INNOVATIONS FOR EXPLOSIONPROOF ELECTRICAL ENCLOSURES

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JEFFREY MINING MACHINERY DIVISION
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And

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R. J. GUNDERMAN

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Dresser Industries, Inc.
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Columbus, Ohio 43216

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16. Abstract (Limit: 200 words) Explosionproof electrical enclosures for coal mine face equipment have been of the same basic design for many years without significant change. Characteristics for potential improvement were investigated through interviews, visits to mines and studies. Improved safety, health and productivity were the goals.

Areas identified for improvement included rapid venting of pressure build-up due to an internal explosion, quick and easy entry or removal of cable entrances, and a quick and easy cover removal for rapid component access. Concepts were identified and evaluated, and the more promising devices were fabricated and tested.

Encouraging results from initial tests led to further design refinement and establishment of design guidelines. These design guidelines for a pressure vent and for an elastomeric grommet type cable entry are described along with the testing used.

An application for an experimental permit was requested from MSHA. After test and evaluation experimental permit #396 for evaluation in an underground coal mine was granted.

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FOREWORD

This report was prepared by the Jeffrey Mining Machinery Division, Dresser Industries, Inc., under USBM Contract Number HO 357107. 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 as Technical Project Officer. 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 1975 to October 1979. This report was submitted by the author in April 1980.

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. Principal contributors to this report at Booz-Allan & Hamilton also included Ani D. Chitaley, Ph.D. and John D. Crabtree.

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1.0 INTRODUCTION

Requirements for explosionproof electrical enclosures are defined in Part 18 of the Code of Federal Regulations (CFR). 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 some 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 electrical enclosures for the underground coal mine. Thus, this program was awarded by the U. S. Bureau of Mines for the purpose of identifying innovations to the design of explosion-proof electrical enclosures.

The program approach, as described in Section 2.0, started with identification of the shortcomings of present enclosures and collecting ideas that might be used for new concepts. The broad objectives were to ensure safety and to improve production. These may be translated into more specific objectives such as simplifying access for maintenance, improved assurance of permissibility, and techniques for cable and cover changes that require less time. In addition to the physical aspects of working with these enclosures, the psychological aspects that influence the workers performance were a consideration.

Many different concepts for improvement were identified and considered. One reason for having the enclosures so heavy and having the tight flame paths is to contain the build up of pressure and heat that occurs during an explosion internal to the enclosure without propagating it outside. Pressure venting devices (capable of large gas flow rates) which preclude internal pressure build up due to any internal ignition 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 re-enter a cable. A suitable new entry should maintain a permissible seal indefinitely, thus eliminating any potential problem of 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 of these types were identified as described in Section 3.0 and the more promising concepts were implemented in hardware for evaluation. Figure 1-1 is a mock-up showing two quick access fasteners on the cover, an innovative cable entry and a pressure vent assembly (on the left side of the box).

Demonstration of innovative devices in an underground coal mine was in the original plan. Early in the Program the decision was made to install the innovative devices on electrical enclosures that would be the same as on an existing continuous mining machine. Two new enclosures, the same as used on the continuous mining machine, were obtained and modified with 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 Admininstration (MSHA). Results of these tests were favorable, but they did indicate 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.

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. This hardware is illustrated in Figure 1-2. However, delays in obtaining the necessary approvals from MSHA precluded conducting this test in time to be contained in this report.

Further efforts were devoted to identifying guidelines for the application of the pressure vents and the cable entries. These developments are described in Sections 4.0 and 5.0 respectively.

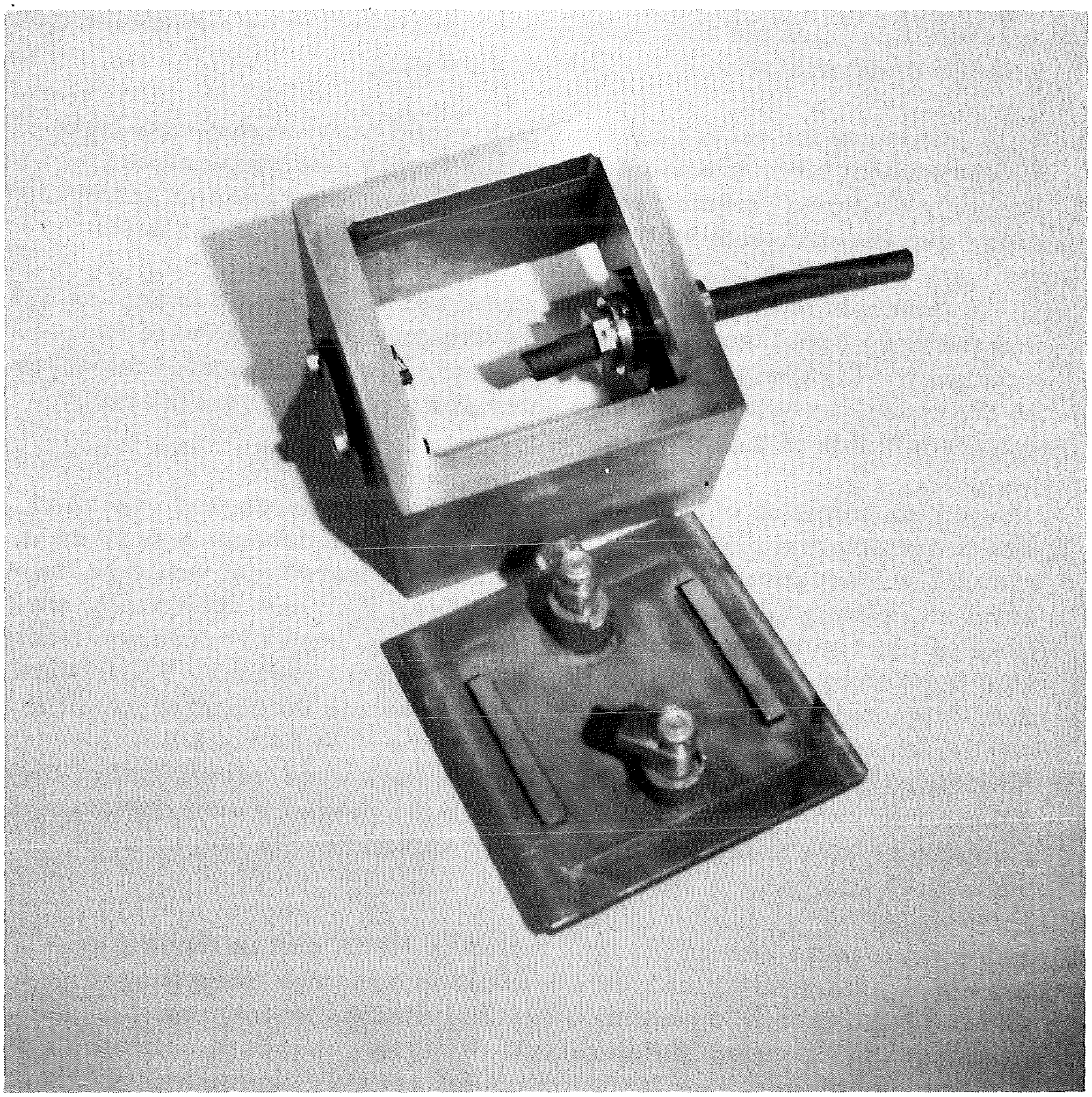

Figure 1-1. Mockup of Innovative Devices

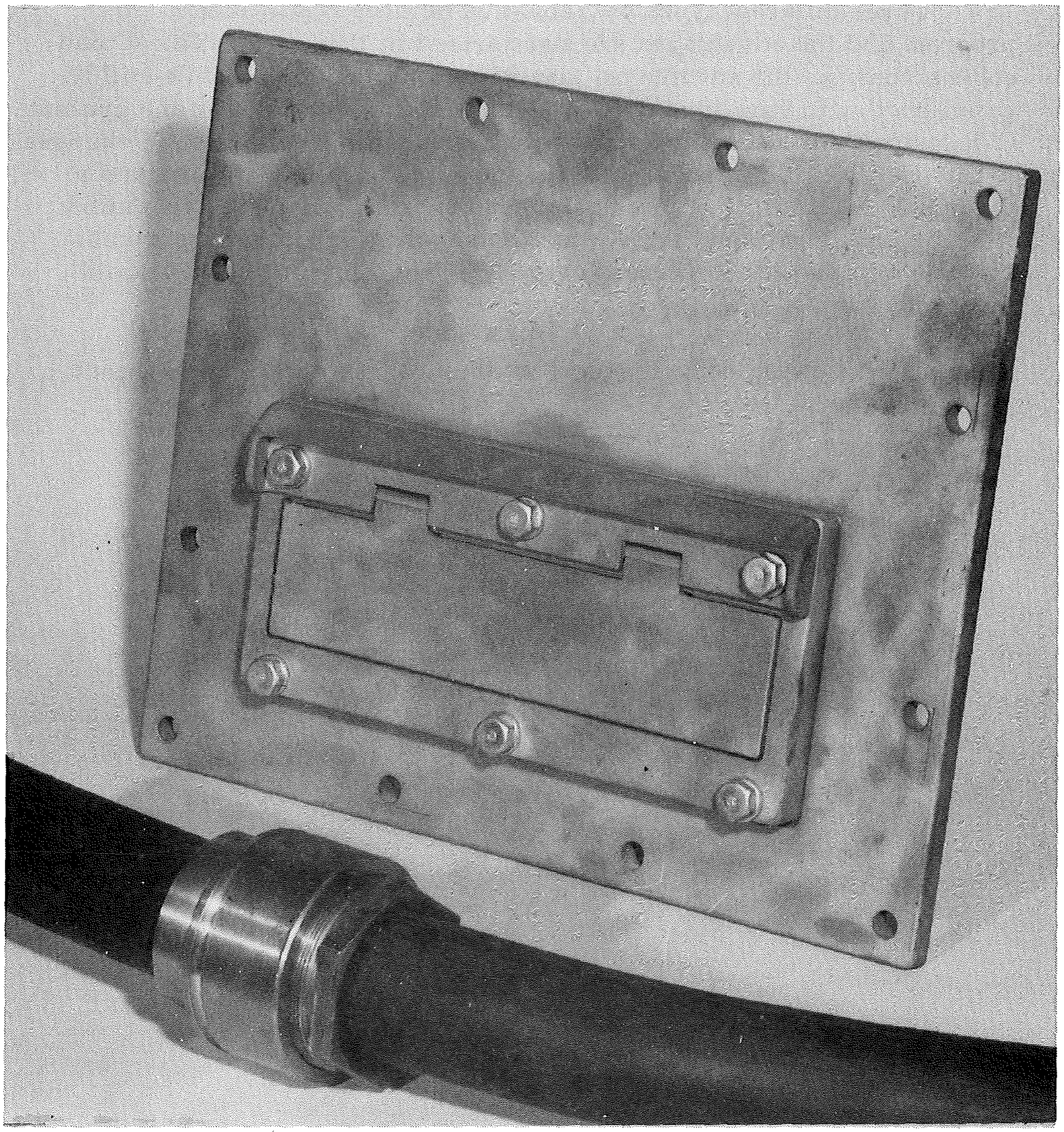

Figure 1-2. Pressure Vent and Elastomeric Cable Entry for In-Mine Demonstration

Three different types of innovative devices resulted from this program and the advantages are summarized in Table 1-1. The second column contains the advantages that may now be obtained while still in compliance with Part 18 of the CFR. There is no provision in the present CFR for pressure venting for the type described herein, so some changes to this CFR would be required to realize those advantages contained in Column 3 of Table 1-1. This is also true for the innovative cable entry wherein only 4 grommet sizes would be required for the range of cable sizes as opposed to the present very stringent tolerance between cable size and grommet size.

The following section describes the program technical approach.

TABLE 1-1 - Summary of advantages with the innovative devices

Device Type	Present CFR	With CFR Revision
Pressure Vent	May be only way a very large enclosure can pass pressure 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 Entry	Simplified entering and removing cable.	Typically only four grommet sizes required for range of cable sizes normally existing on a mining machine.
	Does not normally require any material replacement.	
	Better assurance of a uniform and long lasting seal.	
Quick Access Fastener	Simplifies cover removal and replacement on large enclosures.	Cover fastener spacing may be increased since load is distributed over larger area of cover.

2.0 TECHNICAL APPROACH

The explosionproof enclosures used in coal mines are thick walled metal boxes. This construction enables the enclosures to withstand the high internal pressures generated by explosions and the physical abuse inherent in the mining environment. The juncture of the enclosure body and the cover requires precisely fitted metal flanges. During an explosion these flanges act as a heat exchanger to quench the exiting gases to non-hazardous temperatures. Most enclosures rely on a large number of bolts through the flange to hold the cover in place. When properly tightened, these bolts maintain the required flange gap clearance. Electrical cables enter the enclosures through asbestos package fittings. Emission of flame or dangerously hot gases at this location is prevented by compressing the packing material against the cable.

Increased attention to the inspection and maintenance of safety equipment in recent years has indicated that existing explosionproof enclosure designs have some major shortcomings:

- There are many permissibility violations because of the difficulties in maintaining the required close tolerance fits at the flange paths. Some of these violations may go unidentified.

- Access to much of the current hardware is poor, making it difficult for even a sincere mechanic to achieve a permissible condition under face maintenance conditions.

- The hardware requires frequent maintenance to cope with the wear and tear due to the underground environment.

These shortcomings can lead to the possible compromising of personnel safety because the equipment is operated in a non-permissible condition. There may also be significant economic penalties. The enclosures require frequent maintenance and inspection and repairs usually take a long time to complete.

A third major source of problems stems from the difficutly in manufacturing the equipment. Most enclosures are steel fabrications or castings. Practical cost limitations of the production process makes it difficult to maintain close tolerances. However, the current flame path requirements necessitate close tolerance fits to within 0.004 inch. To meet these requirements, it is necessary to do precision grinding and machining on the flanges. Sometimes parts are even machined to fit and this limits part interchangeability. These difficulties increase the manufacturing cost of the explosionproof electrical hardware.

This section summarizes the major technical steps which were completed during this program. The details of the program methodology are presented in the following sections.

2.1 Problem Identification

Effort was focused on developing a firsthand in-depth understanding of the current problems with the electrical enclosures. Several coal mines were visited to observe typical equipment usage, maintenance and inspection procedures and the environment in which repairs are typically performed. The problems were discussed with mine management, maintenance and face personnel. Actual repair operations were observed at the face and in the mine shop. Additional key information was obtained from the Bureau of Mines personnel, Mine Safety and Health Administration inspectors and technical staff, manufacturers of electrical enclosures and hardware and other Bureau of Mines contractors. Supplementary data was obtained from a variety of published data sources.

The problems were arranged in terms of the hardware item most heavily impaired (e.g., cable entry, enclosure cover, and the like). These were subsequently ranked in terms of their significance to the enclosures' permissibility and safety. This is further discussed in Section 3.0.

2.2 Concept Definition

This effort was focused on developing practical solutions to the most significant problems with explosionproof electrical enclosures. First, a list of general conceptual approaches was developed for solving each of the critical problems. These general alternatives were evaluated in terms of the number of problems they helped to alleviate, their estimated feasibility to meet the functional requirements and their overall suitability for the mining applications. A variety of issues were considered in developing the conceptual approaches and these included techniques used in other countries recent advancements in relevant technologies and innovations in other facets of electrical hardware design [1].

Five innovative approaches were selected for more detailed analysis and these were quick access covers, pressure vents, elastomeric cable entries, light weight construction and continuous flange gap monitoring. A range of hardware alternatives was developed for each of these general conceptual approaches. These hardware concepts were further refined and evaluated to determine which offered the most advantages to the mining industry.

2.3 Hardware Implementation

Three of the concepts were subsequently selected for refinement and implementation. These were the quick access covers, pressure vents and elastomeric cable entries. The strategy was to incorporate these concepts into otherwise conventional explosionproof electrical enclosures. This would facilitate obtaining the required approvals and performing the planned in-mine demonstration. As a result, the following two enclosures were modified:

- The one half cubic foot connection box.
- The 14 cubic feet control case.

The enclosures were equipped with two types of quick access covers, modularized pressure vents and innovative cable entries. The design was completed and a set of detailed drawings was made suitable for part fabrication and submission to MSHA for their approval. These enclosures were subsequently fabricated as per print. In addition to the enclosures, a variety of desk top models were fabricated to aid in communicating the various innovative features of the hardware. Figure 2-1 is a photograph of the innovative hardware which incorporated the new concepts.

2.4 Design Verification

Extensive laboratory tests were performed on these enclosures to evaluate the designs. First the hardware was evaluated to insure compliance with the dimensional and flame path requirements of CFR where these were applicable. Then the quick access covers and elastomeric cable entries were exercised several times to evaluate their overall performance, durability and handling characteristics.

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1 Literature sources have been listed in the Bibliography given in Appendix B.

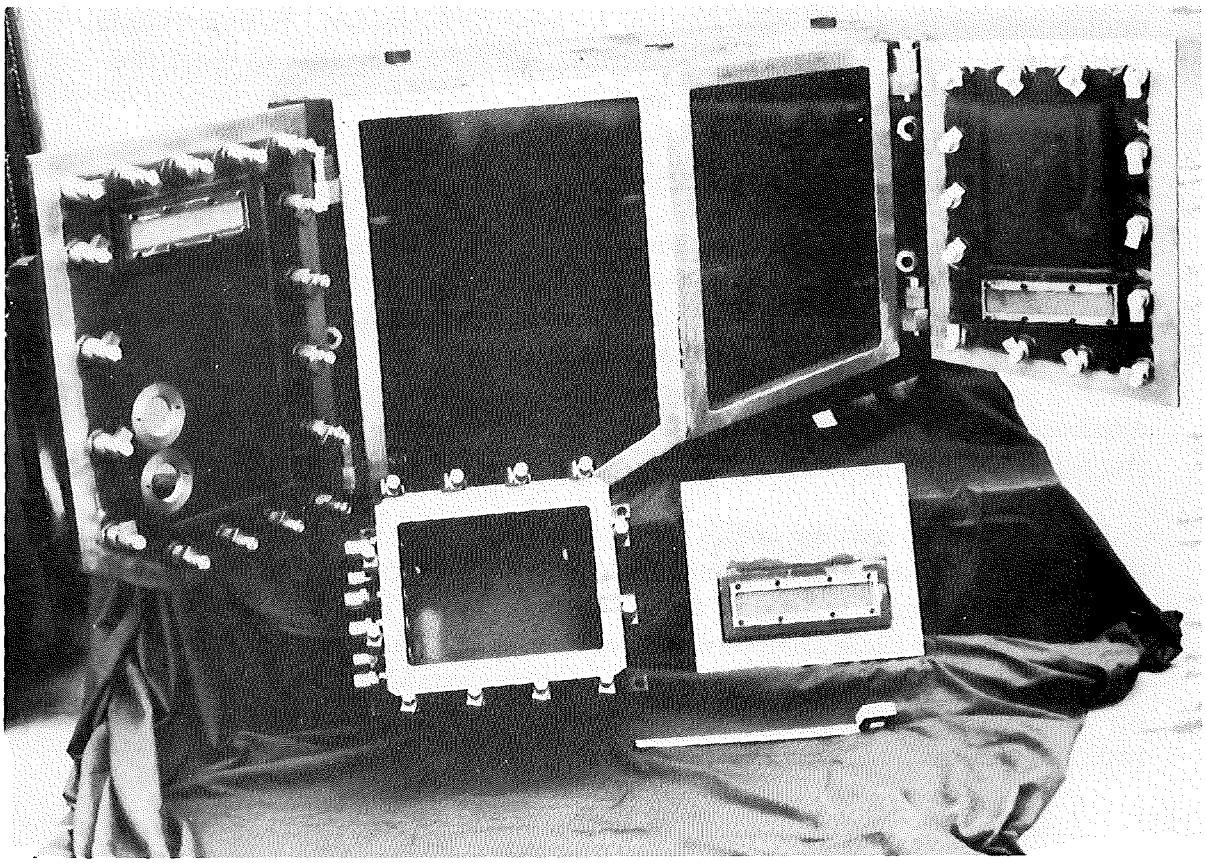

Figure 2-1. Composite Picture of Quick Access Fasteners and Pressure Vents on Enclosures Ready for Explosion Testing

In addition, a series of explosion tests was performed on both enclosures at the MSHA test facility located in Bruceton, Pennsylvania. These tests proved that the innovative hardware was able to meet the explosion test requirements of the CFR.

2.5 Underground Demonstration

Approval was requested from MSHA for the two enclosures containing the innovative devices to be substituted for existing enclosures on a Jeffrey continuous mining machine. These enclosures and all devices within them are identical to existing enclosures and components, except for the addition of the innovative devices as noted earlier. After the explosion tests conducted at Bruceton for engineering verification purposes, the decision was made that only the connection box be tested at MSHA.

Explosion testing of the connection box with the innovative entries, quick access fasteners and pressure vent was conducted by MSHA in their formal test gallery in August 1976. The pressure vent assembly was replaced by a flat plate in order to adequately test the cable entries and quick access fasteners under pressure since there would be minimal pressure build up within the enclosures when the vent is present. These explosion tests indicate the innovative devices are acceptable.

Engineering verification tests on the large control case at the Bruceton explosion test chamber indicated that further development on the pressure vent was needed for larger enclosures. The larger enclosures must vent much larger quantities of hot gases as a result of the internal explosion. Test data suggested that the required area of vent was related to the enclosure volume. The need for further engineering development was obvious. Hence, only the smaller connection box was submitted to MSHA for test and approval.

Placement of these innovative devices on only a connection box underground would allow experience on the pressure vent and the innovative cable entries. As it turned out, there was considerable delay in obtaining the approvals from MSHA and further engineering development led to a different configuration for the cable entries. Consequently, the underground in-mine demonstration was not included in the work reported in this document.

2.6 Guideline Development

Because of the potential opportunities suggested by the innovative concepts, it was agreed that these concepts be studied in substantially more detail. Pressure venting using metal foam seemed highly attractive and offered many potential benefits to the industry. However, large enclosures required very large vents if the metal foam alone were used. It was practically impossible to package and protect such large vents on electrical enclosures. Therefore, techniques had to be developed for reducing the size of pressure vents. Many alternatives were considered and tested. However, the most practical and acceptable solution was to use layers of stainless steel screening on the inside surface of the metal foam material. Once this issue was resolved, specific application and design guidelines were developed to determine for any enclosure the appropriate number of screen layers required as well as the size of the vent.

One of the potential benefits initially hypothesized for pressure venting was that the vents might allow increases in flange gaps without jeopardizing safety. This hypothesis was demonstrated through extensive explosion testing and analysis. In addition, specific design guidelines were developed which established the appropriate relationship between the pressure vent design and appropriate flange gap spacings.

Preliminary testing and verification indicated that the elastomeric cable entry approach offered significant benefits over asbestos cable entries in terms of the speed and ease of operation. However, it initially appeared that a large number of different grommet sizes would be required to accommodate the range of cable size used on the face equipment, causing a substantial inventory problem for both mine operators and equipment manufacturers. Through further analysis, material selection design refinements and testing, it was demonstrated that only four grommets were necessary to cover all cable sizes from 0.39 inches to 2.11 inches. Detailed guidelines were developed for designing the grommet and selecting the proper grommet for each application.

The general methodology for developing both the cable entry and pressure vent guidelines was the same. First, acceptable performance criteria had to be identified. The specific requirements of the CFR were used where applicable. When existing regulations were not applicable, the performance of conventional hardware was measured and this became the performance standard.

Substantial testing and analysis of the results led to the establishment of the criteria. Once the performance criteria were established, extensive testing was used to determine the fundamental relationships between the dimensional and performance parameters. These parametric relationships were then used to develop the design guidelines.

Adequacy of the quick access fasteners was established in the explosion tests conducted at the Bruceton facility and no further development appeared warranted. Also, mechanical devices of this nature may be more readily analyzed and there was less question about their acceptability in the underground mine environment. These fasteners had been installed on the large control case since the advantages are with the larger, heavier covers. When it became necessary to postpone test of the larger control case there was no further work with the quick access fasteners.

New concept identification and development are described in the following section. Significant further development took place on the pressure vent and the cable entry assembly. This is described in Sections 4.0 and 5.0.

3.0 CONCEPT DEVELOPMENT

Four major areas for improvement were identified in existing explosionproof electrical enclosures. These areas are:

- Access cover
- Cable entry
- Moisture entry
- Enclosure weight.

Table 3-1 presents a summary of the identified improvement areas. These areas were closely examined in relation to the difficulties encountered in achieving permissibility of the enclosures and in their in-mine maintenance. A variety of specific conceptual approaches were identified in each area needing improvement. Detailed hardware concepts were then developed for the most promising of these conceptual approaches. These individual hardware concepts were analyzed in detail and the three most promising were selected for implementation. The selected concepts addressed the maximum number of specific improvement opportunities. The balance of this chapter outlines the improvement areas and the specific improvement approaches. It also describes the major improvement concepts which were selected for demonstration through actual design and through hardware implementation.

3.1 Improvement Areas

Field interviewing and on-site observation indicated several major aspects of explosionproof enclosures which warranted improved hardware design. These generally manifest themselves in the form of permissibility violations and maintenance difficulties. The specific areas are discussed in the following subsections.

3.1.1 Access Cover

Access covers of large enclosures aboard mobile equipment present significant improvement opportunities. Cover removal is complicated because a large number of fasteners must be removed and because the covers are often heavy. Frequently, cover removal requires two men working with or without lifting devices. In addition, large enclosures tend to be less well protected and, therefore, are more vulnerable to damage by collisions and roof falls.

Some enclosure covers in the United States are aluminum for lighter weight but corrosion of the aluminum is a problem. Also, regulations in some foreign countries prohibit aluminum in underground coal mines.

- The permanent set of the asbestos, powdering due to vibrations and compaction due to moisture may lead to non-permissibility of the cable entry after some time period.

- An apparently proper entry may actually be non-permissible because of insufficient length of asbestos, voids left between cut lengths of the cord or complete omission or substitution of the proper packing.

In addition, cable entry maintenance is difficult and time consuming due to difficulties such as:

- Breaking of gland lock screws during removal or tightening.

- Forcing of gland nut required to compress a large inital volume of asbestos into the stuffing box of the cable entry.

- Cross threading of gland nuts during their tightening.

Therefore, the current cable entry design could be improved to make these devices more suitable for mining applications.

3.1.3 Moisture Entry

Recent changes in mining procedures have led to the increased and widespread use of water. The equipment is frequently wet because health regulations require that the mine face be continually sprayed during the cutting operations. Also safety regulations require that the equipment be hosed down frequently to remove coal dust build-up. There are several mechanisms by which moisture might enter an enclosure:

- Water seeps into the enclosure through flange gaps and clearances for slip fit cable entries and access covers.

- Moisture is drawn into the enclosure during cooling to ambient temperature from its normal operating temperatures.

- Moisture remains entrapped because the breathers clog or are inadequate.

This moisture might affect the reliability of the electrical equipment inside the enclosure. In addition, the resulting corrosion of flanges and fasteners tends to make maintenance more difficult.

3.1.4 Enclosure Weight

Present mine safety regulations require that explosionproof electrical enclosures withstand 150 psig internal pressure. This requirement stems from the fact that explosive pressures sometimes approach 107 psig and adequate margin is desired for factors such as pressure piling. Moreover, enclosures must be rugged enough to endure the abuse inherent in the coal mine environment. The conventional way to meet these requirements is to cast or fabricate the enclosure with thick metal walls. For many applications this technique is not only economical but also quite satisfactory. However, light weight construction is perferred for some uses including large enclosure covers and enclosures for man-carry applications. For very large enclosures increased wall thickness and weight become necessary in order to withstand the large explosive pressure peak. Therefore, the excessive weight of conventional enclosures and their covers often presents a substantial hardship to mine personnel.

3.2 Potential Improvement Concepts

A wide variety of general conceptual approaches were identified for improving current explosionproof enclosure designs. These are summarized in Table 3-2. These were the result of a review of world-wide literature, in-depth interviews with knowledgable industry personnel and creative efforts of the project team. Of these general approaches, three were rated as having the best potential for resulting in significant improvements in explosionproof electrical enclosures:

- Quick access covers.
- Elastomeric cable entries.
- Pressure vents.

Detailed hardware concepts were developed in each of these areas. These concepts and the resultant hardware are discussed in the following subsections.

TABLE 3-2. - Conceptual approaches

Approach	Major advantages	Conditions improved	Comments
• Quick access cover (A device which allows the enclosure cover to be removed and replaced in a shorter time).	• Reduced time required for cover removal and replacement.	• Man-sensitivity of flange gap permissibility. • Long cover removal/replacement time • Difficulty in removing threaded inspection covers.	• Specific designs may alleviate other problems. - Effects of dirt entrapped in flange. - Loss of fasteners and small parts. - Broken flange fasteners. - Bolt head abrasion. • Quick access covers are more effective and justifiable for larger covers due to greater flange area and number of fasteners required.
• Hinges	• Reduces occurrence of placing cover on mine floor during repair operation. • Alleviates the requirement for man handling the heavy cover.	• Flange gap is sensitive to proper manual tightening. • Cover Weight • Reduced dirt entrapment in flange gap. • Reduced possibility of damaged flanges. • Reduced probability of broken fasteners.	• Designs should allow for easy cover removal under mine conditions. • Required on large covers but not on small light weight covers. • Some manufacturers currently use hinges on explosion proof enclosures.

TABLE 3-2. - Conceptual approaches (continued)

Approach	Major Advantages	Conditions Improved	Comments
• Recessed head fasteners • Faster protector bars	• Protects fastener heads from impact and abrasion.	• Reduced possibility of flange fasteners loosening during machine operation. • Bolt head abrasion.	• Some equipment manufacturers currently provide this feature.
• Light weight construction	• Makes enclosures and covers less heavy to handle.	• Man-sensitivity of flange gap permissibility. • Cover weight.	• Reduced enclosure strength may be justifiable for certain protected applications. • Lighter weight enclosures may allow greater portability for electrical equipment in the mines. • Lighter weight covers are very desirable for large enclosures.
• Flange gap Monitor (A device which continuously monitors the flange gap spacing and indicates when it exceeds the required limits)	• State of flange gap permissibility is always known.	• Time dependence of flange gap permissibility • Effects of loose flange fasteners.	• The development of a satisfactory flange gap monitor presents a formidable challenge. • Specific designs may reduce moisture entry problems if material can be made into a gasket. • The concept improves the quality of inspection but does not offer any means of achieving permissibility.
• Corrosion resistant flange materials	• Flanges would not corrode and pit	• Time dependence of flange gap permissibility • Flange corrosion.	• This concept is current technology and could be implemented on an as required basis.

TAB.E 3-2. - Conceptual approaches (continued)

Approach	Major Advantages	Conditions Improved	Comments
• Captive fasteners	• Fasteners would not be lost during maintenance operations.	• Man-sensitivity of flange-gap permissibility. • Long cover removal/ replacement time. • Lost fasteners.	• This concept is current technology and could be implemented on an as required basis.
• Self locking Bolts (Use inserts or distorted threads of non-standard head design to accomplish locking)	• Fasteners resist loosening during machine operation.	• Time dependence of flange gap permissibility.	• The need for special fasteners may create undesirable inventory and supply problems.
• Captive packing cable entry	• Reusable packing material is not removed for cable	• Man-sensitivity of cable entry permissibility. • Effects of improper packing. • Long cable entry time. • Difficulty in replacing gland nut. • Difficulty in replacing gland nut.	• Proper selection of materials may alleviate other problems. - Time dependence of cable entry permissibility if material does deteriorate. - Water entry through packing if material excludes water. • Compatible with both slip-fit and cable entries. - Water entry through packing if material excludes water. • Compatible with both slip-fit and cable entries.

TABLE 3-2. - Conceptual approaches (continued)

Approach	Major Advantages	Conditions Improved	Comments
• Pin and Socket Connectors	• No man adjustable flame paths between inside and outside of enclosure.	• Man-sensitivity of cable entry permissibility. • Time dependence of cable entry permissibility. • Effects of improper packing. • Long cable entry time. • Difficulty in replacing gland nut.	• Connector would require and explosion proof body. • Device would require pilot circuit to prevent disconnecting plug under electrical load.
• Seal Wire. • Glad Nut Lock Bar • High Strength Corrosion Resistant Lock Screw	• Provide easily removed methods of locking the gland nut.	• Broken gland nut lock screws. • Long cable entry time.	• All concepts are compatible with slip-fit and threaded cable entries except that lock bars may not work with some slip-fit designs. • All concepts are current technology used by manufacturers of mining equipment.
• Elastometric packing material.	• Will Not Deteriorate Under Vibratory loading to open up flame path.	• Time dependence of cable entry permissibility. • Moisture entry through packing.	• Could be incorporated into captive seal cable entries to yield the above mentioned benefits. • Material must meet MSHA flamability requirements.

TABLE 3-3 - Evaluation criteria for quick access cover concepts

- Fast cover replacement.
- Scraping of exposed fastners.
- Manufacturing complexity.
- Captive parts.
- Ease of cleaning flange.
- Effect of corrosion or dirt on operation of mechanism.
- Ease of repairs in the mine.
- Necessity of close tolerance machining.
- Durability in the mine environment.
- Compatibility with all enclosure configurations.
- Ease of fabrication.
- Minimized cover weight.
- Necessity of special fasteners.
- Resistance to accumulation of dirt when cover is removed.
- Projection beyond enclosure contour.

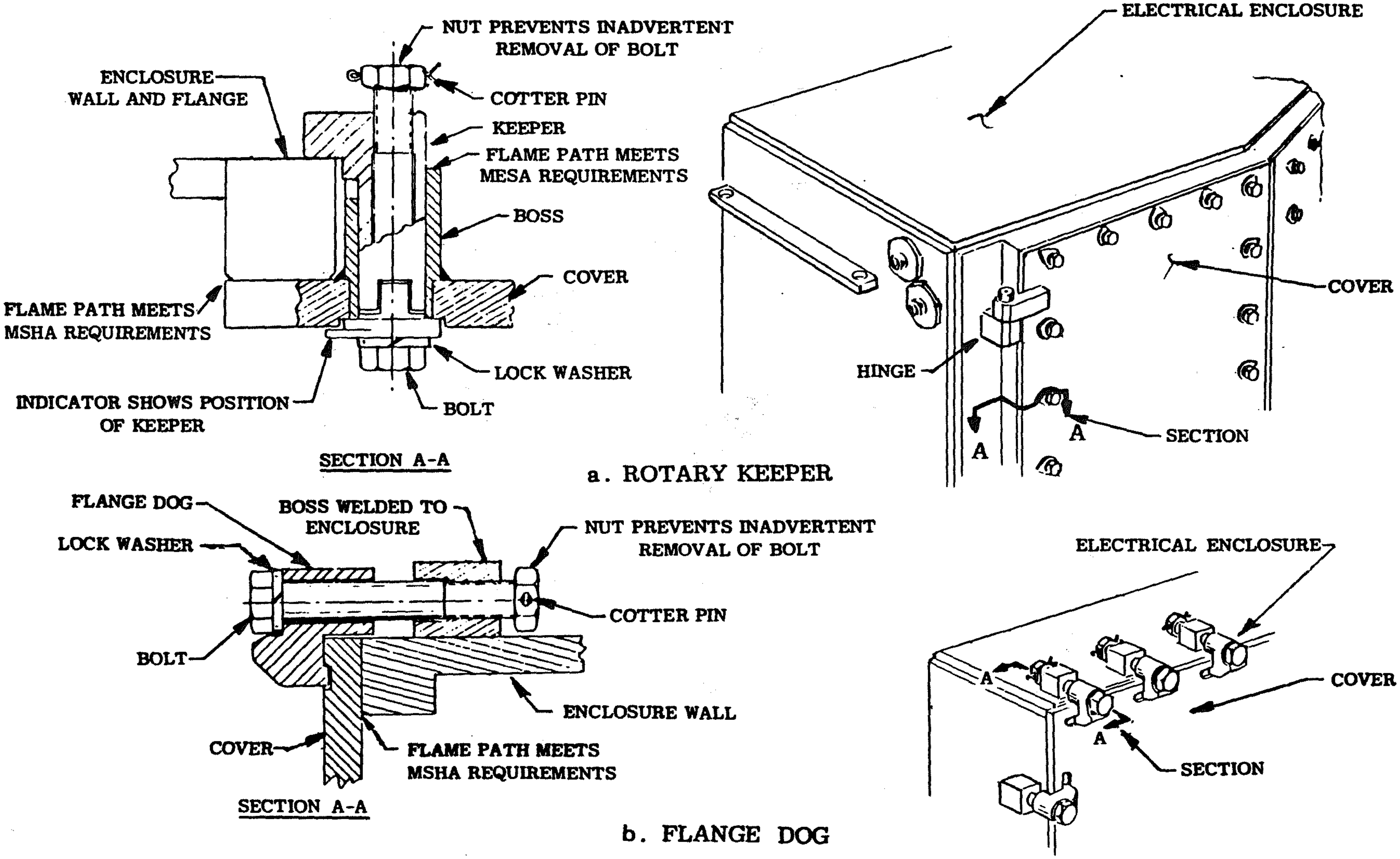

FIGURE 3-1. - Quick access cover concepts selected for demonstration.

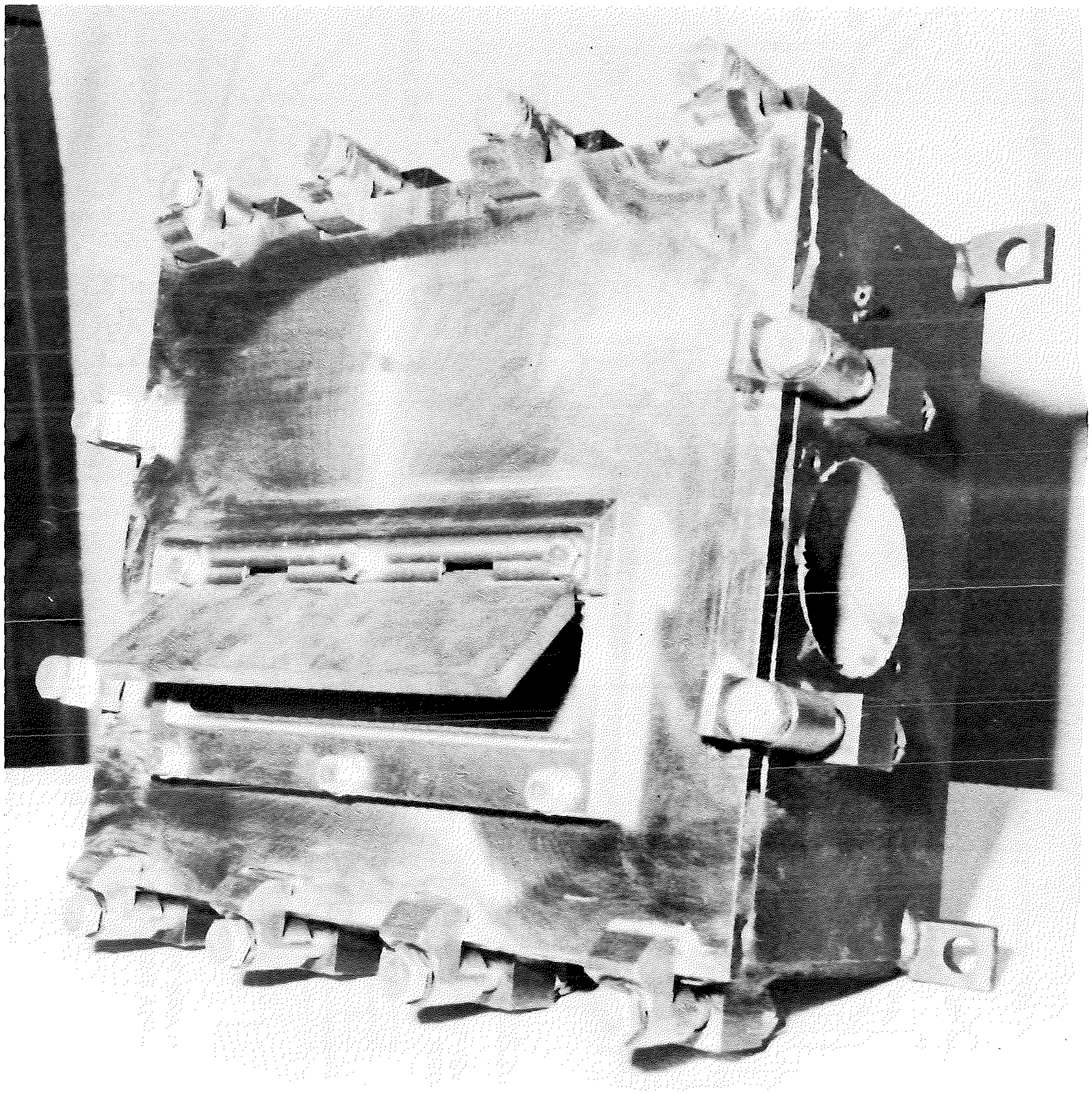

Figure 3-2. Flange Dog Type Fasteners and Pressure Vent on Trailing Cable Connection Box

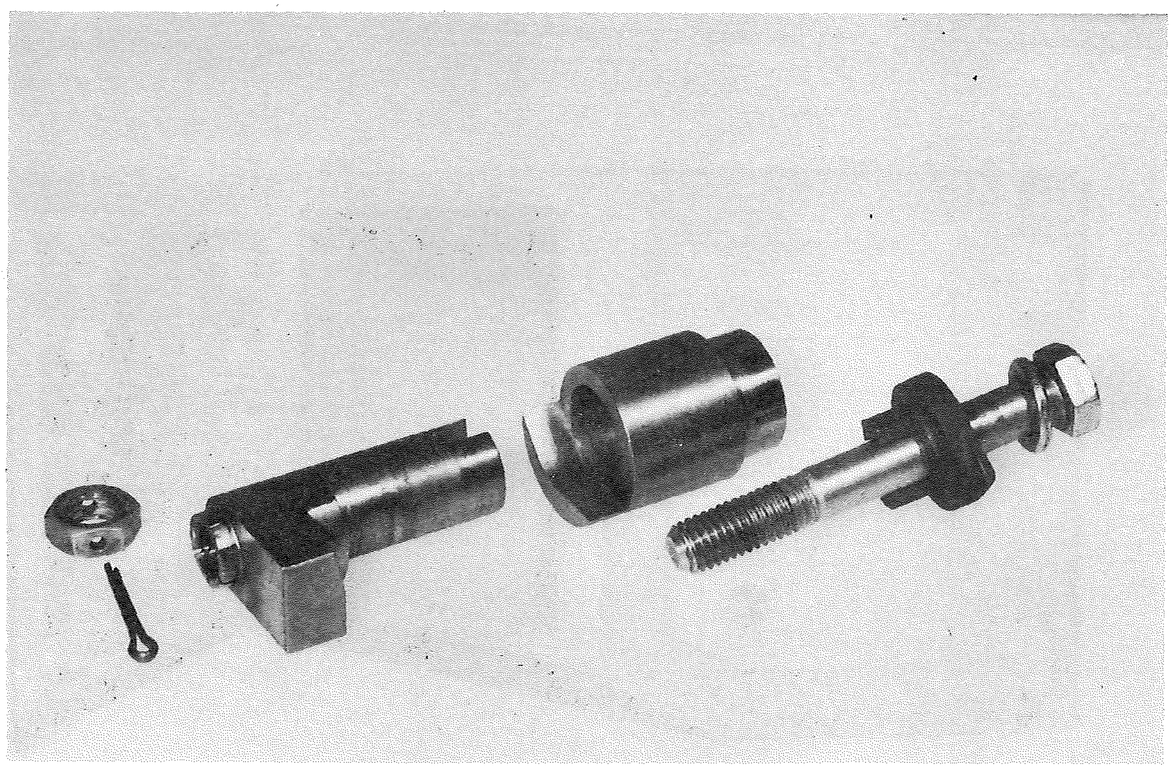

Figure 3-3. Internal Rotary Keeper Parts for Quick Access Covers

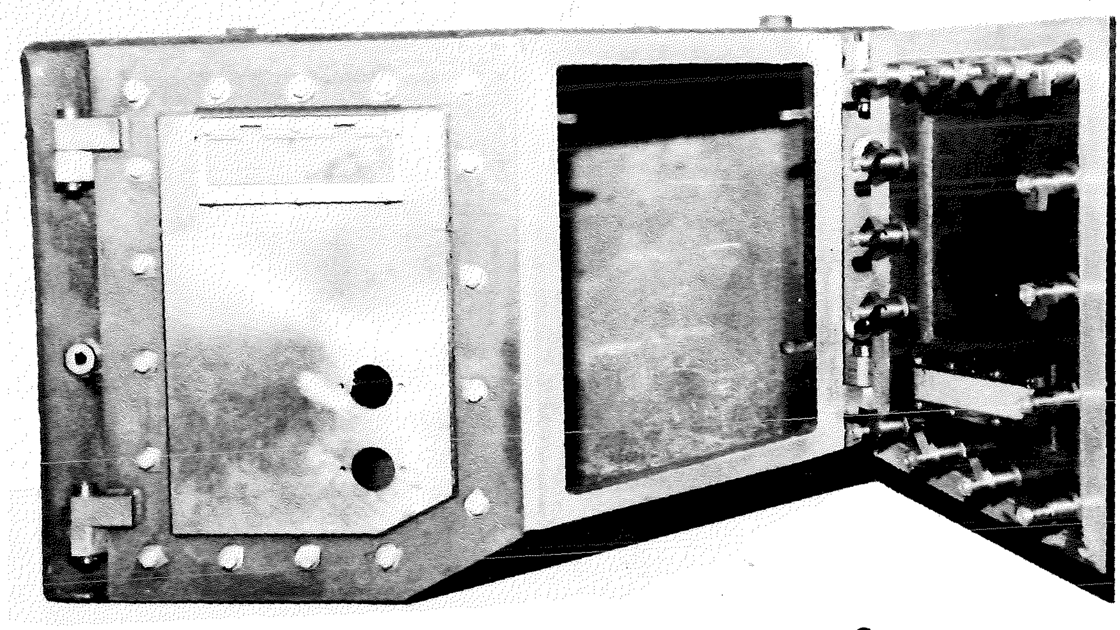

Figure 3-4. Control Case with Rotary Keepers for Quick Access Covers

- The flange gap is easily measured with a feeler gauge around the flange periphery. This is suitable for the current flange gap inspection procedures.

- The dogs or keepers swing away and remain in an open position thus affording easy cover removal.

- The dogs or keepers support the weight of the cover and assist in positioning the cover during the cover closing operation.

3.2.2 Elastomeric Cable Entries

A large number of cable entry concepts were developed to address the improvement opportunities identified earlier. Appendix D illustrates these alternative concepts. Next, these concepts were ranked on the basis of evaluation criteria. These criteria are listed in Table 3-4. Based on the evaluation, a design involving a neoprene grommet and a plastic chuck was initally selected for implementation. This concept is shown in Figure 3-5 and illustrated in Appendix D, Figure D-1. However, preliminary testing demonstrated that this concept did not provide the hoped for advantages.

- The split chuck and elastomeric grommet constitute two assembly parts. A design with only one part would increase the ease of handling.

- The locking taper on the grommet made disassembly difficult. A non-locking taper design would be preferable.

- The plastic split chuck and the soft grommet necessary for proper assembly acquired a permanent set with time. Designs which avoid the permanent set would be preferable.

Based on these improvement needs, several alternative grommet designs were fabricated and tested. The finally selected concept eliminated the split chuck and incorporated an improved taper in the cable entry body. This elastomeric seal cable entry concept is illustrated in Figure 3-6 and a photograph of the hardware is given in Figure 3-7. The concept offers several advantages including the following:

TABLE 3-4. - Evaluation criteria for cable entry concepts.

- Minimum cable entry time.
- Reasonable repeat use of packing.
- Replacement of packing without complete removal of cable.
- Packing allows more cable to be pulled into the enclosure during repairs.
- Repairs needed for special maintenance procedure.
- Need for mechanic to adjust packing size during installation.
- One size packing fits many cable diameters.
- Minimum overall cable entry size.
- Minimum developmental risk.
- Minimum inventory problems.
- Seal reliability.
- Clamping reliability.
- Materials comply with fire and toxicity requirements

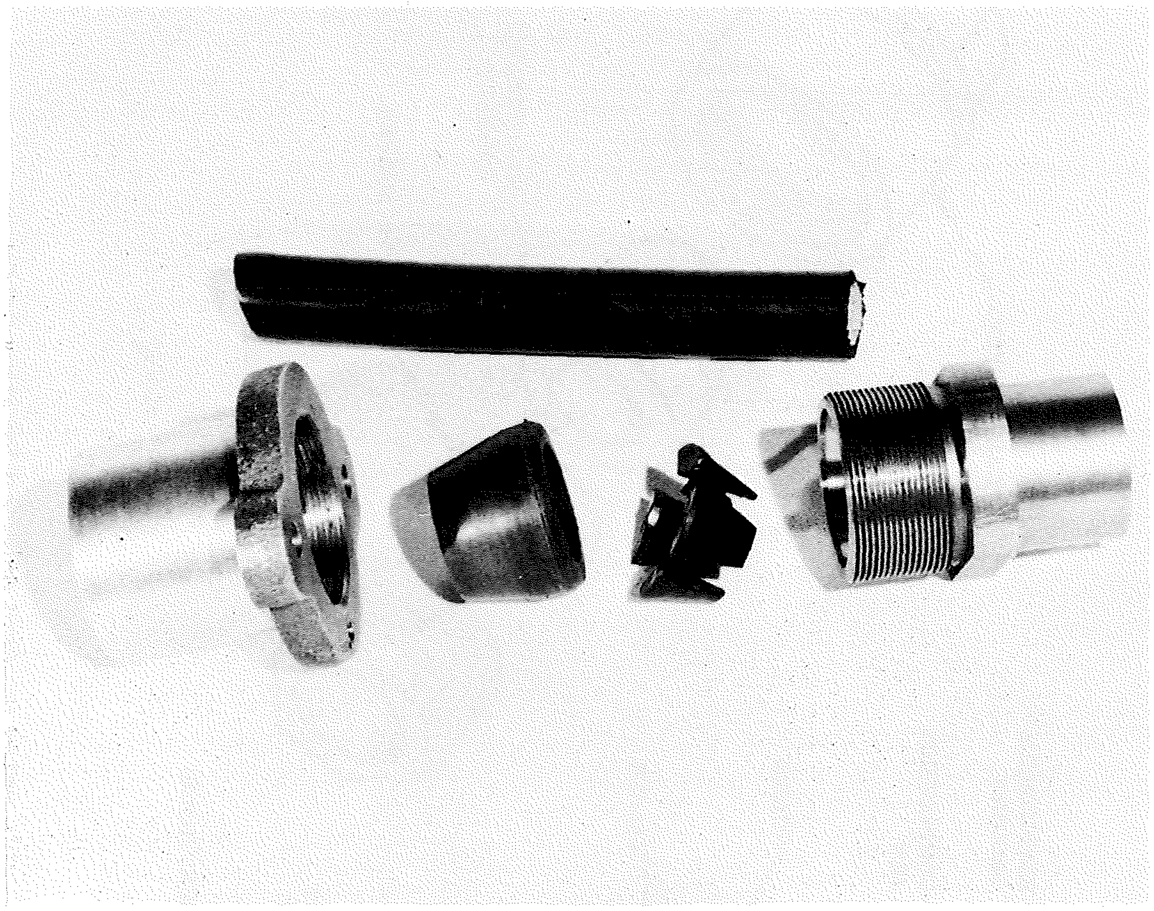

Figure 3-5. Cable Entry with Neoprene Grommet and Plastic Chuck

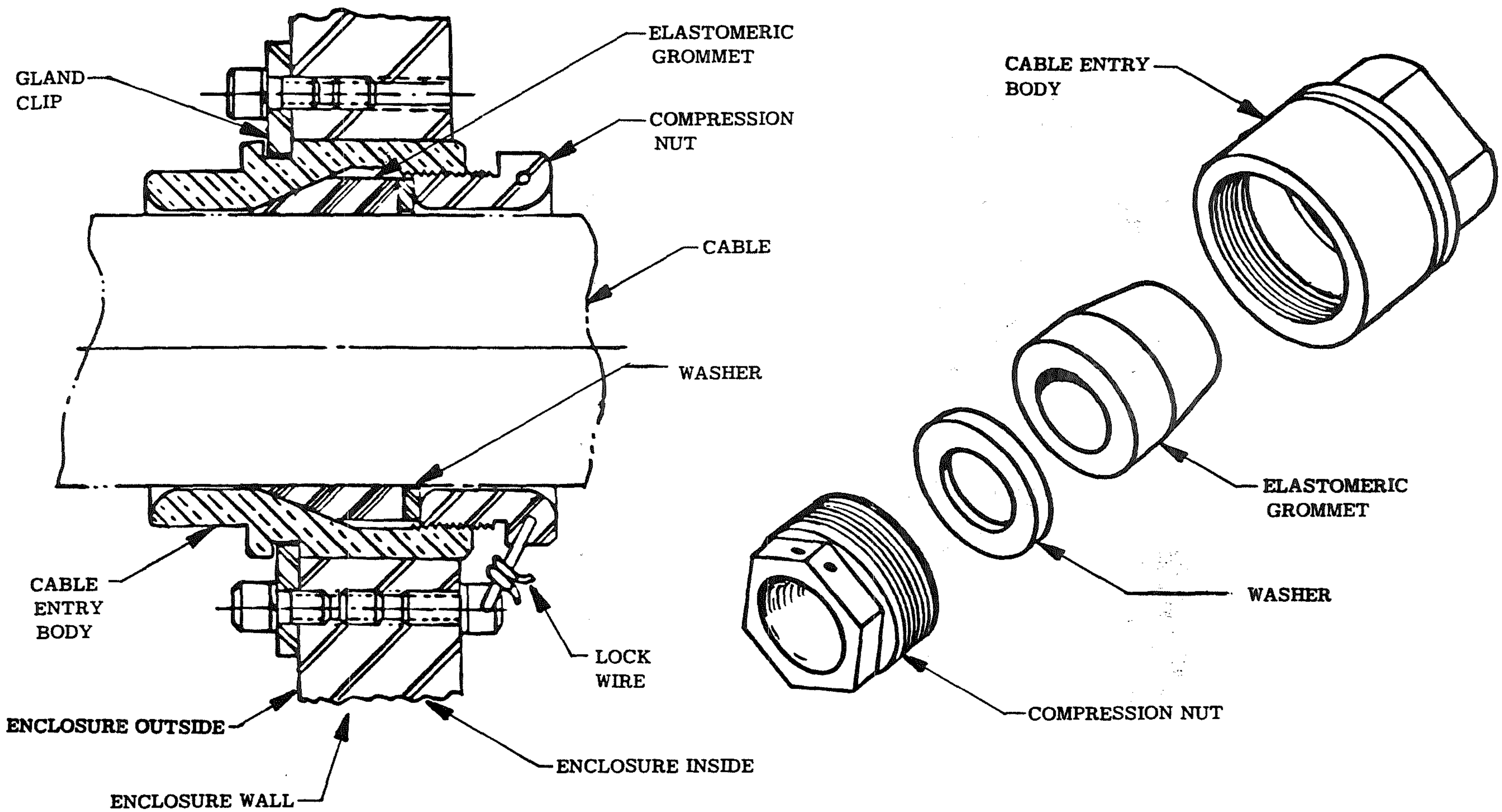

FIGURE 3-6 – Elastomeric cable entry concept selected for demonstration.

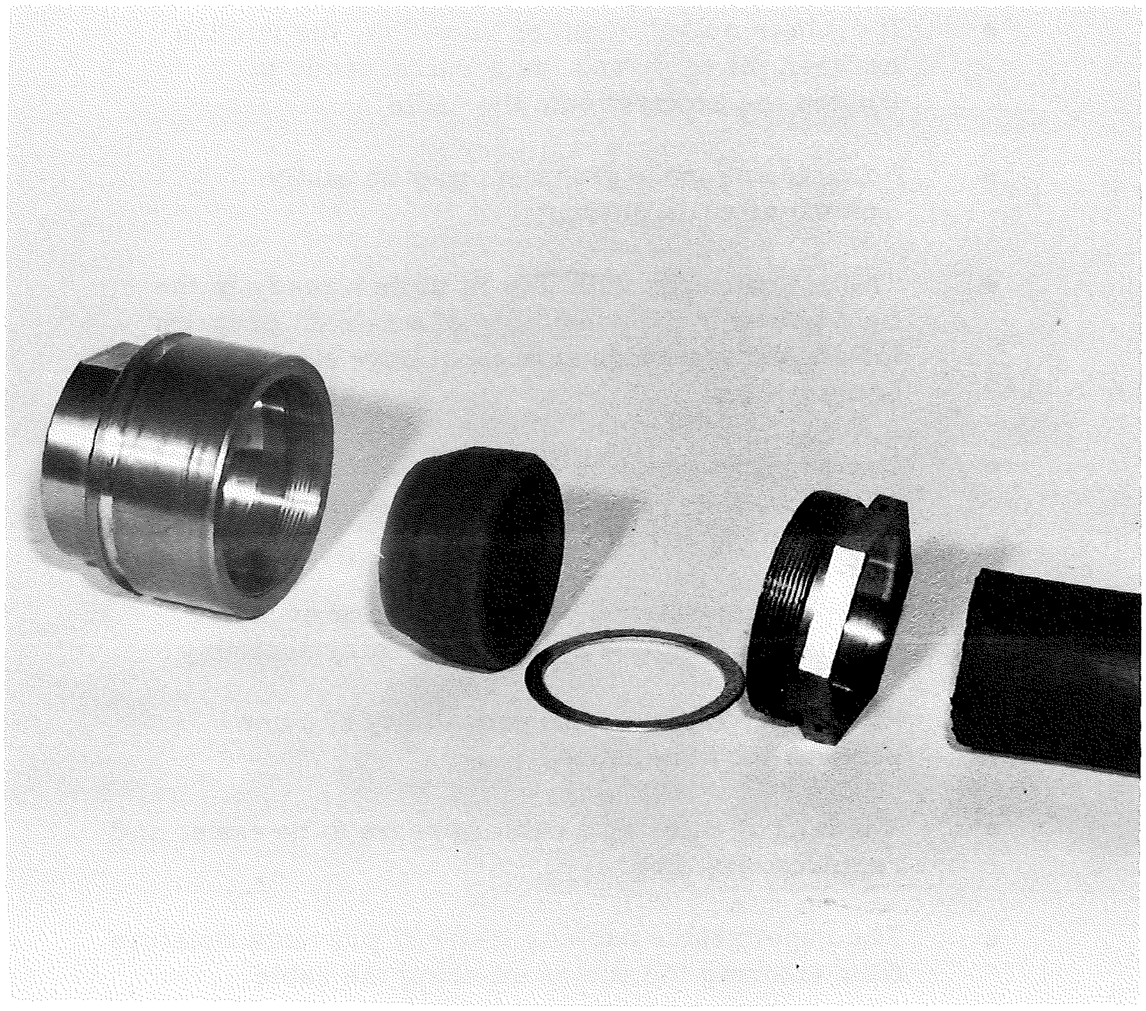

Figure 3-7. Elastomeric Seal Type Cable Entry

- If cable is pulled in either direction, the friction between the cable and the grommet tends to tighten the grommet onto the cable.

- Suitable one piece grommets may be easily manufactured in quantity.

- The compatibility with slip fit units already in the field presents the possibility of a retrofit program for enclosures which at present have slip fit cable entry bodies.

- One grommet could be designed to fit several sizes of cables, thus reducing the number of different sizes to be maintained in stock.

- The packing material cannot be lost or ommitted because it is captive in the cable entry assembly.

- The concept reduces the probability of a non-permissible installation.

- The task of entering a cable appears to be easier and requires less time.

- The impermeable packing material prevents moisture from entering the enclosure along the cable.

- The packing is solid and resilient and appears to resist shrinkage and deterioration in use.

- The assembly can be inspected by manually pulling and twisting the cable to "feel" its tightness. This procedure is being used currently for conventional cable entries.

- The grommet is reusable.

3.2.3 Pressure Vents

A pressure vent is a device which functions during an internal explosion to exhaust large quantities of expanding gas from an electrical enclosure. This alleviation of internal pressure build-up could justify significant changes in the design of explosionproof electrical enclosures without compromising the safety of mining personnel. In addtion, the concept of pressure vents presents the following advantages:

- Man-sensitivity and time dependence of the flange gap and cable entry permissibility does not remain critical because of larger allowable flange gaps and lower internal pressure.

- Damaged flanges, flange corrosion and dirt entrapment do not significantly affect enclosure permissibility because increased flange gaps seem feasible due to reduced internal pressures.

- Designs which reduce moisture accumulation through continuous ventilation are possible.

- Lighter enclosures can be designed for man-carry applications and for use in protected areas inside the mining equipment.

- Even very large enclosures may be fabricated with reasonable wall thickness.

The approach to pressure venting adopted in this program was to develop pressure vent modules. Since these devices are separate hardware assemblies they may be incorporated into enclosure covers or walls as required to meet the venting requirements. This approach offers some significant advantages:

- The same device may be used with many different enclosure sizes and configurations.

- The vent may be easily and quickly removed from the enclosure for servicing or replacement.

The modularized pressure vent application places several major requirements on the permeable venting mechanism. It must:

- Quench both methane gas and coal dust flame fronts.

- Be relatively permeable to gas flow, thereby minimizing vent size.

- Have self-cleaning characteristics which reduce possibilities of clogging during underground use.
- Have sufficient corrosion and mechanical shock resistance to be compatible with the mine environment.

A wide variety of material and construction configurations were analyzed in light of these requirements. These are summarized in Table 3-5. Of these, the open cell metal foam was deemed as offering the best combination of mechanical and flame arresting properties.

For actual hardware designs, "Retimet"[1] which is a stainless steel metal foam was chosen. Figure 3-8 is a photograph of the metal foam. This material was readily available and has a proven performance as a flame arrestor. It has good mechanical strength and high degree of porosity. One concern with metal foam is that the pores might clog in the mine environment and reduce its venting capabilities. It was determined during preliminary laboratory tests that metal foam is resistant to clogging from dust, moisture and other contaminants commonly found in mines. Details of these tests were presented in Appendix E.

The first modularized pressure vent design is shown in Figure 3-9. This design is made to fit into a precisely machined hole in the enclosure cover. Except for the use of the metal foam, this design meets all the current requirements of the CFR. (Neither a flame arrestor such as this nor pressure venting of this type are addressed in the CFR). Protection for the metal foam is provided by a hinged cover which swings open should an explosion occur within the enclosures. Special knife edge hinges minimize binding difficulties which could be caused by corrosion of the hinge components.

A somewhat different configuration was designed and fabricated for engineering tests. Sufficient area must be provided to vent the exhaust gases and the original computations were based upon an effective opening of .25 of actual area. As a result, larger area vents as shown in Figure 2-1 were required for the 14 cubic foot control case. It was also desired to use the same vent hardware in the 1/2 cubic foot connection box for purposes of hardware similarity. The resulting design had a rectangular vent area because of severe space restrictions. This design is illustrated in Figure 3-10. Figures 3-11 and 3-12 show the cover for the connection box with

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1 "Retimet" is a registered trademark of Dunlop Ltd., of Coventry U.K. Grade 45NC13 was chosen. This does not imply USBM endorsement.

TABLE 3-5. - Candidate pressure vent concepts

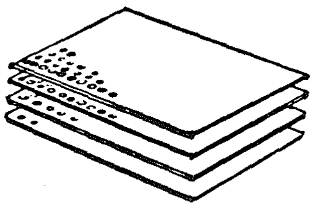
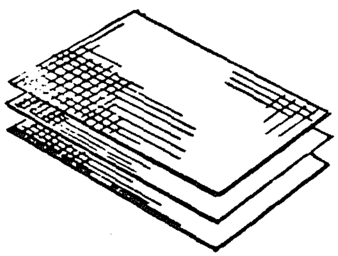
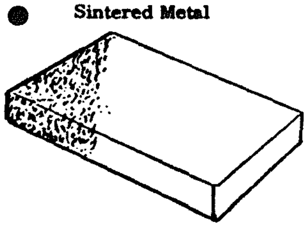
CONCEPT	ABILITY TO QUENCH EXPLOSIONS	ESTIMATED PERMEABILITY	ADAPTABILITY TO MINE ENVIRONMENT	COMMENTS
• Perforated Metal Sheet Assemblies 	Good • Methane: - Used as spark arresters • Coal Dust: - Required hole size and number of sheets must be determined.	Fair • 5 to 20 percent open.	Excellent • Good resistance to vibration and shock. • Stainless materials provide good corrosion protection .	• The construction is very durable but devices with small holes may require protection from clogging. • Development needed to obtain a device with adequate performance.
• Metal Screen Assemblies 	Good • Methane: - Proven to arrest many types of gas flames. • Coal Dust: - Small pores should arrest and quench burning dust.	Fair • 5 to 20 percent open.	Excellent • Good resistance to vibration and shock. • Stainless materials provide good corrosion protection.	• Some assemblies may not require protection from physical damage. • May require protection from clogging. • Technology used in some mine safety lamps. • Development needed to obtain a device with adequate performance.
• Sintered Metal 	Excellent • Methane: - Proven by thorough testing. • Coal Dust: - Proven by thorough testing.	Poor • 1 to 5 percent open.	Excellent • Used as a dust filter on methane monitors. • Used in breathers and drains on permissable equipment.	• Pressure vents would be impractically large. • Must be protected from damage and clogging. • May be feasible as breathing cable entry body.

TABLE 3-5. - Candidate pressure vent concepts (continued)

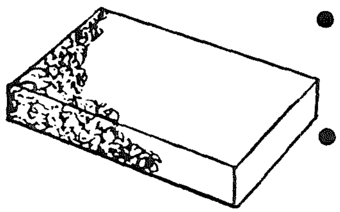
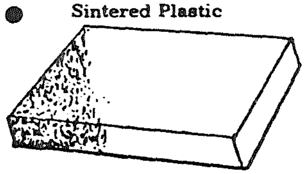
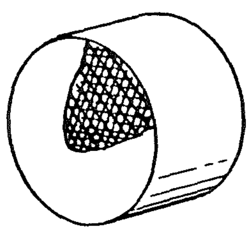
CONCEPT	ABILITY TO QUENCH EXPLOSIONS	ESTIMATED PERMEABILITY	ADAPTABILITY TO MINE ENVIRONMENT	COMMENTS
• Glass Wool Assemblies 	Poor • Methane: - Unproven but may quench gas flames. • Coal Dust: - Unproven but may quench flames.	Good • 20 to 40 percent open	Good • Good resistance to vibration, shock and corrosion.	• May require protection from clogging. • Material may compress during vibration and change flame arresting properties. • Development needed to obtain a device with adequate performance.
• Sintered Plastic 	Poor • Methane: - Poor heat exhcange properties could lead to localized melting.	Poor • 20 to 40 percent open.	Excellent • Good resistance to corrosion, vibration and shock.	• Not suitable because of low melting temperature.
• Ceramic Honeycomb 	Poor • Methane: - Unproven but may quench methane. • Coal Dust: - Required cell dimensions must be determined.	Good • 20 to 40 percent open.	Poor • Poor resistance to vibration and shock.	• Small cell decives should be protected. • Device must be protected from physical damage. • Shock mounting may be required. • Development needed to obtain adequate performance.

TABLE 3-5. - Candidate pressure vent concepts (continued)

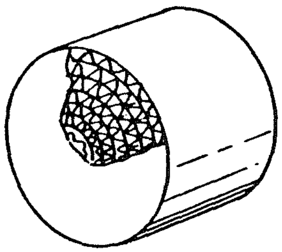
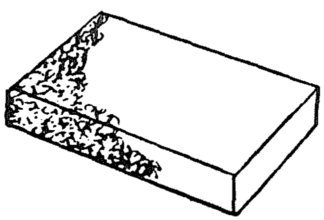
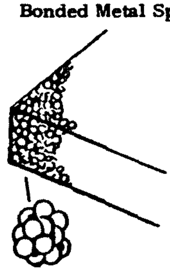
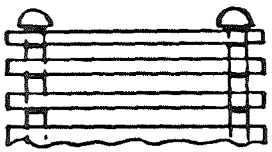
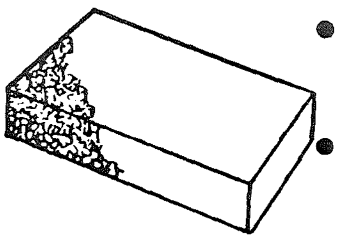
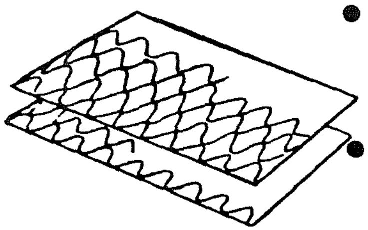
CONCEPT	ABILITY TO QUENCH EXPLOSIONS	ESTIMATED PERMEABILITY	ADAPTABILITY TO MINE ENVIRONMENT	COMMENTS
• Corrugated Metal Assemblies 	Good • Methane: - Proven by testing. • Coal Dust: - Required cell dimensions must be determined.	Good • 20 to 40 percent open.	Excellent • Used in methane monitors on permissible equipment ment.	• Cell sizes small enough to quench burning coal dust may tend to clog. • Corrosion resistant materials are required.
• Metal Wool Assemblies 	Good • Methane: - Proven to arrest some flames. • Coal Dust: - Small pores may arrest and quench burning dust.	Good • 20 to 40 percent open.	Excellent • Good resistance to vibration and shock. • Stainless materials provide good corrosion protection.	• May require protection from physical damage and clogging. • Development needed to obtain a device with adequate performance.
• Bonded Metal Spheres 	Good • Methane: - Proven by testing in Japan. • Coal Dust: - Small pores may arrest and quench burning dust.	Poor • 1 to 5 percent open.	Good • Properly bonded assemblies should have good vibration and shock resistancee. • Stainless materials provide good corrosion protection.	• Must be protected from physical damage and clogging. • Development needed to obtain a device with adequate performance.

TABLE 3-5. - Candidate pressure vent concepts (continued)

CONCEPT	ABILITY TO QUENCH EXPLOSIONS	ESTIMATED PERMEABILITY	ADAPTABILITY TO MINE ENVIRONMENT	COMMENTS
• Parallel Metal Plates 	Excellent • Methane: - Proven by thorough testing. • Coal Dust: - Proven by thorough testing using .004" to .006" plate spacing.	Poor • 1 to 5 percent open.	Excellent • Currently required in flange area of explosion proof enclosures. • Same concept as employed in the flange gap of conventional explosionproof enclosures.	• The construction is very durable but the narrow gap between the plates must be protected from clogging. • May require protection from clogging.
• Open Cell Metal Foam 	Excellent • Methane: - Proven by thorough testing. • Coal Dust: - Proven by thorough testing.	Good • 20 to 40 percent open.	Excellent • Used as intake manifold flame arrester on some permissable equipment. • Stainless materials provide corrosion resistance.	• Must be protected from physical damage. • May not require protection from clogging.
• Expanded Metal Sheet Assemblies 	Good • Methane: - Proven by testing Coal Dust: • - Required cell dimensions and number of sheets must be determined.	Good • 20 to 40 percent open.	Excellent • Good resistance to vibration and shock. • Stainless materials provide good corrosion protection.	• May not be necessary to provide special protection against physical damage. • Small pore material may require protection from clogging. • Development needed to obtain adequate performance.

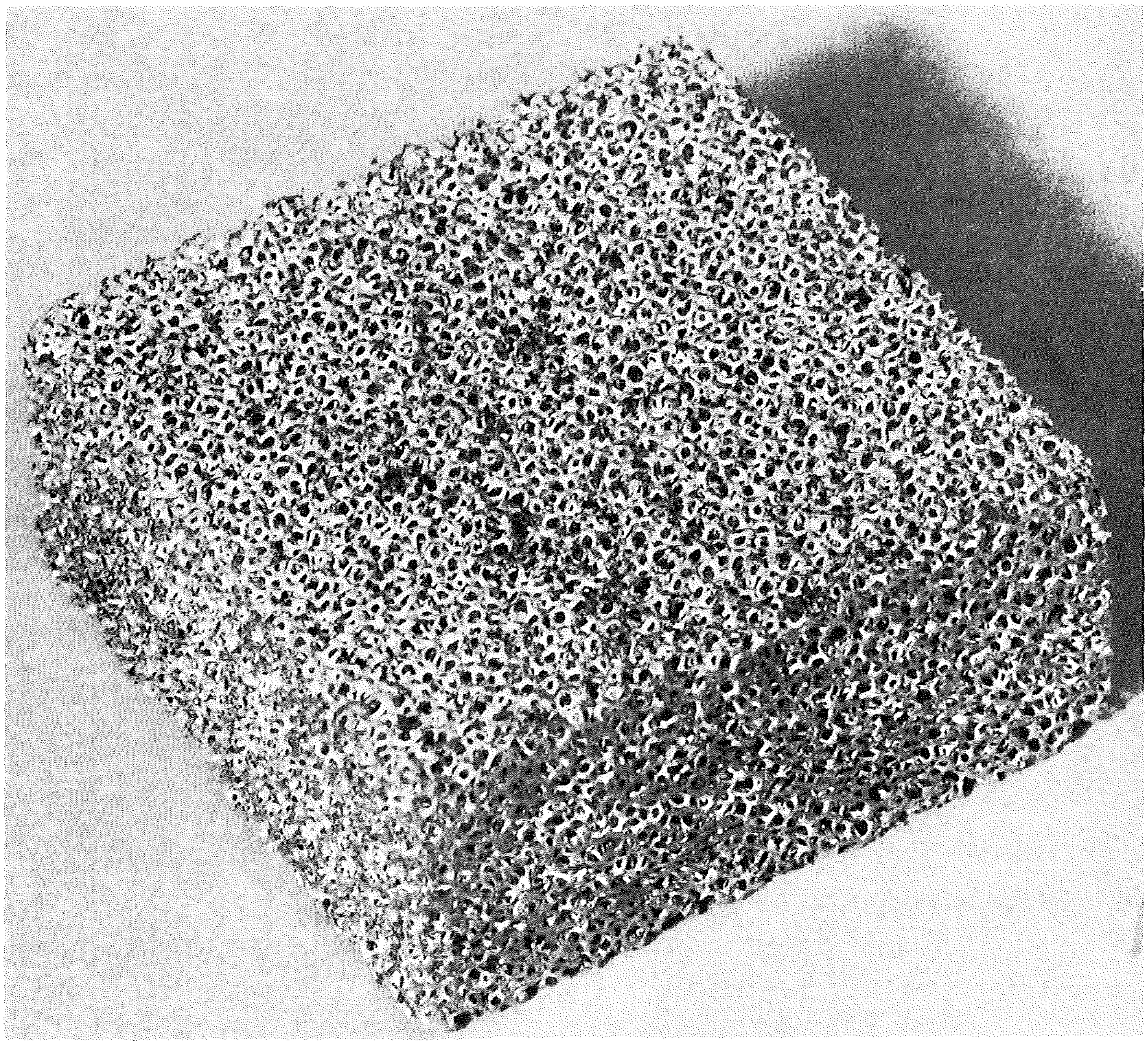


Figure 3-8. Enlarged View of Stainless Steel Metal Foam (RETIMET)

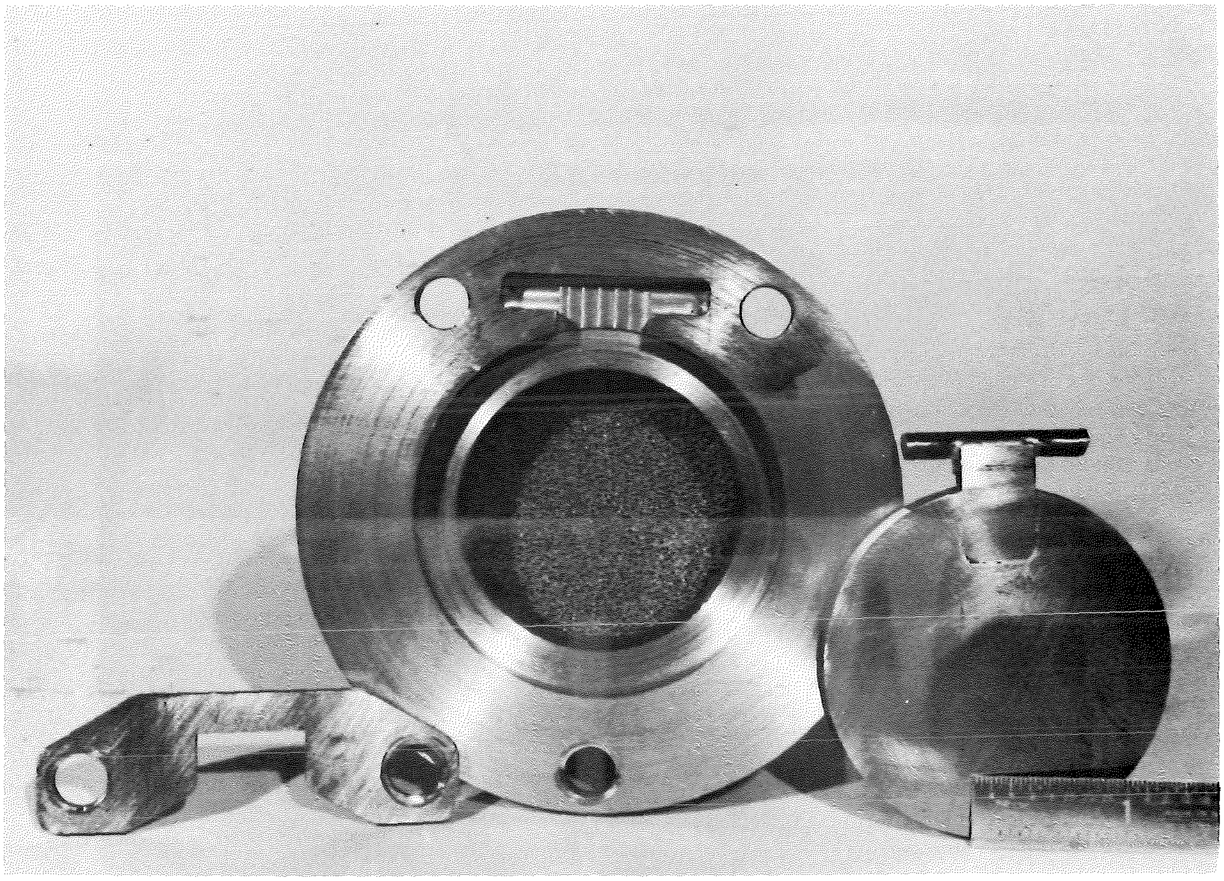
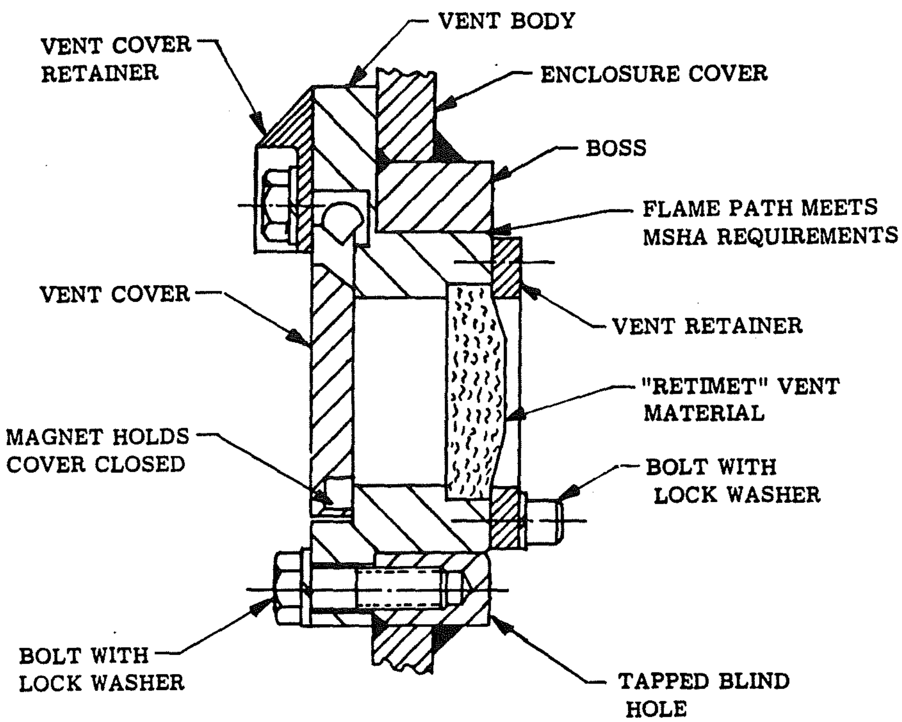


Figure 3-9. Modularized Pressure Vent Assembly (As Fabricated for Mock-Up)



NOTE: The "Retimet" vent material is a high porosity stainless steel foam manufactured by Dunlop Ltd. of Coventry, England. Layers of stainless steel screen may be used at the inside surface of the metal foam in order to provide thermal support.

FIGURE 3-10 - Pressure vent assembly concept selected for demonstration.

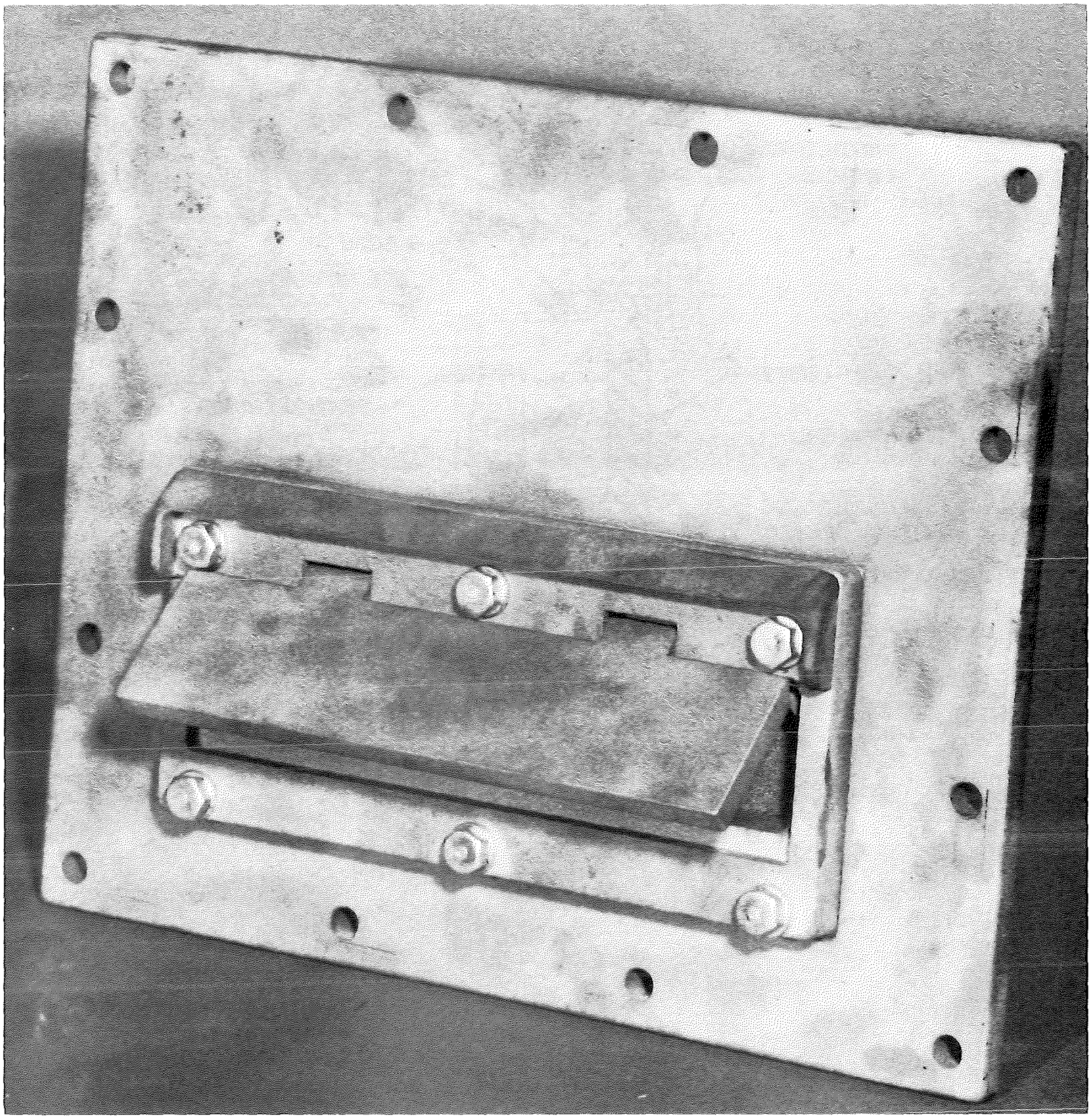


Figure 3-11. Pressure Vent Mounted on Connection Box Cover Showing Protective Cover Open

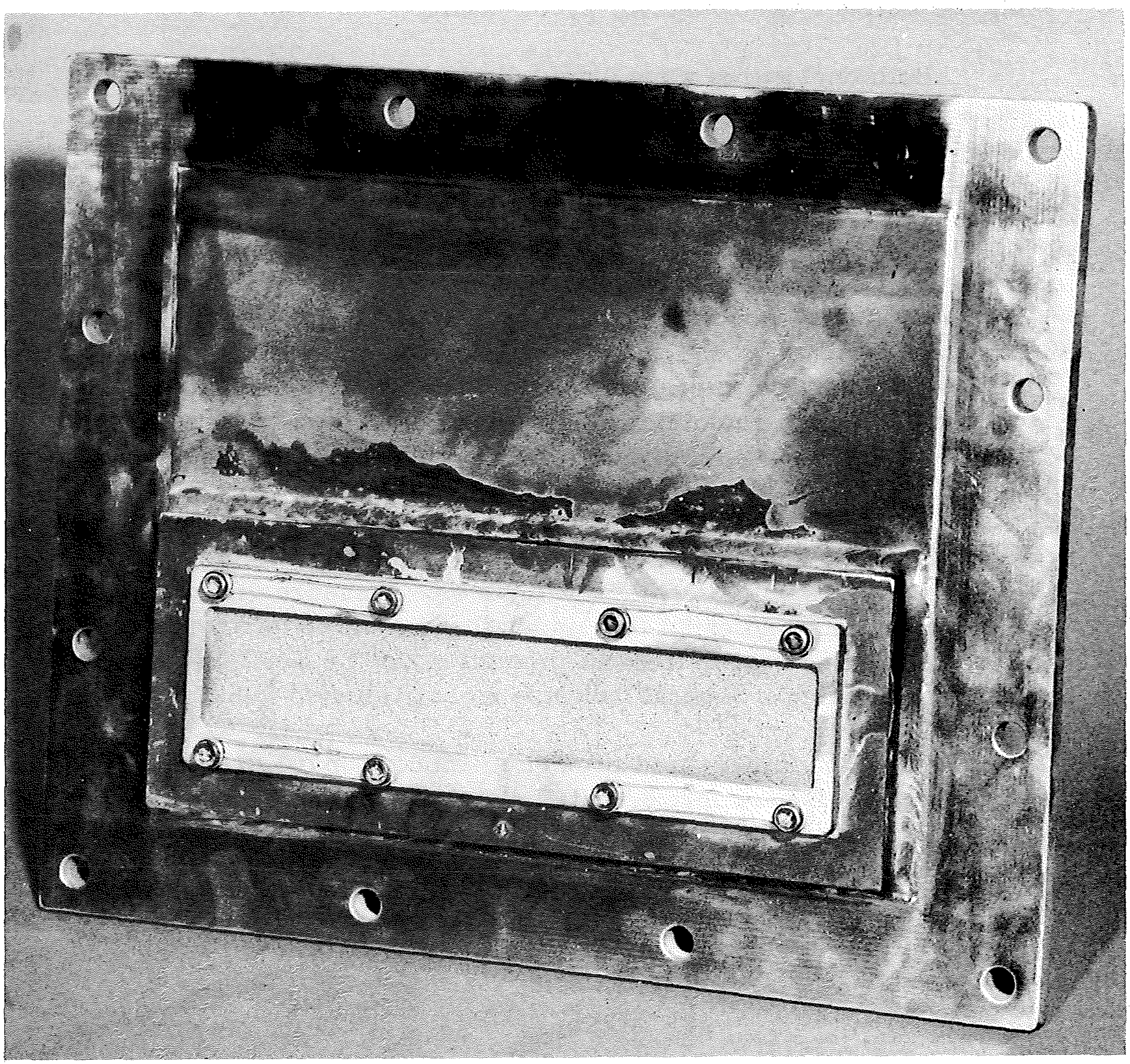


Figure 3-12. Inside View of Pressure Vent Mounted on Connection Box Cover

requirements to interchange with existing hardware, the vent area should normally be round for producibility.

Both enclosures were originally taken to the MSHA test facility at Bruceton for initial explosion testing to verify the design before submitting the devices for formal MSHA approval. This test arrangement is shown in Figures 3-13 and 3-14 and further discussion of the test techniques is contained in Appendix G. These tests showed that while the size of the vent is dependent upon the ability to keep the pressure low an even more important fact is the heat rise that occurs in the vent structure in the process of exhausting the hot gases. The pressure vent was found to be quite adequate for the 1/2 cubic foot connection box, but there were obvious signs of overheating of the vent material in the 14 cubic foot control case. This pointed out the need for further engineering development which is described in Section 5.0 of this report.

For practical considerations, it is often desirable to equip a large enclosure with a relatively small size pressure vent module. Preliminary testing indicated that under these conditions it is necessary to provide some type of thermal protection for the metal foam to keep it from overheating. Several concepts were evaluated for this application

These candidate vent protection concepts have been described in Appendix F. A pack formed out of stainless steel screens[2] was selected as the most suitable in terms of effective flame quenching, negligible obstruction to exiting gas and material stability. This choice was later verified through extensive testing.

[2] 20 mesh, 0.018 inch wire diameter, 304 stainless steel screens

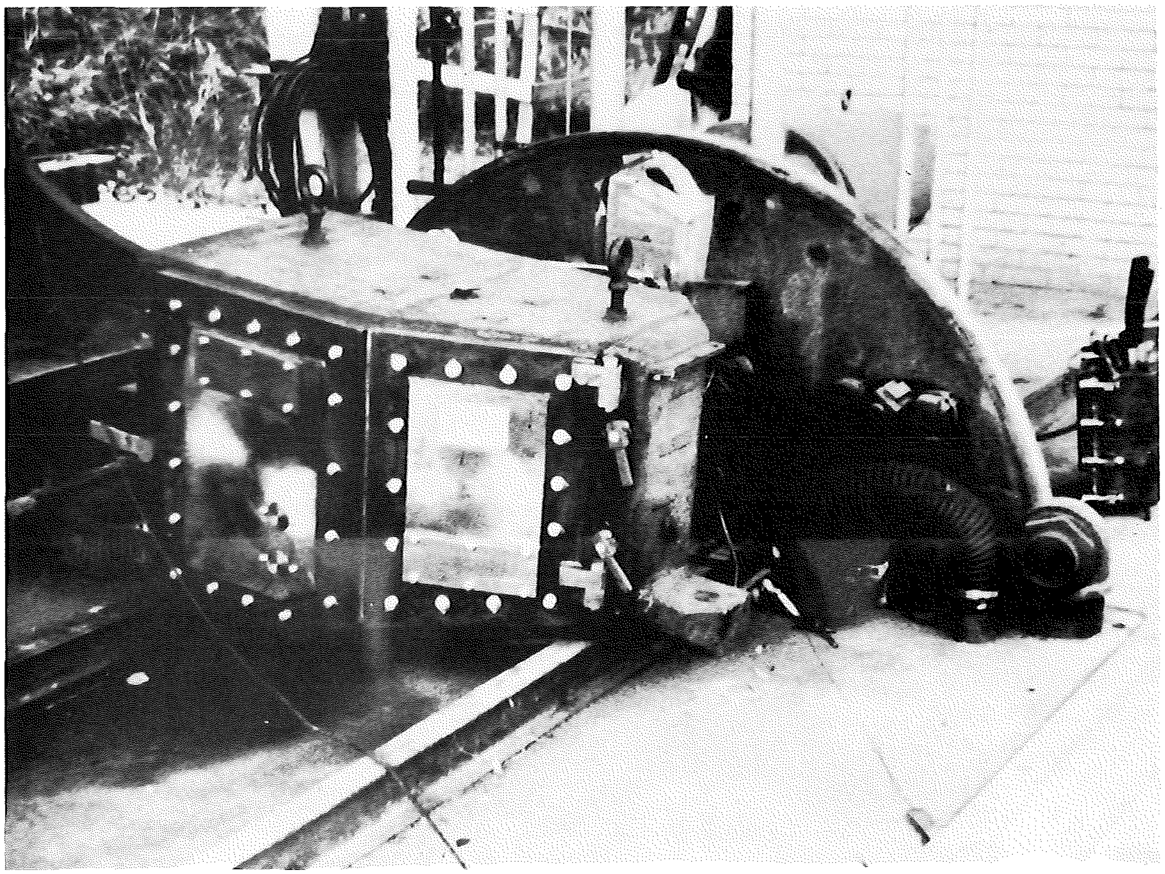


Figure 3-13. Control Case with Innovative Devices Ready for Explosion Test in the MSHA Chamber at Bruceton

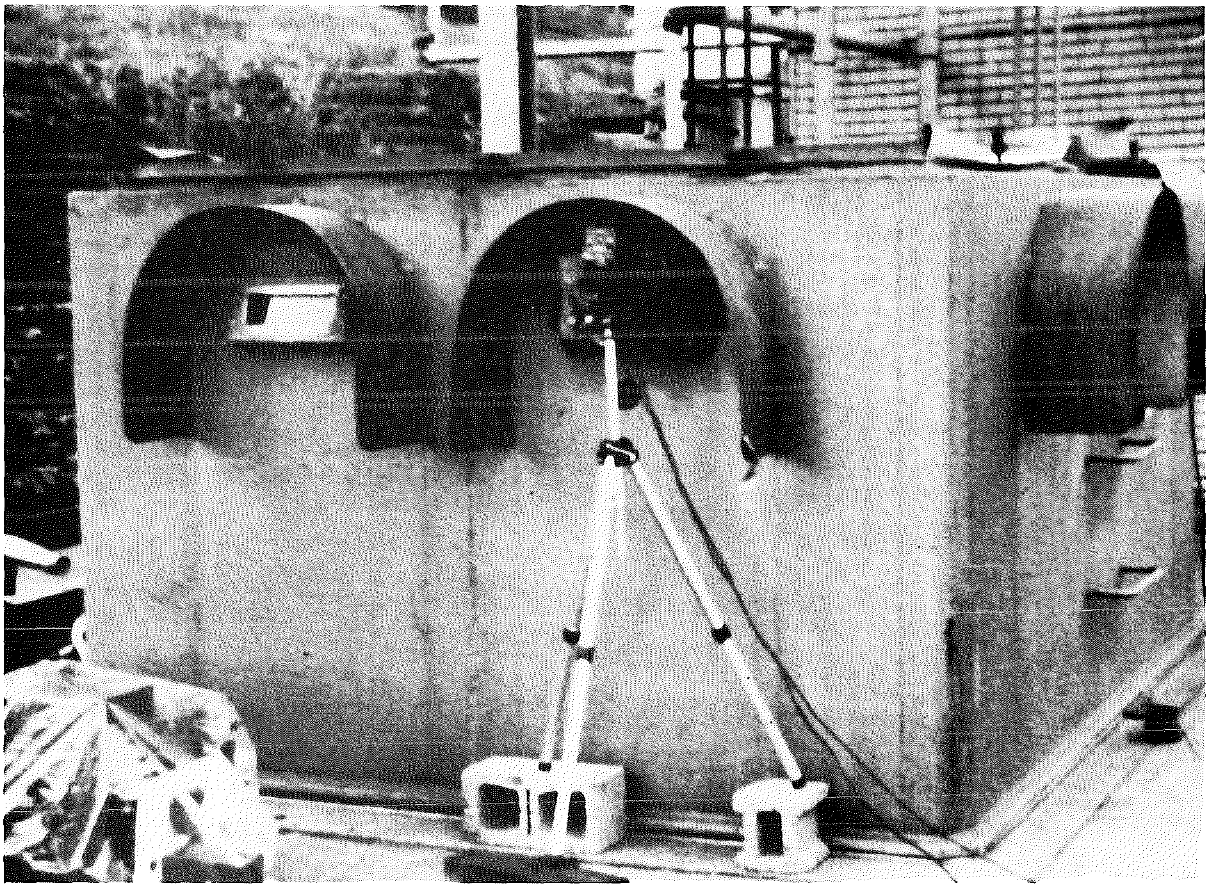


Figure 3-14. Explosion Test Chamber at Bruceton with TV Monitor Camera in Place

4.0 DESIGN GUIDELINES FOR PRESSURE VENTS

Design guidelines were established through extensive laboratory tests in which explosions were created inside the enclosures. The enclosure performance was measured and compared with criteria which would assure the successful working of the enclosure. Testing and analysis indicated that the key parameter for the performance of the pressure vent is the vent area to the enclosure volume ratio.

The following sections deal with the development of the enclosure performance criteria, test parameters, tests to establish parametric relationships for various vent area to enclosure volume ratios and the development of guidelines on the basis of these relationships.

4.1 Performance Criteria

The design and performance requirements to be met by the in-mine explosionproof electrical enclosures have been described in the CFR. The intent and purpose of the code is to assure that the effects of an internal explosion would remain contained inside the enclosure and that the explosive energy would be released in a controlled and non-hazardous manner. Because of the novelty of the pressure venting designs, complete and explicit regulations were not available. Therefore, inputs from several sources were used to develop the criteria for evaluating the performance of pressure vented enclosures:

- Use of the CFR where directly applicable.
- Performance of conventional hardware when the CFR could not be used.
- Testing of hardware and analysis of results.

The following criteria were developed to define acceptable performance of vented enclosures under controlled explosion test conditions:

- No ignition of the test chamber during an explosion test.
- No visible transmission of flame or sparks through the vent since MSHA test criteria considers these as potential ignition sources for surrounding gas.

- No significant erosion, overheating or other thermal damage to the flame-arresting material.

- External vent surface temperatures to be lower than 302°F after soak-out to avoid ignition of coal dust (as required by the CFR).

- Explosion pressures inside the enclosure to be less than 12 psig in order to be a significant improvement.

- Flange gas temperatures not to exceed 1200°F peak in order not to ignite the surrounding gas.

- No visible transmission of sparks or flashes through the flange gap since these could potentially ignite the surrounding gas.

- Survival of the vent hardware of a minimum of 50 explosion tests in order to establish the durability of vent hardware.

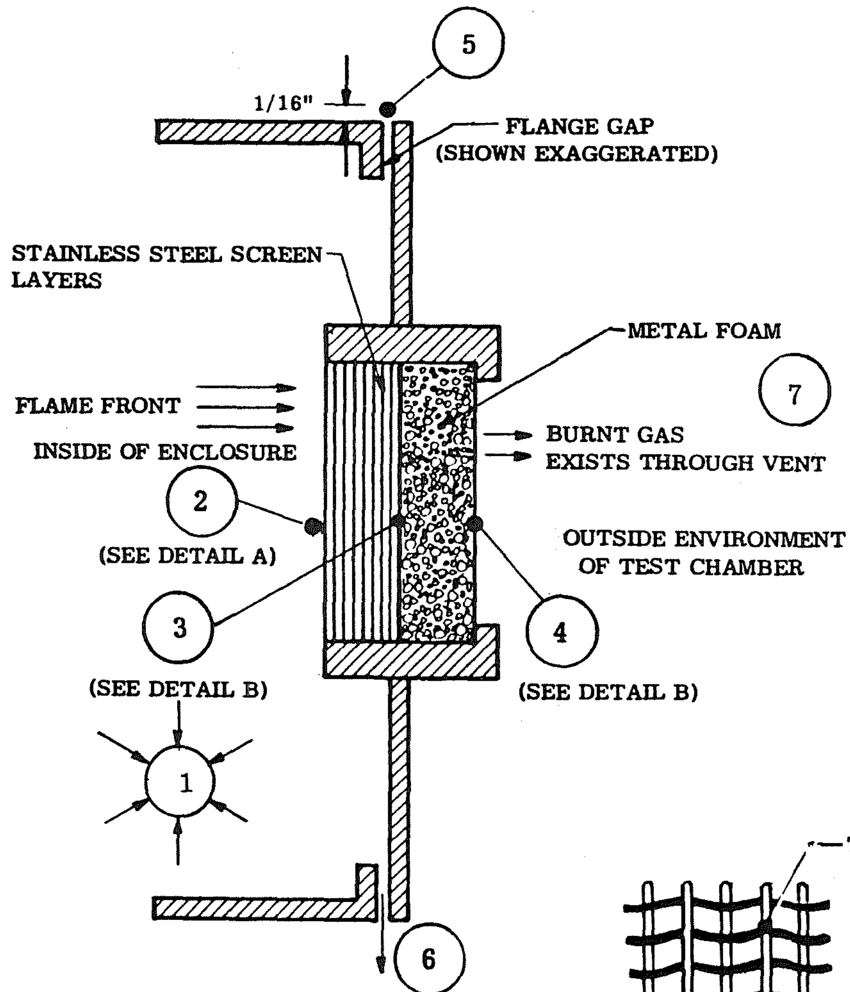
In developing the design guidelines, the performance of vented enclosures was evaluated against the above criteria. This evaluation required extensive explosion testing and establishment of quantitiative relationships between the test parameters under various vent configurations.

Figure 4-1 identifies the test parameters which were used to evaluate the enclosure performance during explosion tests. The following parameters were recorded quantitatively:

- Maximum Enclosure Pressure. This is to be limited to 12 psig for acceptable performance of the enclosure.

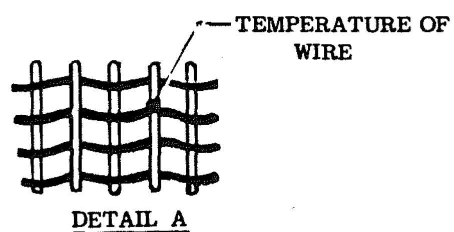
- Maximum Surface Temperature Of The Innermost Screen The surface temperature could be correlated to the observed durability of the screens since their wear occured through oxidation and erosion resulting from the flame front.

- Maximum Inside Surface Temperature Of The Metal Foam. The purpose of the screen pack is to act as a thermal barrier between the flame front and the metal foam. Thus the inside surface temperature of the metal foam is an indication of the effectiveness of the screen pack in protecting the metal foam from oxidation damage due to high temperature and erosion.



TEST PARAMETERS

1. Enclosure pressure (maximum)
2. Inside temperature of screen (maximum)
3. Inside temperature of metal foam (maximum)
4. Outside temperature of vent (maximum)
5. Flange gas temperature (maximum)
6. Visible flame, flash or spark transmission through vent or flange gap
7. Errosion and overheating of metal frame or screen as enduced by heavy oxidation, burn marks or crumpling



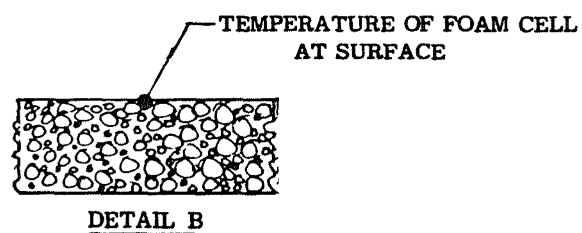


FIGURE 4-1. - Enclosure test parameters.

- Maximum Flange Gas Temperature. The performance criteria required this temperature to be limited to less than 1200°F.

4.2 Explosion Testing of Vented Enclosures

Explosion tests were performed in a wide variety of hardware configurations to meet the following objectives:

- Determine the relationships between explosion pressure, vent area and the enclosure volume.

- Determine the number of screens necessary for thermal protection of the metal foam under various venting conditions.

- Determine appropriate flange gap spacing for various levels of venting.

- Establish the similarity of behavior between large and small enclosures.

- Establish vent durability.

In addition to the initial feasibility testing and concept development testing of pressure vents, more than 500 explosion tests were conducted for the development of design guidelines. The various explosion series for pressure vent guideline development are summarized in Table 4-1. A photograph of the laboratory test set up used for the explosion tests is illustrated in Figure 4-2. During the test, the enclosure and the surrounding test chamber were filled with a combustible mixture of methane and air. The mixture inside the enclosure was ignited with an electrical spark. Further details of the test equipment and test techniques have been given in Appendix G.

4.3 Test Results

The extensive explosion testing undertaken to develop design guidelines resulted in quantitative relationships between the vent area to enclosure volume ratio and other performance parameters. The results have been summarized in the following subsections.

TABLE 4-1. - Expolsion test series for pressure vent guideline development.

	Test Description	Enclosure Volume (ft^3)	Screen Layers	Vent Area To Enclosure Volume Ratio (in^2/ft^3)	Flange Gap (inch)	Data To Be Collected	Anticipated Results
1.	Metal foam temperatures and pressure.	1/2	0	28 24 20 12	0	Metal foam surface temperatures. Enclosure pressure. Video tape of vent.	Pressure and temperature curves for metal foam vents.
2.	Screen and metal foam temperature and pressure.	1/2	8	4 8 10 12 16	0	Screen and metal foam temperatures. Pressure. Video tape of vent.	Pressure and temperature curves for vents with 8 screens. Guideline vent.
3.	Screen and metal foam temperatures and pressure.	1/2	10	2 4 8 12	0	Screen and metal foam temperatures. Pressure. Video tape of vent.	Pressure and temperature curves for vents with 10 screens. Guideline vent.
4.	Flange gap temperature (flange perimeter fully open)	1/2	6	10	0.020 0.030 0.035 0.040 0.050	Flange gas temperature. Pressure. Video tape of flange.	Preliminary flange gas temperature curves.
5.	Flange gas temperature (flange perimeter fully open).	1/2	10	8	0.020 0.030 0.040 0.050 0.070	Flange gas temperature. Pressure. Video tape of flange.	Preliminary flange gas temperature curves.
6.	Flange gas temperature (flange perimeter fully open).	14	6	10	0.030	Flange gas temperature. Pressure.	Preliminary flange gas temperature curves.
7.	Flange gas temperature (flange perimeter fully open).	14	10	6	0.010 0.020 0.025 0.030	Flange gas temperature. Pressure. Video tape of flange.	Preliminary flange gas temperature curves.
8.	Vent gas temperature	1/2	6 10	10 6	0	Vent gas temperature. Pressure.	Personnel safety evaluation.

TABLE 4-1. - Explosion test series for pressure vent guideline development

	Test Description	Enclosure Volume (ft^3)	Screen Layers	Vent Area To Enclosure Volume Ratio (in^2/ft^3)	Flange Gap (inch)	Data To Be Collected	Anticipated Results
9.	Vent gas temperature.	14	6 10	10 6	0	Vent gas temperature. Pressure.	Personnel safety regulation.
10.	Vent door opening.	1/2	0	28	0	Pressure. Vent door opening angle.	Personnel safety regulation.
11.	Clamped vent door.	1/2	0		0	Pressure video tape of vent.	Enclosure pressure build up and vent behavior if vent door is accidentally forced to remain closed.
12.	Vent durability.	1/2	6	10	0	Screen and metal foam temperatures. Pressure. Video tape of vent.	Vent durability.
13.	Vent durability.	1/2	10	6	0	Screen and metal foam temperatures. Pressure. Video tape of vent.	Vent durability.
14.	Flange gas temperature vs. flange gap.	14	6	10	0.020 0.040 0.050	Flange gas temperature. Video tape of flange and vent. Pressure.	Data points on flange gas temperature vs. effective vent area to enclosure volume ratio curves confirm that enclosure volume does not significantly affect flange gas temperatures.
15.	Flange gas temperature (Flange perimeter partially sealed)	4	6	10	0.035	Flange gas temperature. Video tape of flange & vent. Pressure.	
16.	Flange gas temperature (flange perimeter partially sealed).	4	10	6	0.020	Flange gas temperature. Video tape of flange & vent. Pressure.	

TABLE 4-1. - Explosion test series for pressure vent guideline development (continued)

	Test Description	Enclosure Volume (ft^3)	Screen Layers	Vent Area To Enclosure Volume Ratio (in^2/ft^3)	Flange Gap (inch)	Data To Be Collected	Anticipated Results
17.	Flange gas temperature vs. flange gap. (Flange perimeter partially sealed in some tests)	1/2	0	0	0.005 0.010 0.015 0.020 0.025 0.030 0.035	Flange gas temperature. Video tape of flange. Pressure.	Flange gas temperature curves for unvented enclosures.
18.	Temperatures of screen and vent outside surface.	1/2	20 16 12	4	0	Temperatures of screen, metal foam & vent outside surface. Pressure. Video tape of vent.	Number of screens required.
19.	Temperatures of screen and vent outside surface.	1/2	10 8 6	8	0	Temperatures of screen, metal foam & vent outside surface. Pressure. Video tape of vent.	Number of screens required.
20.	Temperatures of screen and vent outside surface.	1/2	4 3 2	16	0	Temperatures of screen, metal foam & vent outside surface. Pressure. Video tape of vent.	Number of screens required.
21.	Flange gas temperature vs. flange gap. (Flange perimeter partially sealed)	1/2	Guideline Level	4	0.010 0.015 0.020 0.025	Flange gas temperature. Video tape of flange & vent. Pressure.	Flange gap guideline level.
22.	Flange gas temperature vs. flange gap. (Flange perimeter partially sealed)	1/2	Guideline Level	6	0.010 0.015 0.020 0.025	Flange gas temperature. Video tape of flange & vent. Pressure.	Flange gap guideline level.

TABLE 4-1. - Explosion test series for pressure vent guideline development (continued)

	Test Description	Enclosure Volume (ft^3)	Screen Layers	Vent Area To Enclosure Volume Ratio (in^2/ft^3)	Flange Gap (inch)	Data To Be Collected	Anticipated Results
23.	Flange gas temperature vs. flange gap (Flange perimeter partially sealed)	1/2	Guideline Level	8	0.020 0.025 0.030 0.035	Flange gas temperature. Video tape of flange & vent. Pressure.	Flange gap guideline level.
24.	Flange gas temperature vs. flange gap. (Flange perimeter partially sealed)	1/2	Guideline Level	10	0.025 0.030 0.035 0.040	Flange gas temperature. Video tape of flange & vent. Pressure.	Flange gap guideline level.
25.	Flange gas temperature vs. flange gap. (Flange perimeter partially sealed)	1/2	Guideline Level	16	0.030 0.035 0.040 0.045	Flange gas temperature. Video tape of flange & vent. Pressure.	Flange gap guideline level.
26.	Flange gas temperature at guideline level. (Flange perimeter partially sealed)	1/2	Guideline Level	4	Guideline Level	Temperatures of flange gas, metal foam & vent outside. Pressure. Video tape of flange and vent.	Multiple tests to verify proposed guidelines.
27.	Flange gas tempera- at guideline level. (Flange perimeter partially sealed)	1/2	Guideline Level	6	Guideline Level	Temperatures of flange gas, metal foam & vent outside. Pressure. Video tape of flange and vent.	Multiple tests to verify proposed guidelines.
28.	Flange gas temperature at guideline level. (Flange perimeter partially sealed)	1/2	Guideline Level	8	G Guideline Level	Temperatures of flange gas, metal foam & vent outside. Pressure. Video tape of flange and vent.	Multiple tests to verify proposed guidelines.

TABLE 4-1. - Explosion test series for pressure vent guideline development (continued)

	Test Description	Enclosure Volume (ft^3)	Screen Layers	Vent Area To Enclosure Volume Ratio (in^2/ft^3)	Flange Gap (inch)	Data To Be Collected	Anticipated Results
29.	Flange gas temperature at guideline level. (Flange perimeter partially sealed)	1/2	Guideline Level	10	Guideline Level	Temperatures of flange gas, metal foam & vent outside. Pressure. Video tape of flange and vent.	Mutliple tests to verify proposed guidelines.
30.	Flange gas temperature at guideline level. (Flange perimeter partially sealed)	1/2	Guideline Level	16	Guideline Level	Temperatures of flange gas, metal foam & vent outside. Pressure. Video tape of flange and vent.	Mutliple tests to verify proposed guidelines.

Figure 4-2. Equipment for Explosion Testing at Contractor Facility

4.3.1 Pressure Versus Vent Area to Enclosure Volume Ratio.

Explosion tests were conducted on the one-half cubic foot enclosure for several vent area to volume ratios between 4 in^2/ft^3 and 28 in^2/ft^3. In some tests screen packs were used to provide thermal support to the metal foam. These contained 6 screens or 10 screens. The tests established that screens did not significantly increase the enclosure pressure but a decrease in vent area to enclosure volume ratio did increase the pressure. Similar tests conducted on the 14 cubic feet and 4 cubic feet enclosures indicated that the pressure behavior of these enclosures also followed that of the small enclosure. The pressure versus vent area to enclosure volume ratio relationship established through these tests is shown in Figure 4-3. Vents larger than 4 in^2/ft^3 appear to limit the enclosure pressures to well below the 12 psig criterion.

4.3.2 Number of Screens Necessary for Thermal Support of Metal Foam.

Explosion tests were run on the one-half cubic foot enclosure for various vent area to enclosure volume ratios, using 6 screens, 10 screens and without screens. Figures 4-4 and 4-5 show the results of the screen temperature, and the inside and outside temperatures of the metal foam. The temperatures increased with decreasing vent area to enclosure volume ratios. The metal foam temperatures were considerably lower when 10 screens were used than with 6 screens. A 28 in^2/ft^3 vent using the stainless steel metal foam without the screens has demonstrated durable behavior in the initial feasibility tests. The metal foam in this vent had evidenced minimal discoloration or oxidation. The maximum inside surface temperature under these conditions was measured to be 1800°F. The test results indicated that the metal foam temperature could be maintained well below 1800°F through the use of 6 screens even for vent area enclosure volume ratios as small as 4 in^2/ft^3. The 1800°F temperature proved to be safe also for the stainless steel screen since it also was exposed to the possibilities of high temperature oxidation and erosion. This was further verified by the durability tests dealt with separately.

The tests also indicated that the outside surface temperature of the vent was significantly dependent on the number of screens. For example, with a 6 in^2/ft^3 vent, the use of 10 screens maintained the outside surface temperature less than the 302°F criterion, but the temperature exceeded the criterion with 6 screens. The number of screens needed to provide sufficient thermal protection of the metal foam and limit the external surface temperature of the vent to less than 302°F were determined for various vent area to enclosure volume ratios by running additional tests at each ratio with different numbers of screens.

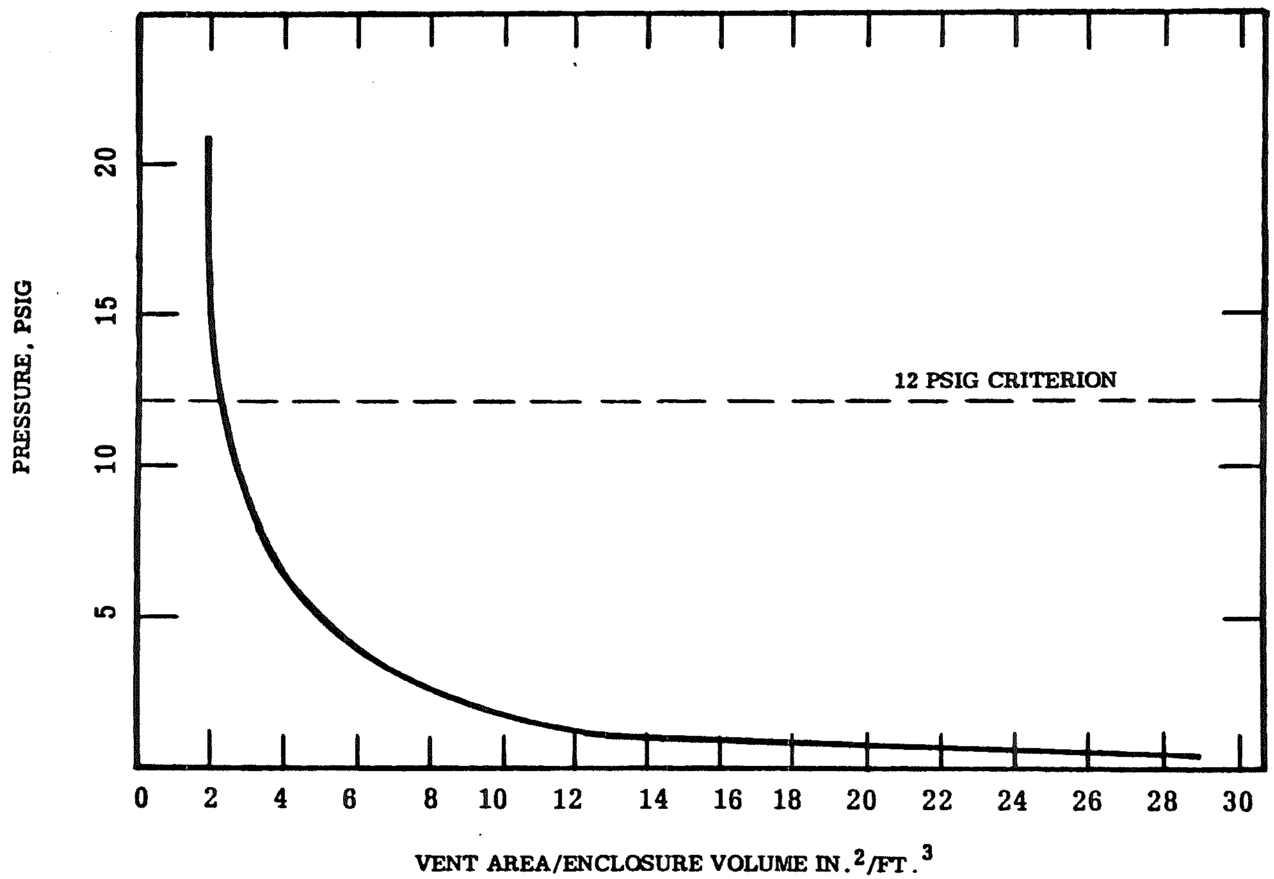


FIGURE 4-3. - Pressure build up in vented enclosures.

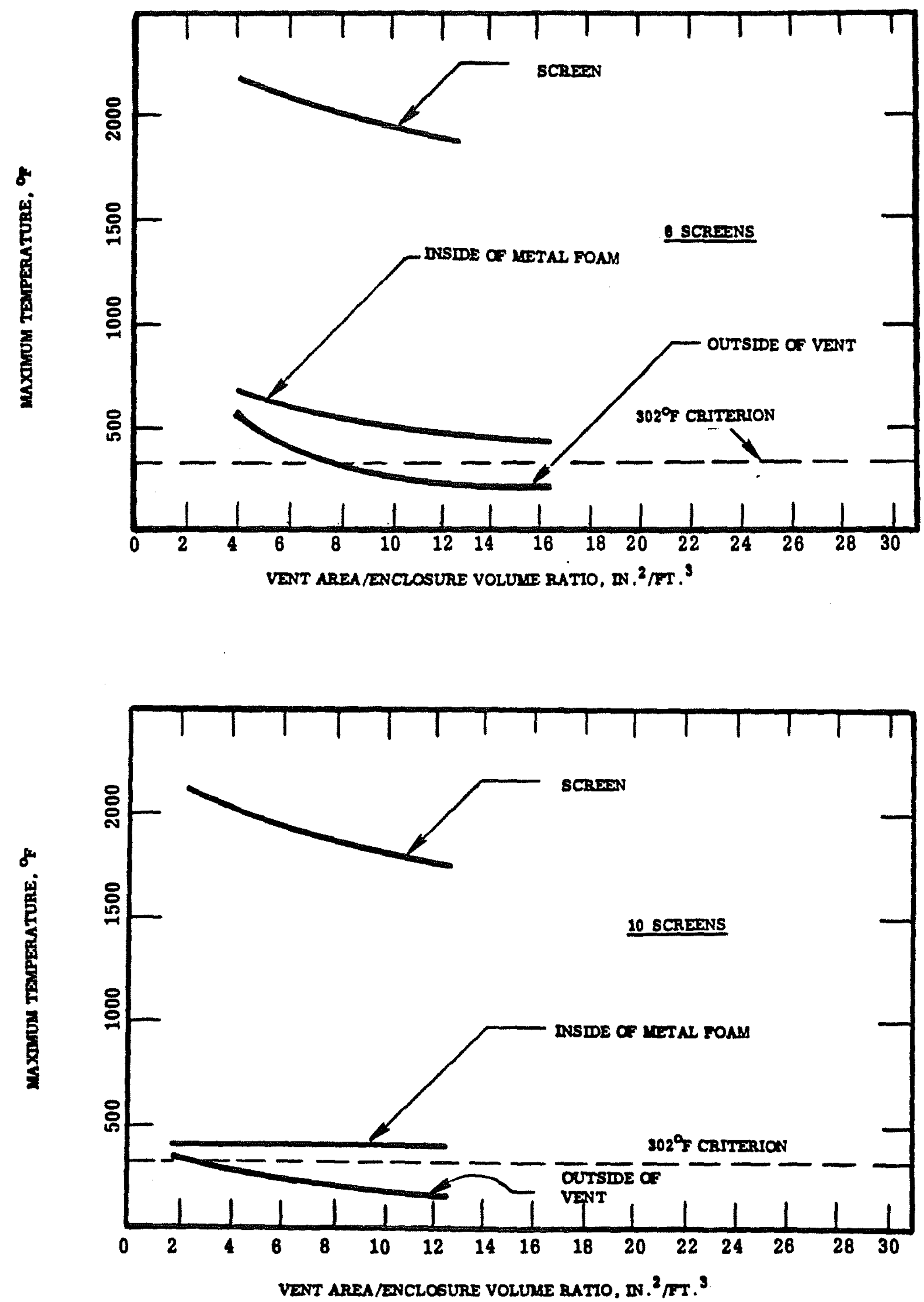


FIGURE 4-4. - Screen and metal foam temperatures with 6 and 10 screens.

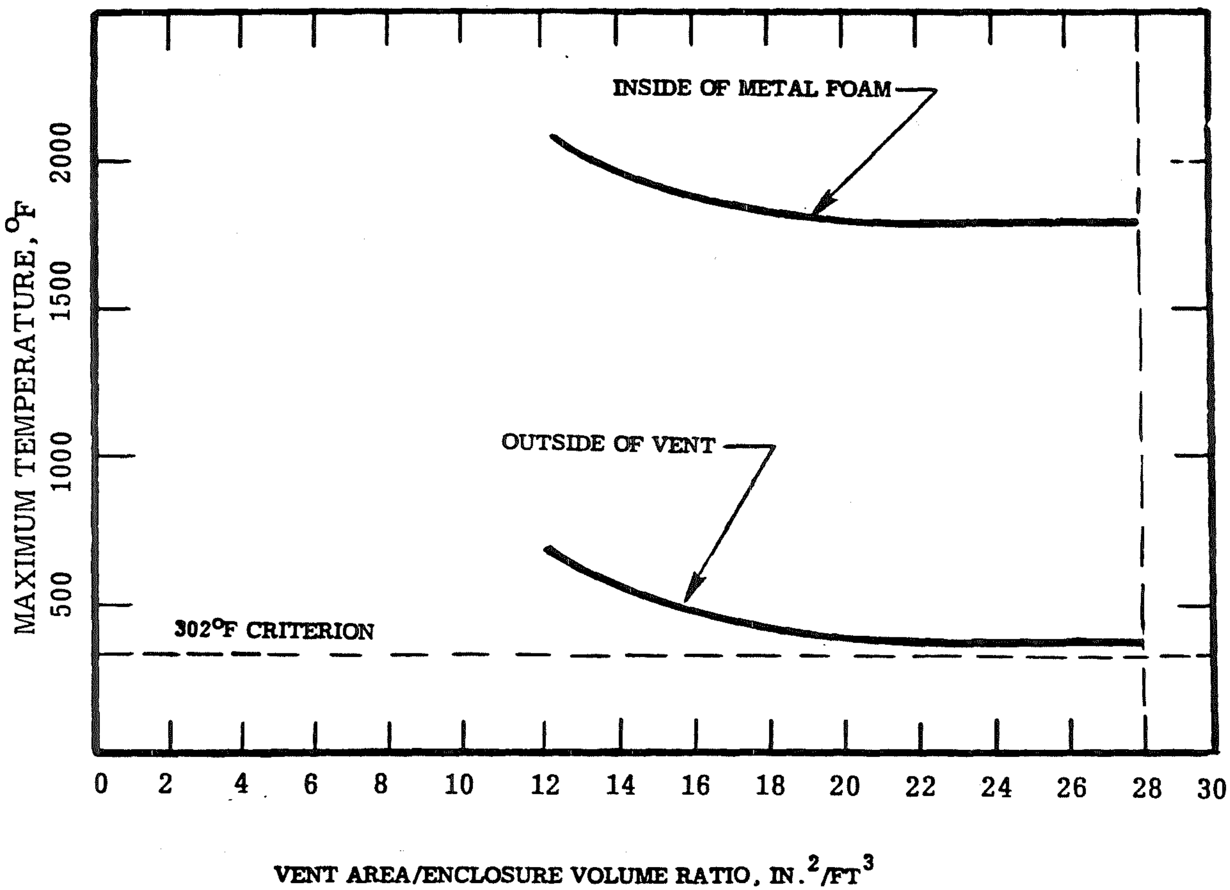


FIGURE 4-5. - Temperatures for metal foam vents without screens.

Table 4-2 shows the results of these tests. Temperature criteria were met by using 16 screens for the 4 in^2/ft^3 vent, 10 screens for the 8 in^2/ft^3 vent, 6 screens for the 10 in^2/ft^3 vent and 3 screens for the 16 in^2/ft^3 vent.

4.3.3 Flange Gaps Allowable for Various Vent Area To Enclosure Volume Ratios .

Tests were run on enclosures with different amounts of venting from 4 in^2/ft^3 to 28 in^2/ft^3. The limiting case of no venting was also tested. The flange gap was set at different values ranging from 0.005 inch up to .070 inch. Most of the flange periphery was sealed off so as to minimize the increase in venting caused by the flange opening. Figure 4-6 shows the results for an unvented enclosure and Figure 4-7 shows the results for various amounts of venting. The flange gap temperature was within the 1200°F criterion (Figure 4-7) for a gap spacing of 0.005 inch with venting of 4 in^2/ft^3 or less. A flange gap of 0.025 inch with venting of 16 in^2/ft^3 also met the criterion. In tests conducted with flange gaps larger than 0.025 inch, even though the flange gas temperature exceeded 1200°F, no sparks or flashes were emitted from the gap and there was no ignition of the test chamber. However, with a flange gap of 0.070 inch, both on unvented and vented enclosures, sparks and flashes were emitted from the gap and the test chamber ignited.

4.3.4 Similarity Of Behavior Between Small And Large Enclosures.

Several tests were conducted to measure pressure, screen and metal foam temperatures and vent gas temperatures on large enclosures (14 cubic feet and 4 cubic feet) under venting and flange gap conditions equal to those on the one-half cubic foot enclosures. The results of these tests indicated that the pressure and temperature behavior of the large enclosures conformed with the relationships established for the small enclosure.

4.3.5 Vent Durability.

More than 50 explosions were conducted on each of the two vents (1) 6 in^2/ft^3 with 10 screens and (2) 10 in^2/ft^3 with 6 screens. The pressure and temperature behavior throughout these tests followed the relationships established in the earlier testing. Examination of the screens and metal foam material at the end of these tests did not indicate any evidence of heavy oxidation, erosion or damage. The vents continued to meet the performance criteria established earlier. Similar durability tests were run on other vents. However, these tests were limited only to 15 for each

TABLE 4-2. - Screen and metal foam temperatures with different number of screens

Vent area/ enclosure Volume (in^2/ft^3)	Number of screens	Maximum inside surface temp. of screen (^oF)	Maximum inside surface temp. of metal foam (^oF)	Maximum outside surface temp. of vent (^oF)	Guideline number of screens
	4	1588	761	164	3
16	3	1516	865	191	
	2	1497	1019	220	
10	6	1927	469	251	6
	20	1961	209	133	10
8	10	2072	335	222	
	8	1705	450	249	
4	20	1481	205	116	
	16	2018	454	202	16
	12	--	677	216	

Note: Values are averages of several data points.

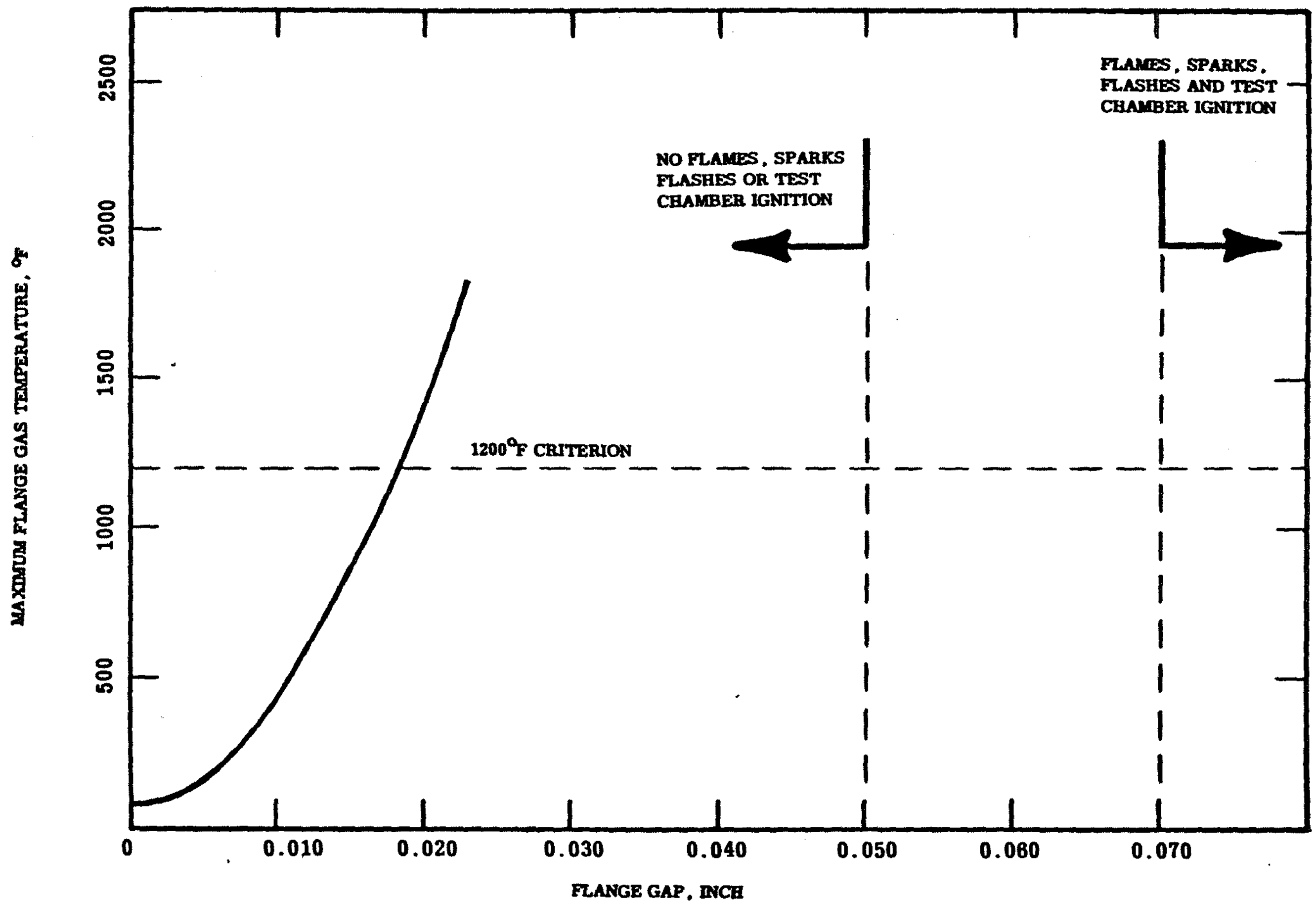


FIGURE 4-6. - Flange gas temperatures for unvented enclosures.

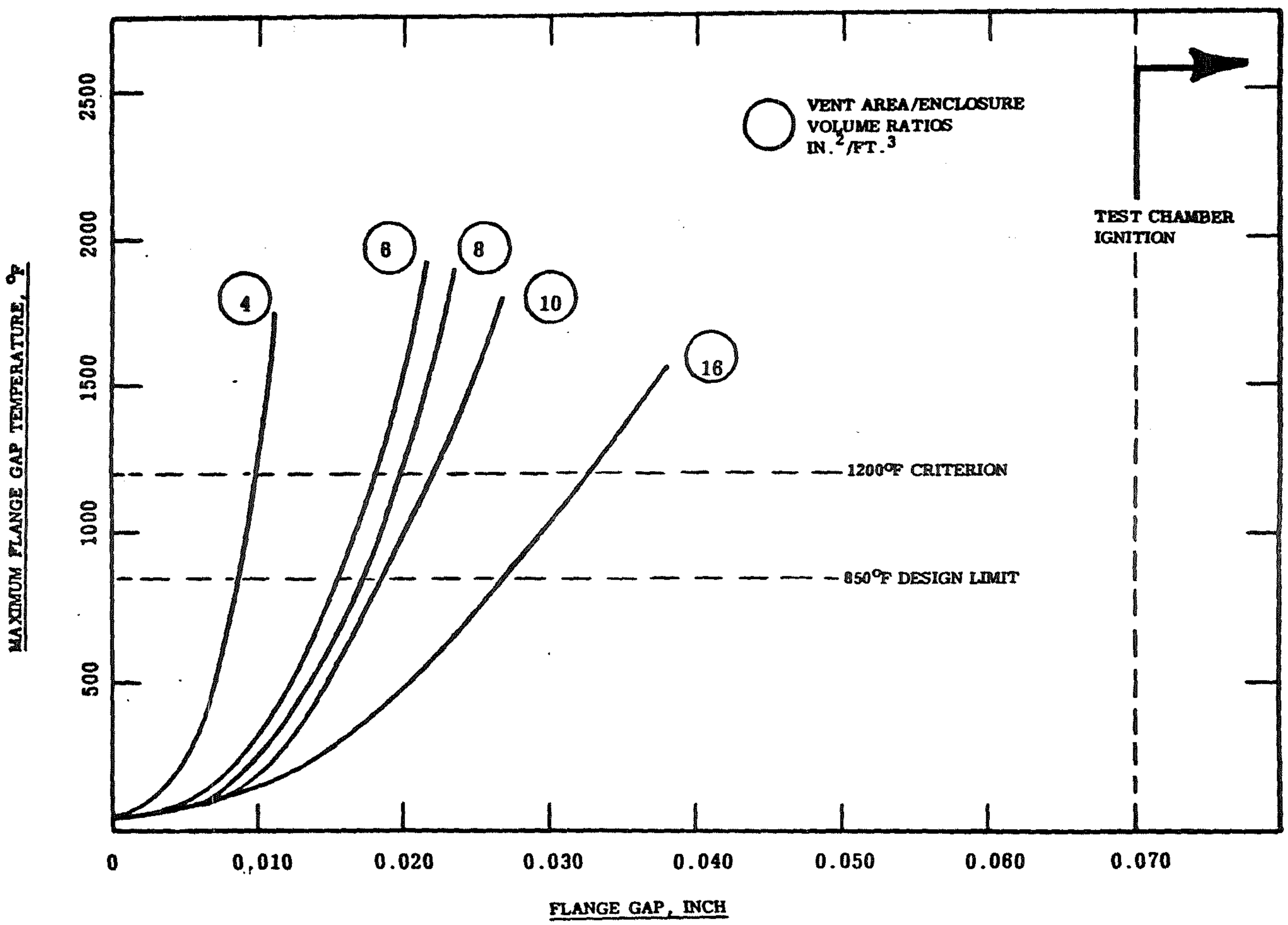


FIGURE 4-7. - Flange gas termperatures for vented enclosures.

vent size since the earlier tests had established that there was no significant degradation of the vent beyond 15 tests. The test configurations were as follows:

- $4\ in^2/ft^3$ vent with 16 screens and flange gap of 0.005 inch.
- $8\ in^2/ft^3$ vent with 10 screens and flange gap of 0.015 inch.
- $16\ in^2/ft^3$ vent with 3 screens and flange gap of 0.025 inch.

These tests established that the screen and metal foam combinations were durable and met the performance criteria even under multiple explosions. In actual practice, a periodic maintenance schedule may be designed to examine the inside surfaces of the vent and to replace the vent which shows evidence of an explosion inside the enclosure. The detailed data collected during the explosion tests for establishing the parametric relationships has been given in Appendix H.

Additionally, tests were conducted to determine what, if any, were the personnel hazards posed by the performance of the pressure vent should an explosion occur within the enclosure. Two major concerns were raised:

- Do the hot gases exiting the vent present a burn hazard?
- Does the hinged cover open at a velocity which might cause injury?

Simulated tests demonstrated that neither of these conditions are likely to cause injury. Details of the testing are included in Appendix I.

4.4 Design Guidelines

The following design guidelines are recommended to be used for the design and application of pressure vents for explosionproof electrical enclosures:

- Mechanical Assembly

  The pressure vent must be provided with a one-half inch thick slab of stainless steel metal foam and a sufficient number of stainless steel screens on the inside face of the metal foam. The screens provide thermal support to the metal foam. The general mechanical fixturing details such as the bolt spacing, wall thickness, flange thickness and the like must meet the revelant requirements of the CFR. Additionally, the mechanical assembly must meet the following requirements:

- Must prevent bulging of screens by providing sufficient mechanical support. Bulging results in oxidation and erosion damage to the screens and reduces the thermal protection given to the metal foam.

- Must assure overlap of the screens so as to avoid directly open paths through the screen.

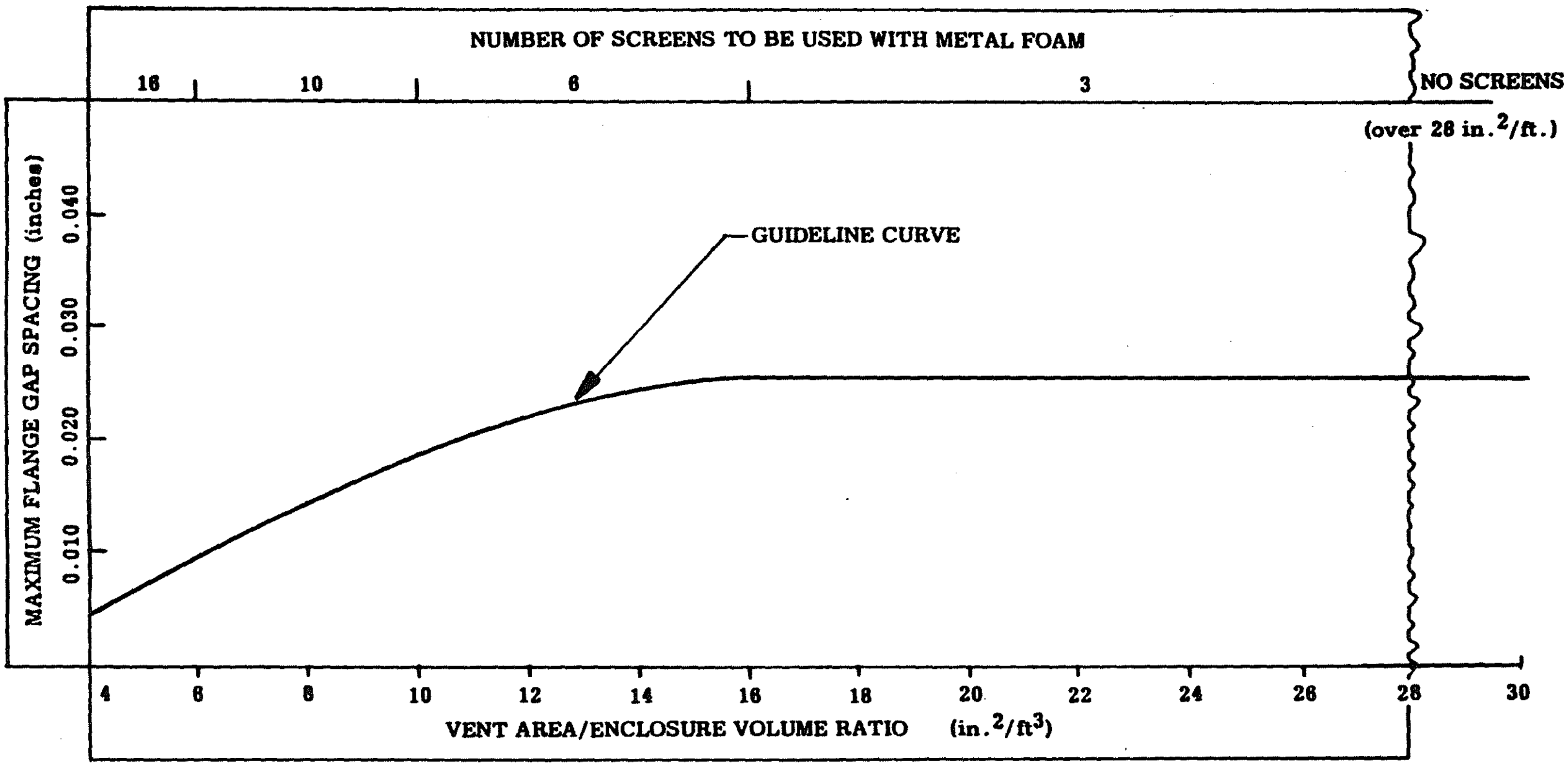
- Must cover the edges of the metal foam and screen pack so as to prevent the bypassing of the hot explosive gases through the edges.

- <u>Number Of Stainless Steel Screens</u>

  The minimum number of screens to be used in a vent increases as the vent area to enclosure volume ratio reduces. The number of screens used in the vent design must be more than or equal to the number of screens shown in Figure 4-8

- <u>Flange Gap</u>

  The maximum allowable flange gap for an enclosure decreases as the vent area to enclosure volume ratio decreases. The enclosure cover must be so designed that the flange gap does not exceed the values given in Figure 4-8.



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 4-8. - Suggested guidelines for number of screens and allowable flange gaps for vents on explosionproof electrical enclosures.

- Vent Materials

  The stainless steel metal foam recommended to be used in the vent is a one-half inch thick slab of Retimet[1] 45 NC 13. This material was used in the extensive explosion test program. The stainless steel screen recommended for the vent is a 20 mesh, 0.018 inch wire diameter, 304 stainless steel screen.

It should be noted that while the guidelines recommend design practice which can assure enclosure performance within the developed criteria, they are not intended to replace the certification testing by MSHA.

1 Registered trade mark of Dunlop Ltd. Coventry, UK.

5.0 DESIGN GUIDELINES FOR ELASTOMERIC CABLE ENTRIES

The objective of this effort was to develop a family of cable entries which uses a minimum number of elastomeric grommets to accommodate most of the cables commonly used on mining machinery. Preliminary testing indicated that a moderately firm polyurethane had the proper combination of material properties for this application. However substantial design refinement coupled with extensive laboratory testing were required to optimize the cable entry design. As was also true of the pressure vent, adequate performance criteria for this type of cable entry did not exist. Therefore, these had to be developed as a starting point.

5.1 Performance Criteria

The criteria used to evaluate the performance of the cable entry hardware were developed on the basis of the following sources:

- Requirements of CFR where applicable.
- Desirable performance features of existing asbestos packed cable entries.

The properties of asbestos packed cable entries were established through extensive dimensional analysis, as well as through tensile and torque testing. These properties formed the basis of the following performance criteria for elastomeric entries:

- The cable must tolerate a tensile load of 30 lbs. before slipping.
- The grommet and compression nut must be properly seated at a torque in the 10 to 60 foot-pounds range.
- The elastomeric grommet must contact the cable at least over one half inch in an assembled entry.
- The cable entry must be compatible with the in-mine inspection techniques currently in use.

- It must be possible to remove or enter a cable without disassembling the cable entry.

- All materials must meet the fire and toxicity requirements of MSHA.

- The cable entry must meet the applicable explosion performance criteria developed for pressure vents such as no explosion of the test chamber, no sparks or flashes and the like.

- The cable must not slip through the grommet during explosion testing.

These criteria provided a basis against which the hardware was evaluated.

5.2 Grommet Material Selection

Evaluation of several candidate materials and laboratory testing led to the selection of polyurethane[1] as the grommet material. It has proven industrial performance as an elastomeric seal material. It is highly resistant to wear, abrasion and the affects of oil, grease and water. The flammability of the selected polyurethane grommet material was tested through an independent test laboratory[2] to verify its conformance with MSHA requirements.

5.3 Cable Entry Sizes

One of the design goals was to achieve a minimum number of grommets necessary to accommodate the commonly used cables. This would avoid inventory problems in underground maintenance. As a first step towards this goal, the cable sizes most commonly used on face mining machines had to be identified. Table 5-1 shows the cables commonly used on Jeffrey machines. It was initially hypothesized that this range of cables could be accommodated with only three grommets. Preliminary testing indicated however that four grommets would probably be required. The cable sizes were grouped in several ways to determine an appropriate diameter range for each grommet. This process was complicated by the wide diameter tolerance for some of the cable types and sizes.

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1 MP-850 thermoset polyester urethane cross linked with Moca, supplied by Newage Industries Incorporated, Willow Grove, Pennsylvania.

2 Foster D. Snell Inc., Florham Park, New Jersey

TABLE 5-1 - Cables commonly used on Jeffrey Mining Machines

Cable	Outside diameter Minimum/maxium (inch)	Tolerance (inch)	Usage*	Re-entry frequency *
3C #14 PVC	.39/.42	.03	3	3
5C #16 SO	.52/.56	.04	3	3
2C #14 NFR	.53/.57	.04	1	3
3C #14 NFR	.56/.60	.04	2	3
4C #14 NFR	.60/.64	.04	3	3
1C #1/O AMA	.60/.65	.05	1	2
2C #10 NFR	.64/.68	.04	3	3
3C #12 X/HVY NFR	.69/.75	.06	1	1
4C #10 NFR	.74/.78	.04	1	3
6C #12 A&S	.75/.79	.04	3	3
5C #14 X/HVY NFR	.75/.81	.06	1	1
3C #8 AMA	.76/.82	.06	2	3
1C #4/O PVC	.77/.81	.04	1	1
1C #4/O AMA	.77/.83	.06	1	1
1C #2 AWG 5KV	.78/.84	.06	1	1
4C #6 A&S	.81/.86	.08	3	3
3C #8 AVA or 9C #14 A&S	.81/.86	.05	1	3
7C #14 X/HVY NFR	.86/.91	.05	3	3
12C #14 NFR	.88/92	.04	1	3
3C #6 GGC	.98/1.04	.06	2	1
6C #6 AVA	1.05/1.13	.08		
3C #4 GGC	1.14/1.20	.06	3	2
3C #2 GGC	1.31/1.37	.06	3	3
3C #1 NFR	1.48/1.54	.06	1	3
36C #14	1.55/1.65	.10	3	2
3C #2/O GGC	1.71/1.79	.08	2	1
3C #1/O SHD 2KV	1.78/2.03	.25	2	1
3C #1/O SHD 8KV	1.82/1.90	.08	3	1
50C #14	1.83/1.93	.10	3	2
3C #4/O GGC	1.99/2.09	.10	1	1

* Ranking scale is 1 to 3, where 1 is the most frequent.

Ultimately the following grommet size ranges were selected:

- Size A for cable diameters from 0.39 inch to 0.672 inch.
- Size B for cable diameters from 0.64 inch to 1.05 inch.
- Size C for cable diameters from 1.02 inch to 1.54 inch.
- Size D for cable diameters from 1.5 inch to 2.11 inch.

The implications are that only four grommets should be needed for cables from the smallest signal wire up through the very large trailing cables. Subsequent hardware testing verified this possibility. The capability of the grommet to undergo large reductions in the inside diameter, so as to grip a wide range of cable diameters is illustrated in the photographs of the actual hardware, Figures 5-1, 5-2 and 5-3. These photographs show the grommet shape before, during and after the tightening of the cable entry.

5.4 Performance Testing

Four cable entries were fabricated and the hardware was subjected to laboratory and explosion tests. For each of the four cable entry sizes, a range of cable diameters was selected to be as near as possible to the high, low and mid-range covered by the elastomeric grommet. The average hardness of the grommet was measured to be 78 on the Shore Durometer A scale. Each cable was entered and inspected by pulling and twisting. The contact length between the grommet and cable jacket was measured by the squeeze-out imprint left on the cable when the cable was coated with a thick coat of printing ink, just prior to assembly. The tightening torque was measured with a torque wrench and the tensile load was measured in a pull test. A photograph of the tensile test apparatus is illustrated in Figure 5-4. The fixture used for holding the cable entry in the apparatus is illustrated in Figure 5-5.

After the mechanical performance of the cable entry designs had been proven, explosion tests were conducted. Cables in each of the three size ranges were entered into the four cable entries. These were subsequently installed on a one-half cubic foot connection box and explosion tests were run in a manner similar to the tests conducted for

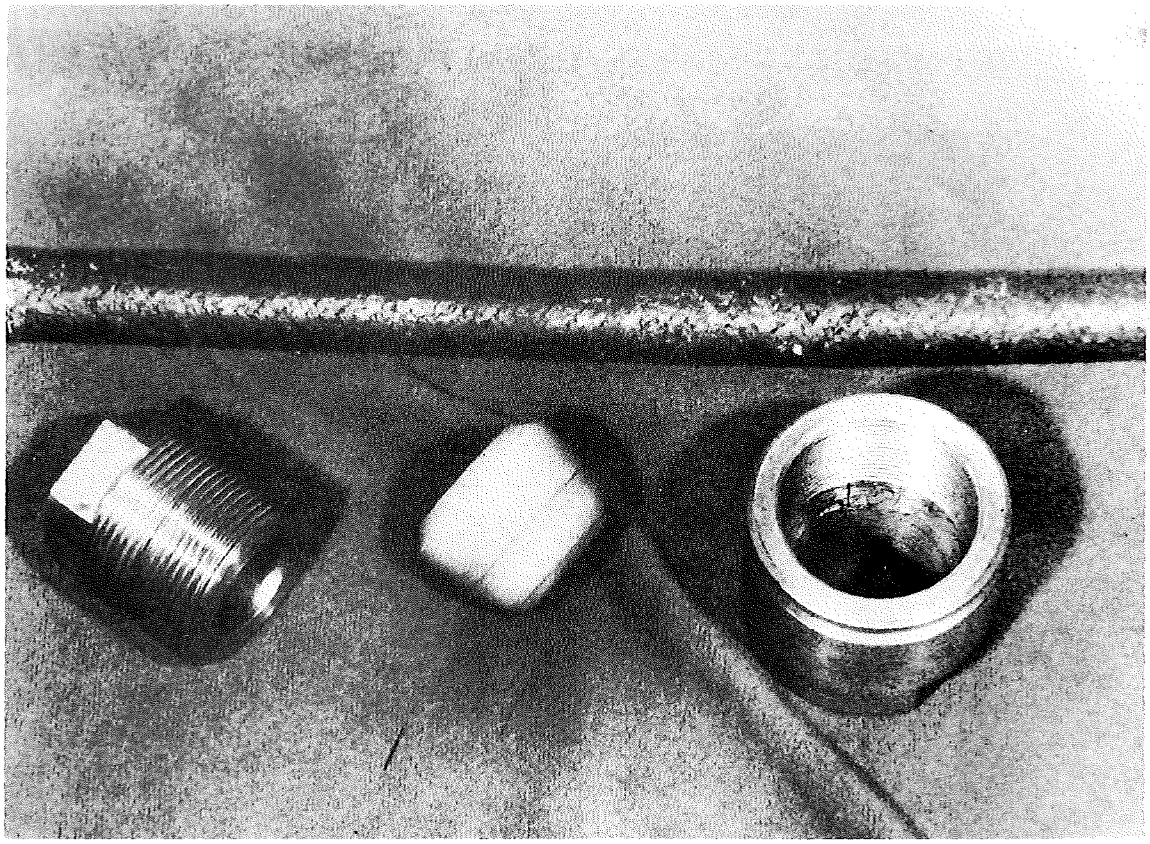


Figure 5-1. Laboratory Test Cable Entry with 4/0 Cable

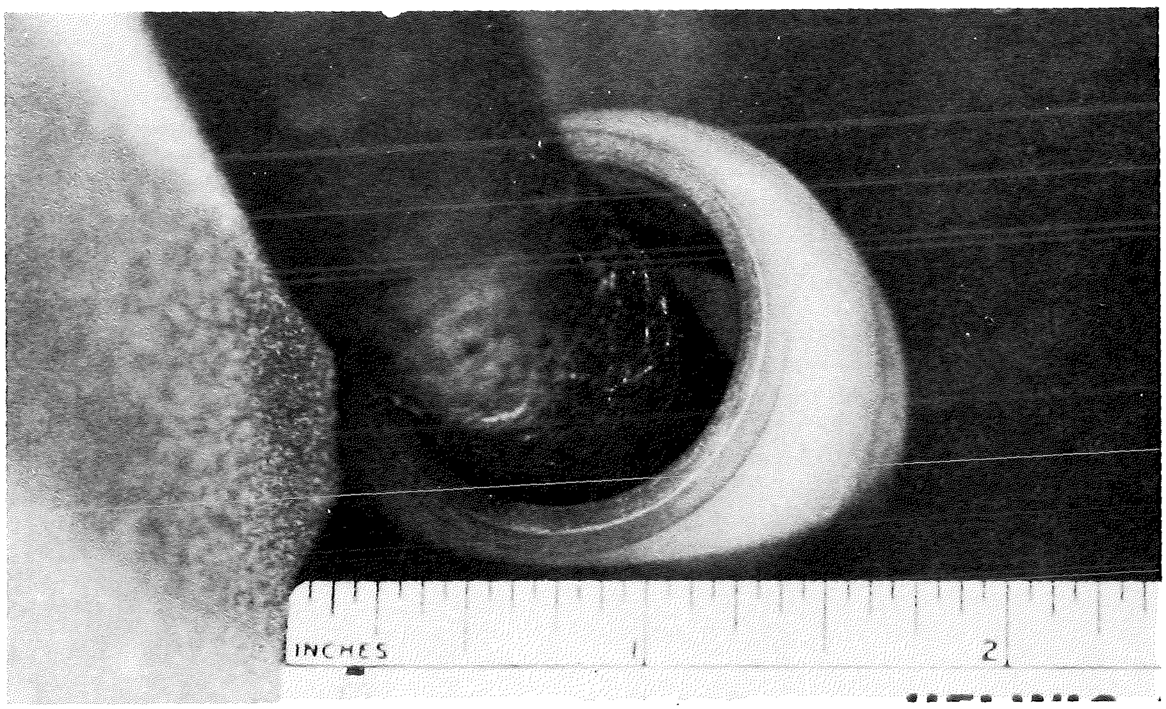


Figure 5-2. Clearance Gap Between Cable and Grommet Before Tightening Entry Compression Nut

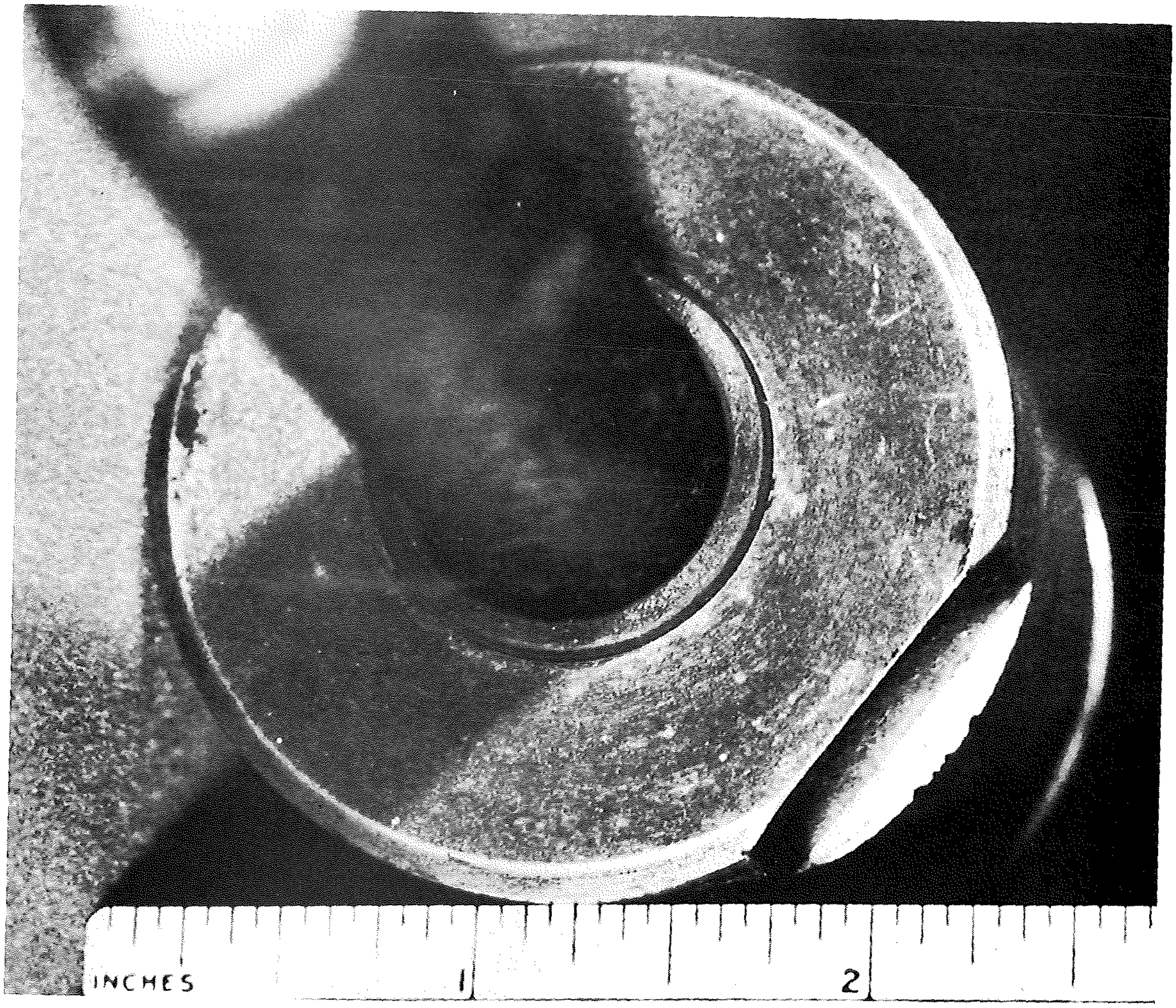


Figure 5-3. Grommet Tight Around Cable After Tightening Compression Nut

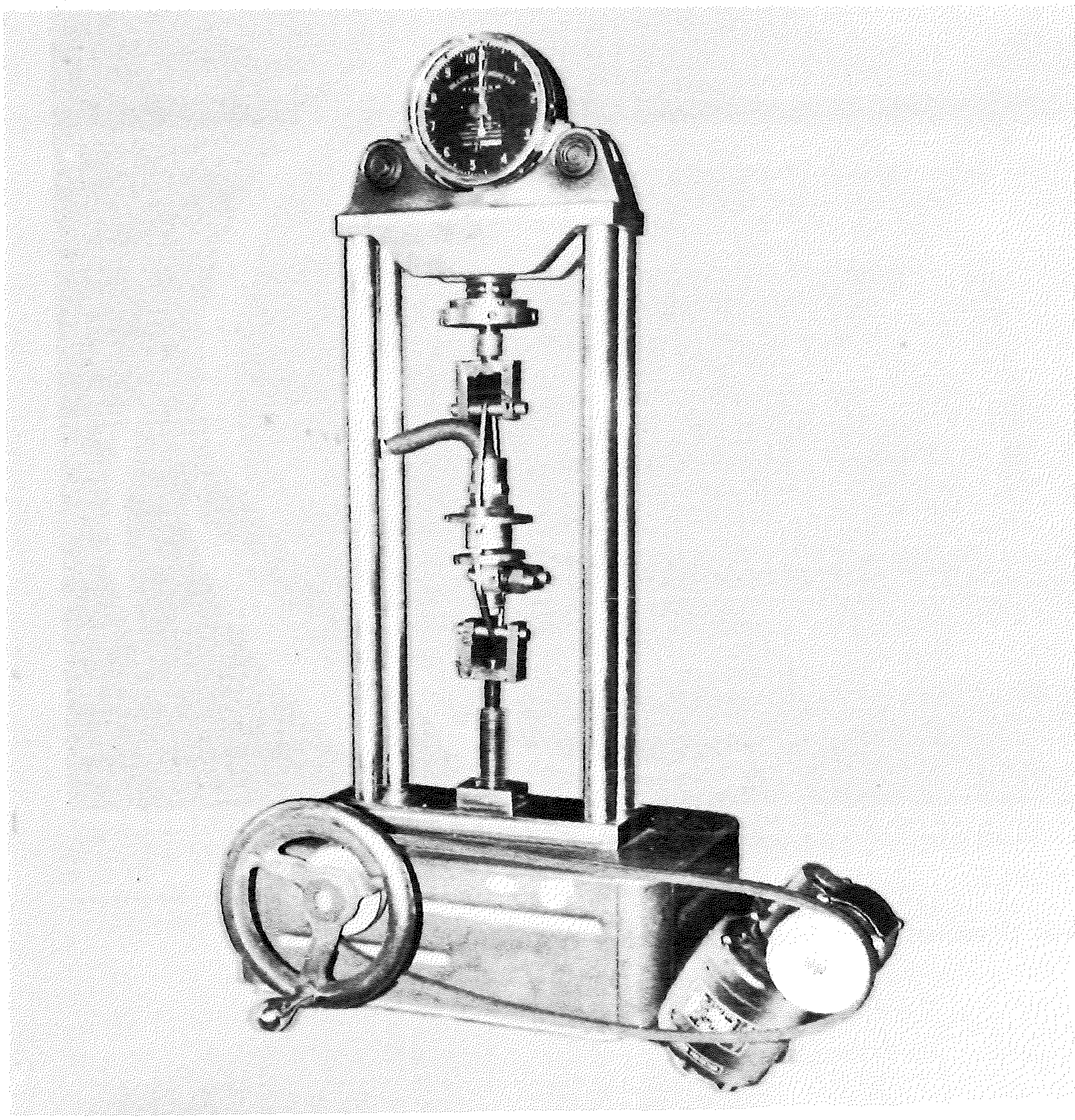


Figure 5-4. Tensile Test Apparatus

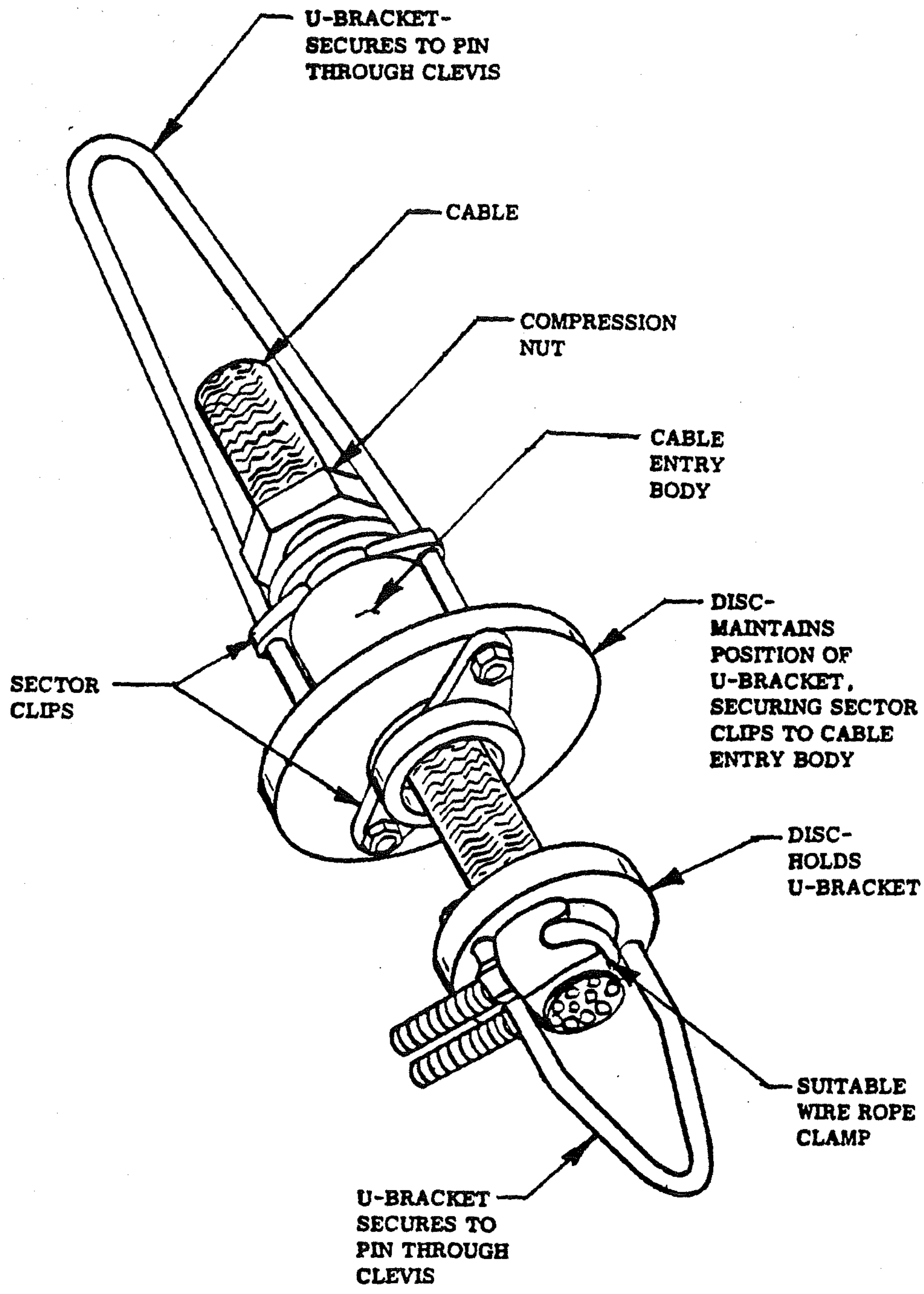


FIGURE 5-5. - Fixture for cable entry pull tests.

the pressure vent hardware. However in the cable entry explosion tests, the enclosure was unvented. Three tests were run for each cable size. The explosion pressure build up in each of these tests was between 58 and 75 psig. No flames, sparks or flashes were emitted from the cable entry. There was no ignition of the test chamber. No displacement of the cables relative to the entry was noticeable in the explosion tests. The hardness of the grommet material remained unaltered. No scorching or burn marks were visible on the grommet material.

Additionally, a series of 10 explosion tests were carried out on a 0.79 inch diameter cable, to evaluate the durability of the cable entry. The average enclosure pressure during these tests was 69 psig. No damage or deterioration of the cable entry was evident. The cable entry met the explosion performance criteria during these tests.

5.5 Design Guidelines

The following design guidelines are recommended to be used for the design and application of elastomeric cable entries for explosion-proof electrical enclosures:

- Cable Entry Size

  The designer must first select the cable entry size that is appropriate for the cable which is to be entered. This selection can be made on the basis of Figure 5-6.

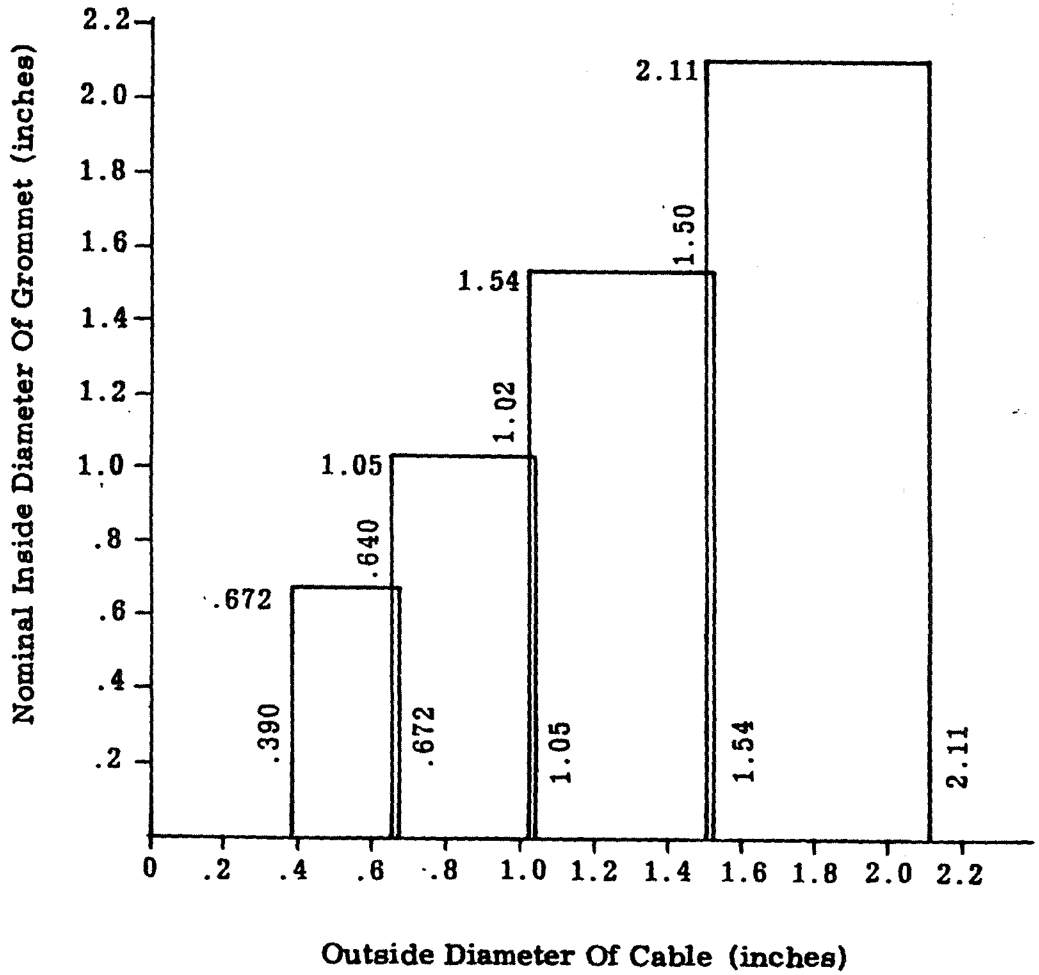
- Grommet Material

  The elastomeric material recommended to be used for the grommet is a standard commercial grade polyurethane equivalent to MP-850[3] with Shore hardness range of 75 to 85 on the "A" scale. It must comply with fire and toxicity requirements specified in the CFR.

- Critical Dimensions

  For effective functioning of the cable entry, the critical dimensions of the grommet, the cable entry body, and the compression nut

3 Grade number designated by the supplier, Newage Industries Inc., Willow Grove, Pennsylvania.



NOTE: **The designer determines the minimum and maximum values for the outside diameter of the cable of interest. He then selects the grommet diameter which will accomodate both of these values.**

FIGURE 5-6. - Suggested elastomeric cable entry sizes for various cable diameters.

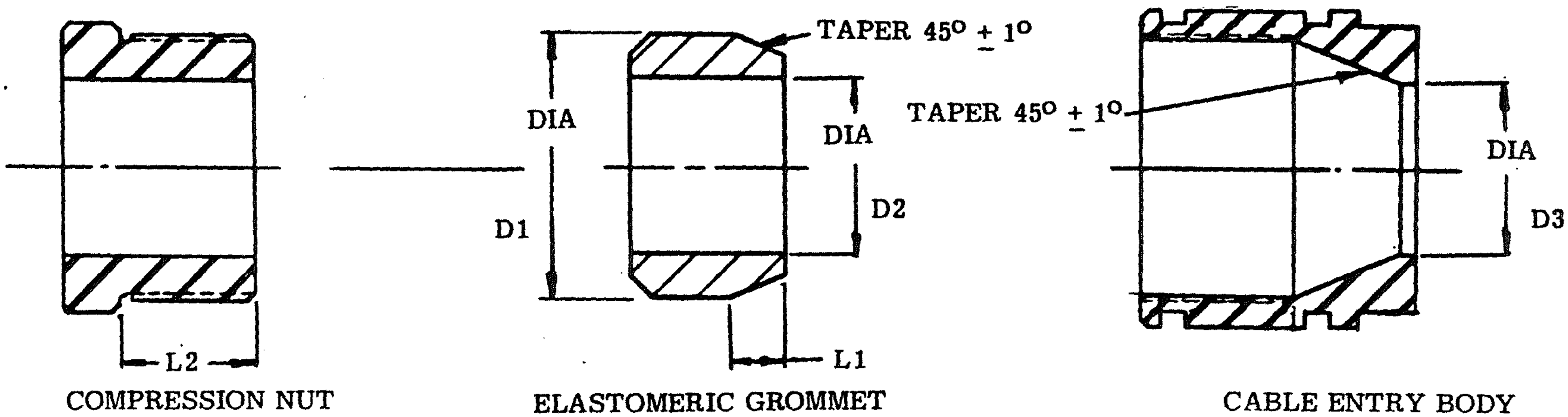
must be maintained within 0.005 inch. These critical dimensions for the four cable entry sizes have been given in Figure 5-7.

Shop drawings corresponding to the four guideline cable entry designs have been given in Appendix J and additional data regarding cable entry performance are given in Appendix K.

It should be noted that while the guidelines recommend design practice which can assure cable entry performance within the developed criteria, they are not intended to replace the centrification testing by MSHA.

The following critical dimensions must be maintained within ± 0.005 inch:

Entry size	D1	D2	D3	L1	L2
A	1.140	.671	.665	.375	1.000
B	1.625	1.046	1.035	.500	1.125
C	2.218	1.531	1.518	.625	1.187
D	2.968	2.109	2.105	.687	1.250



Grommet material is polyurethane with shore hardness 75A to 85A

FIGURE 5-7. - Design guidelines for elastomeric cable entries.

APPENDICES

APPENDIX A UNDERGROUND TEST PLAN

To demonstrate the innovative concepts in an underground coal mine, a connection box for the Jeffrey 120 M continuous miner has been equipped with innovative hardware. This includes:

- A pressure vent which uses a 14 square inch area of Retimet[1] foam metal as the flame arresting medium.
- A cable entry for the trailing cable which uses a tapered polyurethane grommet in place of the conventional asbestos packing.

This hardware has undergone extensive laboratory and explosion testing by both Booz, Allen and MSHA. However, extensive evaluations should be conducted to ensure the suitability of the designs for the mine use environment. This Appendix presents a suggested plan for the conduct of the in-mine demonstration:

- An overview of the in-mine demonstration.
- Monthly inspection procedures.
- Routine inspection procedures.
- Laboratory test procedures.

A.1 An Overview of The In-Mine Demonstration

After the equipment installation, the innovative hardware will be periodically inspected over a three-month period:

- A complete visual inspection of the pressure vent and cable entry assemblies will be made.
- Any damage to the hardware will be noted.
- The accumulation of dust and/or foreign matter on the vent or inside of the enclosure will be recorded.

1 Registered trademark of Dunlop Ltd., Coventry, U.K.

- The vent material and polyurethane grommet will be replaced.

- The dimensions of the Retimet and the grommet will be measured.

- The enclosure will be restored to a permissible condition.

- The section, maintenance and supervisory personnel will be interviewed regarding the performance of the equipment and their acceptance of it.

The nature of some of these activities will require that the machine be temporarily removed from service. Therefore, the hardware inspection and material changes will be planned to take place during a maintenance shift or other appropriate time so as not to disrupt mining operations. The in-mine inspections will be photo-documented to the extent allowed by the miner operator.

During the final mine visit all of the innovative hardware will be removed from the enclosure which will be restored to the original design. This will be done after the final inspection has been performed.

After returning from a mine inspection, a series of laboratory tests will be performed on the materials removed from the innovative hardware:

- Measure the dimensions of the vent material and the polyurethane grommet to determine recovery and permanent set.

- Weigh both the grommet and vent material.

- Perform air flow tests on the vent material to determine the significance of any clogging which may have occurred.

- Determine the durometer hardness of the grommet.

In addition to physical testing, the condition of the material will be fully documented with photographs.

Between the mine visits, the mine operator will perform maintenance and inspection of the innovative hardware in accordance with his established schedule for these activities. More frequent inspections of the pressure vent and cable entry are not anticipated. Weekly phone contact with the designated mine representative will be made to obtain and document the results of the mine operator's regular inspections. The follow-up will be coordinated with the inspection schedule so that the data is obtained in a timely fashion.

A.2 Monthly Inspection Procedures

The pressure vent hardware is illustrated in Figure A-1. The following inspection steps will be carried out during the monthly inspection of the pressure vent hardware:

- Inspect the outside of the pressure vent hardware.
- Check the flange gap at the enclosure covering using a 0.004 inch feeler gage.
- Measure the opening force for the vent cover.
- Open the vent cover and inspect the outside surface of the vent material.
- Check the tightness of the flange bolts.
- Remove the enclosure cover and inspect the inside of the enclosure.
- Inspect the inside vent material surface.
- Check the flange path between the vent body and the cover boss, using a 0.004 inch feeler gage.
- Check the tightness of the vent retainer bolts.
- Remove the vent cover retainer and inspect the hinges.
- Remove the pressure vent assembly from the enclosure cover and inspect it.

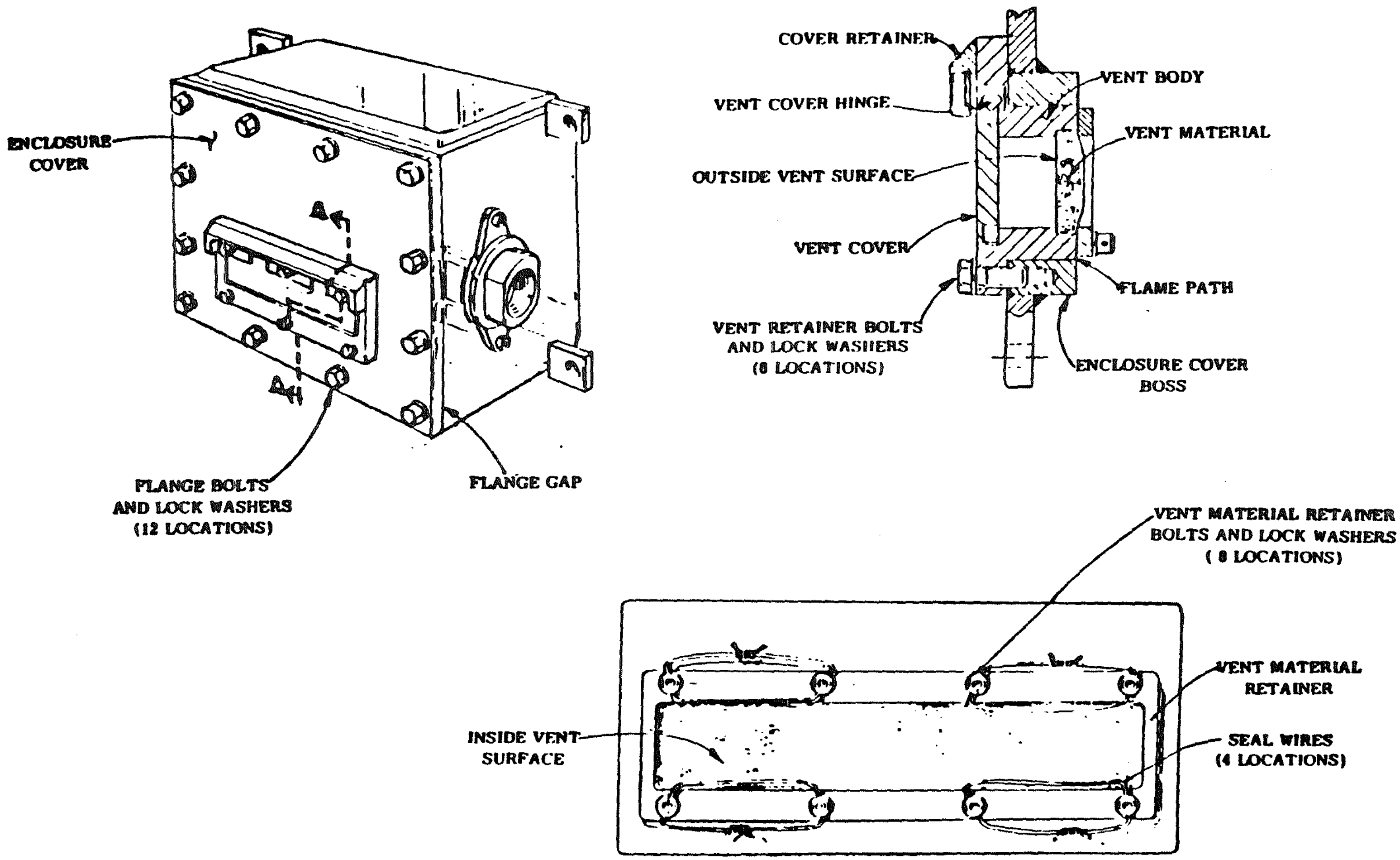


FIGURE A-1. - Pressure vent hardware assembly.

- Inspect the enclosure boss.
- Remove the seal wires and check the tightness of the vent material retainer bolts.
- Inspect the vent material retainer and the vent material.
- Label the inside/outside and top/bottom orientation of the vent material and remove the material.
- Install a new piece of the vent material.
- Install the vent material retainer.
- Install the pressure vent assembly into the enclosure cover.
- Check the flange path between the vent body and the enclosure cover boss, using a 0.004 inch feeler gage.

The cable entry hardware is illlustrated in Figure A-2. After inspection of the enclosure pressure vent, the following steps will be carried out to inspect the cable entry:

- Inspect the outside of the cable entry hardware.
- Loosen the protective conduit and check the trailing cable tightness.
- Inspect the inside cable entry assembly.
- Measure the distance from underneath the compression nut to the cable entry body with a measuring scale. This distance must be at least 1/8" for a permissible assembly.
- Remove the trailing cable from all electrical connections.
- Remove the seal wire and check the tightness of the anchor bolt.
- Check the tightness of the clip retainer bolts and remove the retainer clips.

TABLE A-2.- Routine pressure vent inspection criteria

ITEM	REQUIREMENT	TOOLS/GAUGES	INSPECTION METHOD	CORRECTIVE ACTION
Outside Vent Surface	. 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 filter 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	. Opening unobstructed by accumulation of dust, grease or other foreign matter.	. Wrenches - 9/16" box, open end or socket. - 3/4" box, open end or socket.	. Either remove the vent assembly from the enclosure cover or remove the entire cover. . Visually inspect the condition	. Remove filter 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	. 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. - 3/4" 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.
Flame Path Clearance	. .004" max. between the vent body and the enclosure boss	. .004" feeler gauge and .004" gauge wire.	. With the assembly secured into the enclosure cover, gauge into the flame path . Use the gauge 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.

TABLE A-2. - Routine pressure vent inspection criteria (continued).

ITEM	REQUIREMENT	TOOLS/GAUGES	INSPECTION METHOD	CORRECTIVE ACTION
Vent Retainer Bolts	. 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	. Cover must swing open freely, except for overcoming magnet that keeps cover from flapping.	. Screw driver	. Flip cover open with screwdriver and visually check for freedom to swing and to be held closed by the magnet.	. Remove the hinge cover and the cover, clean and reinstall.

TABLE A-3. - Routine elastomeric cable entry inspection criteria

Item	Requirement	Tools/gauges	Inspection Method	Corrective Action
Retainer Clip	. 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	. 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 2-½" open end wrench and one 2-5/8" open end wrench are required to disassemble and assemble the cable entry.
Flame Path Clearance	. .006" maximum diametrical clearance between the cable entry body and the enclosure wall.	. .006" feeler gauge wire	. With the cable entry secured into the enclosure try to insert the guage 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.

TABLE A-3. - Routine elastomeric cable entry inspection criteria (continued).

Item	Requirement	Tools/gauges	Inspection Method	Corrective Action
Gland nut spacing	. 1/8" minimum clearance between the gland nut flange and the cable entry body.	. 3/4" open end, box or socket wrench . 1/8" guage block or feeler guaspace.	. With the enclosure cover removed, try to insert the guage into the clearance	. Replace the grommet with a new one as required.
Seal wire anchor bolt	. Bolt and lock washer must be present. . Bolt must be tight.	. 3/4" open end, box or secket 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	. Seal wire must be present and secured.	. 3/4" open end, box or socket wrench	. With the enclosure cover removed, visually inspect for the presence of the wire and seal.	. Replace missing components.

metal foam may reduce its effectivenss and a permanent set may degrade the elastomeric grommet. Several laboratory tests have been planned to expose these problems if they occur:

- Measuring the air flow through the vent material at low pressure.
- Weighing the metal foam.
- Weighing the grommet.
- Determining the durometer hardness of the grommet.
- Measuring various critical dimensions of both the grommet and the vent.

These data will be compared with results obtained before installation in the mine so that any changes can be identified and analyzed. The durometer, weight and dimensional analysis will be performed using standard laboratory procedures. However, the flow tests require special apparatus.

A flow test apparatus has been devised using a laboratory flow meter. This apparatus is illustrated in Figure A-3. Initial trials conducted with this apparatus indicate a coefficient of discharge of 0.2 for Retimet metal foam. If the discharge coefficient for the porous metal foam is reduced by clogging, its effectivenss as a pressure vent may reduce. Hence the measurement of the discharge coefficients before and after in-mine use will indicate the degree of loss of effectiveness of the vent material, if any.

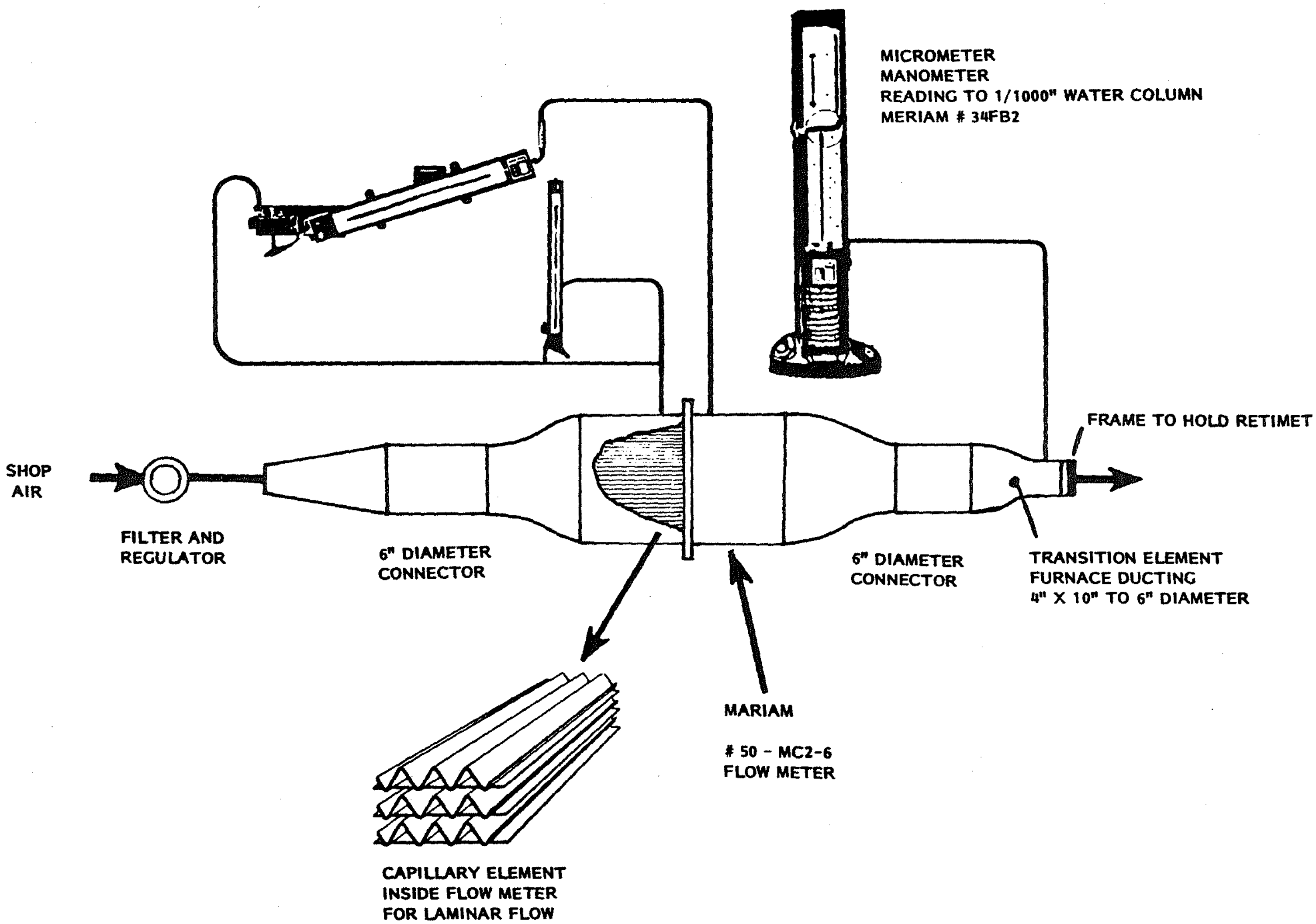


FIGURE A-3. - Apparatus for clogging tests.

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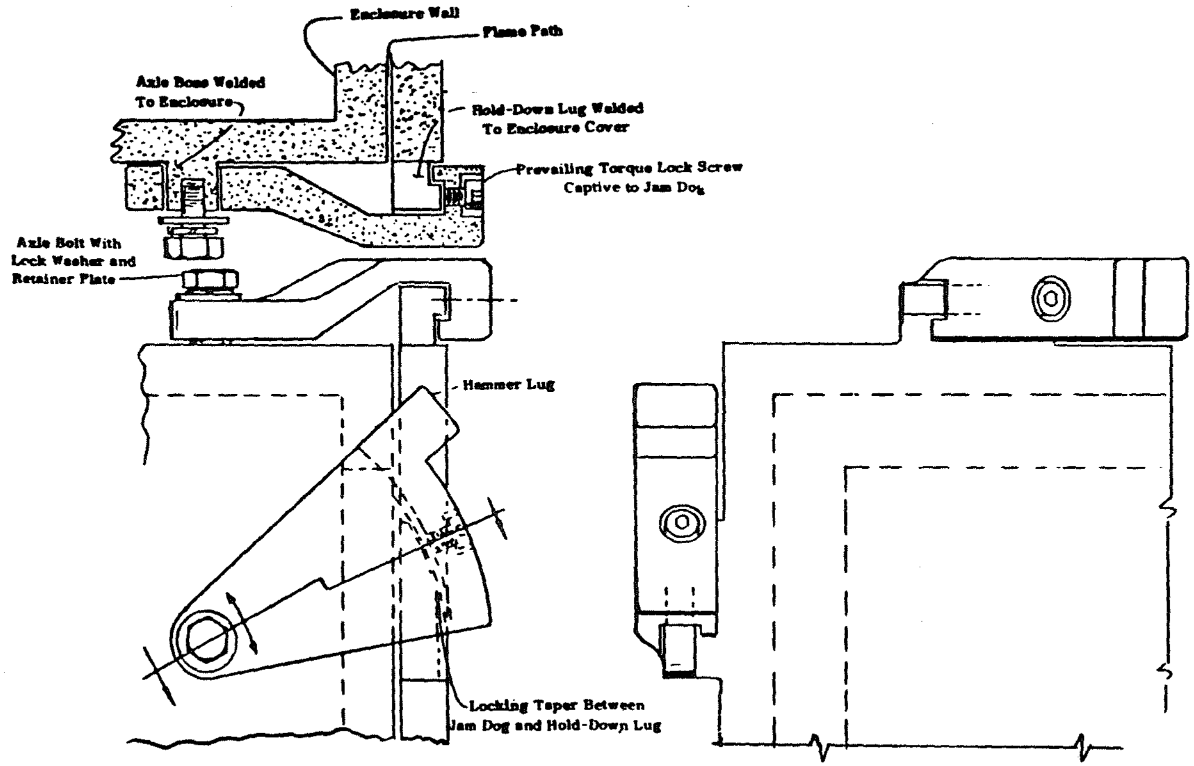
APPENDIX C QUICK ACCESS COVER CONCEPTS

Additional quick access cover concepts for explosion-proof electrical enclosures are described in Figures C-1 through C-8 of this appendix. For various reasons, these concepts were not rated as highly for the mining application as those described in Section 3.0. Therefore, they were dropped from further consideration.



DESCRIPTION

To open the cover, the lock bolt is loosened and the jam dog is rotated clear of the hold-down lug. During the cover replacement operation, the locking taper prevents the jam dog from rotating before the lock screw is tightened.

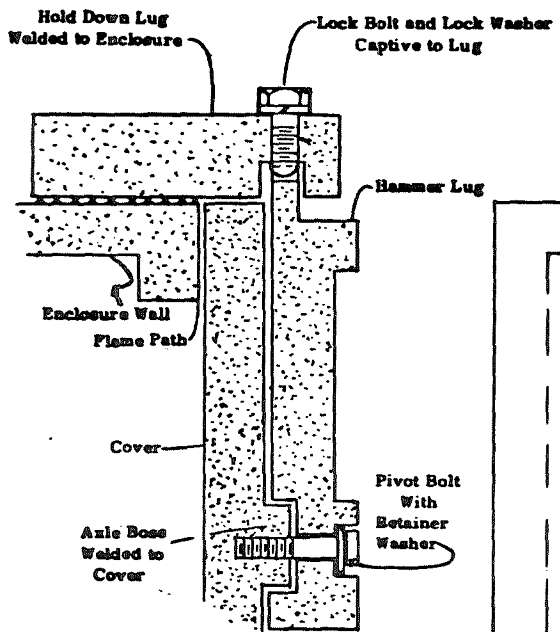
ADVANTAGES

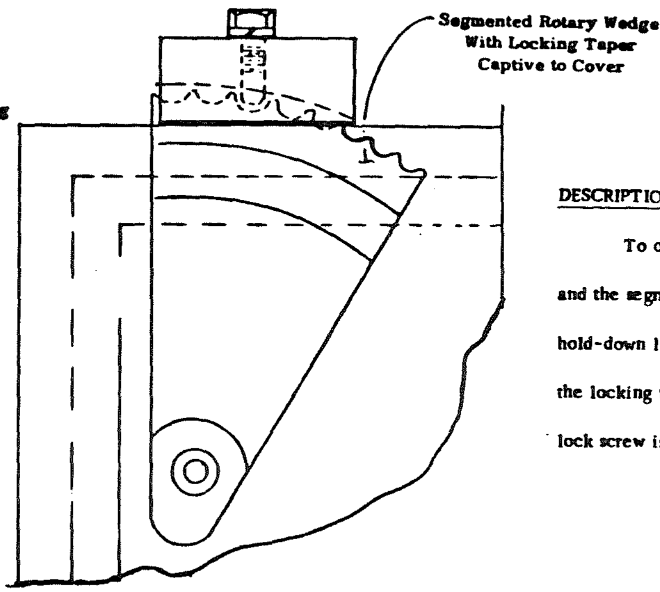
- The mechanism is durable and easily repaired in the mine.
- The jam dog and lug may be cast or forged.
- The flange gap may be easily measured with a feeler gauge.
- All parts are captive.
- Maximum adjustability is 1/4" to 1/2".

DISADVANTAGES

- The mechanism projects 1" beyond the cover.
- The mechanism requires the machining of tapped blind holes.
- Requires the use of prevailing torque lock screws in the jam dog because the lock screw will not normally bottom out against the counter bore shoulder.

FIGURE C-1. - Jam dog concept.





DESCRIPTION

To open the cover the lock bolts are loosened and the segmented rotary wedge is driven clear of the hold-down lug. During the cover replacement operation, the locking taper prevents the wedge from rotating before the lock screw is tightened.

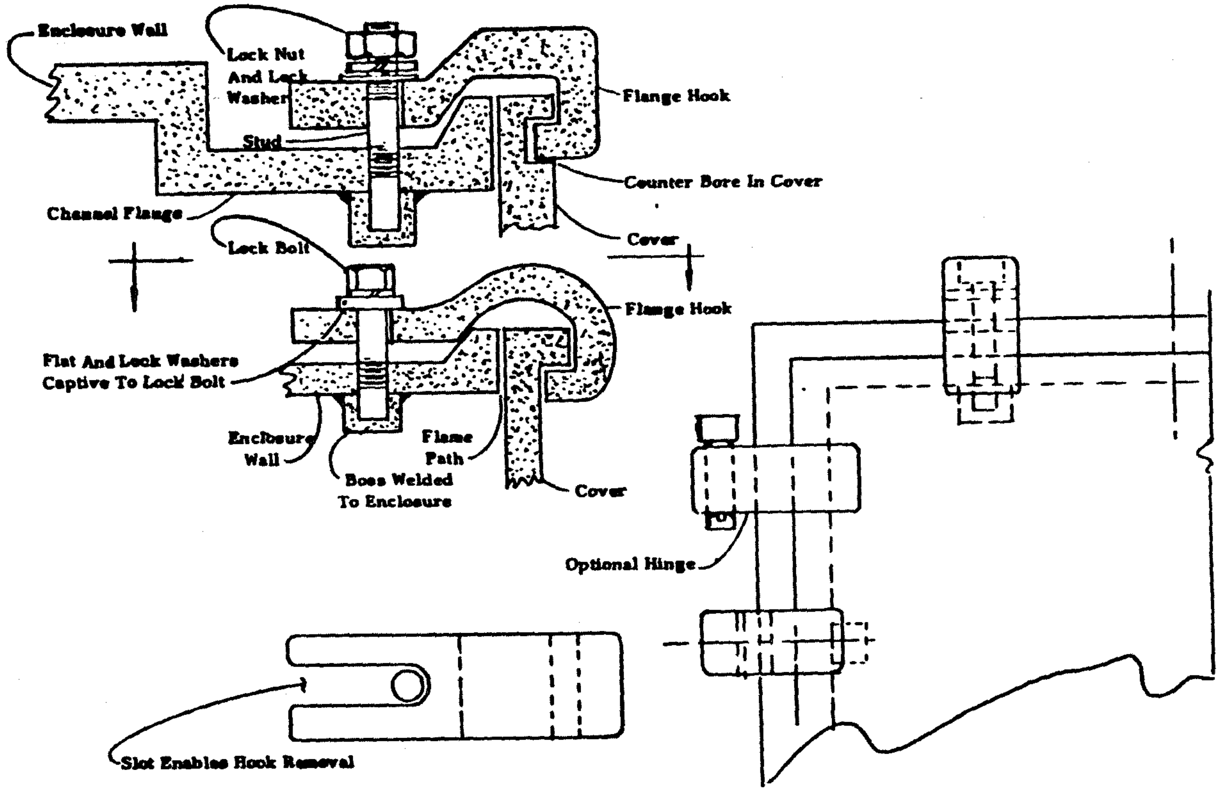
ADVANTAGES

- Mechanism is durable and easily repaired in the mine.
- Segmented wedge and hold-down lug may be cast or forged.
- The large size of the wedge may justify an increase in the spacing between fastening points.
- The flange may be easily measured with a feeler gauge at all locations between the hold-down lugs.
- All parts are captive to either the enclosure or the cover.
- The hold-down lugs projecting from the cover hold the cover weight and assist in positioning the cover during replacement. For this reason, hinges are not necessary but may still be desirable.
- Maximum adjustability is 1/4" to 1/2".

DISADVANTAGES

- Mechanism projects 1" beyond the cover.
- The locations of the hold-down lug and the axle boss are somewhat critical and may require close tolerance welding.
- The mechanism is fairly complex requiring tapped blind holes, some machining and the assembly of several parts.
- The attachment of bosses and segmented wedges to the cover substantially increased cover weight.

FIGURE C-2. - Segmented rotary wedge concept.



DESCRIPTION

To open the cover the lock bolts are loosened and the hooks are removed from the enclosure. When the hook is removed the flat washer remains in place close to the head of the lock bolt thereby assisting in hook replacement. During cover replacement the hooks may be driven tight with a hammer. The shape of the flange or counter bores in the cover prevent the hooks from sliding or rotating when the lock screws are tight.

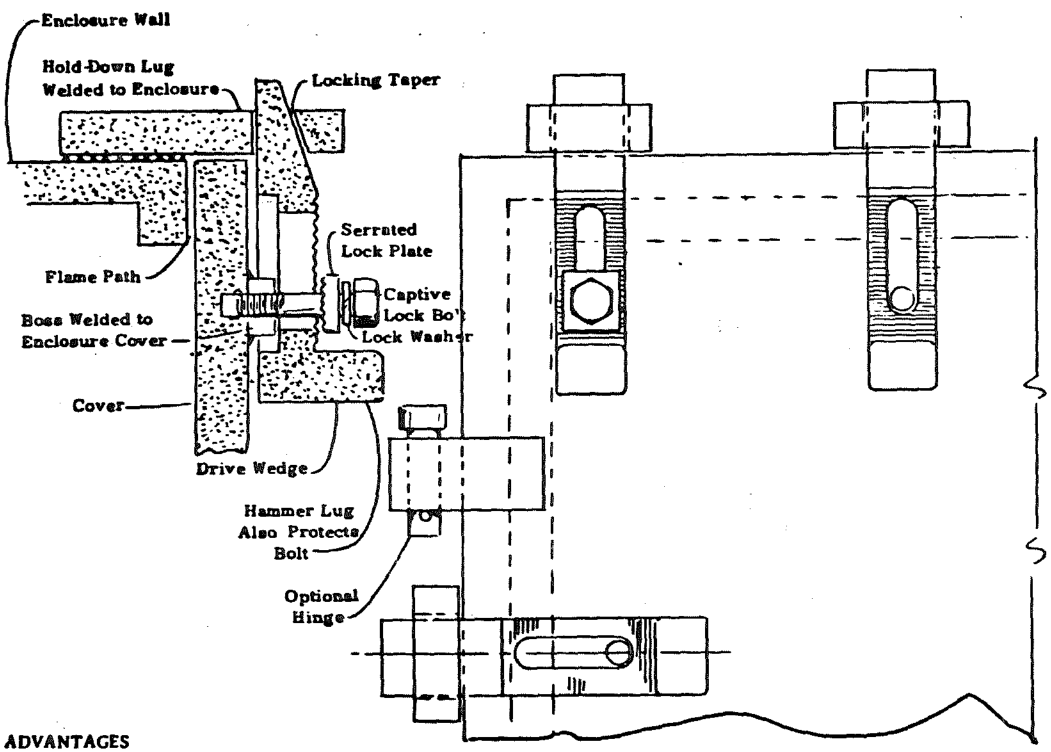
ADVANTAGES

- The mechanism is durable and easily repaired in mine.
- The flange gap clearance can be easily measured with a feeler gauge at all locations between the hooks.
- The hooks may be cast or forged from bar stock.
- The counter bore option projects only about 1/2" beyond the cover.
- Maximum practical adjustability is 1/8" to 1/4".

DISADVANTAGES

- The washers and lock nuts are not captive for the stud option.
- Requires the use of tapped blind holes.
- Access to the lock bolts may be difficult for some enclosure configurations.
- May be difficult to machine the taper on the back edge of the flange.
- Hinges are needed to relieve the mechanic of the cover weight and to help position the cover during the replacement operation.

FIGURE C-3. - Flange hook concept.



DESCRIPTION

To open the cover, the captive lock bolts are loosened and the wedges are driven clear of the lugs with a hammer. Matching serrations on the wedge and the lock plate prevent motion of the wedges when the lock bolts are tightened. Friction developed by the locking taper prevents the wedge from loosening before the lock bolts are tightened.

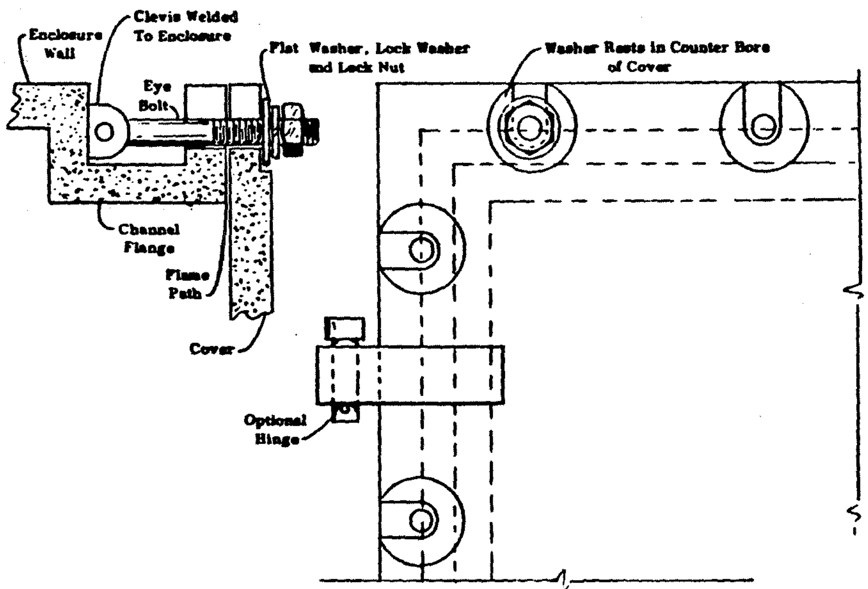
ADVANTAGES

- The mechanism is durable and easily repaired in mine.
- All parts are captive and need not be removed to open the cover.
- The flange gap clearance can be easily measured with a feeler gauge at all locations between the lugs.
- Hold-down lugs projecting from the enclosure hold the cover weight and assist in positioning the cover during replacement. For this reason hinges are not necessary but may still be desirable.
- Wedges and lugs may be cast or forged.
- The integral hammer lug protects bolt heads from abrasion and impact.

DISADVANTAGES

- Mechanism projects about 1" beyond the cover.
- The attachment of bosses and wedges to the cover substantially increases cover weight.
- Requires the use of tapped blind holes.
- Wedges may interfere with cover replacement.
- The location of the hold-down lugs is somewhat critical and may require some close tolerance welding.
- Maximum practical adjustability is 1/8" to 1/4".

FIGURE C-4. - Drive wedge concept.



DESCRIPTION

To remove the cover, the lock nuts are loosened and the eye bolts are swung clear of the cover. Engagement of the lock washers into the cover counter bores prevents bolt movement after the nuts are tightened.

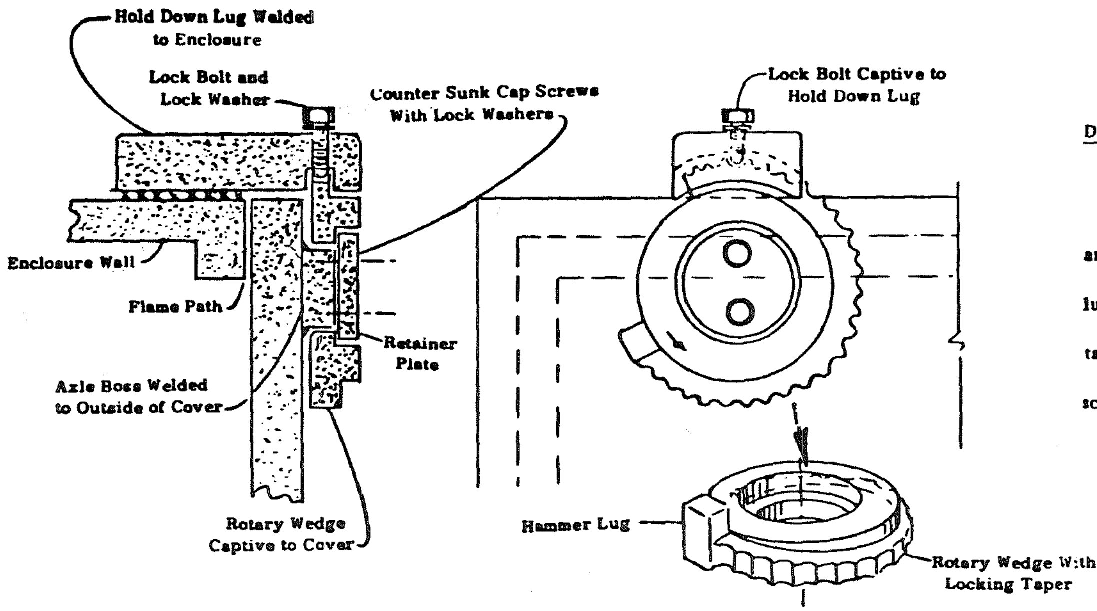
ADVANTAGES

- Broken eye bolts are easily replaced by removing the clevis pins.
- Requires no tapped blind holes or close tolerance machining.
- The clevis could be cast, forged, or fabricated depending on production economics.
- The flange gap clearance can be easily measured with a feeler gauge at all locations between the bolts.
- All parts are captive to the enclosure and need not be removed to open the cover.
- Mechanism projects about 1/2" beyond the cover.
- Maximum practical adjustability is unlimited.

DISADVANTAGES

- Eyebolts are not well protected.
- Use of the special eye bolts is undesirable in mines.
- The use of clevises and external flanges impede packaging the enclosures onboard equipment.

FIGURE C-5. - Clevis bolt concept.



DESCRIPTION

To open the cover the lock bolts are loosened and the rotary wedge is driven clear of the hold-down lug. During the cover replacement operation, the locking taper prevents the wedge from rotating before the lock screw is tightened.

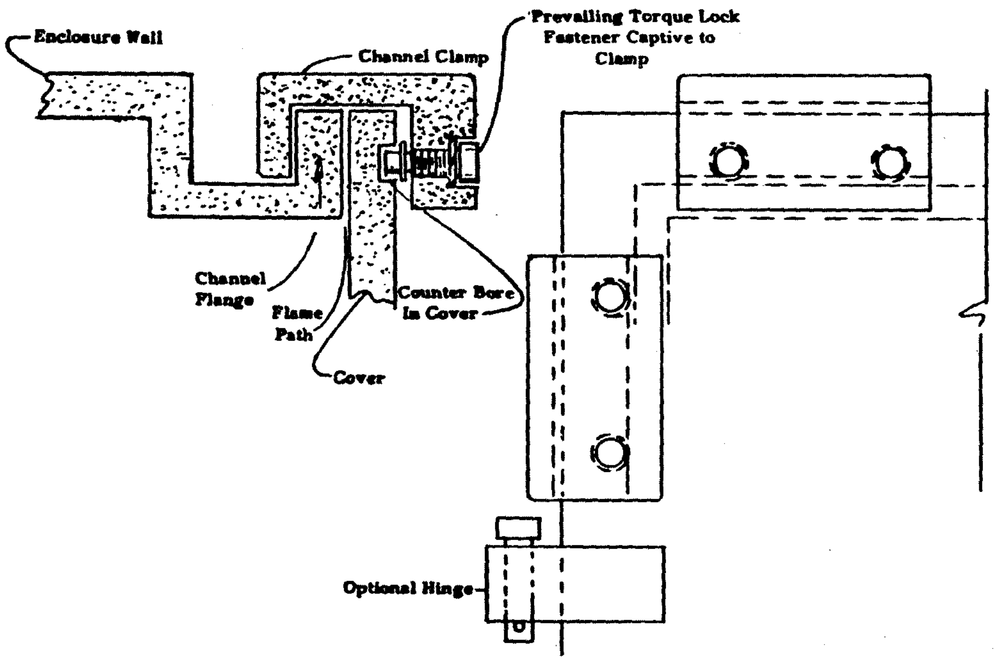
ADVANTAGES

- Mechanism is durable and easily repaired in the mine.
- Rotary wedge and hold down lug may be cast or forged.
- The large size of the rotary cam (4" to 6" diameter) may justify an increase in the spacing between fastening points.
- The flange may be easily measured with a feeler gauge at all locations between the hold-down lugs.
- All parts are captive to either the enclosure or the cover.
- The hold-down lugs projecting from the cover hold the cover weight and assist in positioning the cover during replacement. For this reason, hinges are not necessary but may still be desirable
- Maximum adjustability is 1/4" to 1/2".

DISADVANTAGES

- Mechanism projects 1" to 1 1/2" beyond the cover.
- The locations of the hold-down lug and the axle boss are somewhat critical and may require close tolerance welding.
- The mechanism is fairly complex requiring tapped blind holes, some machining and the assembly of several parts.
- The attachment of bosses and rotary wedges to the cover substantially increases cover weight

FIGURE C-6. - Rotary wedge concept .



DESCRIPTION

To open the cover the cap screws are loosened and the clamps are removed from the enclosure. The counter bores in the cover prevent the clamps from sliding or rotating when the cap screws are tight.

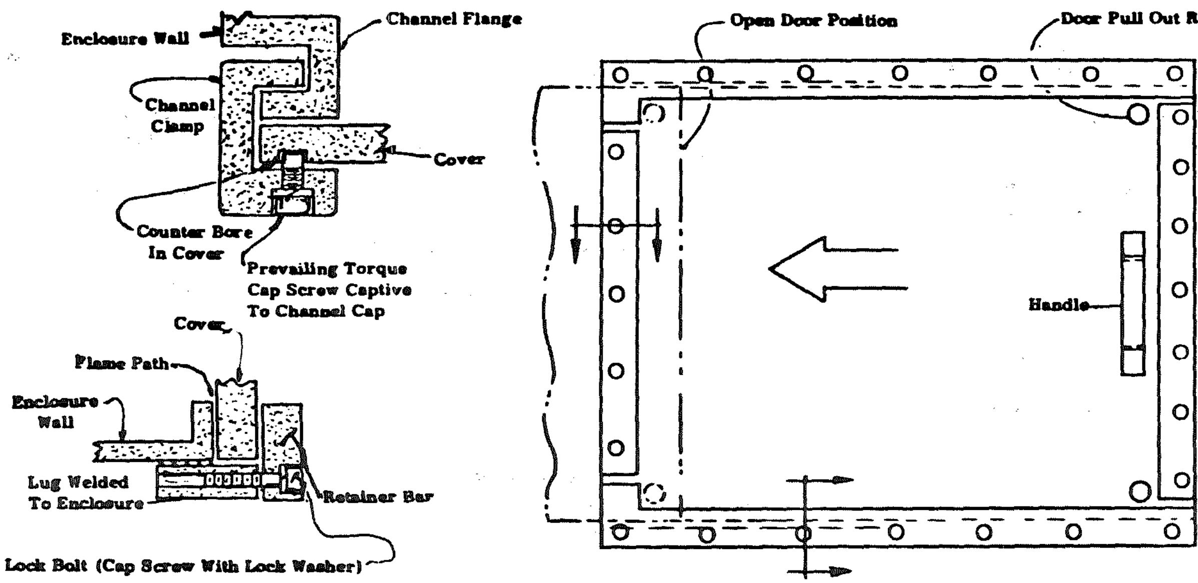
ADVANTAGES

- Flanges are well protected by the clamps.
- Requires no tapped blind holes on close tolerance machining.
- The clamp could be cast, forged, extruded or fabricated depending on production economics.
- The mechanism is durable and easily repaired in mine.
- The flange gap clearance can be easily measured with a feeler gauge at all locations between the clamps.
- The cap screws are captive to the clamp and although these are not captive to the enclosure, they are not likely to be lost.

DISADVANTAGES

- Mechanism products about 1/2" to 1" beyond the cover.
- The use of cap screws is undesirable since their adjustment requires a special tool.
- The use of external flanges may impede packaging the enclosures on board equipment.
- May be necessary to provide inspection slots in the channel clamp to allow feeler gauge access to the flange gap.
- Hinges are needed to relieve the mechanic of the cover weight and to help position the cover during the replacement operation.
- Requires the use of prevailing torque cap screws in the channel clamp since the screw will not normally bottom out against the counter bore shoulder.

FIGURE C-7. - Channel clamp concept.



DESCRIPTION

To open the cover the channel clamp is removed and the lock bolts are loosened allowing the cover to slide across the lugs at the bottom of the cover. The cover keepers secure the cover in the open position and prevent inadvertant cover removal. Where the maintenance situation demands it the cover may be completely removed by removing the retainer bars.

ADVANTAGES

- Flanges are very well protected by the lugs and retainer bars.
- Mechanic does not have to lift the weight of the cover.
- Parts are easily fabricated from standard shapes.
- Requires no tapped blind holes or close tolerance machining.
- The mechanism is durable and easily repaired in the mine.
- The mechanism projects only about 1/2 inch beyond the cover.
- The flange gap clearance can be easily measured with a feeler gauge at all locations between the lugs.

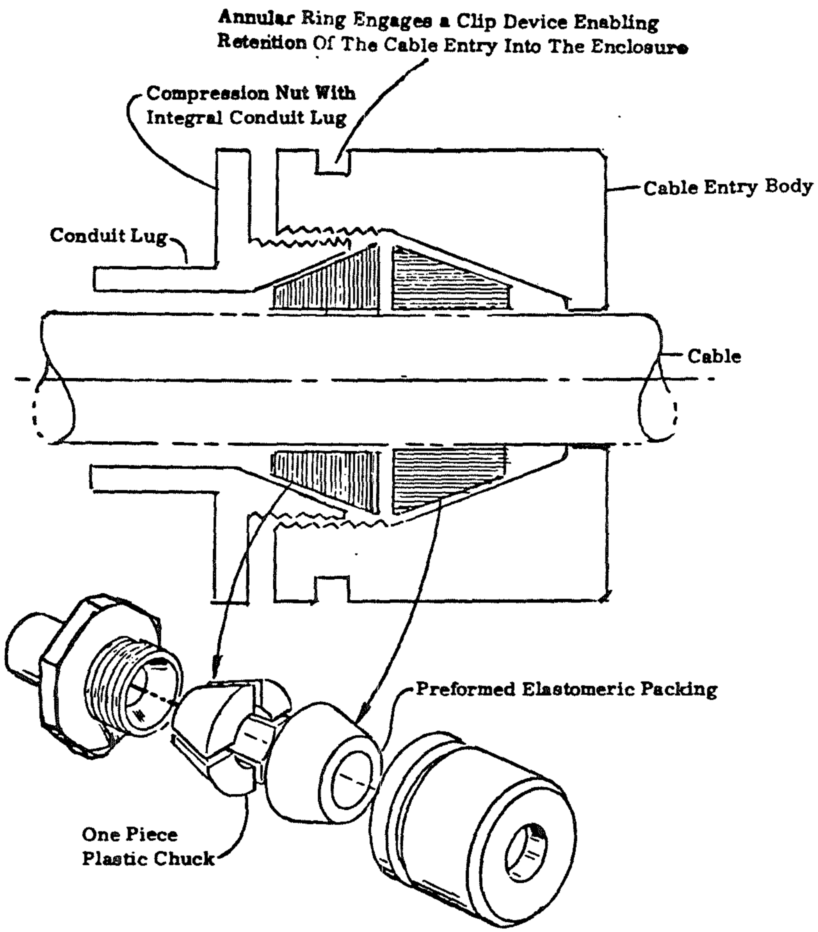
DISADVANTAGES

- The sliding cover is not feasible for many enclosures onboard equipment because there is insufficient space for sliding the cover.
- The use of cap screws is undesirable since their adjustment requires a special tool.
- The use of external flanges may impede packaging the enclosures onboard equipment.
- May be necessary to provide inspection slots in the channel clamp to allow feeler gauge access to the flange gap.
- Requires the use of prevailing torque cap screws in the channel clamp since the screw will not bottom out against the counter bore shoulder.

FIGURE C-8. - Sliding door concept.

APPENDIX D CABLE ENTRY CONCEPTS

Additional cable entry concepts for explosion-proof electrical enclosures are described in Figures D-1 through D-10 of this appendix. For various reasons, these concepts ranked lower for the mining application than those described in Section 3.0.



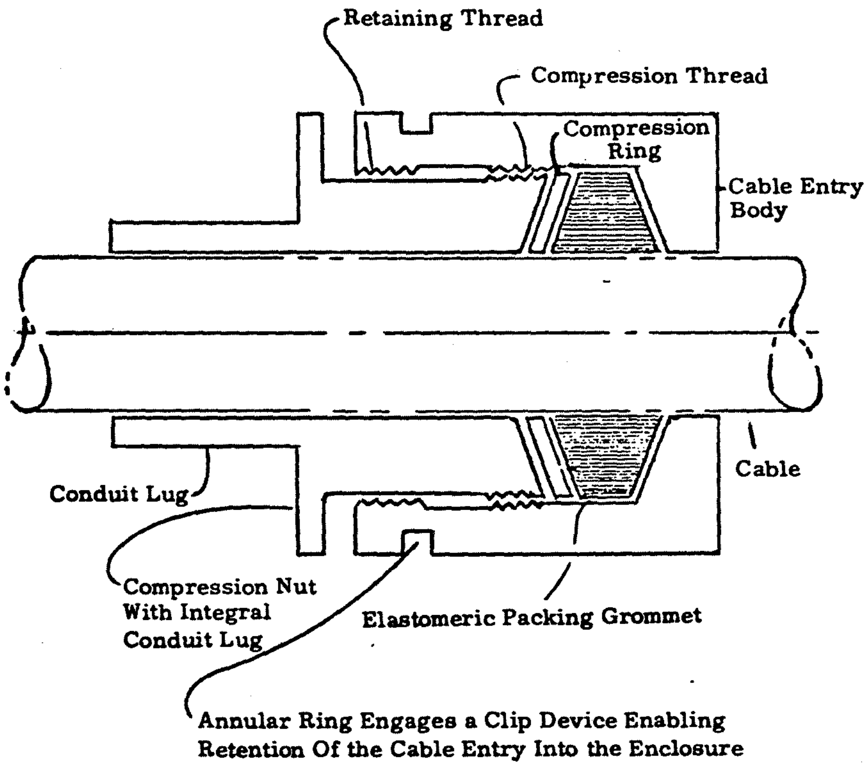
DESCRIPTION

- Tightening the compression nut forces the chuck and the packing into the appropriate tapered recesses of the compression nut and the cable entry body. Further tightening of the compression nut forces the chuck and packing against the cable thereby securing the cable and closing off all the flame paths. The compression nut is secured in place by a lock screw or other conventional means.
- To remove the cable, the compression nut is loosened. This operation relieves the pressure between the grommet, the chuck and the cable enabling removal of the cable. At this point the grommet and the chuck are still retained by the compression nut.
- The compression nut must be removed from the cable entry body in order to remove the packing grommet and the plastic chuck.
- The conduit lug completely engages the hose conduit and prevents water from entering the cable entry along the cable.

COMMENTS

- The use of a split grommet may reduce the number of different packings needed to accommodate all the necessary cable diameters.
- The chuck generates very high clamping forces thereby providing exceptionally good strain relief. However, other concepts described in this exhibit provide adequate strain relief with fewer parts.
- If several different site grommets are required to accommodate the necessary cable diameters, inventory problems could result.

FIGURE D-1. - Split chuck concept.



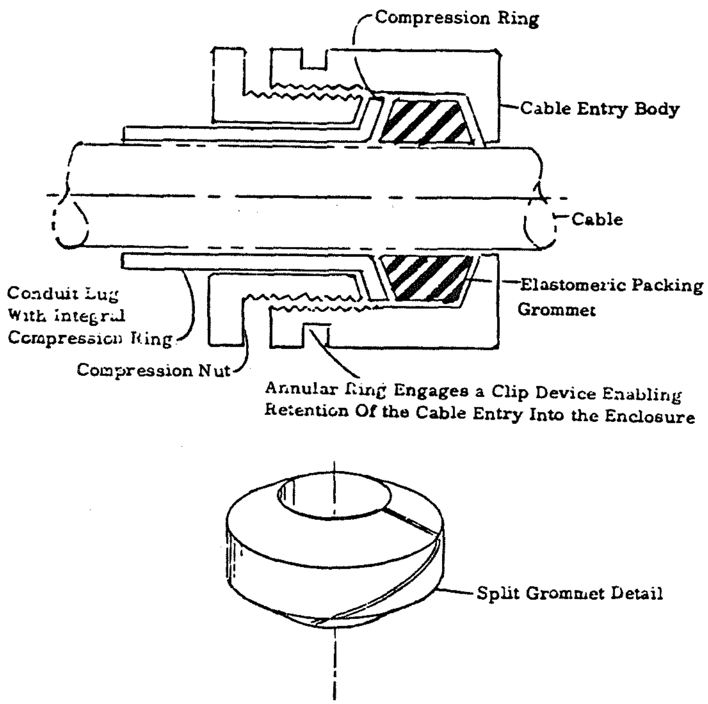
DESCRIPTION

- Tightening the compression nut squeezes the packing between the tapered body and the tapered compression nut thereby securing the cable and closing off all the flame paths. The compression nut is secured in place by a lock screw or other conventional means.
- To remove the cable, the compression nut is completely loosened from the compression threads. This operation relieves the pressure between the grommet and the cable enabling removal of the cable. At this point the grommet is still retained by the compression nut.
- The compression nut must be loosened from the retaining thread in order to remove the packing grommet and compression ring from the cable entry body.
- The conduit lug completely engages the hose conduit and prevents water from entering the cable entry along the cable.

COMMENTS

- The use of a split grommet may reduce the number of different packings needed to accommodate all the necessary cable diameters.
- The grommet may not be reusable if it has been highly compressed for a long time.
- If several different site grommets are required to accommodate the necessary cable diameters, inventory problems could result.

FIGURE D-2. - Double thread concept.



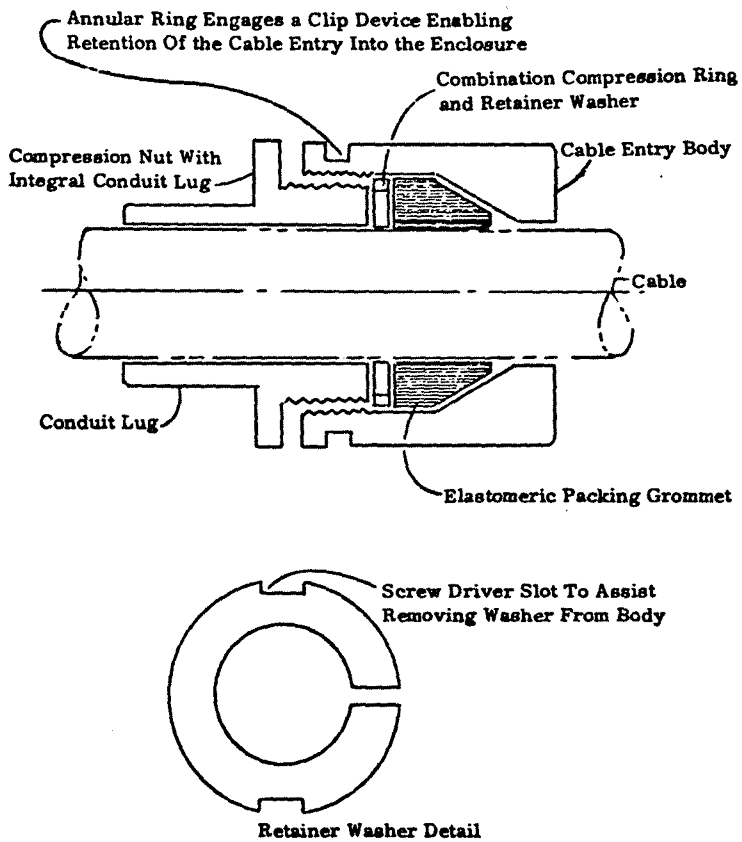
DESCRIPTION

- Tightening the compression nut squeezes the packing between the tapered body and the tapered compression nut thereby securing the cable and closing off all the flame paths. The compression nut is secured in place by a lock screw or other conventional means.
- To remove the cable, the compression nut is loosened. Thus, pressure between the cable and the packing is relieved enabling removal of the cable. At this point the grommet is still retained by the compression nut.
- The compression nut must be loosened from the retaining thread in order to remove the packing grommet and compression ring.
- The conduit lug completely engages the hose conduit and prevents water from entering the cable entry along the cables.

COMMENTS

- The use of a split grommet may reduce the number of different packings needed to accommodate all the necessary cable diameters.
- The grommet may not be reusable if it has been highly compressed for a long time.
- If several different site grommets are required to accommodate the necessary cable diameters, inventory problems could result.

FIGURE D-3. - Modified conventional concept.



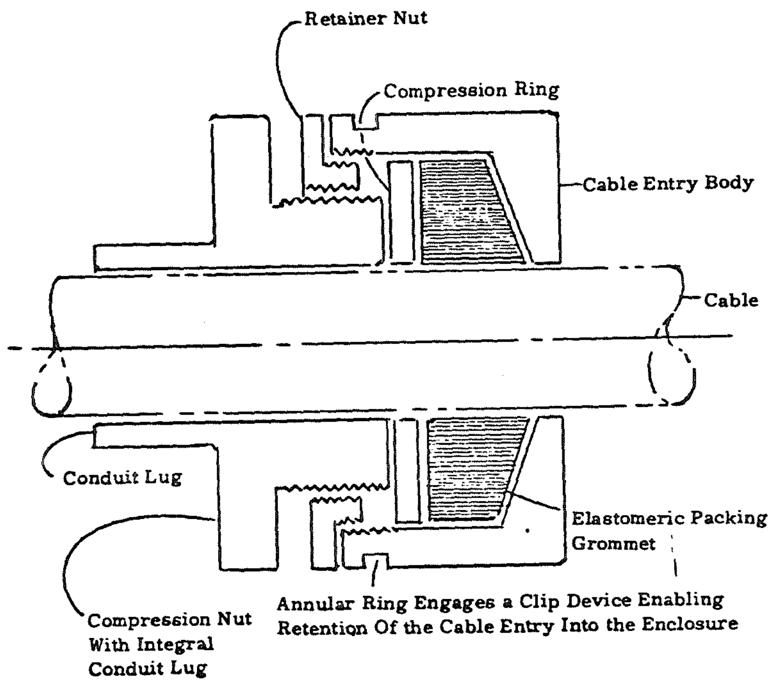
DESCRIPTION

- Tightening the compression nut forces the packing into the tapered body thereby securing the cable and closing off all the flame paths. The compression nut is secured in place by a lock screw or other conventional means.
- To remove the cable the compression nut is loosened. The pressure between the cable and the packing is relieved enabling removal of the cable. At this point the grommet is still retained by the retainer ring.
- The retainer ring must be removed in order to remove the packing grommet from the cable entry body.
- The conduit lug completely engages the hose conduit and prevents water from entering the cable entry along the cable.

COMMENTS

- The use of a split grommet may reduce the number of different packings needed to accommodate all the necessary cable diameters.
- The grommet may not be reusable if it has been highly compressed for a long time.
- If several different site grommets are required to accommodate the necessary cable diameters, inventory problems could result.

FIGURE D-4. - Retainer washer concept.



DESCRIPTION

- Tightening the compression nut forces the packing into the tapered body, thereby securing the cable and closing off all the flame paths. The compression nut is secured in place by a lock screw or other conventional means.

- To remove the cable, the compression nut is loosened or completely removed. This operation relieves the pressure between the grommet and the cable enabling removal of the cable. At this point the grommet is still retained by the retainer nut.

- The retainer nut must be removed in order to remove the packing grommet and compression ring from the cable entry body.

- The conduit lug completely engages the hose conduit and prevents water from entering the cable entry along the cable.

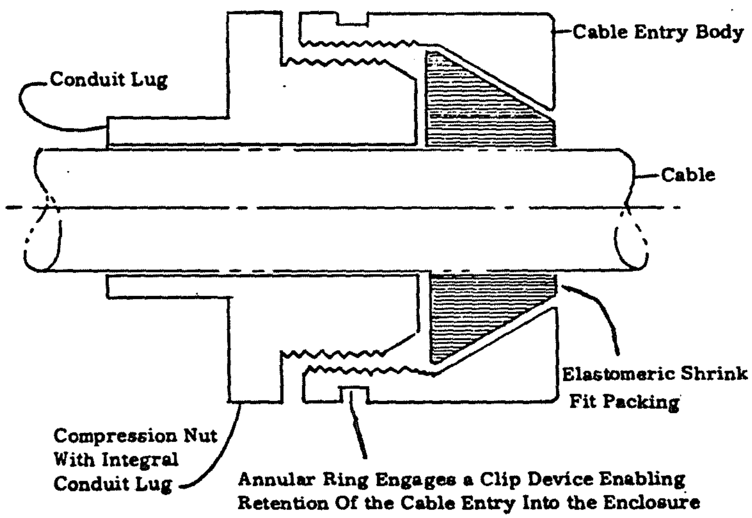
COMMENTS

- The use of a split grommet may reduce the number of different packings needed to accommodate all the necessary cable diameters.

- The grommet may not be reusable if it has been highly compressed for a long time.

- If several different site grommets are required to accommodate the necessary cable diameters, inventory problems could result.

FIGURE D-5. - Retainer nut concept.



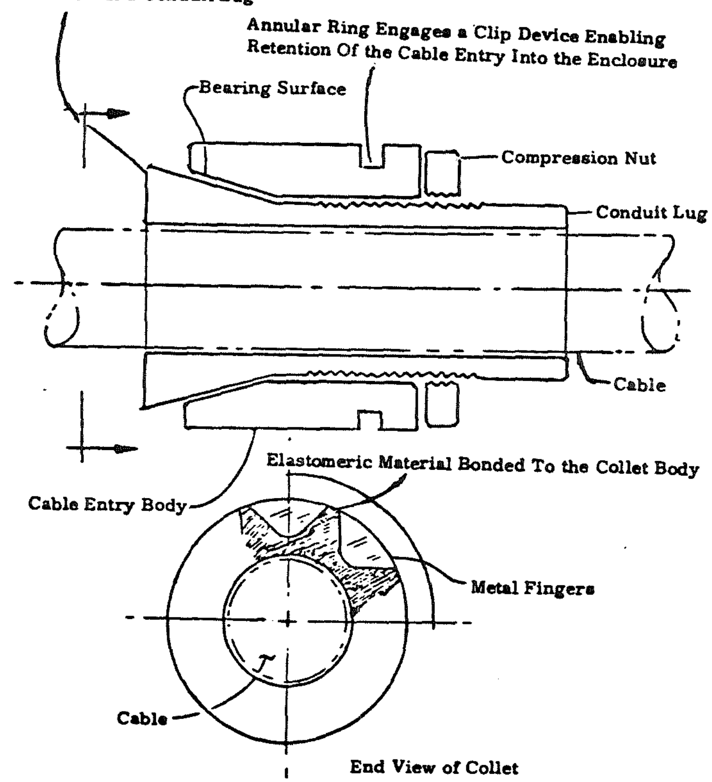
DESCRIPTION

- The application of heat during the installation procedure shrinks and secures the packing to the cable and seals off the flame path. Heat may be supplied by heater tape, heat gun, welding torch or other appropriate means.
- Tightening the compression nut squeezes the packing into the tapered body thereby securing the cable and closing off all the flame paths. The compression nut is secured in place by a lock screw or other conventional means.
- To remove the cable the compression nut is completely removed. The packing is held captive to the cable and cannot be lost.
- The conduit lug completely engages the hose conduit and prevents water from entering the cable entry along the cables.

COMMENTS

- One part accommodates a wide variety of cable diameters.
- In order to seal off the flame path between the cable entry body and the outer surface of the packing, the packing must shrink to an approximately uniform taper that is concentric with the cable. To accomplish this may require some development.
- Because the packing is bonded to the cable, it is destroyed if it must be removed from the cable and it cannot be moved laterally along the cables.

FIGURE D-6. - Modified shrink fit packing concept.



DESCRIPTION

- Tightening the compression nut draws the metal collet fingers tight against the bearing surface of the cable entry body. Further tightening of the compression nut deflects the metal fingers thereby compressing the packing tight against the cable and closing off all the flame paths. The compression nut is secured in place with a set screw or other conventional means.

- To remove the cable, the compression nut is loosened and the metal fingers pull the elastomeric packing free of the cable.

- The compression nut must be completely removed in order to remove the collet device from the cable entry body.

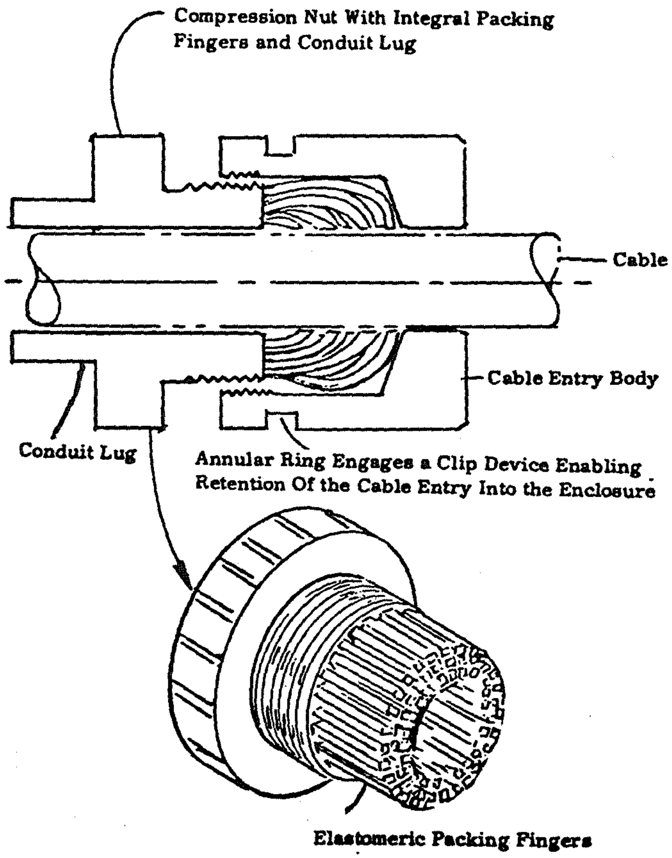
  The conduit lug completely engages the hose conduit and prevents water from entering the cable entry along the cable.

COMMENTS

- One part accommodates a wide variety of cable diameters.

- The operation of this device requires that the elastomeric material tightly engage both the bearing surface of the cable entry body and the cable. Some development would be necessary to determine whether this operation is possible.

FIGURE D-7. - Collet concept.



DESCRIPTION

- Tightening the compression nut twists the packing around the cable compresses the packing into the cable entry body. This operation secures the cable and seals off all the flame paths. The compression nut is secured by a lock screw or other conventional means.

- To remove the cable the compression nut is completely removed. The packing is held captive to the nut and cannot be lost.

- The conduit lug completely engages the hose conduit and prevents water from entering the cable entry along the cable.

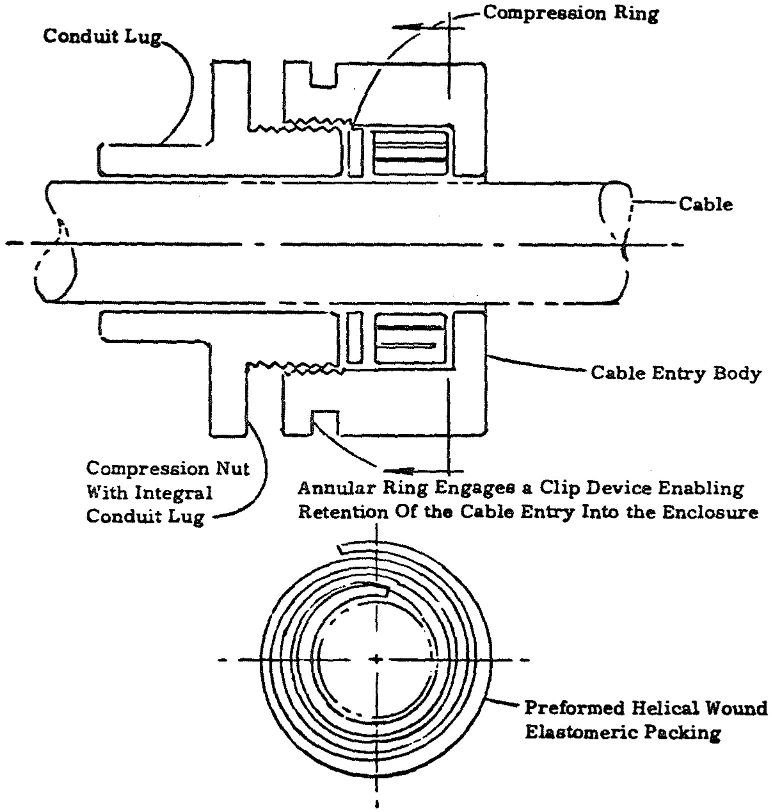
COMMENTS

- Some development would be required to demonstrate that this technique would afford an explosionproof seal around the cable.

- One part accommodates a wide variety of cable diameters.

- Development would be required to obtain an acceptable packing/ compression nut assembly.

FIGURE D-8. - Twist packing concept.



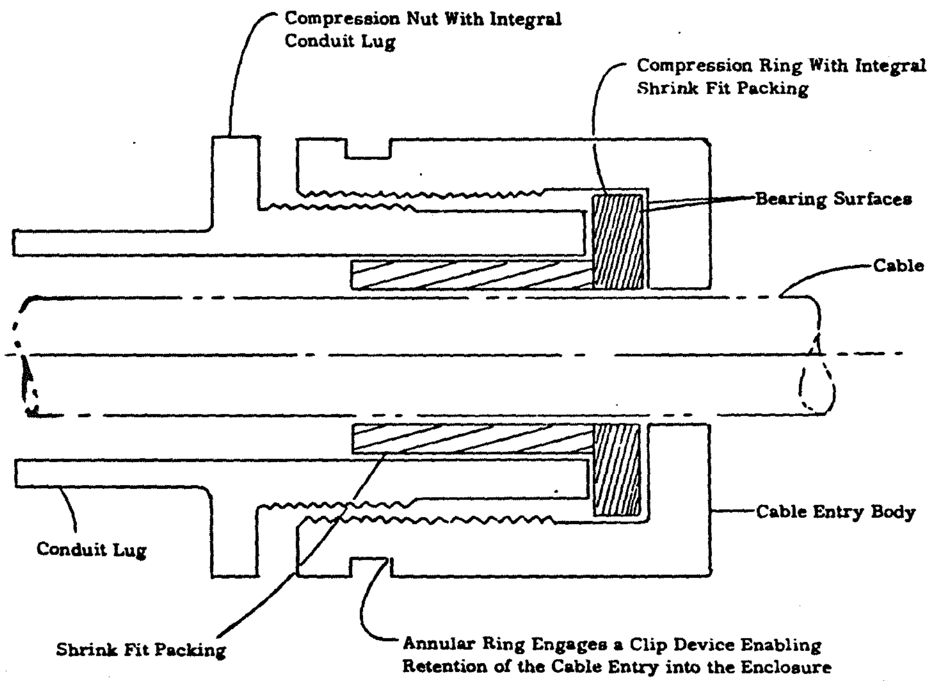
DESCRIPTION

- Tightening the compression nut compresses the sheet form packing into the cable entry body thereby securing the cable and closing off all the flame paths. The compression nut is secured in place by a lock screw or other conventional means.
- To remove the cable, the compression nut is loosened but not removed from the compression threads. This operation relieves the pressure between the grommet and the cable enabling removal of the cable. At this point the packing is still retained by the compression nut.
- The compression nut must be removed from the cable entry body in order to remove the packing grommet and compression ring.
- The conduit lug completely engages the hose conduit and prevents water from entering the cable entry along the cable.

COMMENTS

- It may be difficult to remove or replace the cable without removing the packing.
- Only one size of preformed helical wound packing is required to accommodate a wide variety of cable diameters. However, the packing may have to be trimmed during installation.

FIGURE D-9. - Sheet packing concept.



DESCRIPTION

- The application of heat during the installation procedure shrinks and secures the packing to the cable and seals off the flame path. Heat may be supplied by heater tape, heat gun, welding torch or other appropriate means.
- Tightening the compression nut squeezes the compression ring between compression nut bearing surface and the cable entry body. This operation keeps flames from passing on the outside of the packing and also secures the cable into the cable entry. The compression nut is secured in place by a set screw or other conventional means.
- To remove the cable the compression nut is completely removed. The packing is held captive to the cable and cannot be lost.

COMMENTS

- Some development would be required to obtain a satisfactory packing/compression ring assembly.
- Because the packing is bonded to the cable, it is destroyed if it must be removed from the cable and it cannot be moved laterally along the cable.

FIGURE D-10. - Shrink fit packing concept.

APPENDIX E METAL FOAM CLOGGING TESTS

This appendix describes the testing and analysis conducted to evaluate the resistance of Retimet[1] metal foam against clogging by dust.

Tests were conducted on open orifices, unclogged Retimet, and Retimet coated with various contaminants. The Retimet samples were 2 inch diameter by one-half inch thick discs of grade 45 stainless steel foam. The contaminants included rock dust, coal dust, water, and hydrualic oil. These were used singly and in various combinations. When dry or pasted consistency materials were applied, a shop vacuum cleaner was employed to draw those materials into the metal foam. The application of fluids was accomplished by immersing the sample in the fluid. Some tests were performed in which the contaminants were baked onto the sample. In these instances, a heat gun was used to evaporate the moisture. In performing the clogging tests the sample was weighed before contamination, after contamination, and after the test. These weights were recorded.

The test apparatus used in these tests consisted of a pressure tank with a 2 inch diameter pipe outlet. The test sample was installed in the form of a round disc at the mouth of this outlet pipe. An electric solenoid valve was installed on the pipe between the sample and the pressure tank. Pressure transducers recorded the pressure in the tank (P1) and also the pressure just before the test sample (P2). The transducer output was recorded on a high speed, high frequency response, strip chart recorder. To conduct a test, the solenoid valve was opened and the pressures P1 and P2 were recorded as functions of time while the air stream passed through the sample to the atmosphere.

The important parameters in these tests were:

- P2 max. - The maximum pressure drop across the sample.
- P2/T - A pressure rise parameter related to the time "T" required to clear the sample and establish steady state flow.

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1 Registered trademark of Dunlop Ltd., Coventry, U.K.

- P1/T - A pressure decay parameter related to the steady state gas flow rate through the sample, "T" being the decay time.

If the data for unclogged Retimet is used as a baseline then:

- Higher values of P2 and lower values of P1/T indicate reduced steady state flow due to permanent clogging.

- Higher values of P2/T indicate that clogging is retarding the initial flow through the sample and that it is taking some time for the air flow to clean out the foreign material.

The pressure rise parameter (P2/T) was evaluated at T equal to 10 milliseconds and the pressure decay parameter (P1/T) was evaluated at P2 max. The pressure drop across the sample was mostly less than 85 psig. Since the maximum pressure drop across the sample (P2/T) was not the same for all the tests, the pressure decay parameter was adjusted to a base line of P2 max equal to 75 psig to enable direct comparison of the results. Due to the high sample pressures used in these experiments, the steady state flow conditions were sonic. Under these conditions fluid flow is directly proportional to the absolute pressure. Therefore, the sonic flow equation was used to determine the adjusted pressure decay parameter.

The data obtained by testing the 1-3/16" diameter open orifice was used to estimate the effective open area of the Retimet samples. The ratio of the pressure decay parameters for the sample and the orifice equals the ratio of the effective sample area to the actual orifice area. Calculations indicated that the effective open area of the Retimet samples is 25% of the actual open area.

The following conclusions regarding Retimet Grade 45 stainless steel foam were drawn from these tests:

- Dirt may accumulate on the surface of the material, but the small pores seem to resist deep penetration of contaminants.

- Liquids permeating the foam and contaminants accumulating on the downstream surface of the material tend to be removed during the venting process. The steady state flow rate is not appreciably effected, but there is some variation in the time required to clear the clogging condition.

- Contaminants accumulating on the upstream surface of the material tend to be driven into the pores during the venting process causing significant reductions in the steady state flow rate.

- The one half inch thick slab of grade 45 Retimet is about 25% open to the flow of gas.

APPENDIX F VENT PROTECTION CONCEPTS

The approach in the development of pressure vent hardware was to design relatively small pressure vent modules which permit the escapement of large quantities of gas. Feasibility tests performed in the early part of this program had demonstrated the ability of the stainless steel metal foam vent to reduce the explosion pressure build-up to very low levels. However, due to the high temperature of the exiting gases, some oxidation and erosion of the stainless steel foam was evident, particularly with small vents on large enclosures. To protect the metal foam vent, several material structure concepts and hardware concepts were identified:

- Metal foam sandwich.
- Modified metal foam sandwich.
- Metal foam/screen assembly.
- Metal foam/expanded metal assembly.
- Metal foam/glass wool assembly.
- Metal screen packs.
- Internal baffle.
- Cross flow precooler.
- Direct flow precooler.
- Dual vent.

Figures F-1 and F-2 illustrate these concepts. The metal foam stainless steel screen assembly concept was selected for further development.

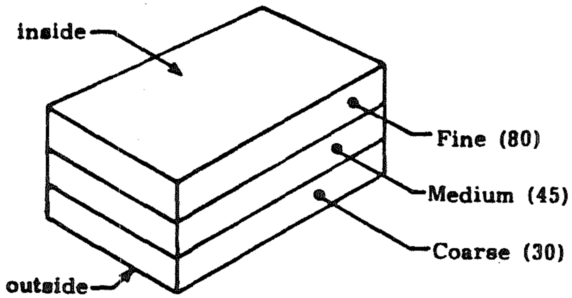
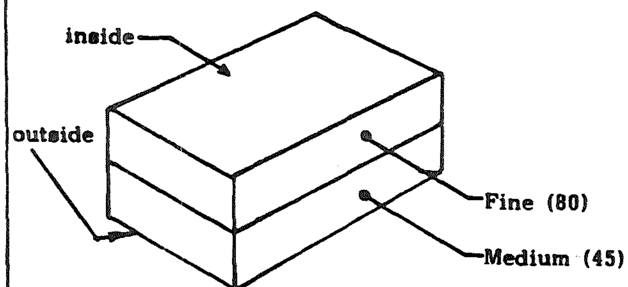
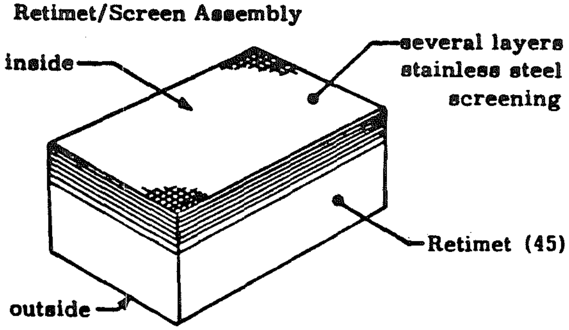
CONCEPT	ESTIMATED SUITABILITY	COMMENTS
1) Retimet Sandwich 	Fair to Good	· Fine grade Retimet on inside surface has greater surface for volume ratio than standard grades. This layer rapidly quenches exiting gases. · Innermost layer may overheat and erode and may therefore require periodic replacement.
2) Modified Retimet Sandwich 	Fair to Good	· This is a simpler version of Concept 1 and performance is expected to be about the same.
3) Retimet/Screen Assembly 	Good to Excellent	· Typical screening is 18 mesh x .030" wire diameter and should resist over-heating and erosion. · Proper orientation of screen layers diffuse and precool the flame front. · Since only a few layers of screen are required, increases in flow resistance can be minimized. · Low cost material is readily available for design optimization.

FIGURE F-1. - Material structure concepts for metal foam vent protection.

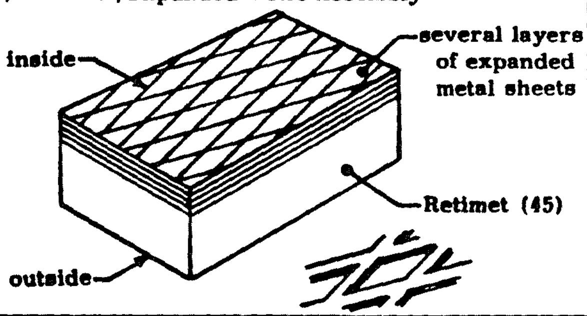
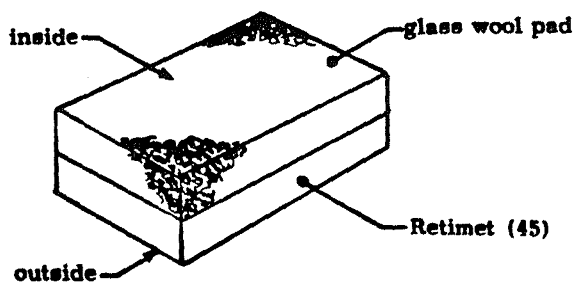
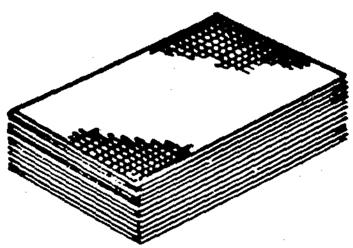
CONCEPT	ESTIMATED SUITABILITY	COMMENTS
4) Retimet/Expanded Metal Assembly 	Poor to Fair	· Because of the large cell dimensions, it may be necessary to use many layers of material to diffuse and precool the flame front. Therefore, the assembly may appreciably increase the arrester's thickners. · Low cost material is readily available for testing and evaluation.
5) Retimet/Glass Wool Assembly 	Good to Excellent	· A suitably designed glass wool pad may provide adequate diffusion and precooling without excessive flow resistance. · Pad uniformity may be a problem. · Because of its high melting temperature chemical resistance, the glass may be completely immune to degradation during an explosion. · Low cost material is readily available for design optimization.
6) Metal Screen Assemblies 	Good to Excellent	· Medium cost samples are available whose gas flow properties approach Phase of Retimet grades 45 and 80. However, since the wire used in these samples is greater than the Retimet fibers, these samples may have improved explosion performance.

FIGURE F-1. - Material structure concepts for metal foam vent protection. (continued)

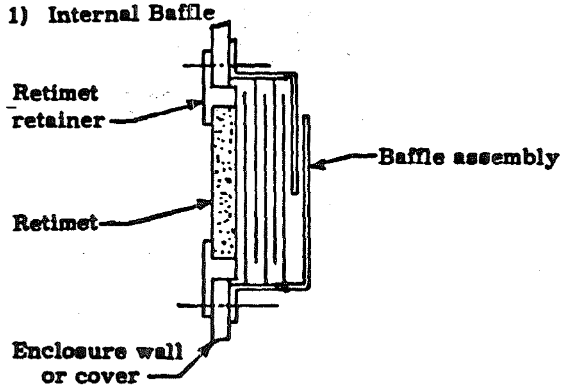
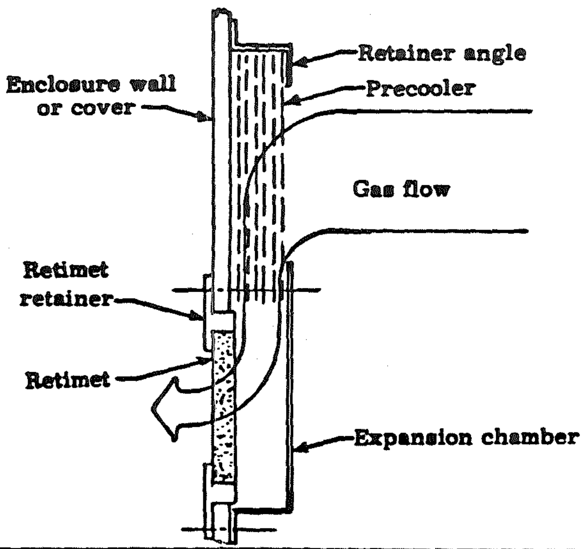
CONCEPT	ESTIMATED SUITABILITY	COMMENTS
1) Internal Baffle 	Fair to Good	• Simple but durable baffle could be largely fabricated from sheet steel. • Development effort is needed to determine the required number of baffles and suitable spacing. • The baffle assembly projects about 2 inches into the enclosure and thus reduces available internal volume.
2) Cross Flow Precooler 	Fair	• Simple precooler may be an assembly of coarse screens, perforated steel plates or expanded metal sheets. • The hot gases and the expanding flame front are cooled and redirected as they pass through the precooler. Additional cooling takes place in the expansion chamber. • Development is needed to insure adequate flow and cooling capabilities. • Hardware can be fabricated from readily available materials.

FIGURE F-2. - Hardware structure concepts for metal foam vent protection.

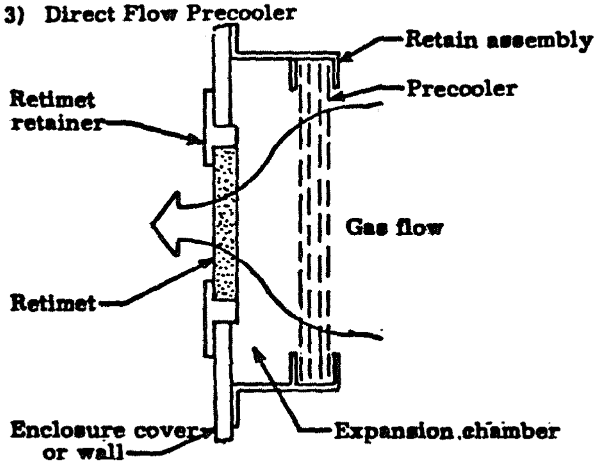
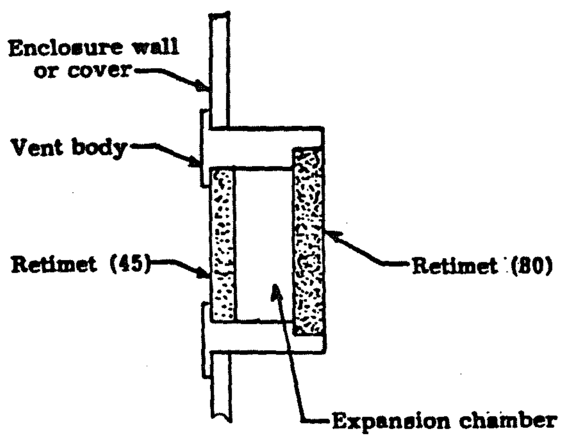
CONCEPT	ESTIMATED SUITABILITY	COMMENTS
3) Direct Flow Precooler  	Fair	This concept is similar to Concept 2 and its operation and performance are expected to be comparable.
4) Dual Vent  	Fair to Good	This approach is especially simple and adaptable to the mining application. The fine grade (80) Retimet filter precools the exiting gases before they contact the flame arrester

FIGURE F-2. - Hardware structure concepts for metal foam vent protection. (continued)

APPENDIX G EXPLOSION TEST TECHNIQUES FOR PRESSURE VENTS

To conduct explosion tests on pressure vent hardware, existing electrical enclosures were modified by incorporating the pressure vent in the enclosure cover. Methane explosions were created inside the enclosure and the performance of the vent hardware was evaluated under these conditions. The pressure vent testing early on in the program was conducted at the MSHA explosion test facility at Bruceton, Pennsylvania. Figure 3-13 is a photograph of the typical test setup. Subsequent explosion testing for developing design guidelines was conducted at the Booz, Allen facilities. An explosion test setup was developed for this purpose. This appendix describes the test setup, measurement techniques and procedures used in the development of design guidelines.

G.1 Test Setup

Figure G-2 illustrates the overall explosion test setup and Figure G-3 is a schematic of the system. To create explosions inside the enclosure under test, a mixture of methane and air was obtained by introducing methane into the enclosure and thoroughly mixing it with a blower. The amount of methane was controlled with a flow meter which was used to monitor the quantity and duration of flow from a high pressure methane tank. The enclosure was installed in a test chamber and surrounded by the same methane and air mixture. This chamber was provided with a paper cover in order to prevent a high pressure build up inside the test chamber in the event of its ignition. The methane concentration inside the enclosure was measured with a conductivity type gas chromatograph. The gas was sampled from a rubber sealed port nearest the enclosure with a needle and syringe. The chromatograph was calibrated against a 10% mixture of technical grade methane in helium.

Most of the tests were performed with methane percentages between 8.5 to 11.5 percent because these resulted in the highest explosion temperatures and pressures. Lower and higher percentages of methane were used primarily to note effects from the lower energy level explosions.

An electrical spark was used to ignite the mixture. The spark was created by a high tension coil with a capacitor discharge circuit powered by a 12 volt battery. The number of sparks, their duration and energy were controlled through the spark circuit and were maintained constant. Figure G-4 illustrates the electrical system.

The modularized vent hardware was installed on the enclosure cover.

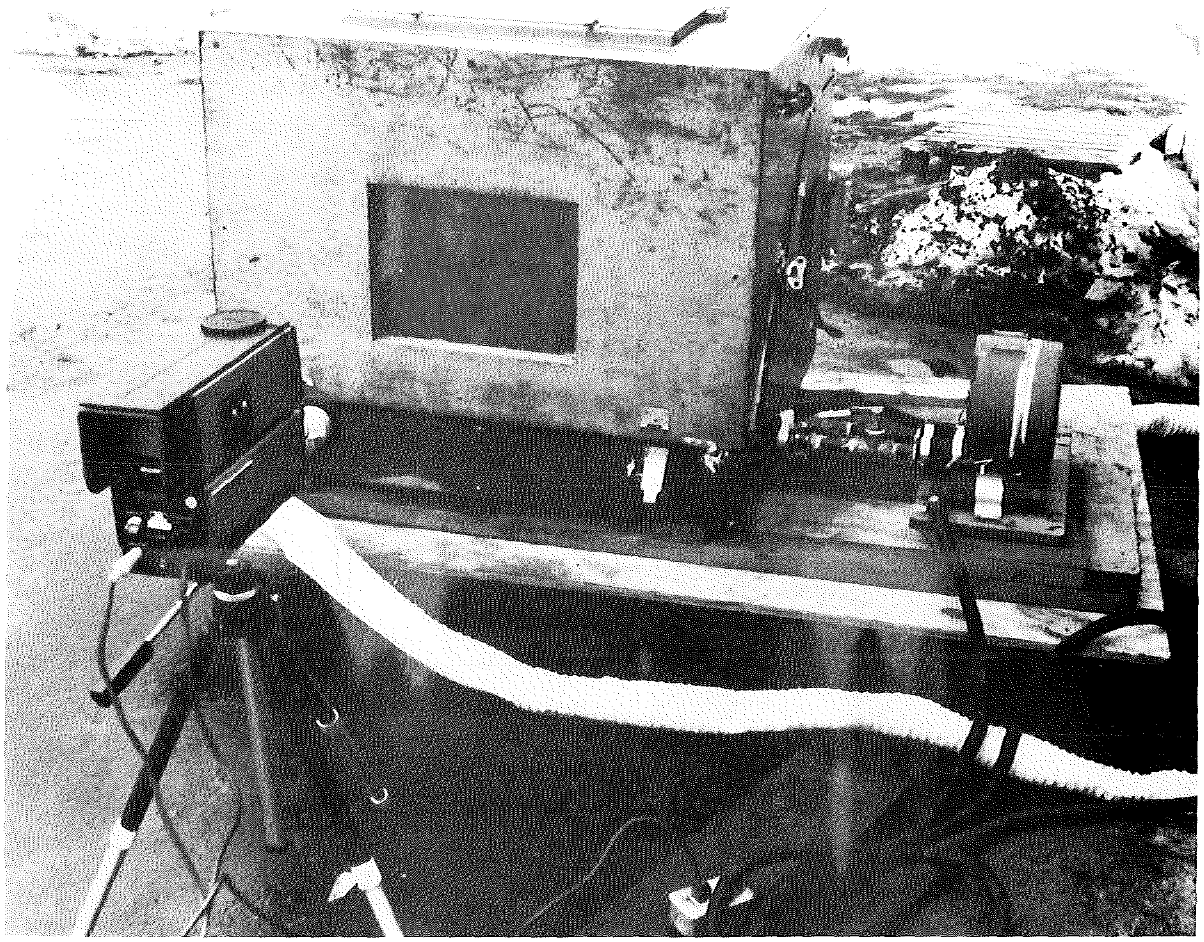


Figure G - 1. Explosion Test Set Up at Contractor Facility

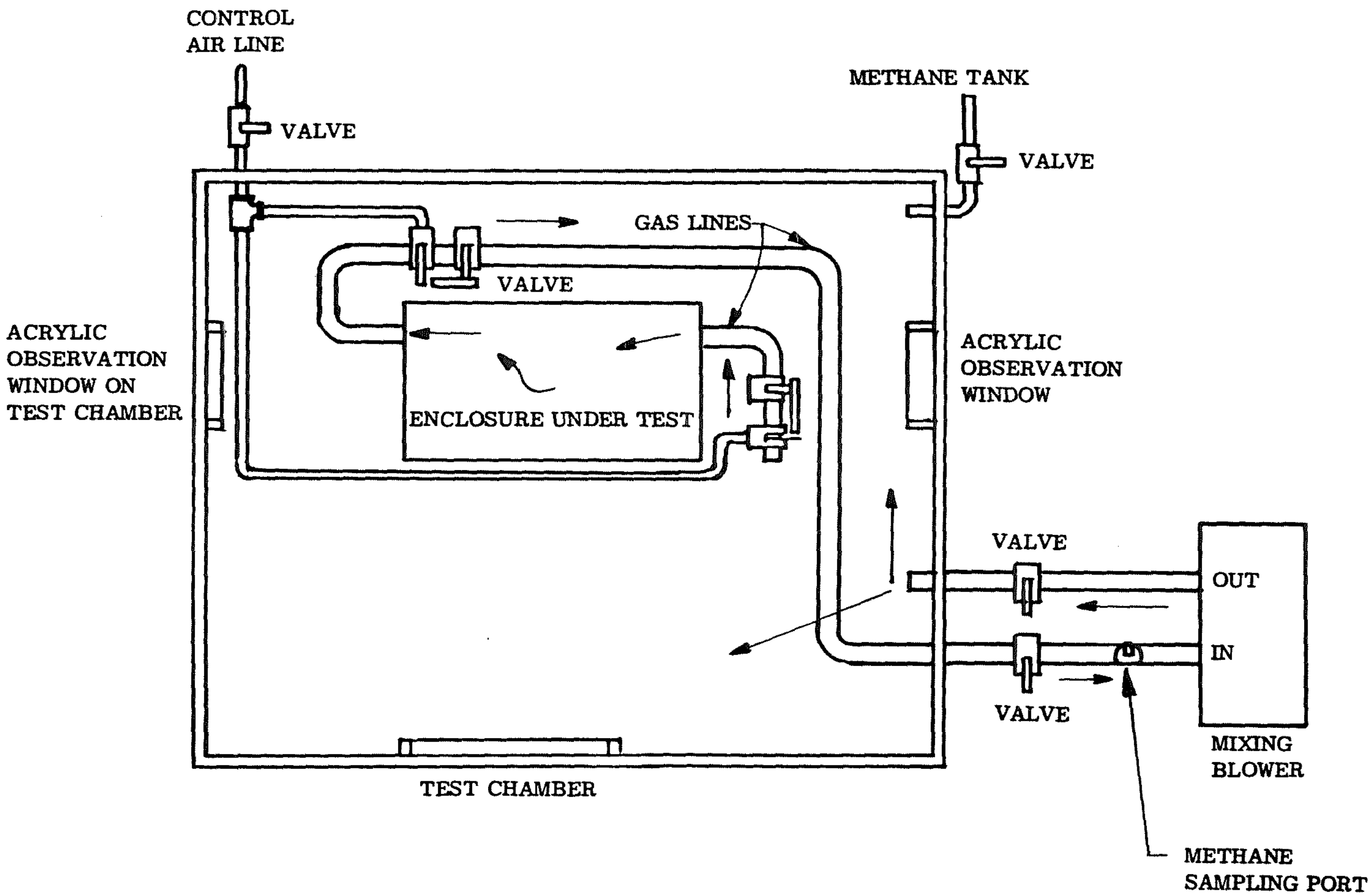


FIGURE G-2. - Laboratory explosion test setup.

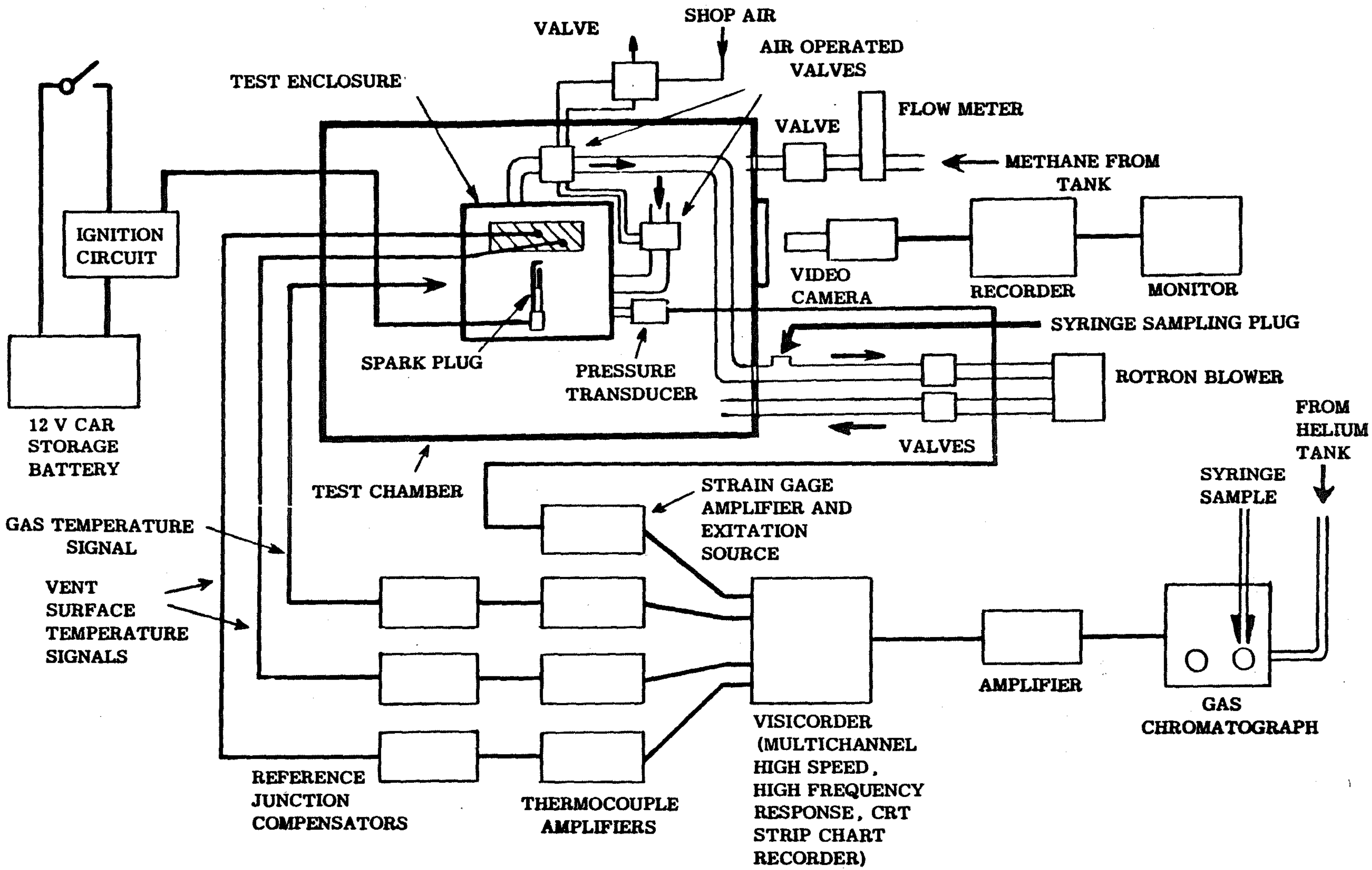


FIGURE G-3. - Schematic of the system for the laboratory explosion test setup.

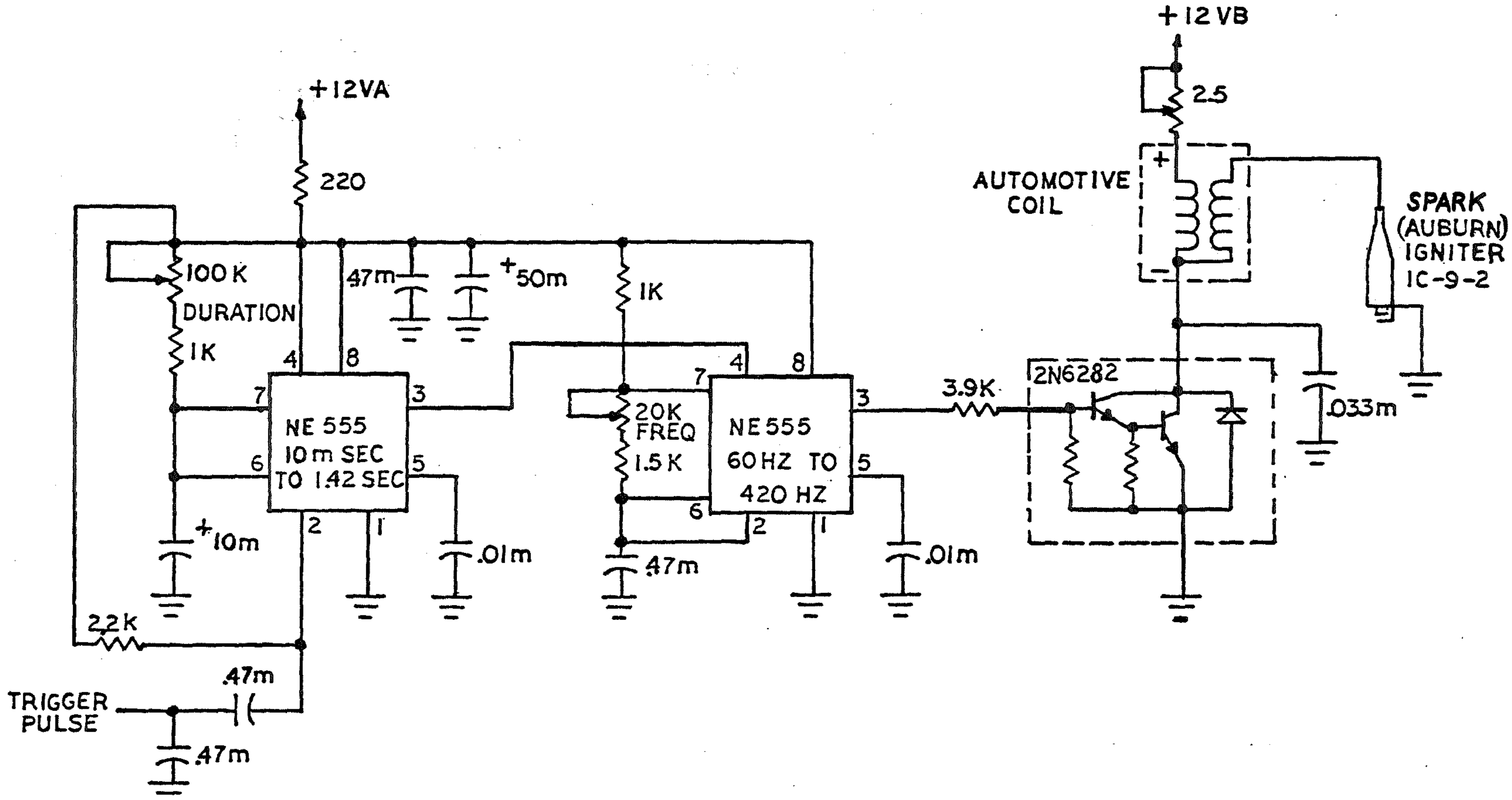


FIGURE G-4. - Electrical spark ignition system.

Pressure was measured with a strain gage type pressure transducer installed on the enclosure cover. Surface temperatures were measured with 0.005 inch diameter wire, Chromel-Alumel thermocouples welded to the stainless steel screen wire or to the metal foam. A capacitor spark discharge technique was found suitable for welding the thermocouples. The flange gas temperature was measured with a specially constructed thermocouple probe which used a 0.002 inch diameter wire Chromel-Alumel thermocouple. The pressure transducer and thermocouple signals were recorded on a high frequency response, high-speed chart recorder. The instrumentation was chosen to achieve sufficiently fast response in order to obtain a faithful record of the short duration events of the explosion. A video camera was used to record the existence of sparks or flashes. The complete equipment used for the test setup has been listed in Table G-1.

Installation of the enclosure in the test chamber was practical only for the one-half cubic foot connection box. However, tests were also carried out on large enclosures such as the 14 cubic feet controller case and the 4 cubic feet connection box. These tests did not require a methane-air mixture to surround the enclosure.

G.2 Measurement Techniques

Techniques were developed for precise and repeatable measurements of the following parameters:

- Enclosure pressure.
- Flange gas temperature.
- Surface temperature of the vent materials.
- Sparks and flashes from the enclosure.

These techniques have been described in the following subsections.

G.2.1 Enclosure Pressure Measurement

Strain gage pressure transducers were selected as the most suitable approach for these tests. These transducers have adequate response and were available in a wide range of pressure sensitivities. The Viatran models, No. 103 and No. PTB 207 G were identified as suitable transducers for this testing. When test pressures were expected to be between 1 to 50 psig, the 30 mv, 50 psi transducer model PTB 207 G was used. For higher pressures, the model No. 103 was used. The transducer specifications and an appropriate wiring diagram are given in Figure G-5.

TABLE G-1. - Explosion test equipment

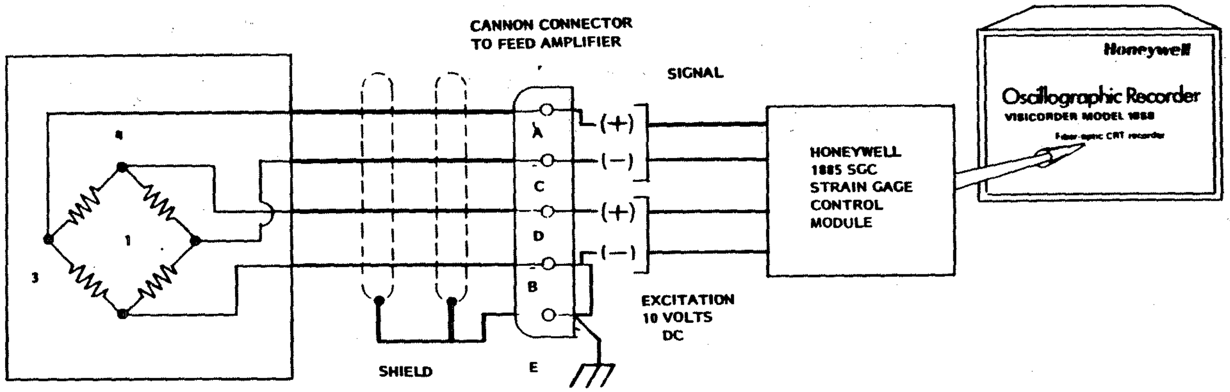
Item	Manufacturer	Equipment	Comments
Test Chamber	Design and Development		Designed to provide personnel safety and control in explosion testing.
Gas Analyzer	Carle Instruments Inc.	Gas Chromatograph Model 8500	Samples gas in the test apparatus and provides millivolt output proportional to methane concentration.
Gas Circulation Blower	Rotron	Spiral Blower Model SL2EA2AB	Circulates the explosive mixture through the test enclosure. 50 SCFM maximum flow and 26" water column maximum pressure.
Gas Circulation Valves		One Inch Ball Valve	Remote operation from outside the test chamber with air cylinders.
Gas Flow Meter	Dwyer	Floating Ball Type Gas Flow Meter, 0-50 SCFM	Measures CFM flow of methane into test chamber. A flow rate of 50 CFM for 3 minutes gives approximately 10% methane in chamber.
Ignition Circuitry	Design and Development		Provides the electrical energy to ignite explosive in test enclosure.
Video System	Sony		Records sparks/flashes fromflange gap or vent. The recorded tape can be played back at normal or slow speed through the monitor.
Pressure Transducer	Viatran	Strain Gage Pressure Transducer Model PTB207G	Pressure range is 0-50 PSIG. Exitation voltage is 10VDC. Full-scale output is 30MV. Frequency response is 30KHz.

TABLE G-1. - Explosion test equipment (continued).

Item	Manufacturer	Equipment	Comments
Amplifier For Pressure Transducer	Honeywell	Strain Gage Control Unit Model 1885A-SGC	Provides 10VDC power to pressure transducer. Amplifies MV signal output of pressure transducer and feeds into recorder.
Vent Surface Thermocouple	Design and Development	0.010 Inch Diameter, Chromel-Alumel Wire Supplied By Omega Bead Welded To Vent surface	Located at inside and outside vent surface or at screen packssurface. Measures vent surface temperatures. Estimated responce time is 0.5 milliseconds.
Thermocouple Reference Junction Compensators	Honeywell	Type K, No.JR-393-A-POC	Provides reference junction compensation which automatically adjusts to ambient temperatures. Thermocouple output can be converted directly to °F without adding ambient temperature. Frequency response is about 10KHz.
Amplifiers For Thermocouples	Honeywell	Thermocouple Control And Microvolt Amplifier Model 1886A-TCU	Amplifies MV signal from thermocouples and feeds into chart recorder.
Gas Temperature Thermocouple Probe	Design and Development	0.002 Inch Diameter Chromel-Alumel Wire Beaded Thermocouple Supplied By Omega Is Installed In A Probe	Measures temperature of gas exiting from vent or flange gap. The probe provides a rugged and durable thermocouple assemble. Estimated response time is less than 20 milliseconds.

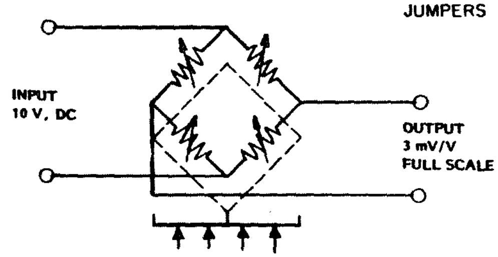
TABLE G-1. - Explosion test equipment (continued).

Item	Manufacturer	Equipment	Comments
Chart Recorder	Honeywell	CRT Fiber Optic Visicorder Model 1858	Records pressure, temperature, and gas chromatograph signals on light sensitive paper. Response is 5KHz. Chart speed of 0.2 inch /sec. is used for chromatograph recording. Chart speed of 2 inches/ sec. is used for temperature and pressure recording.
Amplifier for Gas Analysis	Honeywell	High Gain Differential Amplifier Model 1881 HGD	Amplifies output of chromatograph with sensitivity of 1 MV/ inch. Supplies signal to visicorder.



VIATRAN PRESSURE
TRANSDUCER INSTALLED
ON ENCLOSURE

FOUR EXTERNAL ARM (FULL) BRIDGE. LOCAL SENSING. SOURCE MUST BE FLOATING AND WITH NEGLIGIBLE COMMON-MODE VOLTAGE. BRIDGE ARMS MUST BE MATCHED TO WITHIN ±0.5 OHMS FOR 120 OHM GAGES, ±4 OHMS FOR 350 OHM GAGES. JUMPERS AIJ2, AIJ3, AIJ4 AND AIJ5 INSTALLED.



BRIDGE CIRCUIT OF
STRAIN GAGE PRESSURE
TRANSDUCER

TRANSDUCER SPECIFICATIONS

FOR 1-5 psig

VIATRAN MODEL 103, 30 mV, 5 psig, ± 0.4% FSO ACCURACY, LESS THAN 1 MILLISECOND, INPUT 10 V DC

FOR HIGHER PRESSURES

VIATRAN MODEL PTB 207G, 30 mV, 50 psig OTHER SPECIFICATIONS SAME AS ABOVE.

FIGURE G-5. - Pressure recording system.

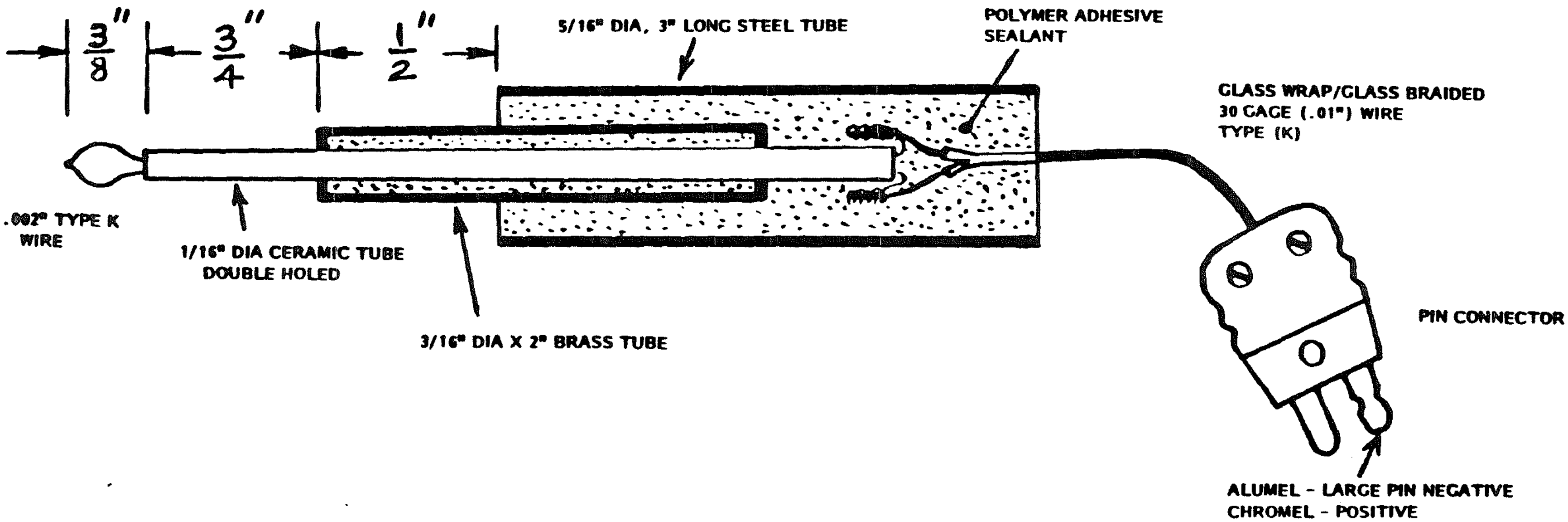


FIGURE G-7. - Gas temperature thermocouple probe.

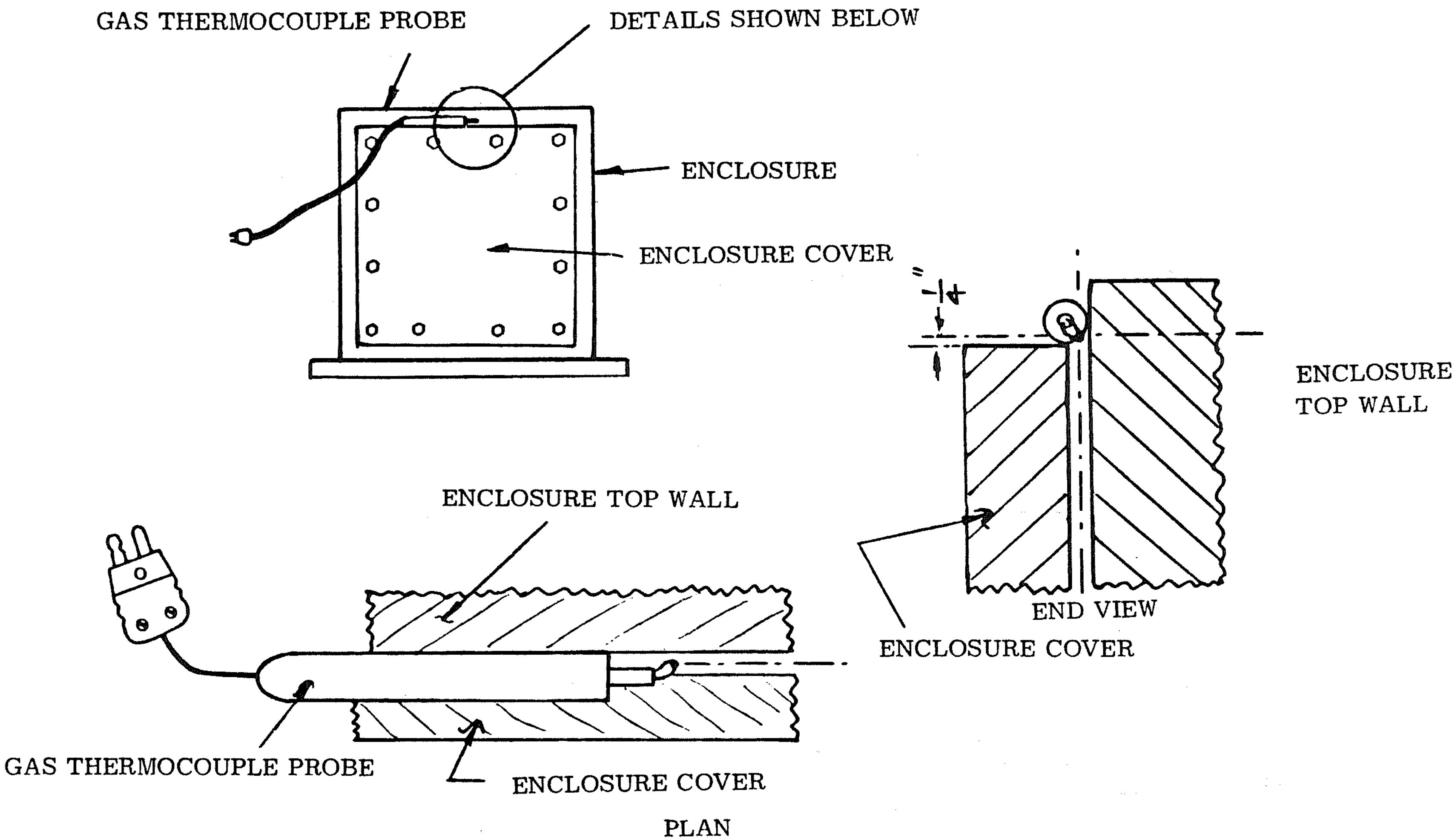


FIGURE G-8. - Location of thermocouple probe for flange gas termperature tests.

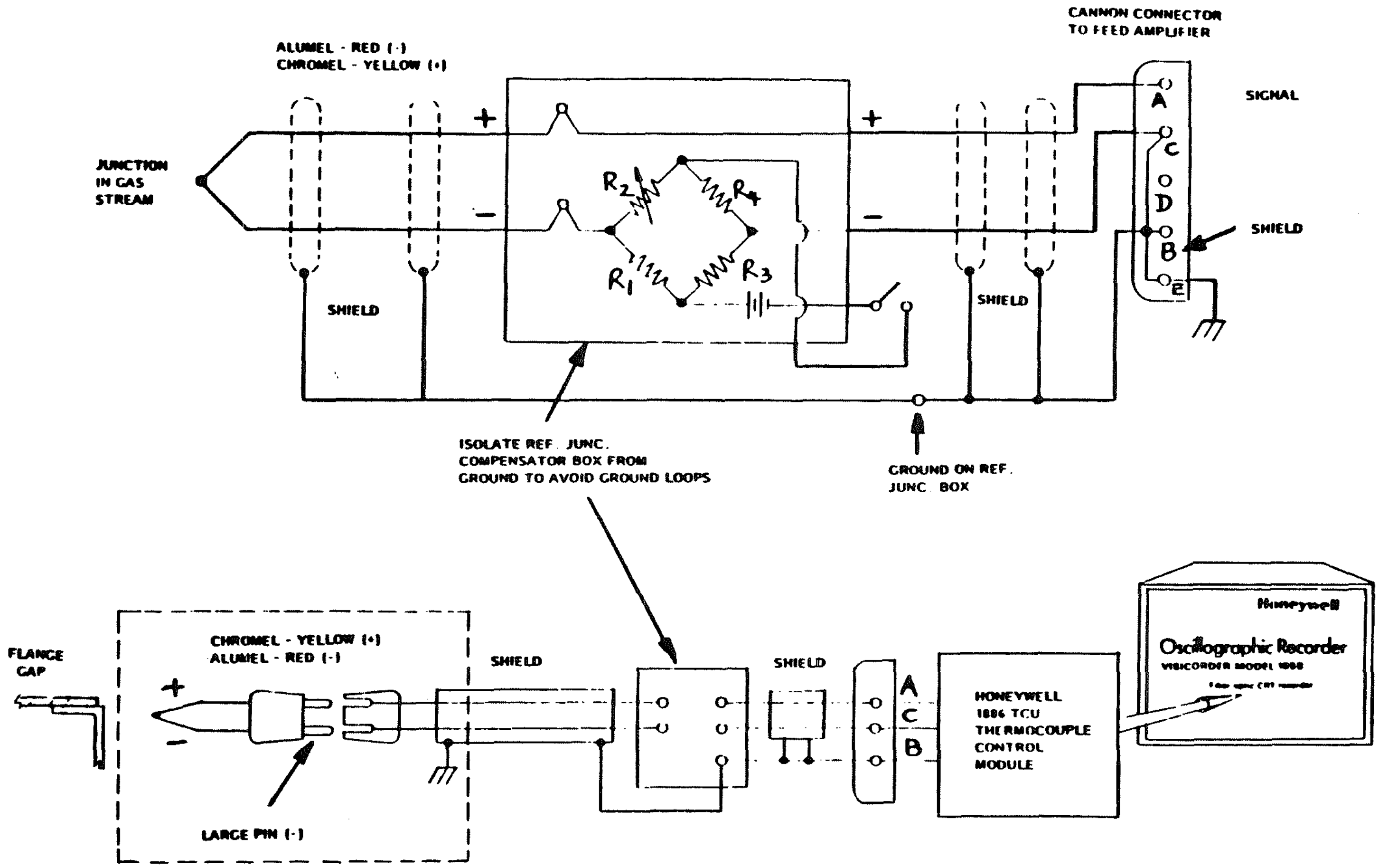


FIGURE G-9. - Flange gas temperature recording system.

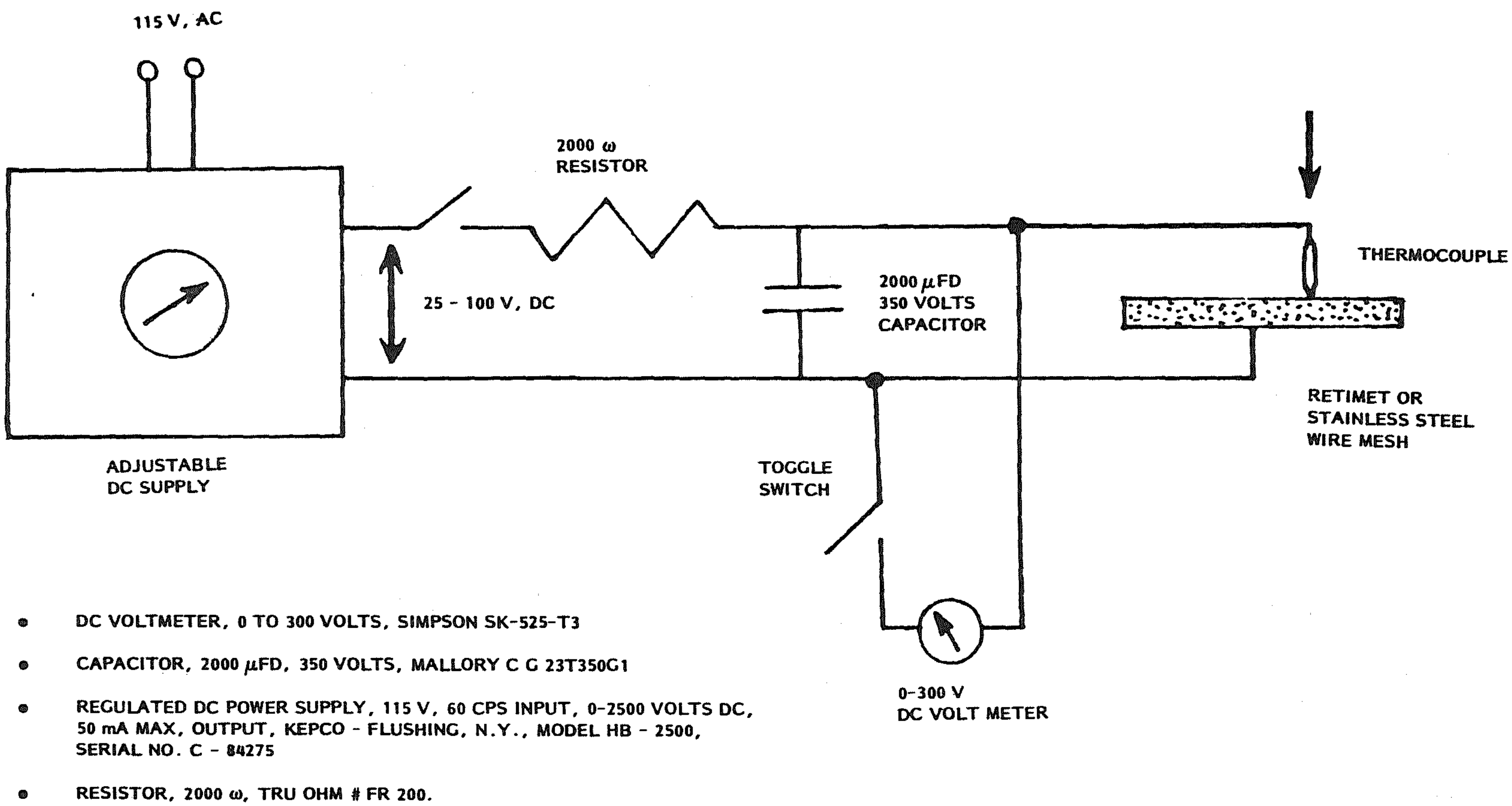


FIGURE G-10. - Circuit for welding thermocouples on to the vent material.

welded to the surface this gives good thermal, as well as electrical contact. If the thermocouple wire touches the surface elsewhere, it will incorrectly measure temperature. To obtain repeatable and reliable temperature readings, electrical insulation of wires is necessary. Running the thermocouple wire along the surface and not perpendicular to it reduces its temperature gradient. This reduces transient heat conduction along the wires. Insulating the wires avoids their direct exposure to the flame and, thus, avoids inaccurate readings. High readings can occur due to flame heat pick-up by wire and conduction into the thermocouple.

A 0.010 inch diameter duplex wire supplied by Omega was chosen. It has a glass wrap, glass braid insulation. Overall size is only 0.043 inch x 0.061 inch. It withstands continuous temperatures up to 1000°F. It has excellent resistance against flames, good flexibility, but poor abrasion resistance. Figure G-11 shows a schematic of a thermocouple welded and fixtured on the vent surface. Figure G-12 shows the circuit diagram for connecting the thermocouple to the reference junction compensator. This feeds into the recorder through a signal conditioning amplifier.

G.2.4 Recording Of Sparks Or Flames From The Enclosure

Video recording was selected as the most suitable approach for detecting sparks or flashes. Playback of the recording at slow speed facilitated careful observation of the spark or flash event. The video system included its own lens optics, photoconductive sensor and electronics. The electron beam scan in the camera tube is an effective way of individually examining small areas of a large field of view. Without scanning, the light signal from sparks or flashes is averaged out over the whole field of view and its intensity is thus greatly reduced.

The direct video viewing of the enclosure presented some difficulties. It is not possible to see all four sides of the flange simultaneously. A close-up view along flange gap is not obtained. To avoid these difficulties, a mirror arrangment was devised to view along the flange gap on all four sides simultaneously and to present the combined view to the video camera. Figure G-13 shows the general arrangement of the mirrors. The arrangement gives a combined view along the flange gap on all sides, at the top right hand corner of the video monitor screen. In the same view, the enclosure vent is also fully visible. Trials were conducted on the arrangement. A flint type cigarette lighter without fuel was used to generate sparks. Even with background light from the shop, sparks generated along all four flange gaps were clearly visible in the video monitor.

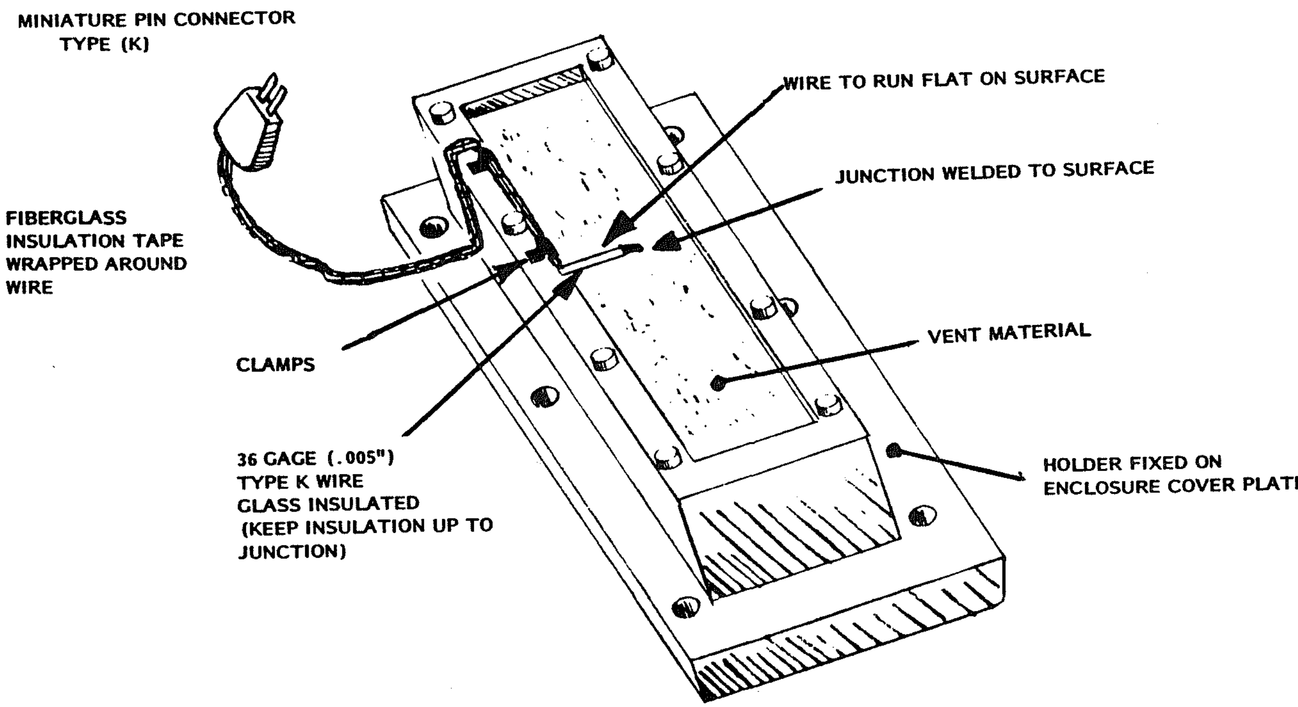


FIGURE G-11. - Fixturing of thermocouple on the vent surface.

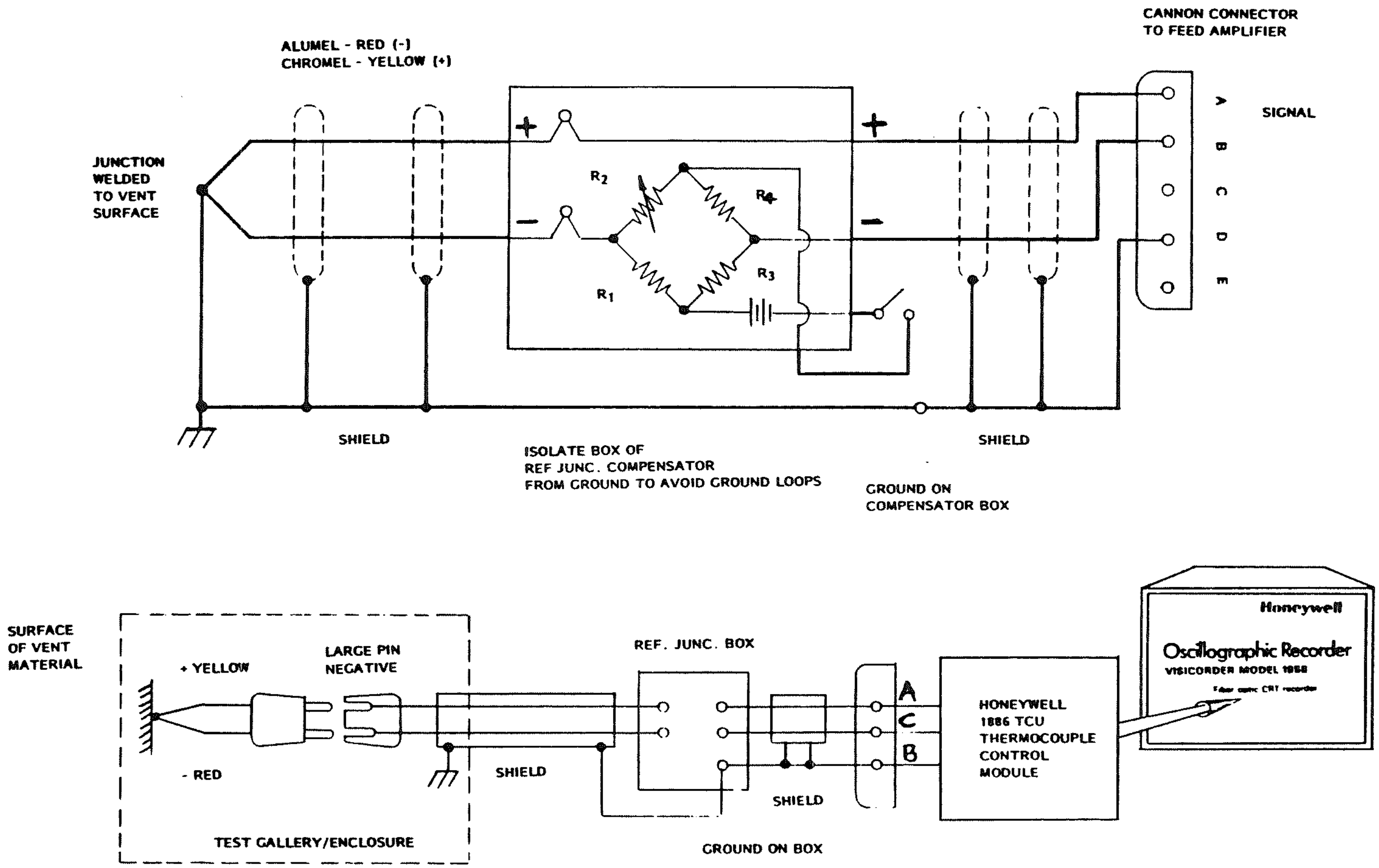


FIGURE G-12. - Vent surface temperature recording system.

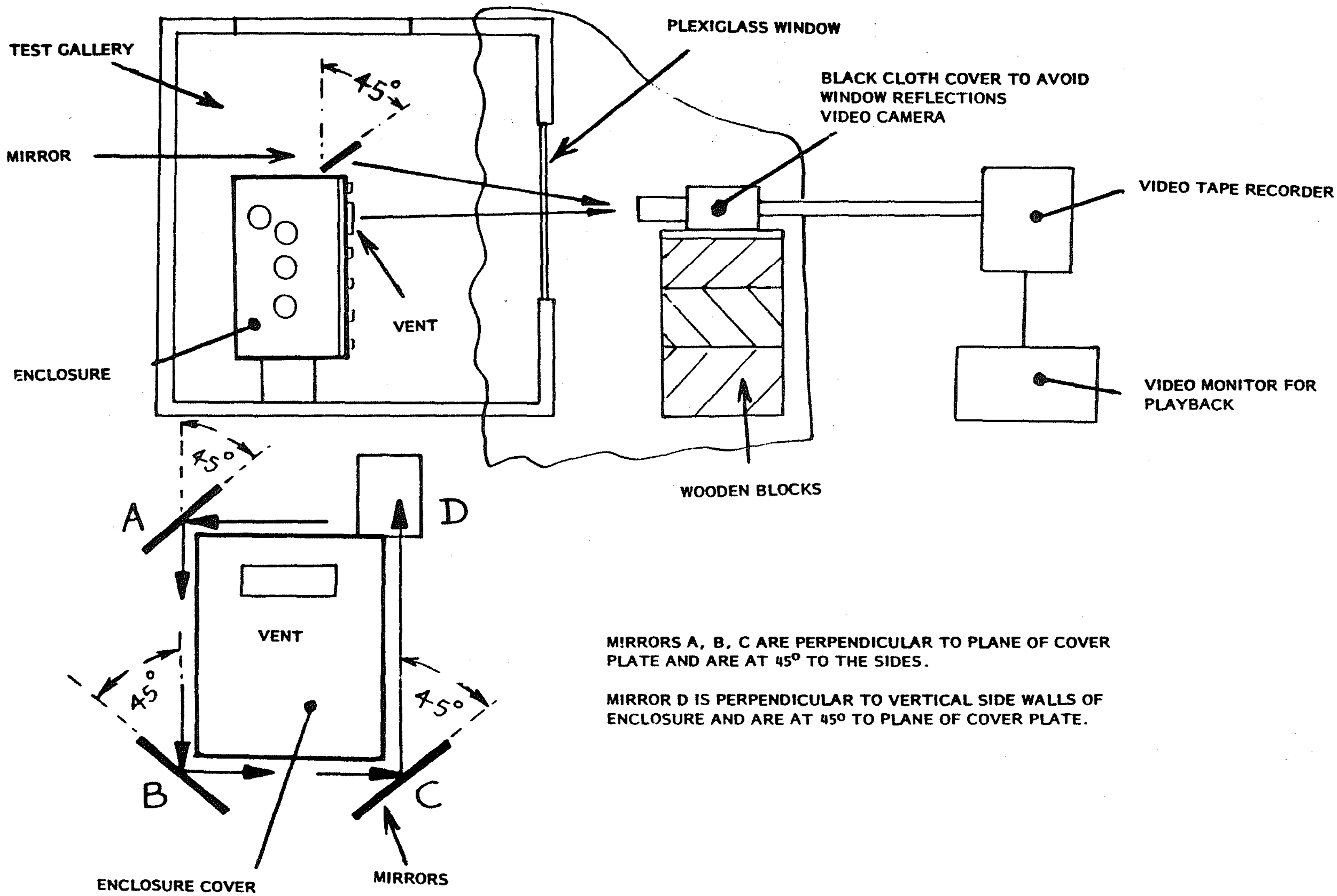


FIGURE G-13. - Mirror arrangement for video recording of sparks or flashes.

Typical data traces obtained on the high speed high frequency response strip chart recorder have been shown in figures G-14, G-15, and G-16.

G.3 Test Procedure

The following steps were performed in sequence to calibrate the instrumentation and prepare it for collecting the explosion test data.

(1) POSITION trace on all amplifier modules of the visicorder. On each amplifier module:

(a) Turn the trace switch to ZERO.

(b) Keep recorder chart speed selectors to OFF and press the chart switch ON.

(c) OPEN the paper roll door and observe the CRT spot corresponding to the amplifier being calibrated. ADJUST the CRT spot to the desired trace position by turning the POS control screw.

(2) CHECK and ADJUST the sensitivity of all of the visicorder amplifier modules. On each module (except for the chromatograph amplifier), SET the calibration/suppression multiplier switch to X1 position. SET the calibration/suppression/polarity switch to "-" (minus) position. ROTATE the calibration/suppression control dial to apply the following voltage signals to the amplifier inputs:

(a) 10mV on 1886 TCU for vent surface temperature.

(b) 10mV on 1886 TCU for vent surface temperature.

(c) 5mV on 1886 TCU for gas temperature.

(d) 1mV on 1885A SGC when using a 0-50 PSIG pressure transducer.

ROTATE the sensivivity screw to obtain 1" deflection of the trace for each amplifier. No special calibration of the high

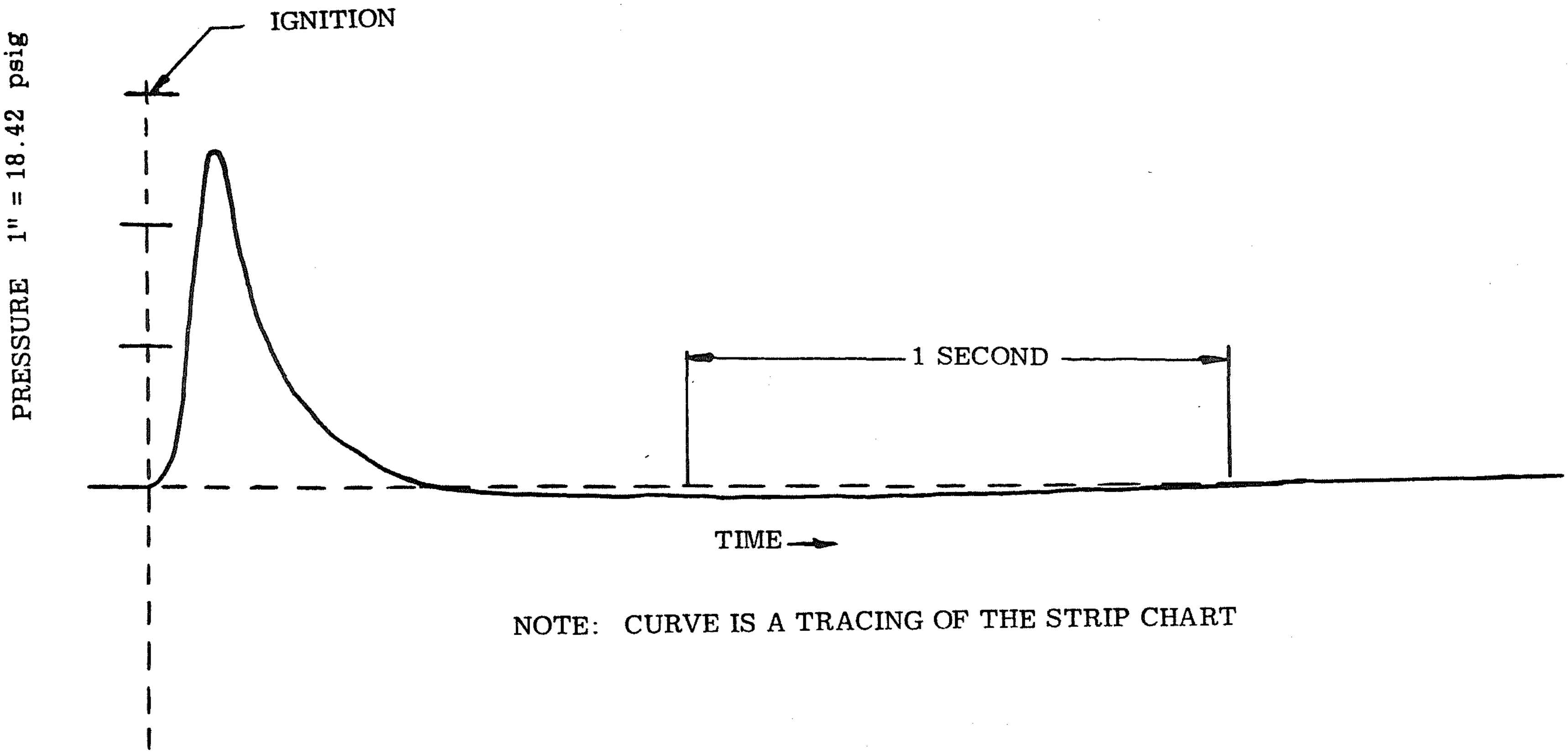


FIGURE G-14. Typical pressure trace in clamped vent door test.

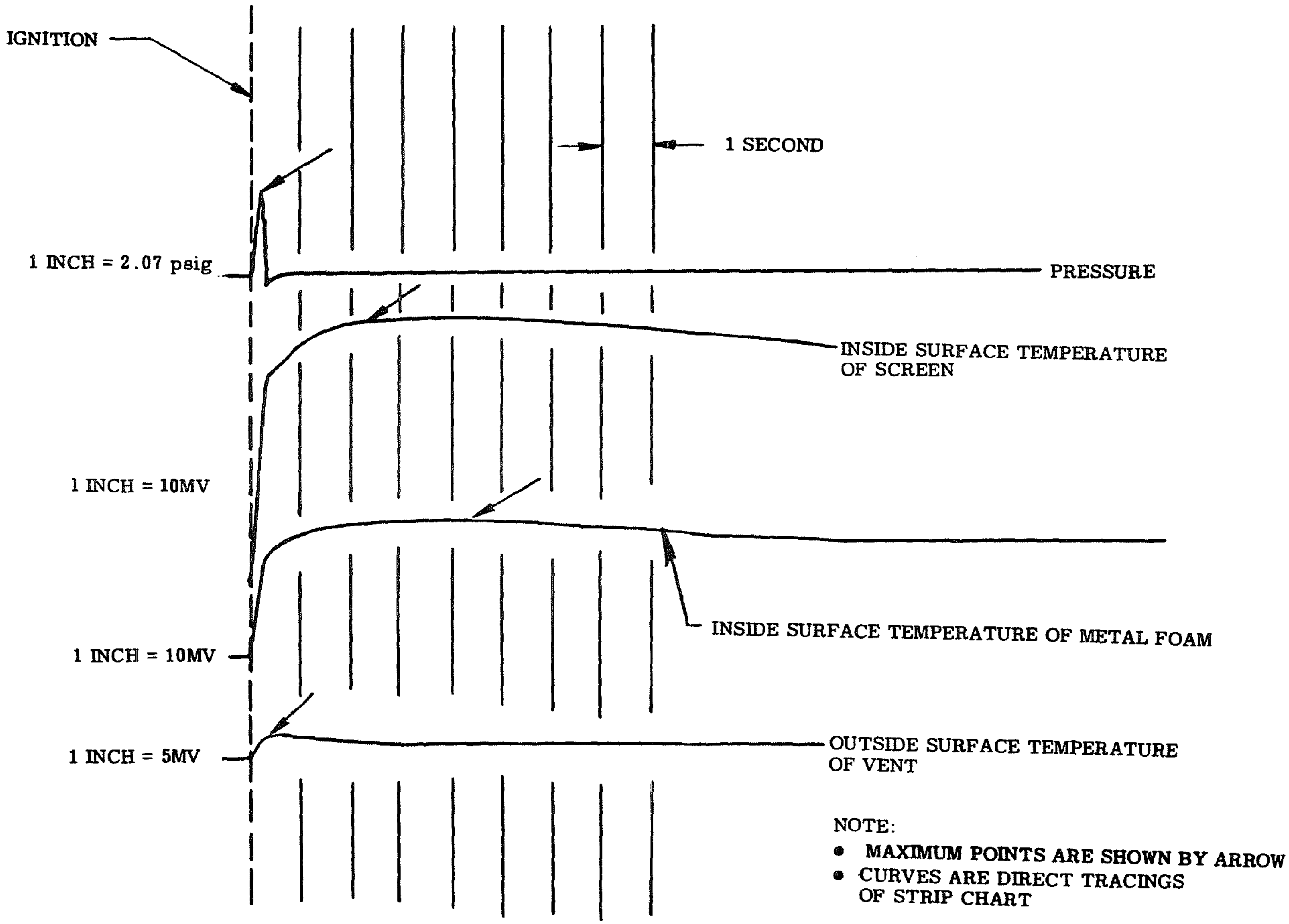
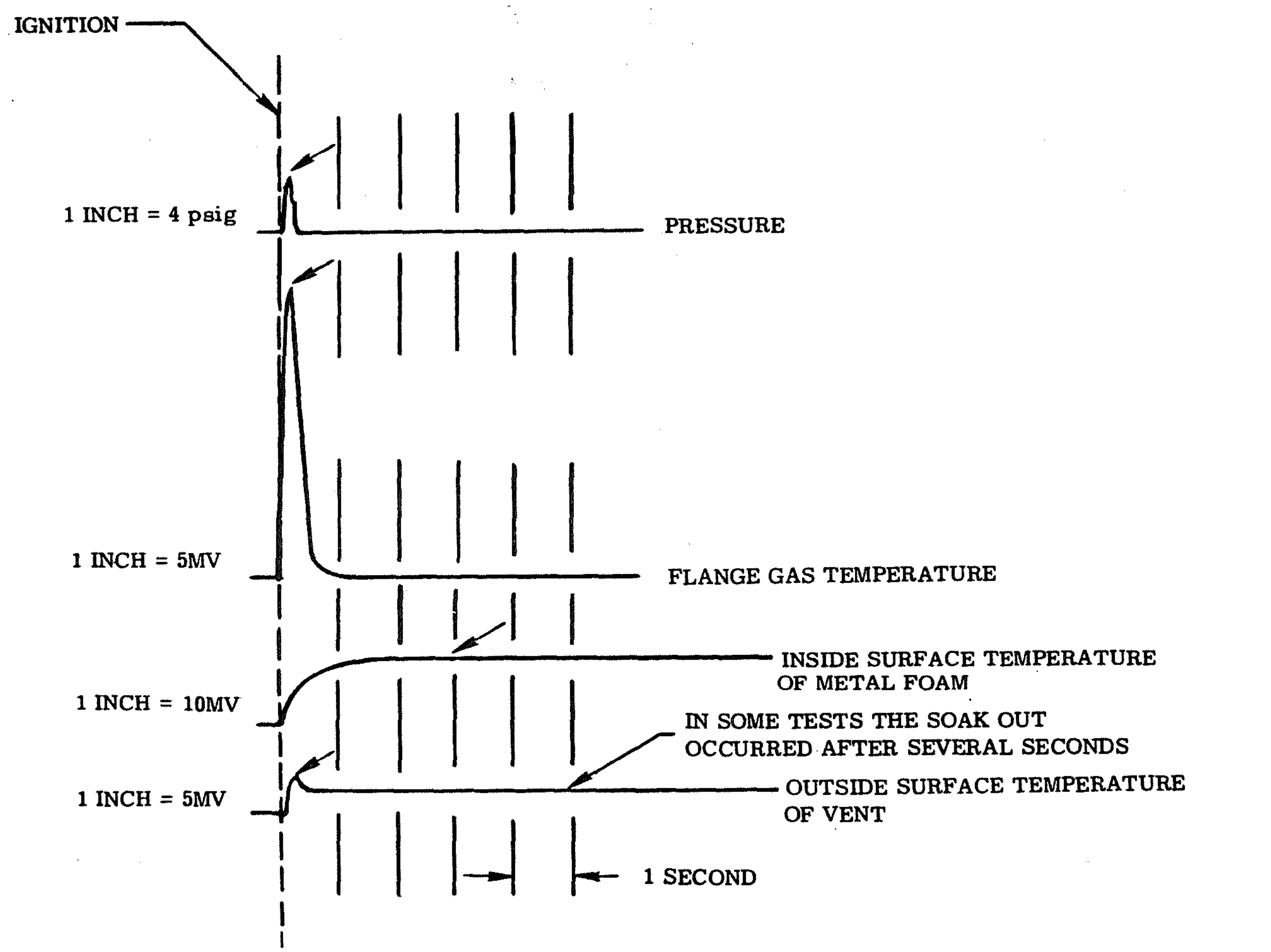


FIGURE G-15. - Typical traces in tests of metal foam and screen pack vents.



NOTE:
- MAXIMUM POINTS ARE SHOWN BY ARROW.
- CURVES ARE DIRECT TRACINGS OF STRIP CHART.

FIGURE G-16. - Typical traces in flange gap tests.

gain amplifier for the chromatograph is necessary. This amplifier is used only for comparative measurement of chromatograph outputs with calibration gas consisting of 10% methane air mixture. After calibration, turn the calibration/suppression switch to OFF.

(3) ROTATE the sensitivity knob on each amplifier and SET at 10mV/division, i.e., 10mV/inch for the vent surface thermocouples, 5mV/inch for gas temperature thermocouples, and 1mV/inch for the pressure transducer. Use 1mV/division sensitivity for the gas chromatograph.

(4) SHORT all input signals into amplifiers. SET the trace switch alternately between ZERO and NORM. ADJUST the balance screw on each amplifier to eliminate trace movement between these positions. REMOVE the shorts.

(5) SET trace switches on all amplifiers to the NORM position. CLOSE the door of the chart recorder and turn the run switch OFF.

(6) SET the chromatograph detector current switch to the ON position. SET the chromatograph attenuation control to 128 and ZERO the visicorder trace with the coarse zero control.

(7) SET the attenuation control to 1 and ZERO the visicorder trace with the fine zero control.

(8) INJECT a methane reference sample into the right sample column and RECORD the calibration trace at a speed of .2" per second.

(9) RETAIN the chromatograph calibration record and COMPLETE an Instrument Calibration Data Record Form.

(10) SET the chart speed at 2" per second and timer markings at 100 millisecond intervals.

(11) CHECK continuity across leads and between each lead and ground for each thermocouple. The instrumentation is now ready for recording test data. The following steps will be performed for an explosion test.

(a) COMPLETE an Explosion Test Data Sheet for the test to be run.

(b) With a feeler gauge, CHECK the flange gap on all four sides. ADJUST the gap as desired by using steel shim stock.[1]

(c) CLOSE and SEAL the test chamber.

(d) Make sure all three switches on the control panels are OFF and that all five gas valves are CLOSED.

(e) CONNECT the methane tank to the test chamber, OPEN the methane gas valve, and allow a 50 CFM flow rate for 3 MINUTES.

(f) CLOSE the methane valve.

(g) OPEN the four gas circulation valves and turn the mixing blower ON for 2 MINUTES.

(h) Turn the mixing blower OFF and take a syringe sample at the methane sampling port.

(i) Check for a correct gas mixture of 10% methane on the chromatograph.

(j) If methane concentration is too low, go back to step (e).

(k) If methane concentration is too large, OPEN chamber, CLOSE again, and go back to step (c).

(l) When the methane is correct, CLOSE the four gas circulation valves.

(m) CLOSE the valve on the methane tank and DISCONNECT the tank from the test chamber.

(n) Turn ON the video tape recorder and television camera.

(o) Turn ON the chart recorder.

1 For tests with normal flange gap, do not use shims. Check that flange gap is not more than 0.001 inch.

(p) Turn the DC power switch ON.

(q) Turn the ignition switch ON.

(r) After the explosion, turn OFF the ignition switch, DC power switch, chart recorder, video tape recorder, and television camera.

(s) OPEN the test chamber.

(t) OPEN the four gas circulation valves and turn the mixing blower ON for 2 MINUTES.

(u) Turn the mixing blower OFF and CLOSE the four gas circulation valves.

(v) Record visual observation of the test and photo-document as required.

The basic procedures given above were modified slightly for special test runs. For example, for tests with increased flange gaps, coal dust was placed in the enclosure prior to the bolting of the cover plate. This dust was obtained by grinding Pittsfield seam coal to 200 mesh.

Tables G-2 and G-3 show the log sheets used for recording the calibration and test data.

TABLE G-2. - Calibration data sheet

Calibration No. ________________

For Test Numbers ____

____

Date: __________________ Time: _______________ Operators: _________

____

1. CHROMATOGRAPH:

   Helium Pressure _____________

   Methane Reference % __________

   Sensitivity Setting ____________

   Chart Speed __________________

   Recorder Output for
   Methane Peak in Inches ________

2. THERMOCOUPLE:

   Location ____________________

   Surface/Gas __________________

   Sensitivity Setting ____________

   Trace Deflection at 10mV
   Calibration Signal ____________

3. THERMOCOUPLE:

   Location ____________________

   Surface/Gas __________________

   Sensitivity Setting ____________

   Trace deflection at 10mV
   Calibration Signal ____________

TABLE G-2. - Calibration data sheet (continued)

4. THERMOCOUPLE:

Location ______________________

Surface/Gas ____________________

Sensitivity Setting _______________

Trace Deflection at 10mV
Calibration Signal _______________

5. PRESSURE TRANSDUCER:

Sensitivity Setting _______________

Trace Deflection at 1mV
Calibration Signal _______________

6. CHART RECORDER:

Chart Speed ______________

Timer Internal _____________

7. THERMOCOUPLE CHECKS:

Thermocouple Location			
Resistance Across Leads			
Resistance of + to Ground			
Resistance of - to Ground			

TABLE G-3. - Explosion test data sheet

Test No: ____________ Date: ____________ Operators: (1) ________________
(2) ________________
(3) ________________
(4) ________________
(5) ________________
(6) ________________

1. DESCRIPTION

1. Enclosure Under Test: ________________
2. Vent Under Test: (Area, materials and assembly) ____________________________
____
____
3. Flange Gap: ________________________
4. Video Tape No. _______ Log Time: Begin ________ End __________
5. Ambient Temperature __________ Barometric Pressure __________
Relative Humidity __________ General Weather __________
6. Coal Dust In Enclosure (Yes), (No) __________
7. Other ____
____

2. TEST RESULTS

1. METHANE REFERENCE SAMPLE (10%)

Before Test: Peak Reading In Inches ______________
After Test: Peak Reading In Inches ______________

2. METHANE INPUT

METHANE INPUT	No. 1	No. 2	No. 3	No. 4	No. 5
A. Flow Rate (CFM)	____	____	____	____	____
B. Time In Minutes	____	____	____	____	____
C. Pressure (PSIG)	____	____	____	____	____

3. METHANE CONCENTRATION

Peak Reading In Inches	____	____	____	____	____
Concentration %	____	____	____	____	____

4. IGNITION

Enclosure Ignition	____	____	____	____	____
Yes/No	____	____	____	____	____

TABLE G-3. - Explosion test data sheet (continued)

5. MEASUREMENTS

Test Chamber Ignition (Yes), (No) ____________

Thermocouple Location	Maximum Temperature	Rise Time
____________	____________	____________
____________	____________	____________
____________	____________	____________
____________	____________	____________

Pressure Transducer: Maximum Pressure __________Rise Time _______

Sparks/Flashes Observed: (Yes), (No) ___________

Locations __________________In Video or Direct _________________

Vent Glow Observed (Yes), (No) __________Video or Direct _________

6. COMMENTS

____

____

____

APPENDIX H PRESSURE VENT TEST DATA

Tables H-1 through H-8 of this appendix present the results of the following tests:

- Temperatures and pressures for vents with metal foam only.
- Temperatures and pressures with 6 screens and 10 screens in pressure vents.
- Flange gap tests on vented enclosure.
- Flange gap tests on unvented enclosure.
- Guideline verification tests on 4 cubic feet and 14 cubic feet enclosures.
- Clamped vent door tests.
- Vent door displacement-personnel safety tests.
- Vent gas temperature-personnel safety tests.

The test data for several other tests conducted during this program has not been included in this report, for the sake of brevity. However, this data has been doucmented in the project files. The data not documented in this report refers to the following tests:

- Equipment debugging tests.
- Initial feasibility and vent concept development tests.
- Durability tests on the one half cubic foot and 14 cubic feet enclosures.
- Preliminary flange gap tests with various size vents on the one-half cubic foot and 14 cubic feet enclosures.

- Multiple tests on the one-half cubic foot enclosure with guideline vents and flange gaps.

TABLE H-1. - Temperatures and pressures for vent with metal foam only

Enclosure volume = ½ cubic foot

	Vent area to enclosure volume ratio (in^2/ft^3)	Pressure (psig)	Maxium inside surface temperature of metal foam (°F)	Maxium outside surface temperature of vent (°F)	Methane concentration (%)
	28	0.51	1606	344	9.5
	28	0.3	1946	411	9.1
	28	0.3	1946	389	10.0
*	28	0.37	1833	381	9.5
	24	0.29	1718	457	10.0
	24	0.35	1808	434	10.1
	24	0.31	1808	394	9.8
*	24	0.32	1778	428	10.0
	20	0.54	1660	344	10.2
	20	0.41	1753	300	8.9
	20	0.62	1872	327	9.5
*	20	0.52	1762	327	9.5
	12	1.9	1927	611	9.0
	12	1.1	2168	741	9.0
	12	0.8	2149	676	9.7
*	12	1.3	2081	676	9.2

*Average

TABLE H-2. - Temperatures and pressures with 6 screens and 10 screens in pressure vents

Enclosure volume = ½ cubic foot

	Vent area to enclosure volume ratio (in^2/ft^3)	Number of screens	Pressure (psig)	Maxium inside surface temperature of screen (^oF)	Maxium outside surface temperature of metal foam (^oF)	Maxium outside surface temperature of vent (^oF)	Methane concentration (%)
	4	6	8.3	2149	674	569	8.8
	4	6	8.9	2125	695	578	9.3
	4	6	1.2	2212	652	556	10.7
*	4	6	6.1	2162	674	568	9.6
	8	6	2.0	---	600	332	8.9
	8	6	1.4	---	587	288	11.2
	8	6	0.2	---	399	245	11.1
*	8	8	1.2	---	529	288	10.4
	10	6	2.1	1901	---	---	9.8
	10	6	2.8	1925	504	273	9.2
	10	6	1.3	1954	433	288	9.8
*	10	6	2.1	1927	469	251	9.6

* Average; --- No data

TABLE H-2. - Temperatures and pressures with 6 and 10 screens in pressure vents (continued)

	Vent area to enclosure volume ratio (in^2/ft^3)	Number of screens	Pressure (psig)	Maxium inside surface temperature of screen (^oF)	Maxium outside surface temperature of metal foam (^oF)	Maxium outside surface temperature of vent (^oF)	Methane concentration (%)
	4	10	4.0	2058	394	295	11.2
	4	10	2.6	2060	361	265	11.8
	4	10	3.2	2015	367	278	11.7
*	4	10	3.3	2044	374	279	11.6
	8	10	.34	1969	271	170	11.5
	8	10	3.4	2103	527	244	9.0
	8	10	.26	1516	260	172	11.0
*	8	10	1.3	1863	353	195	10.5
	12	10	1.6	1629	155	171	10.5
	12	10	0.9	1714	430	172	10.4
	12	10	2.0	1818	510	176	9.3
	12	10	2.0	1779	446	160	9.3
	12	10	1.7	1862	551	188	9.7
	12	10	2.5	1733	540	172	9.5
*	12	10	1.78	1756	439	173	9.8

* Average

TABLE H-2 - Temperatures and pressures with 6 screens and 10 screens in pressure vents (continued)

	Vent area to enclosure volume ratio (in^2/ft^3)	Number of screens	Pressure (psig)	Maxium inside surface temperature of screen (°F)	Maxium outside surface temperature of metal foam (°F)	Maxium outside surface temperature of vent (°F)	Methane concentration (%)
	12	6	1.6	1888	446	221	8.5
	12	6	1.2	1914	417	215	10.4
	12	6	---	---	---	---	11.5
	12	6	0.64	1837	391	201	10.7
	12	6	0.59	1847	432	213	10.0
	12	6	0.51	1874	396	210	10.3
*	12	6	0.91	1872	416	212	10.2
	16	6	---	---	---	---	10.5
	16	6	1.2	919	520	306	9.8
	16	6	1.0	974	529	182	9.5
	16	6	1.3	960	439	179	10.0
	16	6	0.19	918	254	166	10.8
	16	6	0.21	961	341	167	10.7
*	16	6	0.78	946	417	200	10.2
	2	10	21.8	---	---	---	8.7
	2	10	20.6	2013	396	396	9.0
	2	10	---	2061	279	266	11.9
*	2	10	21.0	2037	338	331	9.9

* Average; --- No data

TABLE H-3. - Flange gap tests on vented enclosure

Enclosure volume = ½ cubic foot
Flange perimeter partially sealed off to achieve worst case conditions

	Vent area to enclosure volume ratio (in^2/ft^3)	Number of screens	Flange gap (inch)	Pressure (psig)	Gas Temperature (°F)	Methane concentration (%)
	16	3	.035	.91	1152	10.2
	16	3	.035	.91	1141	9.4
*	16	3	.035	.91	1147	9.8
	16	3	.030	.76	1062	---
	16	3	.030	---	1073	8.9
	16	3	.030	1.06	1221	8.9
*	16	3	.030	.91	1119	8.9
	16	3	.025	.17	796	8.9
	16	3	.025	.42	865	10.3
	16	3	.025	.42	929	8.2
*	16	3	.025	.34	863	9.1
	10	6	.025	.63	1262	7.0
	10	6	.025	1.57	1655	8.9
	10	6	.025	1.26	1526	8.9
*	10	6	.025	1.15	1483	8.3
	10	6	.020	.94	1015	8.9
	10	6	.020	1.26	1142	9.3
	10	6	.020	1.56	1271	10.6
*	10	6	.020	1.25	1143	9.6

* Average; --- No data

TABLE H-3. - Flange gap tests on vented enclosure (continued).

Vent area to enclosure volume ratio (in^2/ft^3)	Number of screens	Flange gap (inch)	Pressure (psig)	Gas Temperature (°F)	Methane concentration (%)
10	6	.015	.94	454	9.7
10	6	.015	1.57	501	9.4
10	6	.015	1.57	546	9.8
* 10	6	.015	1.36	500	9.6
8	10	.020	1.89	1409	9.8
8	10	.020	3.46	1616	9.6
8	10	.020	1.89	1312	10.6
* 8	10	.020	2.41	1446	10.0
8	10	.015	2.20	555	7.9
8	10	.015	2.52	599	8.2
8	10	.015	3.14	729	8.6
* 8	10	.015	2.62	628	8.2
6	10	.025	2.99	1291	---
6	10	.025	3.30	1291	---
6	10	.025	1.73	1080	11.1
* 6	10	.025	2.67	1221	11.1
6	10	.020	3.52	1181	6.9
6	10	.020	4.74	1223	9.0
6	10	.020	1.57	868	9.3
* 6	10	.020	3.21	1091	8.4

*Average; --- No data

TABLE H-3. - Flange gap tests on vented enclosures (continued)

	Vent area to enclosure volume ratio (in^2/ft^3)	Number of screens	Flange gap (inch)	Pressure (psig)	Gas temperature (°F)	Methane concentration (%)
	6	10	.015	3.06	1033	9.4
	6	10	.015	4.58	1046	8.6
	6	10	.015	4.58	1116	6.8
*	6	10	.015	4.07	1065	8.3
	6	10	.010	5.19	195	8.5
	6	10	.010	4.12	437	8.6
	6	10	.010	---	142	10.2
	6	10	.010	4.58	154	---
*	6	10	.010	4.63	232	9.1
	4	16	.010	14.47	1387	9.4
	4	16	.010	19.65	1464	9.1
*	4	16	.010	17.06	1425	9.3
	4	16	.005	15.09	308	8.8
	4	16	.005	10.38	264	8.7
	4	16	.005	5.38	199	9.0
*	4	16	.005	10.27	257	8.8

*Average; --- No data

TABLE H-4. - Flange gap tests on unvented enclosure

Enclosure volume = ½ cubic foot

	Flange gap (inch)	Gas temperature (^{o}F)	Pressure (psig)	Methane concentration (%)
	0.005	171	---	---
	0.005	169	---	10.0
	0.005	153	---	10.0
	0.005	155	17.8	9.5
	0.005	176	22.2	10.0
*	0.005	165	20.0	9.9
	0.010	289	---	7.2
	0.010	151	---	9.0
	0.010	262	---	8.0
	0.010	354	---	8.5
	0.010	642	---	8.5
	0.010	1050	22.2	---
	0.010	267	46.7	10.0
	0.010	202	40.0	10.0
*	0.010	402	36.3	8.7

*Average
--- No data

TABLE H-4. - Flange gap on unvented enclosure (continued)

	Flange gap (inch)	Gas temperature (^{o}F)	Pressure (psig)	Methane concentration (%)
	0.015	1430	37.8	---
	0.015	330	42.2	---
	0.015	218	37.8	8.0
*	0.015	659	39.3	8.0
	0.020	1701	6.7	---
	0.020	1746	11.1	10.0
*	0.020	1724	8.9	10.0

*Average -- No data

TABLE H-5. - Guideline verification tests on 4 cubic feet and 14 cubic feet enclosures

Enclosure volume = 14 ft^3

Vent area to enclosure volume ratio (in^2/ft^3)	Number of screens	Flange gap (inch)	Pressure (psig)	Gas temperature (°F)	Methane concentration (%)
6	6	.020	2.5	2065	5.1
6	6	.020	.6	1217	10.2
* 6	6	.020	1.6	1641	7.7
6	6	.015	1.3	1345	6.8
6	6	.015	.3	664	6.3
6	6	.015	—	489	6.4
6	6	.015	.6	922	10.2
* 6	6	.015	.6	855	7.4
6	6	.010	1.6	708	7.9
6	6	.010	1.9	708	9.8
6	6	.010	1.6	621	9.4
* 6	6	.010	1.7	612	9.0
10	6	.020	.6	1344	8.2
10	6	.020	.6	1387	7.9
* 10	6	.020	.6	1366	8.1

* Average -- No data

TABLE H-5. – Guideline verification tests on 4 cubic feet and 14 cubic feet enclosures (continued)

Enclosure volume = 14 ft^3

	Vent area to enclosure volume ratio (in^2/ft^3)	Number of screens	Flange gap (inch)	Pressure (psig)	Gas temperature (°F)	Methane concentration (%)
	10	6	.015	.6	---	9.8
	10	6	.015	.6	577	7.7
	10	6	.015	.6	620	8.4
	10	6	.015	.6	577	8.0
*	10	6	.015	.6	591	8.5
	10	6	.010	.3	90	8.0
	10	6	.010	.3	222	8.2
	10	6	.010	.6	222	9.8
*	10	6	.010	.4	178	8.7

*Average -- No data

TABLE H-5. - Guideline verification tests on 4 cubic feet and 14 cubic feet enclosures (continued)

Enclosure volume = 14 ft^3

Vent area to enclosure volume ratio (in^2/ft^3)	Number of screens	Flange gap (inch)	Pressure (psig)	Gas temperature (°F)	Methane concentration (%)
10	6	.018	2.6	104	10.4
10	6	.018	2.0	108	8.2
10	6	.018	2.6	113	---
* 10	6	.018	2.4	108	9.3
6	10	.010	5.8	99	6.3
6	10	.010	7.0	99	10.8
6	10	.010	3.8	95	6.9
* 6	10	.010	5.5	98	8.0

* Average -- No data

TABLE H-5. - Guideline verification tests on 4 cubic feet and 14 cubic feet enclosures (continued)

Enclosure volume = 14 ft^3
10 in^2/ft^3 vent using metal foam with 6 screens

Pressure (psig)	Maximum inside surface temperature of screens (°F)	Maximum inside surface temperature of metal foam (°F)	Maximum outside surface temperature of vent (°F)	Methane concentration (%)
1.2	1816	1036	165	6.3
---	1598	787	---	6.7
---	1531	829	---	7.8
6.0	1534	724	151	7.7
0.2	1554	722	171	10.0
* 2.5	1607	820	162	7.7

Enclosure volume 14 ft^3
6 in^2/ft^3 vent using metal foam with 10 screens

Pressure (psig)	Maximum inside surface temperature of screens (°F)	Maximum inside surface temperature of metal foam (°F)	Maximum outside surface temperature of vent (°F)	Methane concentration (%)
2.30	2328	330	---	5.3
1.6	2230	286	---	3.6
2.6	1629	288	---	5.0
* 2.2	2062	301	---	4.6

* Average -- No data

TABLE H-6. - Clamped vent door tests

Metal foam vent 28 in^2/ft^3 on 1/2 ft^3 enclosure.
Vent door firmly bolted by three cross bars.
Vent door magnets in place.

Maximum pressure (psig)	Methane percentage (%)
48.6	9
46.1	9
47.4	9

* Average

TABLE H-7. - Vent door displacement - Personnel safety test

Enclosure volume = ½ cubic foot
Door mass = 2.16 lbs.
Door height = 2.5 inches
Hinged vent door installed on the vent.
28 in^2/ft^3 vent with metal foam only.

Maximum pressure (psig)	Methane concentration (%)	Maximum door displacement angle (degrees)	% door opening (100%=46.15°)
0.1	7.5	23.1	50
0.3	10.0	26.8	58
0.2	9.6	31.0	67
* 0.2	9.0	27.0	58

* Average

TABLE H-8. - Vent gas temperature - personnel safety tests .

	Vent type	Pressure (psig)	Maxium inside surface temperature of metal foam (°F)	Maximum gas temperature (°F)	Methane concentration (%)
	6in2/ft3 vent	2.3	604	475	8.7
	with 10 screens	4.8	737	607	8.5
	1/2 ft^3 enclosures	7.4	826	692	7.8
*		4.8	722	591	8.3
	$10in^2/ft^3$ vent	2.1	824	578	5.4
	with 6 screens	0.5	631	387	9.7
	1/2ft enclosure	1.0	720	468	8.1
*		1.2	725	478	7.7
	$6in^2/ft^3$ vent	2.3	---	674	5.3
	with 10 screens	1.6	---	598	---
	$14ft^3$ enclosure	2.6	---	643	5.0
*		2.2	---	638	5.2
	$10in^2.ft^3$ vent	0.23	466	201	8.1
	with 6 screens	0.9	814	685	7.6
	$14ft^3$ enclosure	0.61	1003	536	10.0
*		0.58	761	474	8.6

* Average --- no data

APPENDIX I PERSONNEL SAFETY TESTS ON PRESSURE VENT HARDWARE

The operation of the vent in the event of an explosion inside the enclosure results in the exit of gas through the vent and a momentary opening of the hinged vent door. One concern was that the exiting gas presented the possibility of skin burns. Another was that the door opening presented the possibility of impact against the body. Laboratory tests indicated that neither of these events seems likely to cause injury. The following sections describe the laboratory tests.

I.1 Vent Gas

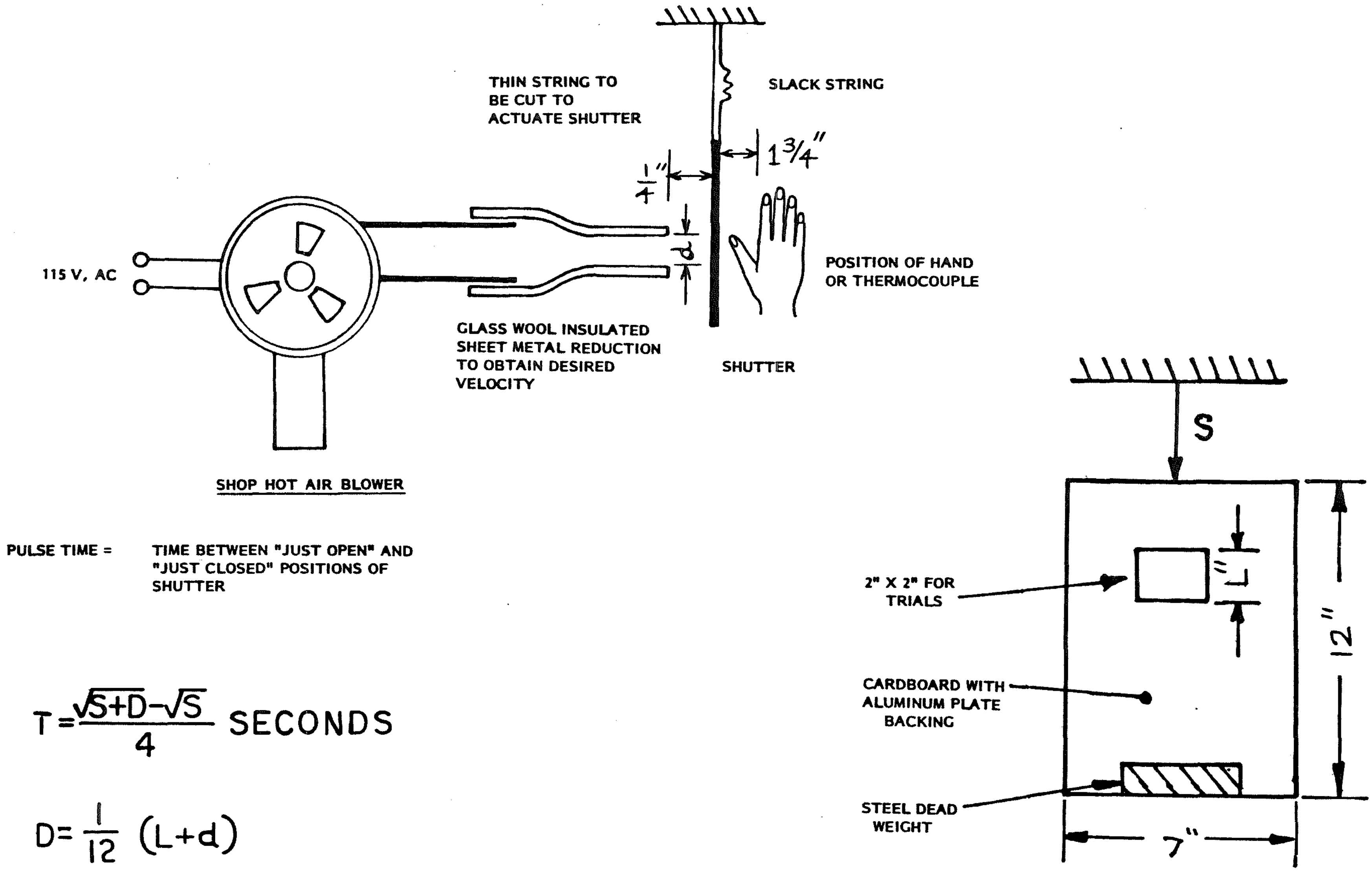
The explosion tests had established that the burnt gas exits through the vent in a very short duration pulse lasting for 200 milliseconds on the average. Its peak temperature at a distance of 1" from the vent was measured to be 692°F. A laboratory set up was built to give an exposure of 500 milliseconds to an air stream at 700°F having velocities equal to those determined for the vent gas. The set up is illustrated in Figure I-1.

Exposing the back of the hand to this gas pulse did not cause any burning or pain. A mathematical approach was also adopted to estimate the skin temperature resulting from exposure to the short duration vent gas pulse. This approach was based on considerations of the thermal response of human skin and was similar to that adopted in work done by Davies[1] on skin simulants. The calculations indicated that the skin termperature would not exceed 11°F under the vent gas exit conditions. Figure I-2 illustrates the heat transfer coefficient curves used for the skin temperature calculations.

I.2 Vent door opening

The opening of the vent door is caused by the momentum received from the exiting gas stream. The door opens to a maximum angle under these conditions and then drops back due to gravity. The maximum opening angle was measured with a potentiometer setup during explosion tests to be 31°. This potentiometer setup is illustrated in Figure I-3. The calibration of the potentiometer has been shown in Figure I-4.

1 Reference listed in Bibliography, Appendix B.



$$T = \frac{\sqrt{S+D}-\sqrt{S}}{4} \text{ SECONDS}$$

$$D = \frac{1}{12}(L+d)$$

FIGURE I-1. - Laboratory simulation of vent exit gas.

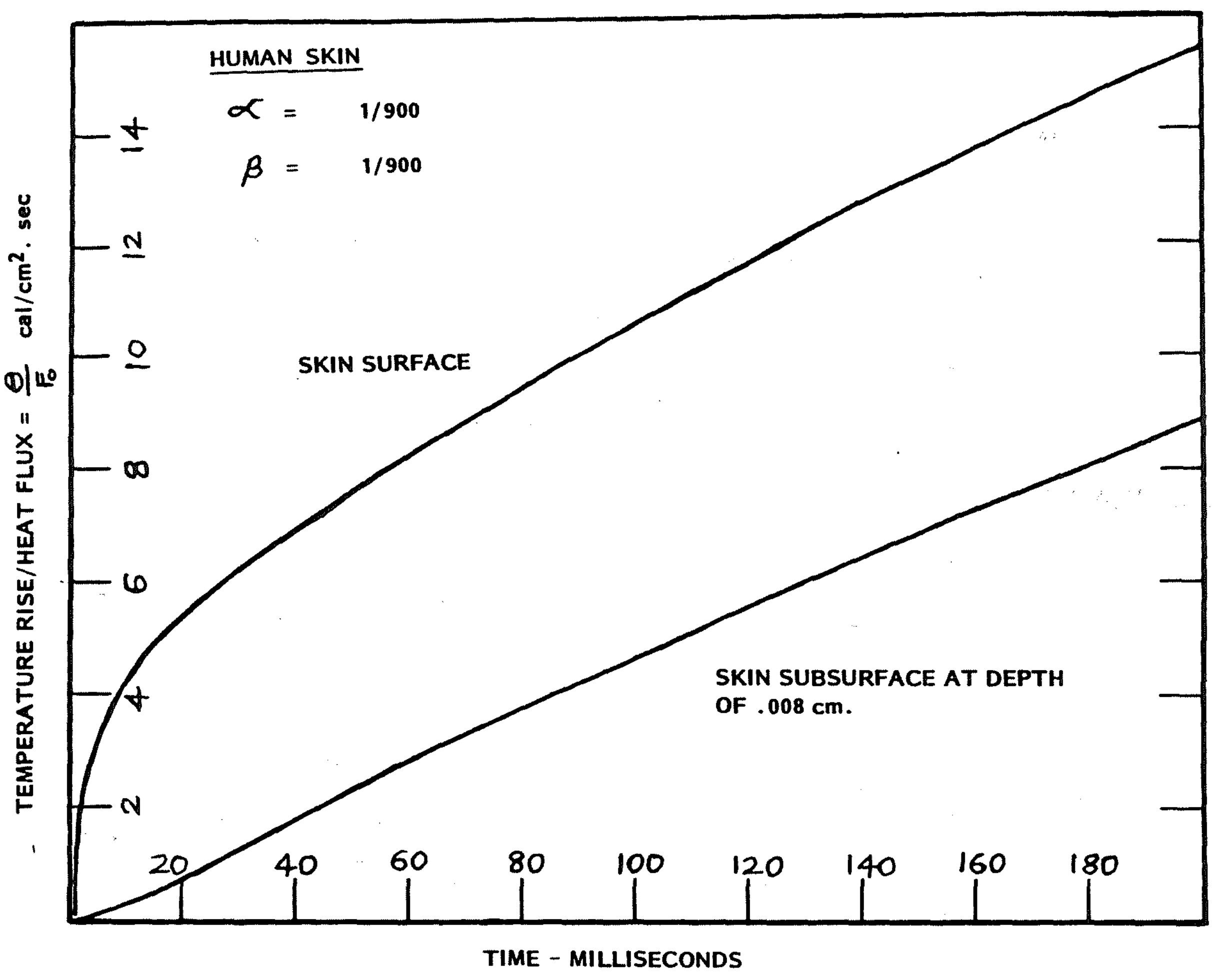


FIGURE I-2. - Skin temperature response to heat flux.

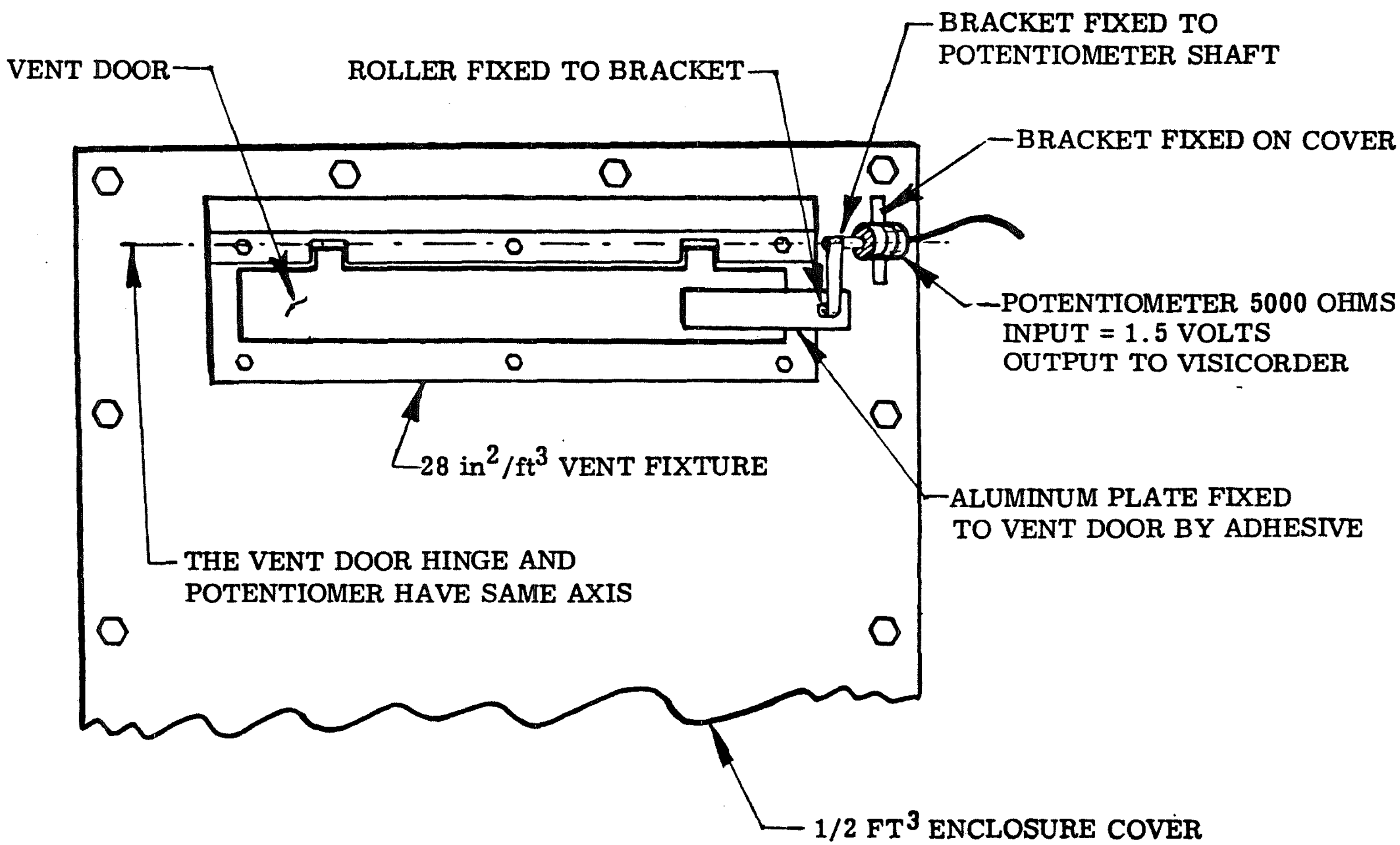


FIGURE I-3. - Potentiometer setup for measuring vent door opening angle.

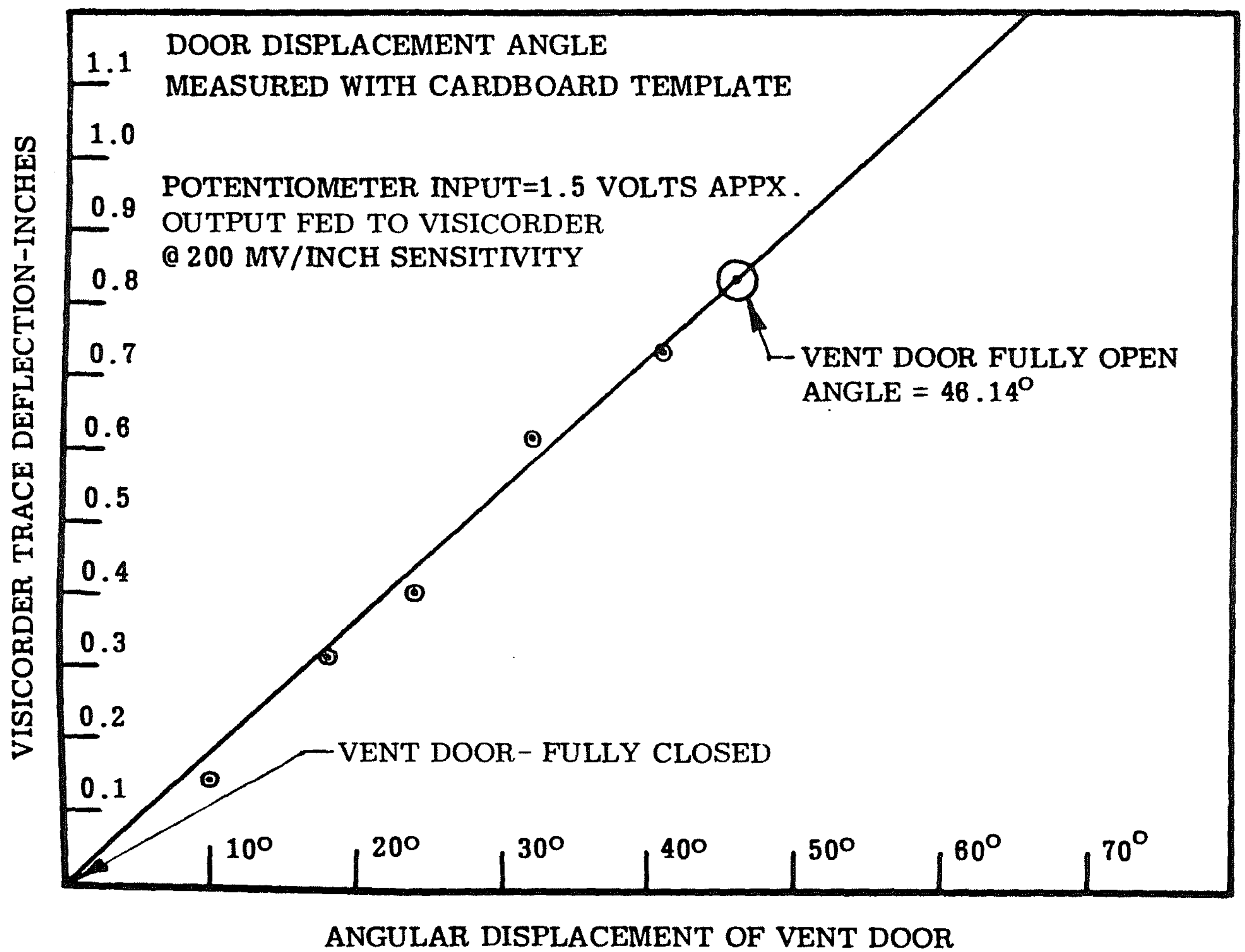


FIGURE I-4. - Calibration of potentiometer setup.

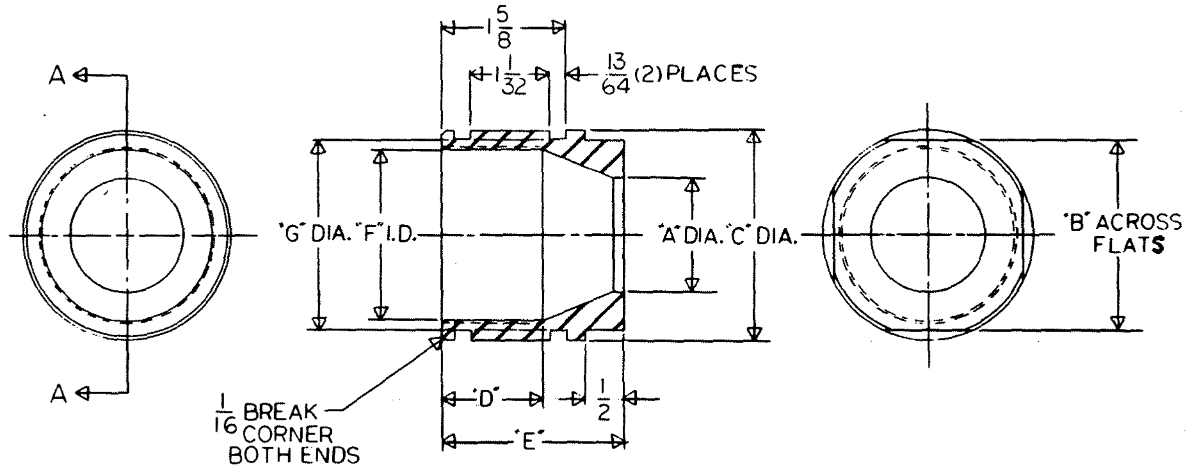
The opening momentum conditions were simulated in the laboratory by impacting the door cover so as to open it to 31° or more. These tests established that the door velocity was low and did not result in any damaging impact conditions on the body.

APPENDIX J SHOP DRAWINGS FOR THE ELASTOMERIC CABLE ENTRY HARDWARE

Figure J-1 through J-3 of this appendix present the shop drawings for the components of the elastomeric cable entries:

- Figure J-1 Cable entry body.
- Figure J-2 Elastomeric grommet.
- Figure J-3 Compression nut.

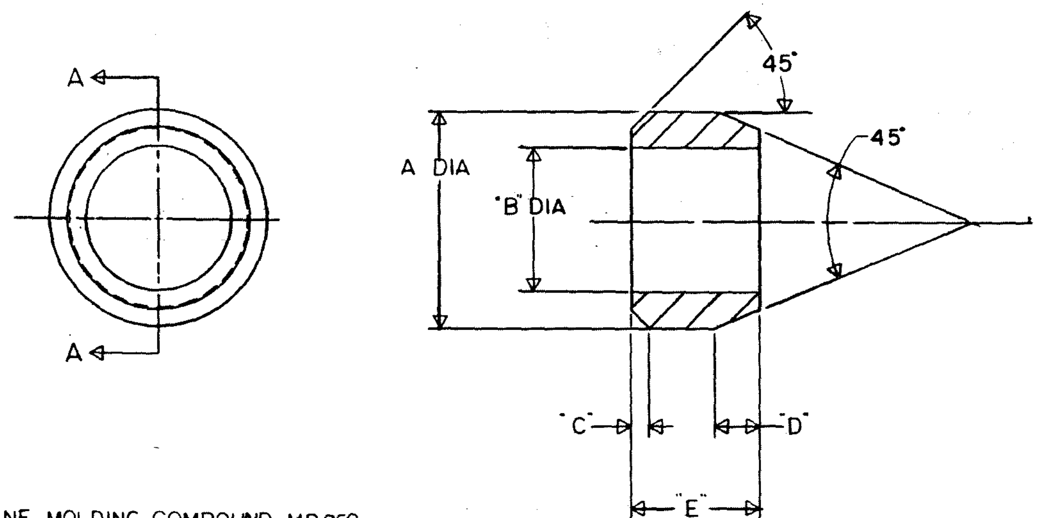
ITEM	"A"	"B"	"C" $^{+.0}_{-.0015}$	"D"	"E"	"F"	"G"	"H"
A-1	.665	1 1/2	1.7495	1 1/16	2 3/8	1.182/1.196	1 15/32	1 1/4-16-UN-2B
B-2	1.035	2	2.2495	1 3/16	2 3/8	1.660/1.678	1 31/32	1 3/4-12-UN-2B
C-3	1.518	2 1/2	2.7495	1 5/16	2 3/8	2.250/2.259	2 15/32	2 5/16-16-UN-2B
D-4	2.105	3 1/4	3.4995	1 1/2	2 5/8	3.000/3.015	3 7/32	3 1/8-8-UN-2B



MATERIAL
C-1018 STEEL

FIGURE J-1. - Cable entry body

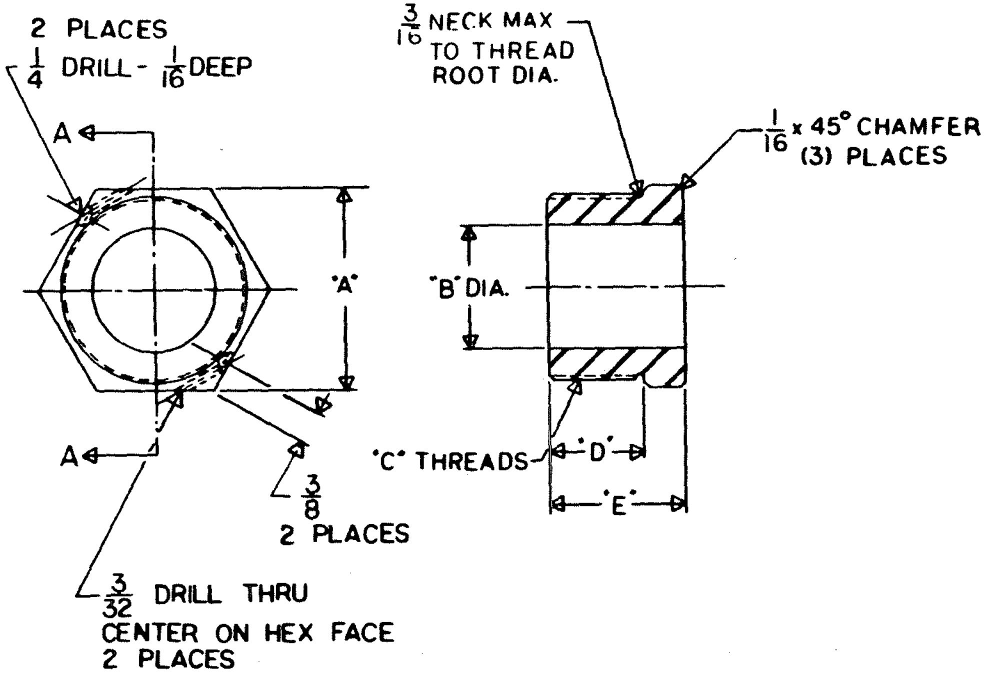
PART NO.	"A"	"B"	"C"	"D"	"E"
A-1	1.140	.671	9/64	.375	1
B-2	1.625	1.046	3/16	.500	1 1/4
C-3	2.218	1.531	1/4	.625	1 1/2
D-4	2.968	2.109	5/16	.687	1 3/4



MATERIAL
POLYURETHANE MOLDING COMPOUND MP 850
(NEWAGE INDUSTRIES)
HARDNESS 75A TO 85A

FIGURE J-2. - Elastomeric grommet.

PART NO.	"A"	"B"	"C"	"D"	"E"
A-1	1 1/2	43/64	1 1/4-16-UN-2A	1.000	1 3/8
B-2	2	1 3/64	1 3/4-12-UN-2A	1.125	1 1/2
C-3	2 1/2	1 17/32	2 5/16-16-UNS-2A	1.187	1 11/16
D-4	3 1/2	2 7/64	3 1/8-8-UN-2A	1.250	1 3/4



MATERIAL
C-1018 STEEL

FIGURE J-3. - Compression nut.

APPENDIX K CABLE ENTRY TEST

An early step in the development of the elastomeric cable entry was analysis and evaluation of the asbestos packed cable entry.

Items studied included typical packing procedures, seating torques, cable slippage and pull out performance, and dimensional considerations for conventional cable entry designs. The purpose of this testing was to quantify the performance of the hardware and then to use these data to establish minimum performance criteria for the elastomeric cable entry designs.

K.1 Cable Entry Procedures

To gain insight into proper packing procedures, production personnel were interviewed and their cable entry procedures were observed first hand. As a result, a detailed description of proper cable entry procedures was developed. Major findings of the packing procedure review are as follows:

- Packing of current cable entries is extremely labor intensive and requires a minimum of ten to twenty minutes labor by a skilled worker under ideal factory conditions.
- Proper packing of cable entries is highly dependent upon the care and skill of the assembler.
- The assembly procedure is basically a matter of cut and try on the part of the installer. From his experience he estimates the amount of asbestos rope which is needed to seal the cable. If his estimate proves incorrect, he adds or subtracts material as required.
- The torque applied to the gland nut is primarily a matter of feel. An experienced installer seems to know intuitively how much resistance should be encountered when turning a wrench against the compression force of the asbestos.

- The key to a proper installation is the workman's own evaluation of this work. He twists and pulls on the cable a reasonable amount and if he does not notice any motion of the cable, he deems the installation adequate.

Therefore, the entry of cables, although highly effective in the industry, is nonetheless a highly subjective procedure.

K.2 Test Procedures

The basic purpose of this testing was to determine gland nut torque and cable pull out forces for conventional asbestos packed cable entries. The procedure involved:

- The compression nut was tightened in small increments of torque, utilizing a suitable torque wrench and socket.
- The inserted cable was pulled and twisted by hand to determine if it was tight. A value of torque was reached for each cable and entry at which the cable did not move when twisted and pulled.
- If the compression nut was not already torqued to a value "felt" to be tight (usually 15 to 25 foot-pounds), the nut was then tightened to this value.
- The completed assembly was then submitted for pull out testing.

These procedures were performed for a wide variety of cable sizes, asbestos diameters, cable entry bodies and cable jacket materials.

The pull out testing was performed using a Dillon Model K tensile testing machine. A picture of this machine is shown in Figure 5-4. Although this is a manual machine, it was believed that more repeatable results would be obtained if the tests were performed under a constant strain. Therefore, a constant speed, gear-reduced motor was installed in the testing system.

Special handling clamps were developed to secure the cable entry into the test machine. A typical holding clamp is shown in Figure 5-5. Different size clamp assemblies were fabricated for each different size cable entry body which was developed. One of the problems encountered during these tests was the tendency of the conductor to slip within the cable jacket. To avoid this source of error in the analysis, a suitable size wire rope clamp was tightly installed around the cable end having the slipping conductors.

K.3 Test Results

Preliminary tensile test data on properly entered cables indicated that force on the cable builds up gradually as the lower clevis travels downward. However, at some point additional displacement does not cause additional load. The load at which this occurs was defined as the slip load and varied from cable to cable. A typical load/displacement curve is presented in Figure K-1. Additional preliminary testing indicated that this slip load is dependent on the velocity of the lower clevis. This velocity was defined as the displacement rate and typical slip load versus displacement rate characteristics are presented in Figure K-2. As a result of this testing, it was decided to perform all subsequent testing at a displacement rate of 0.13 inches per minute.

During these tests, four typical cable entry bodies, having inside diameters from 0.75" to 1.87", were utilized. Cables tested ranged in diameter from 0.54" to 1.76". Jacketing materials included braided asbestos, PVC and neoprene. A total of 36 tests were performed on the conventional asbestos packed cable entries. The details and results of these tests are summarized in Table K-1.

K.4 Conclusions

The following conclusions are drawn from the current asbestos packed cable entry testing:

- A large number of different cable body and compression nut sizes are required to enter all cables within the entire range. For various hardware styles, Jeffrey provides from 16 to 18 body/nut combinations to enter all cables within the entire range previously defined.

- The adequacy of an entered cable is highly dependent upon the skill and knowledge of the assembler. He is required to perform the entry and then inspect his own work, calling upon his past experiences with properly entered cables.

- Torque required to seat the compression nut of an adequately entered cable does not correlate to the adequacy of the entry. During testing, compression nut torque of near zero to 45 foot-pounds resulted in adequately entered cables. A minimum of 15 foot-pounds torque is required before the cable installer "feels" that sufficient compression has been achieved to adequately enter the cable. Therefore, torque required to seat entry compression nuts is not a good criteria for entering cables in elastomeric grommet entries.

- For all cables tested, an adequate entry was verified by pulling and twisting by hand. For all such adequate entries, tensile slip loads varied from 34 to 100 pounds. On this basis, 30 pounds is recommended as the minimum acceptable slip load for an entered cable pulled at a constant rate of 0.13 inches per minute.

- The slip load for any particular cable is friction-related, dependent upon the cable jacket material in contact with the asbestos packing. Three cables having the same outside diameter and differing jacket materials were pull tested. Entry hardware (compression nut, entry body and asbestos diameter and length) and compression nut torque were all held constant. The results showed that the slip load for neoprene was 68% and PVC was 59% of that for asbestos.

TEST CONDITIONS:
.80 DIAMETER, I CONDUCTOR #4/0
ASBESTOS CABLE
DISPLACEMENT RATE: .130 INCHES PER MINUTE
REFERENCE: TEST 45

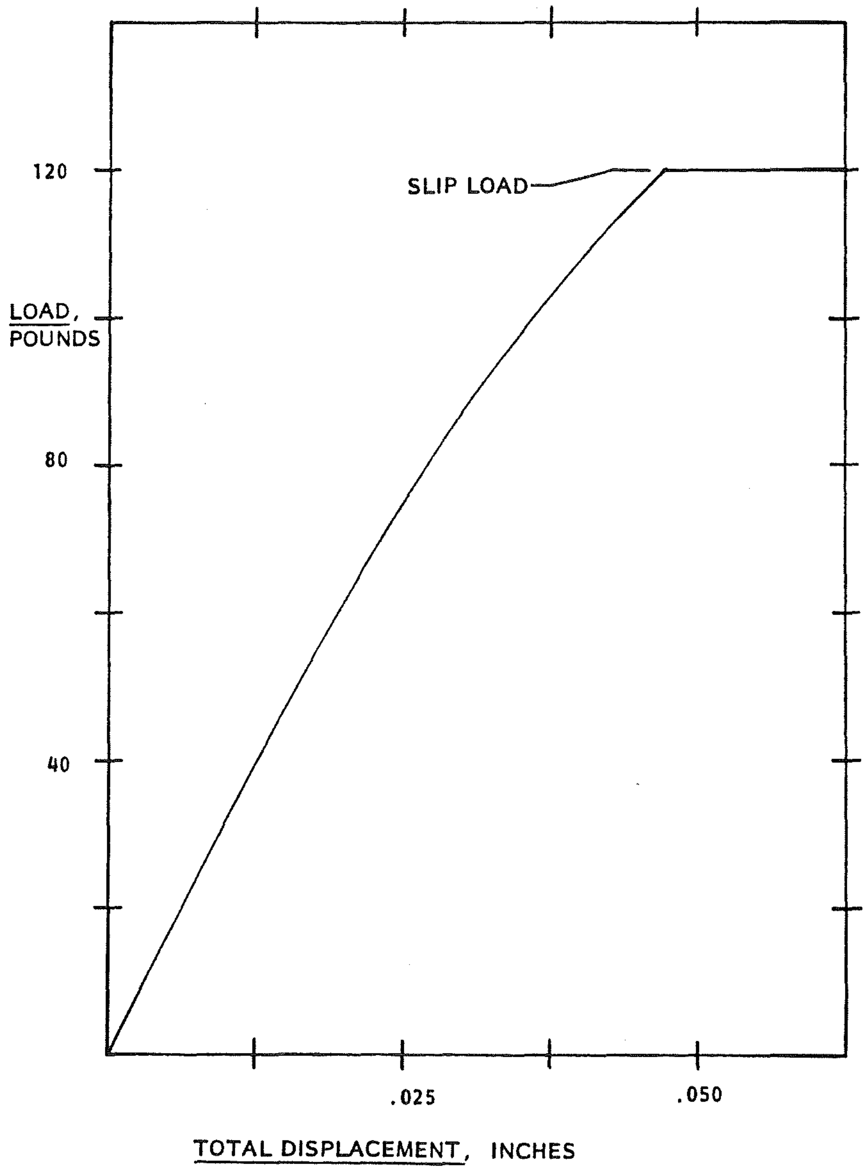


Figure K-1. Typical Cable Load versus Displacement

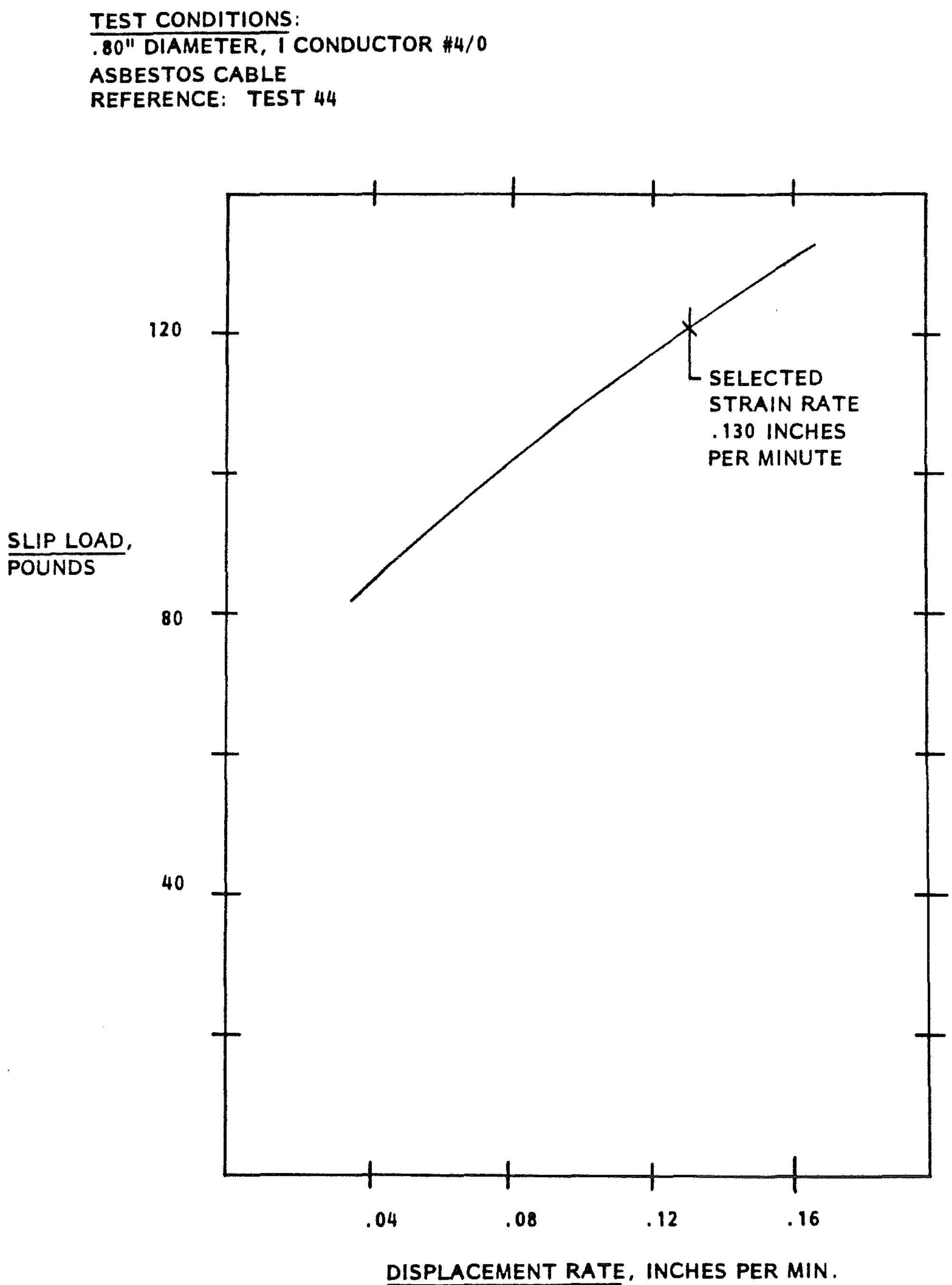


Figure K-2. Typical Cable Load versus Displacement Rate

Table K-1. - Asbestos Packed Cable Entries

Test Number	Insulated Cable				Cable Entry Hardware			Load to Slip†	Cable Adequately Enter	Torque "Feel" Achieved
	Conductors	Gage	Jacket Material	Actual O.D.*	Body & Nut,* I.D.	Nut Torque **	Asbestos,* Dia. x Length			
9	1	4/0	Asbestos	.79	.94	8	1/4 x 12	-	No	No
9	1	4/0	Asbestos	.79	.94	10	1/4 x 12	-	Yes	No
9	1	4/0	Asbestos	.79	.94	15	1/4 x 12	69	Yes	Yes
9	1	4/0	Asbestos	.79	.94	20	1/4 x 12	79	Yes	Yes
10	1	4/0	Asbestos	.79	.94	8	1/4 x 12	-	No	No
10	1	4/0	Asbestos	.79	.94	10	1/4 x 12	-	Yes	No
10	1	4/0	Asbestos	.79	.94	14	1/4 x 12	64	Yes	Yes
10	1	4/0	Asbestos	.79	.94	20	1/4 x 12	76	Yes	Yes
12	12	14	Neoprene	.89	.94	6	1/4 x 9	-	No	No
12	12	14	Neoprene	.89	.94	8	1/4 x 9	-	Yes	No
12	12	14	Neoprene	.89	.94	10	1/4 x 9	51	Yes	No
12	12	14	Neoprene	.89	.94	15	1/4 x 9	100	Yes	Yes
13	12	14	Neoprene	.89	.94	8	1/4 x 10	-	Yes	No
13	12	14	Neoprene	.89	.94	12	1/4 x 10	66	Yes	No
13	12	14	Neoprene	.89	.94	15	1/4 x 10	87	Yes	Yes
14	2	10	Neoprene	.63	.77	6	5/16 x 8 1/2	-	No	No
14	2	10	Neoprene	.63	.77	9	5/16 x 8 1/2	-	Yes	No
14	2	10	Neoprene	.63	.77	9	5/16 x 8 1/2	30	Yes	No
14	2	10	Neoprene	.63	.77	13	5/16 x 8 1/2	34		Yes
15	1	4/0	PVC	.80	.94	7	1/4 x 12	-	No	No
15	1	4/0	PVC	.80	.94	9	1/4 x 12	-	Yes	No
15	1	4/0	PVC	.80	.94	14	1/4 x 12	48	Yes	Yes

Table K-1. - Asbestos Packed Cable Entries (continued)

Test	Insulated Cable				Cable Entry Hardware					
Number	Conductors	Gage	Jacket Material	Actual O.D.*	Body & Nut,* I.D.	Nut Torque**	Asbestos,* Dia. x Length	Load to Slip†	Cable Adequately Enter	Torque "Feel" Achieved
19	3	14	Neoprene	.54	.75	14	1/4 x 15 7/8	-	No	Yes
19	3	14	Neoprene	.54	.75	16	1/4 x 15 7/8	-	Yes	Yes
20	3	14	Neoprene	.54	.75	18	1/4 x 15 7/8	38	Yes	Yes
21	4	14	Neoprene	.62	.75	14	1/4 x 11 7/8	-	No	Yes
21	4	14	Neoprene	.62	.75	16	1/4 x 11 7/8	-	Yes	Yes
22	4	14	Neoprene	.62	.75	16	1/4 x 11 7/8	14	No	Yes
23	4	14	Neoprene	.62	.75	14	1/4 x 14 7/8	-	No	Yes
23	4	14	Neoprene	.62	.75	16	1/4 x 14 7/8	-	Yes	Yes
46	4	14	Neoprene	.62	.75	20	1/4 x 14 7/8	68	Yes	Yes
24	4	10	Neoprene	.78	.94	10	1/4 x 13 7/8	-	Yes	No
25	4	10	Neoprene	.78	.94	25	1/4 x 13 7/8	68	Yes	Yes
26	1	4/0	Asbestos	.80	.94	6	1/4 x 13 7/8	-	Yes	No
27	1	4/0	Asbestos	.80	.94	25	1/4 x 13 7/8	100	Yes	Yes
28	1	4/0	PVC	.70	.94	17.5	1/4 x 14	-	No	Yes
28	1	4/0	PVC	.70	.94	20	1/4 x 14	-	Yes	Yes
29	1	4/0	PVC	.70	.94	25	1/4 x 14	59	Yes	Yes
30	12	14	Neoprene	.89	.94	0	1/4 x 12 1/8	-	Yes	No
31	12	14	Neoprene	.89	.94	20	1/4 x 12 1/8	100	Yes	Yes
32	1	1/0	Neoprene	.76	.94	0	1/4 x 15	-	Yes	No
33	1	1/0	Neoprene	.76	.94	20	1/4 x 15	58	Yes	Yes
34	1	1/0	Neoprene	.76	.94	5	1/4 x 15	-	Yes	No
35	1	1/0	Neoprene	.76	.94	20	1/4 x 15	66	Yes	Yes

Table K-1. - Asbestos Packed Cable Entries (continued)

Test Number	Insulated Cable: Conductors	Gage	Jacket Material	Actual O.D.*	Cable Entry Hardware: Body & Nut,* I.D.	Nut Torque**	Asbestos,* Dia. x Length	Load to Slip^t	Cable Adequately Enter	Torque "Feel" Achieved
36	3	6	Neoprene	1.00	1.12	5	1/4 x 14 3/4	-	No	No
36	3	6	Neoprene	1.00	1.12	10	1/4 x 14 3/4	-	Yes	No
37	3	6	Neoprene	1.00	1.12	20	1/4 x 14 3/4	43	Yes	Yes
38	3	6	Neoprene	1.00	1.12	5	1/4 x 14 3/4	-	Yes	No
39	3	6	Neoprene	1.00	1.12	20	1/4 x 14 3/4	39	Yes	Yes
41	3	2/0	Neoprene	1.76	1.87	45	1/4 x 20	-	No	Yes
41	3	2/0	Neoprene	1.76	1.87	50	1/4 x 20	-	Yes	Yes
42	3	2/0	Neoprene	1.76	1.87	70	1/4 x 20	48	Yes	Yes
43	1	4/0	Asbestos	.80	.94	0	1/4 x 13 3/4	-	Yes	No

UNITS

* Inches
** Foot-Pounds
t Pounds

Note: New torque wrench acquired for tests 19 through 43.