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Laboratory Evaluation of Spray-Applied Rigid Urethane Foams

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UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	h	hour
cfm	cubic foot per minute	in	inch
°F	degree Fahrenheit	in wg	inch water gage
°F Btu^{-1}/min	degree Fahrenheit per British thermal unit per minute	lb	pound
		lb/ft^3	pound per cubic foot
ft	foot	min	minute
ft^2	square foot	pct	percent
ft^3	cubic foot	ppm	part per million
g	gram	psi	pound per square inch
gal	gallon		

LABORATORY EVALUATION OF SPRAY-APPLIED RIGID URETHANE FOAMS

By Robert J. Timko,[1] Mervin D. Marshall,[2] and Edward D. Thimons[3]

ABSTRACT

The objectives of this research were to examine and to document the laboratory performance of several brands of rigid urethane foam. Eighteen brands, produced by 13 manufacturers, were examined. All testing was performed in a laboratory under controlled conditions.

Preliminary laboratory tests included flame spread evaluations, flame penetration, ignition temperatures, air permeability, and adhesion. Having established arbitrary cutoff values, the original 18 candidates were narrowed to 8. More specialized tests followed. The effects of water immersion and dry aging on flame spread performance and other physical properties were then examined.

This Bureau of Mines report was written to provide information for those concerned with using rigid urethane foam as a sealant. Its intent is to describe the various laboratory evaluations performed and to delineate the performance of each candidate. This report neither promotes nor discourages the use of rigid urethane foams. It presents results that will enable those responsible for using or enforcing the use of rigid urethane foams in underground mines to make informed decisions.

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INTRODUCTION

Sealants used in the underground mining industry are vitally important to maintain a safe and productive working environment. Coatings on stopping and overcast faces enable ventilation air to follow its prescribed course through a mine. Applying sealants to the ribs and roof of intake airways greatly reduces the deleterious effects of temperature and humidity on exposed surfaces.

In most coal mines, cementitious sealants are the most prevalent types of coatings used. These are usually hand applied using a brush or trowel. Because cementitious sealants are inorganic, they lack the ability to flex or compress as the substrates undergo external compressive forces. This inability to move with the substrate means that continuous maintenance must be performed to replace damaged sealant (11).[3]

Sealants do exist that can deform with their substrates. These include urethane foams, sodium silicates, and to some extent, cementitious sealants containing solid, flexible additives. Unfortunately, most contain some fraction of organic components. Because organics can burn, these have not been readily accepted underground.

Flexible sealants are divided into two categories of application: by hand and by spray. The hand-applied sealant usually contains some type of latex additive to ensure flexibility when cured. Spray-applied sealants are, for the most part, urethane foam.

Urethane foams are commonly referred to as rigid foams because they become rigid when cured. Urethane foam was introduced several years ago, initially as insulation in the construction industry and as flotation in the shipbuilding industry. Because of its excellent adherence and flexibility, it began to be used as a sealant by the mining industry.

This evaluation of rigid urethane foams was part of a larger contracted effort with the Mine Safety Appliance Research Corporation (MSAR), which included urethane foams as well as other types of rigid foams. All laboratory work was done in MSAR facilities, with Bureau researchers overseeing the effort.

Spray-applied urethane foams are the organic sealants most often used underground. They are best suited for underground use because of their physical properties, ease of application, and relatively low cost. Eighteen different spray-applied rigid urethane foams produced by 13 different companies were selected. A complete list, including specific characteristics, is shown in table 1.

BACKGROUND

CHEMICAL COMPOSITION

Rigid urethane foams are two-part chemical systems that must be metered in specific proportions for successful application. The "A" (activator) component typically contains a polymeric isocyanate, diphenylmethane diisocyanate (MDI), which has a recommended threshold limit value - time weighted average (TLV-TWA) of 0.02 ppm of air. This means that 0.02 ppm is the average concentration to which workers may be exposed for a normal 8-h workday and 40-h work week without adverse effects (1). The principal hazard is respiratory irritation following inhalation of the vapor.

The average concentration of MDI immediately above an open, full container has been found to be less than 0.01 ppm at 110° F (12). The activator should, therefore, present no problems as a vapor.

[3] Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

TABLE 1. - Candidates[1] for tests

Product	Flame-spread index[2]	Density, lb/ft^3	Pct closed cell	1-in-thick application, cost, $\$/ft^2$	Supplier
Chempol 30-2124....	25	2	94	$0.18	Freeman Chemical.
Corofoam G325......	30	2	>90	.19	Cook Paint & Varnish.
CSI 9120...........	20	2	96	.22	Chemetics Systems.
CSI 9152...........	20	2	95	.21	Do.
FMS-20.............	20	2.1	95	.19	Polymir.
FMS-20[3]............	25	2	94	.21	Utah Foam Prod. Co.
FS-24..............	25	2	90	.22	Foam Systems Co.
FS-25..............	25-30	2	90	.22	Do.
FS-234.............	25	2.2	90	.30	Do.
Isonate CPR 468....	25	2	92	.19	Upjohn Co.
Polysystem 7622-02.	25	2.2	ND	.22	Olin Chemical Corporation.
Rigimix E/F........	25	2	>90	.25	Mine Safety Appliance Co.
SS-0640............	25	2	>90	.21	Witco Chemical Co.
SS-0768............	25	2	>90	.20	Do.
Texthane 220-20....	25	2	95	.32	Texas Urethanes.
UFS-250............	25	2	ND	.22	United Foam.
USC-230............	25	2	95	.16	Urethane Systems.
X-156..............	20	2	>90	.33	Mine Safety Appliance Co.

ND No data.
[1]Data provided by MSAR from manufacturer specifications.
[2]Flame spread values determined by ASTM E-84 test method.
[3]No relation to Polymir FMS-20. In the report, this foam will be referenced as FMS-20U.

The B component of the rigid urethane system contains polyols, a blowing agent, a fire retardant, a surfactant, catalysts, and a flushing agent. The polyols (polyalcohols) have very low toxicities. The blowing agent, a fluorocarbon, has a TLV-TWA ceiling of 1,000 ppm. The flushing agent, generally methylene chloride, which has a TLV-TWA of 500 ppm (5), is used to clean the sprays following application. These chemicals are used in sufficiently small quantities to preclude most exposure problems.

When applying rigid urethanes, hazardous concentrations of certain vapors and mists could be generated, especially in poorly ventilated areas. For this reason, most regulatory agencies recommend the use of positive-pressure air masks, including full eye protection, for anyone in the vicinity of the application (13).

The two components of rigid urethane foams have an unmixed density between 65 and 80 lb/ft^3. They are delivered via pump to a spray gun, blended, and sprayed on surfaces at densities approaching 2 lb/ft^3 (fig. 1). The expansion ratio is between 32 and 40 to 1. To obtain a 1-in-thick coating, a 1/32-in-thick unexpanded coating should be applied.

THERMAL DECOMPOSITION PRODUCTS

Many different toxic gases are given off during thermal decomposition of organic substances. Probably the most toxic product liberated by rigid urethane foam decomposition is hydrogen cyanide gas, which has a TLV-TWA ceiling of 10 ppm.

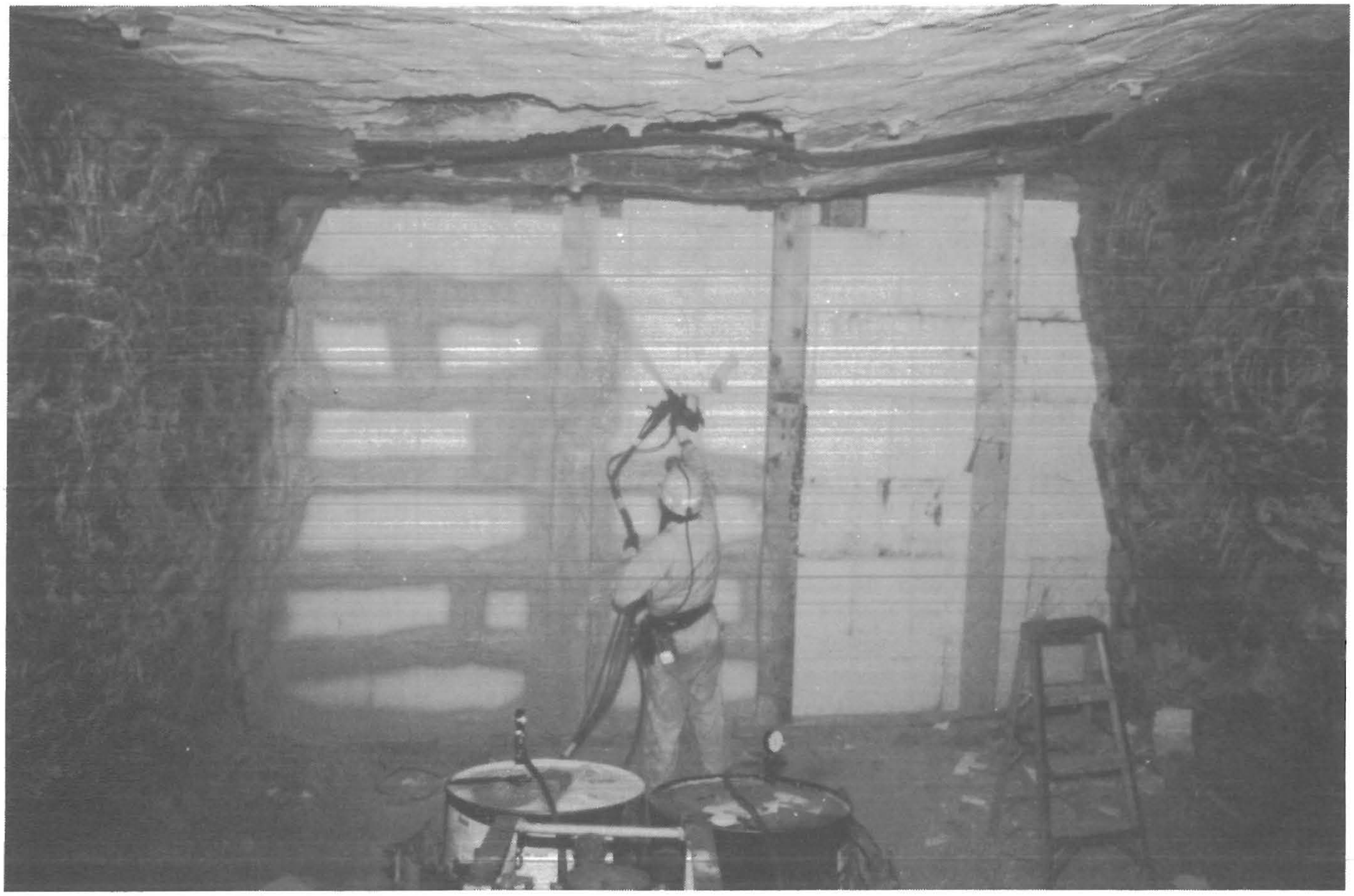

FIGURE 1. - Applying foam to underground stopping.

Gallery fire experiments have been conducted to determine the decomposition products of urethanes (14). In these experiments, an inferior urethane foam was applied to ribs and roof of a simulated mine entry. At temperatures approaching 1,000° C, maximum concentrations of combustion gases are as follows, in percent:

Carbon dioxide...........	18.4
Carbon monoxide..........	6.8
Hydrogen cyanide.........	.3
Oxygen...................	1.0

This is considered an absolute worst-case situation, with ambient temperatures far exceeding human tolerance. Even without the evolved hydrogen cyanide, other gas concentrations would make survival in the immediate area impossible. Toxic gas concentrations downstream of the combustion would depend on the quantity of fresh air ventilating the area.

Several toxicity index studies were conducted on several different materials, most of which are already accepted underground (6, 10). These tests show that once urethane foam has been applied to a surface and cured, it contributes nothing to the overall toxic load of the mine. Even when ignited, its decomposition products appear no more threatening than those of other organic materials.[4]

Most incidents involving rigid urethane foam underground can be traced directly to one of two sources: improper metering of the two components, or the incorrect application of the foam. Improper metering results in an unbalanced chemical

[4]The results obtained reflect the performance only of the specific foams tested. As with any product available in several different brands, performance may vary, depending on the individual components.

mixture. It can cause the expansion rate to be reduced, thus lessening the ability of the foam to adhere or seal. It can also permit an excessive flow of activator, which creates the exothermic (heat given off) reaction and generates heat during the curing process. These problems are overcome by monitoring the flow rates of each component and keeping all fittings and lines clean.

Applications of foam should never exceed 2 in expanded (13), which translates to approximately 1/20 in applied. Since the curing of rigid urethane foam takes place through an exothermic reaction, significant quantities of heat will be generated and retained within the foam after a thick application. This can lead to heating within the foam. This problem can be alleviated by keeping the application thickness less than 1/20-in.

The likelihood of improper metering and incorrect application can be reduced or even eliminated through aggressive training and retraining. Those responsible for applying the foam should be conscientious enough to realize that serious problems can develop through misapplication.

LABORATORY EVALUATION

FOAM SELECTION

All of the 18 candidate foams selected for evaluation had the following characteristics:

- Densities between 2.0 and 2.2 lb/ft^3.
- Flame spread ratings of 20 to 30, based on ASTM E 84 tests.
- Spray application.
- Greater than 90 pct closed cell.
- Less than \$0.35/ft^2 application cost (1-in nominal expanded thickness).

The foams chosen had similar densities because of constraints associated with vertical surface application. The closed-cell density must be above 1.6 lb/ft^3 to prevent collapse. Because of heat dissipation problems, densities above 3.0 lb/ft^3, when applied in expanded thicknesses of 1-in or more, may crack or scorch.

The ASTM E-84 (3) test determines burning characteristics of materials as a function of flame spread over their surfaces. The test equipment includes a 25-ft-long rectangular tunnel, 17-3/4 in wide by 12-in high. Materials are suspended horizontally at the roof and ignited. Flame spread rate, heat evolved, and smoke emitted are measured. The Mine Safety and Health Administration (MSHA), U.S. Department of Labor, accepts only those materials with a flame spread index of 25 or less.

Only sprayable candidates were selected, since this is the most common application method underground. Two application systems are available: a trailer-mounted rig and a portable, manually operated system.[5]

None of the candidates had closed-cell contents of less than 90 pct. This is important because closed-cell content relates directly with air permeability. With smaller closed-cell values, air can flow more easily through the foam coating, rendering it worthless as an air barrier.

All candidates were evaluated with expanded spray-on thicknesses of 1 in and had application costs of less than \$0.35/ft^2. This made some foams approximately three times more expensive than hand-applied cementitious sealants, which average \$0.12/ft^2 with a nominal thickness of 1/8 in. The added expenses are mainly due to (1) higher material costs,

[5] The underground equipment associated with trailer-mounted spraying usually consists of two 55-gal containers, each holding a specific component, a metering pump, hoses, respirator, and spray gun. These are all typically mounted on a vehicle (fig. 2). The portable underground system consists of two disposable, pressurized plastic bottles enclosed in a cardboard case. A flexible spray-wand is included to blend the components and direct the foam onto the surface to be coated.

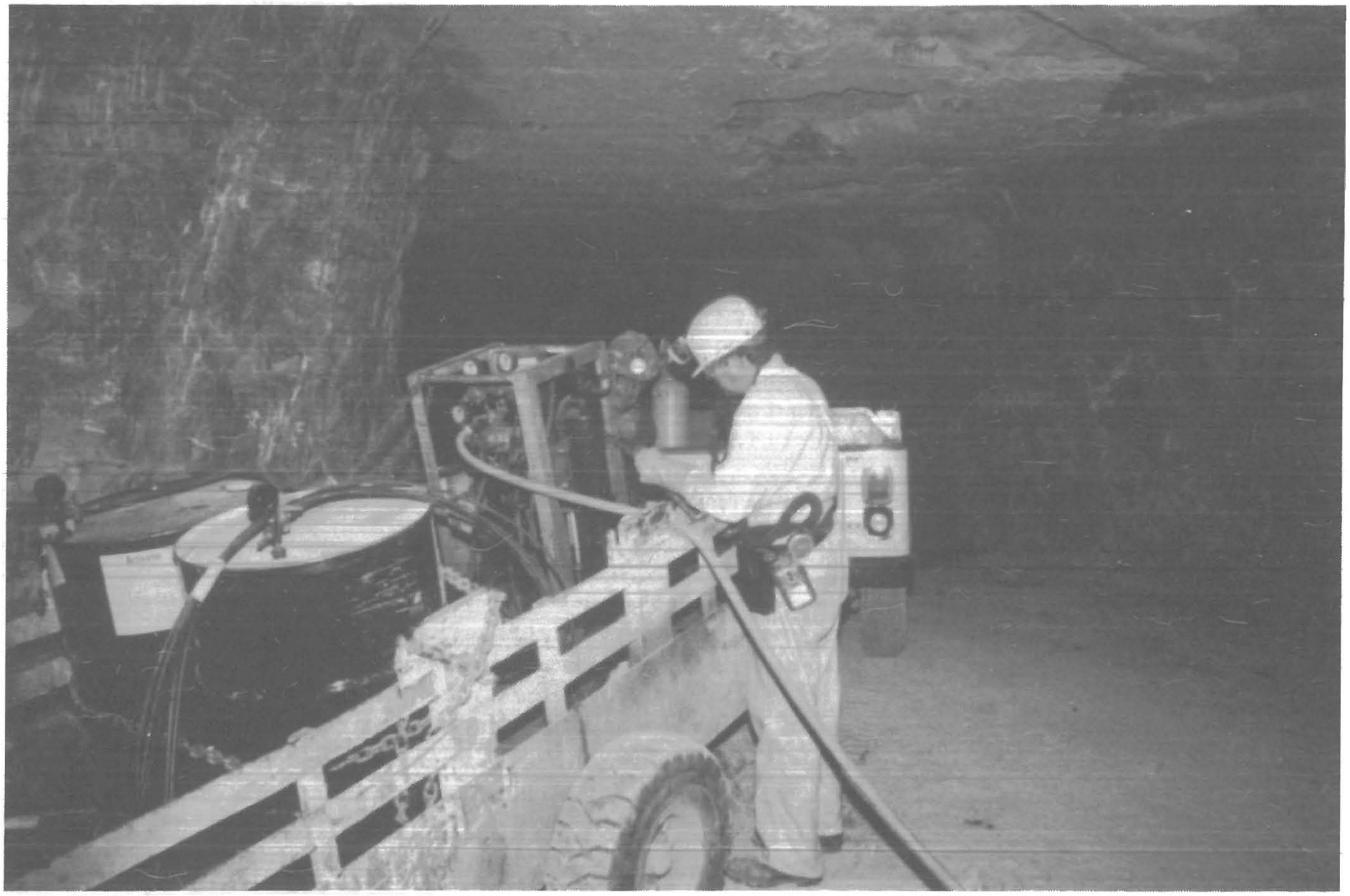

FIGURE 2. - Typical foam spray rig.

(2) more complex application equipment, and (3) additional maintenance required on equipment. However, the added application costs are recoverable because (1) rigid urethane foams seal more effectively, reducing initial leakage through stoppings, and (2) they retain their sealing abilities much longer than do cementitious sealants.

FLAME-SPREAD INDEX

The ASTM E-162 Radiant Panel Test (4) was used to determine the flame-spread index of the foams (fig. 3, panels *A-B*). In this test, a sample is placed in front of a heat-radiating panel of a standard heat flux and ignited by a sample ignition source. Flame propagation with respect to time is measured, along with the heat evolved. These two values are multiplied to give the flame-spread index. Appendix A shows the equations for determining flame propagation rate and heat evolved. Average flame-spread indices for the 18 urethanes are shown in figure 4.

After this initial series of tests, an arbitrary cutoff value of 150 was chosen. Although this value has no real meaning, it appears to reasonably separate the foams into two performance categories.

MODIFIED FLAME-SPREAD INDEX

A modified E-162 radiant panel test was devised by MSAR as a more severe criterion of foam flammability. In this test, the angle that the foam specimen makes with the radiant panel is reversed (fig. 5, *A-B*), bringing the sample closer to the radiant panel at the bottom rather than the top. The ignition pilot is moved from the top to the bottom of the specimen so that the flame front now moves up the panel. The exhaust stack is recentered over the new panel location.

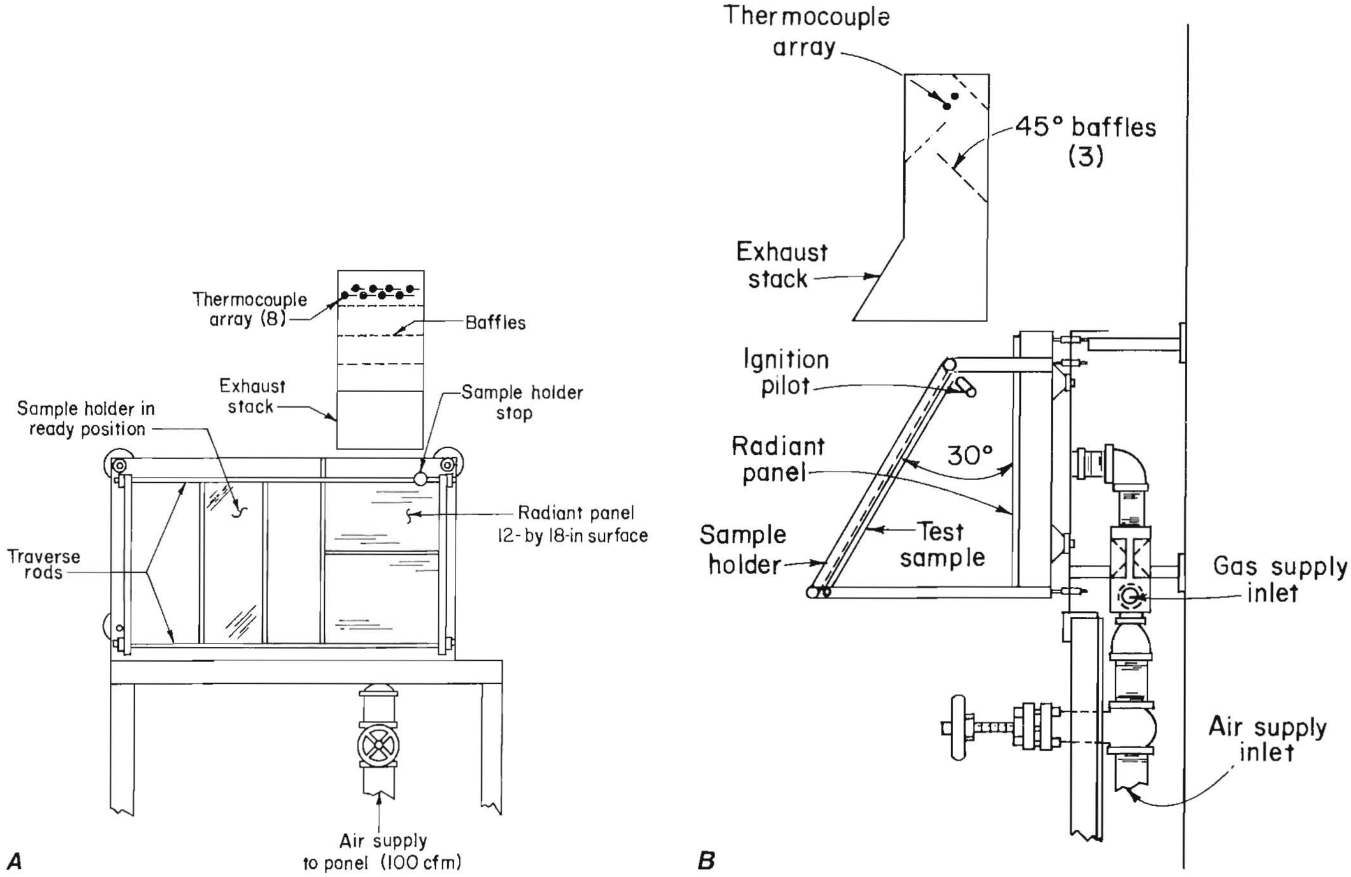

FIGURE 3. - ASTM E-162 radiant panel test apparatus. *A*, Front view; *B*, side view.

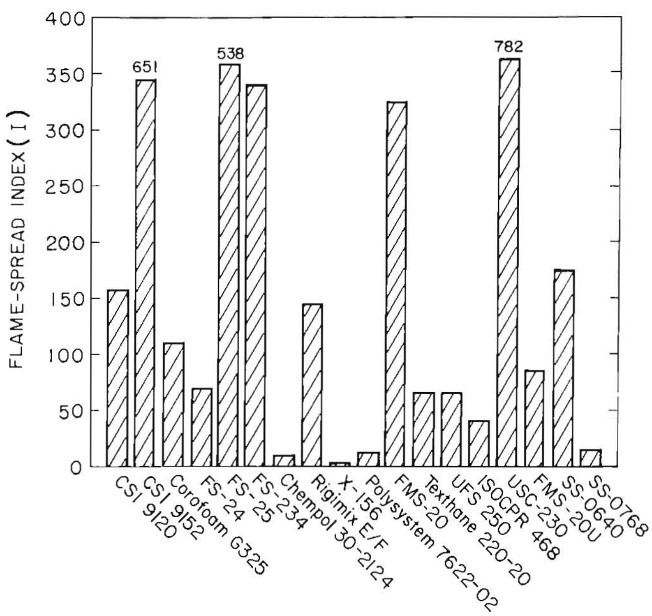

FIGURE 4. - Flame-spread indices for 18 urethane foams.

Results of the modified E-162 radiant panel tests are shown in figure 6. With the ignition pilot at the bottom of the specimen, the flame front spread more rapidly up the foam sample. Flame spread versus time increased for all samples an average of 450 pct, with a corresponding increase in the flame-spread index.

Although the same testing apparatus is used, the E-162 test and modified E-162 test, not accepted by ASTM, give very different results. The intention was not to see how well the samples correlated between the tests, but merely to expose samples to a more severe examination.

In these tests, the arbitrary cutoff point chosen was 2,000, leaving eight candidates for further testing. Again, this value was chosen solely to classify the foams into a group whose properties are more similar.

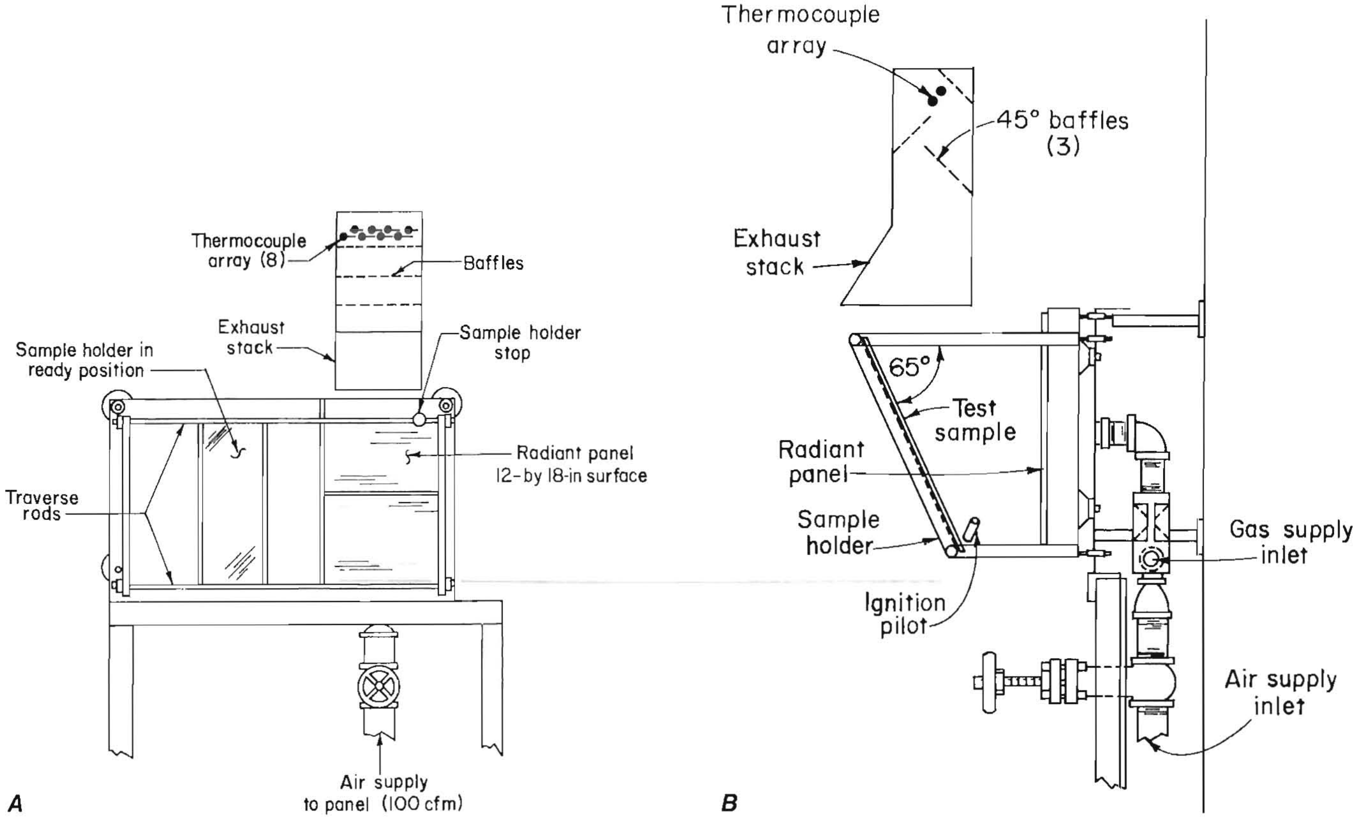

FIGURE 5. - Modified ASTM E-162 radiant panel test apparatus. *A*, Front view; *B*, side view.

FLAME PENETRATION

Rigid urethane foams are used primarily as stopping and overcast sealants to restrict or eliminate air leakage in underground mines. Urethane foams must not only have acceptable flame-spread characteristics, but also they must be able to limit or prevent flame penetration.

Resistance to direct flame exposure is measured by a flame penetration test. This examination was conducted on the eight remaining candidates using a method developed by the Bureau of Mines (9). The test apparatus is shown in figure 7. A 6-in by 6-in by 1-in sample is inserted into the holder. A pencil-point flame is adjusted to 2 in above the foam and set so that a 1.5-in blue cone flame is emitted. The foam surface temperature is measured by a thermocouple. The mirror beneath the test apparatus is used to determine if burn-through takes place within 7 min. None of the samples permitted burn-through within the allotted time.

IGNITION TEMPERATURES

Two temperatures were determined: the flash-ignition temperature and the self-ignition temperature.

Before ignition, foams must undergo sufficient external or internal heating for flammable gases and decomposition products to be released. If a sufficient fuel-to-air ratio exists, an ignition may take place. When a flame exists external to the foam, the products given off may flash and ignite. The temperature at which this occurs is the flash-ignition temperature.

The temperature at which the decomposition products themselves ignite, without any external flame, is the self-ignition temperature. In most cases, self-ignition temperatures are

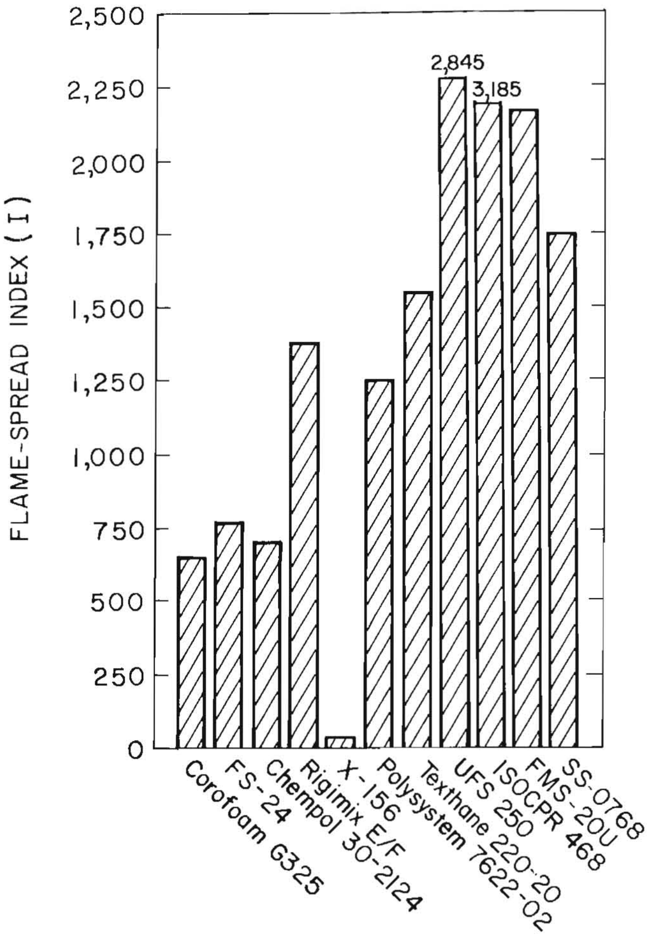

FIGURE 6. - Modified flame-spread indices.

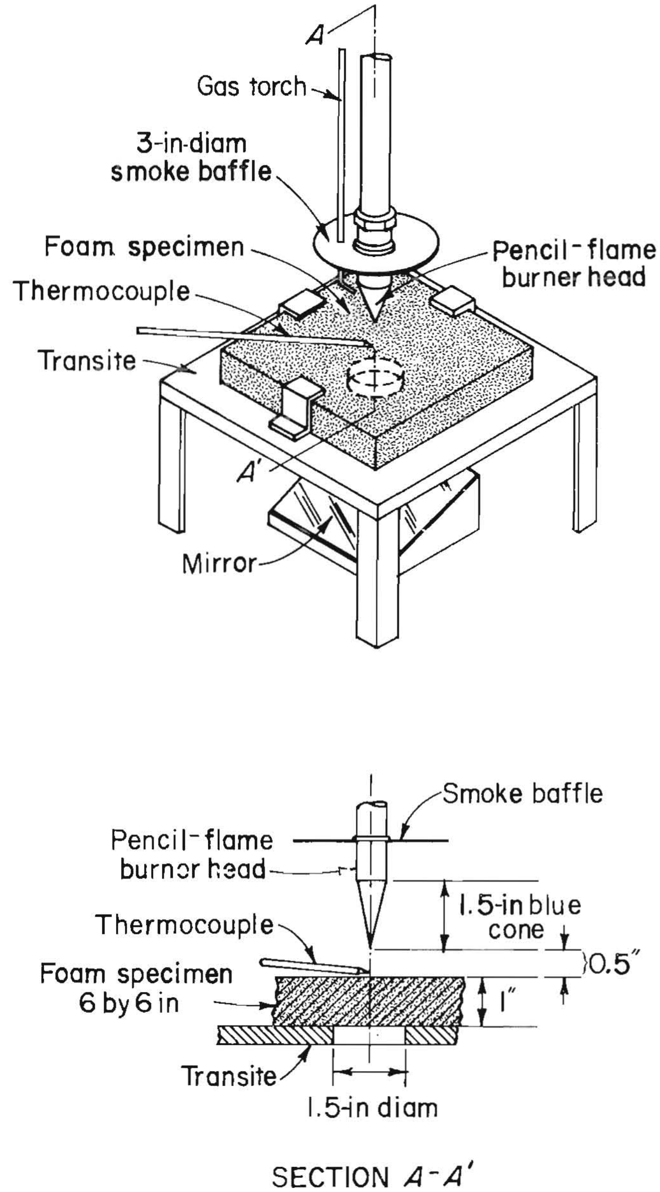

FIGURE 7. - Flame penetration test apparatus.

higher than flash-ignition temperatures. The ASTM Method D 1929 (2) was used to determine self- and flash-ignition temperatures.

Figure 8 shows the temperatures at which ignition problems could occur with rigid urethane foams. Electric arcs, for example, can greatly exceed the flash-ignition temperature required to ignite foam; therefore, care should be exercised in using foam near high-voltage wiring.

Self-ignition usually occurs from applying a thick (more than 2-in) coating of foam to a surface. The foam undergoes an exothermic reaction as it cures. Depending upon component reactivity and the type of catalyst used, the internal temperatures of some foams will exceed the self-ignition temperature. The foam then decomposes rapidly, ignites, then burns from the inside.

AIR PERMEABILITY

Since the main use for rigid urethane foams underground is as sealants on stoppings and overcasts, they must be impermeable to air. The permeability of the eight candidate foams was determined at 1, 5 and 10 in wg. Figure 9 shows a schematic of the test device.

All samples tested had leakages of less than 0.05 cfm per 100 ft^2 at each pressure drop. The closed-cell content of each foam was at least 90 pct. As

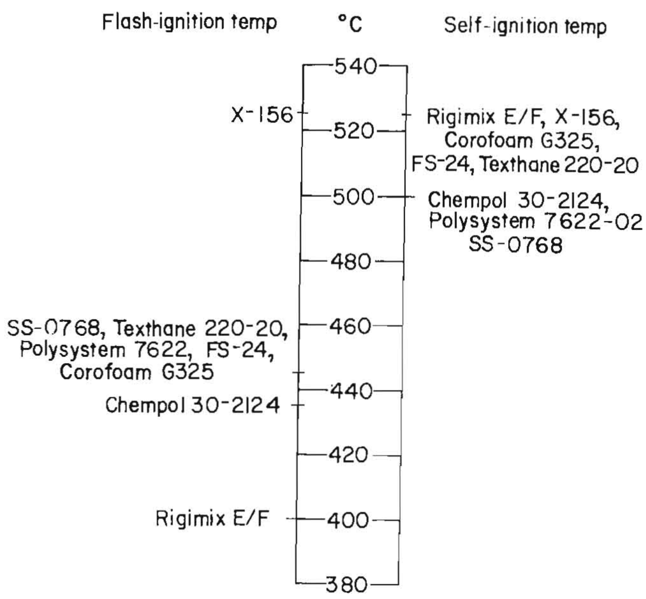

FIGURE 8. - Flash- and self-ignition temperatures of urethane foams.

expected, the high closed-cell content allowed a high pressure differential to be exerted, with no breakdown of the individual closed cells.

ADHESION

Foams that have successfully passed all previous tests may still be unacceptable for underground use if they do not adhere adequately to various substrates. Candidate foams were evaluated by spraying them onto different substrates and permitting them to cure adequately, then measuring the force required to pull a representative sample from the substrate.

Five substrates were used: coal, wood, slate, concrete block, and plastic brattice. Each substrate was used in four different conditions: dry, dry and rockdusted, wet, and wet and rockdusted. For wet tests, water was applied to each surface until the surface was saturated.

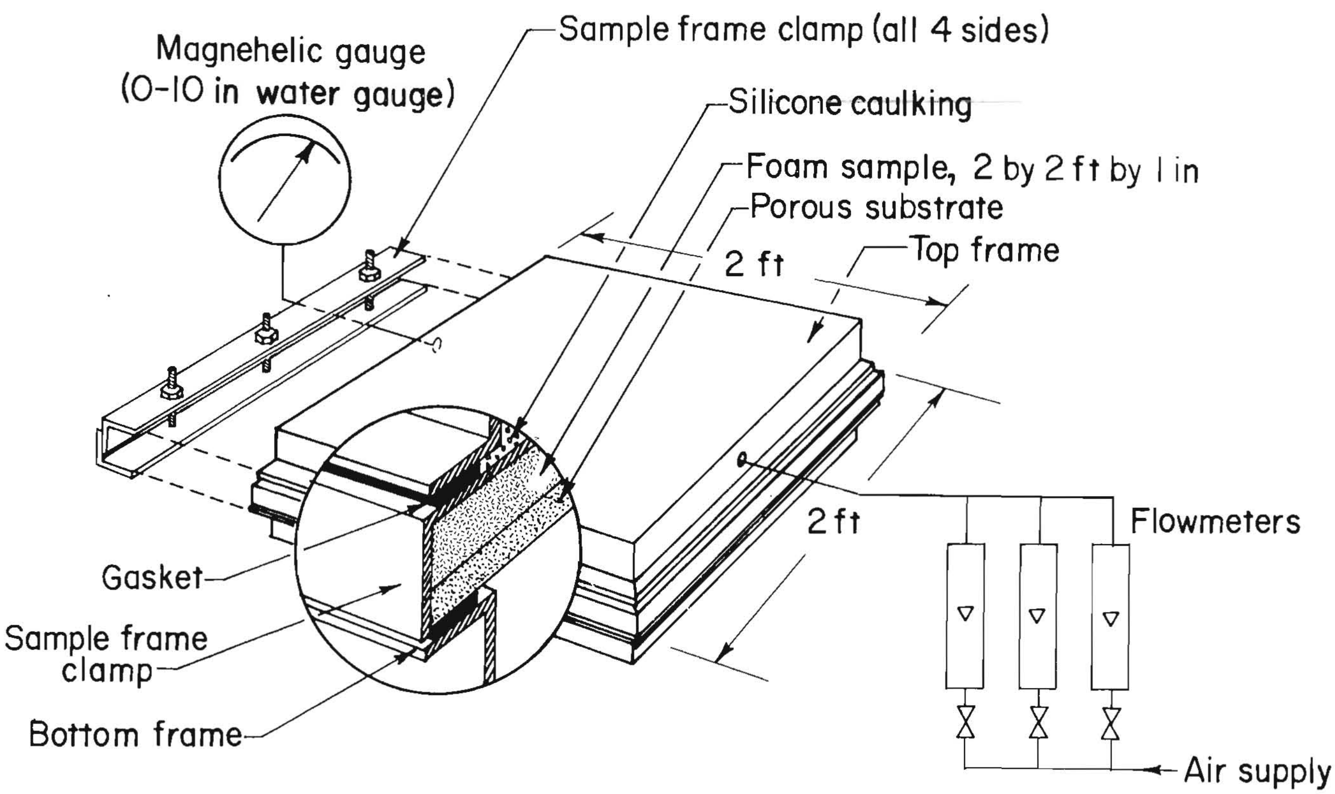

FIGURE 9. - Test device for measuring air permeability.

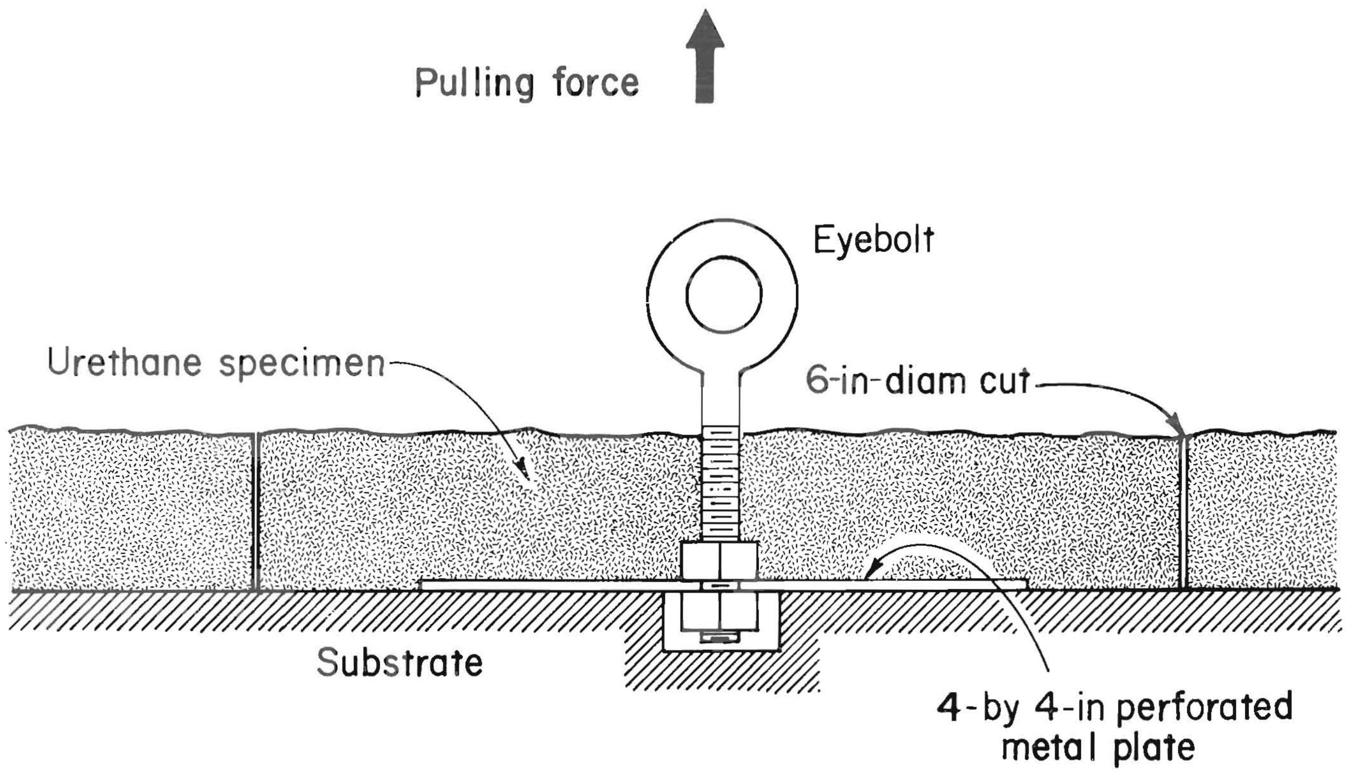

FIGURE 10. - Test device for determining adhesion.

Rockdust was applied until the substrate was completely covered.

An adhesion test, modified from earlier Bureau research, was developed (8). A pull tab, consisting of a 2- by 2-in, flat, perforated metal sheet, with an eyebolt centered in the tab, was placed on each substrate (fig. 10). Approximately 2 in of foam was sprayed onto the substrate and pull tab. After curing, a 6-in-diameter hole saw, centered over the eyebolt, was used to cut a circular sample that was free of the adjacent foam.

Each sample was placed on a tensile evaluation device, the substrate was secured, and the foamed tab was pulled until it separated from the substrate. Data for overall average foam strength on each substrate are shown in figure 11. These were averaged over all substrate conditions and presented as a single result. The averaged values represent realistic information regarding the performance of each brand. Two foams, Rigimix E/F and FS-24, consistently outperformed the others; X-156 and Chempol 30-2124 were the least adhesive. Data for each candidate foam under all four substrate conditions are presented in appendix B.

WATER-IMMERSION TESTS

Rigid urethane foams used as sealants underground should be capable of withstanding both high relative humidities and, at times, actual water contact. Placing the foam in water could cause (1) structural weakening due to the absorption of water, (2) increased flammability due to leaching-out of flame-retarding chemicals, and (3) increased air permeability due to internal cell rupture, reducing the closed-cell content.

Four 6- by 18- by 1-in foam samples of each brand were immersed in distilled water for 96 h. The samples were removed from the water, weighed after 15 to 30 min to determine water retention, and reweighed after 48 h to determine a postimmersion dry weight.

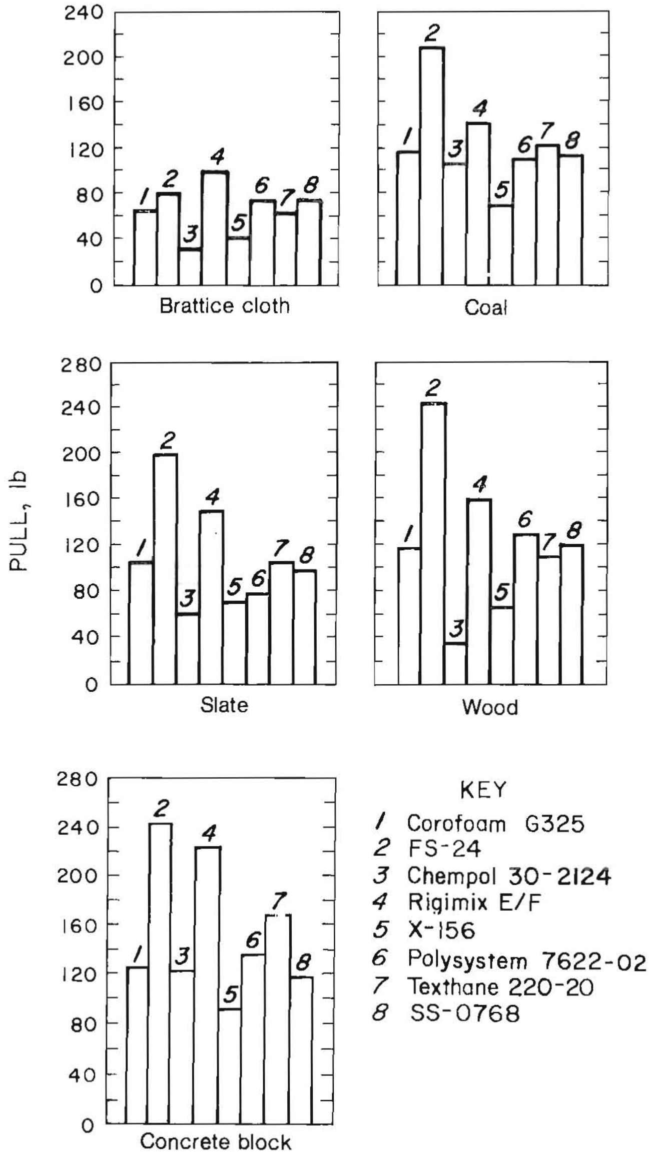

FIGURE 11. - Average adhesion values.

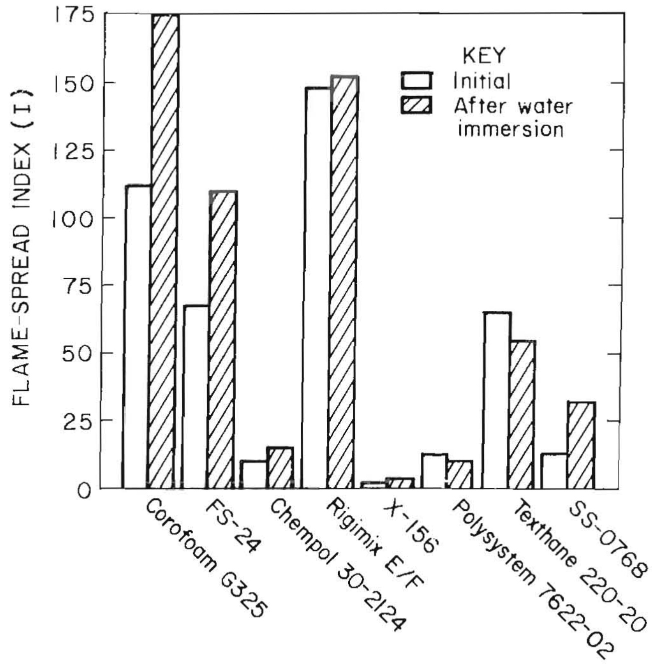

FIGURE 12. - Postimmersion flame-spread test results.

The eight final candidates were again subjected to the E-162 radiant panel test (fig. 12).[6] Most foams showed an increase in flame-spread indices after water immersion, due to leaching-out of the fire retardant additives.

Tests comparing preimmersion values of closed-cell content, compressive strength (determining what pressures are required to initiate specimen compression), and density showed that the differences were small enough to be considered insignificant. All test data are given in appendix C.

DRY-AGING TESTS

In some mines, heat--not moisture--is an important reason for poor sealant performance. This is especially true in deep mines. Heat also has a tendency to drive off certain components of some rigid urethane foams. This can alter the chemical composition and, ultimately, the fire-retarding properties of the foam. Accordingly, dry-aging tests were conducted in parallel with the water-immersion tests.

Nine 6- by 18-in by 1-in samples of each brand were weighed and stored in a 100° C oven for 28 days. After removal, the samples were equilibrated to room temperature and humidity and reweighed. Weight loss due to dry aging is shown in table 2.

[6]The small decrease in flame-spread index of Polysystem 7622-02 and Texthane 220-20 were probably due to laboratory inaccuracy.

TABLE 2. - Effects of dry aging on foam weights

	Mean initial wt, g	Mean final wt, g	Difference, pct
Chempol 30-2124....	59.0	57.9	1.9
Corofoam G325......	58.4	54.9	6.0
FS-24..............	52.0	49.6	4.6
Polysystem 7622-02.	60.8	59.5	2.1
Rigimix E/F........	56.7	56.7	0
SS-0768............	52.0	50.9	2.1
Texthane 220-20....	56.8	55.8	1.8
X-156..............	50.6	48.0	5.1

Next, each foam was subjected to an E-162 radiant panel test to determine if fire retardancy had been compromised by dry aging. A flame-spread index of 25 is the maximum value that MSHA will permit for foams used on stoppings or overcasts underground. Results of the eight urethane foam samples presented in figure 13 show that half of the samples did not meet this criterion.

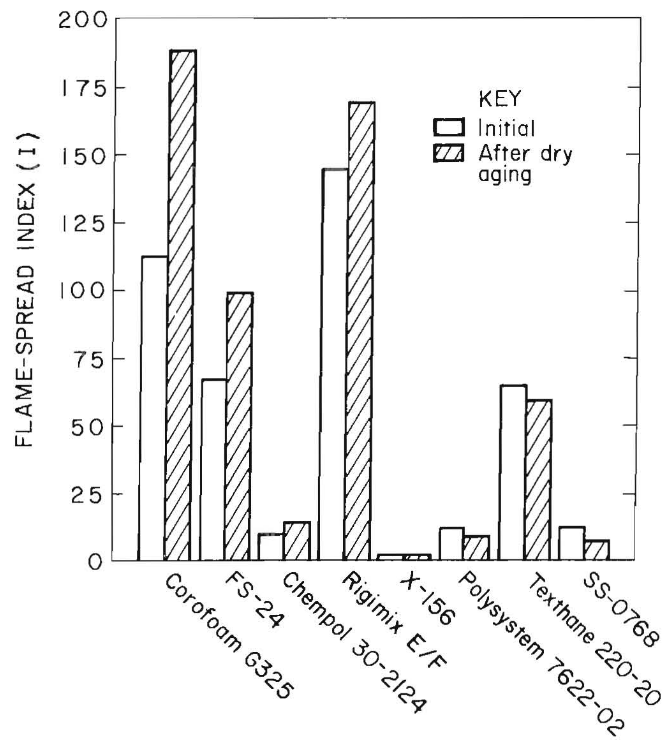

FIGURE 13. - Effects of dry aging on flame spread.

COMPONENT AVAILABILITY PROBLEMS

After the laboratory examinations had been completed, researchers were advised that a specific urethane component, Thermolin RI-230, would no longer be manufactured by Olin Chemical Corp., because of a lack of demand. This polyol was used in five of the eight brands of foam evaluated and was a high-performance fire retardant. The eight foams are shown in table 3 with their initial flame spread and rank. However, the foams containing the discontinued polyol, especially Chempol 30-2124 and X-156, performed less well in the adhesion testing than did other foams with a different polyol. At this time, Thermolin RF-230 is not being manufactured, nor are any plans known to restart production. Foams without this component all had a flame-spread index greater than 25, according to the ASTM E-162 radiant panel test.

TABLE 3. - ASTM E-162 flame-spread index and rank

Foam	Flame-spread index	Rank
Chempol 30-2124......	10	[1]2
Corofoam G325........	112	7
FS-24................	68	6
Polysystem 7622-02...	12	[1]3
Rigimix E/F..........	144	8
SS-0768..............	13	[1]4
Texthane 220-20......	65	[1]5
X-156................	2	[1]1

[1]Contained Thermolin RF 230, a fire retardant.

SUMMARY

Sealants are used on stoppings and overcasts in underground mines to decrease leakage and increase the quantity of air available in working sections. Most coal mines use cementitious sealants, which are inorganic and lack the ability to flex when convergence occurs at the coated surface. The mortar face cracks or spalls, creating a low resistance leakage path for air.

A flexible organic sealant, used predominantly in metal and nonmetal mines, is rigid urethane foam. This is a two-part sealant that is sprayed onto a stopping or overcast in thin coats that expand 32 to 40 times their original volume (fig. 14).

This research was part of a larger contracted effort in which several types of foams were evaluated. The evaluations were done by the contractor with Bureau personnel overseeing the work. Because only spray-applied rigid urethane foams appear feasible for underground sealant work, only sprayed-on rigid urethane foams were evaluated.

Eighteen foams were subjected to two initial flame-spread evaluations. Arbitrary minimum performance specifications were devised for each flame-spread test. After a modified flame-spread test, only eight candidates remained.

The effects of water immersion and the corresponding changes in flame spread, and the effects of dry aging were examined. Again, flame spread differences were noted. Postimmersion samples examined for closed-cell content, compressive strength, foam-area increase, and density showed little difference from virgin samples. Dry-aged samples were evaluated for weight changes and flame spread. Several candidates had a weight loss, and four foams exhibited an increase in flammability.

Virgin foam samples were also tested for flame penetration, self- and flash-ignition temperature, air permeability, and adhesion. Performance in each test was satisfactory.

One urethane foam component common to five of the eight candidates was a high-performance fire retardant. The component was discontinued shortly after the laboratory testing was completed. This effectively eliminated the only foams evaluated that had a flame-spread index of 25 or less, according to the ASTM E-162 radiant panel test.

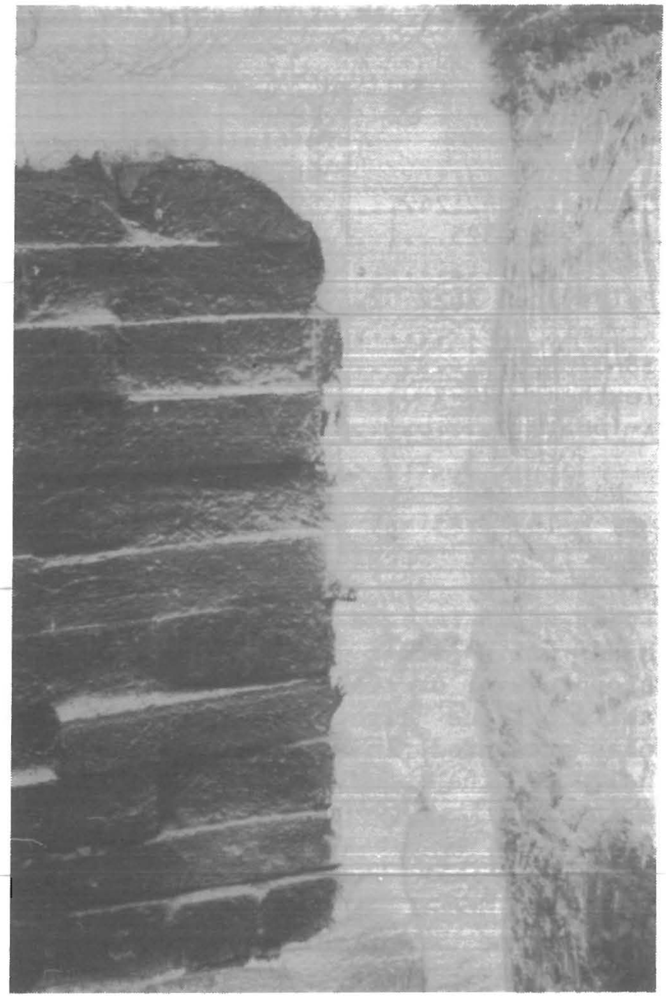

FIGURE 14. - Foam applied to stopping perimeter.

Those responsible for applying the foam must be thoroughly trained in proper application techniques, as well as equipment maintenance. Proper metering of the two components of the rigid urethane system is essential for successful application. This requires thorough cleaning of all equipment after spraying. Probably the most important rule in applying rigid urethane foams is to never exceed 2-in expanded thickness for any one coating. The curing process involves an exothermic reaction which can raise internal temperatures of some urethane foams above the self-ignition temperature and cause a fire within the foam body.

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APPENDIX A.— EQUATIONS FOR DETERMINING FLAME-SPREAD INDEX

ASTM E-162 Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy System (4).

1. Determining Flame Spread, (F_s):

$$F_s = 1 + \frac{1}{T_3} + \frac{1}{T_6 - T_3} + \frac{1}{T_9 - T_6} + \frac{1}{T_{12} - T_9} + \frac{1}{T_{15} - T_{12}},$$

where $t_3 \ldots t_{15}$ = time from initial specimen exposure until arrival of flame front at 3...15 in. position, in min.

2. Determining Heat Evolution, (Q):

$$Q = 0.1 \frac{(T)}{\beta},$$

where 0.1 = arbitrary constant,

T = observed maximum stack thermocouple temperature rise, F,

and β = maximum stack thermocouple temperature rise for unit heat input rate of the calibration burner, F Btu^{-1}/min.

3. Flame-Spread Index, (I_s):

$$I_s = F_s Q.$$

APPENDIX B.--ADHESION PROPERTIES OF RIGID URETHANE FOAM

(All values are in pounds of pull)

	Dry	Wet	Rockdust dry	Rockdust wet
CHEMPOL 30-2124				
Brattice cloth	69	0	58	0
Coal	188	69	138	21
Concrete block	183	66	278	0
Slate	104	7	82	42
Wood	0	41	103	0
COROFOAM G325				
Brattice cloth	97	37	85	45
Coal	143	136	109	66
Concrete block	156	144	130	114
Slate	132	88	143	61
Wood	128	108	151	83
FS-24				
Brattice cloth	133	46	101	35
Coal	289	205	272	48
Concrete block	352	160	408	117
Slate	328	141	300	34
Wood	304	270	274	126
POLYSYSTEM 7622-02				
Brattice cloth	140	39	119	0
Coal	92	113	206	23
Concrete block	169	108	240	59
Slate	88	0	194	28
Wood	153	122	239	0
RIGIMIX E/F				
Brattice cloth	124	73	145	51
Coal	268	40	255	8
Concrete block	236	246	292	181
Slate	246	72	187	92
Wood	208	81	292	57
SS-0768				
Brattice cloth	140	27	126	0
Coal	112	111	158	66
Concrete block	198	79	228	0
Slate	147	82	165	0
Wood	230	44	203	0
TEXTHANE 220-20				
Brattice cloth	122	37	89	0
Coal	172	94	172	55
Concrete block	195	125	308	95
Slate	141	83	155	44
Wood	110	74	252	6
X-156				
Brattice cloth	71	22	63	0
Coal	105	44	115	16
Concrete block	127	83	145	35
Slate	112	18	125	21
Wood	121	20	124	0

APPENDIX C.--EFFECTS OF WATER IMMERSION ON RIGID URETHANE FOAMS

Foam	15-30-min weight change, pct	48-h weight weight change, pct	Density, lb/ft^3		Pct closed cell		Compressive strength, psi[1]	
			Before	After	Before	After	Before	After
Chempol 32-2124...	50.9	-0.14	2.02	2.02	92.1	95.8	517	497
Corofoam G325.....	71.2	-1.20	2.22	2.16	88.8	87.9	644	643
FS-24.............	52.6	-.39	2.11	2.12	95.2	90.7	490	441
Polysystem 7622-02	40.2	-.02	2.40	2.36	94.0	91.4	612	868
Rigimix E/F.......	59.5	-.08	2.20	2.20	98.6	97.0	881	720
SS-0768...........	59.7	.19	2.13	2.11	93.0	92.8	413	406
Texthane 220-20...	39.1	-.31	2.20	2.25	91.2	93.5	682	385
X-156.............	53.6	-.34	2.03	1.94	92.8	90.3	594	541

[1]Compressive strength is determined by placing the specimen into a test apparatus and measuring the pressure required to initiate specimen compression.