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EVALUATION AND ACCEPTANCE CRITERIA FOR INNOVATIONS IN EXPLOSIONPROOF ELECTRICAL ENCLOSURES

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A conventional trailing cable connection box on a continuous mining machine was modified by the addition of two innovative devices. These are a pressure vent to preclude buildup of high pressure due to an explosion inside the enclosure, and a grommet-type cable entry to simplify and speedup cable entering procedures.

The innovative devices were evaluated for eight and one-half months in a working section of an underground coal mine. Laboratory tests before and after the in-mine exposure show no measurable change in the devices.

Following the favorable in-mine evaluation, technical performance criteria were defined to serve as the basis of approval for the use of the innovative devices. Additional tests to measure comparable gripping of the cable by asbestos rope, substitution rope materials and by the urethane grommet-type entry were included in this effort. Also, literature for the last 80 years was searched.

Comments are provided as to how the innovative devices comply with 30 CFR Part 18.

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FOREWORD

This report was prepared by the Jeffrey Mining Machinery Division, Dresser Industries, Inc., under USBM Contract Number HO357107. The contract was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Research Center with Mr. Roger L. King, and Mr. Michael R. Yenchek as Technical Project Officers. Mr. Alan G. Bolton, Jr. was the Contract Administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period July 1980 to March 1982. This report was submitted by the author in March 1982.

Program Management and Expertise on mining machinery was provided by the Jeffrey Mining Machinery Division under the direction of Robert J. Gunderman. Technical work was performed under subcontract to Jeffrey by Booz-Allen & Hamilton, Inc., Technology Management Services, Cleveland, Ohio. Michael W. Riley, Ph.D. was the Program Manager at Booz-Allen & Hamilton. Air flow measurements on the pressure vent were performed by Professor Joseph M. Prahl, Ph.D., at Case Western Reserve University under subcontract from Booz-Allen & Hamilton. The cooperating mine operator was Eastern Associated Coal Corporation, Federal No. 1 mine.

EXECUTIVE SUMMARY

Requirements for explosionproof electrical enclosures are defined in Title 30, Code of Federal Regulations, Part 18. These are, to a large extent, design requirements as opposed to performance requirements. Enclosures of this type are very rugged, heavy and sometimes difficult to access. Frequent inspection must be made to assure that these enclosures are, in fact, permissible.

It has been many years since there has been significant development or change in the design and characteristics of these explosionproof electrical enclosures. There have been technological advancements in many related areas over this period of time, and for this reason it was believed that some new ideas could be applied to explosionproof electrical enclosures for underground coal mines. Thus, the original objective of the overall program was to identify innovations that may be applicable to the design of explosionproof electrical enclosures and to evaluate them under in-mine conditions.

Although the program approach was aimed toward the original objective, the in-mine evaluation had been dropped from the program before the Final Report was written because of delays in obtaining government approvals for the equipment. Work during the earlier phases is described in the Final Report on this contract, entitled "Innovations for Explosionproof Electrical Enclosures", submitted April, 1980.

The program approach in the earlier work started with identification of the shortcomings of present enclosures and collection of ideas that may be used for new concepts. The broad objectives were to ensure safety and improve production. These were translated into more specific objectives such as simplifying access for maintenance, improved assurance of permissibility, and techniques for cable entry and cover changes that require less time. In addition to the physical aspects of working with these enclosures, the psychological aspects that influence the worker's performance were a consideration.

Many different concepts for improvement were identified and considered. These were categorized into pressure venting, cable entering and accessing devices.

One reason for having an enclosure so heavy and having the flame paths so tight is to contain the buildup of flame, pressure and heat that occurs during an explosion internal to the enclosure so that there is no propagation of flame to the outside of the enclosure. Pressure venting devices (capable of large gas flow rates) which preclude internal pressure buildup due to any internal ignition of gas would greatly reduce the forces through the flange gaps, cable packing and other potential flame paths. Consideration might then be given to relaxation of flame path gap requirements in the regulations. Also, lighter weight enclosures would be possible since the structures needed to withstand high pressure would no longer be required for that purpose.

Another area of conceptual work was a cable entry that might eliminate the asbestos packing and greatly simplify and shorten the time required to enter or reenter a cable. A suitable new entry should maintain a permissible seal indefinitely, thus eliminating any potential problem with deterioration of the asbestos packing.

Concepts for access covers which would provide easy enclosure access without labor intensive bolt removal were also considered. Properly designed, a quick access cover should assure easier achievement of the gap requirements without need for a second person to assist.

Concepts for these devices were identified and the more promising concepts were implemented in hardware for evaluation. Two new enclosures, the same as used on a continuous mining machine, were obtained and modified with these innovative devices for purposes of testing the devices. These were then subjected to explosion testing for engineering verification, and the smaller enclosure was ultimately tested by the Mine Safety & Health Administration (MSHA). Results of these tests were favorable, but they indicated need for further work on both the pressure vent devices and the cable entries to improve the range of application for larger size enclosures and various cable sizes.

After further refinement and test of the devices, a pressure vent of the type tested by MSHA and an innovative cable entry were fabricated for a connection box to be interchanged with existing hardware on a continuous mining machine underground. Also, guidelines were identified for the application of these pressure vents and the cable entries to other equipment to be used in underground coal mines. Work up to this point is described in the Final Report submitted in April, 1980.

An experimental permit for the connection box with the pressure vent and the innovative cable entry was granted at the time the Final Report was written. The contract was subsequently modified to reinstate an in-mine evaluation.

The objective of the in-mine evaluation,which is described in this report,was to establish the performance characteristics of the basic pressure vent and the elastomeric grommet when subjected to actual underground coal mining conditions. The planned test duration was 6 months, but the hardware was actually underground for 8-1/2 months.

Results of the in-mine evaluation showed no measurable deterioration of either of the devices. Conditions of the materials were measured in the laboratory both before instalation in the underground mine, and after exposure in the underground production operation.

Following the favorable results of this in-mine evaluation, effort was directed toward defining performance criteria to serve as the basis of approval for the use of these innovative devices. This effort addressed both the technical considerations that would be used in actual evaluation for approval, and considerations insofar as how the devices may be approved under the existing government regulations. This activity was modified somewhat when the Mine Safety & Health Administration (MSHA) requested additional assistance in identifying acceptable alternatives to the asbestos packed cable lead entrances. This request was forwarded to the Jeffrey Mining Machinery Division by the U. S. Bureau of Mines.

Acceptance criteria for both the pressure vented enclosure and the grommet type lead entrance have been defined.

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Section 1.0

INTRODUCTION

This Supplementary Final Report describes the in-mine evaluation of two innovative devices for explosion-proof electrical enclosures and provides recommended acceptance criteria for these type devices. The devices were designed and developed under earlier phases of this program, entitled "Innovative Design of Explosionproof Electrical Enclosures", USBM contract HO357107. The innovative devices, briefly described in Section 2.0, are a pressure vent assembly and an elastomeric grommet cable entry.

The pressure vent device allows any pressure build-up due to a methane air explosion inside the enclosure to be dissipated through the vent before it can become very large. The vent is a porous stainless steel foam material that both arrests flames and cools the gases as they flow from inside to outside the enclosure. Thus, a vented enclosure offers the advantages of improved safety with much lighter weight wall structures, and flame tight joints with greater clearance allowance. The principal difference is the fact that this vent can handle large volumes of air flow rather than acting at a slow rate for pressure equalization.

The elastomeric grommet cable entry assembly for this test was designed for the trailing cable on a continuous miner and was used in lieu of an asbestos packed type gland. This device simplified entering or removing the cable, does not normally require material replacement when re-entering the cable, and gives better assurance of a uniform and long-lasting seal.

The objective of the in-mine evaluation was to determine how well the innovative devices would perform in an actual mine environment. Factors to be observed included function, deterioration and maintenance. All aspects of the pressure vent assembly were of interest in the evaluation. Only the grommet used in the cable entry was of interest because this cable entry complied with diametrical clearance design requirements in Title 30 Code of Federal Regulations, Part 18, and did not represent the design which would accept a wide range of cable outside diameters.

Both innovative devices for the in-mine evaluation were designed to be directly interchangeable on an existing continuous miner trailing cable connection box. No attempt was made in this evaluation to realize the overall advantages of either of the two devices, but rather to achieve the basic objective stated above. Also, the enclosure with these innovative devices was in compliance with Title 30 CFR, Part 18 for all design requirements as well as performance requirements. This was necessary in order to obtain MSHA approval of the experimental devices. Some design requirements in 30 CFR Part 18 do not allow for more recent technological advancements.

The devices were installed on a continuous mining machine being used two shifts per day in retreat mining. They were visually inspected daily by mine personnel and monthly by Jeffrey personnel. The foam vent material and the grommets were exchanged periodically. Characteristics were measured after each item had been in the mine for some time and compared to the characteristics measured prior to installation in the mine. These items functioned normally throughout an 8-1/2 month in-mine evaluation and there was no measurable deterioration of any of the innovative devices.

In order to gain approval of electrical devices that meet the intent of 30 CFR Part 18, but which are different from specified design requirements, the acceptance criteria must be known. This report describes the literature search applicable to the innovative devices and the technical interpretations from the development work that result in recommended acceptance criteria.

Older regulations, reports and publications were examined to determine applicable background information for the new performance criteria. Documents dating back to the turn of the century were examined. This disclosed that the concept for a pressure vented explosionproof electrical enclosure was demonstrated over 75 years ago, but not heretofore made practical.

Additional tests for cable gripping were performed at the request of the Mine Safety & Health Administration (MSHA). MSHA was specifically interested in information as to how well an asbestos packed lead entrance grips the cable. During earlier work on this program, tests were performed both in this regard and to determine the ability of the urethane grommet to grip the cable. As part of developing performance acceptance criteria, controlled comparison tests were made regarding the gripping ability of asbestos packed entries and urethane grommet type entry. Also, some packing rope substitutes for asbestos were evaluated for gripping ability.

The following section describes these innovative devices and briefly reviews some of the development work. It then describes the hardware prepared for the in-mine evaluation. Section 3.0 describes the in-mine test plan, including laboratory tests, and Section 4.0 describes the results from the in-mine tests. Section 5.0 contains background information on the pressure vent and then presents recommended acceptance criteria. Section 6.0 describes background information on the lead entries, laboratory tests for gripping capabilities and then presents recommended acceptance criteria. The performance criteria for the pressure vented enclosure and the grommet type lead entrance are presented in Tables 5-1 and 6-8, respectively.

Product refinement of these innovative devices is required before they are introduced into production machines. Before manufacturers take this logical next step, some assurance is needed that the devices may be approved by government agencies under the regulations. Joint action by MSHA and the U. S. Bureau of Mines is needed to clarify how these devices may be approved under existing federal regulations. Section 7.0 of this report discusses 30 CFR Part 18 and some existing design requirements which fail to allow for these technological advancements.

The work described in this Supplementary Final Report is a modification addition to contract HO357107. Further detail on the development of the innovative devices is contained in the Final Report, USBM Contract HO357107, "Innovations for Explosionproof Electrical Enclosures", submitted April, 1980.

Section 2.0

TEST HARDWARE FOR IN-MINE EVALUATION

This section describes the theory of operation and the hardware that was fabricated to demonstrate the innovations. The two devices described here were the result of establishing and evaluating numerous concepts for improving explosionproof electrical enclosures for safety and increased productivity. These devices were designed for engineering test to prove the functions and to demonstrate properties needed to withstand the harsh environment in underground coal mines.

An in-mine evaluation was contemplated at the beginning of the program, so specific electrical enclosures were selected on which the innovations might be tested. These enclosures were a large control case and a small trailing cable connection box used on Jeffrey type 120-M continuous mining machines. This constrained designs in that existing enclosures, which are densely packed with components, could not be greatly modified.

As a result of the development approach and use of existing enclosures, the innovative devices were used only to establish design approach. Further design refinement is required to apply these devices to production machines.

Delays in obtaining necessary government approvals for installing these devices in an operating underground coal mine resulted in cancellation of the originally planned in-mine evaluation. Thus, the final report, referenced earlier, was prepared and submitted. Eventually, the government approvals were obtained and the contract modified to again include an in-mine evaluation.

2.1 Pressure Vent

A methane/air explosion inside an electrical enclosure produces a very short duration rise in internal pressure, typically in the order of 70 to 80 psi. Theoretically, these pressures could build to a peak of over 110 psi.

Government regulations require that explosionproof electrical enclosures be of specified ruggedness and able to withstand internal static pressure loads as high as 150 psi. Also, very close tolerance flame paths are required so that particles and hot gases escaping from inside the enclosure cannot ignite a potentially explosive mixture outside the enclosure. The pressure buildup inside the enclosure dissipates over a period of time as the gases escape through openings such as the flange gap flame path. It is because of this potentially high pressure differential that the flange gap tolerance must not exceed .004" according to government regulations.

The concept of the pressure vent is to release the gases as the pressure tends to build up inside the enclosure at a rate fast enough so that the peak pressure never builds higher than approximately 12 psi. If the peak pressure is held this low, then the heavy wall requirements for the enclosures and the very close tolerance flame paths may be greatly relaxed. Devices to accomplish this objective have been considered and tested in the past, but up until now none of them have proven adequate. This pressure vent uses a unique material known by the trade name Retimet[1]. It is a stainless steel foam which allows a very large effective opening for passage of gases while at the same time providing a very long tortuous path for the gases so that they are adequately cooled before reaching the other side of the vent material. These openings also inhibit the passage of any flame particles.

The area of pressure vent required for an enclosure is a function of the internal volume. As the volume of the enclosure is larger, so also must the area of the pressure vent be increased so that the maximum pressure difference from inside to outside does not exceed 12 psi. A second, and more restricting factor, in selection of the size of the vent is the maximum temperature which can be withstood by the vent material before erosion or other deterioration begins. For the vent as used in this demonstration, this ratio was found to be 28 square inches per cubic foot. Further refinements of the vent design, as described in the earlier referenced report, allow significant reductions in the vent cross sectional area by incorporating stainless steel wire mesh as a heat sink on the inside of the stainless steel foam material.

The pressure vent assembly consists of a frame in which the piece of stainless steel foam is entrapped. In the unit used here this vent material is 2" x 9" in cross section. Figure 2-1 is a cross section diagram of the pressure vent assembly, including the frame and the vent material. A protective vent cover is used on the outside to protect the vent material from possible impact damage since the vent is sizable in cross section and does not have inherent impact resistance. This protective steel cover is supported on a knife edge hinge so that it can move outward with any appreciable rise of air flowing from inside to outside the enclosure. A small magnet

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1. Retimet is a registered trademark of Dunlop, Ltd., of Coventry U.K. This does not imply USBM endorsement.

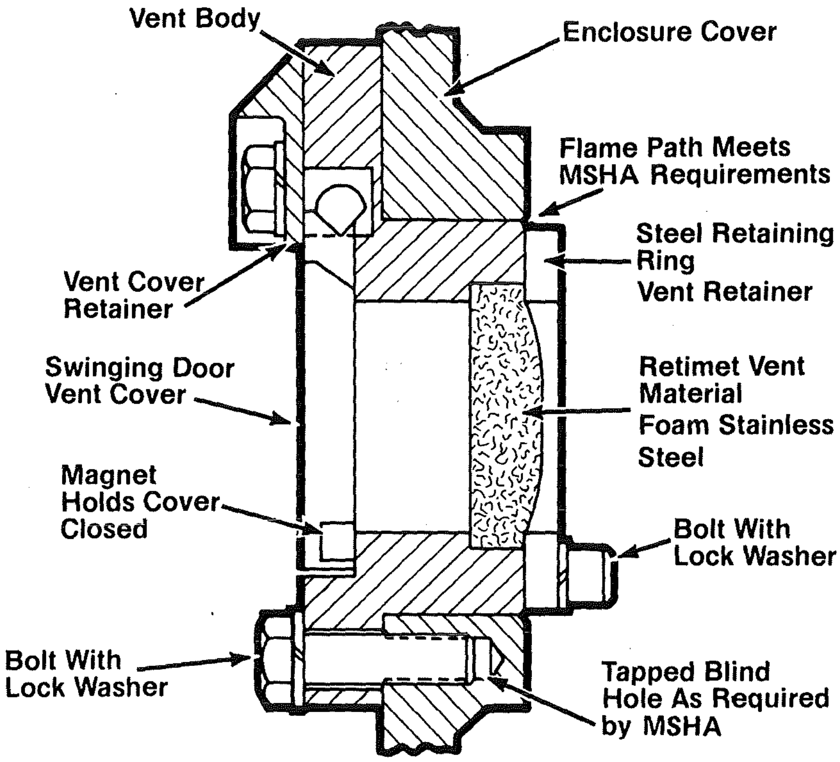


Figure 2—1 Cross Section Diagram Of Pressure Vent

is used in the lower edge of the protective cover to keep the cover from flopping. A pressure differential of approximately 1 psi is adequate to open this protective cover.

The pressure vent used during these experiments was rectangular in cross section because of severe constraints in locating it on the large electrical control case. The object was to maximize the cross sectional area without having to redesign the component placements inside the control case. In a production application, these vents would normally be circular for producibility.

For the in-mine evaluation, the pressure vent was located on the cover of the trailing cable connection box. This allowed simple interchange with the existing solid cover on the machine that was already underground. Figure 2-2 shows the cover with the vent components laid out. On the left in this figure are the vent cover retainer and the vent cover with the knife edges showing on the top. This cover is retained on the vent frame when the cover retainer is bolted in place. On the right in the figure are the stainless steel vent material and the retaining ring. The vent material is placed within the frame and, as the retaining ring is tightened down, it crimps around the outer edge of the vent material. This leaves a small permanent set around the periphery of the vent but does not noticeably affect the gas flow properties through the vent. All potential flame paths are designed to be less than .004" to comply with existing regulations. It should be noted that there is nothing in the present Part 18 of the Regulations with regard the use of the stainless steel vent material.

These pressure vent assemblies were extensively tested during the concept development and were also tested by MSHA. Explosion tests were conducted on both the large electrical control case and on the small connection box. The in-mine evaluation plan was eventually changed so that the pressure vent would be used only on the small connection box along with the trailing cable entry. This simplified both the approval process and the logistics during the in-mine test.

2.2 Cable Entry

Most electrical cable entries for permissible equipment in the United States underground coal mines are packed with asbestos rope. Packing one of these entries is a tedious and time consuming procedure. When performed in the mine, where conditions are far from ideal, the results are frequently subject to question. Entries have been found which either have inadequate asbestos packing or some foreign material. Occa-

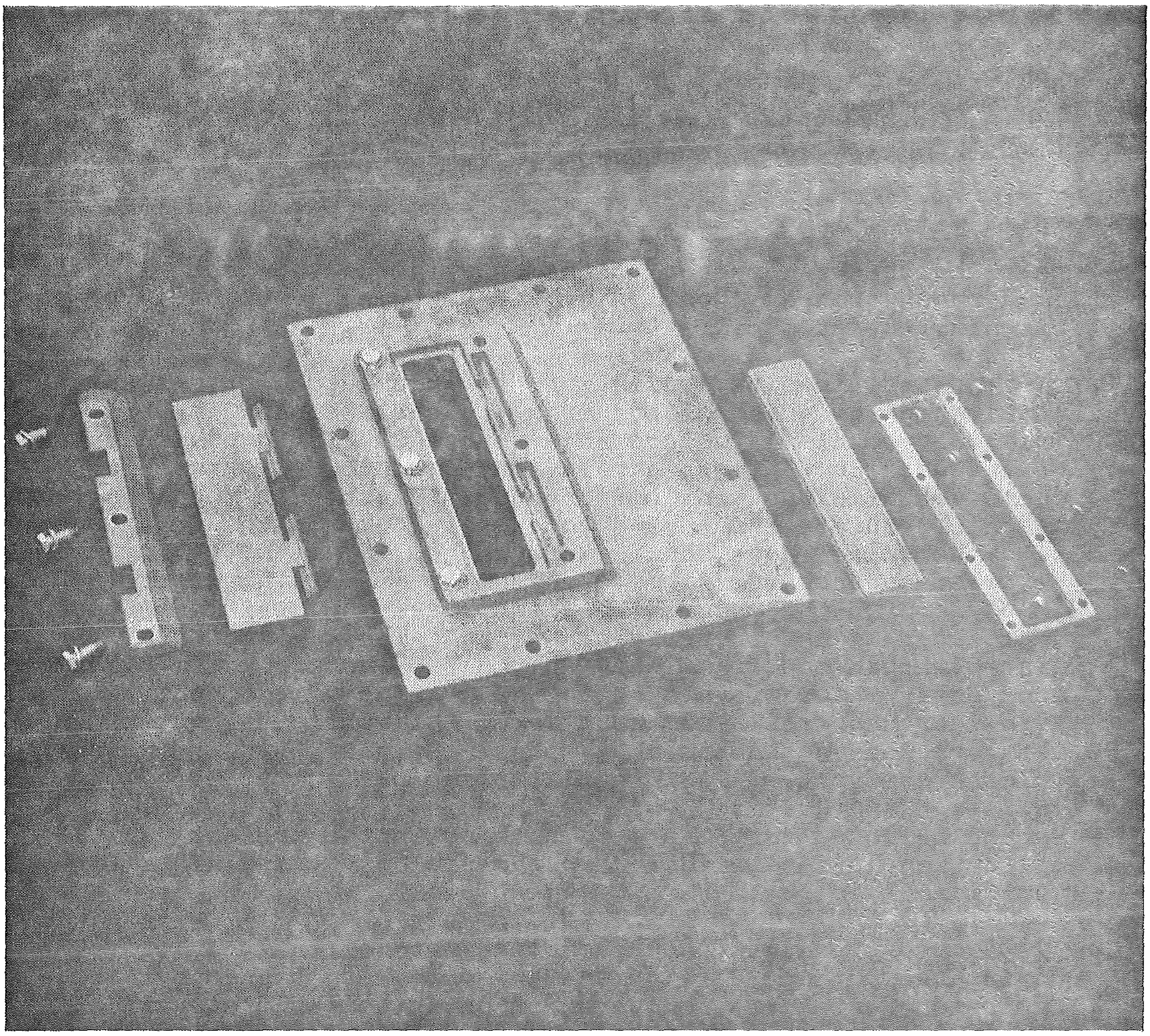


Figure 2–2 Enclosure Cover With Pressure Vent Components

sionally, a cable entry has been found on operating equipment which is completely devoid of any packing material in the stuffing box.

Grommet type seals are occasionally used in the United States and are found even more frequently in some foreign countries. Cable sizes used on underground mining machinery in the United States typically comes in all sizes ranging from .039" to over 2". If cylindrical type grommets were employed, there would be a tremendous logistics problem because of the very limited tolerance allowed by the regulations for each cable diameter.

The innovative cable entry developed on this program uses the wide range of compressibility of urethane to achieve a grommet size and entry body that can compress tight over cable with a wide range of jacket diameters. Laboratory tests showed that the cable jacket sizes from 0.39" to 2.09" may be accommodated with only four different sizes of cable entry bodies and grommets.

The obvious advantages to a grommet-type entry are rapid assembly and the fact that the grommet may be reused repeatedly without replacement. It is also believed that the cable entries will be safer because there is less likelihood of the packing being omitted and also less likelihood of deterioration with age and other conditions.

The conventional trailing cable entry assembly in the connection box uses a slip-fit type body. By designing the innovative cable entry with the same slip-fit dimensions, the interchange process is simplified. This trailing cable entry assembly is illustrated in Figure 2-3.

Various types of tapered grommets are used in industry for electrical cable entries. Many of these are intended to both hold the cable tight and inhibit the entry of water or other liquids. These grommets are generally a neoprene type material. However, neoprene does not work well in this application since a tapered neoprene grommet wedges in tightly with the cable which makes release very difficult.

Material selection for the grommet was one of the most important factors. This material must have a high degree of compressibility, be flame resistant, and have a very low coefficient of friction. A urethane material with a durometer hardness of approximately 70 on the Shore A scale was found to be well suited to this application.

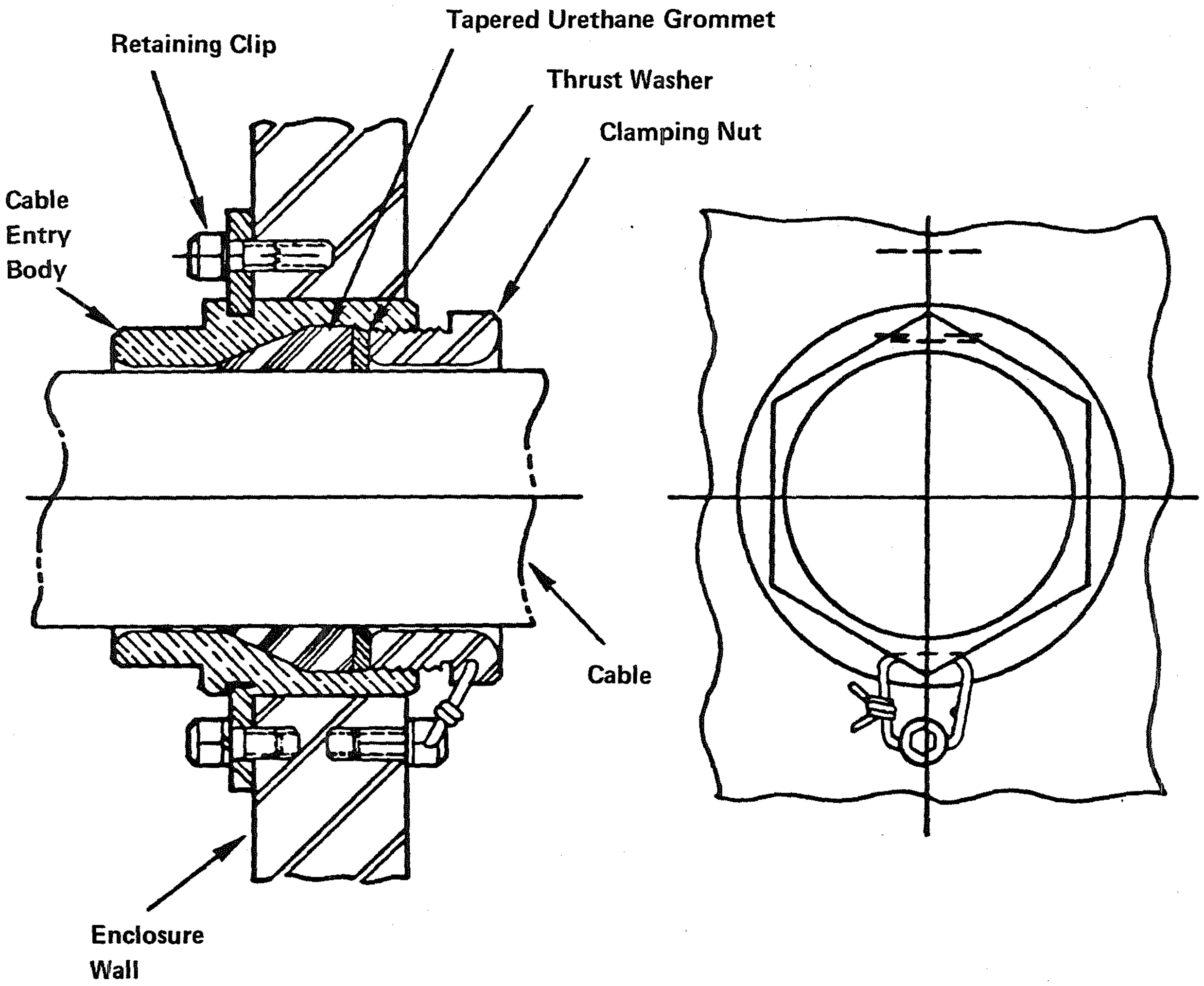


Figure 2—3 Diagram Of Trailing Cable Entry Assembly

The taper angle in the grommet and the entry body was selected empirically to give the best compressibility characteristic as well as release function. As shown in Figure 2-3, a thrust washer is used between the grommet and the clamping nut. This washer was in the design at the time approval was requested from MSHA and therefore was retained in the underground configuration even though the assembly works at least as good without the thrust washer. This is due to the low coefficient of friction for the urethane grommet.

The actual trailing cable entry assembly used in the underground evaluation is shown in Figure 2-4. It should be noted that the radial clearance between the cable jacket diameter and the I.D. of the grommet for this test hardware was no more than .010" in order to comply with the Federal Regulations. Thus, this particular entry assembly did not show the advantage of being able to handle a wide range of cable jacket diameters with a single grommet and entry assembly. It should be re-emphasized that the purpose of the test was to verify the basic grommet sealing capability and material in this environment. The details of the entry body and packing nut may be varied to suit producibility considerations.

2.3 Machine Configuration

The trailing cable connection box on the type 120-M continuous miner is located on the main frame wall adjacent to the operator's seat, as shown in Figure 2-5. This installation is shown without the seat in place in Figure 2-6 for a similar type 120-M machine. Note that the trailing cable enters from the right hand side of the enclosure on this particular machine. That was the expected configuration for the machine underground, however, at the time of installation of the innovative devices it was found that the trailing cable entered on the left hand side of the enclosure with an extremely sharp bend as the cable exits the enclosure. A close-up view of the left side is shown in Figure 2-7. As can be seen, the enclosure has a plug on the left hand side where it is designed for an optional location for the trailing cable entry.

The machines shown in these pictures are designed for 990 volts primary power and therefore have only three cables exiting the rear of the left hand side of the connection box enclosures. The machine used during the demonstration is a lower voltage machine and has six type 4/0 cables exiting from that side of the enclosure. Thus, there is even more congestion in the region of the cable trailing entry.

As stated earlier, the cover containing the pressure vent was directly interchanged with the conventional cover.

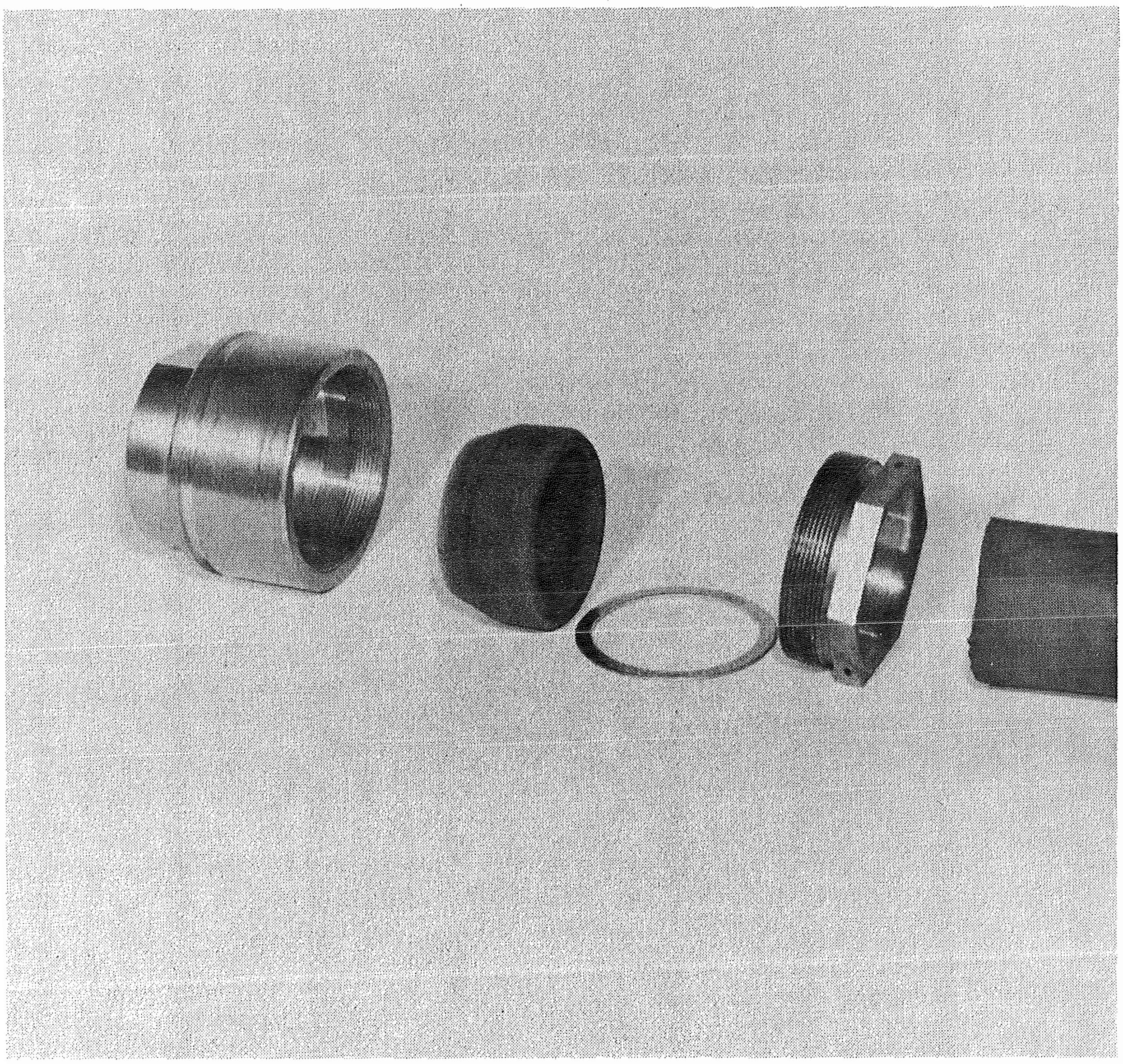


Figure 2—4 Cable Entry Components

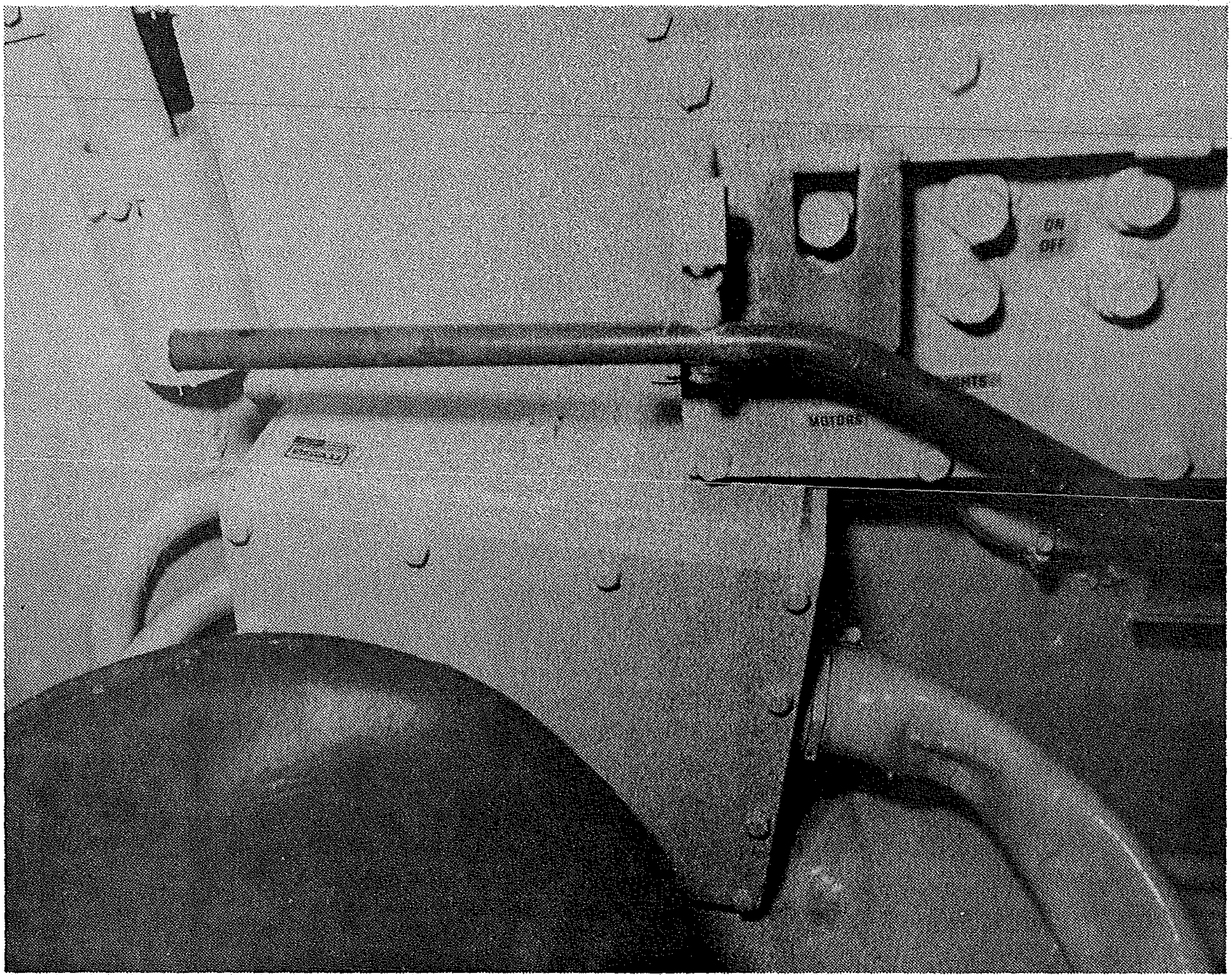


Figure 2–5 Enclosure Next To Operator Seat

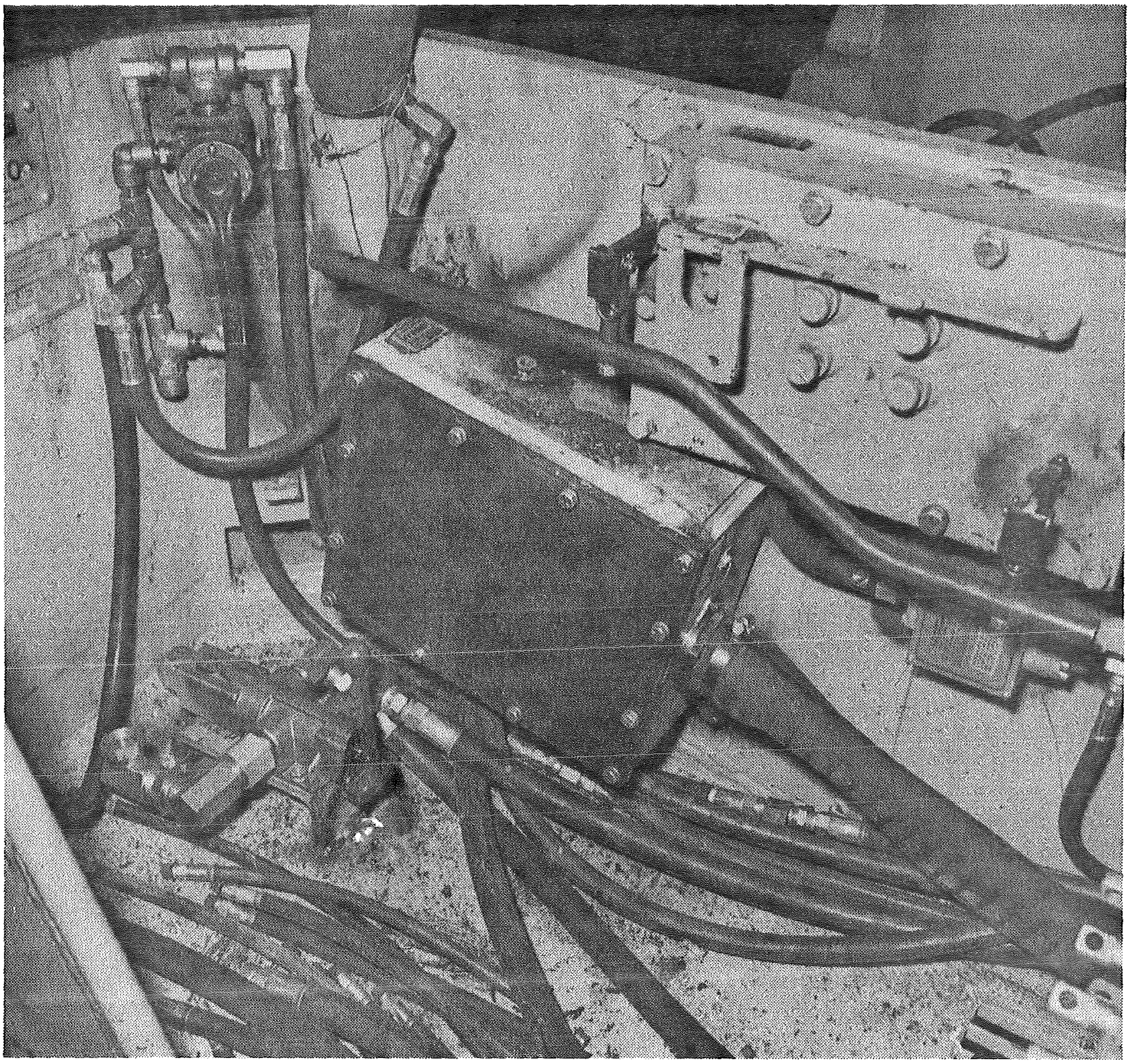


Figure 2–6 Trailing Cable Connection Box On Continuous Miner

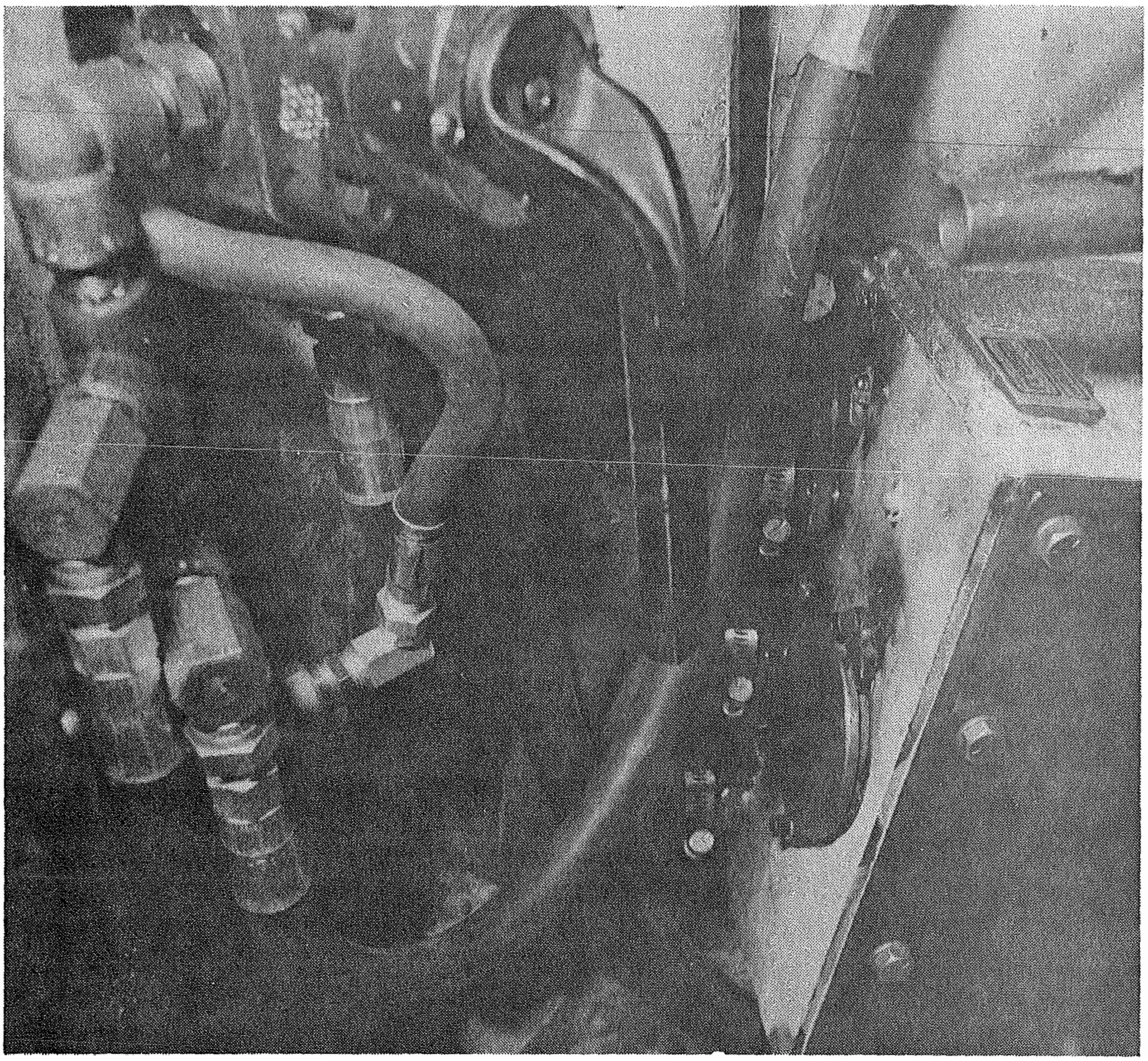


Figure 2–7 Left Side Of Electrical Enclosure

It was oriented so that the protective cover door would close due to gravitational forces. The protective cover was sufficiently below the seat height so that it could open without obstruction. Also, if an explosion were to occur within the enclosure, the exhaust gases would not be directed toward the machine operator.

Fabricated for the in-mine evaluation were:

- 10 pieces stainless steel vent material
- 6 elastomeric grommets
- 2 cable entry body assemblies

Figure 2-8 shows the cover with the pressure vent in place and the trailing cable entry assembly as ready for the in-mine demonstration.

The following section describes the test plan along with the actual procedure that was followed. Results of tests conducted both before and after the in-mine exposure are presented in Section 4.0.

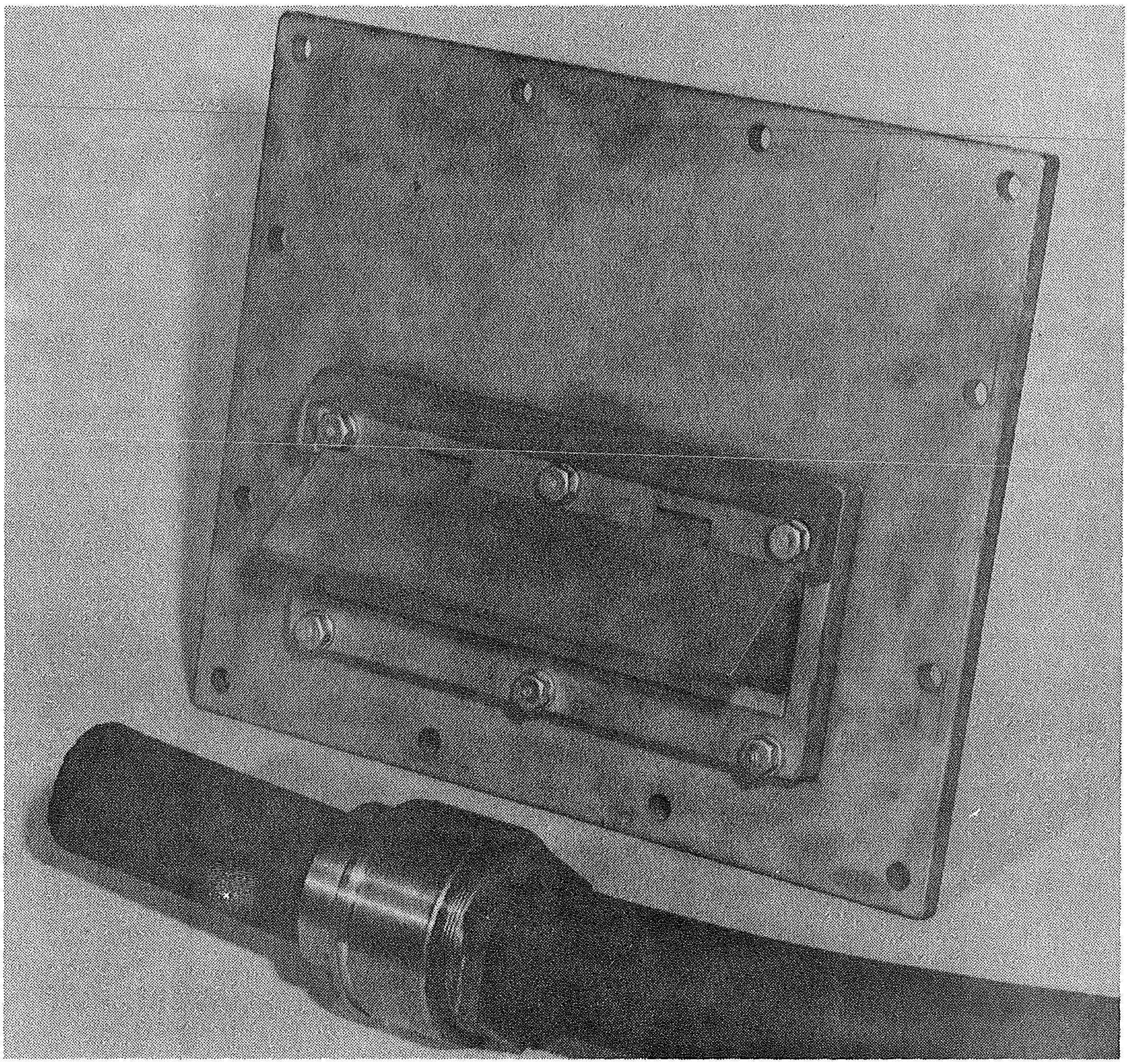


Figure 2—8 Pressure Vent And Elastomeric Cable Entry For In-mine Demonstration

Section 3.0

IN-MINE TEST PLAN

A plan for the in-mine evaluation was prepared as part of the original phase of the program before that phase was cancelled because of delays in obtaining government approvals. This plan is described in Appendix A of the report "Innovations for Explosionproof Electrical Enclosures", submitted April 1980, pp 93-107.

When the in-mine evaluation phase was reinstated, the basic test plan was retained although the schedule was lengthened to six months (from three months) underground. This plan was followed throughout the phase of effort with only a few detail changes.

The test plan included:

- Laboratory tests
- Inspection for permissibility
- Mine personnel training for operation and inspection
- Visits by project personnel
- Other follow-up activities

These aspects of the plan as followed are briefly described in this section.

3.1 Laboratory Tests

Both the stainless steel foam used for the pressure vent and the urethane grommet used in the new cable entry have not heretofore been used in underground coal mines. Many questions could be raised regarding how these two items will hold up in coal mines and therefore it was important that this factor be measured. This called for careful tests of the devices in the engineering laboratory both before they were taken to the mine and immediately following the exposure in the underground environment. Each of the vent insert samples and the grommets were assigned serial numbers, and a record retained with regard to the vent orientation when installed.

Potential concerns for the vent material included blockage of air passages and deterioration of the material. These factors were determined by visual inspection, by weighing, and by careful measurement of air flow through the vent samples. Visual inspection determined whether there was any evidence of discoloration, overheating, material erosion, obvious clogging, and any other change from original properties. Weight measurements helped to determine whether there was any material loss or possible build-up of clogging materials inside the stainless steel foam vents.

Air flow through the pressure vents was considered the most critical item and therefore a very careful laboratory procedure was established for this measurement. This laboratory procedure is described in more detail in Appendix A. The measurement determined the pressure gradient across a vent sample as a function of a carefully measured air flow through the vent. By measuring this pressure gradient, both before and after the in-mine exposure, it should be apparent whether there was any clogging.

During original development of the pressure vent assembly, special tests were made wherein the pressure vent was deliberately clogged with coal and other materials. It was then tested under pressures that might be experienced in an actual explosion condition so as to determine self-cleaning characteristics. The self-cleaning characteristics proved to be very good. During this in-mine evaluation, the intent was to establish what amount of clogging might occur under ordinary circumstances. There was no attempt made during the in-mine evaluation to deliberately clog any of these vents.

Tests on the grommets included visual inspection, weighing, measurement of dimensions, and measurement of the elastomeric hardness. These properties were determined for each of the sample grommets before the mine evaluation began. The objective was to note any deterioration in the grommets, permanent dimensional changes, or any changes in elastomeric properties.

Grommet measurements were taken as noted in Figure 3-1. The internal dimensions were taken by placing the grommet inside the cable entry body in order to support the grommet external surfaces. Inside micrometers were used and the dimensions recorded for 8 different points around the diameter as indicated in Figure 3-1. Outside diameter (OD) measurements were taken by placing the grommet on a mandrel of the same diameter as the ID of the grommet to give it internal support. These outside diameter measurements were taken at the same points around the grommet as were the inside diameter measurements. This allows a specific look at any thickness difference around the grommet as well as looking at the average difference.

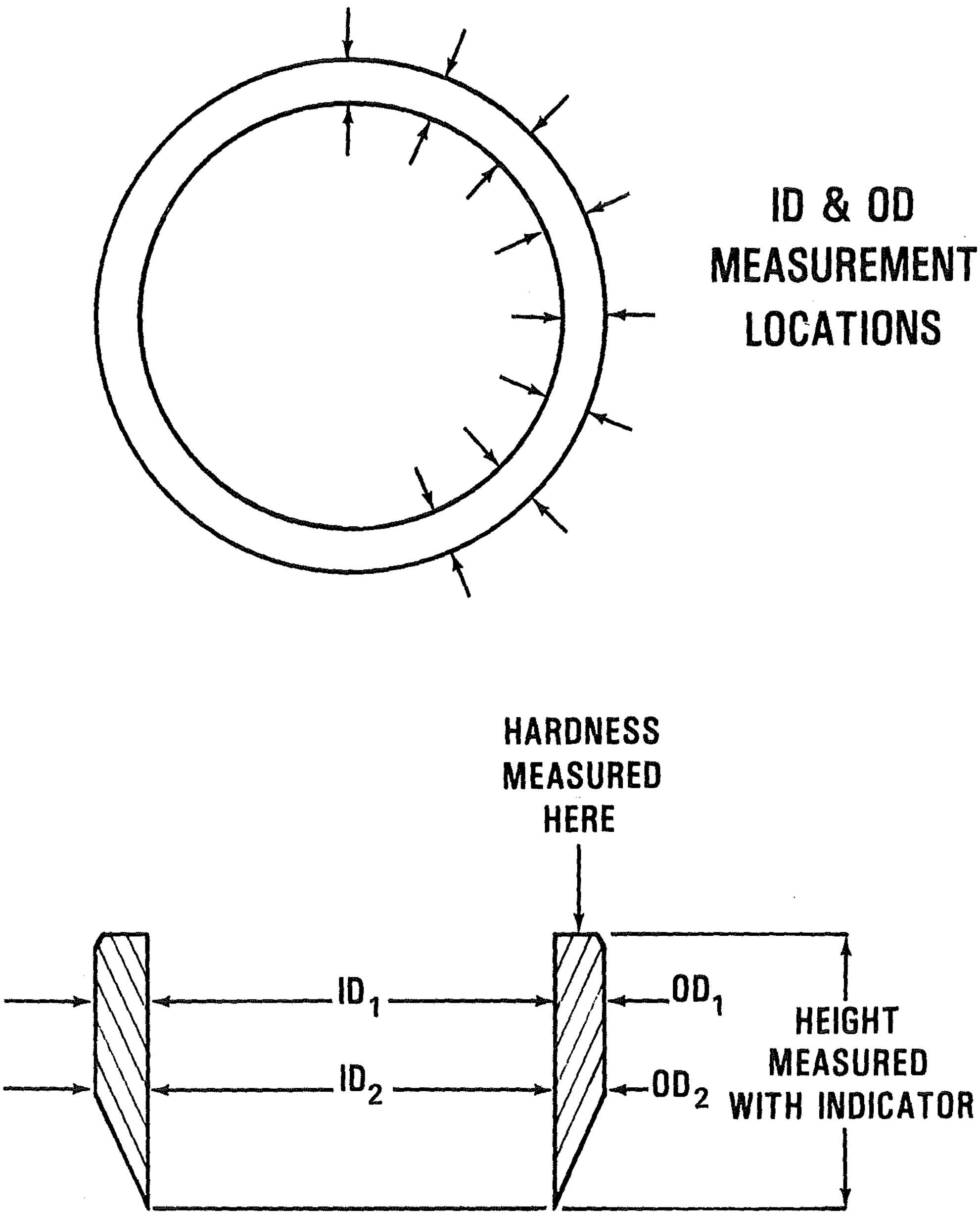


Figure 3–1 Grommet Measurement Locations

In one instance there appeared to be some permanent set on the OD of the grommet where the straight side meets the taper. Outside diameter (OD_2) measurements were taken at this point around the grommet in those instances where there appeared to be a measurable difference in value.

The height measurement of the grommets was taken by placing them on a flat plate and using an indicator on the top surface as noted in Figure 3-1. This dimension is not critical in the application and therefore a single value with ± limits was recorded.

Hardness measurements were taken using a durometer manufactured by the Shore Instrument Company[2]. These measurements were taken on the edge of the grommet as noted in Figure 3-1 and the resulting A-scale values recorded.

3.2 Permissibility Inspection

Specific guidelines were defined for inspection of the innovative devices. These are described in Figure 3-2 and Table 3-1 for the pressure vent, and in Figure 3-3 and Table 3-2 for the innovative cable entry assembly. This inspection criteria was defined in an earlier phase of the program and was included as part of the data package requesting the experimental permit. The following descriptive information was provided with the criteria.

The pressure vent assembly, mounted on the access cover, provides a window to exhaust the pressure from an internal ignition of a methane/gas mixture that would otherwise become quite high while at the same time arresting flame from exiting. The window material is a steel foam which allows air or gases to pass through, but because of the highly irregular passages, any flames are extinguished before penetrating to the outside. As shown in Figure 3-2, this window is protected by a hinged vent cover which is held from flopping by a small magnet mounted in the cover. This cover will protect the metal foam from impact damage, protect it from high pressure water spray which could pass through the foam material, and will minimize exposure to dirt which might build up on the foam metal. Should a methane/gas ignition occur within the enclosure the pressure of gases exiting through the window will push open the vent cover until the pressure is no longer present. Duration of such events was measured as less than one second.

This pressure vent assembly is designed specifically for test purposes. Pressure venting of a permissible electrical enclosure will allow much lighter weight enclosure fabrication and provide added measure of safety around flange gaps and

2. Reference to specific equipment in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

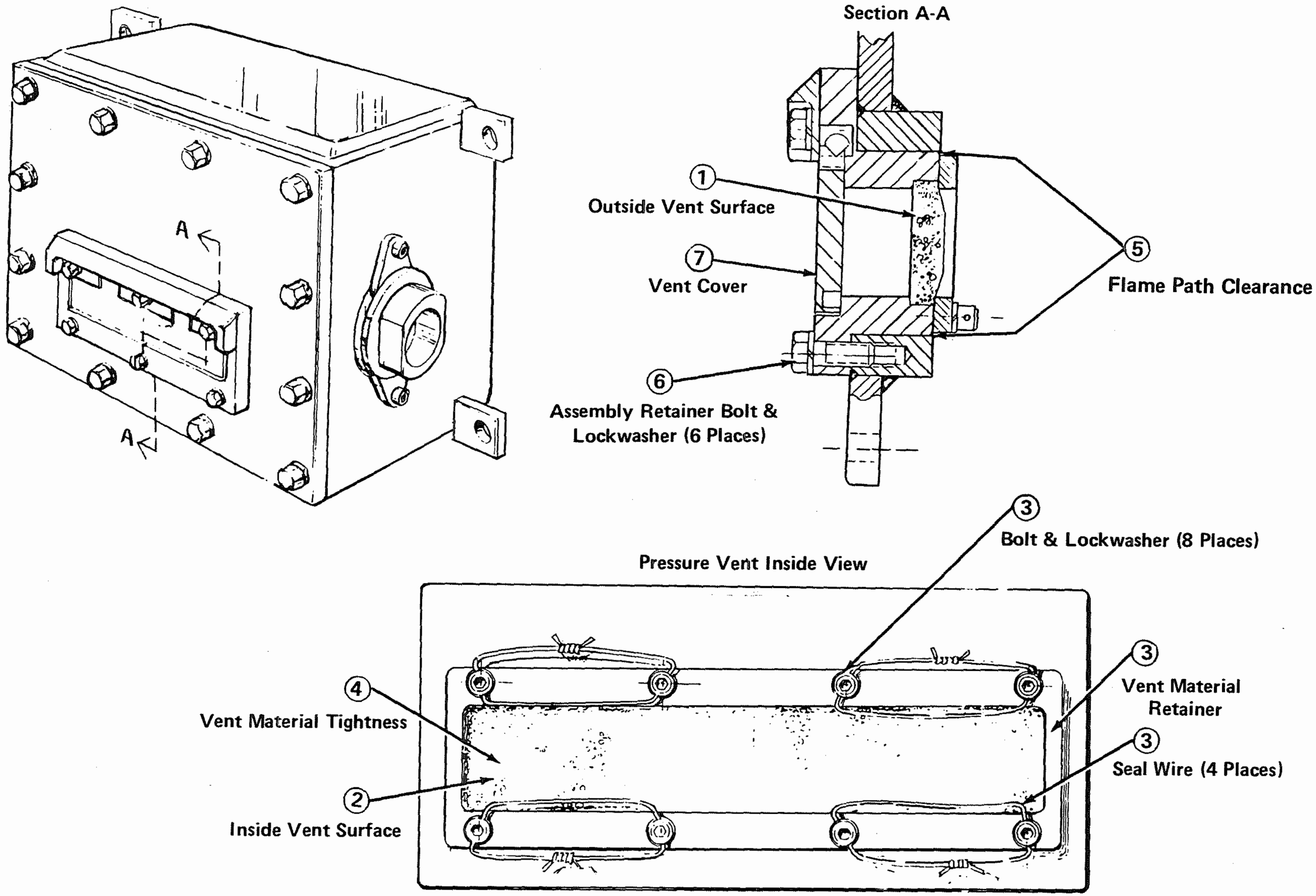


Figure 3–2 Inspection Items For Pressure Vent

Table 3–1 Inspection Criteria For Pressure Vent

ITEM	REFERENCE NUMBER	REQUIREMENT	TOOLS/GAUGES	INSPECTION METHOD	CORRECTIVE ACTION
Outside Vent Surface	1	. Opening unobstructed by accumulation of dust, grease or other foreign matter. . No erosion, cracking or discoloration of the vent material.	. None	. Open vent cover . Visually inspect the condition of the vent material.	. Remove vent and clean by hosing with water or with compressed air. If this fails to completely remove the buildup, replace the Retimet with a clean piece.
Inside Vent Surface	2	. Opening unobstructed by accumulation of dust, grease or other foreign matter. . No erosion, cracking or discoloration of the vent material.	. Wrenches - 9/16" box, open end or socket. - ¾" box, open end or socket.	. Either remove the vent assembly from the enclosure cover or remove the entire cover. . Visually inspect the condition of the vent material.	. Remove vent and clean by hosing with water or with compressed air. If this fails to completely remove the buildup, replace the Retimet with a clean piece.
Vent Material Retainer	3	. Lock washers and seal wires must be in place on all bolts. . Bolts must be in place at all locations. . All bolts must be tight.	. Wrenches - 9/16" box, open end or socket. - ¾" box, open end or socket. - 3/16" Allen key - Seal crimping tool.	. Either remove the vent assembly from the enclosure cover or remove the entire cover. . Visually inspect for presence and tightness of all bolts, washers and seal wires. . Check the tightness of all bolts by turning with a wrench.	. Tighten loose bolts. . Replace missing components. . Install new seal wires as required.
Vent Material Tightness	4	. Vent material must not be loose in the vent body.	. 3/16" Allen key . Seal crimping tool . Wire cutters.	. With the vent retainer secured in place, try to move vent material in the vent body.	. Replace vent material with a new piece if it is loose.
Flame Path Clearance	5	. .004" max. between the vent body and the body of the enclosure.	. .004" feeler gage and .004" gage wire	. With the assembly secured into the enclosure cover, check flame path with gage. . Use the gage wire to inspect clearance at the corners.	. Replace the enclosure cover with a new cover if clearance is excessive. . Rebuild vent assembly and/or enclosure cover as required to obtain acceptable flame path clearances.
Assembly Retainer Bolts	6	. Lock washers must be in place on all bolts. . Bolts must be in place on all locations. . All bolts must be tight.	. 9/16" box, open end, or socket wrench.	. With the vent assembly installed in the enclosure visually inspect for presence of all bolts and washers. . Check the tightness of all bolts by turning with a wrench.	. Tighten loose bolts. . Replace missing components.
Vent Cover	7	. Cover must swing open freely, except for over-	. Screw driver	. Flip cover open with screw driver and visually check for freedom to swing and to be held	. Remove the hinge cover and the cover, clean and reinstall.

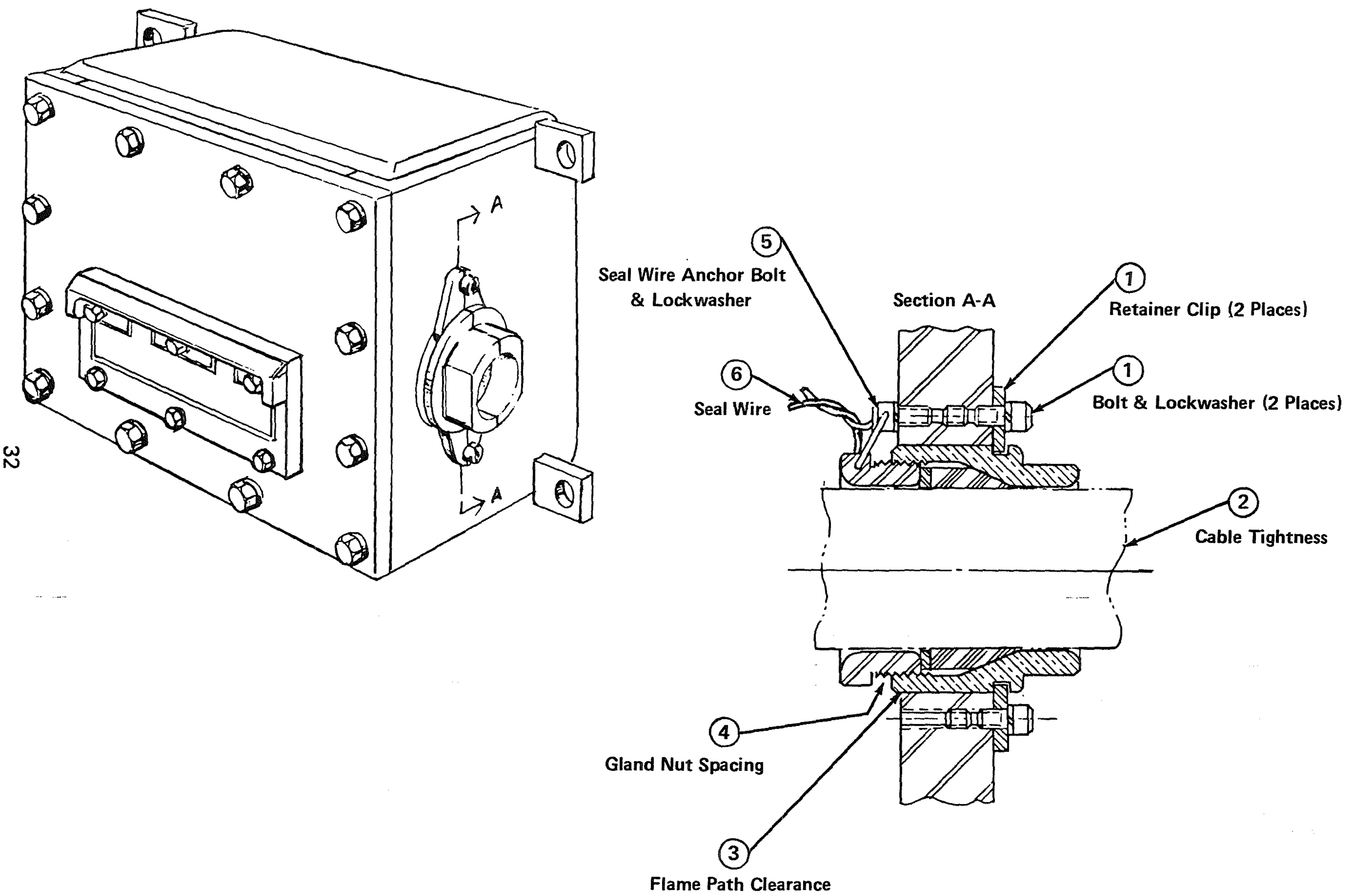


Figure 3—3 Inpection Items For Cable Entry

Table 3—2 Inspection Criteria For Cable Entry

ITEM	REFERENCE NUMBER	REQUIREMENT	TOOLS/GAUGES	INSPECTION METHOD	CORRECTIVE ACTION
Retainer Clip	1	. Clips must be present. . Lock washers must be in place on all bolts. . Bolts must be in place at all locations. . All bolts must be tight.	. 3/16" Allen key	· Visually inspect from outside of the enclosure. · Check the tightness of the bolts with a wrench.	. Tighten loose bolts. . Replace missing components.
Cable Tightness	2	. Cable must not slip when pulled.	. None	. With the cable entry secured into the enclosure pull on the cable from the outside of the enclosure.	. Remove cable entry assembly from the enclosure and tighten the gland nut. . Replace the grommet with a new one as required. . One 2½" open end wrench and one 2-5/8" open end wrench are required to disassemble and assemble the cable entry.
Flame Path Clearance	3	. .003" maximum radial clearance between the cable entry body and the enclosure wall.	. .003" feeler gage wire	. With the cable entry secured into the enclosure try to insert the gage wire into the flame path between the cable entry body and the enclosure wall.	. Replace the cable entry with a new assembly if clearance is excessive. . Rebuild cable entry and/or enclosure wall as required to obtain acceptable flame path clearances.
Gland Nut Spacing	4	. 1/8" minimum clearance between the gland nut flange and the cable entry body.	. ¾" open end, box or socket wrench . 1/8" gage block or feeler gage.	. With the enclosure cover removed, try to insert the gage into the clearance space.	. Replace the grommet with a new one as required.
Seal Wire Anchor Bolt	5	. Bolt and lock washer must be present. . Bolt must be tight.	. ¾" open end, box or socket wrench . 3/16" Allen key . Seal crimping tool . Wire cutters	. With the enclosure cover removed, visually inspect. . Check the tightness of the bolt with a wrench.	. Tighten loose bolts. . Replace missing components.
Seal Wire	6	. Seal wire must be present and secured.	. ¾" open end, box or socket wrench . Seal crimping tool . Wire cutters	. With the enclosure cover removed, visually inspect for the presence of the wire and seal.	. Replace missing components.

cable entries. Pressures in a conventional permissible electrical enclosure may be as high as 80 to 120 psi, whereas with a recommended pressure vent the highest measured pressure was 7 psi.

The new trailing cable entry employs a tapered urethane grommet for packing rather than conventional asbestos. Otherwise, the entry assembly is very similar to the conventional unit. The grommet is highly flexible and, when the packing nut is tightened down on the body, it will compress the grommet around the cable providing a flame tight seal. The grommet greatly simplifies the task of packing the cable entry and provides assurance of a longer term permissible seal.

These devices have been evaluated by MSHA and are being used under experimental permit. They comply with the permissibility objectives stated in Title 30, Code of Federal Regulations (CFR), Part 18, although they are physically new and different from anything presently described in the CFR.

3.3 Mine Personnel Functions

Jeffrey and Booz-Allen & Hamilton personnel jointly provided instructions to mine personnel prior to installation of the innovative devices. This included a description of the devices and their purpose, along with inspection procedures. Written information was provided that briefly described the devices and included copies of the permissibility inspection criteria.

As part of the experimental permit and in order to satisfy state mine regulation authorities, mine personnel made a daily inspection of the innovative devices whenever that equipment was to be used. This inspection was limited to what could be observed without dismantling any components. It included opening the protective cover and observing the condition of the pressure vent material, inspection of external flame paths, and inspection for tightness of the cable as it enters the enclosure. Mine personnel were requested to identify anything that appeared to be a change.

Telephone calls were made to the mine on a weekly basis to ask if there were any detectable changes or other items of significance. Mine personnel were requested to contact Jeffrey Mining Machinery Division in the event that there was anything significant or any question that might occur prior to the time of the weekly telephone contact. As it turned out, only two such contacts were initiated by the mine. One pertained to an information request to satisfy a mine inspector and the other to alert Jeffrey to the need for a spare cable entry body assembly. This is discussed in Section 4.0 under Results.

3.4 Visits by Project Personnel

The project team for mine visits consisted of the Jeffrey Program Manager, a Jeffrey field person, and an engineer from the subcontractor, Booz-Allen & Hamilton. In a couple of instances the visit was made without a Booz-Allen engineer being available.

Visits to the mine by project personnel were planned for the original installation and for approximately every month thereafter. Time between visits was to be stretched in the later months so that a total of 6 visits would be made, including both installation and removal of the innovative devices.

Work to remove or install components was performed exclusively by mine personnel with instructions from the project team. Inspections were performed by project team personnel whenever present. Although some spare components were left at the mine for emergency use, there was only one instance when the cable entry assembly had to be replaced. This is described in Section 4.0.

The plan called for exchanging both the vent insert and the grommet each time a project team would visit the mine. After the second set of hardware was removed from underground and shown to have no measurable deterioration, a decision was made to leave the third set of hardware in place for the longest possible time in order to gain the most operating experience. Consequently, subsequent visits were made for inspection purposes only without an intent to replace components.

During each visit to the mine an attempt was made to obtain reactions from mine personnel to the innovative devices. The plan was to talk with both section operating personnel and maintenance personnel, as well as other supervision. However, the design and physical location of the innovative devices resulted in their being very inconspicuous so that operating personnel paid no attention to them. In essence, they were oblivious to their presence. Therefore, reactions could be obtained only from maintenance and other supervisory personnel.

Other data to be collected during the in-mine evaluation included such things as machine-operating time and knowledge of any other action that might affect the innovative devices. This included such things as noting when the mine personnel had to re-enter the trailing cable due to external damage to the cable. This information was collected verbally during the weekly telephone contacts and during the personal visits.

Laboratory data and other information gained during the visits to the mine are described in the following section.

Section 4.0

IN-MINE TEST RESULTS

Agreement was obtained from the Eastern Associated Coal Corporation to evaluate the innovative explosion-proof electrical enclosure in their Federal No. 1 mine at Grant Town, West Virginia. A model 120-M Jeffrey continuous miner, serial number 36852, was identified for the tests. This machine was being used in section 24-left, where they were in the process of pulling pillars. Arrangements were made with the mine superintendent and most of the follow-up contacts were made with the mine maintenance chief.

Installation of the innovative devices was made on July 22, 1980, and they were removed on April 8, 1981. At the time of removal the trailing cable connection box was returned to its original configuration prior to the installation of the innovative devices.

Information in this section is presented under either the heading of the pressure vent or the innovative cable entry assembly.

4.1 Pressure Vent

A total of 10 pressure vent insert samples were fabricated for this in-mine evaluation. Laboratory tests were made on each of these prior to beginning the underground exposure and the conditions were recorded for reference.

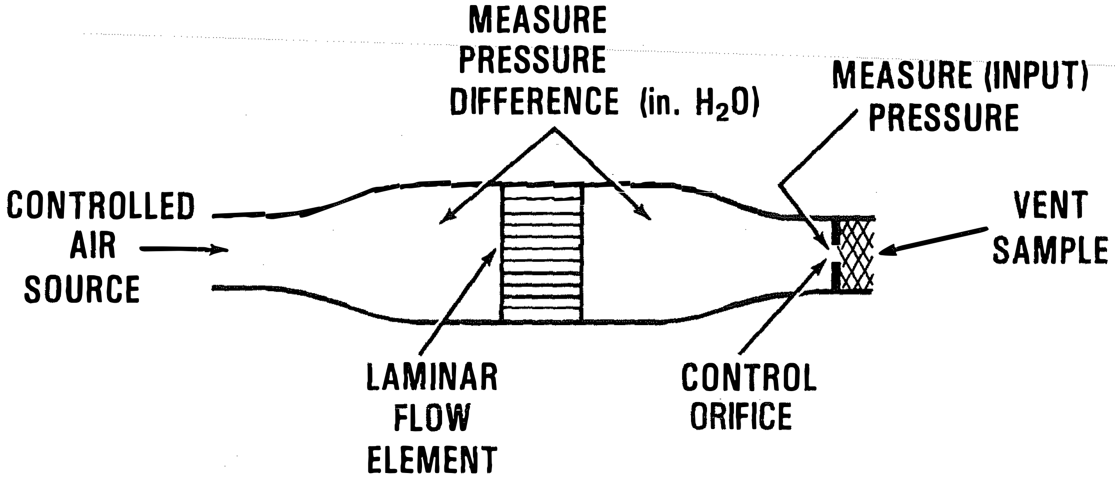
The original weights of these samples are recorded in Table 4-1 in the left hand (before) column. The weight after exposure underground is recorded in the right hand column and it is apparent that there was no significant change. Also noted in Table 4-1 are the dates on which each of the samples was installed and removed. Note that the last sample was in place for 6-1/2 months. A weight gain could occur if there is clogging material or moisture present, and a weight loss could occur if some of the material was eroded away.

Laboratory measurements were made on each sample to determine the pressure drop characteristics across each vent sample as a function of air flow rate. The technique, illustrated in Figure 4-1, is to force a gas to pass through a measured area of the sample of known thickness while measuring the flow rate of gas and the pressure difference across

TABLE 4-1 Pressure vent insert samples installation dates and weights

SAMPLE NO.	DATE IN	DATE OUT	WEIGHT (GRM) BEFORE	WEIGHT (GRM) AFTER
1	7-22-80	8-21-80	98.1	98.1
2	8-21-80	9-26-80	85.5	85.1
3	9-26-80	4-8-81	101.0	101.1
4			85.1	
5			92.8	
6			95.5	
7			105.1	
8			91.7	
9			81.6	
10			83.4	

Note: Only the first three samples were installed in the mine.



$$\frac{\Delta P}{L} = K_1 \left(\frac{Q}{A}\right) + K_2 \left(\frac{Q}{A}\right)^2 = \text{Normalized Pressure Drop}$$

WHERE:

ΔP = Pressure Drop Across Vent Sample = $\frac{\text{Measured Input Pressure}}{\text{Atmospheric Pressure}}$

L = Length of Sample = .512 Inches (also = δ)

Q = Mass Flow Rate (Using Measured Pressure Difference Across Laminar Flow Element And Calibration Tables)

A = Area Of Control Orifice

K_1 And K_2 are Determined Empirically by Least Square Error Procedure

Figure 4–1 Technique For Measuring Vent Air Flow the sample thickness. In this case the gas used was a source of compressed air after being passed through filters to remove moisture. The flow rate was determined by passing this air through a laminar flow element and noting the pressure difference between each side of that element. The pressure drop across the vent sample was determined by measuring the pressure as the air enters the element as compared to atmospheric pressure, which is on the outside of the vent sample. Measured data is then used in the basic flow rate equations to plot a curve of pressure gradient across the sample versus the flow rate through the sample.

Measurements were performed on a number of samples in order to establish the basic characteristics of the vent material and to verify that the pressure gradient may be nominalized across a unit area. Results of these measurements are plotted in Figure 4-2. There was no control orifice in the test setup when a 14.4 square inch sample was measured. Then a controlled orifice was introduced which reduced the opening to 1.61 square inches. Ultimately, a 1" diameter opening with an effective cross section of .785 square inches was tested. As can be seen from the curves in Figure 4-2, the values for the different control orifice sizes fall very much along the same plots. Thus, it was concluded that the data can be nominalized by using a control orifice of 1" diameter.

Also shown in Figure 4-2 is a plot of the discharge coefficient versus the flow rate per unit area. After the flow rate passes 12 feet per second this curve flattens out and rises at a very slow rate. This verifies that the flow characteristics through the vent will remain essentially constant as the flow rate increases. For example, if an explosion occurs within an enclosure having a pressure vent, the flow rate could be very high from the very beginning. A more detailed description of the test setup for air flow measurements is provided in Appendix A.

Each sample prepared for the underground evaluation was carefully measured to determine the pressure gradient. The two constants used in the basic equation were determined from the measured data and then calculations used to establish the pressure gradients noted in the columns of Tables 4-2, 4-3, and 4-4 that are marked "Before". This data is provided for only the first three samples since the other samples were never used in the mine evaluation.

As each sample was removed from the mine, it was measured using the same technique and the pressure gradients were again

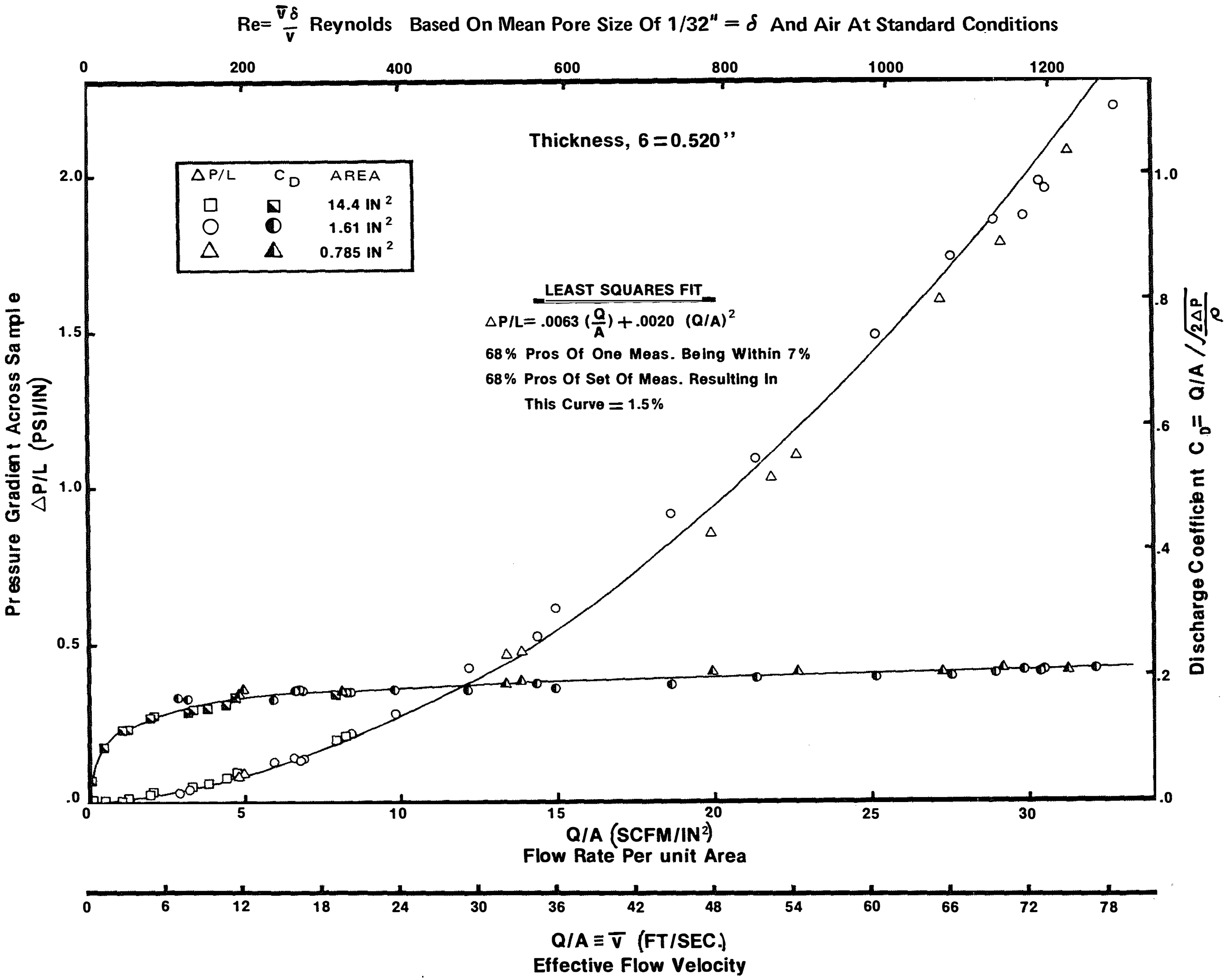


Figure 4—2 Air Flow Characteristics Of Retimet Metal Vents Of Three Different Areas

TABLE 4-2 Percent change in pressure gradient of sample number 1

Percent change in the pressure gradient $\Delta P/L$ was calculated for range of Q/A using K1 and K2 as determined in flow tests performed before and after mine service.

$$\Delta P/L = K1\ (Q/A) + K2\ (Q/A)^2$$

	BEFORE K1= .00362 K2= .00110 e = <1%		AFTER K1= .00333 K2= .000996 e = 1%		
Calculation Number	Q/A SCFM/In.^{2}	ΔPL PSI/IN.	Q/A SCFM/In.^{2}	ΔP/L PSI/In.	% Change ΔP/L
100	0	0	0	0	0
101	6	.0613	6	.0558	(9.0)
102	10	.1462	10	.1329	(9.1)
103	13	.2330	13	.2116	(9.2)
104	17	.3794	17	.3445	(9.2)
105	23	.6652	23	.6035	(9.3)
106	29	1.0301	29	.9324	(9.3)
107	34	1.3947	34	1.2646	(9.3)
108	40	1.9048	40	1.7268	(9.3)
109	44	2.2889	44	2.0748	(9.4)
110	46	2.4941	46	2.2607	(9.4)

TABLE 4-3 Percent change in pressure gradient of sample number 2

Percent change in the pressure gradient $\Delta P/L$ was calculated for a range of Q/A using K1 and K2 as determined in flow tests performed before and after mine service.

$$\Delta P/L = K1\ (Q/A) + K2\ (Q/A)^2$$

Calculation Number	BEFORE K1= .00351 K2 = .00104 e = <1%		AFTER K1= .00193 K2 = .00102 e = 1%		% Change $\Delta P/L$
	Q/A SCFM/In.^{2}	$\Delta P/L$ PSI/In.	Q/A SCFM/In.^{2}	$\Delta P/L$ PSI/In.	
200	0	0	0	0	0
201	6	.0585	6	.0483	(17.4)
202	10	.1391	10	.1213	(12.8)
203	13	.2214	13	.1975	(10.8)
204	17	.3602	17	.3276	(9.1)
205	23	.6309	23	.5840	(7.4)
206	29	.9764	29	.9138	(6.4)
207	34	1.3216	34	1.2447	(5.8)
208	40	1.8044	40	1.7092	(5.3)
209	44	2.1679	44	2.0596	(5.0)
210	46	2.3621	46	2.2471	(4.9)

TABLE 4-4 Percent change in pressure gradient of sample number 3

Percent change in the pressure gradient ΔP/L was calculated for a range of Q/A using K1 and K2 as determined in flow tests performed before and after mine service.

$$\Delta P/L = K1\,(Q/A) + K2\,(Q/A)^2$$

Calculation Number	BEFORE K1=.00307 K2= .00117 e = <1% Q/A SCFM/In.^{2}	ΔP/L PSI/In.	AFTER K1=.00337 K2 = .000985 e = <1% Q/A SCFM/In.^{2}	ΔP/L PSI/In.	% Change ΔP/L
300	0	0	0	0	0
301	6	.0605	6	.0557	(7.9)
302	10	.1477	10	.1322	(10.5)
303	13	.2376	14	.2103	(11.5)
304	17	.3903	17	.3420	(12.4)
305	23	.6895	23	.5986	(13.2)
306	29	1.073	29	.9261	(13.7)
307	34	1.4569	34	1.2532	(14.0)
308	40	1.9948	40	1.7108	(14.2)
309	44	2.4002	44	2.0552	(14.4)
310	46	2.4833	46	2.2393	(9.8)

determined for the same air flow rates. These values are listed in the columns of Tables 4-2, 4-3, and 4-4 that are marked "After". If any blockage of the vents occurred during the in-mine exposure then the pressure gradients should have increased as a result of that mine exposure. In each of the three cases the actual pressure gradient, as measured after removal from underground, showed a slight decrease in pressure gradient across the vent samples. This meant that there was a more free air flow rather than any clogging. The amount of difference is rather inconsequential and is typically in the order of 5 to 14%.

When the vent samples were originally measured they were held tightly in the test setup but there was no permanent distortion of any of the vent material. Installation of the vent into the frame, as used in the explosionproof enclosure, results in a small permanent deformation around the periphery of the vent. It was designed in this fashion to insure a very tight fit around the edges. It is theorized that this slight deformation around the periphery caused the air flow in the test setup to be slightly less obstructed and that this accounts for the modest decrease in the pressure gradient measurement.

The significant point from the measurements comparing the samples before and after the in-mine exposure is that there was definitely no measurable increase in resistance to air flow. It is therefore concluded that there was no clogging buildup as a result of in-mine exposures up to 6-1/2 months.

Visual inspection of the pressure vents was very important. In earlier phases of this program, when these vents were being developed, there were conditions which resulted in erosion of vent material and also conditions which caused deterioration due to overheating of the surfaces. Also, visual inspection can be used to help detect the presence of corrosion and clogging.

The procedure used in inspecting the pressure vents for permissibility is described in Section 3.2. That was followed by the project team during each visit. Limited visual inspections were made by the mine operators during their daily inspection.

The vent protective cover was watched very closely because of the possibility of buildup around the knife edge hinge that might inhibit the door opening. It is important that the door be free in order to achieve the vent function. As stated earlier, this door opens when the pressure on the exit side of the vent exceeds approximately 1 psi. There was never any noticeable collection of dirt or other material around the knife edge hinges and it was always found to be free to swing open. In addition, even though the parts were left unpainted so as to hasten corrosion effects, this did not inhibit the door either. The door is shown in Figure 4-3 propped open on the cover just after removal from the mine.

Flame path gaps were carefully checked and there was never any detectable change on any of the innovative devices. There were a few instances where the basic enclosure flange gap would allow penetration of a .002" feeler gauge to a depth of approximately 5/8". This apparently was due to a collection of corrosion and other particles on the flange surface. Carefully scraping and sanding of these surfaces eliminated any measurable gap.

Visual inspection of the vent from the outside did not show any changes. The vent that was in place for 6-1/2 months can be seen in Figure 4-3 and the surface looks the same as when it was first installed. The inside surface of the vent sample was inspected during each project team visit and it too did not show any change from original installation. In one instance there was a trace of rust particles showing two paths where moisture from the inside edge of the basic cover had run down the inner edge leaving a small trace of rust particles. This was noted on the sample that was in place for over 6 months and is visible to some extent in Figure 4-4. However, this deposit did not have any measurable effect upon the vent.

The vent samples were removed from the frame only when being replaced. As stated earlier, there is a slight deformation that occurs around the periphery due to the retaining ring pressing the vent sample into the frame. This deformation can be seen in Figure 4-5.

Each time the vent sample was replaced the orientation was carefully noted so as to preserve the continuity for the subsequent laboratory measurements. Figure 4-6 shows sample No. 3 after removal from the vent frame. The traces from the water and rust particles are visible in this figure. Figure 4-7 compares this vent sample to a new unused sample on the right.

It may be concluded from these tests that the pressure vent assembly and samples showed no discernible degradation after the result of in-mine exposure under actual productuion conditions. There was no measurable clogging effect in the vent material. The unexpected reduction in resistance to air flow through the vent appears due to an anomaly of the test procedure and not any change in the vent assembly itself.

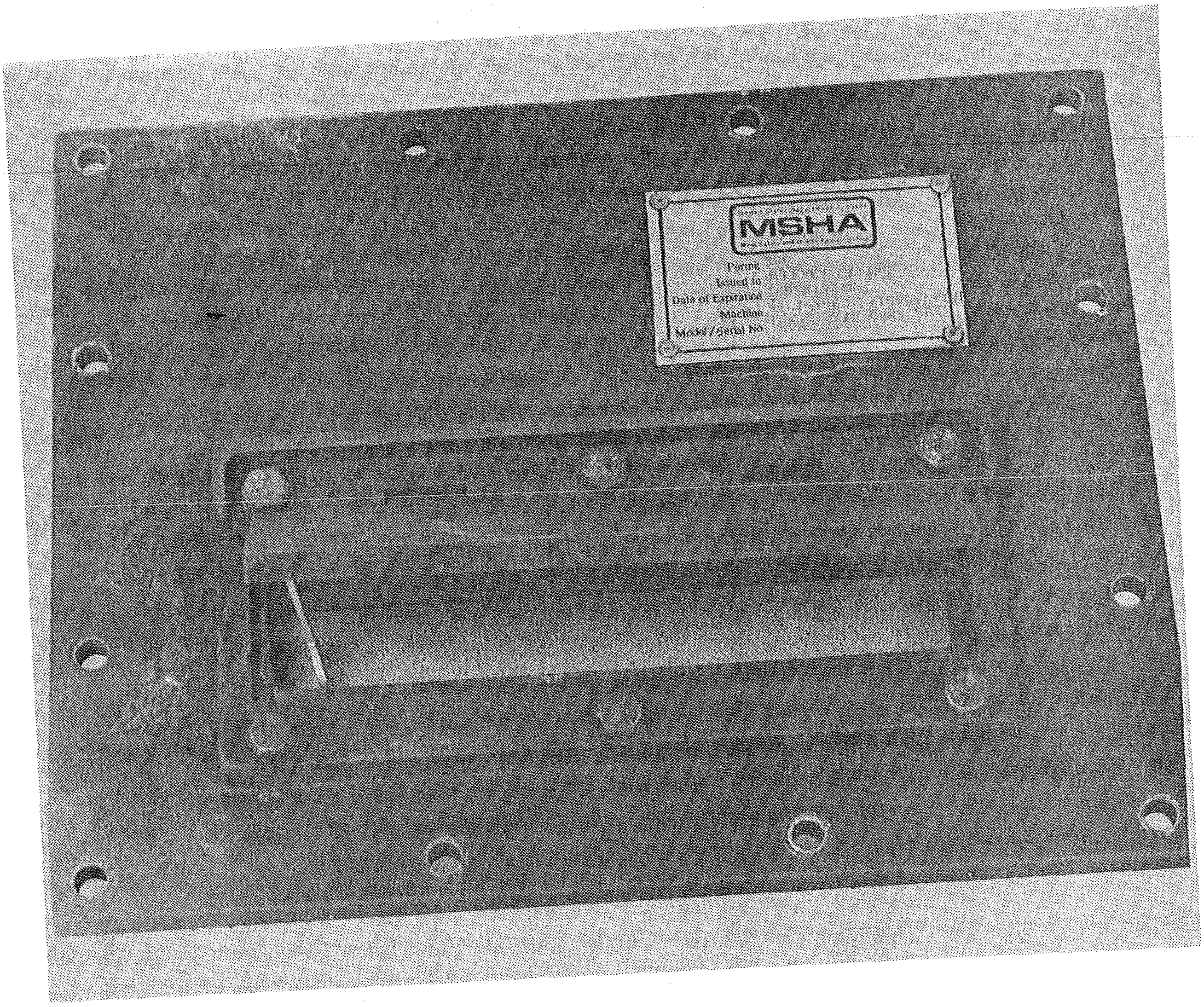


Figure 4–3 Enclosure Cover And Vent After Removal From Mine

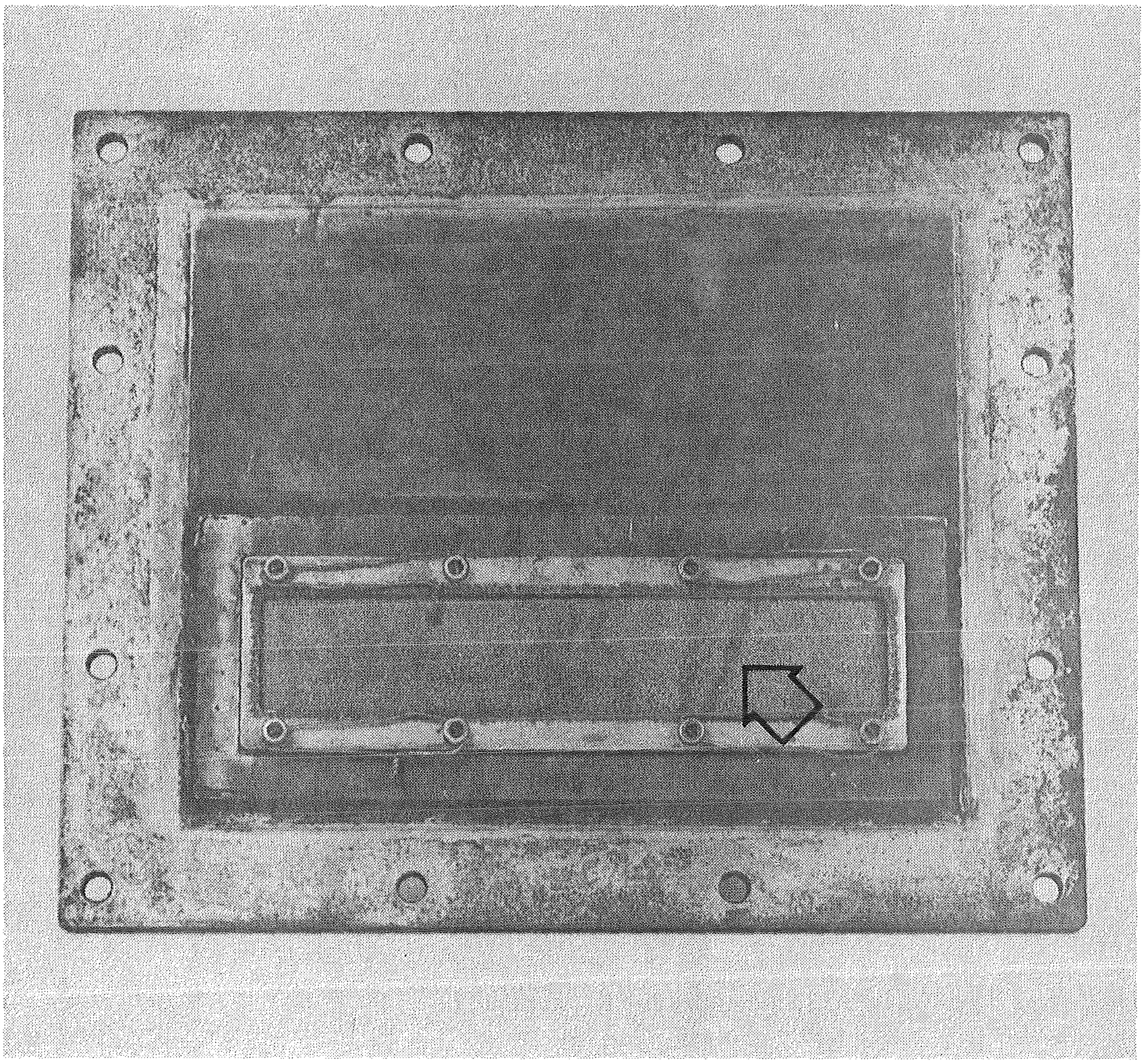


Figure 4—4 View Looking At Inside Of Cover And Vent After Removal From Mine

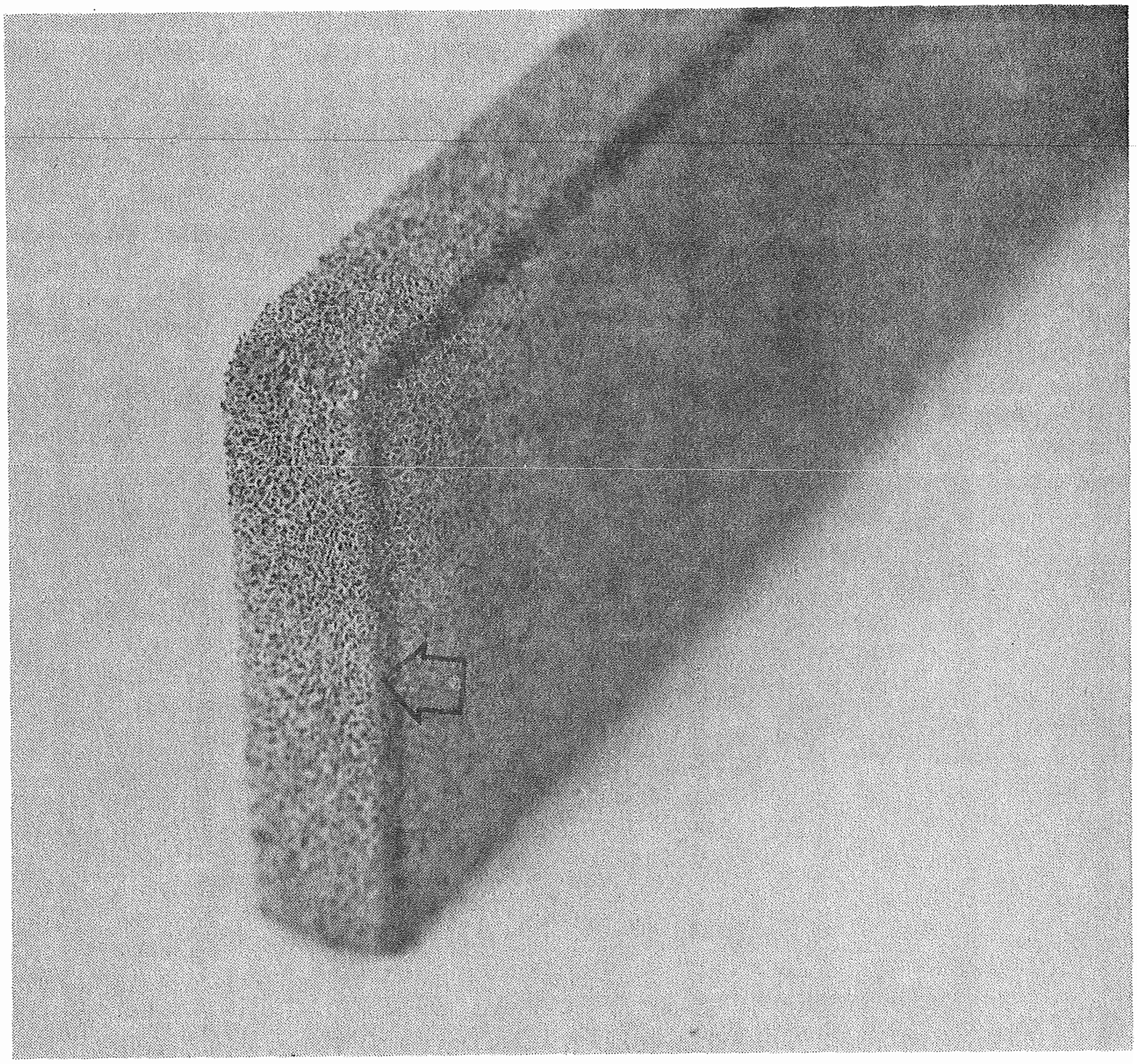


Figure 4–5 Pressure Vent Sample Showing Deformation Resulting From Retention In Vent Frame

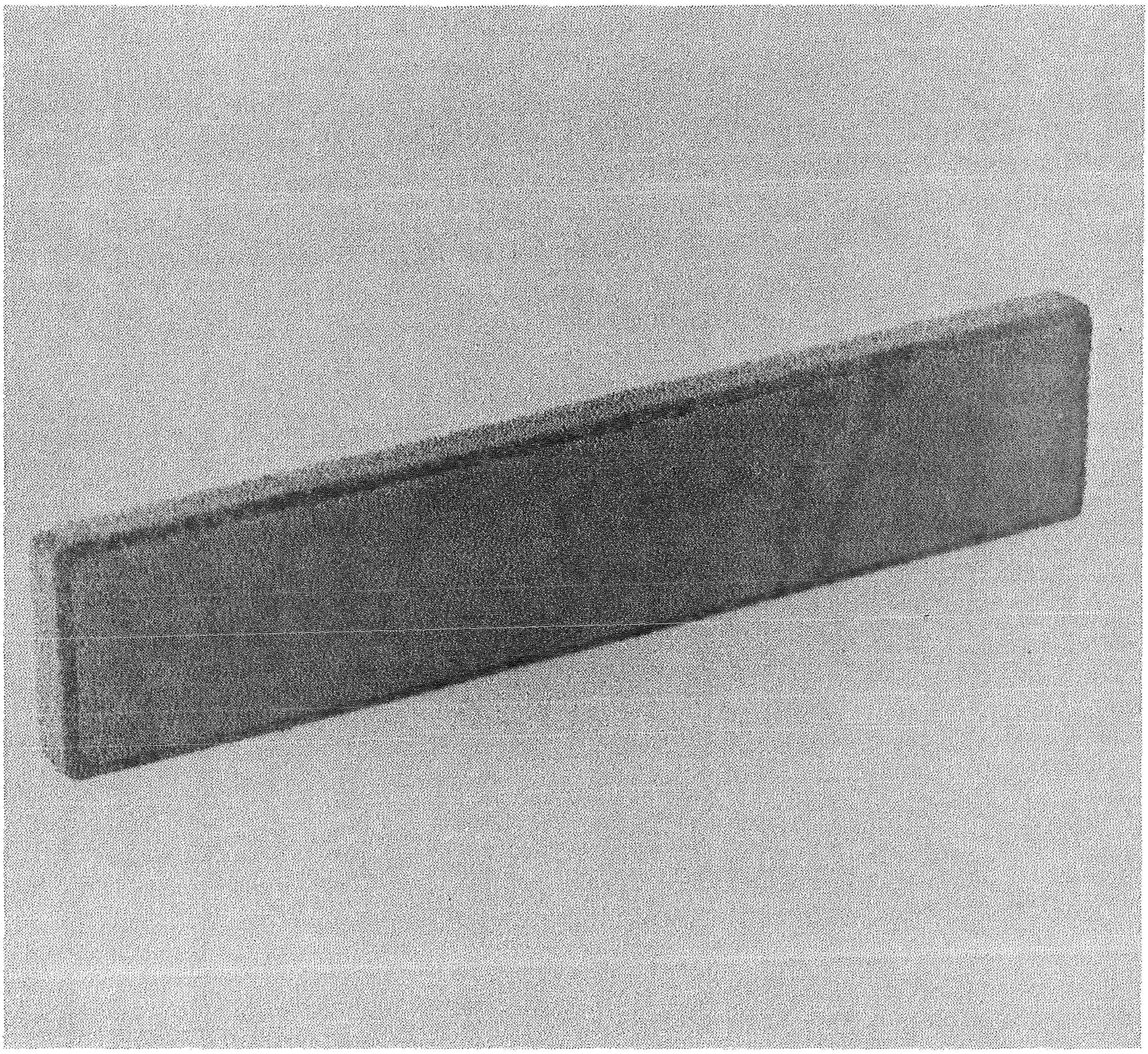


Figure 4—6 Looking At Inside Surface Of Vent Sample Number 3 After Removal From Mine

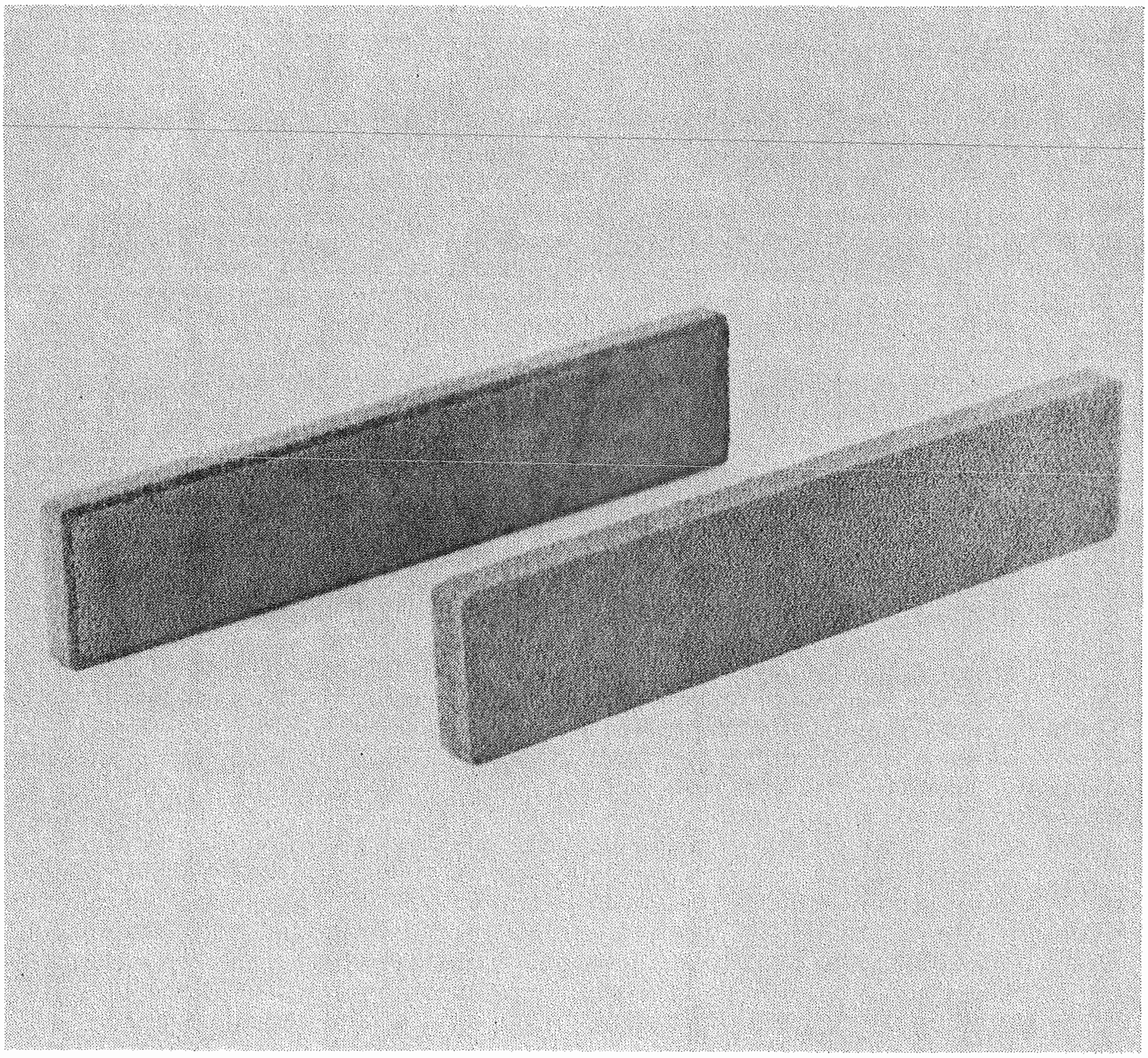


Figure 4—7 Vent Sample Number 3 (Left) After Removal From Mine Compared To New Vent Sample (Right)

4.2 Elastomeric Cable Entry

The innovative elastomeric cable entry assembly was used for the trailing cable on the connection box. There are 6 other cable entries on this connection box that carry primary power to the control case, but these continued to use conventional asbestos packed cable entry assemblies. Interchange of the trailing cable entry assembly was simple because of the slip-fit type body employed. The external configuration of the elastomeric cable entry assembly was made basically similar to the conventional assembly.

Two cable entry body assemblies and six grommets were fabricated for this in-mine evaluation. Data was taken on each of the grommet samples prior to the start of the in-mine test. This data included weight, dimensional information, and material hardness. Figure 3-1 shows where the dimensions and hardness measurements were taken on these grommets. Table 4-5 presents a summary of the data both before and after the in-mine tests. Also included in Table 4-5 are the dates for installation and removal for each of the grommets.

Project personnel were present each time a grommet was installed or removed, except for February 3, 1981 when the mine operator replaced the entry body assembly and grommet after external damage to the trailing cable. During the in-mine evaluation, there were three instances when the mine personnel had to reenter the trailing cable because of external damage. The first two times it was done without replacing parts and without any project personnel being present. Jeffrey was advised that the cable entry body had been damaged in the process of removing it from the enclosure and therefore a spare assembly was made available to the mine in the event that the cable had to be reentered again. This did occur on February 3. Mine personnel removed the old entry and returned it to Jeffrey.

Figure 4-8 shows the first cable entry assembly as removed from the mine by the mine operator. It is also shown in Figure 4-9 on the left and the second cable entry assembly is shown in Figure 4-9 on the right. Considerable damage is apparent due to the use of tools and difficulty in removing the cable entry body from the enclosure wall. A subsequent inspection of the enclosure, when the second entry assembly was removed in April, showed that there was a sizeable nick in the enclosure opening for the entry body which caused the body to bind when either inserting or removing the body from the enclosure wall. Both entry bodies showed a similar pattern of damage due to this nick, but more care was taken with the second cable entry body after the original difficulties were experienced. This nick in the enclosure wall appeared due to

TABLE 4-5 Elastomeric grommet data summary

SAMPLE NO.	DATE IN	DATE OUT	WEIGHT (GRM) BEFORE	WEIGHT (GRM) AFTER	O.D. (IN)* BEFORE	O.D. (IN)* AFTER	I.D. (IN)* BEFORE	I.D. (IN)* AFTER	HEIGHT (IN)* BEFORE	HEIGHT (IN)* AFTER	SHORE GAUGE "A" SCALE * BEFORE	SHORE GAUGE "A" SCALE * AFTER
1	7-22-80	8-21-80	40.2	40.4	2.640	2.635	2.140	2.156	1.395	1.392	76	75
2	8-21-80	9-26-80	40.2	40.3	2.630	2.641	2.146	2.141	1.385	1.391	77	77
3	9-26-80	2-3-81	40.4	40.5	2.640	2.672	2.140	2.168	1.405	1.403	77	73
4			40.1		2.655		2.165		1.390		76	
5	2-3-81	4-8-81	40.4	40.3	2.650	2.651	2.160	2.167	1.393	1.387	76	74
6			40.5		2.640		2.154		1.400		75	

*Average of eight readings around grommet

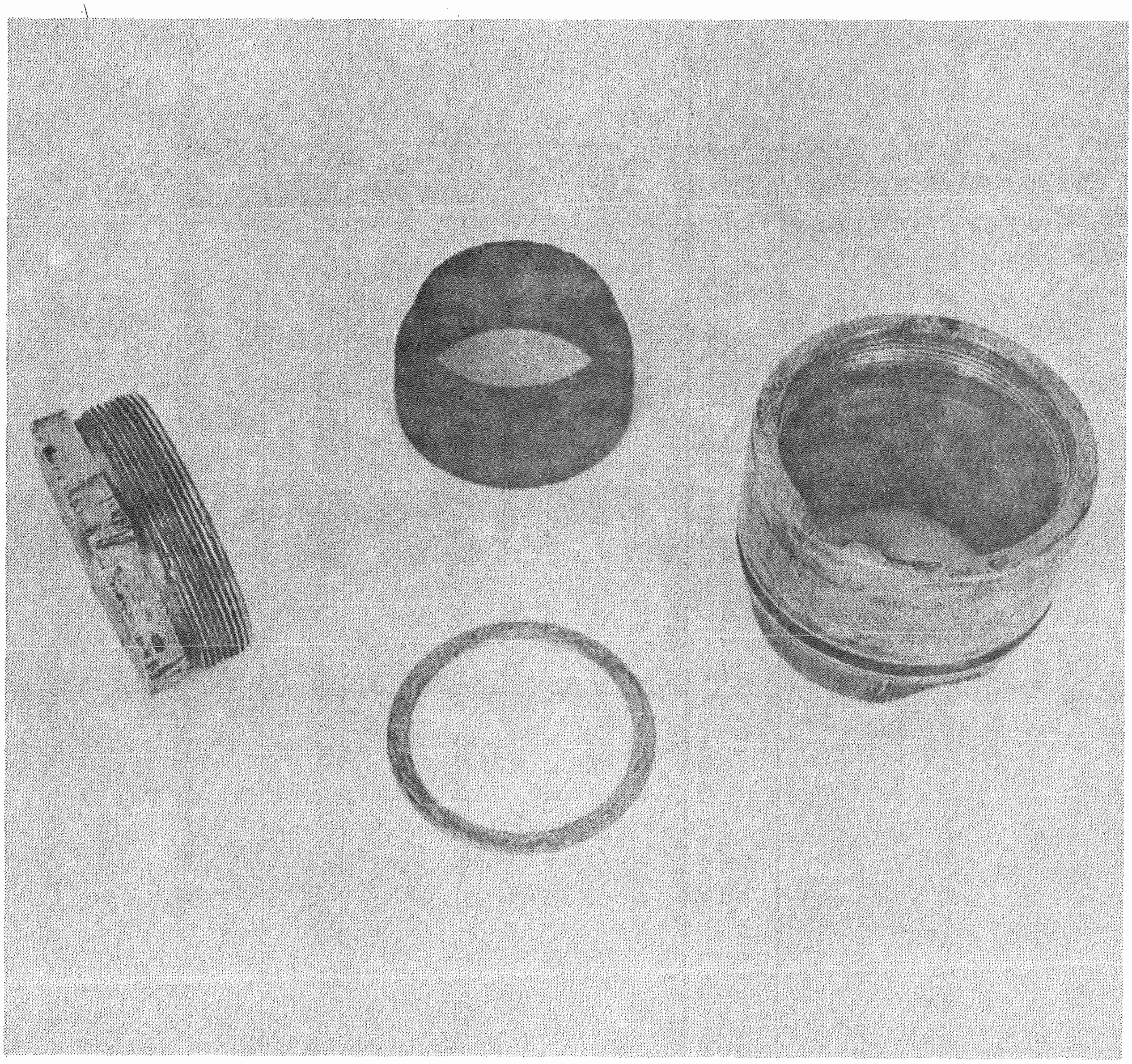


Figure 4–8 Cable Entry Assembly Number 1 With Grommet Number 3 After Removal From Mine

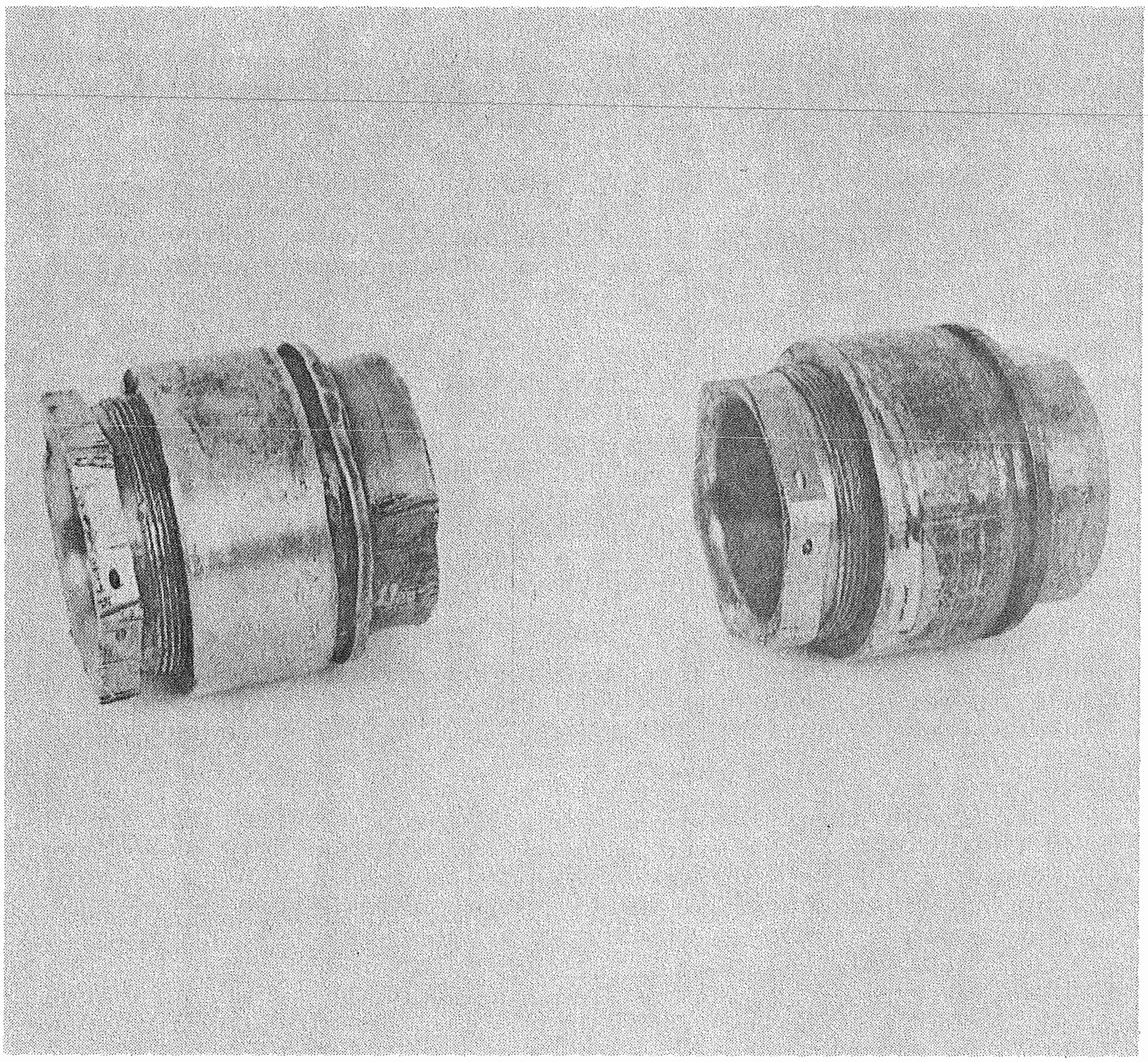


Figure 4—9 Cable Entry Number 1 (On Left) And Entry Number 2 (On Right) After Removal From Mine

some maintenance action, but was not apparent at the beginning of this in-mine evaluation. It should be noted that this does not impact the innovative cable entry assembly considerations since the conventional cable entry would have exactly the same situation.

Figure 4-8 shows the number 1 cable entry body and the number 3 grommet. Figure 4-10 shows the number 2 cable entry body and the number 5 cable entry grommet. The number 3 grommet showed more darkening or discoloration than did any of the others. That grommet was in place for 4-1/2 months and also had been coated with a lubricant to facilitate assembly. The lubricant was applied via an aerosol can and is claimed to be a moisture dispelling type which is non-explosive and is safe on rubber, plastic, paint and finished surfaces. Grommet number 1 and number 2 showed a similar discoloration as number 3, although not quite to the same extent. It is known that the spray lubricant was used on these first two grommets as well as number 3. The number 5 grommet shows only a slight darkening from the rather light color of the unused grommets.

Weight measurements, as shown in Table 4-5, show less than 1/2% difference after mine exposure as compared to initial weight before mine exposure. This is considered insignificant and is probably within measurement accuracy limits.

Average dimensional readings for the outside, the inside and the height are listed in Table 4-5 both before and after the mine exposure. These measurements were taken at 8 locations around the grommet as illustrated in Figure 3-1. The maximum differences in the 8 measurements before the grommets were installed in the mine were noted as .0035" for the ID and .003" for the OD. Maximum differences on the 8 measurements for grommets after mine exposure were .010" for the ID and .002" for the OD.

Measurements of the elastic material, such as these grommets, is difficult because of the material and the fact that the body is not rigid. As noted earlier, the grommets were supported either within the entry or on a mandrel to provide some amount of stiffness. The variance noted in any of the measurements, the maximum being .010", is not much more than the limits of accuracy in measurement.

Comparison of OD and ID measurements both before and after, as listed in Table 4-5, show a slight enlargement in the order of .010" for the most part, although the OD of the number 1 grommet was slightly less after the mine exposure. This change is considered insignificant.

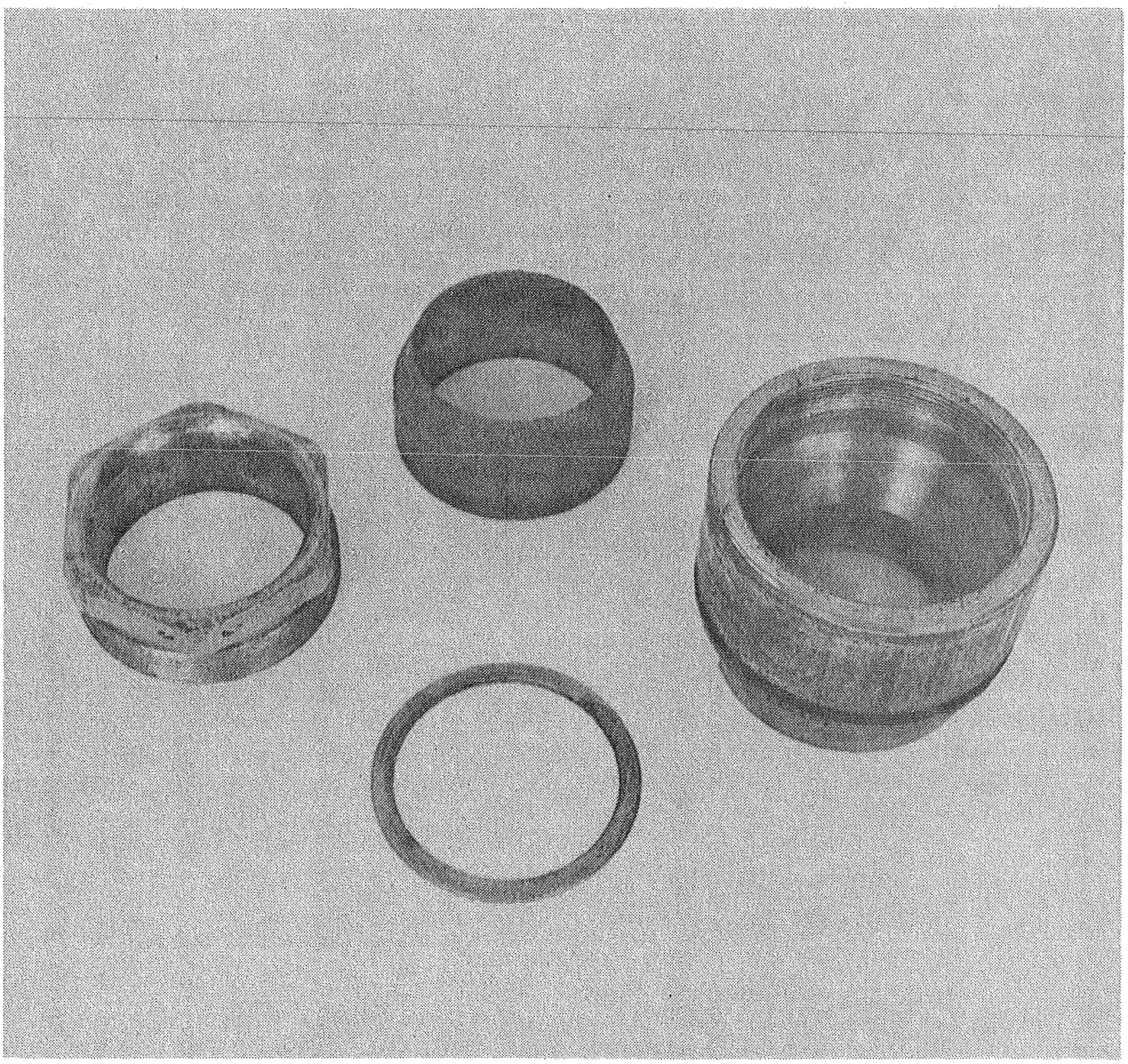


Figure 4–10 Cable Entry Assembly Number 2 And Grommet Number 5 After Removal From Mine

Changes in wall thickness of the grommet are considered more important. Table 4-6 lists this wall thickness, which is the difference between the ID subtracted from the OD, for the four grommets both before and after the mine exposure. The maximum change of 4.2% (in the number 1 grommet) is again insignificant. There was no definite pattern of change since two of the grommets showed a very slight decrease in wall thickness, and the other two grommets showed a very slight increase in the thickness. These results are considered very good, especially considering the fact that the trailing cable was bent at a radius of approximately 6" as it comes out of the cable entry to leave the machine. This placed a very high abnormal load on the grommet within the cable and should have represented one of the most severe conditions.

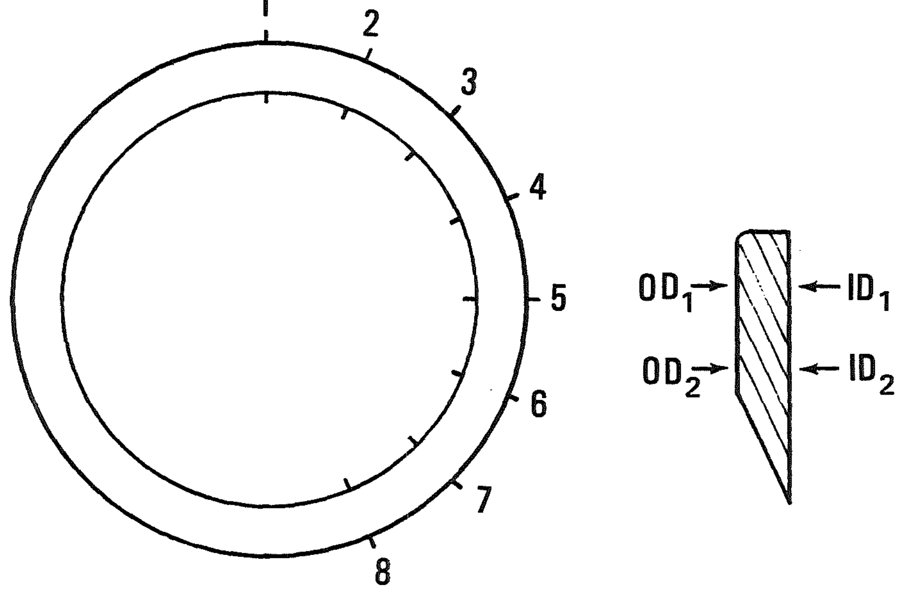
The number 3 grommet, which was in place for 4-1/2 months, showed the maximum permanent set of any of the grommets. This change in grommet dimensions occurred at the point where the taper meets the uniform radius of the grommet, and is identified as OD_2 and ID_2 in Figure 4-11. Listed in this figure are the OD and ID measurements at the 8 locations around the grommet for both the normal location and for the location where the taper meets the uniform radius. These measurements, of course, are for the grommet after removal from the mine. Wall thickness at the normal place of measurement OD_1 ID_1 was only .004" larger after the mine exposure. At the junction point between the taper and the constant radius (OD_2) the wall thickness average was .031" larger than before. This is considered to be a permanent set that resulted from the pressures exerted upon the elastomeric grommet while packed in the cable entry assembly with the cable.

Some permanent change in dimensional characteristics is normal for any elastomeric material that has been constrained to other than original dimensions since there is no perfect elastomer. The amount here appears to be within limits identified for urethane materials by the supplier. A significant change of material hardness could indicate a potential problem and the loss of resiliency. As can be seen in Table 4-5, there was no significant change in measured hardness after mine exposure from those measured before mine exposure.

Results from the four (4) grommets exposed to the underground mine environment are very favorable. The grommets performed their function well with no measurable degradation. The only difficulties experienced in the cable entry assembly were conventional, mechanical difficulties totally unrelated to the innovative features of the grommet type cable entry. This mine demonstration verified the ability of the urethane

TABLE 4-6 Grommet wall thickness data summary

GROMMET NUMBER	WALL THICKNESS (in) BEFORE	AFTER	% CHANGE
1	.500	.479	(4.2)
2	.484	.500	3.3
3	.500	.504	0.8
4	.490	.484	(1.2)



Installed in Mine 9-26-80
Removed from Mine 2-3-81

POSITION	OD	ID	Wall Thickness	OD	ID	Wall Thickness
1	2.671	2.1675		2.6465	2.1125	
2	2.6715	2.175		2.645	2.113	
3	2.672	2.1695		2.6445	2.113	
4	2.672	2.1675		2.644	2.1135	
5	2.672	2.166		2.644	2.113	
6	2.6725	2.1655		2.643	2.113	
7	2.672	2.165		2.643	2.1128	
8	2.672	2.166		2.643	2.1128	
After Avg.	2.6719	2.1678	.504	2.6441	2.1130	.531
Before Avg.	2.640	2.140	.500			

Figure 4—11 Dimensional Data For Grommet Number 3

tapered grommet to adequately seal around the cable and to hold up under extended in-mine exposure.

Measured performance of both the pressure vent and the elastomeric cable entry was as good as could be expected. Recommendations are made in the following section for future work to introduce these devices to the mining industry.

Section 5.0

PRESSURE VENT ACCEPTANCE CRITERIA

Both the pressure vent and the cable entry (or lead entrance) assemblies described in the preceding sections were designed to be in accordance with Part 18, Title 30 CFR as presently established. These particular test devices were built with limitations to assure that approval to test in an underground coal mine could be obtained under the most strict interpretation of the existing regulations. As a result, they demonstrated only the basic characteristics and not the wide range of advantages that accrue from full utilization of these concepts.

Practical implementation of the concepts is possible because of advancements in the technological state-of-the-art. The regulations, as now stated, are restrictive on certain design factors that do not take into account the technological advances. The intent of work reported here is to provide technical information that may be used by government agencies to evaluate and approve pressure vented explosionproof enclosures and the urethane grommet type lead entrance. It is hoped that these devices can be approved under proper interpretation of 30 CFR Part 18, or appropriate changes made to the regulations to account for these technological advances.

This section and the following section on lead entrances describe the background search for information, interpretation of data, and present recommended criteria that may be used for approval of devices using these concepts to the fullest extent.

5.1 Background Investigation

Advantages of pressure venting devices to minimize pressure build-up due to a gas explosion inside an electrical enclosure were identified during work performed at Gelsekirchen-Bismark in 1903, 1904, and 1905, and reported by C. Beyling in 1906. Even though instrumentation available at that time was limited, considerable understanding was gained. Various types of net or wire gauze material were tried in order to provide flame resistant paths for escape of gases due to the rising pressure. Phenomena, now termed pressure piling, were noted, and the influences of the point of ignition location and the location of effective baffles were studied.

These tests clearly showed that pressure build-up due to an explosion internal to an enclosure could be kept very low by using a pressure vent. This, in turn, would allow much greater tolerance for other possible flame paths from the enclosure and much simpler construction since the enclosure did not have to withstand pressure differentials as high as 100 psi. In fact, in his conclusions Dr. Beyling advises that flame paths (flange gaps) not be packed with India rubber, asbestos, or other such material. He recognized that these gaps provided some pressure venting.

While the advantages of pressure venting an explosionproof enclosure were clearly shown, there had been no success in identifying a suitable pressure vent structure. In some instances wire gauze material was found to survive one explosion test, but did not survive under repeated testing whenever there was appreciable internal gas volume. The only success with this vent material was in small enclosures such as lamps.

Another problem experienced in this early work was afterburning. Assuming that the vent structure survived the initial explosion, there may be an inflow of combustible gases from outside the enclosure after the initial explosion and flame inside the enclosure. These fresh combustible gases could then be ignited by hot particles inside the enclosure and lead to new or sustained burning. This afterburning phenomena can be sustained only as long as combustible gases are present around the outside of the enclosure.

Labyrinth devices were tried for vents. These could be made much more durable and the tortuous paths could be made sufficient to extinguish any flame before exit from the enclosure. Experiments helped define allowable opening sizes and path lengths. Unfortunately, the labyrinth devices in most applications could not provide sufficient venting capability to achieve the effect of minimizing build-up of pressure due to an explosion inside an enclosure.

Another concern was also identified during this early work. This was the ruggedness of the net or wire gauze material. Being fragile, the material could easily be punched through from the outside. Also, the material was not sufficiently self supporting over a very large area.

There is mention in the Beyling report of a specific minimum ratio of vent area to enclosure gas volume, but this factor is for specific limited tests. At least the relationship was established in a qualitative manner in order to accomplish the venting and not burn through the vent.

In summary, work almost eighty years ago with explosionproof electrical enclosures showed that:

1. Pressure vents can keep pressure build-up inside the enclosure very low.
2. Reduced internal pressure build-up significantly reduces requirments for enclosure ruggedness from the explosionproof standpoint and reduces the flame path requirements.
3. Pressure vent size required is related to the volume of gas internal to the enclosure.
4. The pressure vent must withstand repeated explosions, regardless of the point of ignition within the enclosure.
5. Afterburning can occur and must be avoided.
6. The pressure vent must be sufficiently rugged to avoid damage due to handling, shock, vibration or possible impact.

Very little additional information was found in U.S. Bureau of Mines documents regarding pressure vents for this purpose. Vents for slower rate equalization and to provide air exchange have been used for many years and are allowed by Part 18.28 of the CFR, Title 30. These vents are typically a labyrinth configuration and made with rugged castings. While these work well for small air flow, they have a tendency to clog with coal and dirt. Consequently, they must be cleaned frequently. This experience should be considered in setting requirements for the high flow rate pressure vent.

Other work, outside the USBM, has sought effective pressure vent devices for explosionproof containers. Some of this is described in those reports listed in Appendix B of the earlier report on this contract, "Innovations for Explosionproof Electrical Enclosures", submitted in April 1980. Much of this work was independent from applications in underground coal mining. While these programs provided refinement to understanding this subject, they did not identify any additional basic requirements that need to be considered.

Survivability in the real environment is, of course, a fundamental overriding requirement. The in-mine evaluation described earlier in this report, was performed to help verify this criteria for the pressure vent developed during this program.

The factors discussed above were considered in establishing the criteria contained in the following section.

5.2 Recommended Acceptance Criteria

Acceptability criteria for high flow rate pressure vents are recommended in this section. The criteria are based upon meeting the requirements described above and the knowledge gained during development and test as described in the report submitted in April 1980.

The material used in the vent is critical to achieving the performance. Many different types have been tried, both during this program, and by many others over years of time. Therefore, emphasis is placed on the specific metal foam vent material characteristics.

Questions have been asked about this metal foam and most of these are addressed in the recommended performance criteria. Because the foam is actually molded from stainless steel, it is resistant to corrosion. Compared to other cellular foam material, this metal foam is very strong. However, since it is foam, it does not have the rugged properties of steel plate.

The recommended performance criteria are provided in Table 5-1. Explanations for specific statements in the table are provided in Appendix B.

Section 6.0 describes both cable lead entrance performance criteria and some tests performed with some direct substitutions for asbestos rope.

TABLE 5-1 Recommended performance acceptability criteria for high flow rate pressure vents

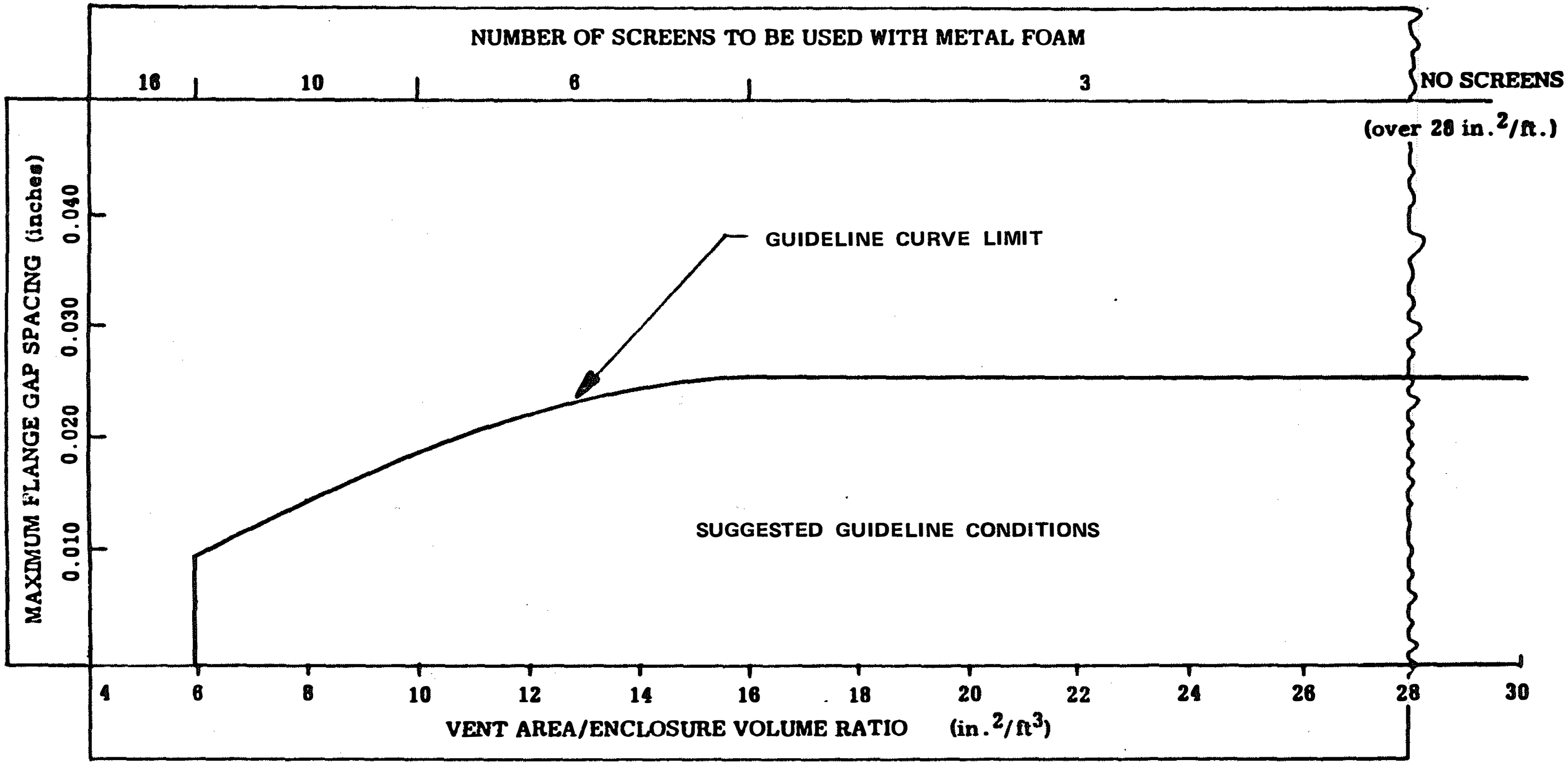
1.0	A high flow rate pressure vent may be used to allow gases due to an explosion inside an electrical enclosure to be vented to the outside such that the peak pressure inside the enclosure never exceeds 12 pounds per square inch. A pressure vented enclosure of this type shall comply with the following:
1.1	The gases being vented shall be cooled while flowing through the vent such that the temperature on the outside surfaces shall not exceed 302°F and there shall be no flames or hot particles visible outside the vent or enclosure.
1.2	The pressure vent shall consist of porous stainless steel foam of a type approved for this application by MSHA, which may be combined into a multilayer package with the number and type of screens in accordance with Figure 5-1. The foam material shall be at least 1/2 inch thick and the area shall be at least that required by Figure 5-1. The foam and the layers of screen shall be permanently bonded together around the periphery by a steel box frame. This frame shall be arranged such that the wire screens will always face the inside whenever the multilayer vent assembly is mounted in a pressure vented explosionproof electrical enclosure.
1.3	The foam and screen assembly shall be recessed into a holder from the inside surface of the enclosure and retained with flame tight joints around the periphery. All fastening devices shall be secured to preclude coming loose.

TABLE 5-1 Recommended performance acceptability criteria for high flow rate pressure vents (continued)

1.4	Mechanical support shall be provided for the foam and screen assembly such that any unsupported surface area shall not exceed 50 square inches.
1.5	The maximum flange gap on a cover on a pressure vented explosionproof electrical enclosure shall not exceed the value specified in Figure 5-1.
1.6	Any explosionproof electrical enclosure using this pressure vent shall be designed and tested to withstand an internal static pressure of 15 psi with the vent removed and the opening blocked with solid metal.
1.7	Mechanical protection from physical impact or direct water spray shall be provided over the foam material on the outside of the enclosure. This protection may consist of a steel door mounted on hinges such that it closes due to gravitational forces and will open so as not to impede the flow of gases from inside to outside the enclosure with no more than 1 pound per square inch rise in pressure on the outside surface of the vent.
1.8	Pressure vented explosionproof electrical enclosures shall be tested in accordance with 30 CFR Part 18.62.
2.0	The porous stainless steel foam shall be of a type approved by MSHA for this application and have the following characteristics.
2.1	The metal foam shall comprise a series of continuous metal tubes enclosing a series of interconnecting pores.

TABLE 5-1 Recommended performance acceptability criteria for high flow rate pressure vents (continued)

2.2	The average composition shall be: Chromium 15% min. Iron 10% max. Others 3% max. Nickel Balance
2.3	Density shall be 0.5 gm/cm^3 min.
2.4	Air flow resistance of the metal foam shall be measured in terms of the discharge coefficient which shall not exceed 0.25 for material nominally 1/2 inch thick.
3.0	The pressure vent assembly shall be located on an enclosure such that inspection and maintenance can be performed as follows:
3.1	It shall be possible to visually inspect for the presence and condition of the pressure vent assembly from outside the enclosure as mounted on the machine without requiring any unbolting or similar dissassembly.
3.2	There shall be no evidence of erosion or discoloration on the outside surface of the metal foam material as the result of explosions internal to the enclosure.
3.3	Gaps around the periphery of the multilayer vent assembly shall comply with the flange gap requirements for that pressure vented enclosure.
3.4	The pressure vent assembly shall be removable for cleaning, after removing the enclosure access cover.



NOTE: The designer determines a convenient size for the pressure vent assembly or the enclosure. He then calculates the vent area to volume ratio. Using this, he determines the number of screens required from the top axis and the maximum flange gap spacing from the left axis.

The screens are 20 mesh, 0.018 inch diameter, 304 stainless steel packaged on the interior surface of the vent material. The vent material is RETIMET grade 45 NC 13 stainless steel metal foam.
Care should be taken to prevent bulging and separation of the stainless steel screens.

FIGURE 5-1 Suggested guidelines for number of screens and allowable flange gaps for pressure vents on explosionproof electrical enclosures

Section 6.0

CABLE LEAD ENTRANCES

Requirements for cable lead entrances into explosionproof electrical enclosures are defined in Section 18.37 of the Code of Federal Regulations, Title 30. Reasons for these requirements are generally understood, and may be specifically identified as:

1. To assure that there is no leakage path for flames or hot particles, even under repeated explosions within the enclosure.

2. To secure the cable adequately for strain relief.

3. To secure the cable so that it does not move under the force of repeated internal explosions.

Common practice in sealing a lead entrance has been the use of asbestos rope in a stuffing box, although compressible materials, in the form of cylindrical grommets, are used to some lesser extent. Asbestos rope is relatively inexpensive.

This program for innovative design of explosionproof electrical enclosures considered existing lead entrance practice from the standpoint of both productivity and safety. In the early days of electrification of underground coal mining equipment there were only a few lead entrances involved on any one machine. The relatively simple technique of asbestos packed lead entrances was quite adequate. With the introduction of more sophisticated mine equipment there are now many lead entrances into explosionproof electrical enclosures on any one machine. These lead entrances must be maintained in a permissible manner and it is necessary to occasionally remove and reenter cables. With the larger quantity of lead entrances the time and effort required for asbestos packing of these cables becomes more significant. Thus, this program looked at alternatives.

The compressible grommet for sealing a lead entrance is obviously simple from the standpoint of entering a cable.

However, the compressible grommet as allowed by present regulations is used infrequently because of the close tolerance requirements in the gaps between the cable and the grommet, and between the grommet and the stuffing box. Tolerances on the outside diameter of some jacketed cable may be larger than the allowable entry clearances under the existing regulations for compressible grommets. This means that for any one type of cable entry a number of grommets of varying size would have to be available. The logistics, combined with cost consideration, makes the grommet approach unrealistic, especially when the machinery is located underground thousands of feet from the nearest shop.

As noted in the report "Innovations for Explosion-proof Electrical Enclosures", submitted in April 1980, a grommet-type cable entry has been developed under this contract wherein the grommet has a large range of compressibility, enabling a wide range of cable diameters to be accommodated by any single grommet size. The compression of the grommet is accomplished by forcing the grommet against a taper, which in turn tightens the grommet against the cable. Design characteristics and laboratory tests of these new design cable entries are described in the referenced report.

Sections 2.0, 3.0 and 4.0 in this report describe an underground evaluation wherein a cable entry using the urethane grommet was evaluated for over 8 months in an operating coal mine. The objective of work on lead entrances, described in this section, is a set of recommended performance criteria that might be used as a basis for approval under existing government regulations of alternatives to asbestos rope packed lead entrances, especially a grommet-type cable entry. The recommended performance criteria for the lead entrances are provided in Section 6.5 following the sections describing work during this phase of the program.

6.1 General Considerations for Lead Entrances

Present day practice with asbestos packed cable entries was examined to establish both factors that should be considered for any lead entrance along with identifying what is done in practice that may be over and beyond that stated in regulations. In addition, a literature search going back to the turn of the century, including old regulations, reports and other documents, was made to learn why the present technical requirements were established, and what additional factors were originally considered but no longer contained in recent documentation. Appendix C lists some of these documents.

A very significant consideration concerns what may be inspected or checked after a cable entry is accomplished. There are only two things that may be inspected on a cable entry without disassembly One is the tightness or gripping of the cable which is checked by manually pulling and/or twisting the cable by hand to detect whether there is any possible slippage. The other, of course, is inspection in accordance with the Federal Regulations of the gap between the stuffing box shoulder and the head of the packing nut. By regulation this must measure between 1/8 to 1/4 inch. There is no way to externally inspect a cable entry to determine whether the proper packing material is in place, whether the diameter or length of the packing material are proper, and whether the packing is indeed in contact with the cable for a minimum of 1/2 inch.

Measurement of at least 1/8 inch gap from the packing nut head to the stuffing box shoulder only assures that the nut can be turned further without bottoming out on the threads. It is possible for foreign objects to keep the nut from tightening down or to cause binding in the threads which prevents the nut from going down further. Thus, it does not absolutely assure that all of the force imposed on the packing nut is exerted upon the packing rope. If the gap is more than 1/4 inch, then there may not be a sufficient number of threads engaged in the packing nut and/or the nut may not be adequately tightened. Thus, the measurement of the packing nut gap between 1/8 to 1/4 inch assumes that the proper packing material is in place and that there is no binding in the threads. Then the measurement indicates that there is a proper amount of packing material to achieve at least a 1/2 inch length of contact with the cable if the cable is found to be tight and cannot be moved by hand.

Questions not addressed in the regulations concerning cable entries include:

- Ease of installation
- Ability to verify adequate installation

- Gripping ability
- Life characteristics
- Ease of removal
- Reusability
- Materials available at the face

Each of the factors listed above are discussed with consideration for asbestos rope packing in the following paragraphs. Where appropriate, comparison is also made to the potentials for the newly developed urethane grommet.

Ease of installation may be more important for the psychological impact upon the worker than it is with regard to the length of time involved. If the task is awkward or the materials do not work easily, then the worker finds himself fighting the situation with the potential for a less than satisfactory completion.

Under the best conditions, considerable time, dexterity and patience are required for entering a cable with asbestos rope packing. This assumes reasonably clean conditions, good lighting and accessibility. Even in the factory installation, these factors are not always favorable. Underground it is generally anything but clean and sometimes it is extremely awkward to get at the cable entry. A task which takes 20 minutes to accomplish in the factory may take an hour or more when performed in the face area. Component density on some mining machines is so great that cable leads may be buried in among other components rather than being readily accessible. The worker may or may not be able to look directly into the stuffing box to see how the packing is going into place.

The potential for a faulty installation can be significant, especially if the installation is difficult. Adequacy of the seal for the intended purpose depends to a large amount upon the integrity of the worker. A good installation requires that the stuffing box, cable and packing nut be clean and that new asbestos rope material of the proper size is available. If the task takes too long or is too difficult to accomplish the worker is tempted to stop and let it go as is, rather than to persist for what he feels is an adequately entered cable. If all the steps are followed, then the cable should be adequately sealed in conformance with the regulations. Unfortunately, there is no way to visually inspect cables that have already been entered to verify the proper procedures. Lead entrances on equipment underground have been found to be less than adequate at times, but fortunately at least most of these have not been the cause for a disaster.

Gripping ability of asbestos on the various cable jacket materials is generally good. A cable entry packed with asbestos rope and subjected to manual attempts to twist or pull the cable to verify tightness will normally pass explosion testing with no sign of problems. For example, in the process of conducting an explosion test, short lengths of cable are entered into the lead entrances and the cables marked on the outside such as by driving a nail through them. One can then determine whether the explosive forces inside the enclosure can move the cables outward.

Life characteristics of asbestos packed cable entries are generally good. The asbestos material is relatively impervious to most substances and can withstand up to $500^{\circ}F$ with no significant problem. Some shrinkage does occur with time and/or presence of flame and high temperatures. This is probably due more to the non-asbestos contents in the rope. This can result in a cable entry which was marginally tight at the beginning, being noted as loose after an extended period of time or test. There is also some tendency for the rope to disintegrate under pressure and time, but this should not present a problem as long as the packing nut is not loosened.

An asbestos packed cable entry is generally removed with ease. It is necessary to use a pick or other tool to start the rope material out of the stuffing box and then most of the pieces can be pulled out by hand. Once the rope material is out of the stuffing box the cable will readily slide in or out.

Once used in a cable entry, asbestos rope should not be reused. Unfortunately this is not always followed in the actual underground environment. Asbestos rope is usually available in the face area but when it is not available, or not available in proper size, an older piece may be occasionally reused. Because of the way the rope crumbles and takes a preset as a result of prior use, the ability to accomplish a proper entry is jeopardized.

The untreated asbestos rope is typically 75% (commercial grade) asbestos with cotton or other materials comprising the rest. According to the suppliers, the asbestos fibers are encapsulated in such a way as to preclude floating in dust, and therefore, they claim there is no potential health hazard. Mine mechanics usually carry asbestos rope packing with them and are thoroughly experienced in entering cable.

Two factors threaten the continued use of asbestos rope packing for permissible cable entries. One is the allegation that asbestos presents a health hazard, in spite of manufacturer claims to the contrary. Because of this claimed potential hazard there is reluctance to use the asbestos rope. The other factor is the possible non-availability of untreated asbestos rope. At least some manufacturers are discontinuing production of untreated asbestos rope because of potential health hazards claimed for the manufacturing process, added expense for extra safeguards in the manufacturing process, and the relatively low volume sales of this product. Therefore, there is a strong requirement to identify alternatives to packing cable entries with asbestos rope.

The simplest alternative is to identify rope packing that may be used as a direct substitute for asbestos rope in existing cable entry stuffing boxes. A number of manufacturers now offer products which they claim may be a non-asbestos rope substitute. Caution must be exercised in the choice of other materials. For example, ceramic and glass fibers can be crushed or broken when the rope is compressed. This may adversely effect the resiliency of the rope or ability to grip the cable.

In accordance with a request initiated by MSHA, and coordinated through the USBM, plans were made to test gripping ability of asbestos packed (conventional practice) cable entries, entries using two different type direct substitutions for asbestos rope, and the urethane grommet type entry developed earlier in this program. The objective was to identify characteristics of the asbestos for specification purposes and to determine how some substitute materials compare with the asbestos.

Ongoing discussions with vendors have considered a number of rope materials as potential direct substitutions for asbestos rope. One of these was selected by Jeffrey Mining Machinery Division (JMMD) personnel for the gripping test along with asbestos rope and the urethane grommet. This material, identified in Table 6-1 as substitute A, had

A mechanic working in the face area is supposed to have some asbestos rope packing material with him. At least one size rope is generally available although it may not always match the size required. If the right packing material is not available, improvision may be tried since it is usually quite a distance to the shop where the proper size may be obtained. If a larger diameter is called for than presently available, then one attempt to make up for it would be to add extra layers of rope to fill the void. In some rare instances there have been reported cases where other material such as from old rags has been used in lieu of asbestos rope inside the stuffing box. Obviously, safety demands that the proper materials be available at the proper place and at the proper time.

The urethane grommet developed on this program offers potential improvement for many of the factors noted above. It is easy to install since only tightening is required. It is readily reusable for an indefinite number of times and for this reason there is no need for new materials to be available at the face. With an easier and more straight forward installation the probability of an adequately entered and safe cable entry is much higher. So far the tests indicate that the life of the urethane grommet will be indefinite.

Limited tests during an earlier phase of this program appeared to verify the ability of the urethane grommet to adequately grip the cables. This factor was investigated further during this most recent phase of work when the question was seriously raised as to what are the qualities for the present asbestos rope packed cable entries in regard to considering asbestos substitute materials. This is discussed further in the following sections.

6.2 Cable Entry Gripping Tests

Asbestos rope packing for cable entries has been in use since before any of the coal miners working today first started working in the mines. This asbestos is untreated; that is, there are no additives such as graphite which is commonly used in valve stem asbestos packing for plumbing. Typical non-mining applications use asbestos rope to pack around stems or shafts that move. Consequently, a lubricant in the asbestos rope is required in those applications.

TABLE 6-1 Potential Rope substitution materials for tests

SUBSTITUTE IDENTIFICATION	MANUFACTURER	TRADE NAME	STYLE
A	AMATEX CORPORATION	NOR-FAB	400PN
B	CGR PRODUCTS	FIBERGLASS ROPE	CGR 2430
C	CRANE PACKING CO.	RITE PAK (KEVLAR)	K1730

been submitted to and tested by MSHA for fire and toxicity. Material substitute B was included in the plan as a result of referral of the vendor to JMMD after discussions with MSHA personnel. After the tests were underway, a vendor requested that JMMD evaluate substitute C. This material looked as if it had good potential for cable entry applications and was included as a last minute add-on to the plan. However, it was tested to only a limited extent.

A number of different outer jacket materials may be used on cables approved for use in underground coal mines. Variances in jacket surface characteristics, including the coefficient of friction, may influence the ability of the cable entry packing material to grip the cable. Six different type jacket materials were found on cables used at the Jeffrey Mining Machinery Division. These are neoprene, hypalon, AMA, butyl, fiberglass and silicone. These represent a good cross section of possible jacket characteristics, although three of these are not used frequently.

Two different size ranges of cable were selected as a compromise of total number of variables, cables and entry bodies available for test, and the effect of a major change of cable size. The six different jacket materials were on cables less than one inch diameter (.74 to .84 inches diameter). Only two different jacket materials were available on cables approximately two inches diameter. The larger cable sizes were a neoprene jacket with an O.D. of 2.04 inches and a hypalon jacket with an O.D. of 1.88 inches. The cable entry pull test procedure is described in Appendix D.

6.3 Cable Entering Experience

Ability to pack or seal a cable entry may be of more concern than the resulting gripping ability. Ease of entering the cables varied from very simple to impossible.

Table 6-2 is a simplified subjective rating made after the tests for the various types of packing. It is useful in highlighting factors to be more closely considered, but is not intended to indicate which type of packings are acceptable and which are not acceptable. The following paragraphs provide more description of what was learned during this program.

TABLE 6-2 Relative factors for cable entering

Type Packing	Time Required	Ease of Stuffing	Ease of Getting Right Length	Ability to Achieve Packing Nut Gap Requirement	Potential for no Thread Interference	Packing Nut Torque Requirement
Asbestos	Fair	Acceptable	Acceptable	Good	Good	Lowest
Substitute A	Fair	Fair/ Acceptable	Fair	Fair	Good	Low
Substitute B	Worst	Poor	Very Poor	Poor	Poor	Moderate
Substitute C	Fair	Acceptable/ Fair	Fair	Fair	Good	Low
Substitute U Urethane	Best	Excel- lent	N/A	(gap is a function of cable size)	Excellent	Highest

Entering the cables in the laboratory with asbestos rope for the pull tests was accomplished without significant difficulty, although two items required extra effort. The length of asbestos rope used required judgement, and frequently, removal of the packing nut with the addition of more rope. The additional packing rope is needed to achieve the desired nut tightness, while maintaining 1/8 to 1/4 inch clearance between the packing nut and the shoulder of the stuffing box. The second item requiring extra effort was the fact that the actual O.D. of the asbestos rope used for packing the 2.04 inch diameter cable was larger than the clearance between the cable and the wall of the stuffing box. This asbestos rope had to be forced into place with a punch or blunt tool. In fact, asbestos rope is typically larger in actual diameter than the specified diameter. (See Table 6-3).

Asbestos rope is braided jacket over jacket with a dense center section. It is easy to work since it is plyable and is not too resilient. It can be pushed or forced into restricted openings without springing back out. It is somewhat compressible and yet readily fills a cavity because it is a solid weave. The asbestos squeezes into place filling the voids with only a modest amount of torque on the packing nut.

The literature search, going back to 1906, failed to disclose why asbestos was selected as a packing material for lead entrances. Selection of materials with desirable properties was limited in the early days of underground mining machinery. It may be that asbestos was one of very few materials available, other than for molded (such as plaster of paris) seals, and was considered so adequate that no attempt was made to find any optional material. The first mention of asbestos rope packing in U.S. regulations appears in Schedule 2C, dated February 3, 1930.

Within the past 20 to 30 years, new mining machinery with considerable electrical wiring has become available. This resulted in a manyfold increase in the number of permissible cable lead entrances and, thus, more interest in optional ways to accomplish permissible lead entrances. Drawbacks in the use of asbestos packed cable entries include potential safety hazards if the workmanship and/or materials are not proper, and the labor time required. Nevertheless, the asbestos rope packed entry is acceptable

TABLE 6-3 Measured versus specified rope packing diameter

TYPE	SPECIFIED DIA. (INCHES)	MEASURED DIA. (INCHES)
ASBESTOS	1/4 5/16	.300 .390
SUBSTITUTE A	1/4 5/16 3/8	.270 .345 .415
SUBSTITUTE B	1/4 5/16	.30/.11 .37/.17
SUBSTITUTE C	1/4	.260

and is the most common lead entrance technique for the U.S. underground coal mining machinery. Consideration of any options or substitutions for the asbestos rope packed cable entry must compare the substitutions against asbestos.

Rope substitute A is a heat-resistant textile consisting of a combination of synthetic fibers blended together by a unique process. The rope is a braided jacket over a rope core. Like the asbestos rope, it has a dense cross section and is somewhat easier to handle because the exterior surface is a more solid weave and feels more slippery. This material also measures larger in cross section (Table 6-3) than specified. This material is slightly easier to push into the stuffing box because of the surface texture. It is more resilient than asbestos and, thus, there is somewhat more difficulty in forcing the proper length into the stuffing box. Packing nut torque is also slightly greater. Cable entering time was similar to that for asbestos. The texture is such that very few pieces of the rope material break loose to clog the packing nut threads. However, the fibers are very strong and cutting the rope with a sharp knife is difficult.

When first entering cables with substitute material A, it seemed that the grip on the cable would be less because of the slippery feel of the rope. Also, the slightly higher torque required on the packing nut gave the feel that this would not grip the cable as well. However, review of the slip load results shows the grip to be adequate, and only slightly less than with asbestos. Surprisingly, the grip of substitute material A was better than asbestos on the fiberglass cable jacket material.

Substitute rope, material B, is made from finely textured silica yarns which are braided into rope form. It is a low-density, highly compressible material, unlike the other materials tested. While it can withstand higher temperatures, the texture and density make it difficult to use in entering a cable. This difficulty resulted in additional time being required to enter a cable.

Because of the resiliency, along with the low density, the material tends to pop back out of the stuffing box before the packing nut is in place. This presented significant problems in starting thread engagement. Usually, the first time the packing was tightened it would bottom out without the cable being adequately gripped. It was somewhat of a fight to hold the rope in the stuffing box after the packing nut was removed and to add additional rope material.

The factors noted above required longer lengths of rope B as compared to asbestos. For example, eighteen inches of asbestos rope were used to pack the 2.04 inch diameter cable and sixty-six inches of substitute rope B were required.

There was no serious attempt to pack the cable entries during these tests with the gap between the packing nut and the shoulder of the stuffing box maintained within 1/8 to 1/4 inch. The primary concern was to have the material adequately packed for the grip test, and to be able to torque the packing nut down to at least three values. In the test with the 2.04 inch diameter cable it was impossible to get enough of this rope B in the stuffing box so that the packing nut could be torqued down more than 50 FT-LB.

As noted earlier, the stuffing box for the test with the 1.88 inch diameter cable had a large clearance around the cable. It was not possible to pack this combination with substitute rope B as it would push out between the cable and the hole in the stuffing box. Thus, there is no gripping test data for this combination.

A nominal diameter for the substitution material B has no significance. With the very low density, the rope is more like sleeve material where the diameter varies constantly as the slightest pressure or tension is applied. There is no ready interpretation whether this material can meet requirement 18.37 (d), (2) of the Code of Federal Regulations, Title 30 which reads, "The allowable diametrical clearance between the cable and the holes in the stuffing box and packing nut shall not exceed 75 percent of the nominal diameter or width of the packing material". The first number provided in Table 6-3 under measured diameter is an approximation in the material relaxed condition, and the second number is an approximation of the thickness when squeezed flat between the thumb and index finger.

Another problem was noted with material B. It (the fiberglass) will fray very easily making it undesirable to work with bare hands. Also, it tends to clog threads for the packing nut. One series of tests had to be repeated because the packing nut torque values were found more due to binding in the threads rather than compression of the packing.

Rope substitution material C is braided from a special aramid fiber to produce a high tensile strength packing and is impregnated with a special lubricant. It was provided unsolicited and included in a couple test series since it appeared different than the other materials. Only these gripping tests were performed with this material, and no attempt has been made to investigate other properties for potential application in underground coal mine cable entries.

Like substitute A, material C is tightly woven with a dense section. Texture is smooth, and the surface looks more glossy. It is comparable to substitute A for the first four factors in Table F, although the measured diameter is closer to specified size and it seems less compressible. However, fibers come loose, at least from the cut ends, and could add some interference with the treads. These loose fibers are somewhat longer and stronger than those from material A. Also, like material A, it is very difficult to cut.

Slip loads in the two test series with material C were somewhat better than for asbestos. That means that the required packing nut torque for equal slip loads is slightly less than for asbestos. However, the tests were not as extensive as for the other materials, so the torque required is only identified as low in Table 6-2.

There are safety and productivity factors that favor something better than asbestos rope packed cable entries. Entering a cable with asbestos rope (or a substitute rope) packing is labor intensive. Observation shows that it takes typically 10 to 20 minutes per lead entrance for an experienced mechanic working under good conditions in the factory. Entering a cable underground can take much longer because of limited accessibility and harsh working conditions. There have been instances where packing has been insufficient, some material other than asbestos rope had been used for packing, or the packing nut not properly tightened or secured.

Substitute U is a urethane grommet rather than rope packing. These grommets are cylindrical for part of their length and tapered for the rest. The urethane is highly moldable and it squeezes in against the cable when forced into the tapered stuffing box by tightening the packing nut.

Entering a cable with the urethane grommet for a seal is simple and fast. The cable may be slid through the entry with the grommet and packing nut already engaged in the stuffing box, or these packing parts may be individually slid over the cable before assembly. There is no requirement to force packing rope into the stuffing box and no trial and error process to get the right amount (length) of packing in place. Thus, only a fraction of the time and effort corresponding to an asbestos sealed entry is required.

Because the urethane grommet is designed to handle a wide range of cable sizes, the compression will be a large amount for a cable having a diameter at the small end of the grommet range. For example, in the tests described here the grommet was compressed from an I.D. of 1.05" to an I.D. of 0.74" for some cables. Since the compression of the grommet is accomplished by tightening the packing nut, the clearance between the packing nut head and the shoulder of the stuffing box is a function of the cable jacket diameter. This clearance may actually vary as much as 5/8 inch. Therefore, with this design with the wide range of compressibility the requirement for a packing nut head to stuffing box shoulder clearance between 1/8 to 1/4 inch cannot be met, and certainly is not indicative of the adequacy of a properly entered cable. A minimum clearance, such as 1/8 inch, can be retained to assure that the packing nut has not bottomed out, but the upper limit for the packing nut head clearance must allow for the range of compressibility.

The urethane material has a good surface texture. There is no tendency to peal, chip or otherwise give off particles that might clog the packing nut threads. The same grommet may be reused repeatedly.

While the urethane has good compressibility, it must be forced down against the taper and the wall of the stuffing box in order to move against the cable jacket. The grommet is one piece rather than several layers such as the rope. As a result, more torque is required on the packing nut for the urethane grommet than on the packing nut for rope. Results discussed in the following section show that an additional torque of 10 to 20 FT-LBS on the packing nut should provide an equivalent grip on the cable.

6.4 Grip Test Results

In the tests performed earlier during this program, the packing nut was torqued until the cable felt tight in the entry. Then the slip loads were measured by applying a constant displacement (pull) rate. In the later tests described here, the nut was torqued to pre-established values so as to allow direct comparison with cables having different jacket materials. In some cases higher torque on the packing nut was required because the cable could otherwise be moved by hand.

Slip load was found to increase as the displacement rate was increased (see Figure 6-1). As the packing nut torque was increased the change in slip load with displacement rate became less. A static load to cause slip, such as used in Underwriters Laboratories (U.L.) tests, would be different than those measured in these comparison tests. Such a slip value would probably be somewhat lower under static load conditions (static vs. sliding friction of the packing against the cable jacket).

U.L. test techniques add force (weights) to the cable conductor until slip occurs. The tests during this program add displacement (to the jacket and conductor) until the force reaches the level to cause slip. In this latter technique the displacement rate is low enough that it should be comparable to the force (weights) technique. An advantage of this approach is that it gives a very precise readout of force vs. slip, whereas measuring slip with weights requires a larger amount of slip before it can be detected. The test set-up and procedure is described in Appendix D.

If the primary purpose of the cable entry was for strain relief then the load should be applied to the conductor and the cable entry, such as in the U.L. test. However, in the underground mining application the primary purpose is to seal around the cable to withstand repeated explosions internal to the enclosure. These may cause forces around

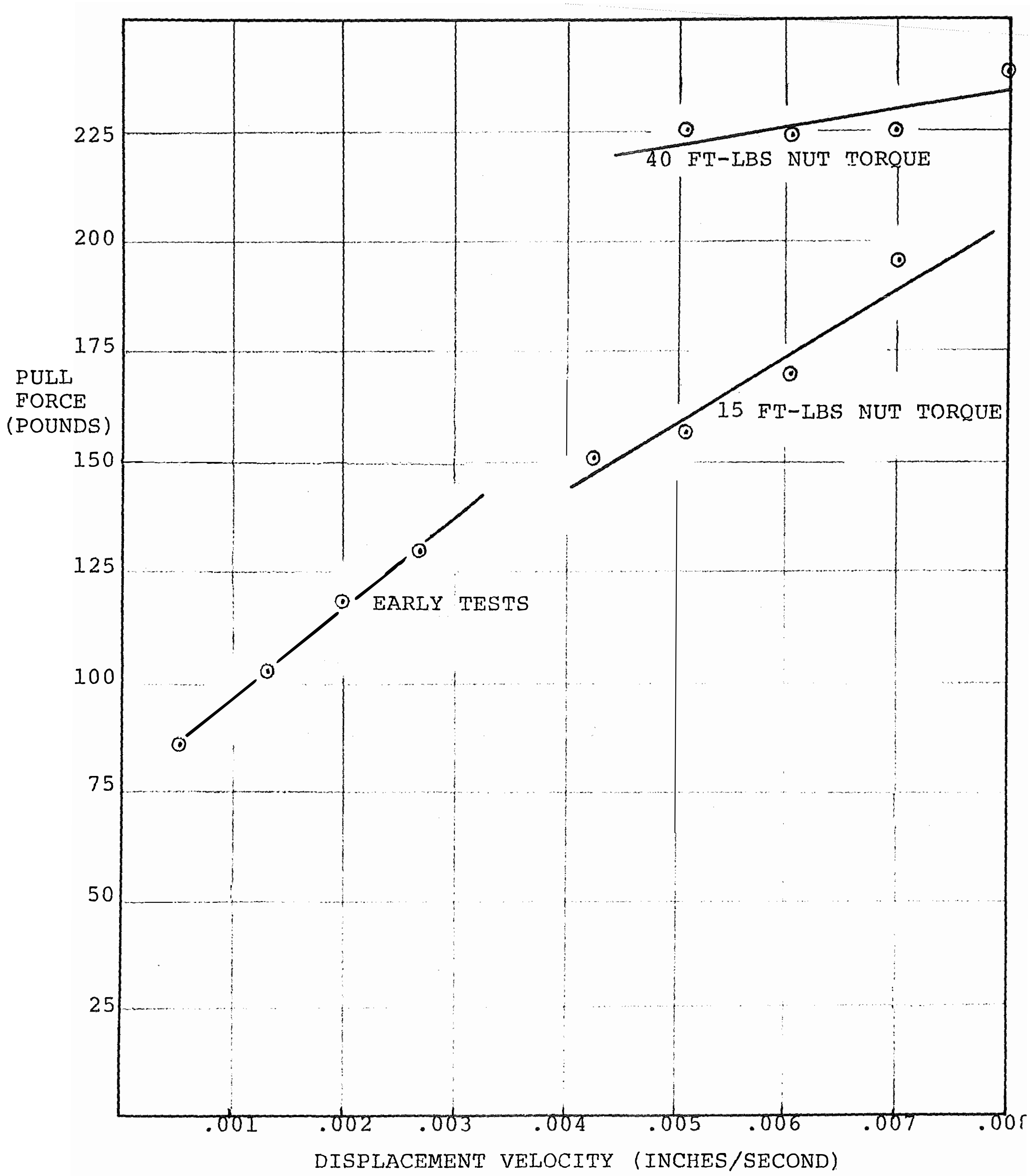


FIGURE 6-1 Cable slip load as a function of displacement vel

the jacketed cable which tend to push the cable outward. Therefore, slip of the (cable) jacket in the packed entry is more important.

The U.L. requirement for slip load is 30 pounds, but the minimum required for the mining machinery application is not easily identified. In earlier tests with asbestos packed entries the lowest measured slip load was 34 pounds when the entry felt adequate and the applied strain rate was .0022 inches per second. This led to the recommendation that the minimum required slip load be 30 pounds when measured at a strain rate of .002 inches per second. The more recent tests, at a displacement rate of .006 inches per second, tend to substantiate a requirement to withstand 30 pounds, either static load or with an applied displacement rate.

Unfortunately, there is no consistent quantitative relationship between the packing nut torque and the cable slip load. The uncertainty is further compounded by the selection of cable jacket material, the type of entry packing material, the length or size of the packing material, and the jacketed cable diameter. Therefore, the value of torque on the packing nut is useful only for comparison and has little value in the absolute sense.

The lowest measured (recent test series) slip load for a cable that felt adequately entered was 25 pounds. This was for a packing nut torque of only 10 FT-LBS and with a substitute rope material. This leads to two conclusions. First, the present practice of pulling and twisting the cable by hand to determine if it is adequately gripped in the cable entry is acceptable. Second, a cable slip load should measure more than 30 pounds when tested under a constant strain rate between .002 to .006 inches per second.

Asbestos rope packing has been an accepted practice for cable entries in underground coal mining machinery in the U.S. Therefore, substitution materials may be compared to asbestos for performance characteristics.

Tables 6-4 and 6-5 show the cable slip loads measured on cables less than one inch diameter and on cables approximately two inches diameter. Measured values for asbestos packing were generally quite high. The lowest

TABLE 6-4 Slip loads for cables less than one inch diameter

Jacket Type	Neoprene		AMA		Hypalon		Glass		Silicone		Butyl	
Packing Type	Torque (FT-LBS)	Slip Load (LBS.)	Torque (FT-LBS)	Slip Load (LBS)	Torque (FT-LBS)	Slip Load (LBS)	Torque (FT-LBS)	Slip Load (LBS)	Torque (FT-LBS)	Slip Load (LBS)	Torque (FT-LBS)	Slip Load (LBS)
Asbestos Rope	10	30	10	210	10	120	10	154	10	117	10	118
	20	50	20	237	20	177	20	192	20	170	20	159
	20	73	20	272	20	180	20	211	20	146	20	167
	20	91	20	277	20	184	20	208	20	142	20	168
	40	120	40	341	40	227	40	308	40	98	40	187
Substitute A	10	25	10	120	10	72	10	77	10	100	10	
	20	55	20	195	20	127	20	262	20	140	20	80
	20	56	20	250	20	122	20	275	20	126	20	75
	20	50	20	258	20	118	20	270	20	104	20	87
	40	67	40	350	40	212	40	370	40	147	40	188
Substitute B			10	102	10	60	10	187	10	31	10	47
	20	70	20	170	20	57	20	226	20	83	20	100
	20	70	20	201	20	52	20	236	20	95	20	125
	20	67	20	223	20	54	20	256	20	105	20	75
	40	89	40	200	40	152	40	344	40	187	40	165
Substitute C	10	60										
	20	82										
	20	190										
	40	223										
Substitute U	27	40	10		33	90	10		33	107	10	
	30	43	27-1/2	96	44	180	20	35	44	180	20	40
	30	44	27-1/2	135	44	190	20	48	44	192	20	42
	30	43	27-1/2	140	44	195	20	100	44	175	20	50
	40	103	40	220	55	205	40	225	55	187	40	170

TABLE 6-5 Slip loads for cables of approximately two inch diameter

Jacket Type	Neoprene		Hypalon	
Packing Type	Torque	Slip Load	Torque	Slip Load
	(FT-LBS)	(LBS)	(FT-LBS)	(LBS)
Asbestos Rope	20	98	20	52
	40	240	30	57
	40	243	40	60
	40	237	40	55
	80	348	80	191
Substitute A	20	94		
	40	186	50	46
	40	240	50	30
	40	257	50	45
	80	356	80	95
Substitute B	30	57		
	40	85		
	40	115		
	40	117		
	50	132		
Substitute C			20	67
			40	147
			40	147
			40	163
			80	202
Substitute U	20	72		
	40	139	60	174
	40	184	60	170
	40	160	60	164
	80	200		

slip loads with asbestos were experienced with the neoprene jacket cable. Although the cable jacket appeared clean, there could have been some oil or other substance on the neoprene jacket that lowered the grip values. The grip of asbestos rope on the AMA jacket was so high that the outer jacket on the cable was actually pulled apart on the last test.

Comparison of rope substitutes A, B and C shows them all to be acceptable from the slip load standpoint, if they can be adequately packed. A couple anomalies occurred at the 10 FT-LBS torque on the packing nut, but these are believed due to erratic conditions on the packing nut threads. Material substitute C was received late and only tested as an unplanned addition.

Substitute U, the urethane grommet for the smaller cables, was designed to accommodate a wide range of cable sizes from 1.05 inch diameter down to 0.64 inch diameter. The cables tested ranged from 0.72 to 0.82 inch diameter. These were closer to the smallest diameter limit of the grommet and required significant compression of the grommet. Therefore, much of the packing nut torque was required for the basic compression of the grommet before loading against the cable jacket.

When the urethane grommet was tightened so that the cable felt adequately entered, both the required packing nut torques and the slip loads were noted. The lowest measured slip load was 35 pounds, which compares favorably with the grip of asbestos rope packing.

The larger size urethane grommet was designed for the specific size neoprene jacket cable. It was also tested with a smaller diameter hypalon jacket cable (2.04" vs. 1.88") although the entry was not designed for that small a diameter. A torque on the packing nut of 60 FT-LBS was required to compress the grommet small enough to grip the cable. Slip load measured 170 pounds, which is somewhat more favorable than the same cable in an asbestos packed entry. The packing nut was bottomed out to achieve the 60 FT-LBS value so it was the only value tested (although multiple times).

Rope substitute B could not be used for packing with the hypalon jacket 1.88 inch diameter cable because this rope material compressed too much for the clearance between the cable and the stuffing box inside diameter. The only stuffing box available also fit the 2.04 inch diameter cable which left a gap in excess of 1/16 inch between the cable and the small diameter of the entry body. Material B is loosely woven with a low density center and pushed out of the stuffing box through the gap.

Pull tests were performed using substitute rope C and the 1.88 inch diameter hypalon jacket cable. Slip loads were somewhat better than with asbestos rope.

6.5 Recommended Acceptance Criteria

This section discusses other questions pertaining to innovative or substitute materials for cable lead entries into explosionproof electrical enclosures. It then presents recommendations to support USBM establishment of performance specifications for the urethane grommet type cable entry. Also included in this section are recommendations for direct substitutions for asbestos rope that are limited to observations during the packed cable entry pull tests.

In considering alternatives to the asbestos rope packed cable entry, a number of questions were raised for consideration. These questions included:

1. The item must conform to the requirements of Title 30, CFR
2. Gripping ability of the material
3. Flammability and toxicity
4. The material must not flake or crack
5. Reuseability
6. Compressibility
7. Resistance to mine acids and mine acid treatment agents
8. Aging characteristics from temperature, humidity and pressure on loose materials, as well as packing glands
9. Chemical compatibility (resistance to corrosive agents)
10. Durability
11. Performance during explosions
12. Parts compatibility
13. Seating torque
14. Cold flow

As a starting point, the long existing practice of asbestos packed entries was investigated to determine what requirements are met with this technique. A lengthy search was made starting with literature available today and going back to the turn of the century.

The asbestos rope packing, as confined around the cable within the stuffing box and compressed by the packing nut, provides the features noted in the beginning of Section 6.0. These are:

1. Assures that there is no leakage path for flames or hot particles, even under repeated explosions within the enclosure.
2. Secures the cable adequately for strain relief.
3. Secures the cable so that it does not move under the force of repeated explosions.

Very little information is provided by suppliers of asbestos rope. The commercial grade, typically used in the mining industry, is 75% asbestos, with other fibers, usually cotton, comprising the remainder. The untreated rope has no graphite or similar materials that might compromise the flammability characteristic. It can withstand temperatures up to 500^{o}F. It is used in a braid over braid construction which provides a dense cross section.

Accounts of early work in Germany state that some attempts at sealing lead entrances were not adequate because the seal material (for example ,leather) could char as the result of the repeated explosions internal to the enclosure. Although not stated directly in any of the literature that was reviewed, it is reasonable to assume that one reason for choosing asbestos was that it would not char. In this regard, the fact that asbestos is rated only up to 500^{o}F, leads to the conclusion that rope packing in this application does not have to be rated for any higher temperature. Experimental work earlier during this contract showed peak temperatures due to explosions normally not exceeding 1000^{o}F and less than one millisecond in duration. This data also supports the conclusion that 500^{o}F continuous rating is adequate for the high temperatures.

As noted earlier, ease of entering a cable is a very significant question that should be added to the previous fifteen. Asbestos must be rated acceptable in this category, but certainly it leaves much to be desired. The shortcomings may influence workmanship, which in turn may influence permissibility. Ease of entering a cable with any substitute rope material must be one of the acceptability criteria.

Responses to the fourteen questions noted above on how asbestos rope performs are provided in Table 6-6. These same questions are addressed in Table 6-7 for the urethane grommet-type entry. Many of these responses are based upon data provided by the suppliers of urethane material. Appendix E provides copies of pertinent data on the urethane material.

Characteristics provided by the suppliers of urethane are in agreement and the products have been in multiple commercial applications for years. Only those urethane characteristics applicable to the application as a grommet for sealing lead entries are included in the recommended performance criteria.

Based upon the studies, tests and underground evaluation, the tapered urethane grommet is a favorable substitute for the conventional asbestos rope packed cable entry. However, some additional product refinement is recommended to better define the range of cable sizes and to establish an acceptable procedure for in-mine inspection of cables that have the grommet entry. Also, the basis for acceptance for approval by MSHA under Part 18, Title 30 CFR, must be clarified. Table 6-8 presents the recommended acceptance criteria for the urethane grommet type cable entry. Further explanation on the choice of this criteria is presented in Appendix F.

Certain rope packing materials that do not contain asbestos can be used as direct substitutes for asbestos rope insofar as the ability to stuff the gland and grip the cable is concerned. The determining criteria here is the ability to accomplish the actual cable entering.

Table 6-9 presents recommended performance criteria for substitute rope materials. This is considered a partial listing of criteria because only the cable grip testing was included in the scope of work. There may be additional factors pertaining to the use of rope materials for packing lead entrances that should also be considered. Additional investigation is also required if some of the criteria must be defined in more specific detail.

TABLE 6-6 Asbestos rope characteristics in response to questions

	QUESTION	RESPONSE
1.	Title 30, CFR	Acceptable as specified in Title 30, CFR
2.	Gripping ability	Good. See Tables 6-4 and 6-5
3.	Flammability & Toxicity	Acceptable. Impervious to burning
4.	Flaking or Cracking	Does flake and crack, but holds together sufficient for one time use. Flakes do not cause significant problem
5.	Reusability	Questionable. Recommend no reuse
6.	Compressibility	Good.(Range requirement is limited by Title 30, CFR, 18.37(e)
7.	Resistance to Acids	Good
8.	Aging	Good, although mechanical stress causes some disintegration
9.	Chemical Compatibility	Good
10.	Durability	Good, but reuse not recommended
11.	Explosion performance	Good. Accepted practice for many years
12.	Parts compatibility	Good
13.	Seating torque	Good. 10 to 20 FT-LBS adequate
14.	Cold flow (creep)	Good. Braid is tight enough to preclude significant creep

TABLE 6-7 Urethane grommet entry characteristics in response to questions

	QUESTION	RESPONSE
1.	Title 30,CFR	Elastomeric grommets are now allowed per 18.37(f)
2.	Gripping ability	Good. See Tables 6-4 and 6-5
3.	Flammability	Samples tested by MSHA at two separate times were passed
4.	Flaking or cracking	Excellent. Better than any rope packing
5.	Reusability	Excellent. Better than any rope packing
6.	Compressibility	Very good. (See Appendix E, page 128) (Range requirement is limited by 30 CFR, 18.37(f), but capable of much larger range)
7.	Resistance to acids	Good. (See Appendix E, page 129)
8.	Aging	Good from $-20^{\circ}C$ through $+121^{\circ}C$ (See Appendix E, page 130)
9.	Chemical Compatibility	Good. (See Appendix E, page 129)
10.	Durability	Very good. May be reused indefinitely. (See Appendix E, page 131)
11.	Explosion performance	Many tests performed to date. No evidence of deterioration or leakage
12.	Parts Compatibility	Good. Size differences are obvious
13.	Seating torque	Requires 10 to 20 FT-LBS more torque on packing nut than for asbestos rope
14.	Cold flow	Moderate. (See Appendix E, page 132)

NOTE: Supplier data is provided in Appendix E

TABLE 6-8 Recommended performance acceptability criteria for urethane grommet type lead entrances

1.0	The cable entry configuration shall comply with the following:
1.1	The stuffing box, urethane grommet and packing nut shall be of the configuration shown in Figure 6.2.
1.2	The taper angle on the stuffing box and the grommet shall be $22.5^{o} \pm 1^{o}$ as shown in Figure 6-2.
1.3	Dimension L1 shall be at least 0.375 inches.
1.4	Dimension D3 shall be no larger than dimension D2.
1.5	The maximum diametrical clearance between the nominal diameter of the cable outside jacket and the inside diameter (D2) of the grommet in the relaxed condition shall not exceed 0.7 X L1.
1.6	Dimension L6 shall be at least 0.7 X L1 or larger.
1.7	Dimension D4 shall be at least 0.4 X L1 plus D2.
1.8	The length of the grommet (L5) shall be at least $4 \times (\frac{D1-D2}{2})$.
1.9	The packing nut shall engage the threads of the stuffing box for at least 1/8 inch of the threaded length before starting to compress the grommet.
1.10	There shall be at least 1/8 inch clearance between the head of the packing nut and the shoulder of the stuffing box when the packing nut is securely tightened with the smallest diameter cable for which the entry is designed.

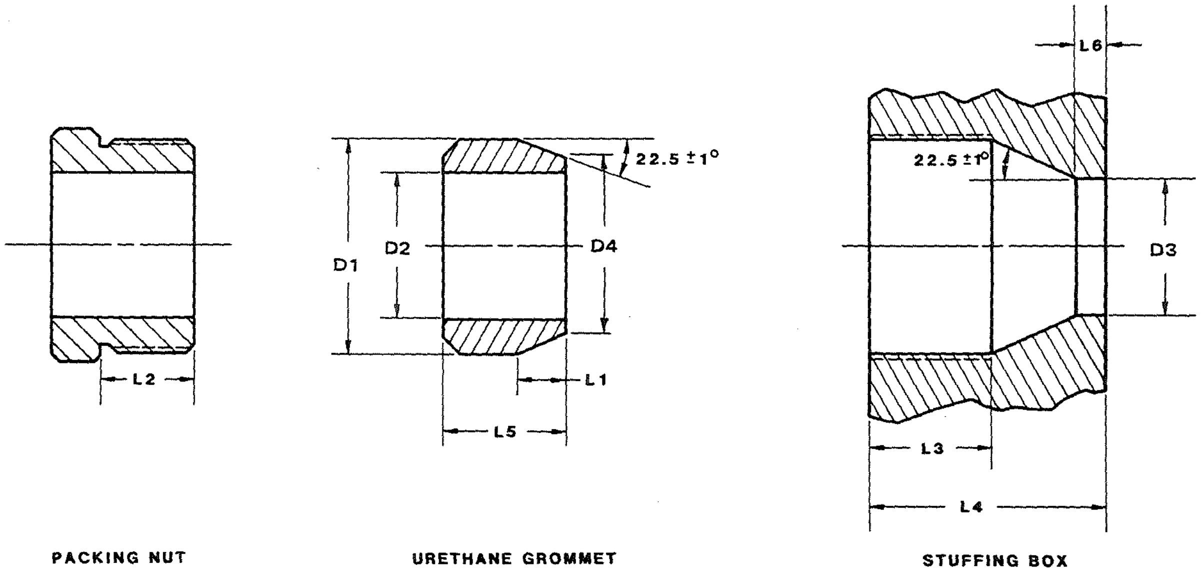


FIGURE 6-2 Urethane grommet-type cable entry configuration

TABLE 6-8 Recommended performance acceptability criteria for urethane grommet type lead entrances (continued)

2.0	The grommet shall be a polyester or polyether urethane material of a formulation approved by MSHA and having the following characteristics (as measured on test specimens):
2.1	Hardness shall measure between 75 to 85 on the Shore "A" scale durometer (ASTM D2240).
2.2	Compression set, as measured in accordance with ASTM-D-395, Method B, shall not exceed 35%.
2.3	Elongation at break, as measured in accordance with ASTM D-412, shall be at least 550%.
2.4	The tensile modulus at break, as measured in accordance with ASTM D-412, shall be at least 4400.
2.5	Compression set for service temperatures of -25°C, as measured in accordance with ASTM D-1229, shall not exceed 40%.
2.6	The percent tensile retention when subject to heat aging at +125°C for 72 hours, in accordance with ASTM D-412, shall be at least 80%.
2.7	The grommet material shall be evaluated and found acceptable in accordance with the flammability requirements of 30 CFR, Part 18, and the MSHA Interim Fire and Toxicity Criteria.
3.0	The cable entry shall grip the cable such that the cable does not move either when subjected to actual explosion testing of an electrical enclosure or when attempts are made to manually (without tools) twist and/or pull the cable.

TABLE 6-8 Recommended performance acceptability criteria for urethane grommet type lead entrances (continued)

3.1 Adequate grip on the cable shall be obtained when no more than 35 FT-LBS of torque are applied to the packing nut for cable diameters up to 1 inch and no more than 50 FT-LBS for cable diameters up to 3 inches. Under these conditions there shall still be at least a 1/8 inch clearance between the head of the packing nut and the shoulder of the stuffing box.

3.2 Laboratory tests may be performed on samples by performing pull tests on the cable at a constant velocity between .002 and .006 inches per second. The test machine shall be capable of securely holding the stuffing box and the cable, and shall record the force exerted as the two are pulled apart at a constant velocity. The load force under these conditions at which slip of the cable as gripped in the entry occurs shall be at least 35 pounds. Prior to performing this pull test, the grip of the entry shall be verified as noted in 3.0 and the value of torque applied to the packing nut recorded.

TABLE 6-9 Recommended partial performance acceptability criteria for direct substitutes for asbestos rope in lead entrance

Rope material to be used in stuffing boxes for electrical cable lead entrances to explosionproof electrical enclosures shall comply with the following requirements:

1. The rope shall have a dense cross section such as a braided jacket over jacket.

2. The rope material shall be available in diametrical size increments of 1/16 inch beginning with 3/16 inch diameter.

3. Actual diameter of the uncompressed rope shall measure between the limits of the specified catalog size and 125% of the specified catalog size.

4. The rope material shall compress no more than 50% from the original uncompressed diameter when squeezed 300 psi over a length of at least 10 times the diameter.

5. Resilience and stiffness characteristics of the rope shall be low enough that it may be pushed into the stuffing box around the cable without the tendency to pop back out. (moldability)

6. The ability to successfully enter the electrical cables with the substitute rope material shall be demonstrated for representative cable sizes by evaluating the ease of entering the cable with the proper length of rope, the grip on the cable, and the performance when subjected to explosion testing.

7. The substitute rope material shall not fray or lose fibers at the cut ends that could interfere with the thread engagement between the stuffing box and the packing nut.

8. The rope shall be free from treatment or impregnation with flammable or electrically conductive particles such as graphite (untreated).

9. The substitute rope material shall be evaluated and found acceptable in accordance with the flammability requirements of 30 CFR, Part 18, and the MSHA Interim Fire & Toxicity Criteria.

10. Shrinkage of the rope when subjected to the flammability test shall not exceed 3%.

TABLE 6-9 Recommended partial performance acceptability criteria for direct substitutes for asbestos rope in lead entrances (continued)

11. Compression set for service temperatures of -20°C shall not exceed 40%.

12. Tensile retention when subjected to heat aging at +125°C for 72 hours shall be at least 80%.

13. The substitute rope shall be capable of withstanding continuously high temperaturs of at least 500°F.

Section 7.0

COMPLIANCE WITH REGULATIONS

Explosionproof electrical enclosures used in underground coal mines must conform to the requirements of 30 CFR Part 18 as well as local regulations. The state regulations vary from one state to the next although they typically resemble the federal regulations. This section contains some comments on how these new innovative devices comply with the existing Part 18.

The data shows that these innovative devices can perform the intended functions in a safe manner in underground coal mines. Admittedly, only limited underground experience is available to date and further experience under actual operating conditions could show some unforeseen problems in application. Performance criteria have been defined and the design characteristics to comply with these criteria have been established. It is concluded that these innovative devices at least meet the intent of 30 CFR Part 18.

Subpart C, Inspections and Tests, of Part 18 is important and there should be no difficulty in meeting these requirements for both the pressure vented enclosures and the grommet type cable lead entries. These enclosures, with the cable entries, should be subjected to explosion testing as defined in 18.62. Test specimens of the grommet material should be subjected to flammability testing under Part 18.65 and the more recent interim fire and toxicity requirements as defined by MSHA. The hardware that was evaluated in the underground mine successfully passed these requirements.

Part 18.67 defines static pressure tests that must be conducted when MSHA determines that visual inspection will not reveal defects in castings or in single seam welds. The static pressure tests must be 150 pounds per square inch or more, and this would be an unrealistic requirement on the pressure vented enclosure. However, it should be possible to build enclosures that may be readily inspected so that Part 18.67 does not have to be invoked.

Subpart B, Construction and Design Requirements, contains design requirements that are not necessarily up to date with the advancement in technology. Part 18.28 describes devices for pressure relief, and the pressure vented enclosure may be considered under this requirement. The requirement, as worded, is broad enough to apply to the high gas flow rate for the pressure vented enclosure, although according to available information, only small devices with very low flow rate capability are used in production equipment.

Part 18.31, defines very specific design requirements for enclosure joints and fastenings, along with wall thickness and clearances. These design requirements are predicated upon a box that must withstand internal pressures upwards of 150 pounds per square inch. These specific requirements do not recognize the techniilogical advancement of the pressure vented enclosure, and therefore are not applicable if many of the advantages of the pressure vented enclosure are to be achieved. The maximum internal pressure for a pressure vented enclosure should not exceed 15 pounds per square inch, (versus 150 pounds per square inch required in Paragraph (a)(1). For the same high pressure reason, 18.31 (a)(6) identifies specific minimum requirements for material thickness, joint clearance, widths of joints, bolt spacing, maximum diametrical clearance, etc. All of these latter requirements are based upon pressures inside the enclosure building upwards to 150 pounds per square inch. As noted in Table 5-1, much less stringent requirements are recommended for the pressure vented enclosure.

Requirements for lead entrances are identified in Part 18.37. The grommet type cable lead entrance can comply with most of these requirements. However, 18.37 (f)(2) and 18.37 (f)(3) are restrictive. The advancement in technology with the tapered urethane grommet provides a very high degree of moldability that was not possible with the cylindrical grommet type lead entrance, or the simple asbestos rope packed type lead entrance. This clearance requirement under lead entrances is another example of a design requirement that does not recognize the advancement in technology. As noted in Table 6-8, item 1.5, a much larger diametrical clearance with the urethane grommet is recommended.

Table 7-1 summarizes the interpretation as to how the present federal regulations allow the advantages of the innovative devices to be realized.

TABLE 7-1 Advantages of innovative devices with regard to conformance to federal regulations

DEVICE	PRESENT CFR	WITH CFR CLARIFICATION
PRESSURE VENT	MAY BE ONLY WAY A VERY LARGE ENCLOSURE CAN PASS EXPLOSION TEST	WALL THICKNESS MAY BE REDUCED AND LIMITED ONLY BY RUGGEDNESS CONSIDERATIONS
	FLAME TIGHT JOINTS AND WALLS WILL NOT BE SUBJECTED TO HIGH PRESSURE, THUS IMPROVING SAFETY	FLANGE GAP AND FLAME PATH REQUIREMENTS MAY BE RELAXED
		COVER FASTENER SPACING MAY BE INCREASED
INNOVATIVE CABLE	SIMPLIFIED ENTERING AND REMOVING CABLE	AS FEW AS FOUR GROMMET SIZES MAY ACCOMMODATE A TYPICAL RANGE OF CABLE SIZES
	DOES NOT NORMALLY REQUIRE ANY MATERIAL REPLACEMENT	
	BETTER ASSURANCE OF A UNIFORM AND LONG LASTING SEAL	

It is recommended that the government agencies address these comments at the earliest possible time to clarify interpretation of the regulations and, if necessary, take action to initiate any amendment to the regulations.

APPENDIX A

FLOW RESISTANCE TEST PROCEDURE

This appendix describes the experimental setup, instruments, procedures and data handling used by Professor Prahl in performing air flow resistance tests on Retimet samples used in the pressure vents.

A.1 Experiment Setup

To determine the flow rate pressure drop characteristics of a porous metal material, Retimet, the general idea is to force a gas to pass through a measured area of the sample of known thickness while measuring the flow rate of gas and the pressure difference across the sample thickness. The gas source chosen for this purpose was the building air supply in Glennan Space Engineering Building on the Case Western Reserve University Campus. This supply could sustain sufficient volume flow rate at more than adequate pressures provided that the sample area was restricted to 1 square inch or less. Initial results (Figure 4-2) indicated that the results are insensitive to the area masked off in the range of 1 to 15 square inches.

This area masking consisted of a metal plate with a 1 inch diameter aperture. The Retimet sample was held against this plate. Later a piece of duct tape was put on this plate to act as a gasket in the event that some air might have been leaking around the surface of the Retimet sample.

The building air was filtered, regulated to a suitable pressure for the test, passed through a Meriam[1] Laminar Flow Meter, and a sheet metal holder in which was mounted the Retimet sample. The air escaped to the atmosphere after passing through the sample. A pressure difference across the Laminar Flow Element was measured with a Meriam Micromanometer and the pressure difference across the Retimet sample was measured with a Wallace and Tiernan Pressure Gauge. See Figure A-1 for the details on the equipment and a schematic sketch of the apparatus. Figure A-2 shows the test apparatus.

The Meriam Flow Meter was checked with a Datametrics Linear Flow Meter Model 800L, which had been calibrated at Gould Laboratories. The agreement between the two was within 2% after the Meriam Laminar Flow Element had been cleaned and reassembled. The Wallace and Tiernan Pressure

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1. References to specific equipment in this appendix are made to facilitate understanding and do not imply endorsement by the Bureau of Mines.

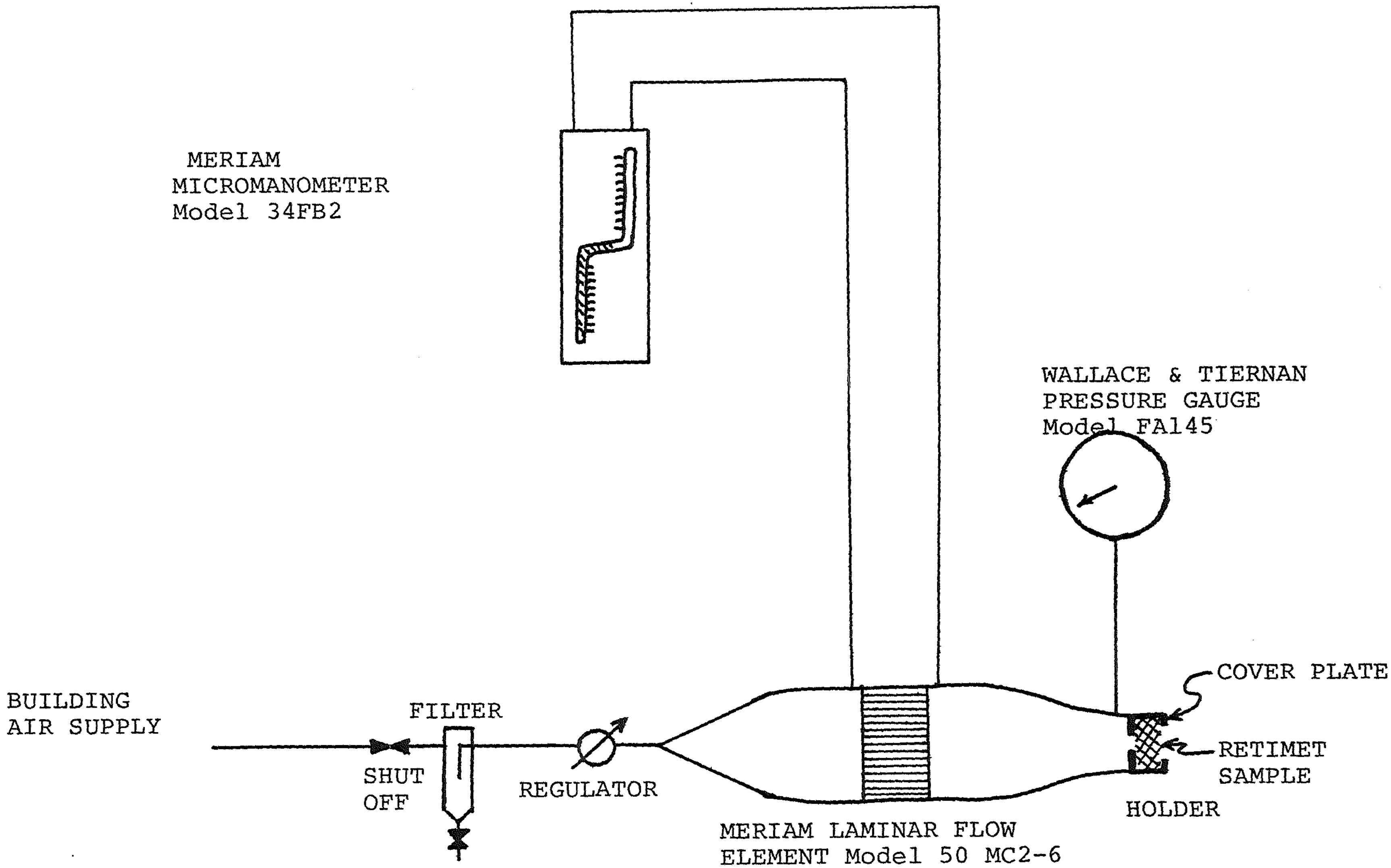
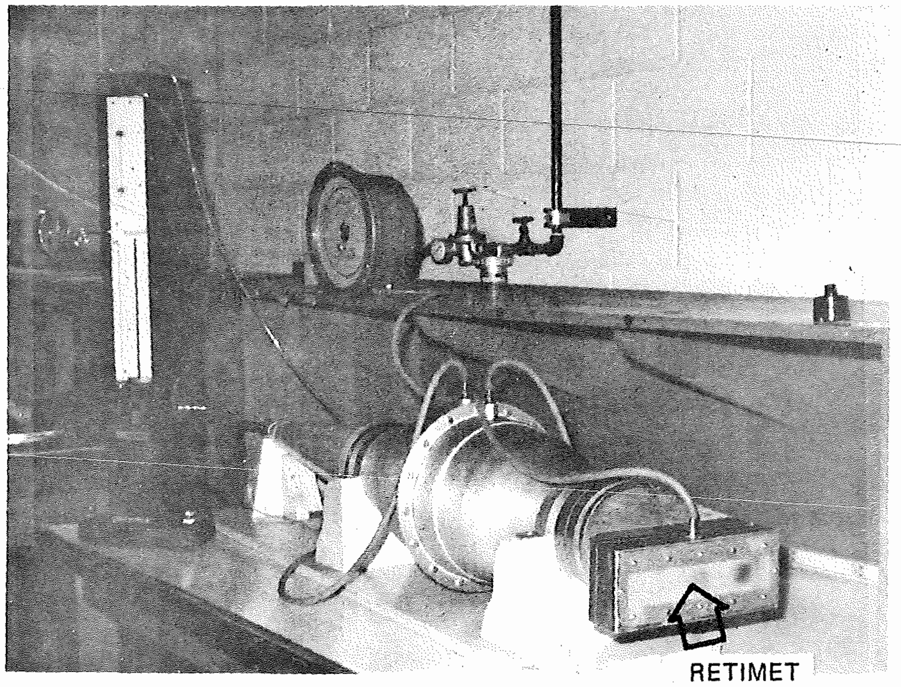


FIGURE A-1 Schemetic of flow diagram and instruments



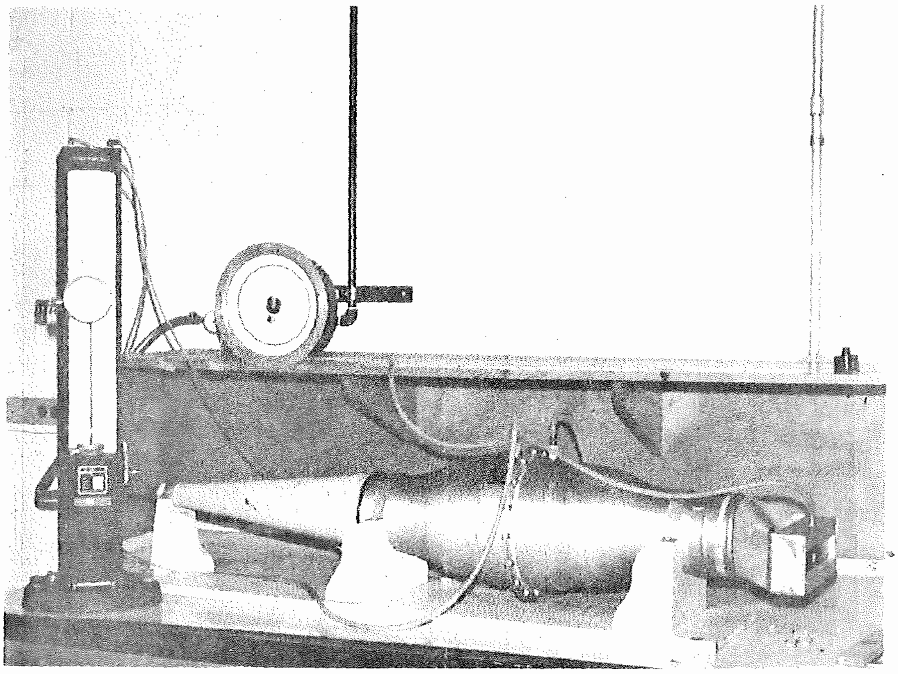


FIGURE A-2. Apparatus with and without Retimet sample in holder

Gauge was a high precision piece of equipment for pressures in the range of 0 to 630 psf; although here it was restricted to the range of 0 to 200 psf, or about 1.3 psig.

A.2 Test Procedure

The thickness of the sample to be tested was measured at several positions prior to mounting in the sample holder. The area of the sample masked off for the flow test was recorded; for all tests that was a 1 inch diameter circle, area = 0.785 in^2. All the samples were very nearly 0.500 inches thick.

The room atmospheric pressure and temperature were noted for the period of testing, since this information is required to make corrections on the calibration curves for the Meriam Flow Meter.

After opening the shut off valve on the air supply, the filter valve was opened to blow off any residual contamination from the bottom of the filter. With the regulator closed and no flow of air, the micromanometer was zeroed and the Wallace and Tiernan Gauge was zeroed. The regulator was opened until a desired pressure was obtained across the Retimet sample. When this pressure remained stationary, the micromanometer was adjusted so that the fluid meniscus returned to its original position and the new setting in inches of H_2O was recorded as well as the pressure reading in psf across the sample. A new pressure level was chosen and the process repeated.

All relevant data was recorded on specially prepared data-results sheets (see sample sheet included as Table A-1).

A.3 Results and Data Handling

By referring to the calibration tables provided by Meriam and correcting for temperature and atmospheric pressure, the volume flow rate in standard cubic feet per minute was determined for each micromanometer reading in inches of H_2O. The volume flow rate, Q was divided by the flow area, 0.785 in^2 to yield the desired result, Q/A. The pressure drop (ΔP) across the sample was converted to psi and divided by the sample thickness (δ) to yield the effective pressure gradient across the sample, $\Delta P/\delta$.

Since the fundamentals of fluid flow through porous materials, pipes, or other conduits, indicate that the pressure gradient will be produced by viscous effects which are linear with the flow rate, and inertial effects, i.e. turbulence, which are quadratic with flow rate, the normal form for the pressure gradient flow rate dependence is,

$\Delta P/\delta = k_1(Q/A) + k_2(Q/A)^2$ where k_1 and k_2 will be constants if the viscosity and the density of the fluid are constants. A slightly more general form, necessary when the fluid properties might change substantially from test to test would be

$$f = \frac{\Delta P/\delta}{\frac{1}{2}\rho(\frac{Q}{A})^2/d} = \frac{C_1}{\rho}\frac{\mu}{\frac{Q}{A}d} + C_2,$$

where ρ is the fluid density, μ is the fluid viscosity, d is a nominal pore size, and C_1 and C_2 are constants independent of fluid properties. f is called the friction factor and the parameter $\rho\frac{Q}{A}d/\mu$ is the pore size Reynolds number. It is trivial to show that $k_1 = C_1\mu/2d^2$ and $k_2 = C_2\rho/2d$.

For purposes here, the first dimensional form is a little more physical and adequate since the temperature and pressure of the air does not vary significantly from day to day.

The k_1 and k_2 are found for any set of N measurement pairs, $[(\Delta P/\delta)_j; (Q/A)_j]$, j = 1, 2, ..., N, by minimizing the sum of the square errors, E^2, for that set,

$$E^2 \equiv \sum_{j=1}^{N} \left\{ (\Delta P/\delta)_j - [k_1(\frac{Q}{A})_j + k_2(\frac{Q}{A})_j^2] \right\}^2.$$

This procedure is commonly called the least square curve fitting procedure and is generally performed on a computer. Once k_1 and k_2 are found for a set of N pairs for a sample, assuming that the N pairs of measurements are distributed randomly about the resulting curve, i.e., are normally distributed, then there is a 68% probability that one more measurement pair, N+1, taken anywhere in the domain for that Retimet sample will have $(\Delta P/\delta)_{N+1}$ within $\pm E/\sqrt{N-2}$ of the value predicted by

$k_1(Q/A)_{N+1} + k_2(Q/A)^2_{N+1}$. In addition, if another sample of N pairs were measured for the same Retimet sample and another k_1 and k_2 were found by the same procedure above, the new <u>resulting</u> curve would have a 68% probability of being within $\pm E/\sqrt{N(N-2)}$ of the original <u>curve found.</u> It is this standard deviation on the mean curve, $E/\sqrt{N(N-2)}$, that is recorded as, e, on the data sheets.

TABLE A-1 Typical measurement data sheet

BOOZ, ALLEN, and HAMILTON RETIMET FLOW TESTING

performed by J. M. Prahl, Ph.D., P.E.

Sample Characteristics

Sample Number 02 ; Sample mean thickness. δ 0.510" ; 0.500"

Length of in-mine service 8/21/80 — 9/26/80

$\Delta P/\delta = k_1 (Q/A) + k_2 (Q/A)^2$, where k_1 and k_2 are determined to minimize the the square error e^2.

Flow Characteristics

Before

"2" in upper LFT. corner

Date 12 June 80

Operater J.M. Prahl JMP.

P_{atm} = 29.65

T_{amb} = 71°F △ ✓

After

Date 6 Oct 80

Operater J. Prahl

P_{atm} 29.55" Hg

T_{amb} 70°F ; 20°C

Run	Δh "h_2O	ΔP psf	Q/A SCFM/in^2	ΔP/δ PSI/in.	Run	Δh "h_2O	ΔP psf	Q/A SCFM/in^2	ΔP/δ PSI/in.
200	0	0	0	0	2000	0	0	0	0
201	.0366	4.2	6.06	.0572	2001	0.0420	4.4	6.95	.0599
202	.0588	10.3	9.76	.140	2002	0.0653	10.8	10.8	.147
203	.0761	15.9	12.7	.217	2003	0.0813	16.3	13.5	.222
204	.1003	26.5	16.8	.361	2004	0.1074	27.0	18.0	.368
205	.1359	45.7	22.9	.622	2005	0.1365	44.5	23.0	.606
206	.1695	72.0	29.0	.980	2006	0.1822	77.2	31.2	1.05
207	.1987	98.8	34.4	1.35	2007	0.2030	98.0	35.1	1.33
208	.2290	132.2	40.2	1.80	2008	0.2354	131.0	41.3	1.78
209	.2470	156.9	43.9	2.14	2009	0.2554	155.0	45.3	2.11
210	.2589	175.3	46.4	2.39	2010	0.2620	173.1	46.9	2.36
211	.0006	0			2011	-0.0011	0		

Before: k_1 = 0.00358; k_2 = 0.00104; e = <1%

After: k_1 = 0.00193; k_2 = 0.00102; e = 1%

The resulting curves for 4 sets of 10 pairs each for Retimet sample No. 2, are shown in Figure A-3. Note that the sample had been altered by compression between June 12 and October 6, and that a different kind of holding gasket was used on the second run of November 20. The important fact to recognize is that there was no discernable difference between the resulting curves of 6 October and the first run on 20 November.

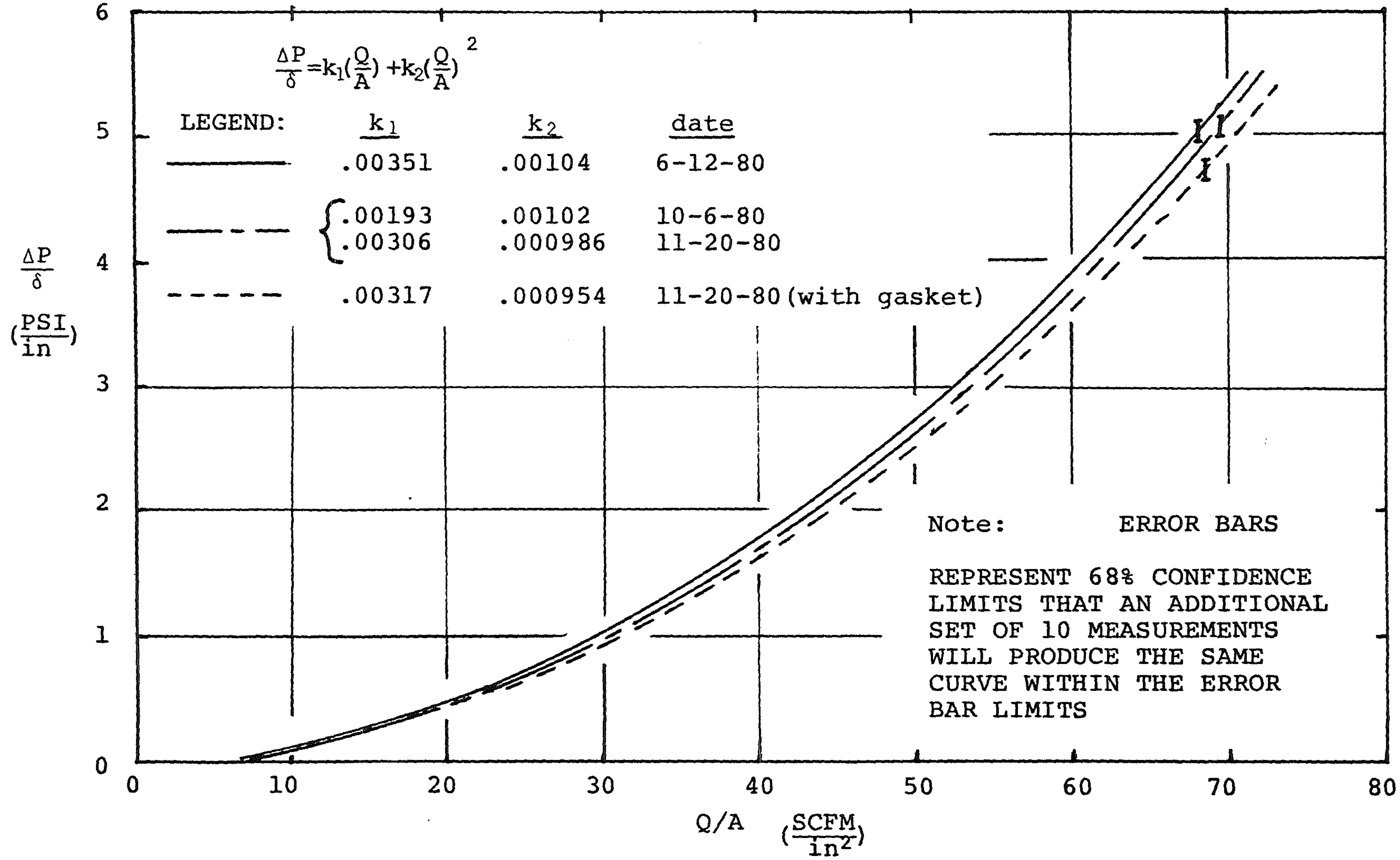


FIGURE A-3 Experimental results comparison for sample No. 2

APPENDIX B

BASIS FOR PRESSURE VENT ACCEPTANCE CRITERIA IN TABLE 5-1

This appendix provides reference information and rationale for the recommended performance acceptability criteria for high flow rate pressure vents as identified in Table 5-1. Reference numbers in this appendix correspond directly with the paragraph numbers in Table 5-1.

1.0 A value of 12 psi was identified in Figure 4-3 of the final report. That curve shows that peak pressure in the enclosure at the recommended vent area to enclosure volume ratio should normally be less than 2 psi.

1.1 The value of 302°F and other requirements are already defined in Part 18.

1.2 Data for Figure 5-1 came from original work described in Figure 4-8 of the Final Report. Wire screens added on the inside surface of the vent provide a heat sink, which allows some reduction in the required area of the steel foam. The bonding together around the periphery by a steel box frame is an additional requirement to assure that the proper number of wire screens are used along with the foam vent material, i.e., never left out. Also, the requirement is added to assure that the wire screens are always on the inner surface of the enclosure.

1.3 This follows the original design concept where the vent assembly is inserted from the inside into a frame assembly and retained with fastening devices that preclude coming loose. The purpose is to preclude removal of the vent multilayer package from the outside as if it were an access cover.

1.4 Tests performed with large areas of metal foam material showed some tendency toward warpage and led to concern for the structural integrity. The pressure vent assembly tested underground has a cross sectional area of less than 20 square inches. This appeared to be adequate in strength. The assignment of a 50 square inch maximum unsupported area is a subjective judgement call.

1.5 The maximum safe gaps were established experimentally during the early work, and the values are presented in Figure 4-8 of the Final Report.

1.6 A test of the enclosure at 15 psi internal pressure is good engineering practice and represents some margin over the 12 psi value stated in paragraph 1.0.

1.7 The requirement for both mechanical protection and protection from direct water spray was identified during early experimental work. This cover is also needed to minimize the possibility of afterburning due to unburned combustible gases leaking back into the enclosure. The limit value of 1 pound per square inch rise in pressure is necessary to avoid pressure build-up inside the enclosure. Tests during early work substantiated the ability to open up the door with less than 1 psi.

1.8 Testing of any new electrical enclosure design appears necessary.

2.0 The characteristics of the vent material are very important and must be approved by MSHA.

2.1 This definition of metal foam comes directly from the vendor's specification sheet.

2.2 This composition breakdown comes directly from the vendor's specifications.

2.3 The density value comes directly from the vendor's specification sheet.

2.4 This air flow resistance value was established as a requirement during early testing with the foam vent material. It is generally in accordance with values specified on the vendor's specification.

3.0 It is important that the vent can be readily inspected when the enclosure is mounted on a machine to both assure it is present and that it does not appear to be obviously damaged.

3.1 This requirement for easy access is obvious.

3.2 Erosion or discoloration on the outside surface were determined during experimental effort to be a reasonable measure of the condition of the vent assembly.

3.3 The gaps around the vent assembly will be a step configuration and there does not appear to be a more stringent requirement than allowed for an ordinary cover flange gap. It should be noted that all the experimental work was performed by directly compressing the Retimet into the frame without a steel box frame around the Retimet. The criteria stated in this Table should provide the same protection from a flame path standpoint.

3.4 Although it was experimentally demonstrated that the vent assembly is self-cleaning, it appears prudent that provision be allowed for cleaning and reinsertion of a vent assembly. Also, the vent assembly should be removable only from inside the enclosure because it should not be removed very often. The vent sandwich package is not as rugged as a simple steel cover plate. If the vent sandwich is mounted on the enclosure removable cover, the cover should be removable without disturbing the vent sandwich flame path.

APPENDIX C

LITERATURE SEARCH ON EXPLOSIONPROOF ELECTRICAL ENCLOSURES

Many old files and documents were searched for information applicable to either pressure venting or lead entrances of explosionproof electrical enclosures. Listed in this appendix are those documents pertinent to this investigation.

1. Beyling, C. "Versuche zwecks Erprobung der Schlagwettersicherheit besonders geschetzter elecktrischer Motoren und Apparte sowie zur Ermittlung geeignetter Schutzvorrichtungen fur solche Betriebsmittel", Ausgefuhrt auf der berggewerkschftlichen Versuchstrecke in Gelsenkirchen, 1906. (Translation by O.L. Schwarz, "Trials for the Purpose of Testing Gas Mine Safety of Particular Specific Electric Motors and Apparatus to Achieve Ascertainment of Suitable Safeguards for Such Devices").

2. British Standards Institution. "Specification for Mechanical Cable Glands for Rubber and Plastics Insulated Cables", British Standards House, B.S. 4121, 1967.

3. Gleim, E. J. "USBM Standard for Inspection & Test of Explosionproof Enclosures for Mining Equipment", USBM RI 5057, 1954.

4. Gleim, E.J., and H. B. Freeman. "Maintenance of Electrical Mine Equipment from the Viewpoint of the Safety Inspector", USBM TP 537, 1932.

5. Gleim, E. J., R. S. James, and H. B. Brunot. "Explosionproof Design & Wiring for Permissible Mining Equipment", USBM B541, 1955.

6. Ilsley, L.C. "Operation and Maintenance of Electrical Equipment Approved for Permissibility by the Bureau of Mines", USBM, 1922, TP 306.

7. Ilsley, L.C. "Points to be Considered in the Design of Covers for Explosionproof Compartments", USMB, May 1930, IC 6267.

8. Ilsley, L.C. "Safeguarding Electrical Equipment used in Gassy Mines, European Practice, I: Great Britain, IC 6134, 1929.

9. Ilsley, L.C. "Safeguarding Electrical Equipment used in Gassy Mines, European Practice, II: Belgium, IC 6135, 1929.

10. Ilsley, L.C. "Safeguarding Electrical Equipment used in Gassy Mines, European Practice, III: Germany, IC 6143, June 1929.

11. Ilsley, L.C. "Safeguarding Electrical Equipment used in Gassy Mines, European Practice, IV: France, IC 6146, 1929.

12. Ilsley, L.C. "Selected List of Bureau of Mines' Publications Covering Safety Studies & Activities of the Electrical Section", IC 6310, 1930.

13. Ilsley, L.C., and E. J. Gleim. "Suggestions for the Design of Electrical Accessories for Permissible Mining Equipment", USBM, 1926, B258.

14. Ilsley, L.C., E. J. Gleim, and H. B. Brunot. "Inspection and Testing of Mine-Type Electrical Equipment for Permissibility", USBM B 305, 1928.

15. Nagy, J., J. E. Zeilinger, and I. Hartmann. "Pressure-Relieving Capacities of Diaphrams and Other Devices for Venting Dust Explosions", USBM RI 4636, January, 1950.

16. Shell, H. R., J. E. Comeforo, and W. Eitel. "Synthetic Asbestos Investigations, Synthesis of Fluoramphiboles from Melts", USBM RI 5417, 1958.

17. Shell, H. R., R. A. Hutch, and D. L. Brown. "Synthetic Asbestos Investigations, III, Synthesis and Properties of Fibrous Potassium-Lead Silicate", USBM RI 5293, January 1957.

18. Stefanko, R., and L. A. Morley. "Mine Electrical Systems Evaluation-Explosionproofing of Mine Containers", Pennsylvania State University, USBM Contract G0133077, July 18, 1974.

19 USBM. "Inspection & Testing of Mine-type Electrical Equipment for Permissibility (Revision of Information Circular 7185)", USBM IC 7689, June 1954.

20. USBM, "Explosion-Proof Motors", USBM Schedule 2, January 1, 1912.

21. USBM. "Procedures for Establishing List of Permissible Explosion-Proof Electric Motors for Mines", Schedule 2A, November 2, 1915.

22. USBM. "Procedures for Establishing Lists of Permissible Electric Motors", USBM Schedule 2B, August 16, 1921.

23. USBM. "Explosion-Proof Mine Equipment; Requirements for Approval of Storage-Battery Locomotives and Power Trucks, Junction Boxes, and Electric Motor-Driven Equipment", USBM Schedule 2C, February 3, 1930.

24. USBM. "Explosion-Proof Mine Equipment; Requirements for Approval of Storage-Battery Locomotives and Power Trucks, Junction Boxes and Electric Motor-Driven Equipment", USBM Schedule 2D, May 23, 1936.

25. USBM. "Procedure for Testing Junction Boxes and Electric Motor-Driven Mine Equipment for Permissibility", USBM Schedule 2E, February 15, 1945.

26. USBM. "Electric Motor-Driven Mine Equipment, Junction Boxes and Other Accessory Equipment", USBM Schedule 2F, August 3, 1955.

27. USBM. "Electric Motor-Driven Mine Equipment and Accessories", USBM Schedule 2G, March 19, 1968.

APPENDIX D

CABLE ENTRY PULL TEST DESCRIPTION

Tests to determine the gripping ability of the various cable lead entrance assemblies were performed in a similar manner as during original development of the urethane grommet type entry. The sample cable lead entrance assembly was packed around a test specimen of the cable and this was inserted into a machine that pulled between the cable and the packed lead entrance assembly at a constant displacement velocity.

At the start of a test, the cable is in a relaxed condition and the machine starts to pull the entry body from the cable at a fixed velocity while the load in tension in the cable is being monitored. The load builds as the displacement is increased until such time as the jacketed cable starts to slip in the packed lead entrance assembly. Figure D-1 shows a typical plot of the cable load versus time. The slip load is identified as that load on the cable where slippage is obvious by the fact that the load no longer increases. In some instances this is a very pronounced flattening of the curve and in others it is a more rounded knee.

The tests described in this part of the program were performed on a material test system which is capable of very accurately controlled tension or compression functions up to 220,000 pounds. This test system with a sample cable entry and cable installed is shown in Figure D-2. The console on the right provides all of the control functions and a chart recorder (visible on the upper part of that console). Each test run was separately plotted automatically. The control functions were set for a tension mode at a fixed displacement rate. The load was applied to the test specimen by the hydraulic cylinder located in the lower part of the stand on the left.

A different type of tension testing machine was used in the original urethane grommet-type entry development and very slow displacement could be used. As shown in Figure 6-1, displacement values as low as .0005 inches per second were tried experimentally. Most of the developmental tests were performed at a displacement velocity of .0022 inches per second because it provided the most dependable results.

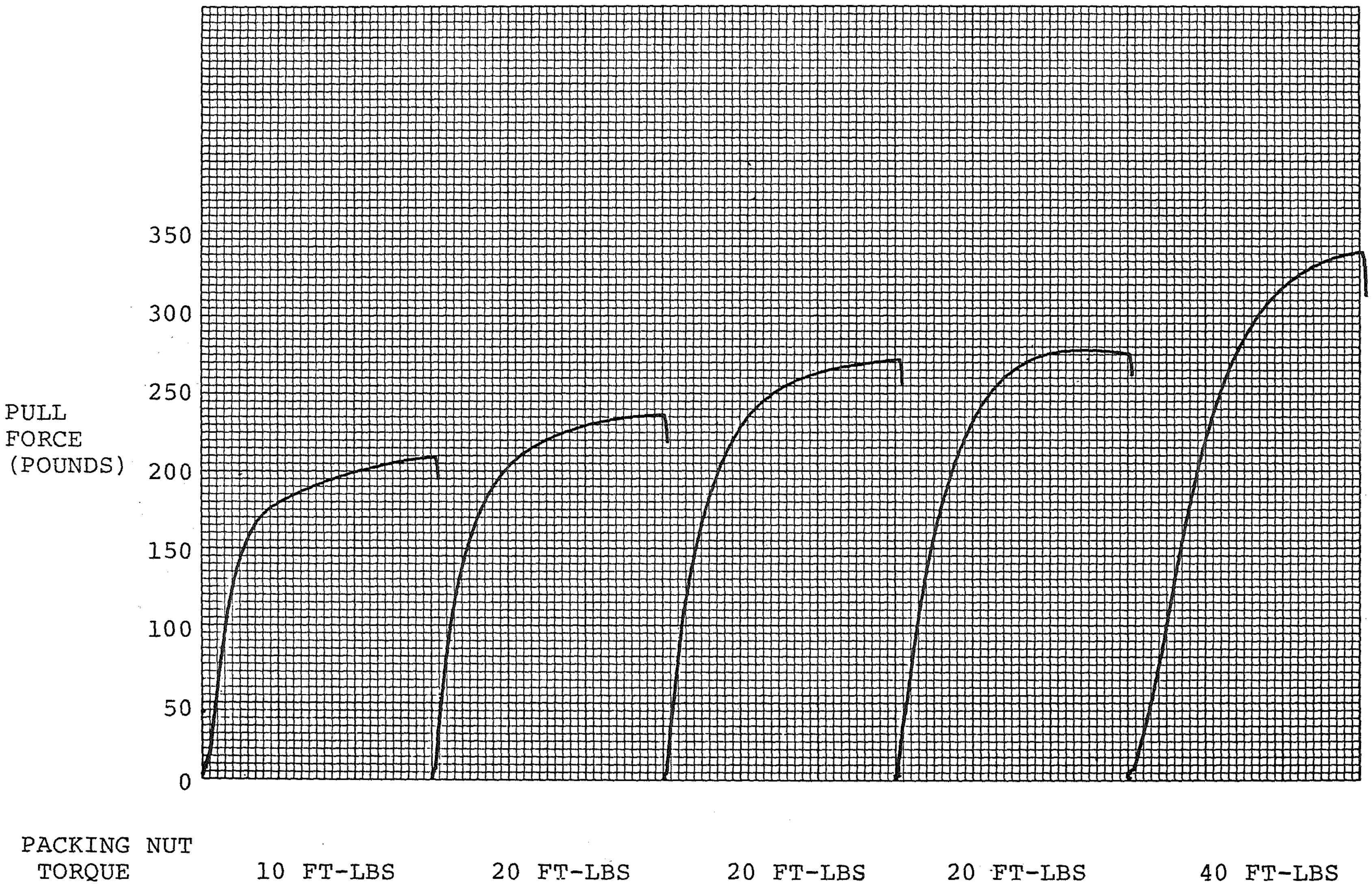


FIGURE D-1 Typical trace of cable entry pull force versus time (displacement)

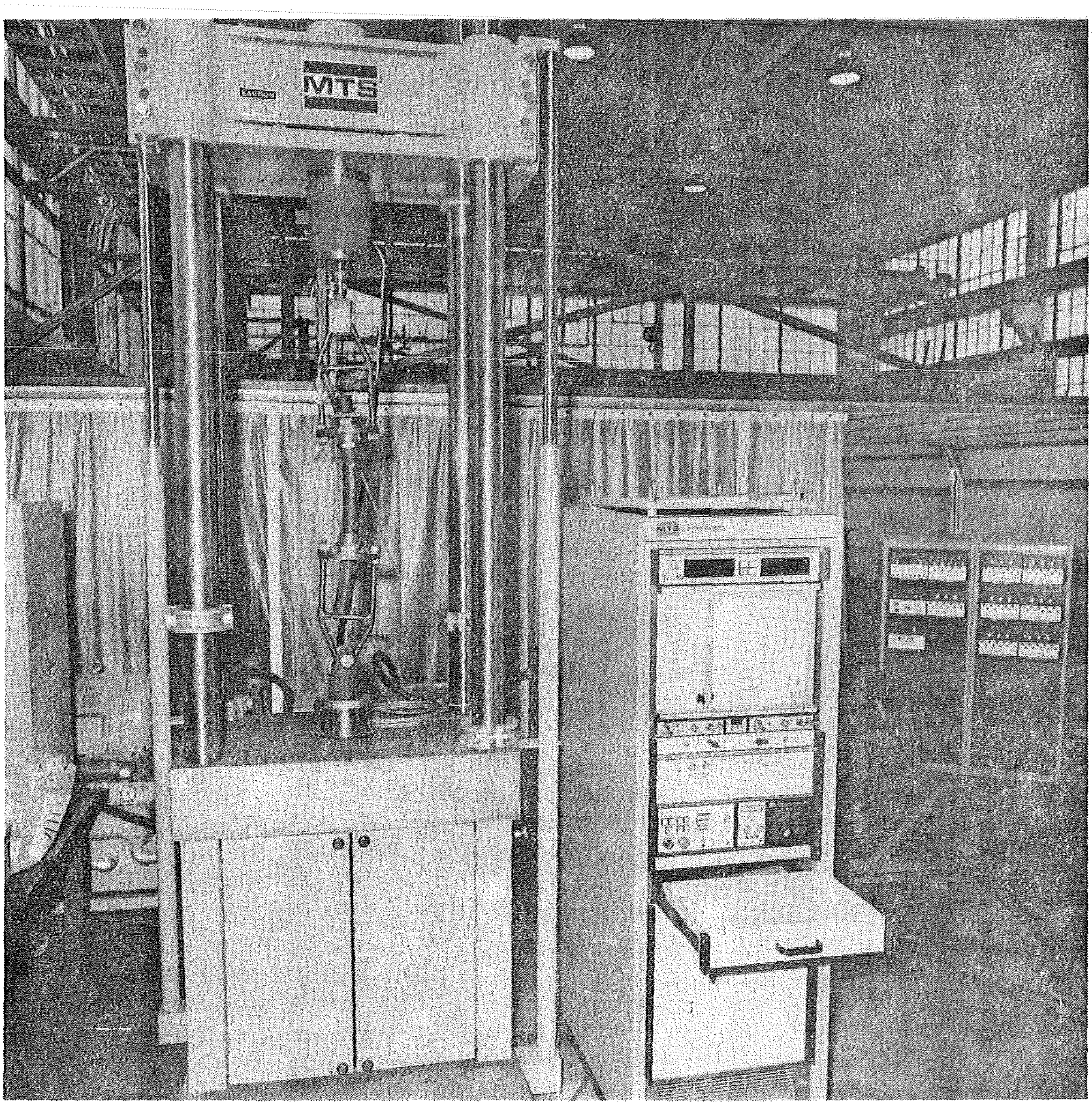


FIGURE D-2 Test setup for cable entry pull tests

In this newer material test system, displacement velocity is a function of the cycle time of the applied function waveform and the total displacement. These are preprogrammed. Thus, the slowest displacement velocity available with this system was .004" per second.

As noted in Figure 6-1, the load at which slip occurs tends to increase as the displacement velocity is increased. Initial tests were run with an asbestos packed cable entry torqued at 15 FT.LBS, and then torqued at 40 FT.LBS. As shown in Figure 6-1 the slope of the curve is similar to that for the early work. The ultimate choice of a displacement velocity of .006 inches per second was necessary to assure that all samples would reach the point at which slip occurs.

Some of the more tightly packed entry bodies would not reach the slip load within the applied function time if the displacement velocity was less than .006 inches per second. A main objective in these tests was to obtain comparative information among the asbestos packed entry, the substitute rope type entries, and the urethane grommet-type entry.

On this particular machine the maximum time for a linear pull in one direction was 25 seconds. It was experimentally determined that at least 0.1 inches of displacement was required to reach slip load. Consequently, the ultimate selection was a displacement of 0.15 inches. Even under these conditions there were a few instances where larger displacements (and larger displacement velocities) had to be tried in order to assure identifying the load at which slip occurred.

Figure D-3 is a closeup view of a length of trailing cable with a packed asbestos rope type entry set up in the machine and ready for test. The upper anchor point is adjustable in height to accommodate the test specimens. Attached directly below this upper anchor point is a load cell. The electrical connector from the load cell going over to the test console may be seen in this view. Attached below the load cell is a heavy anchor to which the upper end of the cable is clamped. In this instance an asbestos packed cable entry was used to hold the cable at the upper end with an additional U clamp on top of the stuffing box assembly. The object was to hold the cable tight enough at the top end so that there would be no slippage with the forces involved. The cable entry under

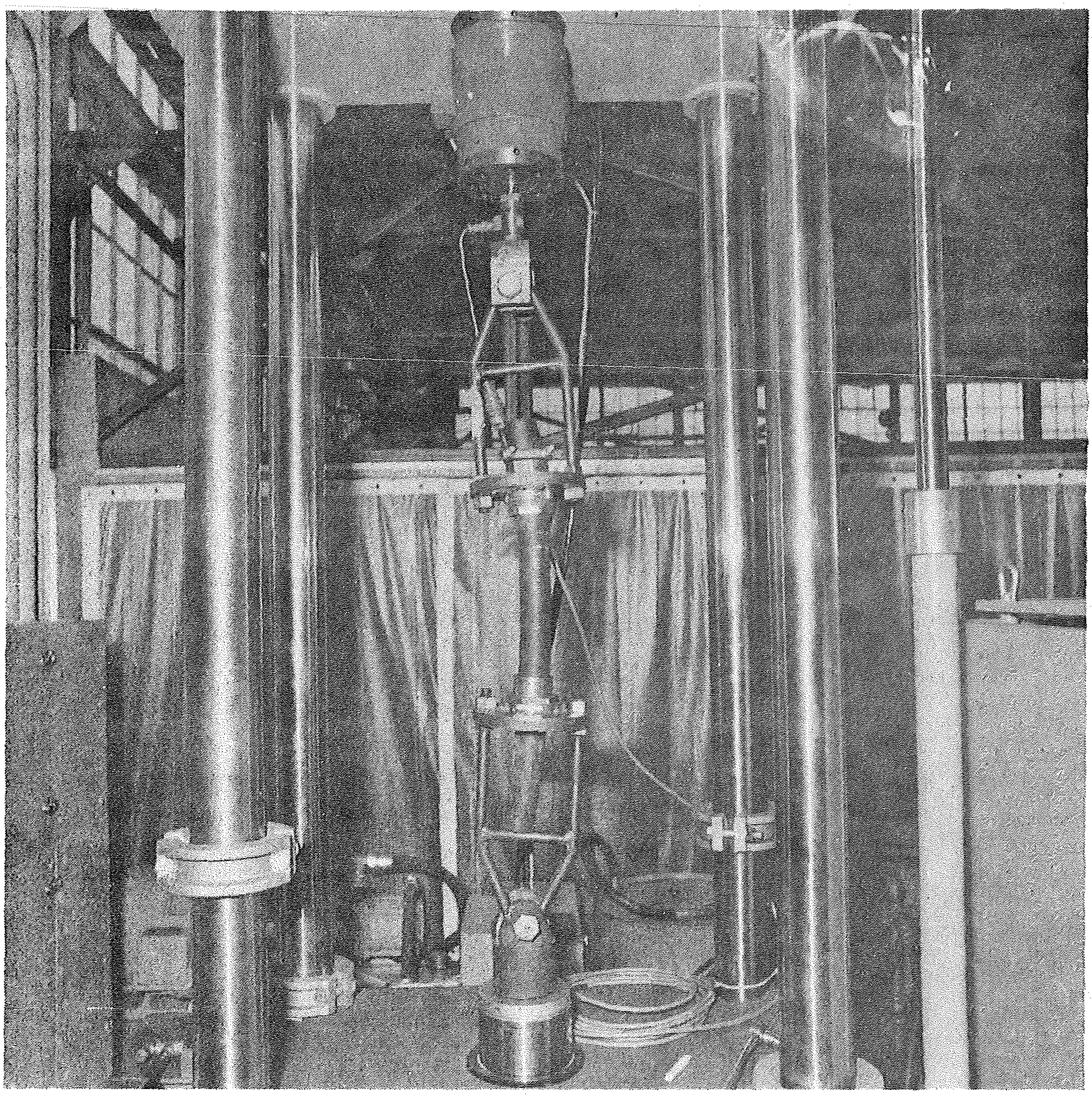


FIGURE D-3 Close-up view of trailing cable with asbestos rope packed entry in pull test machine test is at the lower end and is mounted in another test fixture which in turn is mounted to the lower anchor point. The lower anchor point is attached to the hydraulic cylinder which is pulled at a controlled rate. In this view the cable assembly in the test fixtures is relaxed without tension.

In each test run all of the equipment settings are calibrated and then enough load is applied via the lower hydraulic cylinder to put the cable under a minimum load in tension. Then the machine is started and the lower cylinder moves at a fixed velocity downward. Output from the load cell is plotted on the vertical axis of the chart as a function of time.

A number of sample test runs were made before starting the actual series of comparative tests. This took considerable time and adjustment of the setup conditions, but this effort proved to be well justified. Approximately 200 cable entry pull test runs were made after the test conditions were established.

APPENDIX E

DATA ON URETHANE MATERIAL

This appendix contains information on the characteristics of the urethane material as used in the grommet-type cable lead entrance. Pages 125 and 126 are copies of a letter from the supplier of the urethane material actually used in the grommets subjected to the evaluation. This letter identifies the formulation and process control. Page 127 is a copy of a letter from MSHA stating that specimens of the urethane were tested for flammability and evaluated for toxicity.

Pages 128, 129, 130 and 131 are from the E. I. duPont de Nemours & Co. (Inc.), Elastomers Division document "Engineering Properties of DUPONT ADIPRENE Urethane Rubber"[1]. DuPont supplies basic chemicals that are used by suppliers such as identified on page 125. DuPont emphasizes the importance of compounding to provide the best performance to match individual specifications.

Cold flow or creep characteristics are important when the urethane is held under compression to a different shape than in the original relaxed condition. When the urethane grommet is used in a cable lead entrance it must not creep such that the grip on the cable would be adversely affected, and when the grommet is removed from an entry body it should return to the original shape. These characteristics are typically described in the Mobay Chemical Corporation document, "Multrathane Cast Elastomers, a Processing Guide"[2]. Page 132 is from this document.

1.&2. Reference to tradenames and manufacturers in this appendix is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

NEWAGE INDUSTRIES INCORPORATED

TWX 510 665 6084
(215) 657 3151
2300 MARYLAND ROAD, WILLOW GROVE, PENNSYLVANIA 19090

October 21, 1977

Booz, Allen & Hamilton Inc.
8801 E. Pleasant Valley Rd.
Cleveland, OH 44131

Attn: Michael W. Riley, Ph.D.

Dear Dr. Riley:

Following is the detailed information you requested for the Mine Safety people. I'm sorry this has been rather a long time in coming to you.

Material: MP-850 is a thermoset polyester urethane consisting of TDI polyester prepolymer, cross linked with Moca.

Controls used in the manufacturing process are:

a. Temperature controls-used on both polymer-catalyst containers. Both containers are airtight for no moisture contamination.
b. Humidity controls-none, other than airtight containers.
c. Curing controls-during processing the mold platens are heat regulated.

   Metering devices are used to control proper ratio of polymer to catalyst.

   A material blender is used to insure consistent mix.
   Material is demolded only after initial curing is complete.

   Molded item is placed in a final cure oven for a set time under a controlled heat, which has time and temperature recorded.

Record keeping:

a. Item being molded is evaluated by use of a test ply from a test mold, used in conjunction with manufacturing.
b. Test ply is given a production procedure and identified by an MP number, a pour number and date produced.

(continued)

c. Sample from mold is given to our lab for evaluation of:
   1. hardness
   2. elongation and set
   3. modulus @ 300%
   4. ultimate tensile
   5. tear C

Results are recorded, disposition made and information filed.

I trust this will give you sufficient information with which to work with these people so that this material can be spec'd out.

I understand that you also require that we certify that the material being shipped is MP-850 and that if there are any changes in the formula you are to be notified prior to your order being processed. We have already agreed to that request so it would seem that we've about cleared up all remaining loose ends.

Sincerely,

Kenneth H. Hicks
Sales Manager

KHH/mcc

U.S. DEPARTMENT OF LABOR
MINE SAFETY AND HEALTH ADMINISTRATION
APPROVAL AND CERTIFICATION CENTER
Box 201B, Route 1
Industrial Park Blvd.
Triadelphia, West Virginia 26059

In Reply Refer to:
A&CC:DM&E:PAR #0024990

AUG 24 1978

Jeffrey Mining Machinery Division
Dresser Industries, Incorporated
Attention: Robert J. Gunderman
Post Office Box 1879
Columbus, Ohio 43216

Gentlemen:

Your request for use in underground mines of an innovative trailing cable entry grommet was evaluated by the Division of Materials and Explosives. As stated in your application, this grommet (drawing 507D238) is to be used in assembly drawing 507E234 which is one of the Innovative Electrical Enclosure devices being developed under USBM Contract HO 357107.

A development flame test was conducted per 30 CFR, Part 18, Section 18.65 on the grommet material, trade name: Superthane, formulation number MP850; the material passed this test for flame resistance. A review was also made of the formulation and toxicity of the grommet material.

On the basis of our review, this grommet material may be used on an experimental basis for underground mine evaluation as part of USBM Contract HO 357107. The use of the "Superthane" grommet material is limited to 120 days from the date of this letter. If an extention of this time limit is required, please submit a written request explaining the need.

Should the grommet material prove successful, then an application should be submitted to us for formal acceptance of the material under Part 18 and the Interim Fire and Toxicity Criteria.

A fee of $15.00 is charged as shown on the attached fee disposition sheet for the development flame test.

Sincerely,

Harry C. Verakis

Harry C. Verakis
Chief, Division of Materials
and Explosives
Approval and Certification Center

Enclosure

mechanical properties

dispensable tool to the rubber compounder and are almost universally used to determine the effects of various additives.

Tensile stress-strain curves (Figure 4) for compounds of ADIPRENE* urethane rubber of several hardnesses show that they possess high strength, especially at low elongations, and that even very hard compounds exhibit good elongation.

COMPRESSION PROPERTIES

ADIPRENE has far greater load-bearing capacity than do conventional elastomers of comparable hardness. Figure 5 compares the compressive stresses required to make a ten percent deflection with samples of ADIPRENE and natural rubber of similar hardnesses. This high load-bearing capacity is an important advantage in some designs and in others is the very factor that makes them possible.

SHEAR PROPERTIES

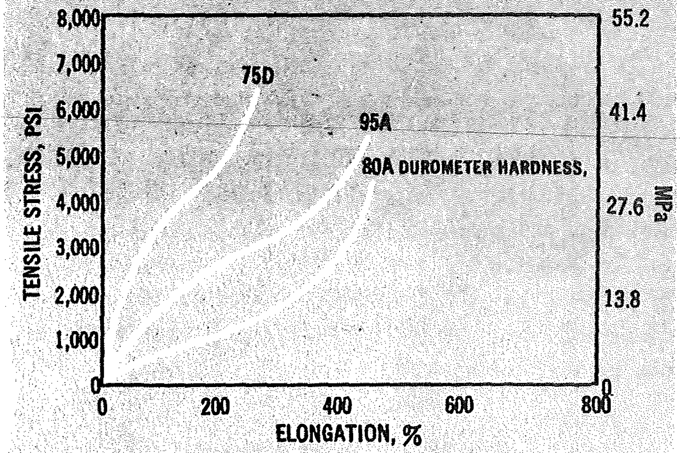
Shear stress-strain curves for ADIPRENE ranging in hardness from 75 to 97 durometer A are given in Figure 6. As expected from its high load-bearing capacity in tension and compression, ADIPRENE also shows a high load-bearing capacity in shear.

FLEX PROPERTIES

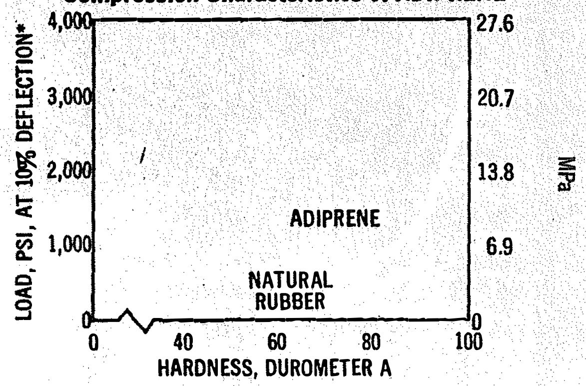
ADIPRENE resists cracking under repeated flexure quite well, as evidenced by its successful use in many dynamic applications. As with any elastomer, its rate of cut growth under flexing may be reduced by decreasing the thickness of the part. Unlike other elastomers, however, ADIPRENE can be practically utilized in very thin sections because of its exceptional strength and toughness.

*Reg. U.S. Pat. & Tm. Off.

FIGURE 4 Stress-Strain Properties of ADIPRENE in Tension (ASTM D412-61T)

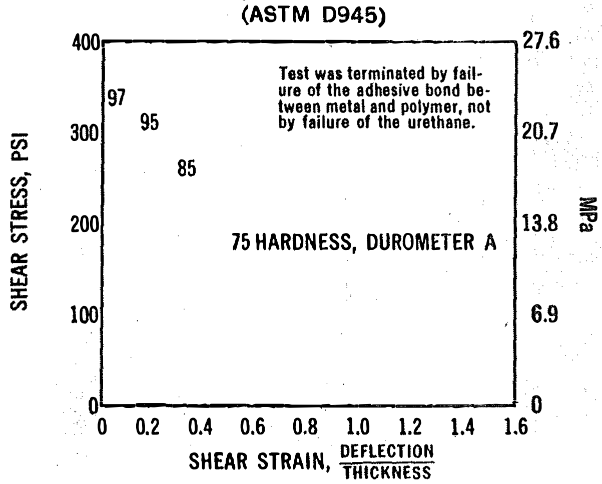


Compression Characteristics of ADIPRENE



*Determined on a Baldwin-Lima-Southwark 5.44×10^4-kg (60-ton) compression machine at a loading rate of 0.23 MPa/s (2,000 psi/min.) on samples with a shape factor of 1.0.

Stress-Strain Properties of ADIPRENE in Shear (ASTM D945)



The following tabulation has been prepared as a guide to the fluid resistance of properly compounded products made from Du Pont ADIPRENE* urethane rubber. We emphasize that the table should be used as a guide only. Other requirements necessary for satisfactory performance must also be taken into consideration.

The best way to determine whether or not the product will be entirely satisfactory for a given application is to test it in actual service. If this is impractical, then tests should be devised which simulate actual service conditions as closely as possible. Obviously, your supplier should be provided with complete details on the conditions involved, since correct compounding and processing are important to the success of any resilient part where chemical resistance is one of the service requirements.

*Reg. U.S. Pat. & Tm. Off.

A few words of explanation about the rating system used in the table. Unless otherwise noted, all ratings are at room temperature and the concentrations of all aqueous solutions may be considered saturated. The parenthetical temperatures listed are those that were actually used in tests or service applications, but do not necessarily represent temperature limits.

The A, B and C ratings are based upon data from laboratory tests and records of actual service performance. In some instances, where specific information is not available, T and X ratings are indicated. These are educated guesses based upon experience, analogy and a familiarity with the chemistry involved. T means, "test before using but most likely to be satisfactory". X means, "most likely to be unsatisfactory".

FIGURE 1[illegible]

Oil, Chemical And Solvent Resistance of ADIPRENE

CHEMICAL	RATING
Acetic acid, 20%	B
Acetone	C
Aluminum Chloride solutions	T
Ammonia, anhydrous	T
Ammonium hydroxide solutions	A
ASTM hydrocarbon test fluid	T
ASTM oil #1 (70°C/158°F.)	A
ASTM oil #3 (70°C/158°F.)	B
ASTM reference fuel A	A
ASTM reference fuel B (50°C/122°F.)	B
ASTM reference fuel C	C
Barium hydroxide solutions	A
Benzene	C
Borax solutions	A
Boric acid solutions	A
Butane	A
Calcium bisulfite solutions	A
Calcium chloride solutions	A
Calcium hydroxide solutions	A
Calcium hypochlorite, 5%	X
Carbon dioxide	A
Carbon monoxide	A

CHEMICAL	RATING
Carbon tetrachloride	C
Castor oil	A
Chlorine gas, dry	X
Chlorine gas, wet	X
Chromic acid, 10-50%	C
Copper chloride solutions	A
Copper sulfate solutions	A
Cottonseed oil	A
Cyclohexane	A
DOWTHERM A	B
Ethyl acetate	C
Ethyl alcohol	C
Ethylene glycol	B
Formaldehyde, 37%	C
Formic acid	C
FREON*-11	B
FREON-12 (54°C/130°F.)	A
FREON-22	C
FREON-113	A
FREON-114	T
Fuel oil	B
Gasoline	B
Glue	A
Glycerin	A
n-Hexane (50°C/122°F.)	B
Hydraulic oils	B
Hydrochloric acid, 20%	B
Hydrochloric acid, 37%	C

CHEMICAL	RATING
Hydrogen	A
Hydrogen peroxide, 90%	T
Isooctane (70°C/158°F.)	B
Isopropyl ether	B
JP-4	C
JP-5	C
JP-6	C
Kerosene	C
Lacquer solvents	X
Linseed oil	B
Lubricating oils	B
Magnesium chloride solutions	A
Magnesium hydroxide solutions	A
Mercury	A
Methyl alcohol	C
Methyl ethyl ketone	C
Mineral oil	A
Naphtha	B
Naphthalene	B
Nitric acid, 10%	C
Oleic acid	B
Palmitic acid	A
Perchloroethylene	C
Phenol	C
Phosphoric acid, 20-70%	A
Phosphoric acid 85%	C
Potassium hydroxide solutions	B

CHEMICAL	RATING
SAE #10 oil (70°C/158°F.)	A
Sea water	A
SKYDROL 500	C
Soap solutions	A
Sodium hydroxide, 20%	A
Sodium hydroxide, 46½%	B
Sodium hypochlorite, 5%	C
Sodium hypochlorite, 20%	C
Soybean oil	B
Stearic acid	A
Sulfur dioxide, liquid	T
Sulfur dioxide, gas	T
Sulfur trioxide	T
Sulfuric acid, 5 to 10%	A
Sulfuric acid, 10 to 50%	B-C
Sulfuric acid, 50 to 80%	C
Sulfurous acid	C
Tannic acid, 10%	A
Tartaric acid	A
Toluene	C
Trichloroethylene	C
Tricresyl phosphate	B
Trisodium phosphate solutions	A
Tung oil	B
Turpentine	C
Water (50°C/122°F.)	A
Water (100°C/212°F.)	C
Xylene	C

A—Little or no effect.
B—Minor to moderate effect.
C—Severe effect to complete destruction.
T—Test before using. No data but most likely to be satisfactory.
X—No data but most likely to be unsatisfactory.

*FREON is a registered trademark of E. I. du Pont de Nemours & Co. (Inc.)

environmental properties of Adiprene

While ADIPRENE* urethane rubber is more noted, perhaps, for its mechanical properties, it does possess satisfactory resistance to many environmental influences. Particularly good, versus other elastomers, is its performance at low temperatures. Compared with other urethane rubbers, ADIPRENE also exhibits outstanding water resistance.

In this section, the effects of normally encountered environmental factors upon ADIPRENE are described.

COLD RESISTANCE

ADIPRENE remains flexible at very low temperatures and possesses outstanding resistance to thermal shock. Standard compositions do not become brittle at temperatures below −62°C (−80°F.) although stiffening gradually increases as the temperature is reduced below −18°C (0°F.). Special compositions can be made which retain some flexibility at temperatures as low as −87°C (−125°F.).

ADIPRENE has been used successfully at cryogenic temperatures in handling non-oxidizing liquefied gases.

HEAT RESISTANCE

Products of ADIPRENE can be compounded for many continuous service applications at temperatures from 85 to 121°C (185 to 250°F.). Holding a typical compound for one week at 121°C (250°F.) (Figure 11) causes only a minor decrease in physical properties as tested at 24°C (75°F.).

Figure 12 illustrates the unusually high retention of physical properties of a similar compound, modified for improved heat resistance, when tested at 100°C and 121°C (212°F. and 250°F.). Nevertheless, even intermittent use of ADIPRENE above 121°C (250°F.) is not recommended and each contemplated use at 93°C (200°F.) or above should be individually evaluated beforehand.

Effect of Exposure to Elevated Temperature on Properties of ADIPRENE L 100
(All measurements made at room temperature)

	Original	After 1 Wk. at 100°C (212°F.)	After 3 Wk at 100°C (212°F.)	After 1 Wk. at 121°C (250°F.)
100% modulus, MPa (psi) (ASTM D412-61T)	7.6 (1,100)	7.4 (1,070)	6.6 (950)	6.2 (900)
Tensile strength, MPa (psi) (ASTM D412-61T)	31.3 (4,500)	31.3 (4,500)	29.5 (4,300)	18.9 (2,750)
Elongation at break, % (ASTM D412-61T)	450	520	610	780
Hardness, Durometer A (ASTM D676-59T)	90	90	89	88

Properties of ADIPRENE L 100 at Normal and Elevated Temperatures

	Measured at 24°C (75°F.)	Measured at 100°C (212°F.)	Measured at 121°C (250°F.)
100% modulus, MPa (psi) (ASTM D412-61T)	6.7 (975)	5.3 (775)	5.3 (775)
Tensile strength, MPa (psi) (ASTM D412-61T)	27.6 (4,000)	19.3 (2,800)	10.3 (1,500)
Elongation at break, % (ASTM D412-61T)	440	480	350
Hardness, Durometer A (ASTM D676-59T)	89	88	88

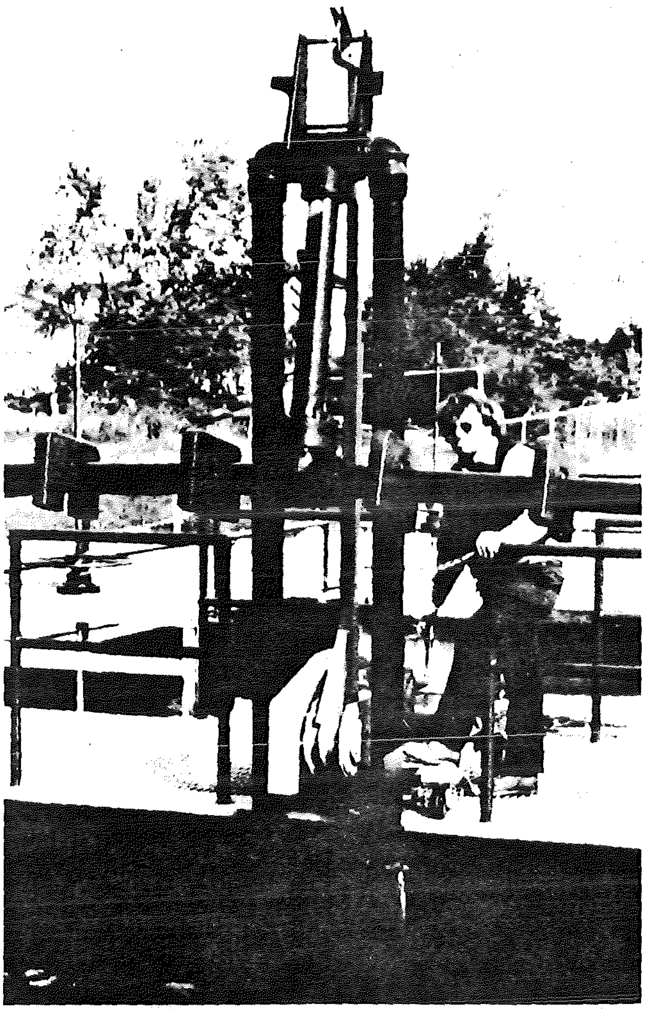
RESISTANCE TO AGING

Passage of time under static, room temperature conditions has little effect upon properly compounded products of ADIPRENE* urethane rubber. This statement can be substantiated by data on specimens stored at least fifteen years. Shelf aging is not a problem. Nor is prolonged use in normal service.

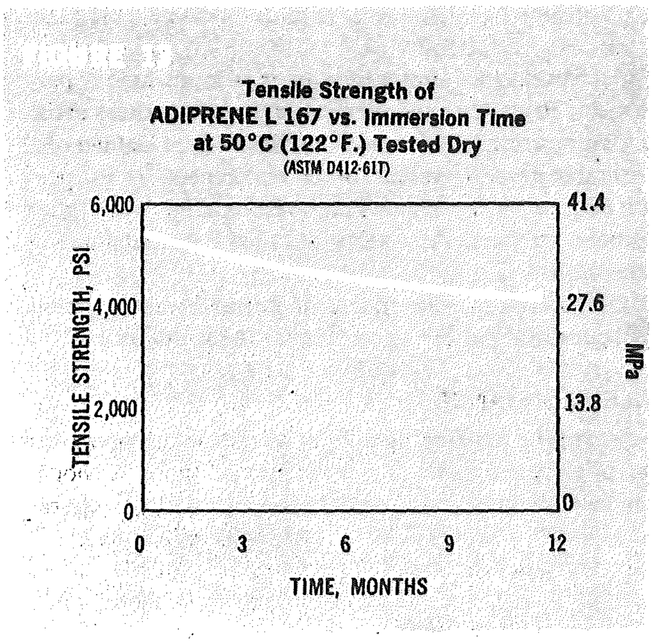
Introducing other factors, however, can accelerate deterioration. It is well known that increasing temperature will promote chemical changes in organic materials and, in ADIPRENE, this influence is reflected in progressive loss in physical properties. Heat aging effects on ADIPRENE are illustrated in Figure 11.

Dynamic forces or chemical agents acting upon a product over a period of time can also intensify the aging process. But in such multiple attacks the effects strictly due to aging may be so masked as to become unrecognizable. The influences of other environments are considered separately in this booklet.

*Reg. U.S. Pat. & Tm. Off.



ADIPRENE Replaces Iron Pipe Fittings On New Sludge Aeration Assembly



WATER RESISTANCE

ADIPRENE is resistant to the swelling and deteriorating effects of immersion in water and has excellent long-term stability in water at temperatures as high as 50°C (122°F.). The chart in Figure 13 shows that even after immersion in water for as long as one year at 50°C (122°F.), a typical compound retained 76 percent of its original strength.

The same degree of water resistance is exhibited in exposures where water is present in a mixture or an emulsion with oil. This excellent hydrolytic stability is characteristic of the specific chemical structure of the polymer. In this respect ADIPRENE is far superior to urethane polymers which have different chemical structures.

D. Tensile Creep and Recovery

Knowledge of the creep properties of engineering materials is important because of the correlation of this property to the dimensional stability of elastomer materials under prolonged loads. Also, the ability of the materials to recover from such deformation is important when they undergo low-frequency cyclic stress.

The sample chosen for the investigation of the creep and recovery behavior was 1,4-butanediol extended Multrathane F-242 system, formulated at 1.03 NCO/OH and prepared under normal conditions, as described in Tables 2, 4 and 6.The samples were ASTM Die D dumbbells died from standard test slabs. Creep and recovery data were observed at a stress level of 1000 psi. The sample was held under this stress for approximately 6000 hours, during which periodic measurements were taken; then, the specimen was permitted to relax for 970 hours, during which the recovery was periodically measured.

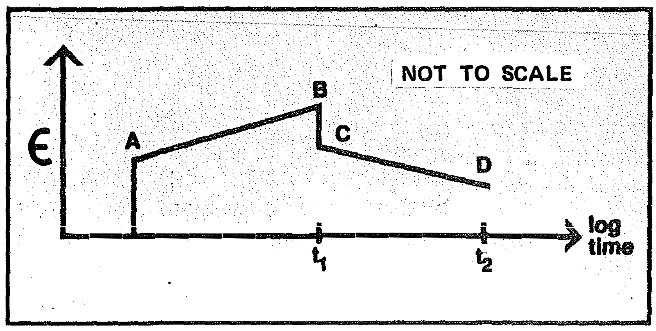
The stress is applied to the specimen and the instantaneous elongation "A" is reached. Under the sustained load for t_1 hours (6066), the sample had crept to "B", at which time the load was removed and the sample instantaneously recovered to elongation "C". After t_2 hours ($t_2-t_1=970$ hours) the sample had recovered to "D". Values for "A" through "D" are shown in Table 8.

Table 8-Tensile Creep and Recovery Data

Initial Stress Level, psi	Elongation at:			
	A	B	C	D
1000	230	280	170	23

More detailed information concerning the creep behavior of Multrathane systems is available from Mobay Chemical Corporation.

Figure 2
Diagram of Tensile Creep and Recovery



E. Electrical and Thermal

The ability of Multrathane elastomers to withstand physical abuse suggests utilization of these elastomers to help protect electrical components and assemblies from physical and/or thermal shock.

Tables 9 and 10 summarize some of the electrical and thermal properties of the Multrathane elastomers, and can be used for design engineering guidance in developing such applications.

Table 9-Electrical Properties

Property, 25°C	Durometer Hardness (Shore A)		
	60-65	80-85	90-95
Breakdown Voltage, volts/mil (Sample 80 mils thick)	530	450	525
Surface Resistance, ohm	4×10^{10}	5×10^{10}	1×1^{10}
After 24 hrs in water	3×10^{8}	9×10^{9}	1×10^{10}
Volume Resistance, ohm	9×10^{10}	5.6×10^{9}	3×10^{11}
After 4 days at 80% RH	1×10^{10}	5×10^{10}	2×10^{10}
Volume Resistivity, ohm-cm	2×10^{11}	2×10^{11}	3×10^{11}
Dielectric Constant,			
800 cycles	7.5	7.6	6.7
10^6 cycles	7.1	7.1	6.4
Loss Factor, tan.			
800 cycles	0.015	0.016	0.017
10^6 cyles	0.073	0.058	0.050

Table 10-Thermal Properties

	Durometer Hardness (Shore A-2)		
	60-65	80-85	90-95
Thermal conductivity			
kcal./m.hr°C	0.200	0.200	0.205
Btu-in./ft^2 hr°F	1.6	1.6	1.6
Linear Coefficient of Expanison $\times10^{-6}$/°C	145	200	174
Specific Heat, cal./°C/g	0.46	0.44	0.42

APPENDIX F

BASIS FOR URETHANE GROMMET-TYPE LEAD ENTRANCE ACCEPTABILITY CRITERIA IN TABLE 6-8

This appendix provides the background and references for the criteria recommended in Table 6-8. The paragraphs below reference the specific item number as listed in Table 6-8.

1.0 The grommet-type cable lead entrance has unique configuration requirements which must be defined.

1.1 The configuration for the grommet-type entry is based upon the original work described in Section 5 of the previous report entitled, "Innovations for Explosionproof Electrical Enclosures", submitted in April 1980.

1.2 Selection of the optimum taper angle was determined through empirical effort and should be adhered to closely. Therefore, this value is defined on Figure 6-2 as $22.5^{o} \pm 1^{o}$.

1.3 Dimension L1 is chosen on the basis of the cable diameter to be handled by the grommet assembly as well as to assure a minimum of 1/2 inch contact along the length of the cable by the grommet when in compression. Therefore, the minimum value for L1 is identified as 0.375".

1.4 Dimension D3 will normally be slightly less than dimension D2. D3 should not be any larger than D2 in order to assure that the grommet will not squeeze out of the stuffing box when compressed against the smallest diameter cable.

1.5 Identifying the maximum diametrical clearance between the nominal diameter of the cable outside jacket and the inside diameter of the grommet in the relaxed condition as 0.7 X L1 is slightly more conservative than the specific values given in Figure 5-6 of the Final Report. The 0.7 is chosen on the basis of the taper angle and L1 being identified in order to assure that the grommet can be squeezed tight against the cable for 1/2 inch of length.

Using this criteria, six cable entry sizes may accommodate cables with outside jacket diameters between 2.41 inches and 0.30 inches as follows:

Entry Size	D2 (inches)	Maximum Cable Dia. (inches)	Minimum Cable Dia. (inches)
A	2.44	2.43	1.96
B	2.00	1.99	1.56
C	1.58	1.57	1.19
D	1.20	1.19	.85
E	.86	.85	.56
F	.56	.55	.30

Cable entry sizes should be standardized for logistics considerations. The ranges listed above may be varied as long as they adhere to the 0.7 X L1 criteria.

1.6 The dimension L6 is important insofar as the minimum length is concerned. This precludes the grommet being pushed far enough through the stuffing box that it might come out of the back end and enlarge due to no longer being confined around the diameter. When this happened in earlier experiments, it was found that the grommet would then tend to lock in place rather than come free when the packing nut was removed.

1.7 Dimension D4 is related to L1, the taper angle, and D2. Specific values for the sample sizes tested were determined empirically. The factor of 0.4 X L1 fits closely to the empirically determined values.

1.8 Dimension L5 is chosen to assure a ratio of 4:1 between the length of the grommet and the wall thickness. This appears to be optimum insofar as accomplishing the compressive function when the packing nut tightens the grommet against the cable.

1.9 Thread engagement for at least 1/8" of length with the grommet in the relaxed condition is necessary because of the very coarse threads normally used.

1.10 The 1/8" clearance between the head of the packing nut and the shoulder of the stuffing box is a carry-over from existing practice.

2.0 This identifies the type of material and the requirement for test specimens.

2.1 The value of hardness between 75 and 85 on the Shore "A" scale was determined empirically in order to obtain the best combination of moldability, grip on the cable jacket, and the ability to release when the packing nut is removed.

2.2 This test on sample material is to assure that the grommet does not take a permanent set after an extended period of time.