     Manual application of Thiokol sealer and putty.

231. Wright, F. R. "Requirements for Mechanical Pipe Joints," A.G.A.
     Monthly, pp. 77-80, February, 1935.

     Test procedures used for bell joint clamps.

232. Wright, F. R. "Use of Leak Clamps in Repairing Cast Iron Pipe
     Joints," A.G.A. Monthly, pp. 5-8, January 1932.

     General testing procedures.

V. Insertion and Relining

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        September 1973.

        Steel pipe inserted in old cast iron mains to upgrade the New
        York Facilities System.

234. Badner, Tom. Kerotest Manufacturing Company, Pittsburgh, PA.
        Persona' conversation of November 2, 1981.

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235. "Big Plastic Inserts Help Boston Gas Beat the High Cost of Paving,"
        <u>Pipelines</u> <u>and</u> <u>Gas</u> <u>Journal</u>, 198:83-4, October 1971.

        1630 feet of main inserted with Aldyl pipe -Dupont PE2306.

236. Colthorp, Alger B. Insituform of North America, Inc., Memphis, TN.
        Personal conversations of March 5, 1982 and June 14, 1982.
        Correspondence of June 14, 1982.

237. <u>Construction</u> <u>Manual</u> <u>for</u> <u>the</u> <u>Reverse</u> <u>Seal</u> <u>Method</u>. Translated by Masaaki
        Sakagami. Tokyo: Tokyo Gas Company, April 1981.

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        54:243-6, Sept. 17, 1956.

        Describes the use of specially designed pigs to coat a pipeline
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        <u>Pipeline</u> <u>and</u> <u>Gas</u> <u>Journal</u>, 207:22-4, August 1980.

        Upgrading of Michigan Consolidated Gas Company system.

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        <u>World</u>, 179:569-71, Nov. 74.

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VI. Additional References

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ALH Systems, Ltd., Westbury, Wiltshire, England

ALH System, Inc., Chicago, IL

American Gas Association, Arlington, VA

Anderson Development Co., Adrian, MI

Arthur D. Little, Cambridge, MA

Baltimore Gas and Electric Co., Baltimore, MD

Battelle Columbus Laboratories, Columbus, OH

Boston Gas Company, Boston, MA

British Gas Corporation
    London Research Station, London, England
    Engineering Research Station, Newcastle-on-Tyne, England

Brooklyn Union Gas, Brooklyn, NY

BTR Silvertown Ltd., Burton-on-Trent, Staffordshire, England

Cincinnati Gas & Electric Co., Cincinnati, OH

Commonwealth Gas Co., Cambridge, MA

Consolidated Edison Company of New York

Cook's Industrial Lubricants, Linden, NJ

Dresser Manufacturing Division, Bradford, PA

Edmund Nuttall, Ltd., London, England

Evode, Ltd., Stafford, England

Ford, Bacon and Davis, Inc., Monroe, LA

Fuelling, Inc., Decatur, IN

Gas Energy, Inc., Brooklyn, NY

Gas Line Renovators, Inc., Sanford, FL

Gas Research Institute, Chicago, IL

Gollob Analytical Service, Berkeley Heights, NJ

Heath Consultants, Inc., Stoughton, MA

Holyoke Gas & Electrical Dept., Holyoke, MA

Howson-Durion Ltd., Bracknell, England

Insituform (Pipes and Structures), Northampton, England

Insituform of North America, Memphis, TN

Institute of Gas Technology, Chicago, IL

Institution of Gas Engineers, London, England

International Gas Union, Paris, France

Jerto, Inc., Dunellen, NJ

Kerotest Manufacturing Company, Pittsburgh, PA

H.P. Linck, Essen, West Germany

Miller Pipeline Corporation, Indianapolis, IN

3M, Bristol, PA

Mil-Mar Associates, Woburn, MA (Winn and Coates, Ltd.)

New England Gas Association, Boston, MA

Northern Illinois Gas Co., Aurora, IL

Northern Utilities, Portland, ME

Osaka Gas Co., Ltd., Osaka, Japan

Peoples Gas Light & Coke Co., Chicago, IL

Philadelphia Electric Co., Philadelphia, PA

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Press-Seal Gasket Manufacturing Co., Ft. Wayne, Indiana

Public Service of New Jersey, Newark, NJ

Raychem Corporation, Menlo Park, CA

Rees Instruments, Inc., Orange, CA

Shell International Petroleum Co., Ltd., London, England

Tate Pipe Lining Processes, Ltd., Manchester, England

The Society of British Gas Industries, Warwickshire, England

T.D. Williamson, Inc., Tulsa, OK

Thiokol Corporation, Specialty Chemicals Division, Trenton, NJ

Tokyo Gas Co., Ltd., Tokyo, Japan

U.K. Construction and Engineering Ltd., Liverpool, England

U.S. Department of Transportation, Office of Pipeline Safety Regulation, Washington, D.C.

Union Carbide Corporation, Hackensack, NJ

West Chester Chemical Company, West Chester, PA

Winn and Coales, Ltd., London, England

Mr. Chris P. Xenis, New York, NY

Mr. Gene G. Yie, Canton, WA

APPENDIX C - LIST OF RELEVANT PUBLICATIONS

The following publications and journals have contained the majority of the relevant references:

Ameriican Gas Association Monthly

American Gas Asociation Proceedings

Commissioner of Patents and Trademarks

Engineering (London)

Gas

Gas Age (Gas Age Record)

Gas Digest

Gas Engineer

Gas Engineering and Management

Gas Journal

Gas World

Institute of Gas Technology Technical Reports

Institution of Gas Engineers Journal

Oil and Gas Journal

Petroleum Management (Petroleum Engineers for Management)

Pipeline and Gas Journal (American Gas Journal)

Pipeline Industry

Pipes and Pipelines International

APPENDIX D - SUMMARY TABLE OF SEALING TECHNIQUES

I. Gas Conditioning

	A. Humidification	B. Oil Fogging	C. MEG[b] Vaporization
Description	Steam Injection to keep jute moist	Atomize or vaporize oils; fix main dust; swell rubber gaskets	Vaporizing ethylene glycol; swells jute even after drying out
Applicability	Into gas stream without service Interruption	Same.	Same; on mains where jute has dried out
History	In U.S. by several utilities; very few continue. In U.K. by all Gas Boards before using MEG[b] vaporization	In U.S. to fix dust; and some attempts to seal leaks. In U.K. to swell rubber gaskets in mechanical joints.	Developed by British Gas and used throughout the U.K. Several utilities in the U.S. have tried method with mixed results
Manufacturers		Shell (WOB)[c]	ALH Systems, Ltd. Miller Pipeline, Co.
Available Test Results(note a)	Skeen;[79] BGC[d],[56]	IGT[e] Tech Report No. 2[25]	BGC;[47] ConEdison[54,92]
Advantages	No service Interruption No cleaning required Inexpensive Seals leaks as they occur Keeps leaks from getting worse	No service Interruption No cleaning required Inexpensive Lays main dust	No service Interruption No cleaning required Inexpensive Seals leaks as they occur Rehabilitates old jute
Disadvantages	Will not seal all leaks; Continuous; will not work on dry jute; Control problems; Freezing and condensation difficulties; jute must be in good condition	Continuous; Does not seal leaks in Bell/Spigot joints consistently; low pressure only; control problems	Will not seal all leaks; Continuous; Control problems; Jute must be in good condition; not proven effective in U.S.
Conclusions	Good only if begun upon conversion to NG. Not proven effective based on available test.	Only good to lay dust; Ineffective to seal leaks	May be effective in U.K.; but not proven effective for use in U.S. with drier jute.

Notes
a. Superscripts refer to the bibliography in Appendix A.
b. Monoethylene glycol
c. WOB Is a brand name for a fogging oil technique
d. British Gas Corporation
e. Institute of Gas Technology

II. Jute Swellants

	A. Carbo-seal	B. Weasal	C. Saturseal
Description	Contains Diethylene Glycol; swells jute; poured or sprayed.	Same	Liquid polymer that saturates jute before curing
Applicability	Into small diameter mains without service interruption	Same	Presumably fogged into gas stream without service interruption
History	Developed in the 1930's; Auto-seal method of Con-Edison consisted of slowly pouring along pipe invert, discontinued in 1973 because capillary rise of liquid not effective.	Prevalent swellant in in the U.K.: successful application in England, Scotland; do not know if continued after MEG treatment	1939 article announced method; no further documentation
Manufacturers	Union Carbide discontinued the liquid because of a lack of a strong demand	Unknown	Unknown
Available Test Results(note a)	Skeen[79]; IGT Tech Report No. 5[27]; ConEdison[80]	BGC[76]	None
Advantages	No service interruption; No cleaning required; Relatively inexpensive; Fixed dust at same time; No special skills required.	Same	Unknown
Disadvantages	Will not seal all leaks Not permanent; depends on condition of jute; not complete sealing; Interferes with future sealing techniques; does not seal joints with heavily deposited jute.	Same	Unknown
Conclusions	Unreliable, works only if jute is in good condition; No longer manufactured.	Same; Do not know if still manufactured	Not available

Notes
  a. Superscripts refer to the bibliography in Appendix A.

II. Jute Swellants - continued

	D. IGT 2-part Sealant	E. Jerto
Description	Sealant swells jute and cures by one of three methods	Light lubricating oil is sprayed into mains to swell jute; special fittings allow inexpensive re-treatment
Applicability	Into gas mains without service interruption	Same
History	IGT developed for AGA in 1962; tested at NIGas[f] with inconsistent results; no further development; no commercialization; never tested on live main	Oil used as replacement to Carbo-seal. Several utilities have used method.
Manufacturers	Not Applicable	Shell manufacturers the oil. Jerto, Inc. is the contractor
Available Test Results (note a)	NIGas[f,69] AGA[g] Project PB37a[91]	None
Advantages	No service interruption (theoretical); No cleaning required (theoretical)	No service interruption. No cleaning required; special fittings allow inexpensive retreatment; relatively inexpensive
Disadvantages	Not developed; 2-phase may block main if uncontrolled; probably difficult to control polymerization accurately	Retreatment required; may interfere with future sealing techniques; requries jute to be in good condition. Requires excavation to install fittings
Conclusions	Not available; undeveloped; probably be too many difficulties in controlling polymerization; would need excellent quality control; would need positive method of controlling liquid sealant to insure that it would not block the main.	May be effective if jute is in good condition.

Notes
  a. Superscripts refer to the bibliography in Appendix A.
  f. Northern Illinois Gas Company
  g. American Gas Association

III. FIII-and-Drain

	A. Con-Seal ("Never-Leak")	B. CF16	C. Gutentite
Description	Water-based neoprene emulsion; swells jute and neoprene cures blocking leak paths	Water-based bitumen emulsion; swells jute and blocks leak paths	Plastic colloidal solution inpregnated joint packing
Applicability	Fill main with material, pressurize to impregnate jute packing; drain off excess.	Same	Same
History	Developed by ConEdision and West Chester Chemical; full commercialization for over 20 years; only sealed 532 miles of main in 19 years.	Marketed in Europe by Shell from 1968 to 1972	Developed by Milwaukee Gas Light Company in the late 1950's
Manufacturers	West Chester Chemical Ford, Bacon, and Davis (contractor)	Shell, Intl. (discontinued)	Not Applicable
Available Test Results (note a)	IGT Tech. Report No. 5[27]	BGC[1]	None
Advantages	Reliable and effective; limited excavation; rehabilitate all weak areas of system; does not require good jute.	Limited excavation; lower inpregnation pressure than Con-Seal	Limited excavation
Disadvantages	Service interruption; Pretreatment with solvent required 4 months before; line pressure restricted for 2 months; must replace items not able to hold impregnation pressures; may seal present leaks only; large overhead required.	Not effective; Limited to low pressures; shrank upon curing	Not effective; leaks reappeared in a year
Conclusions	Effective but limited by 2 service interruptions; pressure restriction; required use of solvent very expensive	Did not work	Did not work

Notes
a. Superscripts refer to the bibliography in Appendix A.

III. FIII-and-Drain - continued

	D. Gas Phase	E. Evostic	F. Organic Solvent Materials
Description	Two gas phase chemicals react with moisture to form a plug	Bitumen and additives in water-based emulsion; like CF16	Organic-solvent based sealant
Applicability	Sealant in a nitrogen carrier fill the main; sealant is purged after leaks stopped.	Fill main with material; drain off excess.	Same
History	Initiated in early 1970's; patents are now in trust while owners attempt to find sponsors for further development. Currently being represented as a method with a live main.	BGC developed low and medium pressure sealants after CF16. Not developed further	Early attempts at applying all available materials to sealing gas mains; no serious efforts made at commercialization
Manufacturers	A.D.I. Corporation	Evode, Ltd.	3M (EC776)
Available Test Results (note a)	Anderson[96]	BGC[1,111]	None
Advantages	Limited excavation; easy to handle; may be cheaper to use than Con-Seal; lower impregnation pressure No cleaning	Limited excavation; easily removed from services; laboratory development comprehensive	limited excavation; available materials
Disadvantages	Service interruption; expensive chemicals; no definite overall cost advantage over Con-Seal	Service interruption; cleaning required; not fully developed	Toxicity and flammability; venting of solvent vapors after sealing
Conclusions	Unproven by full development; limited by service interruption; no clear cost advantage over proven Con-Seal.	Limited by service interruption; no clear advantage over Con-Seal; not developed fully	Initial response to leaking mains; not serious

Notes
   a. Superscripts refer to the bibliography in Appendix A.

IV. Bridge-The-Gap Manual Methods

	A. Manual Application	B. Weko-Seal	C. Spring-Band
Description	Manually apply synthetic rubber or epoxies into the joint recess; chemical bond	Wide nitrite rubber strip held in place with 2 steel retaining bands. Manually installed; mechanical seal	Steel spring band hold polysulfide liquid polymers against pipe wall; Band removed after curing
Applicability	Large diameter main (20 inch); removed from service and purged	Same; up to 30 psig	Same
History	Early response to necessity. Used when could not excavate	Developed in W. Germany; wide use; replaced most other large diameter methods	Developed by ConEdison; did not lend itself to mass production
Manufacturers	Many	ALH Sytems, Ltd. Miller Pipeline Corp.	ConEdison; Thiokol (material)
Available Test Results (note a)	None	None	Con Edison visual observations[11]
Advantages	Ease of Quality control	Reliable; mechanical seal; limited excavation; seals future leaks; leak test on each joint; no special skills; easy application	Seals all joints; limited excavation
Disadvantages	Service interruption; cleaning required for adhesive bond	Service interruption; cleaning required;	Not reliable; Service interruption; react with odorant; difficulties with mixing and quality control; cleaning required for adhesive bond
Conclusions	Superceded by Weko-Seal	The best available for large diameter mains; limited by service interruption	Not reliable; discontinued

Notes
a. Superscripts refer to the bibliography in Appendix A.

IV. Bridge-The-Gap Manual Methods - continued

	D. Strip-Seal	E. Dresser Internal Clamp	F. PLCS[h], Ltd.
Description	Sandwich of rubber and metal built in place; retaining bands installed; mechanical seal	Buna-N Gasket held in place by segmented follower ring; mechanical seal	Unknown
Applicability	Large diameter main (20 inch); removed from service and purges; up to 35 psig	Same	Same
History	Replaced by Weko-Seal; found to sag from the top	High profile clamp replaced by low profile; available only by special order	Under developement and test awaiting full commercialization
Manufacturer	ALH Systems, Ltd.	Dresser Manufacturing Co.	Press Leakage Control Services, Ltd.
Available Test Results (note a)	None	None	None
Advantages	Seals all joints; limited excavation	Reliable; limited excavation; mechanical seal; seals all joints	Limited excavation
Disadvantages	Not reliable; service interruption; cleaning required; labor intensive	Service interruption; cleaning required	Service interruption
Conclusions	Not reliable; superceded by Weko-Seal; limited by service interruption	More labor intensive than Weko-Seal; may require more skill; supposedly equal in cost to Weko-Seal; limited by service interruption	Deferred until more information received

Notes
 a. Superscripts refer to the bibliography in Appendix A.
 h. Press Leakage Control Services, Ltd.

V. Bridge-The-Gap Machine Methods

	A. Interseal	B. Gasloc	C. Fuelling
Description	Mandrel applies layers of aluminum urethane and burlap to each joint; cleaning done by scrapers and dessicants; adhesive bond	Mandrel "slings" epoxy into recess and across gap; cleaned with 6000 psig water jet; TV control; adhesive bond	Mandrel paddles polysulfide rubber into recess; Cleaning by flails or sand blasting; adhesive bond
Applicability	4-20 inch diameter; 360 feet long without bends, offsets; service interruption, up to 30 psig after 48 hours	Small diameter mains up to 500 feet long; will pass through tees and bends; up to 100 psig after 24 hours	Small diameter; greater than 8 inch; could go through tees, but not around bends; medium pressure after 48 hours.
History	Called "Joint Interne" in Europe. Full commercialization	Originally marketed by C.O.E. Corp; ten years of experience; attempting to expand marketing	Developed in the late 1950's; sold in 1978 to W. German firm; Polysulfide would react with odorant
Manufacturer	Gas Energy, Inc.	Gas Line Renovators, Inc.	Fuelling, Inc. Thiokol (material)
Available Test Results (note a)	None	None	None
Advantages	Reliable; limited excavation; seals all joints; locates all leaks	Reliable; limited excavation; seals all joints; maps interior; effective cleaning method	Limited excavation; seals all joints
Disadvantages	Service interruption; intensive cleaning required for adhesive bond; limited to restricted sections of main	Service interruption intensive cleaning required for adhesive bond	Unreliable; service interruption; intensive cleaning required for adhesive bond
Conclusions	Limited to straight sections of main that can be removed from service; cleaning must be adequate or will not work	More flexible use than Interseal; better cleaning system; limited by service interruption	Unreliable, and no longer available

Notes
a. Superscripts refer to the bibliography in Appendix A.

V. Bridge-The-Gap Machine Methods - continued

	D. Trace	E. "Internal Device"	F. "Apparatus"
Description	Mandrel paddles silicone rubber into recess; cleaned by flails; adhesive bond	Mandrel expands a rubber gasket against pipe; held in place by self-locking steel band; mechanical seal	Mandrel sprays 2-part sealant of section 4.3.4 in live mains
Applicability	6 to 8 inch diameter straight sections of pipe; 200 yards max. length; service interruption; up to 50 psig after 23 hours	Small diameter mains	Small diameter mains without service interruption (theoretical)
History	Developed in the U.K.; water and glycols fouled cleaned area; no further development	Never developed; patent sold and new owners under litigation	As a result of AGA Project PB-37a; never tested
Manufacturer	Tate Pipe Lining Processes, Ltd.	NIGas Original Patent Press-Seal Gasket Manufacturing	IGT Patent
Available Test Results (note a)	None	None	None
Advantages	Limited excavation	Mechanical seal; limited excavation	Without service interruption; limited excavation
Disadvantages	Did not work; service interruption; cleaning inadequate to insure bond	Service interruption; some cleaning is probably necessary	Undeveloped
Conclusions	Did not work because could not maintain high level of cleaning required for adhesive bond	Mechanical seal is in right direction	Depends on success of sealant. Need to prove sealant gets into jute first

Notes
a. Superscripts refer to the bibliography in Appendix A.

VI. External Methods

	A. Manual Methods	B. Concrete Methods	C. Mechanical Clamps
Description	Recaulking or refacing the joint with chemical materials; cleaning required	Concrete bonded to cast iron, and sealed with additives. Gas vented until curing	Follower ring presses gasket against face of bell; mechanical seal
Applicability	To any joint that could be excavated; usually low pressure	Same	Any excavated joint
History	Attempts to reduce cost of clamping; "Epi-Seal" is only commercialized method found.	"Antileke" (1933) used alemite gum pumped into vent to seal concrete; "Leak-Pruf" (1936) used Ivory Flakes; IGT (1960's) used special concrete to control shrinkage, etc.; none used widely	Early clamps cracked, or bolts corroded; gasket must be contained and protected; current clamp uses Buna-S gasket
Manufacturer	Bonded Products, Inc. (Epi-Seal)	Not Applicable	Dresser Manuf. Co.
Available Test Results (note a)	None	None	None
Advantages	No service interruption; use where cannot use clamp	Cheap materials, no service interruption	Reliable No service interruption; used as emergency repair; limited cleaning required
Disadvantages	Excavation required at each joint; cleaning required for adhesive bond; may be brittle at low temperatures	Unreliable; time to cure; excavation; weight may cause main to break; shrinks upon curing	Excavation; limited to standard sizes and shapes.
Conclusion	Initial attempt to cut costs; encapsulation provides more reliable seal	Not a viable alternative. Encapsulation is better seal	Reliable as long as put on right; excavation is largest cost

Notes
  a. Superscripts refer to the bibliography in Appendix A.

VI. External Methods - continued

	D. Encapsulation	E. Keyhole	F. Avonseal
Description	Polymer sealant is contained in disposable or reusable muff or mold. Sealant is injected under pressure; adhesive bond	Earliest form of encapsulation; excavation performed with air lance and vacuum	Strip of thermoplastic material is pressed against bell until cooling and curing; must be grit-blasted
Applicability	Any excavated joint; any configuration can be encapsulated; medium pressure must have external supports for muff	Same; excavation method may be limited by the type of soil	Same
History	All types have approached similar design to be stored on repair truck for use in emergencies. Early Types: Avon Series III Avon BGA BTR Ready-Seal PLCS LC80 Densofoam	Developed in the late 1950's by the Phila. Elect. Co.; still has wide use in the U.S.; BGC did not think excavation as effective as advertised	Initial configuration needed oven to heat strip and special hydraulic harness; Avonseal II is a strip heated in boiling water and compressed by bolt-tightened harness. Avonseal II is only method with full BGC approval
Manufacturers (current methods)	ALH Systems, Ltd (Series IV) BTR Silvertown, Ltd ("Silver-Kits") Press Leakage Control Services, Ltd. (Encapress "Zip-Kit"; Encapress MP80)	Ford, Bacon, and Davis, Inc., West Chester Chemical Co.	ALH Systems, Ltd
Available Test Results (note a)	ALH, Ltd.[167]	None - Long history of use	ALH[167]; BGC/PS/LCB[171]
Advantages	Reliable; easy to use; emergency repair; use for any leak; no interruption of service	Reliable; minimum excavation; no interruption of service	Reliable; easy to install no service interruption
Disadvantages	Excavation; must be grit-blasted	Excavation; contractor necessary; specialized tools; must be grit-blasted	Excavation; specialized equipment necessary
Conclusion	Well engineered for use in field. Only real drawback is required excavation	Reliable if properly cleaned and installed. Minimum excavation reduces costs.	Well engineered and reliable; special equipment usually carried on repair trucks.

Notes
   a. Superscripts refer to the bibliography in Appendix A.

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VI. External Methods - continued

G. Gas Repair Sleeve

Description	Heat-shrinkable sleeve; heat is provided by an open propane torch, or by a catalytic heater; cleaning by scaler, but more extensive than for encapsulation
Applicability	Any excavated joint up to 5 psig; sleeves joined together for larger diameter mains.
History	Current configuration has wide market as an emergency repair method
Manufacturers	Raychem Corp. Nitto CANUSA
Available Test Results (note a)	Raychem[183,188,228]
Advantages	No service interruption; reliable; easy to install; emergency repair; mechanical seal; not as intensive cleaning required; inventory advantages
Disadvantages	Excavation; open flame causes some concern
Conclusion	Reliable repair method; hard to install improperly

Notes
   a. Superscripts refer to the bibliography in Appendix A.

VII. Insertion

	A. Steel/Plastic (PE)[1]	B. Kerotest
Description	Replacing existing main by inserting higher pressure steel or polyethylene replacement inside	Replacing existing main with PE while maintaining service. Cut off each service only once: when attaching to new main
Applicability	Into straight sections of cast iron mains. Service lines must be reconnected	Straight sections of main, 700 feet long without branches
History	Widespread use of both steel and PE; usually intended as a replacement of main than as leak sealing method. Steel must be protected against corrosion	Used in several utilities in suburban locations; found to be too expensive because there must be an excavation at each service. One utility used with branches with potential safety hazards
Manufacturers	Varied	Kerotest Manufacturing Co.
Available Test Results (note a)	None	None
Advantages	Reliable; limited excavation; cheaper than relaying; no cleaning required	Reliable; limited excavation; no cleaning required; only one interruption for each customer
Disadvantages	Service interruption; major capital outlays; special skills required	Safety hazard; expensive; special skills and equipment required; may not be cost effective
Conclusion	Useful as replacement; not as a leak sealing service.	Very limited application to few sites. Safety hazard of high pressure gas in low pressure system. No longer used in U.S.

Notes
   a. Superscripts refer to the bibliography in Appendix A.
   1. Polyethylene Pipe

VIII. Relining

	A. Insituform	B. Howson-Ross	C. Coating With Pigs
Description	A felt liner is turned inside out and is cured with hot water.	Lines pipe interior with nylon film; adhesive added on insertion; cleaning and solvents needed.	Main coated with sealant between two captive pigs; cleaning is essential; adhesive bond.
Applicability	Into straight sections of main; service lines must be reconnected	Same	Usually distribution pipelines with no service lines; main removed from service
History	Tested in England but gas passed between liner and pipe. Attempting to introduce new product into American gas industry. Tokyo Gas cures liner with steam	Tested in England in 1974; modifications supposedly make it effective	Various citations on on successful applications on transmission pipelines
Manufacturers	Insituform, Ltd Tokyo Gas Co., Ltd.	Howson-Durlon, Ltd	Varied
Available Test Results (note a)	None	None	None
Advantages	Limited excavation	Limited excavation	Limited excavation
Disadvantages	Service interruption; cleaning and bonding; untested; specialized skills; probable difficulty in reconnecting services	Same	Same
Conclusion	Maybe useful as a replacement method; probably not as effective with gas as with water mains	Probable difficulties in insuring adhesive coating is uniform; probably restricted to use for main replacement	Not applicable for for distribution mains; Devices may be able to be modified in Phase II.

Notes
    a. Superscripts refer to the bibliography in Appendix A.

Appendix E - LABORATORY TEST OF MONOETHYLENE GLYCOL VAPORIZATION METHOD

E.1 General

ALH Systems, Ltd. markets a method for conditioning natural gas in distribution systems by injecting monoethylene glycol vapors into the gas stream. The glycol vapor is intended to be absorbed by the jute packing which swells, reducing the leakage through the bell and spigot joint. Previous efforts had attempted to swell the jute by injecting diethylene glycol aerosol particles into the gas stream. These previous efforts had failed because of the short distances that the aerosol particles could travel before dropping out of suspension. Monoethylene glycol was favored over diethylene glycol because its higher vapor pressure allowed more glycol to be carried by the natural gas as a vapor. The vapor could travel much farther than would the aerosol particles. However, because of the higher vapor pressure, gas conditioning by monoethylene glycol must be continuous, rather than the periodic treatment by diethylene glycol fogging.

Previous laboratory and field tests of the ALH method were primarily conducted in the U.K., in the distribution system of the British Gas Corporation. The field tests conducted by several utilities in this country have not resulted in any useful data because of procedural errors and because of the difficulty in accurately measuring changes in leakage rates in very complex distribution systems. These tests are more fully described in Section 4.2.3 of the main report. These tests indicate that, although monoethylene glycol conditioning may be effective for leak

reduction in the distribution system of the British Gas Corporation, its performance cannot yet be confirmed for use in the United States.

Laboratory tests that have been performed in this country either used liquid glycol to saturate the test jute, or significantly altered the condition of the jute prior to testing. Under actual conditions, the glycol is carried to the jute as a vapor in very low concentrations. To be accurate, the test should duplicate this condition. Liquid glycol, while accelerating the test, may affect the manner in which the jute responds to the glycol. Under normal conditions, the jute is similar in appearance to rope. It is expected that the spaces between the large twists of the jute are the significant leak paths. Previous tests prepared the jute sample by mechanically working the jute and compacting the fibers into one-half inch diameter tubes. It is expected that one of two effects may have resulted in previous tests. If the leak paths of the jute in the in-situ condition were closed by manipulating or over-compacting, the glycol treatment would appear to be more effective than it would be in actual service. Conversely, if partially-deteriorated jute fibers were crushed and powdered, the laboratory treatment would yield poorer results.

E.2 Research Goal

The goal of the research conducted at M.I.T. is to test jute that is removed from the ConEdison system under the actual conditions that are found in that distribution system. The jute samples are treated by nitrogen partially saturated with ethylene glycol vapor rather than by directly saturating the jute with liquid glycol. The jute samples them-

selves are contained in holders that are geometrically similar to the joints from which the jute was removed.

E.3 Jute Sample Holders and Sample Preparation

The holders are designed to allow the jute to act as if it were still confined in the original joint. Manipulation of the jute is minimized to protect the jute's rope-like structure. Because the orientation of the jute is preserved, the gas flows in the same direction as if the original joint were leaking. The lead backing taken from the joint with the jute was used in the sample holder to uniformly compact the jute sample. The American Gas Association 1929 Specifications[1*] were used in the initial design of the holders which was verified by direct measurement of the actual joints. The design insured that only the jute sample could provide the seal against the test gas, and that leakage around the ends of the sample was eliminated. All pieces of the holder were machined to allow easy passage of the gas to and away from the jute. The sample holder is shown in Figure 30 and Photos 13, 22 and 23.

The jute samples were taken from three joints removed from the ConEdison system sometime in March 1982. The joints were broken apart with a sledge hammer and the jute and lead backing carefully removed and protected until use. The jute was very stiff, and still looked like a rope.

* Superscripts refer to references contained in Section E.10 of this Appendix.

It could be evenly cut using a band saw. In general, the jute was disco-
lored on the surface or coated with manufactured gas condensates. Where
the jute pressed against the wall, its surface was stained a deep blue or
black color. The deep blue color results from the presence of a compound
called "Prussian blue," indicating that hydrocyanic acid in the manufac-
tured gas had corroded the iron of the pipe. (See reference 27 in
Appendix A). The black color may be corrosion, or residual Carbo-seal.
(See Section 4.3.1 of the main report). Where it did not press against the
pipe wall between the larger twists of the jute, the jute was usually
coated with the same deposits as found on the interior of the main. This
condition indicates that the manufactured gas easily passed between the
twists of the jute. For both the dark staining and the surface coating,
fibers in the interior of the jute samples appeared relatively unaffected
by the manufactured gas. A three-inch long section of jute with its adja-
cent lead backing was used in each test sample. (See Photos 8-12.)

The test sample holders were constructed primarily of clear
plexiglas. Glass liners were used to protect the acrylic from aromatic
hydrocarbons or solvents that may remain in the jute samples. Aluminum
inserts were used to simulate the curved sections of the spigot and bell
pipe pieces. (See Photos 13-16.) The lead backing was used to compact
the sample as it had been compacted in the original joint. (See Photos
12, 17 and 18.)

The ends of each jute sample were filled with epoxy to insure that
the gas would not pass around the ends, shortcutting the jute sample. The
individual fibers of the jute sample end were permanently sealed by

allowing liquid epoxy to be absorbed by the fibers before curing. A
second application insured that the fiber ends were completely sealed and
coated by a smooth covering of epoxy. (See Photos 19 and 20.) Epoxy
putty was then forced around the ends of the jute sample and into all
corners of the sample holder. The epoxy was compacted by clamping a
plexiglas cover to the holder. (See Photo 21.) Separate laboratory
tests were conducted to verify that this method of sealing the jute sample
ends was adequate.

E.4 Preliminary Tests with Liquid Glycol Saturation

Before constructing all sample holders and test equipment necessary
to perform tests with glycol vapors, two samples were saturated with liquid
glycol in an accelerated test. If the jute removed from the ConEdison
system had not significantly responded to liquid glycol, then it would not
respond to glycol vapors. Because the liquid glycol-saturated test samples
did show significant reductions in leakage, the glycol vapor test was ini-
tiated as described in Sections E.6 and E.7.

In the preliminary liquid glycol saturation test, the two test
sample holders were filled with liquid glycol for four days and then
drained for three more. The leakage rates of air through the holders were
measured while maintaining an air pressure drop across the sample holders
of six inches of water. Before and after leak measurements showed at least
a 79 percent reduction of leakage over 50 days. The sample holders were

isolated and sealed between leak tests. The results of the leak tests are tabulated in Table 18, and shown graphically in Figure 31.

To insure that the surface tension of the liquid glycol was not contributing to the sealing capabilities of the jute, high pressure air (~15psi) was blown through the sample holders to clear all potential leak paths. The leakage rate increased after the high pressure air test for one sample but decreased for the second.

Leakage was measured by a simple device that measures over time the volume of water displaced by the leaking gas. The device was designed to insure that the pressure drop across the test sample remains constant for each time interval, and is described in Section E.8, Equipment and Discussion.

Concurrently with the test on the two sample holders, jute fibers were saturated by liquid glycol and observed under a microscope. No perceivable change in size was observed in three hours.

E.5 Preliminary Calculations

Preliminary calculations showed that more glycol could be carried to the leaking joint in the actual system in one year than could be absorbed by the jute in the area of the leak. These calculations were performed to insure that the amount of liquid glycol absorbed by the two test samples was of the same order of magnitude as what could be expected to be carried to the joint in a reasonable treatment time. If the amount of glycol carried to the leak had been insignificant compared to the volume of the jute sample, the liquid saturation tests would have been repeated using that amount of glycol to saturate the samples. It was estimated that in ConEdison's system the gas could possibly carry 9.4 cubic centimeters of

glycol to a joint in one year. The jute samples have volumes of approximately 18 cubic centimeters. Therefore, the actual system could carry more glycol to a joint than could be absorbed by the jute samples. The liquid glycol saturation tests were considered to be reasonable, and were not repeated.

Average monthly temperatures for New York City were used in the calculations, and it was assumed that the natural gas was 20 percent saturated with the glycol vapor. This saturation percentage is what was expected to be found in ConEdison's field tests. (See Section 4.2.3 of the main report). Saturation data of glycol in natural gas was taken from Crompton in reference 47 of Appendix A of this report. It was assumed that the leakage rate through the hypothetical joint was 1.87 cubic feet per hour. This value was determined by experience by Gas Energy, Inc. of Brooklyn, NY, in their use of the Interseal method of leak sealing, and is from a conversation recorded as reference 116 in Appendix A of the main report.

E.6 Preliminary Drying Test

As a result of the previous tests, ten additional samples were constructed. As a final check before initiation of the glycol vapor test, the jute in these samples was found to respond to a change in ambient moisture concentrations. By passing dry nitrogen through each sample, the leakage rates increased and the weighus decreased. The hydroxyl radicals of hemicellulose enables it to absorb water or polyols such as ethylene glycol[2]. The desorption of water vapor by the jute inferred that it should also absorb glycol vapor.

All samples were weighed and the leak rate measured. All samples, except No. 2, were treated with dry nitrogen at 0.1 SCFH at a pressure of 5 inches of water to evaporate any moisture in the jute and in the recirculation system. After ten days the ten samples were again weighed and the leakage rates measured. The average leak rate increased 2.4 percent after drying, and the average weight of the sample holder decreased by 0.934 grams, or 11 percent of the approximate average weight of the jute within the sample holders (8.4 grams). The results of these tests are in Table 19.

It can be assumed that the weight decrease and the leak rate increase were the result of evaporation of moisture from the jute. Even though the distribution system from which the sample joints were removed had been converted to dry natural gas 30 years ago, the hydroscopic jute had probably absorbed water vapor from the air in the six months that the joints were in storage. These assumptions are consistent with Section 4.2.1, Humidification, of the main report. Similarly, the weight decrease and leak rate increase could not be attributed to the desorption of volatile hydrocarbons. Most of these substances probably left the jute in the 30 years of exposure to natural gas.

E.7 Glycol Vapor Test

Of the twelve samples, nine were treated with nitrogen partially saturated with glycol vapors at a total flow rate of about 1.0 SCFH and a pressure of about 6-10 inches of water. Two samples were treated with dry nitrogen; one as a test control (Sample No. 12), and one which was

previously saturated with liquid glycol (Sample No. 2). The final sample (Sample No. 1) which had been treated with liquid glycol has been sealed and will be leak tested at the end of the test period.

The recirculating system was designed to bubble nitrogen at near-ambient temperature continuously through a glycol bath maintained at a lower temperature. It was calculated that the saturation temperature of the resulting nitrogen-glycol mixture is approximately equal to the temperature of the glycol bath. By adjusting this temperature, the nitrogen mixture could be maintained between 40 and 70 percent of saturation. (See Figure 32.)

Figure 33 contains the saturation and concentration curves for ethylene glycol vapor in nitrogen and natural gas, and Figure 34 relates the percent of saturation to the ambient and glycol bath temperatures for the test system.

Under the test conditions, the nitrogen at 47 percent of saturation has a glycol concentration of 4.4 mg/ft^3. This concentration is approximately seven times that probably found in the natural gas during the field tests at ConEdison. More discussion concerning concentration comparisons and estimates of glycol absorption by nitrogen bubbles is included in Section E.8, Equipment and Discussion.

Leak measurements of all eleven test samples were made at least once each week using the device described in Section E.8. It was expected that the leakage rates of the nine samples in the partially-saturated recirculating system may initially increase as moisture is desorbed, but they should decrease as the jute absorbs the glycol. The leakage rate

through Sample No. 2 should increase as the liquid glycol in the jute is desorbed by the dry nitrogen. The leakage rate through the control sample should remain relatively constant, perhaps increasing as moisture is desorbed.

After a reasonable period of time, several samples will be removed from the recirculating system, opened up, and the jute analyzed to measure how much glycol has been absorbed.

E.8 Equipment and Discussion

Two separate systems were used in this test: one for dry nitrogen and one for recirculating conditioned nitrogen (See Figure 32). The dry system allowed dry nitrogen to pass through the two control samples arranged in paralled at a very s'ow flow rate at a pressure of about one inch of water.

The nine samples of the recirculating system were arranged in parallel attached to two manifolds with the volume of each about 4200 cubic centimeters. The gas was recirculated by a 0.5 SCFH Dayton Speedair Mini-Compressor Model 4Z026. The filter was removed to avoid absorbing the glycol. This diaphragm pump was selected because of its capacity, but also because it would not introduce petroleum lubricants into the gas stream.

E.8.1 Glycol Bath. As previously described, the test gas was continuously bubbled through liqi id glycol kept at a temperature lower than ambient. The glycol was cooled by passing tap water through a copper coil in the glycol bath. The temperature of the cooling water could be adjusted by mixing hot and cold tap water available in the laboratory. The

temperatures of the laboratory, and the hot and cold water were stable enough on a daily basis for the intended purpose. The water temperature was adjusted to account for seasonal variations in the cold water supply. Care was taken to insure that the test was not invalidated by allowing glycol to condense in the test samples.

Preliminary calculations estimated that under worst case conditions, bubbles containing dry nitrogen would absorb about 50 percent of the glycol that the gas mixture would contain under steady-state conditions. It was also conservatively estimated that it would take less than two and one-half hours before the system would reach steady state. The concentration in the gas mixture would never exceed that which is possible when the saturation temperature is the glycol bath temperature.

In making these estimates, natural convective currents within the gas bubbles are assumed to be negligible. The mass transfer into the bubble is analogous to conduction heat transfer within a sphere for which there are published analytical solutions.[3] The boundary condition is that the glycol vapor partial pressure at the bubble interface is the vapor saturation pressure at the glycol bath temperature. The volume average concentration of the glycol in the gas mixture was calculated by interpolating between the center and the interface concentrations.

The amount of glycol diffusing into the bubble is proportional to the time the bubble takes to reach the top of the bath and inversely proportional to the square of the bubble radius. Without using cine photography, it was impossible to measure the transit times and radii of the bubbles. However, it could be assumed that the bubbles are probably

less than one inch in diameter, and would rise to the surface in a time longer than 0.04 seconds. With these two conditions met, at least 50 percent of the steady-state glycol concentration would be absorbed during the first pass through the glycol bath. During succeeding passes, the mass flux decreases as the concentration asymptotically approaches the steady-state concentration. Continuing this same conservative estimate, the concentration becomes effectively steady (97 percent of steady) in less than two and one half hours after five passes through the bath. This time is insignificant compared to the total duration ot the test.

Steady state conditions result in no mass transfer because the concentration of the gas in the bubble is the same as the vapor saturation concentration at the glycol temperature. If this gas were to contain glycol at a higher concentration than that represented by the glycol temperature, a mass flux would exist between the gas mixture and the liquid, reducing the glycol concentration in the mixture.

E.8.2 Condenser. To remove glycol vapor from the test gas, the gas was passed inside a plexiglas tube which contained a copper tube cooled by cold tap water. The glycol vapors would then condense on the copper tube, the temperature of which was measured by a thermocouple. The condenser was isolated from the gas stream when not needed. Condensation will only occur when the tube wall temperature was less than the saturation temperature of the gas mixture. This condition did not limit the use of the condenser because it was used only to reduce the glycol content from dangerously high to more moderate levels. It was not intended to remove all the glycol from the gas mixture.

The performance of the condenser was verified by estimating the mass flux of glycol from the gas mixture to the copper tube. The mass transfer coefficient was estimated by the analogous heat transfer coefficient for the flow conditions within the condenser annulus. The Chilton-Coburn j-Factors for heat and mass transfer were equated.[3] The heat transfer coefficient was conservatively estimated by assuming laminar flow with fully developed velocity and temperature profiles.[4] Turbulent flow with the velocity profile not fully developed resulted in a higher coefficient. The low Reynolds number flow (Re ~ 16) would be more likely to be laminar than turbulent. By assuming that this copper tube is "wet" with liquid glycol, the mass transfer rate to the tube was estimated at 18 mg/hr. This diffusion rate was more than sufficient to lower the gas mixture glycol concentration which was approximately 4.4 mg/hr under normal test conditions. The heat flux of .he condensing glycol was insignificant compared to the amount of heat the cooling water would be able to remove from the condenser.

E.8.3 Traps. To protect the test samples from liquid glycol that might have accidently been blown into the recirculating system, traps were placed upstream and downstream of the glycol bath (see Figure 32). These traps also removed glycol aerosol particles from the test gas stream. The traps were small cylindrical reservoirs with the tubes from the glycol bath extending through the top about half way down into the cylinders. The other tubes were connected to the sides of the trap near the top. In this configuration, pressure-driven liquid was collected at the bottom of the trap and the gas exited from the top. The tube extending into the trap

forced the gas to make a sharp bend back up to the exit. Because of their mass, aerosol particles would probably not make the bend and would continue downward to the bottom of the trap.

E.8.4 Glycol Measurements. It had been originally planned that the amount of glycol carried by the nitrogen in the recirculating system would have been calculated by measuring the wet-bulb and dry-bulb temperatures of the gas,[3] and using ethylene glycol saturation data provided by the National Physical Laboratory of the United Kingdom.[5] However, upon receipt of the thermophysical data (see Figure 33) from the National Physical Laboratory[5], calculations showed that a wet-bulb thermometer was theoretically infeasible. The vapor pressure and latent heat of vaporization of glycol were too low to accurately measure concentrations of glycol vapors in nitrogen. This conclusion was verified by a simple laboratory test of passing nitrogen across a commercial wet-bulb thermometer soaked with ethylene glycol.

As an alternative to wet-bulb thermometers, dew-point hygrometers of the mirror and lithium chloride varieties had been considered.[6] These devices were disregarded because of cost and because they are calibrated to measure water vapor concentrations rather than concentrations of glycol.

The amount of glycol actually carried by the gas was measured by passing a known volume of test gas through a silica gel gas chromatograph absorption column analyzed at the ConEdison Astoria Laboratory.

Two absorption columns treated with 10 ft^3 of nitrogen and glycol vapors were found to contain 118 and 89 mg of glycol. The average of 10.35 mg/ft^3 is more than twice the amount of glycol estimated to be carried by the gas. For this reason the bubbling of gas through glycol is assumed to be effective.

E.8.5 Leak Rate Measuring Device. A leakage rate measuring device was constructed to insure that a constant pressure drop could be maintained across the sample during testing, simulating leakage from a distribution main (see Figure 35). The nitrogen test gas passing through the sample displaces water from the closed cylinder. The volume of the displaced water over a time interval is the leakage rate through the sample. To insure that the gas pressure drop across the test sample remains constant, the hydrostatic pressure at the measuring device inlet point must remain constant. The displaced water is forced up into a smaller open cylinder where it spills over the top. The hydrostatic pressure at the gas inlet remains constant as the height of the smaller cylinder above the inlet. For all measurements, a pressure drop across the test sample of six inches of water was chosen as a representative gauge pressure of a natural gas distribution main. Before beginning each leakage measurement for each sample, the test gas inflow is adjusted to set the pressure drop at six inches of water. The manifold of the recirculating system was designed to isolate each test sample individually for leakage rate measurements.

E.8.6 Comparative Glycol Concentrations. It was expected that the laboratory test described in this Appendix would show results in a shorter period of time than was possible under field conditions. Figure 33 shows that the nitrogen test gas and natural gas can carry about the same amount of glycol at the same temperature. However, the constant room temperature of the laboratory allowed the test to proceed at a higher temperature than was possible in field tests, allowing the test gas to carry more glycol. In the laboratory, the ambient temperature remained at a relatively steady 80°F, and the glycol temperature was adjusted to 65°F. From Figures 34

and 33 the test gas is shown to be about 47 percent of saturation at a concentration of 4.47 mg/ft.^{3}

The annual average temperature in New York City is 54.1°F,[7] and by taking monthly averages, the average glycol concentration under saturated conditions is 3.21 mg/ft.^{3} As described in Section 4.2.3 of the main report, the saturation condition of the glycol in the natural gas was estimated to be approximately 20 percent. Using an ambient temperature of 54.1°F, natural gas at 20 percent of saturation has a glycol concentration of 0.64 mg, glycol/ft,^{3} or about one seventh the concentration in the M.I.T. test system. If the saturation condition of the natural gas were to increase to 60 percent, the test concentration would still be 2.32 times the field glycol concentration.

E.8.7. Estimate of Mass Transfer into Jute Sample. An estimate of the mass transfer was made to determine if glycol could be expected to diffuse into the jute sample in a reasonable period of time. It was estimated that glycol, once absorbed at the jute surface, would diffuse throughout the jute in both the laboratory and field environments in much less than one hour. Therefore, some other mechanism besides mass transfer must control the reaction of the jute in the presence of glycol.

To estimate the diffusion within the jute, the internal resistance to mass transfer was assumed to be much greater than the surface resistance. Using an analogy of conductive heat transfer into a cylinder[3], the jute, when initially exposed to gas carrying glycol and if there is no surface resistance, could absorb more glycol than carried by the gas. This conclusion was valid under laboratory and field conditions and for

one-eighth inch diameter fiber bundles and three-quarter inch
diameter jute samples. The diffusivity of glycol through jute was conser-
vatively estimated by comparing the diffusivities of glycol and water in
air with the diffusivities of moisture through fiber board and other
construction materials similar in structure to jute.

As a refinement of the previous estimate, the leaking gas was
assumed to flow in a channel formed by the twists of the strands making up
the jute sample. A convection heat transfer analogy was used to estimate
the mass transfer. The Nusselt number for the laminar flow in the channel
was calculated for developing velocity and temperature profiles.[4] It was
assumed that the internal resistance was insignificant compared to the
surface resistance to diffusion. Under laboratory conditions, jute
initially exposed to glycol vapors would absorb mor glycol than the test
gas could carry. Under field conditions, dry jute would absorb more glycol
than the natural gas could carry as long as the leak flow rate was less
than 0.65 ft^3/hr.

This analysis was continued for field conditions where the leak flow
rate was greater than 0.65 ft^3/hr. For this case it was assumed that both
the internal and surface resistances should be considered. An analogy of
conductive heat transfer into a semi-infinite body was used to estimate the
mass transfer into the jute surrounding the leak channel. At a depth of
one quarter inch for a flow rate of 1.87 ft^3/hr, it would take only 15
minutes before the glycol concentration would be 90 percent of the free
stream gas concentration.

As a result of the preceeding calculations, glycol was found to
diffuse into jute in an insignificant amount of time. Another mechanism

besides mass transfer must be responsible for the slow rate at which jute will react to glycol treatment under both field and laboratory conditions. Examples of other mechanisms could be the deterioration of the jute or excessive tar build-up on the jute.

E. 9 Interim Results of the Glycol Vapor Test

As a result of the previously described preliminary tests, the glycol vapor test was initiated and there was a general downward trend in the leakage rates of the nine samples treated with glycol. After 63 days, the average leakage rate for all nine samples decreased by 12.2 percent. However, Samples 3 and 4 had decreases of 36.2 and 22.2 percent respectively. The average leakage rate for the remaining samples (No. 5 through 11) decreased by only 7.3 percent. Concurrently, the leakage from the text control (No. 12) decreased by 4.5 percent. The leakage rate from Sample No. 2 (which had previously been saturated with liquid glycol) increased by 44.0 percent, presumably as glycol is desorbed. The data for all samples are contained in Table 20 and Figure 36. Normalized leakage rates are plotted in Figure 37.

On the basis of these results to date, the leakage rates in this test are not decreasing as rapidly as those in the tests conducted in the British Gas Corporation.[2] The leakage rates can be assumed to decrease exponentially according to the following equation:

$$\frac{Q(t)}{Q_0} = e^{-t/t_0}$$

where $Q(t)$ is the leakage rate at time t, Q_0 is the initial leakage rate,

and t_o is the time constant for the equation. (the time constant, t_o, is the time at which $\frac{Q(t_o)}{Q_o} = \frac{1}{e} = 0.368$). In the British tests, leakage rates from joints made up with new jute decreased 63 percent in only 40 and 100 days. In other words, the time constants for these tests were 40 and 100 days. In tests on joints removed from service, the leakage rates reduced 70 percent in 600 days.[2] This corresponds to a time constant of around 500 days. By roughly approximating the slope of the leakage rate decrease, the time constant for the test at M.I.T. is about 800 days, much longer than the test conducted in England. For this last computation, leakage rates from Samples 5 through 11 were averaged. The data from Samples 3 and 4 (36.2 and 22.2 percent respectively) were not used.

The British tests also concluded that there was a direct relationship between the initial leakage rate and the percentage leakage rate decrease.[2] In the M.I.T. tests to date, there are no strong relationships between initial leakage and percentage decrease. There is, however, indications of an inverse relationship between these two parameters. Samples 3 and 4 which had the greatest percentage decreases were two of the three samples with the lowest initial leakage rates.

There were no strong relationships between leakage and the joints from which the jute samples were removed, or between leakage and the location of the jute samples on the jute ring. However, it is interesting to note that Samples 3 and 4 (with low initial leakage and large decreases) were both removed from the same six inch diameter joint. Samples 9 through 11 were removed from another six inch diameter joint and all had similar initial leakage rates and percentage decreases. Samples 5 through 8 were

removed from one four inch diameter joint, but had greaty varying initial
leakage rates. All had percentage decreases of less than 10 percent.

Upon examination of Figure 37, the normalized leakage rates show an
unexplained peak on day 28 and troughs on days 21 and 35. These wide
variations under ideal laboratory conditions illustrate the sensitivity of
leakage rates to factors other than glycol concentration. Even wider
variations can be expected in the less-than-ideal conditions of a
distribution system.

The glycol vapor test will continue at M.I.T. to try to determine
the actual time constant. Questions that should be answered are whether
this test jute has a much longer time constant than the duration of field
tests conducted at ConEdison, or whether this M.I.T. test has a time
constant similar to the British test, but with a higher asymptotic leakage
rate. The final results of this test will be discussed in a supplementary
report to the Consolidated Edison Company.

E. 10 References

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Table 18

PRELIMINARY TEST RESULTS WITH LIQUID GLYCOL SATURATION.

Date	Leakage Rate (cc/min)		Remarks
	Sample 1	Sample 2	
6/18/82	11,400		Leaking Seam on No. 2
6/22/82		6,056	Seam sealed
6/24/82	4 days soaking		Filled with liquid glycol
6/28/82	3 days draining		Glycol drained out
7/01/82	3,705	428	Leaking Seam on No. 1
7/08/82	1,486 1,375		High Pressure Test to clear "leak paths"
7/15/82		459.1 622.4	High Pressure Test to clear "leak paths"
7/16/82	3,124	537.8	
8/07/82	2,372	474.4	

$$1 - \frac{2,372}{11,400} = 79.2\% \text{ Leak Reduction} \qquad 1 - \frac{474.4}{6,056} = 92.2\% \text{ Leak Reduction}$$

TABLE 19

INITIAL TEST SAMPLE LEAKAGE RATES AND WEIGHTS

Sample Number	Test Before Drying		Test After Drying		Remarks
	Leakage Rate (cc/min)	Weight (gm)	Leakage Rate (cc/min)	Weight (gm)	
2	367	712.75	-	-	#2 not dried with Nitrogen
3	1133	791.74	1332	791.04	
4	2071	795.63	2112	794.84	
5	1765	719.58	1791	730.12*	
6	2765	721.09	2939	720.32	
7	2051	726.30	2189	725.65	
8	2918	710.50	2969	709.73	
9	2836	834.76	2954	833.39	
10	2836	801.99	2847	812.48*	
11	2959	820.16	2734	818.90	
12	2286	854.38	2311	853.22	#12 is test control

Average Increase In Leakage = 2.4%

Average Decrease in Weight: 0.934 grams, or
11.0% of the approximate
initial weight of the jute
sample

*Leaking seams repaired with silicone rubber (RTV), and
these samples are not included in weight calculations.

TABLE 20

GLYCOL VAPOR TEST DATA

DAYS	LEAKAGE RATE (cc/mn)	NORMAL. LEAKAGE RATE	DAYS	LEAKAGE RATE (cc/mn)	NORMAL. LEAKAGE RATE	DAYS	LEAKAGE RATE (cc/mn)	NORMAL. LEAKAGE RATE
	SAMPLE 2	(control)		SAMPLE 3			SAMPLE 4	
1	627	1.000	1	1367	1.000	1	2183	1.000
7	582	.927	7	1255	.918	7	2066	.946
14	627	1.000	14	1071	.784	14	1898	.869
21	673	1.073	21	1071	.783	21	1913	.876
28	750	1.195	28	1087	.795	28	1867	.855
35	704	1.122	35	1056	.772	35	1837	.841
42	811	1.293	42	980	.716	42	1745	.799
49	8.72	1.391	49	949	.694	49	1760	.806
56	826	1.317	56	949	.694	56	1745	.799
63	:03	1.440	63	872	.638	63	1699	.778
	SAMPLE 5			SAMPLE 6			SAMPLE 7	
1	1755	1.000	1	2862	1.000	1	2143	1.000
7	1775	1.012	7	2908	1.016	7	2219	1.036
14	1791	1.020	14	2755	.963	14	2234	1.043
21	1806	1.029	21	2755	.963	21	2112	.986
28	1898	1.082	28	2831	.989	28	2189	1.022
35	1837	1.047	35	2785	.973	35	2097	.979
42	1714	.977	42	2709	.947	42	1990	.929
49	1745	.994	49	2709	.947	49	2051	.957
56	1ь99	.968	56	2632	.920	56	1944	.907
63	1668	.950	63	2663	.93	63	2005	.936

TABLE 20 Continued

GLYCOL VAPOR TEST RESULTS

DAYS	LEAKAGE RATE (cc/mn)	NORMAL. LEAKAGE RATE	DAYS	LEAKAGE RATE (cc/mn)	NORMAL. LEAKAGE RATE	DAYS	LEAKAGE RATE (cc/mn)	NORMAL. LEAKAGE RATE
	SAMPLE 8			SAMPLE 9			SAMPLE 10	
1	3413	1.000	1	3000	1.000	1	2938	1.000
7	3137	.919	7	3092	1.031	7	2893	.984
14	3153	.924	14	2893	.964	14	2816	.958
21	3137	.919	21	2847	.949	21	2770	.943
28	3183	.933	28	2938	.979	28	2862	.974
35	3046	.892	35	2816	.939	35	2648	.901
42	2938	.861	42	2755	.918	42	2724	.927
49	2943	.862	49	2801	.934	49	2709	.922
56	3076	.901	56	2740	.913	56	2709	.922
63	2984	.874	63	2755	.918	63	2678	.912
	SAMPLE 11			SAMPLE 12	(control)			
1	2877	1.000	1	3030	1.000			
7	2938	1.021	7	2969	.980			
14	2984	1.037	14	2969	.980			
21	2938	1.021	21	3046	1.005			
28	2954	1.027	28	2969	.980			
35	2877	1.000	35	2801	.924			
42	2862	.995	42	2938	.970			
49	2801	.974	49	2908	.960			
56	2847	.99	56	2877	.950			
63	2785	.968	63	2893	.955			

FIGURE 30 JUTE SAMPLE HOLDER

GAS OUTLET

PLEXIGLAS

LEAD BACKING

GLASS LINER

ENDS SEALED WITH EPOXY

JUTE SAMPLE

ALUMINUM SPIGOT PIECE

BELL PIECE

GAS INLET

SECTION A-A

A

SPIGOT

LEAD BACKING

JUTE

BELL

CAST IRON BELL JOINT
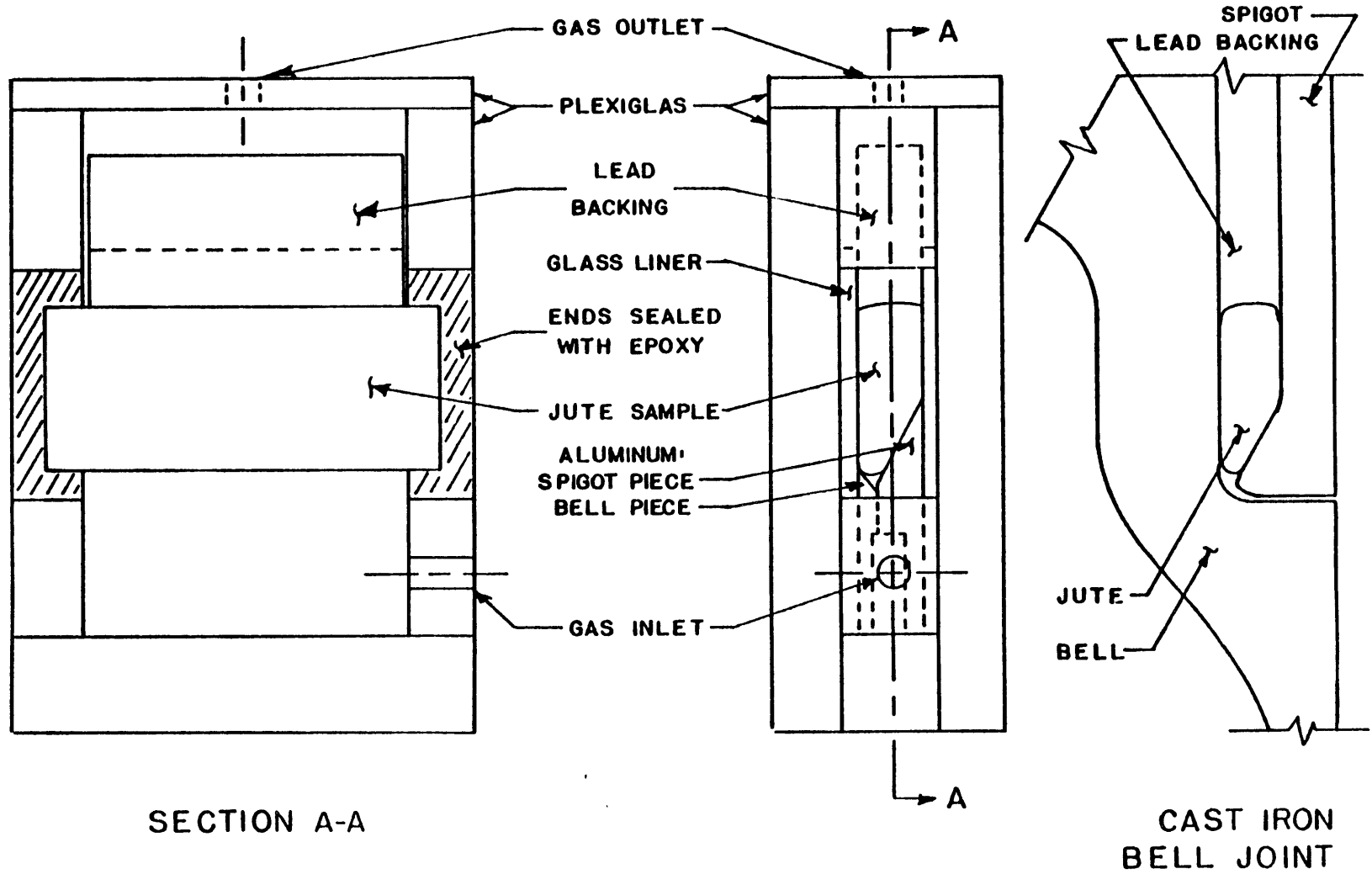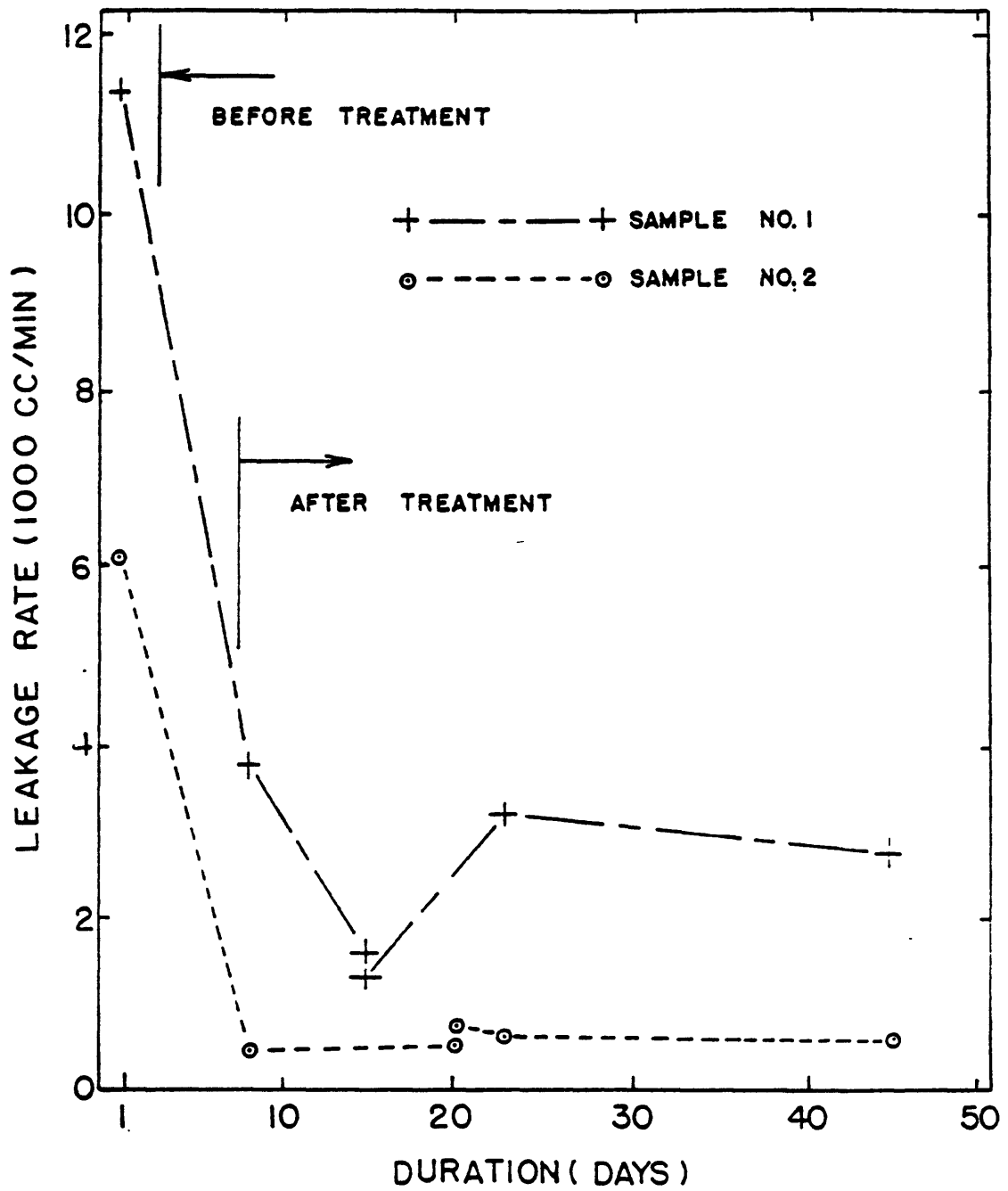
FIGURE 31   SATURATION TEST RESULTS
LIQUID ETHYLENE GLYCOL

-333-
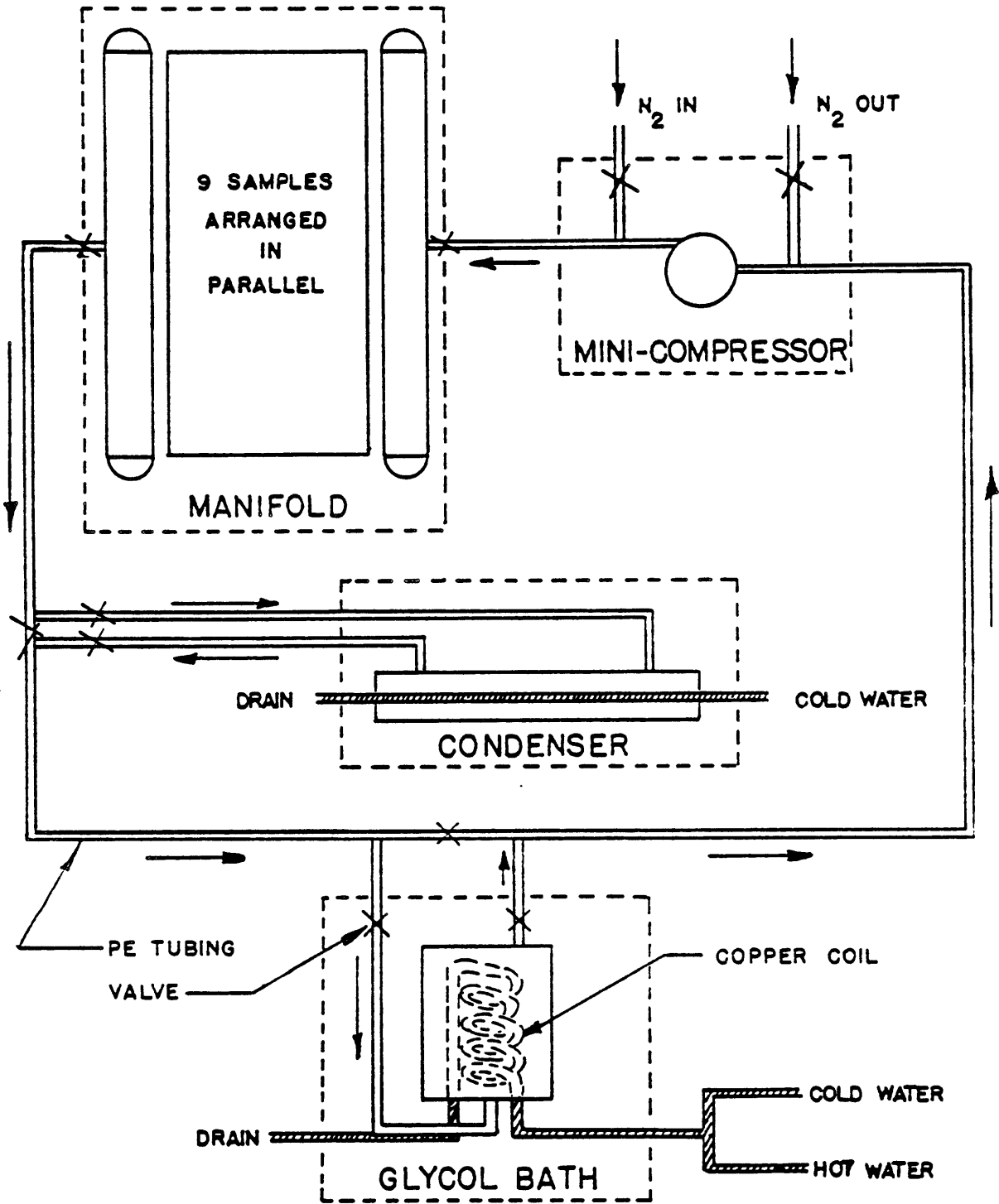
FIGURE 32 RECIRCULATING SYSTEM SCHEMATIC
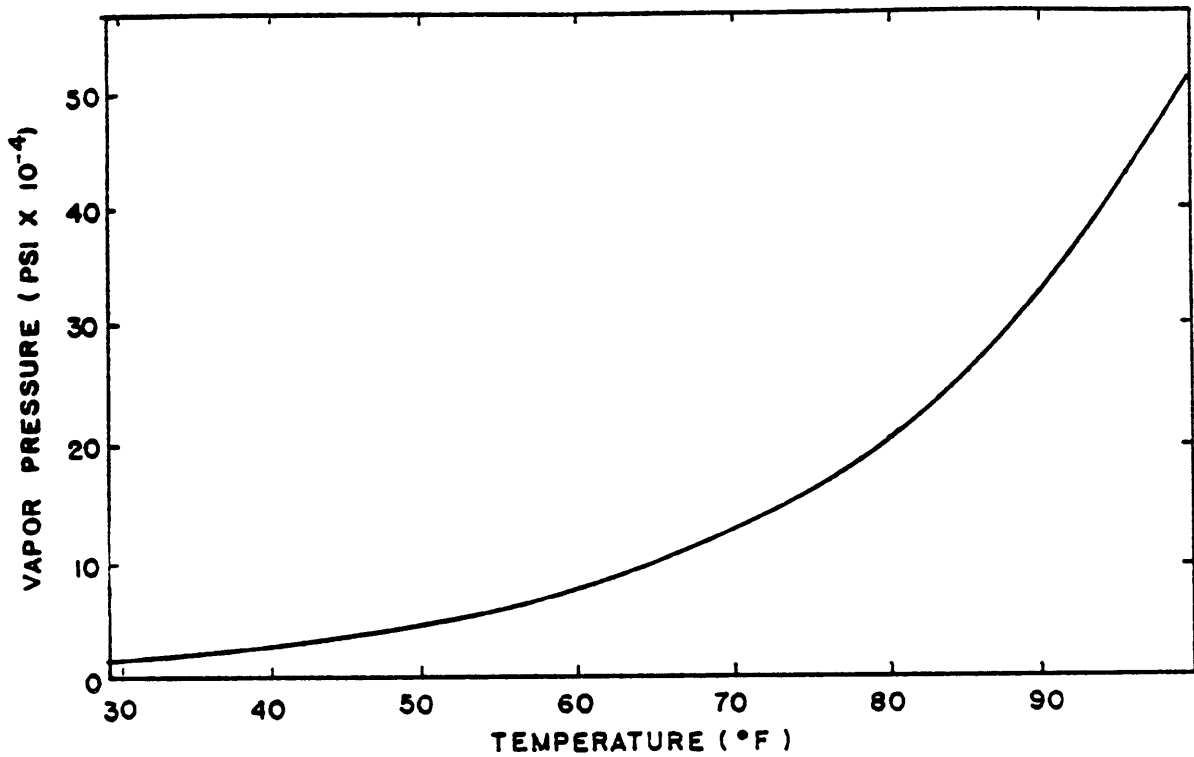
SATURATION CURVE (REF. 5, APP. E)
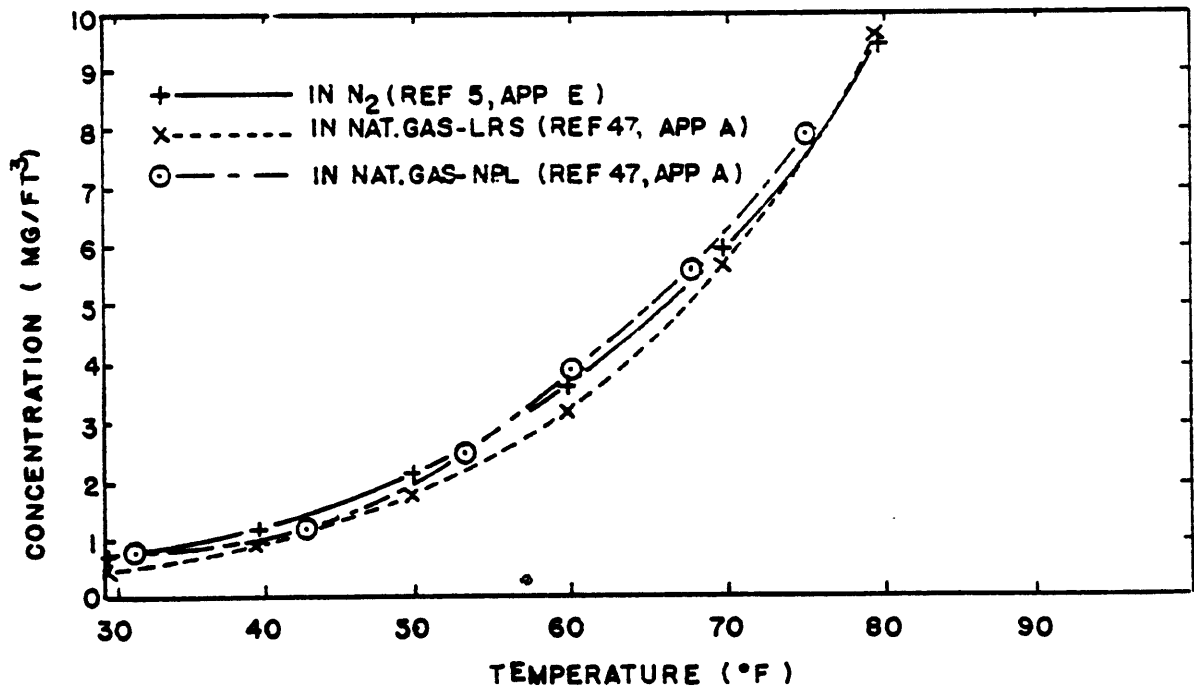
CONCENTRATION CURVES AT SATURATION

FIGURE 33 ETHYLENE GLYCOL SATURATION CURVES
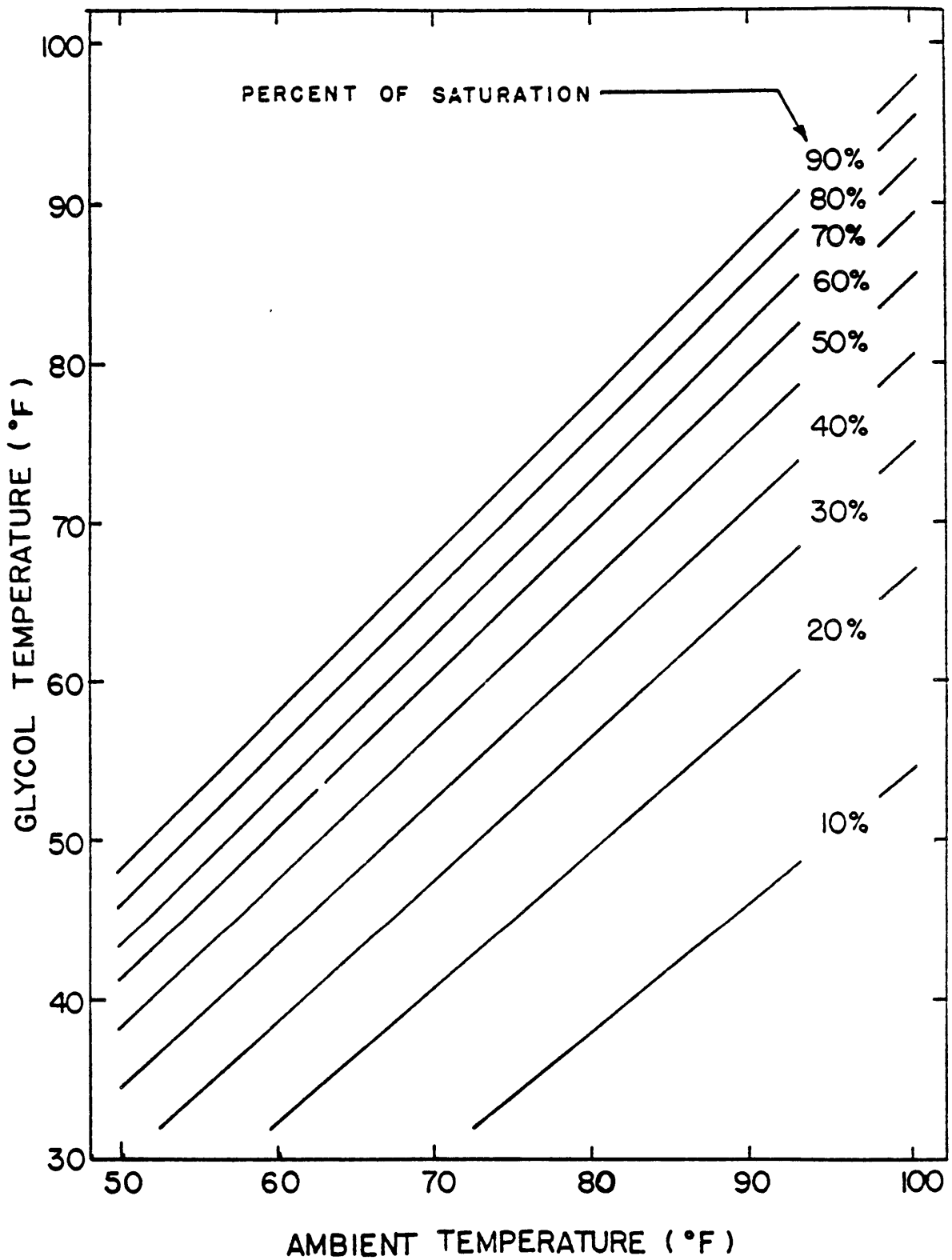
FIGURE 34 GLYCOL AND AMBIENT TEMPERATURES
FOR DIFFERENT SATURATION CONDITIONS
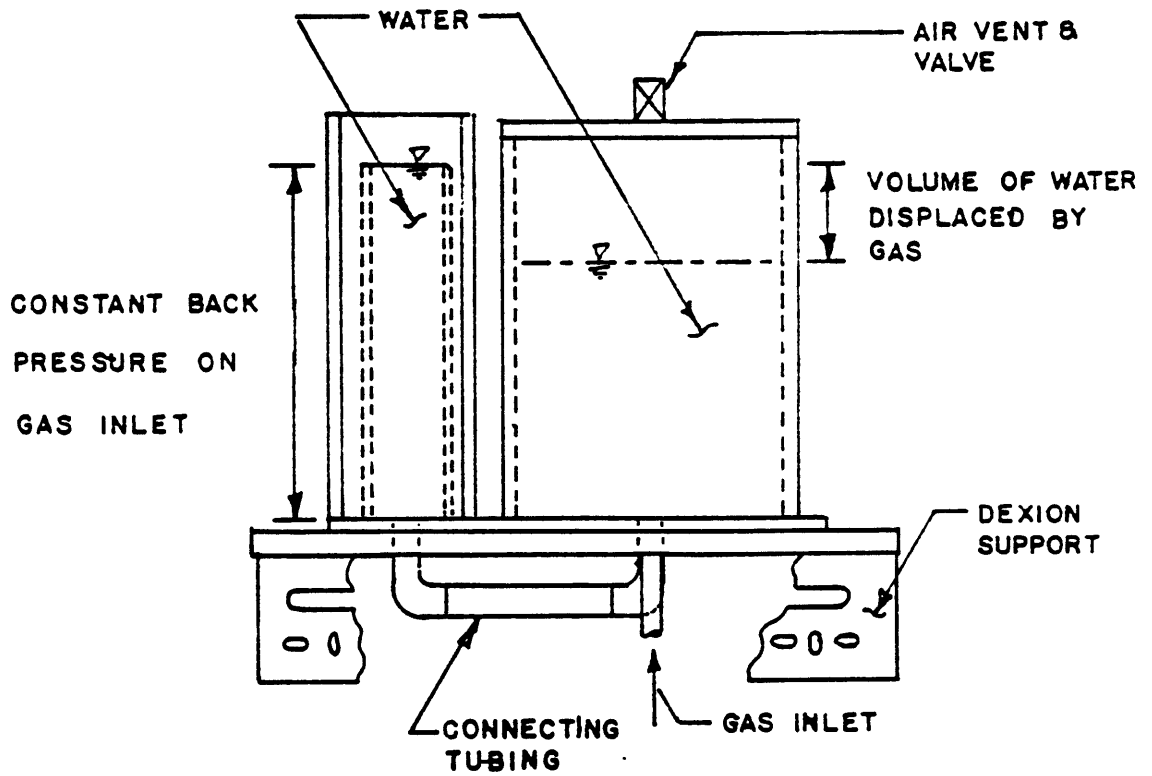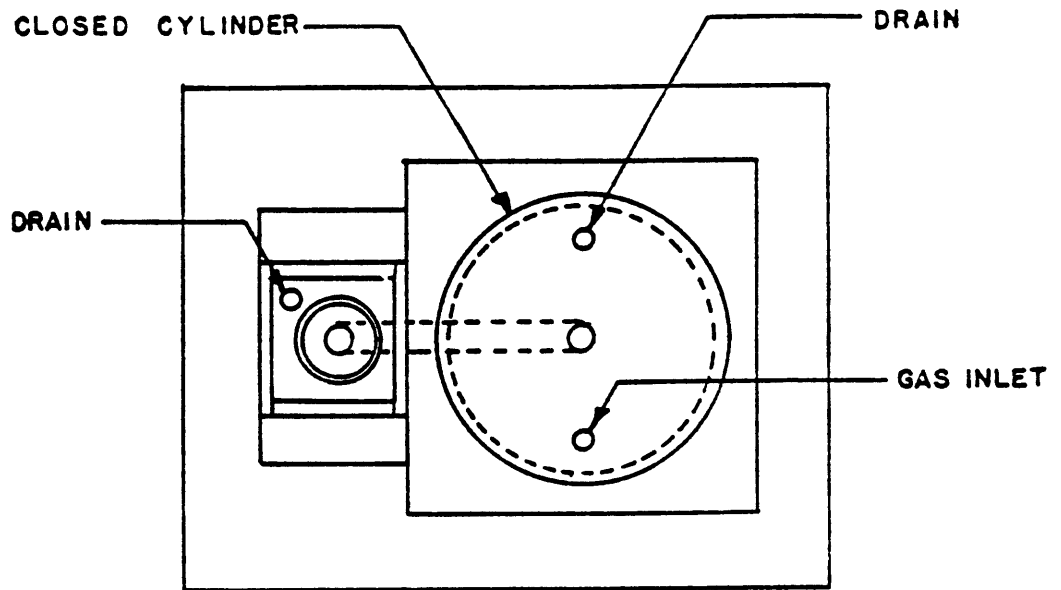
FIGURE 35   LEAKAGE RATE MEASURING DEVICE
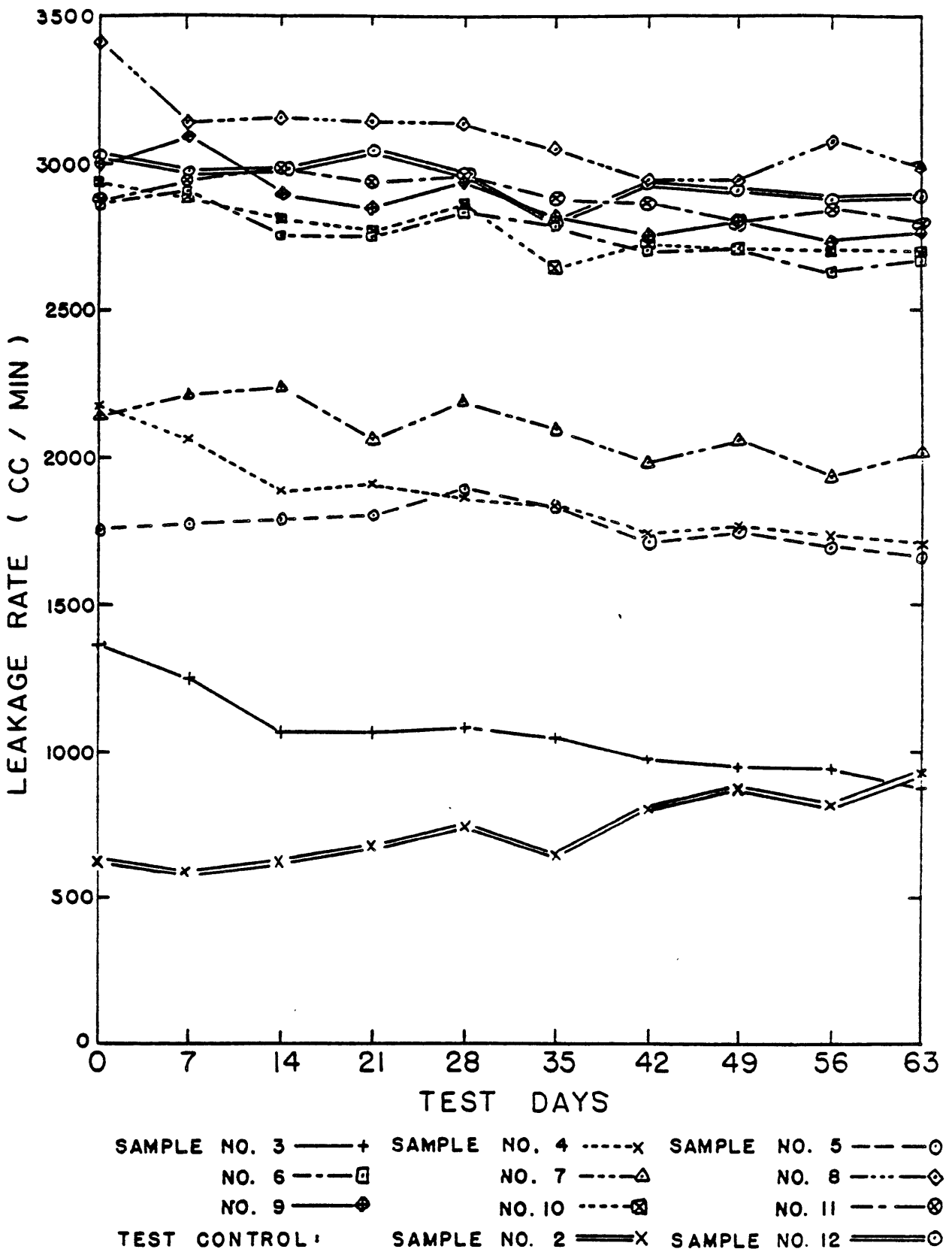
FIGURE 36 GLYCOL VAPOR TEST RESULTS
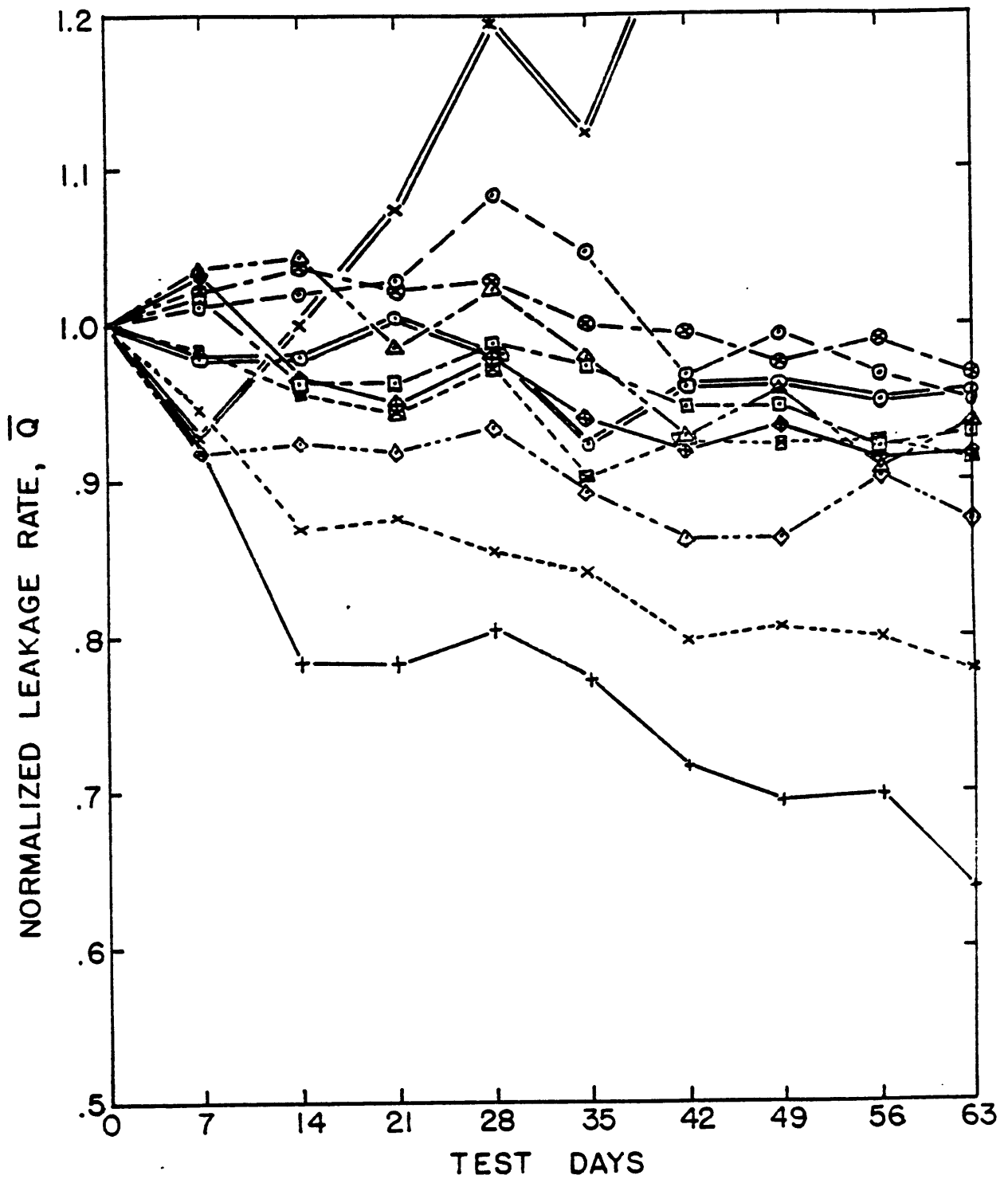
$$\overline{Q} = \frac{Q_M}{Q_{INITIAL}} \quad , \text{ WHERE } Q_M \text{ IS THE LEAKAGE RATE AT DAY } M$$

FIGURE 37   NORMALIZED RESULTS OF GLYCOL VAPOR
          TEST
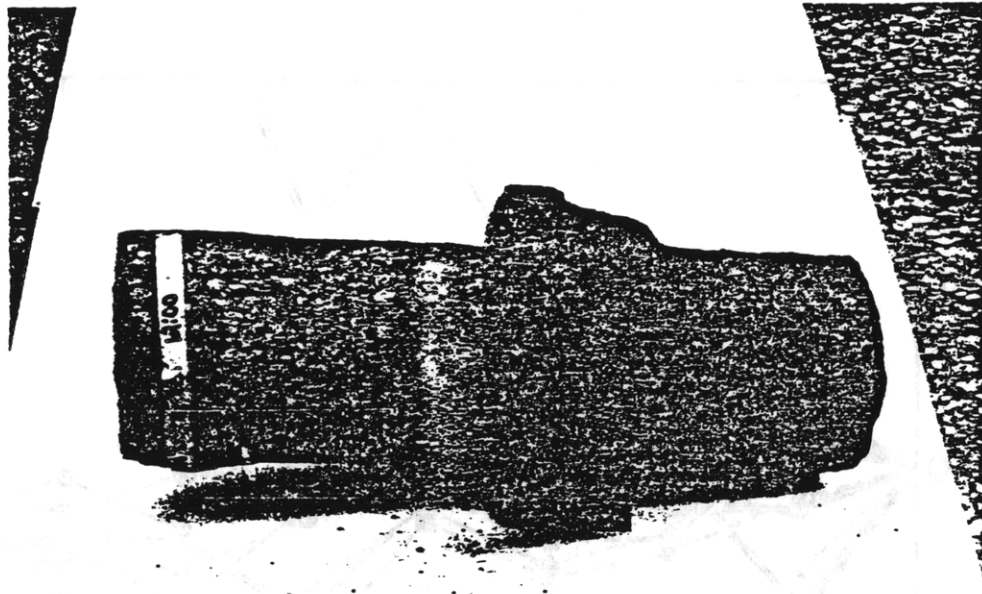
Photo 8   6 inch Cast Iron Bell-and-Spigot Joint
Removed from the ConEdison system
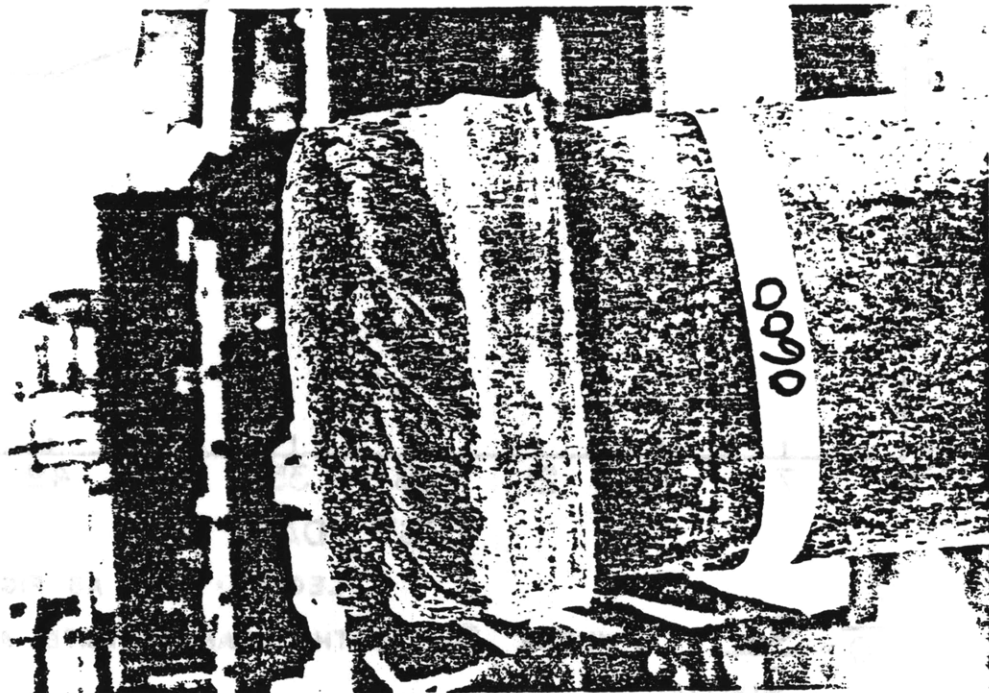
Photo 9   Jute Packing around the spigot at the
Bottom of the Pipe
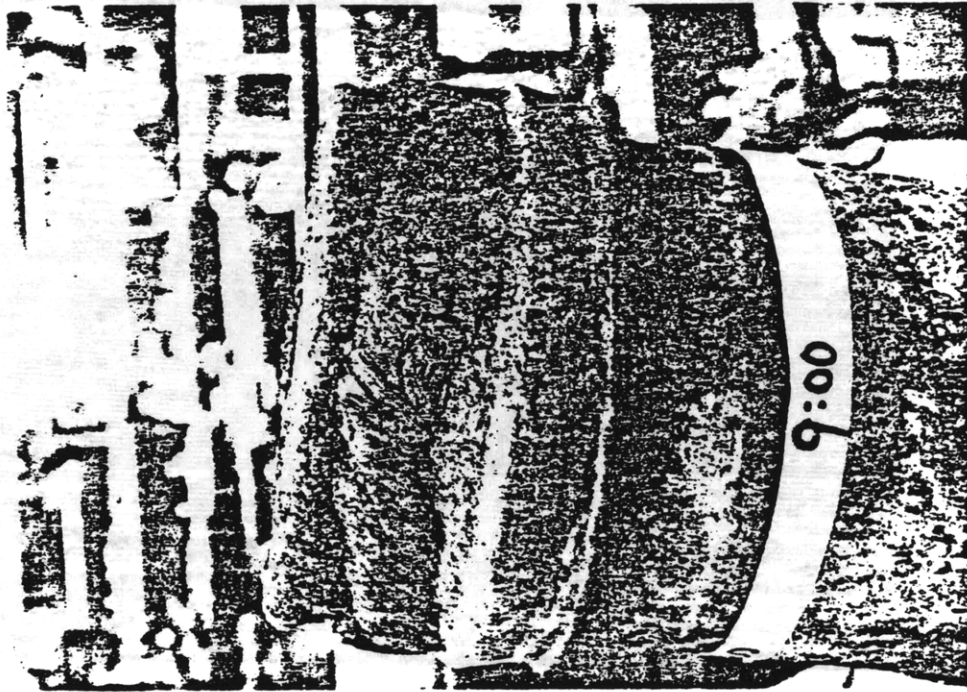
Photo 10 Jute Packing on the side of the Pipe
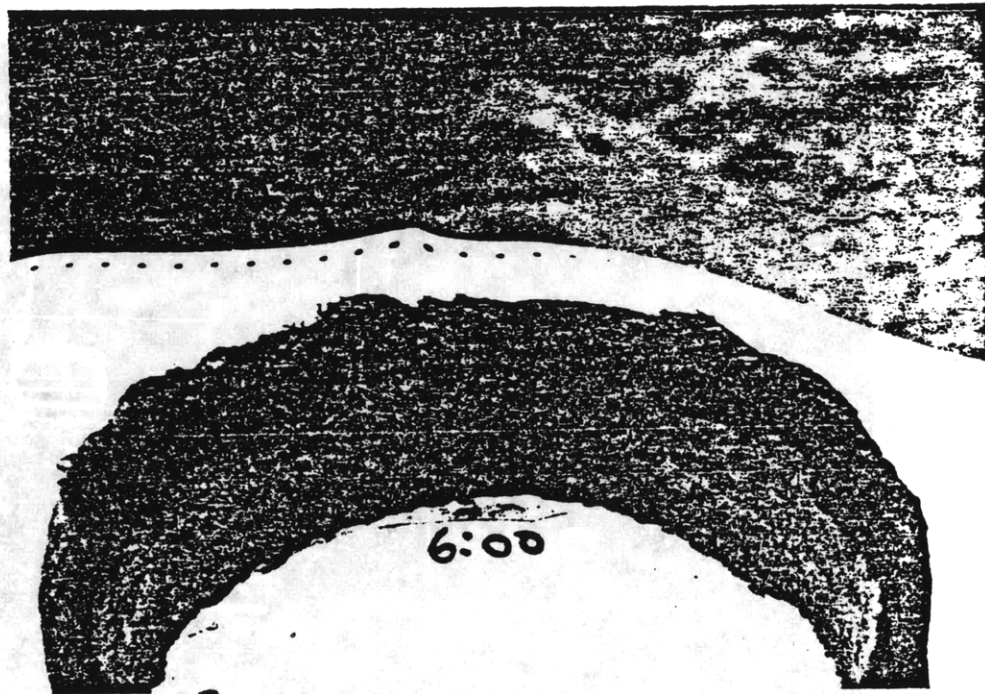
Photo 11 Jute and Lead Ring from the Bottom of the Pipe.
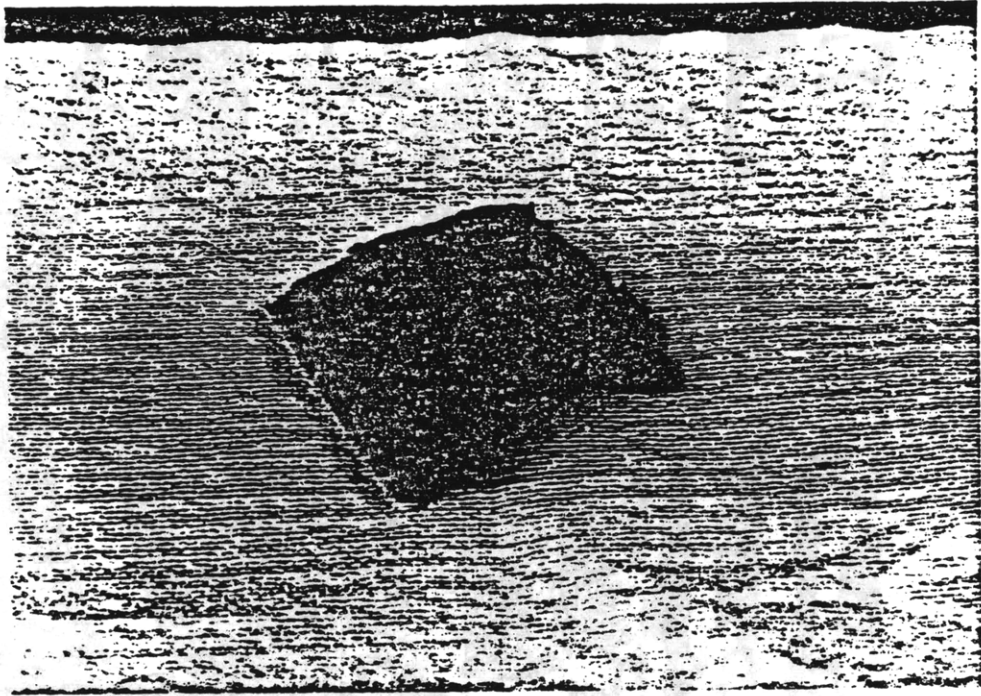
Photo 12   Sample No. 12 (Control) Jute and Backing.
This sample was between 7:00 and 8:30
of photos E.2 and E.3.
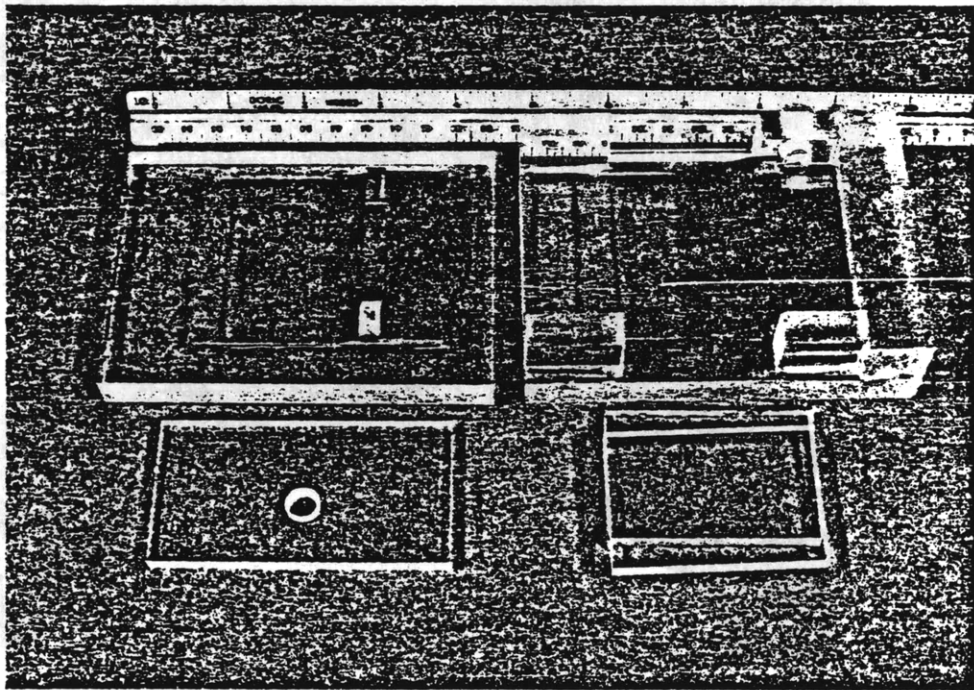
Photo 13   Sample Holder Pieces
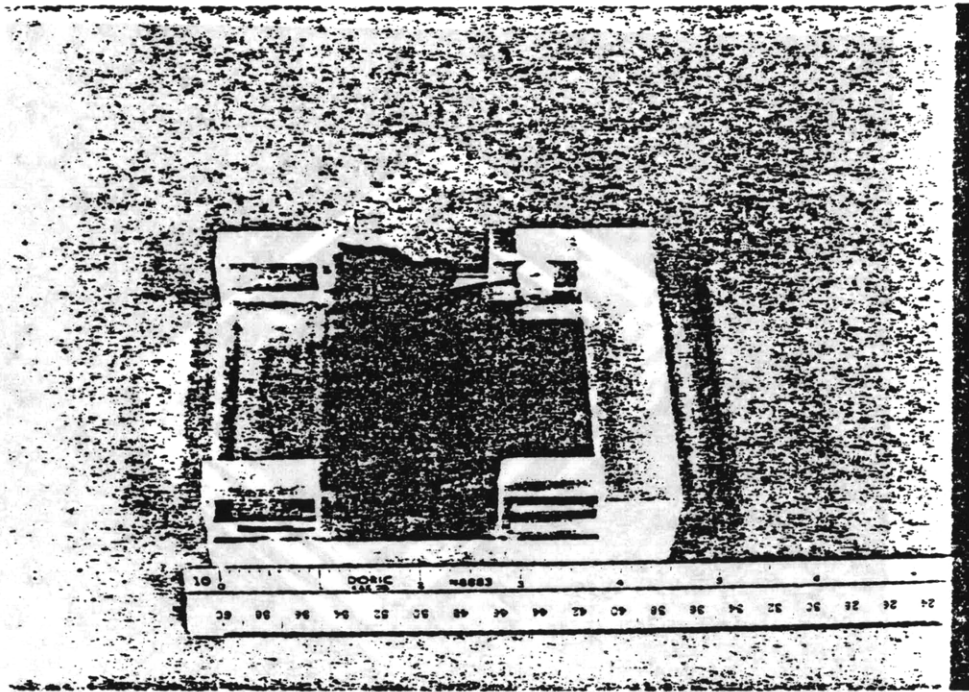
Photo 14   Sample Holder with Jute Sample
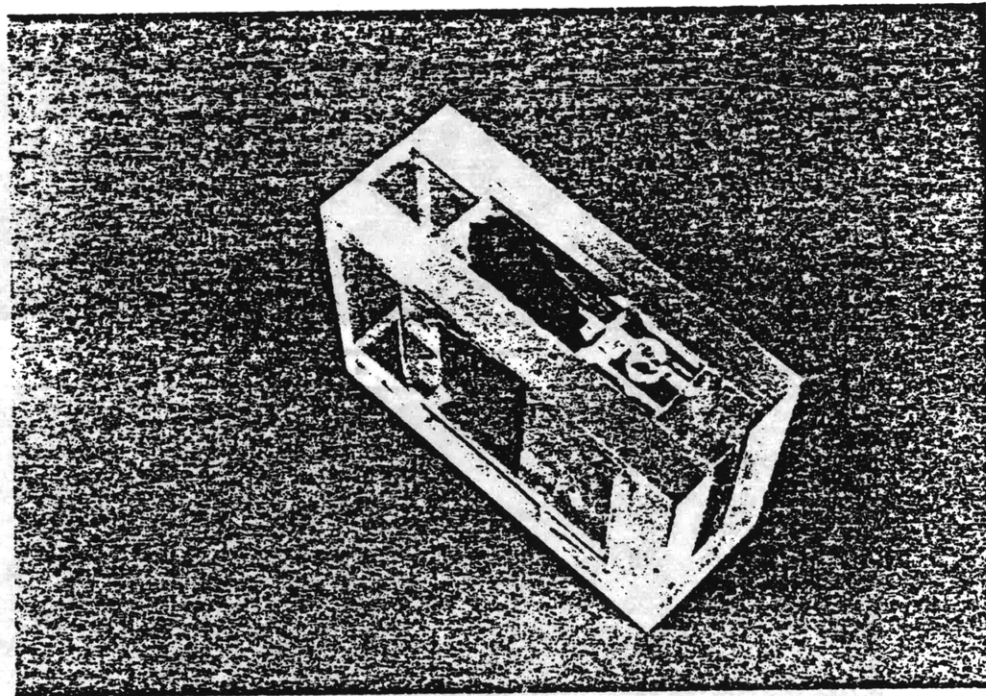
Photo 15   Sample Holder with Front and Back
Plates Joined
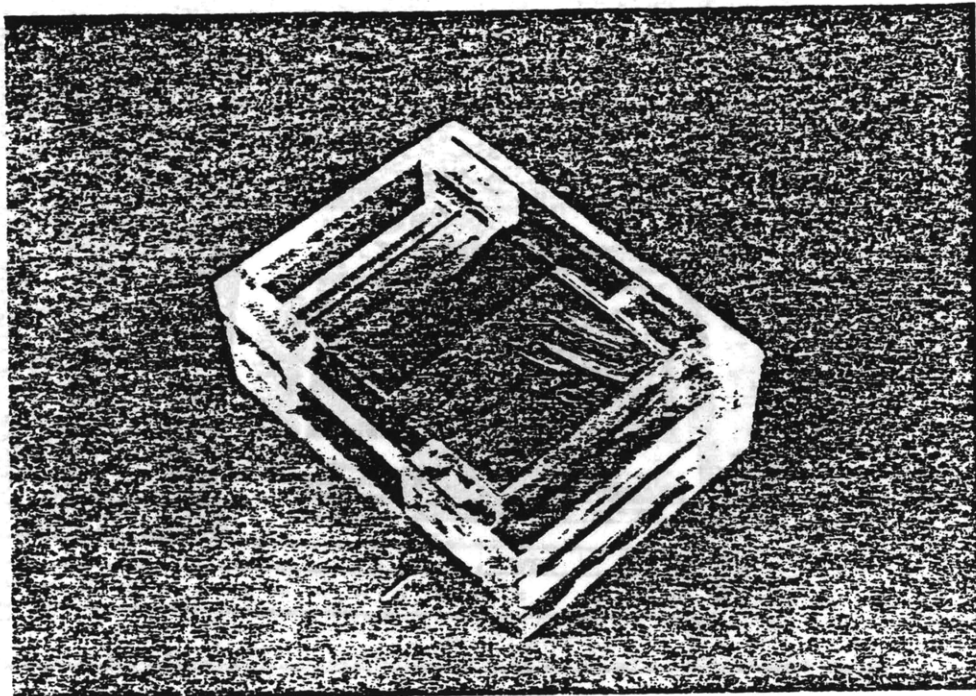
Photo 16   Sample Holder with Front and Back
            Plates Joined
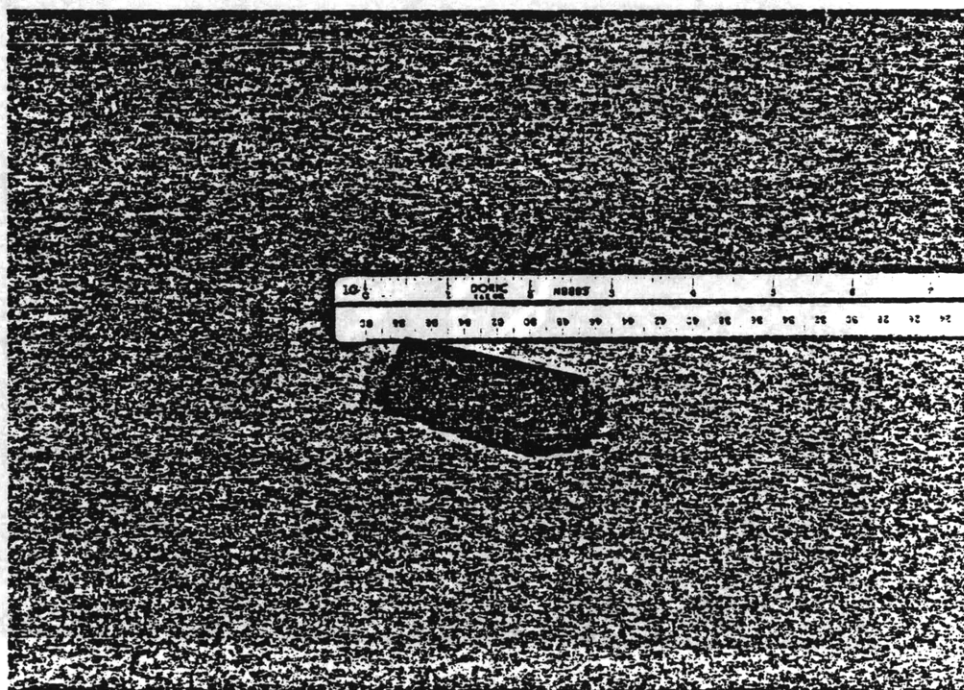
Photo 17   Lead Backing Cut to Size
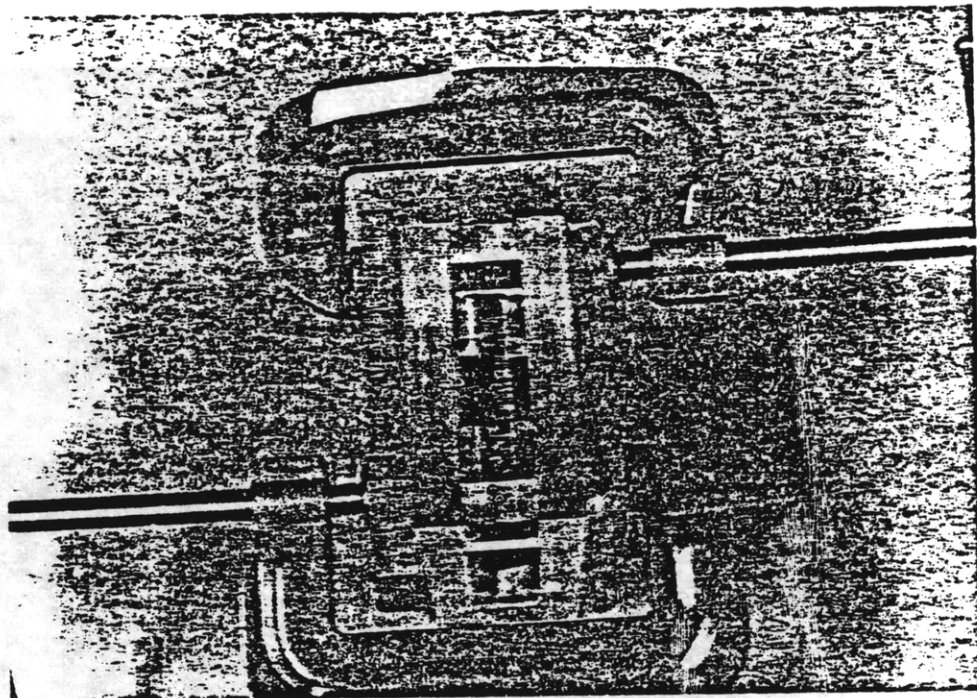
Photo 18 Details of Lead Backing Held in Place by Small Pieces of Acrylic.
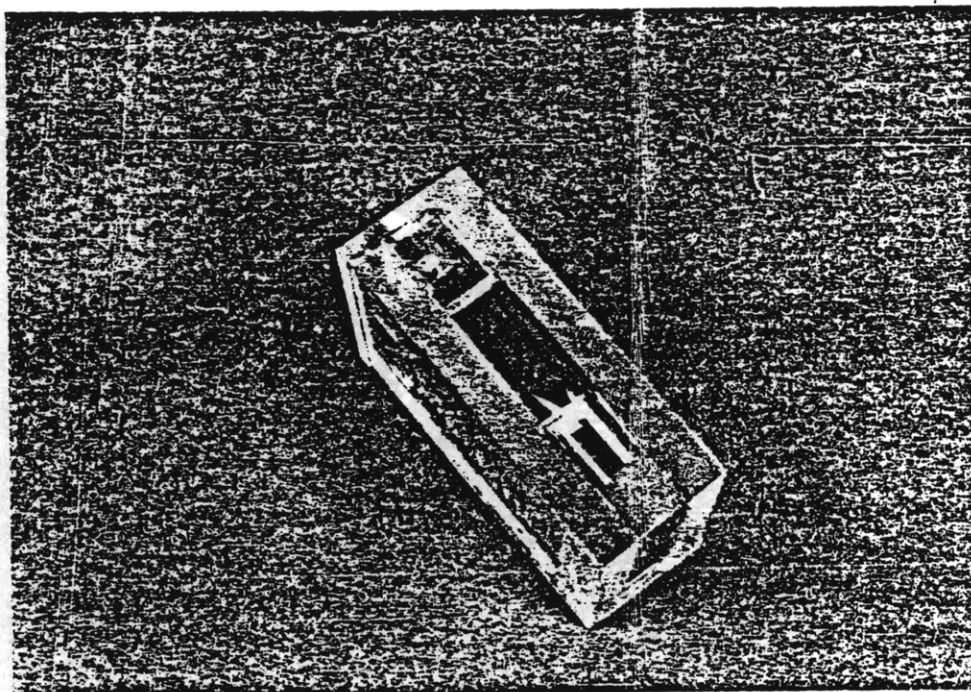
Photo 19 Jute Ends Ready for Sealing
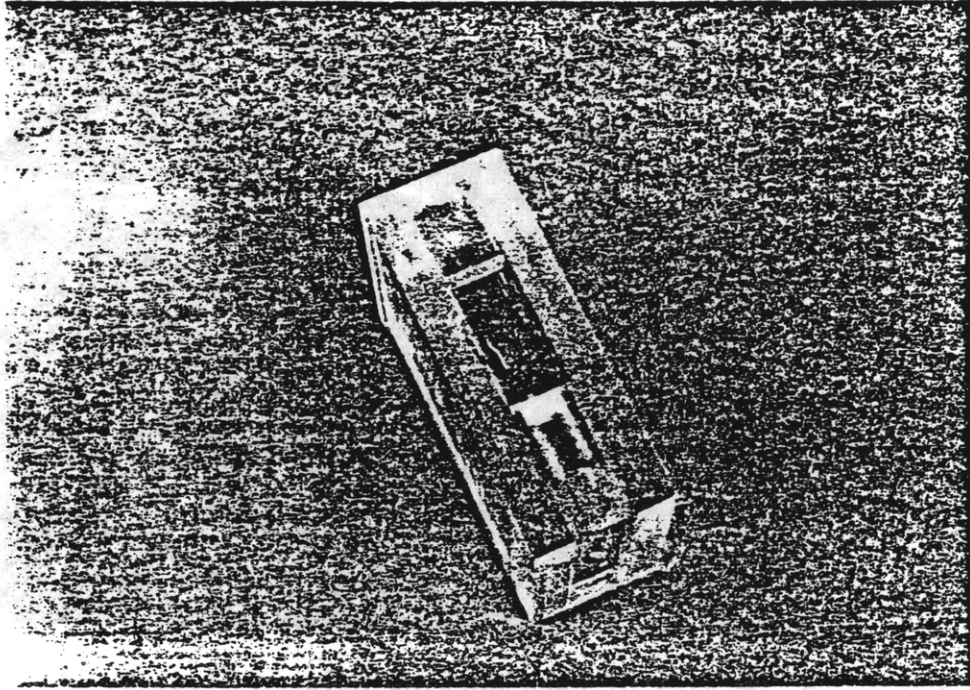
Photo 20   Jute Ends Sealed with Liquid Epoxy
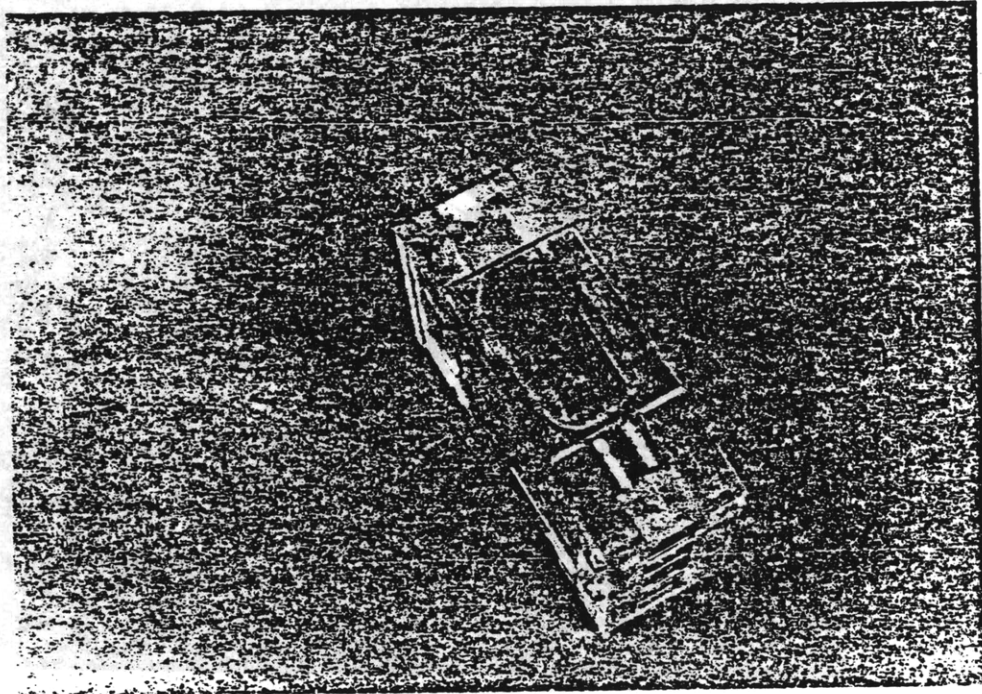
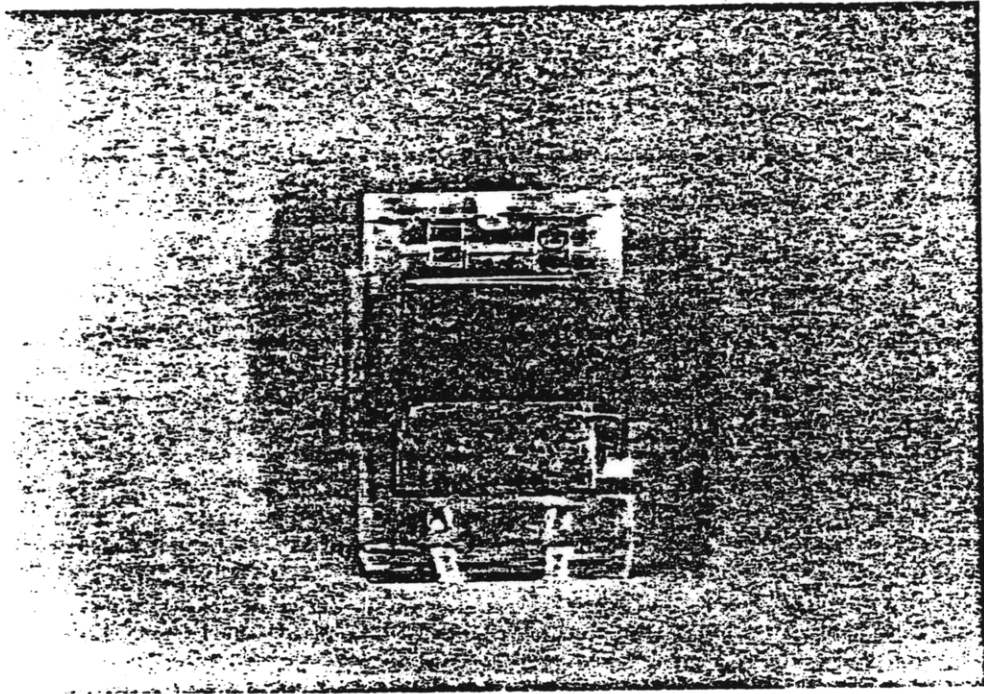Photo 21   Jute Ends Sealed with Epoxy Putty and Covered with a Piece
of Acrylic

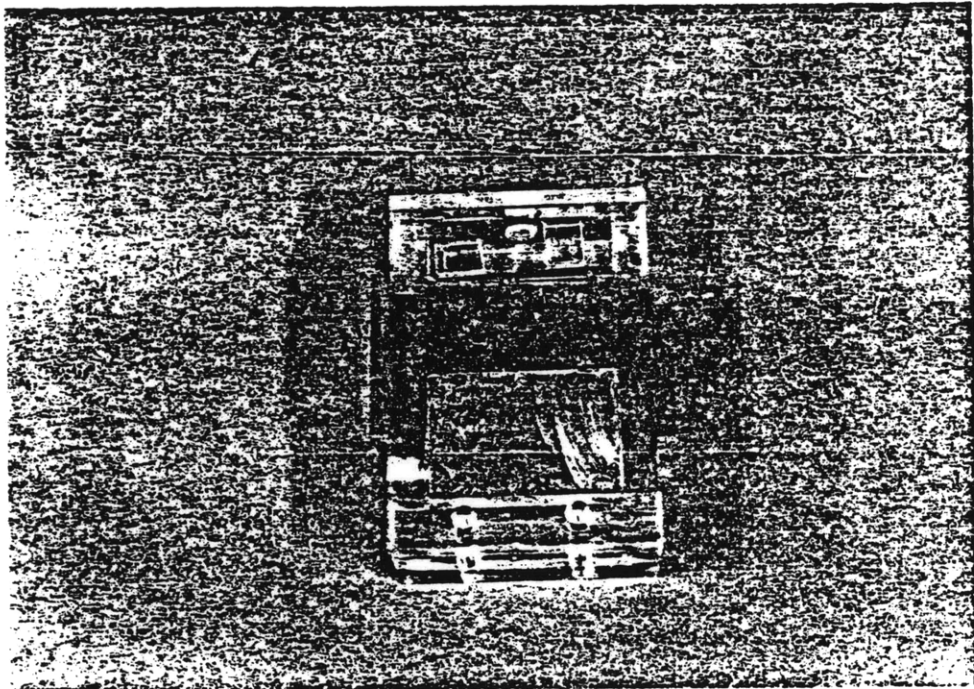Photo 22   Front of Completed Sample No. 12.

Photo 23   Back of Completed Sample No. 12.

APPENDIX F - REFERENCES FOR PART TWO

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APPENDIX G   EQUIPMENT

This Appendix contains detailed information about the equipment used in Chapter 7.0 of this thesis to aid in the duplication of the experiments. This Appendix describes the profilometer used to measure surface roughness, and a cleaning stand used to measure the force required to clean pieces of pipe.

G.1 Profilometer

G.1.1 General Description. As described in Section 7.3.2, a stylus at the end of acantilevered aluminum strip was used to record the surface profile of a piece of cast iron. The vertical defection at the end of the strip was measured by two strain gages fastened to the aluminum strip. The support end of the strip was held rigid by the chuck of a milling machine. The cast iron piece to be measured was bolted to the milling machine table. Figure 38 contains a sketch of the profilometer, which is also shown in Photo 1.

The two strain gages were connected as two adjacent arms of a Wheatstone Bridge circuit. Section G.1.2 contains more information on the circuitry. The output from the bridge circuit was amplified and recorded on strip charts by a Sanborn Model 321 Dual Channel Carrier Amplifier-Recorder. Both this recorder, and the aluminum strip with strain gages, were borrowed from the Materials Processing Laboratory at MIT.

6.1.2 Strain Gages and Circuitry. A Wheatstone Bridge circuit was used to convert resistance changes in the strain gages to changes in voltage. The output signal from the bridge circuit was doubled by using two strain gages located on top and bottom of the cantilever strip.[16] (See Figure 38.) This gage arrangement also eliminated any torsional components of strain. The sensitivity was maximized for a two-active arm circuit by placing the gages in the R_1 and R_4 positions. (Refer to Figure 39.) The sensitivity of this arrangement approaches that of a four-active-arm bridge which is the most sensitive possible.[16] No temperature compensation dummy gages were used in this application.

All circuitry needed to use the bridge, except for the resistance arms were contained in the Sanborn Recorder. The strain gages had nominal resistances of 500 Ω. Trim potentiometers adjusted to 500 Ω were used as the other two arms of the bridge circuit. A five-prong hex connector attached the gage leads to the other two resistors located in a shielded aluminum box attached to the cantilever assembly. (See Photo 1.) A shielded cable connected the circuit to the recorder using Amphenol MS 3101-14S-5S connectors on each end. A complete diagram including connector pin designations is in Figure 39.

6.1.3 Calibration. The profilometer was calibrated by pulling the probe over feeler gages of known thicknesses. It was found that a vertical deflection of .002 inches of the stylus would be recorded as one division on the recorder. This sensitivity was found to be more than adequate for the rough surfaces measured.

6.1.4 Other Methods. Several other commercial methods of measuring roughness were investigated. In both cases, the devices required planar test samples and could not have been modified to accept curved pieces of pipe. Both devices had sensitivities far in excess (± 25 microns) of what was needed for this application.

G.2 Cleaning Stand

G.2.1 General Description. The cleaning stand was used to record the radial and tangential forces of a cleaning wheel as described in Sections 7.4.3 and 7.4.4. The pieces of cast iron pipe to be cleaned were bolted to a flat steel plate which was in turn fastened to a milling table dynamometer. The dynamometer was mounted on a milling machine table. The flat steel plate was a platform designed to hold down pieces from 3 inch, 4 inch, and 6 inch diameter mains. The bolting mechanism was adjustable for any configuration pipe piece from 3 inches to one foot in length. Wood pieces cradled the pipe piece deforming to irregularities on the outside of the pipe piece. Figure 5 is a representation of the cleaning stand and Photo 2 shows a piece of pipe being cleaned by a radial wire wheel.

G.2.2 Required Equipment. The dynamometer was borrowed from the Material Processing Laboratory at MIT. Weights were placed on the dynamometer to calibrate it. Calibration curves used for cleaning are Figures 40 and 41 for horizontal and vertical forces respectively. A Sanborn Model 321 Dual Channel Carrier Amplifier-Recorder was borrowed from the Material Processing Laboratory to record the output from the dynamometer. The right channel was used for vertical (radial) measurements and the left for horizontal (tangential). A Bridgeport milling machine was used to support the dynamometer and to power the cleaning wheel. The electric motor was rated at 1/2 horsepower at 960 rpm. The belt drive of the machine reduced the shaft speed to 723 rpm. A stoboscope tachometer was used to measure shaft speed. Even when the cleaning wheel exerted very high loads on the pipe piece, the speed did not decrease.
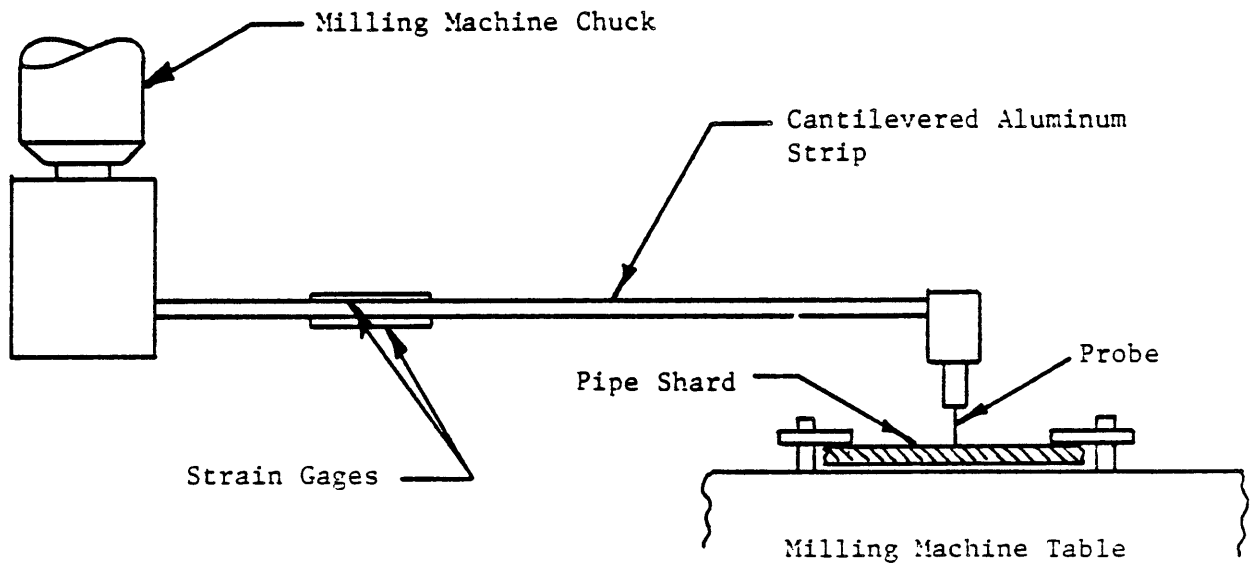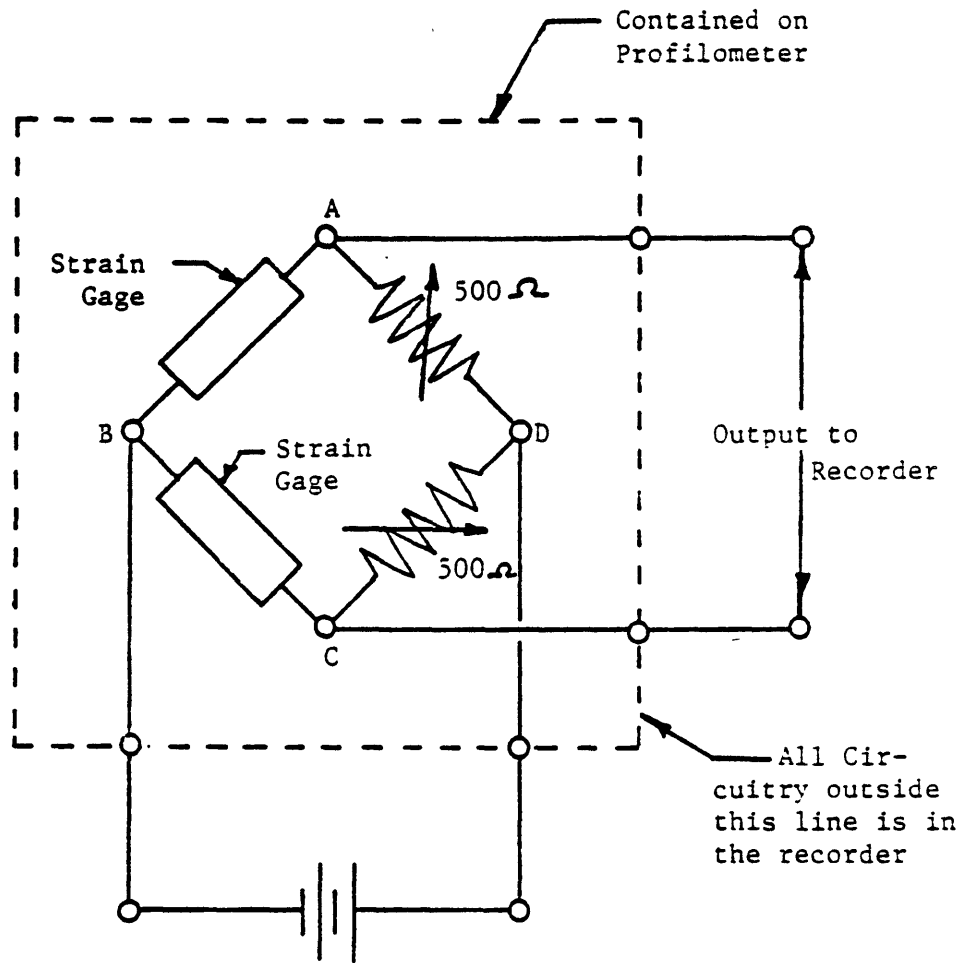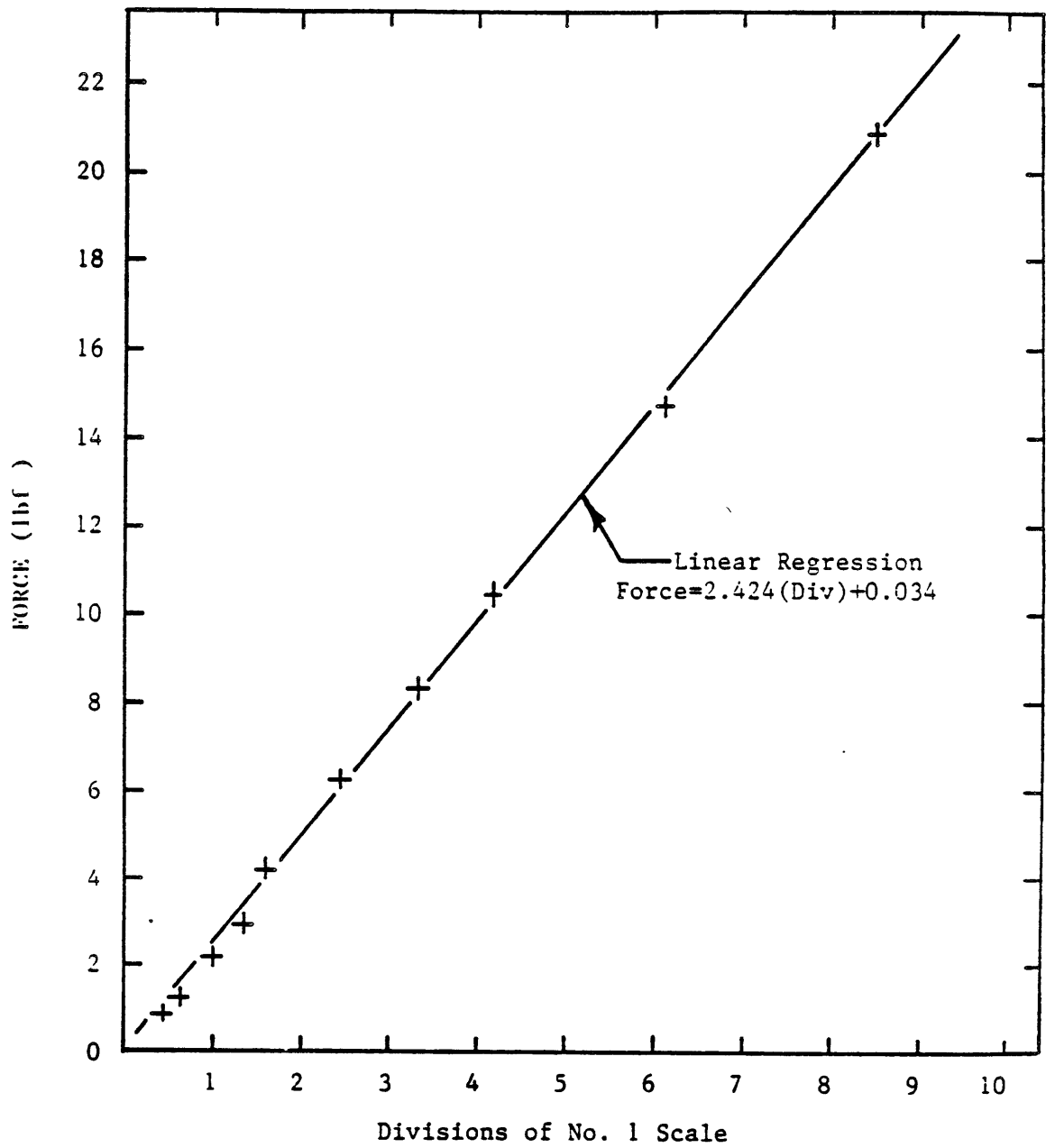
FIGURE 38   PROFILOMETER

CONNECTOR PIN DESIGNATION
A) Amphenol MS 3101-14S-5S from Profilometer to
to Recorder - Pin letters the same as the circuit
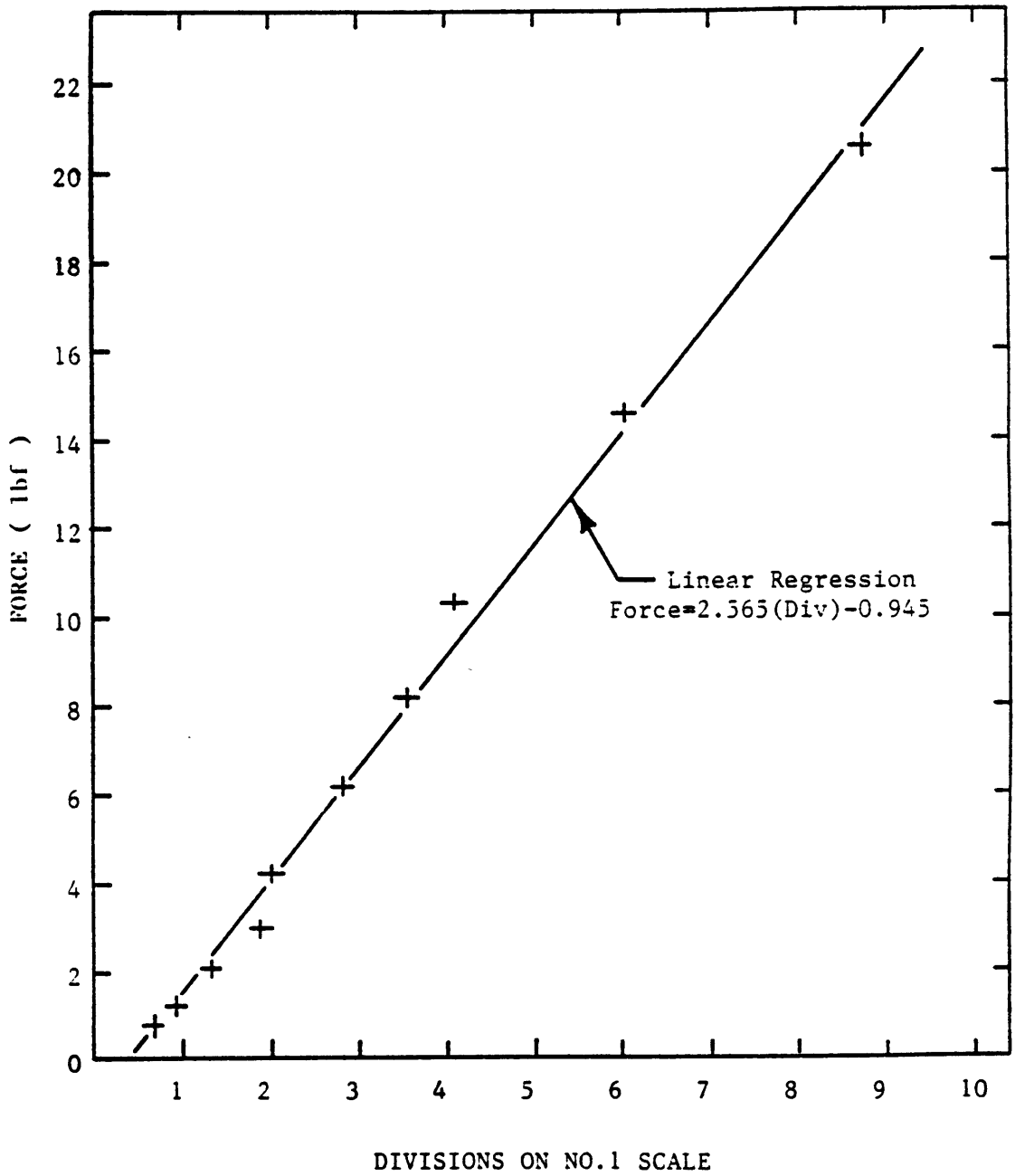
B) Amphenol Mini-Hex Connector 126-010/126-011

Gage	Hex	Circuit	Hex	Circuit
A-B	A	A	B	B
C-D	C	C	D	B

FIGURE 39   Profilometer Circuit Diagram

FIGURE 40 Dynamometer Calibration Curve - Horizontal on No.1 Scale

FIGURE 41   Dynamometer Calibration Curve - Vertical on
              No. 1 Scale