Information Circular 9051

An Overview of Research on Explosionproof Enclosures

By L. W. Scott and M. R. Yenchek

UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
Robert C. Horton, Director

Library of Congress Cataloging in Publication Data:

Scott, Lawrence W

An overview of research on explosionproof enclosures.

(Information circular ; 9051)

Bibliography: p. 17-18.

Supt. of Docs. no.: I 28.27: 9051.

1. Mine explosions–Safety measures. 2. Coal mines and mining–Safety measures. I. Yenchek, M. R. (Michael R.). II. Title. III. Series: Information circular (United States. Bureau of Mines) ; 9051.

TN295.U4 [TN313] 622s [622'.334] 85-600164

CONTENTS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	J/c	joule per cycle
°F	degree Fahrenheit	kV	kilovolt
ft	foot	KE	kinetic energy
ft^3	cubic foot	lb	pound
ft-lb	foot pound	lb^2	square pound
ft-lb/ft^2	foot pound per square foot	mm	millimeter
gal	gallon	mph	mile per hour
in	inch	mV	millivolt
in^2	square inch	psig	pound per square inch, gauge
in^3	cubic inch	V	volt
in/ft	inch per foot	V ac	volt, alternating current
in^2/ft^3	square inch per cubic foot	V dc	volt, direct current
J	joule		

AN OVERVIEW OF RESEARCH ON EXPLOSIONPROOF ENCLOSURES

By L. W. Scott[1] and M. R. Yenchek[1]

ABSTRACT

This report presents an overview of explosionproof (X-P) enclosure research being conducted by the Bureau of Mines. This report emphasizes the increasing importance of research related to the safety considerations of X-P enclosures used in underground coal mines. Selected topics are included that summarize results of research in the areas of electrical clearances, reliability of enclosures with windows, safety factors in X-P enclosures, potting materials, performance tests for X-P enclosures, protection against high-voltage explosions, and innovative X-P devices.

[1]Electrical engineer, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

For several years, the Bureau of Mines, through in-house and contract research, analyzed several of the critical factors involved in the design of X-P enclosures (1).[2] The study of X-P enclosures is an area requiring investigation regarding materials, methods of construction, and acceptance and testing criteria. The X-P enclosures used in underground mines are constructed according to rigid design requirements that contribute to the difficulties in maintaining the enclosures in a permissible condition. If designers were permitted more freedom, it would be possible to construct enclosures that are easier to maintain in a permissible condition. These new enclosures would be performance tested to ensure that they would be as safe as the enclosures being constructed to the design requirements.

The objective of this research is to determine the safety factors in the present design requirements and to develop and demonstrate the feasibility of performance tests. The progress presented here should be of considerable interest to the mining industry in general and to designers of X-P enclosures in particular.

ELECTRICAL CLEARANCES

It has been known for many years that the flame front of a methane-air explosion produces free ions that can cause a current to flow when the front bridges two conductors of opposite polarity. If the voltage is high enough, this current can increase to a value that would be self-sustaining, and a dangerous arc discharge can occur. Arc discharges produced in this way could cause premature failure of electrical equipment, produce excessive heating, or burn through an enclosure wall. This study was initiated to obtain experimental results that would be useful in determining safe levels of voltages and clearances required to protect X-P enclosures from failures due to arc discharges.

The critical arcing voltages (single phase, alternating current) for various air gaps are shown in figure 1 (2). Curve A shows the minimum arcing voltage versus electrode spacing in air. This curve was obtained by selecting the spacing and increasing the voltage until arcing occurred. Curve B shows the minimum arcing voltage versus electrode spacing in a 9.8% methane-air mixture. Because it was necessary that an explosion occur for each measurement, it was not possible to conduct the experiments as simply as those on arcing-in-air. For curve B, again a spacing was selected and the voltage was varied until arcing occurred. However, at this point, the voltage was decreased by 100 V, and the explosion test repeated. If arcing occurred, the voltage was decreased again by 100 V. This procedure was continued until no arcing was observed. At the level of voltage where no arcing occurred, 10 tests were conducted. If no arcing was observed, the previous level of voltage was considered to be the minimum arcing voltage.

The minimum arcing voltage was found to increase with the distance between the electrodes. It follows that the danger of arcing can be decreased in X-P enclosures by using larger air-gap spacing between live conductors of opposite polarity and between live conductors and earth.

Figure 1 is a plot of the actual minimum arcing voltage versus air-gap spacing. However, since these experiments were conducted for design purposes, and because of limited space for X-P enclosures, it was decided that a factor of 1.5 should be applied to the spacing obtained in figure 1, in order to provide a reasonable margin of safety. For example, curve B indicates that arcing will occur at a spacing of 1.2 in (30 mm) if 5,000 V are impressed across the electrodes in a 9.8% methane-air mixture

---
[2]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

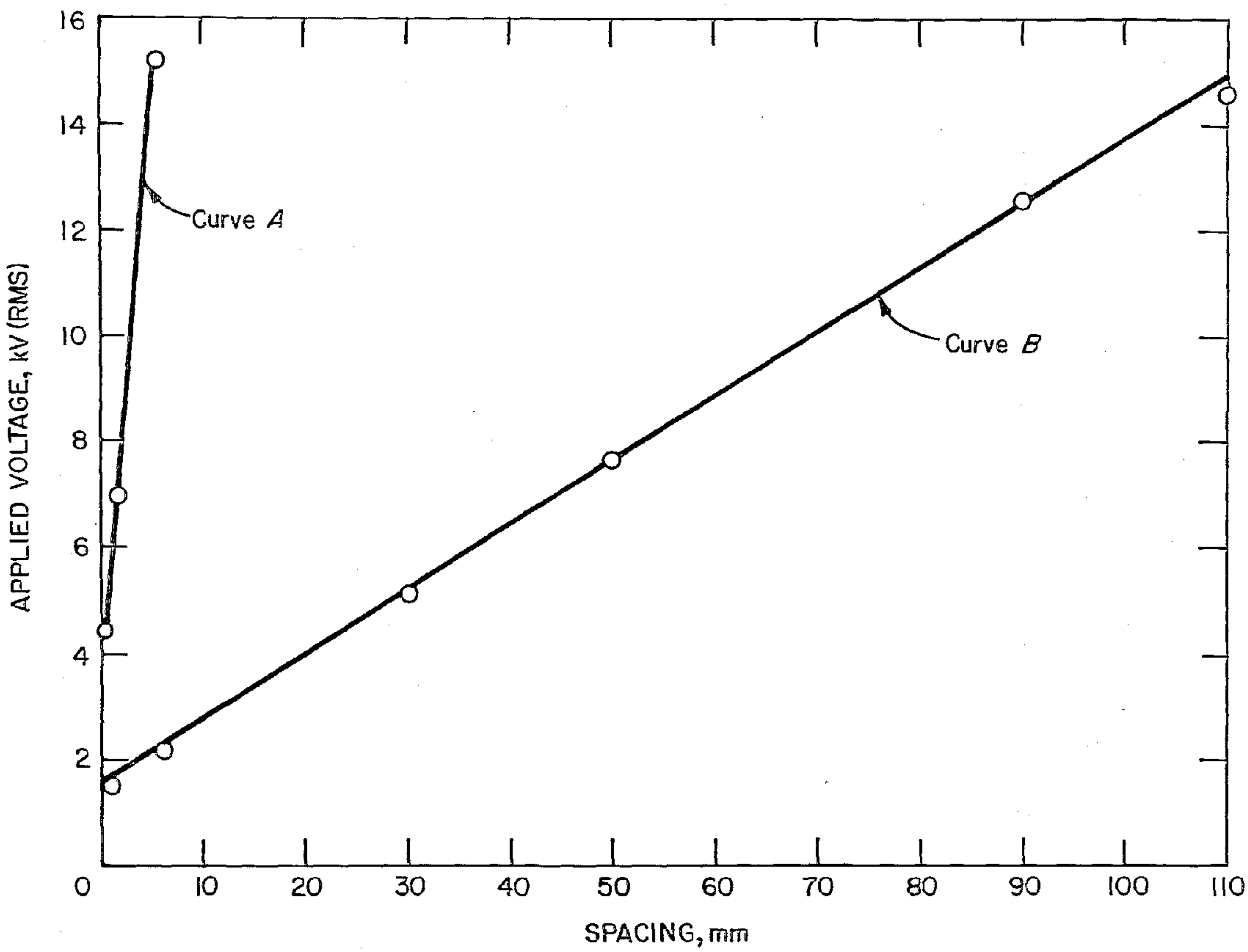

FIGURE 1. - Minimum arc voltage versus air-gap spacings of electrodes.

(compared to a spacing of 0.071 in (1.38 mm) for normal atmosphere, as shown in curve A). Therefore, a spacing of 1.8 in (45 mm) [0.106 in (2.07 mm) for curve A] should provide adequate clearance for this voltage.

All clearance data were obtained using 0.5-in (12.5-mm) diameter spherical brass electrodes at room temperature and atmospheric pressure, thus giving optimistic values of clearances. The required clearance for pointed electrodes are considerably greater. Pointed terminations should be avoided, and every effort should be made to employ rounded terminations with smooth surfaces.

RELIABILITY OF ENCLOSURES WITH WINDOWS

Windows in X-P enclosures require careful design, fabrication, and installation. The designer must be certain that the window or lens is adequate for the design conditions of the enclosure, particularly the dynamic pressure, temperature, point impact, thermal shock, and corrosive effect of the underground environment.

Windows and lenses should be fabricated only from materials suited for the operational environment encountered in mines. The suitability of a material is based either on documented extensive past experience or on exhaustive evaluation by a materials testing laboratory in simulated mine environments. At present, glass and polycarbonate plastic are considered the only practical materials for fabrication of windows and lenses (3).

Glass

The chemical composition, casting process, and thermal treatment determine the physical, chemical, optical, and electrical properties of glass. Because of a very complex relationship among these variables, no single glass composition, casting process, or thermal treatment is considered superior to others. Thus, the designer is free to select the combination of fabrication parameters that best matches a specific set of product requirements.

The primary advantages of glass are its ability to retain its physical and optical properties under high ambient temperature, ultraviolet radiation, and humidity for a long period of time; to resist surface abrasion by rock particles; and to tolerate immersion in aqueous and organic solvents without initiation of stress cracking or corrosion. Glass windows can tolerate 100% relative humidity, temperature of 400° F (204° C), intensive ultraviolet radiation, and continuous or intermittent immersion in basic or acidic water or organic solvents for indefinite periods.

The primary shortcomings of glass are its brittleness and low tensile strength. To compensate for these shortcomings, the design of the window seat assembly must provide, whenever feasible, protection against point contact with the metallic components of the enclosure and impact by rock fragments capable of fracturing the window. The protection against fracture initiated by point contact is usually accomplished by inserting gaskets between the glass and metallic components of the seat assembly. Protection against breakage by impact is generally provided by an external shield in the form of a cage or plastic envelope, or by precompressing the glass window surfaces with thermal tempering or chemical ion exchange.

Because of their history of successful use in enclosures, the following are practical for use as windows in enclosures: (1) borosilicate glasses, (2) soda lime glasses, and (3) silica glasses.

Plastic

The high temperature, humidity, intensive ultraviolet radiation, and presence of vapors from petroleum-base oils tend to rapidly degrade the mechanical properties of plastic windows and lenses in X-P enclosures. Some plastics deteriorate in lamp enclosure service faster than others, but even the most resistant ones age sufficiently to mandate their removal from service in less than 10 years. For this reason, a thorough engineering evaluation of plastic material must be conducted prior to its selection for service as a window in an X-P enclosure. At present, polycarbonate plastic is considered practical for fabrication of windows and lenses for enclosures; however, the Mine Safety and Health Administration (MSHA), U.S. Department of Labor, policy limits the design temperature to 240° F (115° C). Industrial experience has shown that three other restrictions should be noted:

1. Contact with hydraulic oil and petroleum-based lubricants are prohibited.
2. Low ultraviolet (UV) environment.
3. Service life should be limited to 4 years.

SAFETY FACTORS IN X-P ENCLOSURES

The design requirements for X-P enclosures used in underground coal mines are contained in Part 18 of Code of Federal Regulations Title 30 (30 CFR 18) (4). However, these requirements do not allow for much deviation and the approval process is based primarily on enclosures constructed to these requirements. Any innovative design attempts by enclosure manufacturers would require substantial effort to prove that the enclosure is as safe as an enclosure built to the requirements of 30 CFR 18.

One phase of Bureau research has consisted of determinating the characteristics of materials commonly used in enclosures. Such materials include steel, aluminum, polycarbonates, and various sealants. Emphasis is placed on determining (1) how these materials satisfy design requirements and (2) the minimum safety factors contained in the requirements.

A finite-element computer model was used to ascertain the structural integrity of four existing X-P enclosures (1). A finite-element model consists of many small elements, each of which has stress and deflection characteristics defined by classical theory. By proper element selection and by writing any necessary constraint equations at the corners or "nodes" of the elements, a good estimate can be obtained of the stresses generated in an enclosure by an internal loading function.

The computer code ANSYS selected to perform the finite-element analysis is commercially available and contains all the capabilities necessary for analyzing X-P enclosures. It has a library of finite elements that includes general shells, three-dimensional beams and solids, and gap elements. It has the capability of performing elastic, elastic-plastic, or thermal stress analysis, and static and dynamic loading.

In determining the yielding of the enclosures, the von Mises yield criterion was used (it assumes that the structure will yield when the distortion energy equals the distortion energy in simple tension). A combined stress, called the von Mises stress, is defined as

$$\sigma_{VM} = 0.707 \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2},$$

where σ_1, σ_2, σ_3 are principal stresses. The von Mises criterion expressed in terms of stresses states that yielding will occur when

$$\sigma_{VM} = \sigma_o,$$

where σ_o is the yield stress in simple tension.

In determining the safety factors for the four enclosures analyzed, a design pressure of 150 psig (as specified by MSHA) was used. A safety factor for each component of the enclosure was determined by

$$\text{Safety factor} = P_{VM}/P_{design},$$

where P_{VM} is the pressure that will give the von Mises stress.

Safety factors for the four enclosures analyzed are summarized in table 1. For each enclosure, multiple factors of safety were calculated for different components and with different finite-element models. Table 1 gives the minimum safety factor for each enclosure, which is the factor that governs the failure mode of the enclosure; other factors were calculated for evaluation and comparison only.

As table 1 shows, there is a wide variation in the strength of X-P enclosures. Although enclosure 1 showed a safety

TABLE 1. - Summary of safety factors for four enclosures

Enclosure	Enclosure description	Enclosure volume, in^3	Minimum strength component	Safety factor
1.......	Steel rectangular box, aluminum cover.	926	Enclosure bottom.....	0.73
2.......	Steel rectangular box, small steel cover.	234	Cover bolts..........	1.60
3.......	Rectangular luminaire, aluminum casting.	140	Bottom plate, aluminum casting.	1.20
4.......	Cylindrical junction box, steel casting.	142	Cover, steel casting.	4.83

factor of less than 1, all of these enclosures have been certified as explosionproof. However, it should be remembered that the design criterion of 150 psig used to compute the safety factors is a much more severe load than that presented by the internal methane-air explosion specified by MSHA.

POTTING MATERIALS USED IN X-P ENCLOSURES

Potting materials are frequently used in X-P enclosures to reduce hazards by separating potential ignition sources from flammable environments. They may serve as heat sinks to quench sparks as well as heat from zones where abnormal operating conditions arise. Under normal conditions, materials serve as an electrical insulator, whether the material is a solid, liquid, or gas. Besides the usual mechanical and electrical properties exhibited by a potting material, two additional factors are important in evaluating materials. One factor concerns the flammability of the material. The second factor relates to the flammability of the products produced when the material is decomposed by an electric arc caused by failure of the potted electrical equipment.

Organic potting materials will, in general, undergo decomposition, carbonization, and burn in an oxidizing atmosphere. In an inert atmosphere, pyrolysis is likely to occur. However, no general guideline exists for establishing an acceptance criterion for potting materials for use in X-P enclosures used in underground mines.

The purpose of this phase of Bureau research was to develop a testing methodology where a rank ordering of candidate materials may be established based on arc decomposition products. A list of the arc decomposition products of seven potting compounds evaluated in this study is presented in table 2. A prescribed number of arcing cycles were produced by a cycle timer (cycles per second) that when multiplied by the average energy per cycle gave the energy dissipated in the arc. Results show clearly the potential for addition of more sensitive hydrocarbons and hydrogen (5).

Results obtained indicate that a ranking order could be based on the least amount of flammable gas (hydrogen) evolved. This is evidenced by results obtained during arcing tests conducted at 43 J/c for 30 cycles. Therefore, the materials tested should be ranked in the following order, (from best to worst):

- Eccosil[3] (solid, liquid, gas).
- DPR242H (solid).
- Eccothane (gas).
- DPR242 (solid).
- Epoxy (solid).
- Dow Silicone Oil (liquid).
- RS#3 (asphaltic solid).

PERFORMANCE TESTS FOR X-P ENCLOSURES

Since 1977, the Bureau has conducted research to develop performance standards for X-P enclosures. These new standards are intended to provide a method of approving enclosures for use in underground mines based solely on the performance of the enclosure during specified tests. When enclosures are evaluated in this way, rather than by specifying certain dimensions as in 30 CFR 18, the enclosure designers will have more freedom in their design approach.

Two performance tests have been developed to date: (1) a structural performance (hydrostatic pressure) test and (2) a ruggedness test.

STRUCTURAL PERFORMANCE

The purpose of the structural performance test is to verify that X-P enclosures are designed for a minimum static pressure of 150 psig.

[3]Reference to specific products does not imply endorsement by the Bureau of Mines.

TABLE 2. - Arc-decomposition products

Material	Environment	Cycles	Average energy per cycle, J	Decomposition products		Total combustibles, %
				Component[1]	ppm	
Epoxy.........	Nitrogen...	60	43	H_2	22,712	71.5
				CH_4	943	2.9
				C_2H_2	5,217	16.4
				C_2H_4	2,609	8.2
				C_3H_6	26	.1
				C_3H_4	48	.2
				C_6H_6	230	.7
		15	43	H_2	1,458	87.3
				CH_4	87	5.2
				C_2H_2	109	6.5
				C_2H_4	16	1.0
	Air........	15	43	CH_4	27	84.3
		60	43	CH_4	5	100
		30	43	CH_4	<5	NC
	Nitrogen...	30	43	H_2	11,288	94.5
	Air........	30	21.5	CH_4	10	50
	Nitrogen...	30	21.5	H_2	4,101	91
RS#3..........	...do......	60	43	H_2	27,979	67
				CH_4	4,496	8.4
				C_2H_2	4,783	11.5
				C_2H_4	3,913	9.4
				C_3H_6	661	1.6
				C_3H_4	430	1.1
				C_6H_6	361	.9
		15	43	H_2	8,305	85.9
				CH_4	435	4.5
				C_2H_2	739	7.6
				C_2H_4	163	1.7
				C_3H_8	22	.3
	Air........	15	43	CH_4	32	59.3
				C_2H_2	22	40.7
		60	43	H_2	339	48.6
				CH_4	109	15.6
				C_2H_2	152	21.8
				C_2H_4	98	14.0
		30	43	CH_4	<5	15.6
				C_2H_2	22	68.8
				C_2H_4	<5	15.6
	Nitrogen...	30	43	H_2	39,424	89.1
				CH_4	739	1.7
				C_2H_2	2,935	6.6
				C_2H_4	1,033	2.3
				C_3H_6	98	.3
	Air........	30	21.5	CH_4	13	34.2
				C_2H_2	15	39.5
				C_2H_4	10	26.3
	Nitrogen...	30	21.5	H_2	11,864	86.1
				CH_4	526	3.8
				C_2H_6	24	.2
				C_2H_2	926	6.7
				C_2H_4	441	3.2

See notes at end of table.

TABLE 2. - Arc-decomposition products--Continued

Material	Environment	Cycles	Average energy per cycle, J	Decomposition products		Total combustibles, %
				Component[1]	ppm	
Silicone oil..	Nitrogen...	60	43	H_2	5,085	97.8
				CH_4	35	.7
				C_2H_2	65	1.3
				C_2H_4	15	.2
	...do......	15	43	H_2	3,119	94.7
				CH_4	108	3.3
				C_2H_2	54	1.6
				C_2H_4	11	.4
	Air........	15	43	CH_4	5	100
	Air........	60	43	CH_4	27	100
	Air........	39	43	CH_4	<5	NC
	Nitrogen...	30	43	H_2	17,797	96.9
				CH_4	217	1.2
				C_2H_2	283	1.6
				C_2H_4	54	0.3
				C_3H_6	<5	0
	Air........	30	21.5	CH_4	5	NC
				C_2H_2	<1	NC
	Nitrogen...	30	21.5	H_2	7,458	95.3
				CH_4	245	3.1
				C_2H_2	106	1.4
				C_2H_4	17	.2
Isoprene......	Air........	30	21.5	CH_4	7	46.7
				C_2H_2	5	33.3
				C_2H_4	3	20.0
	Nitrogen...	30	21.5	H_2	11,186	76.2
				CH_4	580	7.9
				C_2H_2	1,030	14.0
				C_2H_4	135	1.9
DPR 242.......	...do......	30	43	H_2	5,593	79.0
				CO	1,300	NC
				CO_2	580	NC
				CH_4	565	8.0
				C_2H_2	500	7.1
				C_2H_4	413	5.8
				C_2H_6	13	.1
	Air........	30	43	CO	210	NC
				CO_2	4,700	NC
				CH_4	9	50.0
				C_2H_2	7	38.9
				C_2H_6	9	.2
	Nitrogen...	30	21.5	H_2	2,034	82.0
				CO_2	350	NC
				CH_4	130	5.2
				C_2H_2	217	8.8
				C_2H_4	98	4.0
	Air........	30	21.5	CO_2	1,700	NC
				CH_4	3	50.0
				C_2H_2	3	50.0

TABLE 2. - Arc-decomposition products--Continued

Material	Environment	Cycles	Average energy per cycle, J	Decomposition products: Component[1]	Decomposition products: ppm	Total combustibles, %
DPR 242H......	Nitrogen...	30	43	H_2	3,898	72.1
				CO_2	1,700	NC
				CH_4	576	10.6
				C_2H_2	609	11.3
				C_2H_4	315	5.8
				C_2H_6	9	.2
	Air........	30	43	CO	340	NC
				CO_2	4,800	NC
				CH_4	14	56.0
				C_2H_2	11	44.0
	Nitrogen...	30	21.5	H_2	3,390	85.0
				CO	480	NC
				CO_2	300	NC
				CH_4	217	5.5
				C_2H_2	250	6.3
				C_2H_4	109	2.7
				C_2H_6	12	.3
	Air........	30	21.5	CO_2	1,600	NC
				CH_4	14	63.6
				C_2H_2	5	22.7
				C_2H_4	3	13.7
Eccosil.......	Nitrogen...	30	43	H_2	1,661	88.0
				CH_4	174	9.2
				C_2H_2	43	2.3
				C_2H_4	9	.5
	Air........	30	43	CO_2	1,300	NC
				CH_4	7	100
	Nitrogen...	30	21.5	H_2	2,034	95.7
				CO	330	NC
				CH_4	65	3.1
				C_2H_2	17	.8
				C_2H_6	9	.4
	Air........	30	21.5	CO_2	1,100	NC
				CH_4	14	87.5
				C_2H_2	2	12.5
Eccothane.....	Nitrogen...	30	43	H_2	5,593	79.3
				CO	1,300	NC
				CO_2	150	NC
				CH_4	228	3.2
				C_2H_2	1,011	14.3
				C_2H_4	217	3.2
	Air........	39	43	CH_4	3	25.0
				C_2H_2	6	50.0
				C_2H_4	3	25.0
	Nitrogen...	30	21.5	H_2	1,186	89.0
				CH_4	33	2.5
				C_2H_2	87	6.5
				C_2H_4	27	2.0
	Air........			CO_2	2,200	NC
				CH_4	3	33.3
				C_2H_2	6	66.7

NC Not considered in the calculation of percentage total.

[1] H_2 = hydrogen; CH_4 = methane; C_2H_2 = acetylene; C_2H_4 = ethylene; C_3H_6 = propylene; C_3H_4 = propyne; C_3H_6 = benzene.

In order to routinely test X-P enclosures for structural performance as specified in 30 CFR 18, the apparatus shown in figure 2 is required. This setup consists primarily of a water reservoir, a regulated nitrogen source, interconnecting hardware, and pressure-sensing instrumentation.

The water tank should be at least 50 gal in volume and be rated for 300-psig water service. A regulated high-pressure bottle of nitrogen (2,000 psig), or the equivalent, is used to provide the input pressure to the water tank. The geometry, size, and complexity of the test enclosure will dictate how it is connected to the pressurization apparatus.

Once a pressure connection is available, the next step is to provide a tight seal between the cover and the enclosure if one has not been provided by the manufacturer. Two sealing methods have been found to be satisfactory for hydrostatic testing. The most suitable method for the enclosure being tested can be used.

Method 1 (suitable for small, regular shaped enclosures).--In this method, a continuous gasket is cut from 1/16-in-thick reinforced neoprene. The gasket should extend outside the bolt circle, but no closer than 3/16 in from the outer edge of the flange or cover. Clean the mating surfaces with acetone or an equivalent solvent before placing the gasket and closing the enclosure. No sealants are necessary. Torque bolts to their rated load.

Method 2 (suitable for enclosures of all sizes).--This method uses General Electric Silicon Construction Sealant 1200 series. Clean the surfaces to be sealed with acetone or an equivalent solvent and apply the sealant in a uniform bead 1/16 to 1/8 in. in diameter. A zigzag pattern, as shown in figure 3, has been found to work satisfactorily.

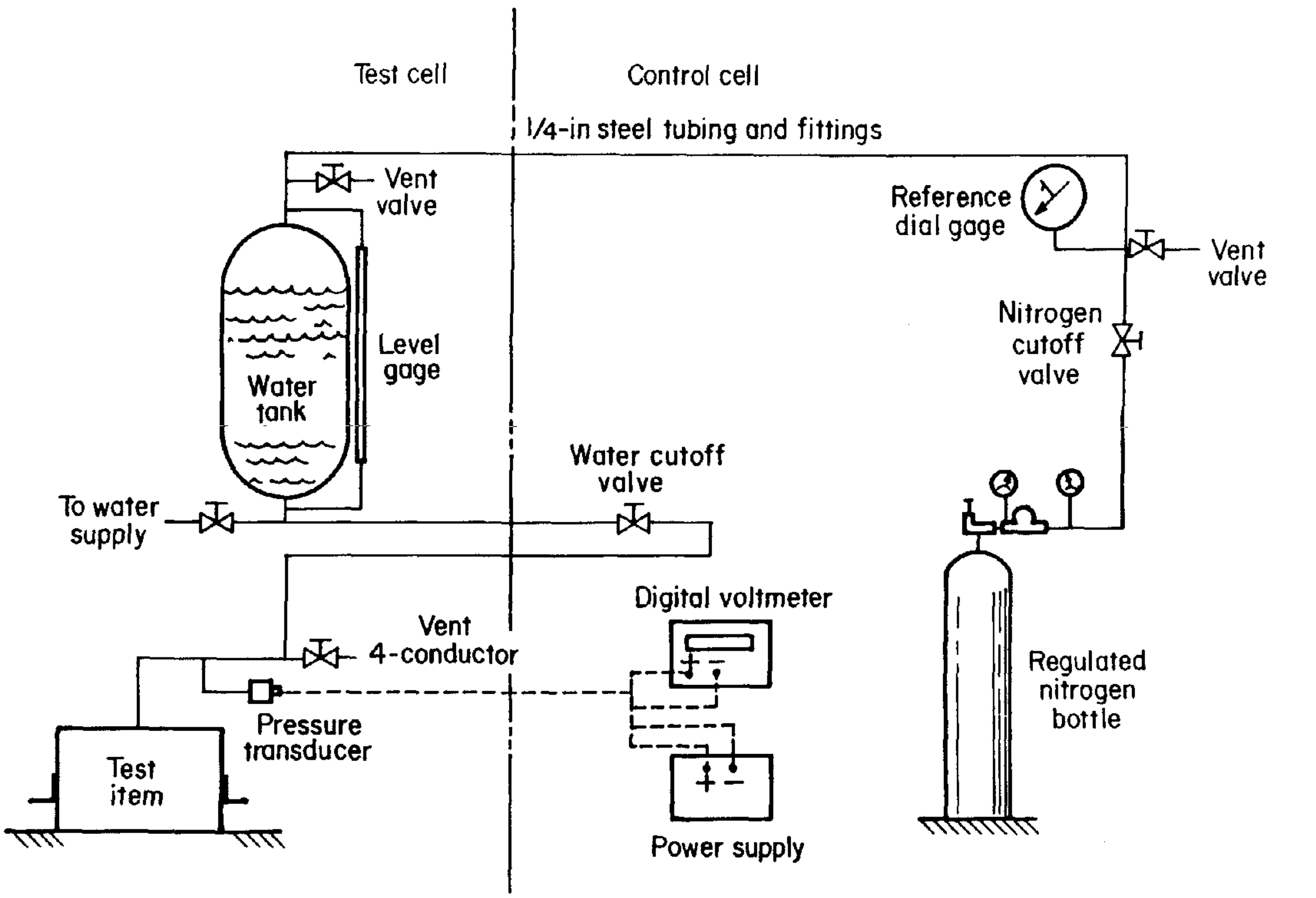

FIGURE 2. - Hydrostatic test apparatus.

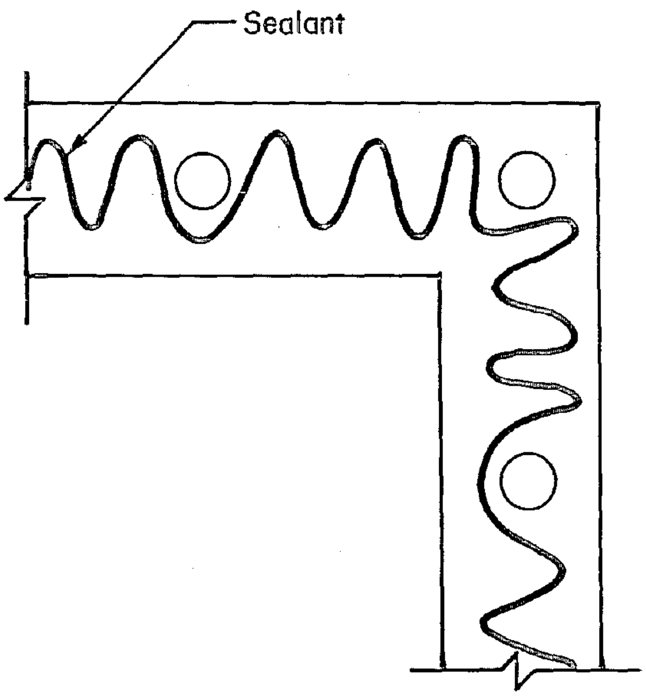

FIGURE 3. - Recommended sealant pattern.

Some sealant will be extruded from the outer edge of the enclosure by this method, but there will also be spaces for a feeler gage. Use heat lamps to raise sealant temperature above 110° F (43.3° C) for a faster cure. The lid can be applied after the sealant "skims" or after it has cured completely. High humidity and high heat reduce the curing time. A faster cure should occur without the cover in place. Torque bolts to their rated loads.

For both methods, prior to connecting the enclosures to the pressurization system and bolting the cover, check all surfaces for flatness so that a pretest baseline can be established. Deformations, if any, due to the hydrostatic test can then be determined. Use a steel straightedge against every flat surface; measure and record any undulations. Measure across the width and length of each side, and, if necessary, across the two diagonals.

When all of the pretest measurements have been recorded, place the enclosure on the test stand with the sealing surface level and at the highest point on the enclosure. Connect the enclosre to the pressurization system and completely fill the enclosure with water. Eliminate or minimize air pockets when filling the enclosure. Apply the sealant or gasket and allow it to cure if necessary. Curing time can be accelerated with heat lamps.

The enclosure is now ready to be closed for pressurization. Top the enclosure with water if necessary (water can overflow), open the vent valve, install cover, and torque bolts to rated load. Using feeler gages, measure and record the gap, if any (between the enclosure and its cover) on all sides of the enclosure, with at least one measurement between each pair of bolts. If the extruded sealant precludes insertion of the feeler gages, it can be easily removed with a fine-bladed knife.

After an enclosure has been connected to the water tank, the hydrostatic test is conducted as follows:

1. Open regulator and gradually apply pressure to the system in 30-psig increments.
2. After each pressure step, close nitrogen cutoff valve and inspect the enclosure for water leaks. Very small leaks can be tolerated, particularly at the higher pressures.
3. In case of a flowing leak, shut off nitrogen cutoff valve, close the water cutoff valve, and close the regulator. Open vent valve by reference dial gage. Reseal the enclosure before starting test again.
4. After the test pressure reaches 150 psig, close the nitrogen cutoff valve.
5. Shut off the regulator and open vent valve by reference dial gage.
6. Close water cutoff valve.
7. Measure and record the gap between the enclosure and its cover at the same locations surveyed after sealing.
8. Remove enclosure.
9. Remeasure and record flatness of each side to determine if any permanent deformations resulted from the hydrostatic pressure test.

The enclosure will have passed the structural performance test if (1) no deformations larger than 0.04 in/ft are measured on any side, and (2) the gap has not increased more than 0.002 in relative to pretest measurements.

RUGGEDNESS

The environment in which X-P enclosures must operate underground can be so severe that loads produced by internal methane-air explosions may not govern the design of some components of the enclosure (i.e., covers and sides). Other loads may be greater. As enclosures evolve, the venting of enclosures through X-P vents may become permissible. If this occurs, the internal pressure loads may be quite low and other design criteria, such as ruggedness, will control. The purpose of this work was to evaluate the environment in the mines and to identify suitable criteria that an enclosure should meet to ensure that it will function properly.

To estimate the forces that can occur in typical mining operations (forces that can be applied to exposed surfaces of X-P enclosures), operating mines were examined for evidence of damage, and forces that might be produced by different mine accidents were calculated. The forces evaluated were--

- Forces required to produce observed damage in a mining machine.
- Contact forces when a mining machine strikes a rib.
- Impact forces when a shuttle car rams a mining machine.
- Impact forces produced by roof falls.

Figure 4 gives the kinetic energy (KE) per unit area at the top of a continous-mining machine versus the cumulative percentage of roof falls (1). The height was taken as 6 ft above the mine floor, but no higher than 1 ft below the mine roof. For X-P enclosures located on top of the mining machine, the height above the mine floor was taken as 3 ft. The data are bounded by upper and lower curves, and values are read from the lower bound, which gives the highest KE at any percentage level. For example, 60% of all roof falls should produce KE levels equal to or less than 3,200

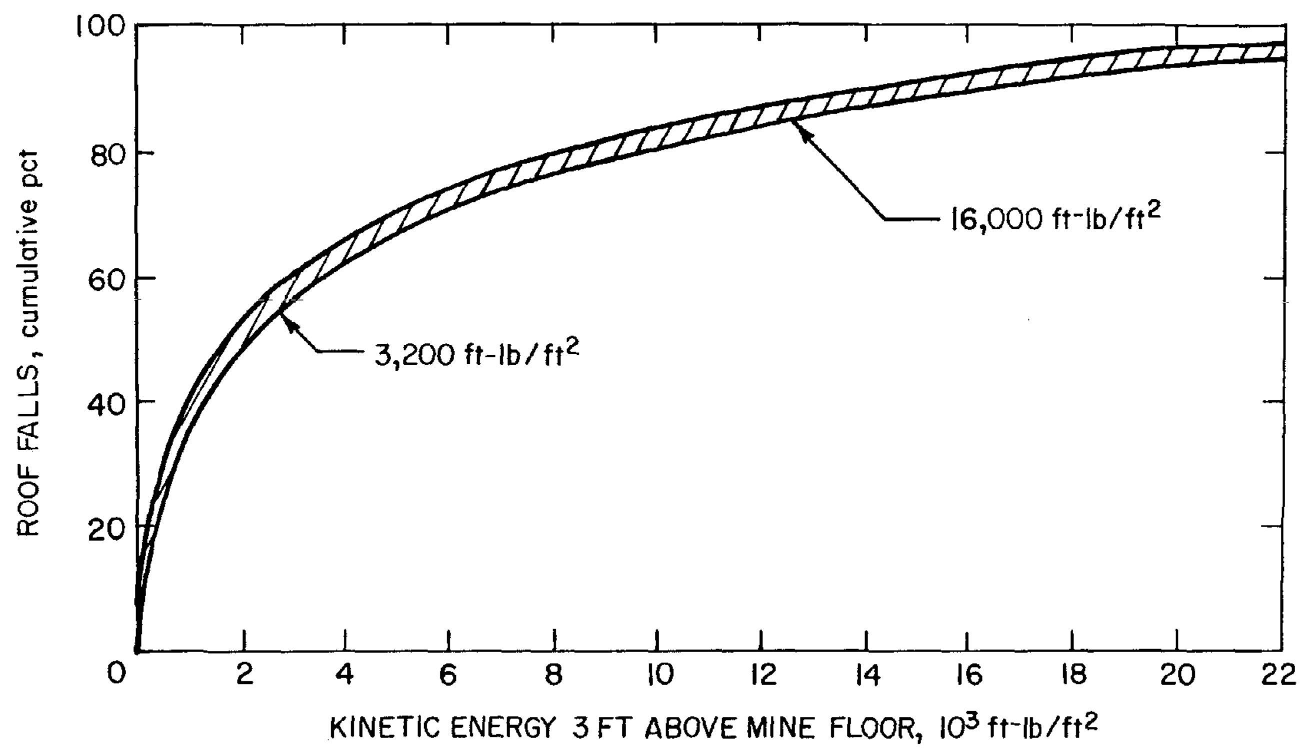

FIGURE 4. - Kinetic energy produced by roof falls at top of continuous-mining machine.

$ft\text{-}lb/ft^2$. Thus, to protect against 60% of all roof fall accidents, X-P enclosures should be designed for a KE level of 3,200 $ft\text{-}lb/ft^2$. To protect against 90% of all roof falls, the enclosure should be designed for a KE level of 16,000 $ft\text{-}lb/ft^2$.

In summary, the following recommendations are made:

- Test enclosure surfaces exposed to the roof at a KE level that will protect against 60% of roof falls.
- Test enclosure surfaces exposed to side impacts to an energy level that corresponds to a 60,000-lb shuttle car impacting at 2 mph.
- Design protected surfaces to a KE level that is 10% of that required for side impact.

These recommendations correspond to the following energy levels:

- Top exposure: Design and test to KE = 3,200 $ft\text{-}lb/ft^2$.
- Side exposure: Design and test to KE = 8,000 $ft\text{-}lb/ft^2$.
- Protected areas (such as under the operator's canopy): Design and test to KE = 800 $ft\text{-}lb/ft^2$.

Only impact forces produced by roof falls are discussed here. Detailed information on the other forces are contained in a Bureau contract report (1).

EFFECTS OF HIGH-VOLTAGE ON EXPLOSION-PROTECTION TECHNIQUES

The development of more efficient coal removal equipment for use in underground coal mines has resulted in a demand for more electrical power at the working face. This could be accomplished in several ways; however, the most cost-effective way appears to be the increase of the supply voltage. The Bureau is reviewing the effects of increasing the high voltage limit (presently limited to 4,160 V by MSHA) to 15,000 V. One aspect of this review is the effect of this new limit on explosion protection techniques.

The Bureau has conducted research on the three methods of explosion protection: X-P enclosures, pressurization, and potting (5). The three methods present varying degrees of difficulty in protecting the mine environments from potential ignition. The effects of high voltage on conductor isolation, insulator selection, and power dissipation must be considered when comparing explosion protection techniques.

High-voltage conductor isolation must be reliably accomplished within the selected enclosure based on the available energy and the potential for damage to enclosure materials during breakdown. The theory of operation for the potted enclosure assumes inherent conductor isolation. However, practical application of this method requires definition of various verification and certification tests, the potting compound specification, and the protective enclosure specification. The explosion-proof method provides conductor isolation by separation and insulation. It has been demonstrated that separation is not a reliable isolation technique at high voltages for uninsulated conductors during methane combustion. High-voltage conductors should be insulated to provide reliable isolation in an X-P enclosure. The pressurized enclosure provides conductor isolation by the separation and insulation. However, the inherent lack of methane combustion within the enclosure greatly increases the reliability of the isolation method of isolation separation.

A high-voltage insulator must reliably isolate the conductor under any conditions anticipated for the enclosure. The selection of an insulation material is most critical in the X-P enclosure owing to the harsh conditions present during methane combustion. These insulators must not only survive these combustion episodes, but they also must resist the effects of corona discharge. The insulators selected for use in pressurized and potted enclosures are not required to survive methane combustion due to the lack of flammable gas concentrations within these enclosures. However, the insulators must be resistant to the effects of corona discharge.

The power dissipation of a given machine will increase as the supplied power is increased. The potted enclosure is very sensitive to variations in the power dissipation owing to the natural thermal insulation of the potting compound. Small changes in the power dissipated within this enclosure can produce large temperature gradients in the potting compound. The resultant temperature gradients are dependent on the heat capacity, conductivity, and thickness of the potting compound. The pressurization and X-P enclosures provide air circulation around equipment by forced circulation or convection. Thus, these two methods are relatively insensitive to changes in the machine power dissipation.

INNOVATIVE X-P DEVICES

PRESSURE VENT

The design requirements for X-P enclosures used in gassy areas of underground mines are contained in 30 CFR 18. These regulations define an X-P enclosure as "an enclosure that complies with the applicable design requirements in Subpart B of this part and is so constructed that it will withstand internal explosions of methane-air mixtures: (1) Without damage to or excessive distortion of its walls or cover(s) and (2) without ignition of surrounding methane-air mixtures or discharge of flame from inside to outside the enclosure." The intent of this regulation is to provide criteria to ensure that the explosive energy will be contained within the enclosure.

Since internal pressure may exceed 100 psig, these enclosures are characterized by heavy wall construction, tight flange gaps, and a multitude of cover bolts. If an enclosure could be designed to release or vent the heat and pressure in a safe, controlled manner, the design criteria of 30 CFR 18 could be relaxed to permit lighter enclosures and less stringent flame path requirements. Lightweight construction would facilitate handling of large enclosure covers or complete enclosures by one person. In addition, larger allowable flange gaps would negate the present effects that corrosion and dust entrapment have on attempts to comply with 30 CFR 18.

Under contract H0357107 (7-8), the Bureau investigated numerous concepts including venting, designed to reduce the internal pressure generated in X-P enclosures during internal methane-air explosions. From this study, it was determined that any venting mechanism must--

- Quench both methane gas and coal dust flame fronts.
- Be relatively permeable to gas flow to minimize vent size.
- Have self-cleaning characteristics to reduce the possibilities of clogging during use underground.
- Have sufficient corrosion and mechanical shock resistance to be compatible with the mine environment.

In light of these requirements, an open-cell metal foam was judged to offer the best combination of mechanical and flame-arresting properties. For actual hardware designs, Retimet, a stainless steel foam from the United Kingdom, was chosen; it is an excellent flame arrestor and was the only open-cell metal form available. For the prototype vent, a 1/2-in-thick foam slab of Retimet was fixed in a metallic frame and mounted in the enclosure wall. A cross-sectional view is shown in figure 5. The foam was protected against mechanical damage by a hinged metal cover that swung open when internal pressure exceeded 2 psig. Normally, this cover was held in place by a small permanent magnet.

To have a significant impact upon enclosure design, it was determined that a vent must limit internal explosion pressure to a 12-psig maximum. To determine the relationship between vent area size, the internal pressure developed, and the enclosure volume, a vent area-to-volume ratio was established through laboratory tests. As illustrated in figure 6, any enclosure with a vent area to volume ratio larger than 4 in^2/ft^3 will meet the 12-psig criterion.

To protect the metal foam from oxidation damage due to high temperature, a series of 20-mesh stainless steel wire

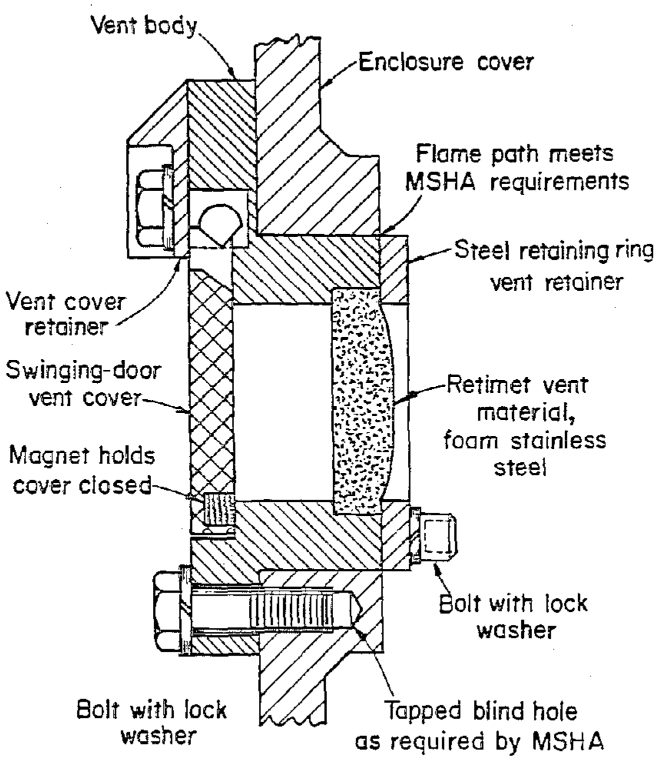

FIGURE 5. - Pressure vent.

screens was placed on the inner face of the foam and acted as a thermal barrier to the flame front. The minimum number of screens to be used increases as the vent area-to-enclosure volume ratio decreases. The number of screens used in the vent design must be more than or equal to the number of screens indicated in figure 7.

It was determined that flange-gap temperatures must not exceed 1,200° F (649° C) peak to preclude ignition of a surrounding external gassy atmosphere. Since one of the goals of utilizing pressure vents was to permit the safe use of larger flange gaps, a series of laboratory tests was conducted to determine allowable gaps for various vent area-to-enclosure volume ratios. The maximum allowable gap was found to decrease as the vent area-to-enclosure volume decreases (see figure 7).

To use figure 7, the designer determines a convenient size for the pressure vent assembly or the enclosure. Using this, one then can determine the number of screens required from the top axis and the maximum flange gap spacing from the left axis. The enclosure could then be designed solely on the basis of ruggedness for the mine environment.

ELASTOMERIC GROMMET CABLE ENTRY

Conventional asbestos-packed cable entries require considerable skill, experience, and motivation on the part of the mine mechanic to achieve a permissible installation. Proper cable entry is time-consuming. It not only entails packing the correct length of asbestos rope in the stuffing box but also tightening the gland nut to the correct depth in accordance with 30 CFR 18.

Under contract H0357107 (7-8), the Bureau investigated numerous cable entry concepts in addressing the deficiencies of asbestos entries. A cross section of the optimum design is shown in figure 8. It incorporates a tapered elastomeric grommet compressed against the cable jacket by a clamping nut. The advantages of this arrangement are as follows:

- Reduced entry time.
- Reusability.
- One size fits many cable diameters.
- Captive grommet cannot be lost.

Evaluation of several materials led to the selection of polyurethane as the grommet material. It is highly resistant to wear and abrasion, and impervious to oil, grease, and water. Laboratory tests of the grommet proved its equivalency to conventional asbestos packing in the following areas:

- Ability to grip the cable.
- Gland nut torque required.
- Distance in contact with cable.
- Flammability.
- Explosion-proof integrity.

Both the pressure vent and the grommet cable entry were successfully field tested at an active underground coal mine. Approval for this demonstration was obtained via an experimental permit from MSHA. The innovative devices were installed on the connection box of a Jeffrey 120M continuous-mining machine for 8-1/2 months. Subsequent laboratory tests revealed no measurable deterioration in their condition.

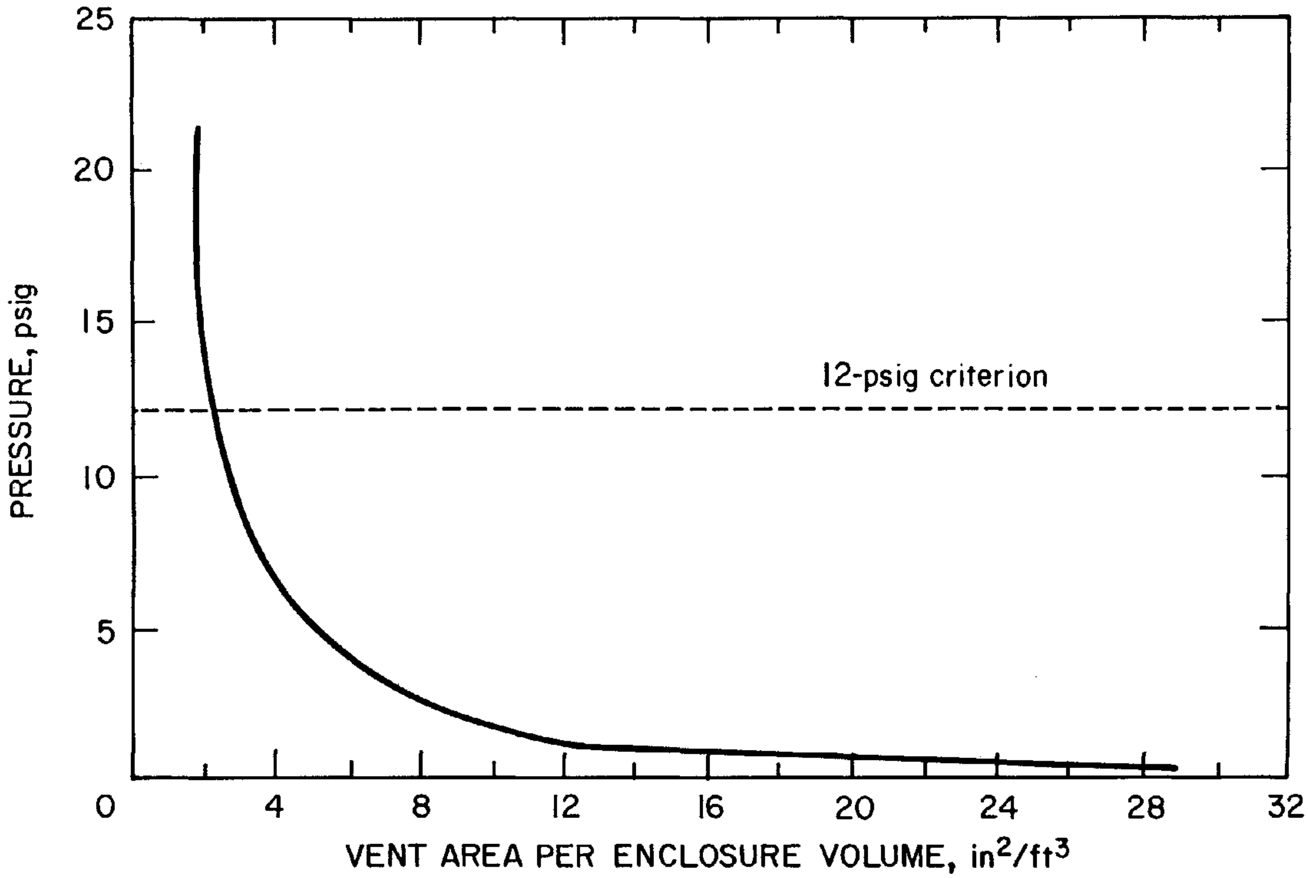

FIGURE 6. - Pressure buildup in vented enclosures.

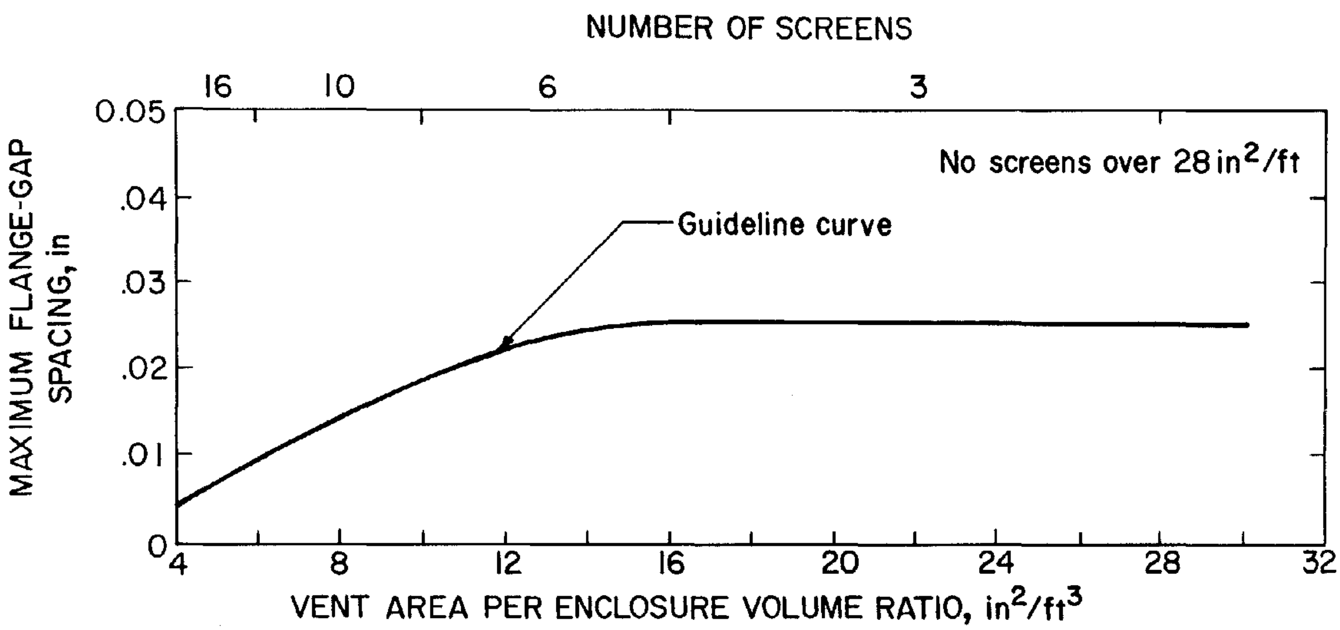

FIGURE 7. - Suggested guidelines for number of screens and allowable flange gaps for vents and explosionproof electrical enclosures.

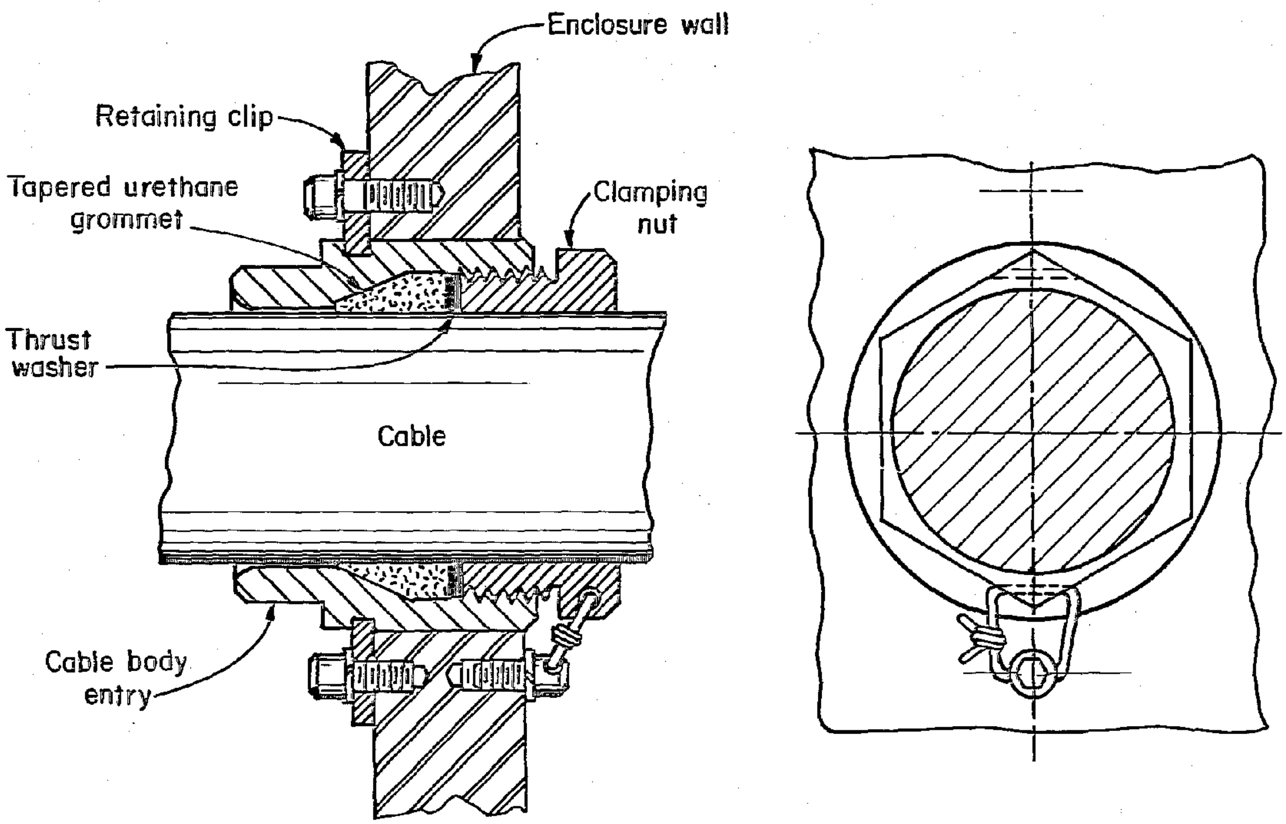

FIGURE 8. - Trailing-cable entry assembly.

SUMMARY

Research by the Bureau has revealed much about the mechanisms of containing a methane-air explosion. Finite-element analysis and hydrostatic pressure tests revealed wide variations in the margin of safety of selected X-P enclosures. Results of research on electrical clearances showed that clearances that would be safe in ordinary locations are insufficient when there is a possibility of a methane-air explosion. The use of glass and polycarbonate have proved satisfactory for window materials in X-P enclosures with certain restrictions.

When choosing potting materials for use in X-P enclosures, attention must be given to the possibility of the accumulation of arc-decomposition products, especially when used in high-voltage enclosures. The lack of definition, specifications, and basic research on most potting materials make this method a difficult choice. The X-P enclosure and the pressurized enclosure can be applied directly to high-voltage conditions using the present state of the art. Additionally, research results showed that the pressure vent precludes a buildup of high pressure caused by an explosion inside a permissible enclosure, and the elastomeric grommet simplifies and hastens cable entry while minimizing worker error.

REFERENCES

1. Cox, P. A., O. H. Burnside, E. D. Esparza, F. D. Lin, and R. E. White. A Study of Explosionproof Enclosures (contract H0377052, Southwest Res. Inst.). BuMines OFR 96-83, 1982, 426 pp.; NTIS PB 83-205450.

2. Scott, L. W., and J. G. Doglos. Electrical Arcing at High Voltage During Methane-Air Explosions Inside Explosionproof Enclosures. BuMines TPR 115, 1982, 9 pp.

3. Scott, L. W. Some Design Factors for Windows and Lenses Used in Explosion-proof Enclosures. BuMines IC 8880, 1982, 9 pp.

4. U.S. Code of Federal Regulations. Title 30--Mineral Resources; Chapter I, Mine Safety and Health Administration. U.S. Department of Labor; Subchapter D--Electrical Equipment, Lamps, Methane Detectors; Tests for Permissibility; Fees; Part 18--Electrical Motor-Driven Mine Equipment and Accessories; July 1, 1984.

5. Herrera, W. R., R. E. White, L. M. Adams, and H. S. Silvus. Recommended Acceptance Criteria for Potting Materials Used in Explosionproof Enclosures in Coal Mines (contract J0100041, Southwest Res. Inst.). BuMines OFR 168-83, 1982, 100 pp.; NTIS PB 83-254722.

6. Linley, L. J., and A. B. Luper. Performance Criteria Guideline for Three Methods of Electrical Equipment Rated Up to 15,000 Volts AC (contract J0318081, NASA). BuMines OFR 60-84, 1982, 63 pp.; NTIS PB 84-172303.

7. Gunderman, R. J. Innovations for Explosionproof Electrical Enclosures (contract H0357107, Dresser Ind., Inc.). BuMines OFR 121-81, 1980, 109 pp.; NTIS PB 82-104936.

8. _____. Evaluation and Acceptance Criteria for Innovations in Explosion-proof Electrical Enclosures (contract H0357107, Dresser Ind., Inc.). BuMines OFR 127-83, 1982, 141 pp.; NTIS PB 233379.

☆U.S. GPO: 1985-505-019/20,111

INT.-BU.OF MINES,PGH.,PA. 28121

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. BuMines IC 9051	2.	3. Recipient's Accession No. PB86 156429/AS
4. Title and Subtitle: An Overview of Research on Explosionproof Enclosures			5. Report Date: 1985
			6.
7. Author(s): L. W. Scott and M. R. Yenchek			8. Performing Organization Rept. No.
9. Performing Organization Name and Address: U.S. Bureau of Mines, Pittsburgh Research Center, P.O. Box 18070, Pittsburgh, PA 15236			10. Project/Task/Work Unit No.
			11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address: Office of Assistant Director--Mining Research, Bureau of Mines, U.S. Department of the Interior, Washington, DC 20241			13. Type of Report & Period Covered: Information Circular
			14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report presents an overview of explosionproof (X-P) enclosure research being conducted by the Bureau of Mines. This report emphasizes the increasing importance of research related to the safety considerations of X-P enclosures used in underground coal mines. Selected topics are included that summarize results of research in the areas of electrical clearances, reliability of enclosures with windows, safety factors in X-P enclosures, potting materials, performance tests for X-P enclosures, protection against high-voltage explosions, and innovative X-P devices.

17. Document Analysis a. Descriptors

Mining
- Enclosures
- Explosion-proof
- Containment
- Safety

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group 18/09

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited by NTIS.	Unclassified	
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI–Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4–77) (Formerly NTIS–35) Department of Commerce