Evaluating Rigid Foams for
Construction and Repairing
Mine Stoppings

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# EVALUATING RIGID FOAMS FOR CONSTRUCTION AND REPAIRING MINE STOPPINGS

Contract J0308006
MSA Research Corporation

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR

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16. Abstract (Limit 200 words)

Twenty-seven commercially available rigid foam materials were tested to delineate those most suitable for use as a sealant in underground mine stoppings. The rigid foam industry was surveyed for possible candidates based on published properties, cost, and application equipment. Using a process that recognized those properties of rigid foams that were important for use as mine stopping materials, laboratory tests reduced the initial listing to two. Flammability, air permeability, and mode of application comparisons played major roles in the selection process, with adhesion and cost comparisons being minor factors. Standard ASTM tests were employed where applicable.

17. Document Analysis a. Descriptors

Rigid foams
Urethane foams
Isocyanurate foams
Phenolic foams

Silicone foams
Flammability
Air permeability
Adhesion

b. Identifiers/Open-Ended Terms

Mine stoppings
Mine ventilation
Plastics, foam

c. COSATI Field/Group 08I

# FOREWORD

This report was prepared by MSA Research Corporation, a division of Mine Safety Appliances Company, Evans City, PA under USBM Contract number J0308006. The contract was initiated under the Minerals Health and Safety Technology Program. It was administered under the technical direction of Pittsburgh Research Center with Robert Timko acting 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 December 1979 to August 1983. This report was submitted by the authors on December 1983 and contains no patentable features.

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# INTRODUCTION

Industrial workplace standards, implemented by the Mine Safety and Health Administration, designate the ventilation of underground mines to reduce methane concentrations and control dust levels. Distributing the enormous quantities of ventilating air required to maintain these standards in underground mines constitutes a continuous, expensive problem to the mining industry. Air leakage does not allow designed and needed quantities of air to get to the face where air is needed. Wasted energy in nonproductive air is very expensive.

Construction and maintenance of mine stoppings have been persistent problems throughout years of development and experience. Many energy intensive operations are necessary to obtain the required ventilation throughout the maze of shafts and passageways which comprise a mine. Stoppings must be erected regularly, as the face advances, to assure a flow of fresh air to the work face. Older stoppings must be repaired periodically, as subsidence and erosion take their toll. both new and old stoppings must be impermeable, or they will lose their function in directing the ventilating air into work areas.

Concrete blocks are almost universally employed in the construction of mine stoppings. Since all construction materials must be brought into the mine from the surface, this practice constitutes a significant logistics problem, which could be mitigated by the use of foamed materials.

When introduced to the mining industry years ago, urethane foams received wide acceptance as a partial answer to the stopping construction problems. Their impermeability, flexibility and adhesive properties were nearly ideal for coal mine stoppings. Unfortunately, the indiscriminate use of polyurethane, including poor spraying applications and the use of foams with poor flammability properties resulted in their involvement in mine fire situations. As a result, all foam materials have gained a reputation as a potential fire hazard in mine use.

Since the problems of constructing and maintaining stoppings universally influence the economics of mining operations, considerable interest has been generated for discovering alternative solutions to these problems.

This investigation has been designed to identify rigid, foamed materials which could be used to alleviate the problems involved in constructing and maintaining mine stoppings. It has been developed to fulfill a three-fold objective: tabulating, testing and selecting commercially available, foamed materials as alternatives for mine stoppings. This three-fold objective has been used in delineating a three-phase program; which is defined in the following manner:

Phase I    - <u>List and Describe Rigid Foam Candidates;</u> consisting
             of a survey of the rigid foam industry for possible
             candidates for the program, tabulate available prop-
             erty, cost and application equipment data to aid in
             the selection of 30 foams for laboratory testing.

Phase II   - <u>Lab Test of Rigid Foams;</u> selecting 30 foams for
             laboratory testing.   Laboratory tests consist of
             comparing those properties that are most important
             for an in-mine stopping material, and subseqently
             selecting 2 for in-mine testing.

Phase III  - <u>In-Mine Testing;</u> consists of the design, construc-
             tion and testing of rigid foam stoppings in a co-
             operating mine.

This report describes the approach, mechanics and results of an
investigation of the rigid, foamed materials industry in search of mater-
ials which would provide alternatives for constructing and maintaining
mine stoppings.

# APPROACH

In summary, the job consisted of selecting the two best rigid foam candidates for use in mine stopping construction and testing designs incorporating their use in actual mine conditions. To a considerable extent, the program success depended on the selection of the final candidates and demonstrating that the foam candidates would have practical applications underground.

The validity of the process for the selection of the two "best" rigid foam candidates for final testing depended on two parameters in Phase I. First, on an extensive industry survey to insure that all potential candidates were recognized. Second, on a screening and selection process that recognized those characteristics of rigid foams that are important for their use as mine stopping construction materials.

Data and information were sought on 22 generic types of foams from 94 manufacturers. From this information, 27 candidates representing 5 generic types of foam were selected for testing. The selection was based primary on reported flame spread data, mode of application and availability.

In the first test series, the 27 foams selected for testing were subjected to two laboratory-scale flame spread tests, ASTM E-162 and Callery's E-162-CCC-2. These test results were used to reduce the number of candidate foams to 15, using an arbitrary cut-off value, and discarding those candidates testing higher.

In the second test series, the 15 selected foams were subjected to water immersion tests. These tests determined the resistance of the foams to loss of fire retardancy, strength or closed cell content (related to air permeability) and their results were used to reduce the number of candidate foams to 10. Again, arbitrary cut-off values were employed.

In the final test series, the 10 remaining candidate foams were subjected to adhesion, air permeability, ignition, flame penetration and aging tests. All candidates "passed" these tests (i.e., met minimum requirements). Therefore, the flame spread data was used as the major criteria for selecting the "final 2." These "final 2" were then used to seal stoppings in several typical locations in a working mine.

# SELECTION OF POTENTIAL FOAM CANDIDATES

## FOAM SURVEY

A thorough examination of rigid, foamed materials was conducted in the first phase of this investigation. A preliminary goal was to contact representative manufacturers of all foamed materials and to compile data concerning each foam that would be sufficient to appraise the foam's adequacy for constructing and maintaining mine stoppings. During the initial search no material was eliminated off-hand from consideration.

## Survey Mechanics

The survey of rigid foam manufacturers progressed through a series of five steps. Both telephone and letter communications were used to provide a clear definition of the objective of the survey and to compile data on potential products. The general mechanics and chronological order of the steps involved in this survey are outlined below.

1. Representative companies that market foamed materials were selected from manufacturers' indices, such as the Modern Plastics Encyclopedia and Thomas Register. Company names, addresses and telephone numbers were catalogued according to the generic type(s) of their product(s).

2. A general outline of the physical properties and other descriptive data required for evaluating candidate materials was prepared as a format for collecting data. Written inquiries included a cover letter which 1) explained the objective of this investigation, and 2) included brief summaries of the analytical approach and performance goals to be used in the evaluation of candidate materials.

3. Telephone contacts were made with the companies selected. Special efforts were taken to speak with individuals concerned with product research and development within the company. The individual's name, company products, pertinent data, experiences and opinions were noted on the data sheet for each contact. Address and/or telephone number changes were also verified at this time. References were noted for consideration and possible contact.

4. Data sheets were compiled for each company summarizing product information obtained from telephone contacts, product and safety data sheets. Where necessary, additional contacts were made for clarification.

5. Data for all potential candidates were collected into a composite tabulation of foam materials. This would be used in the comparison and selection of candidates during the second phase of the program.

This general sequence was followed in communications with 94 companies. Descriptions and responses were compiled in a chronological order to provide a means for following the progress of the survey of manufacturers. These original notations were expanded to include company names, addresses, telephone numbers, person(s) contacted and their responses.

Seventy-two companies representing 20 generic foam types, were initially selected to be contacted. These contacts provided further leads which culminated in communications with 22 additional manufacturers and added 2 more foam types. A list of the manufacturers contacted is given in Table 1. A more detailed list, including the manufacturer's address is given in Table A-1 of the Appendix. An alphabetical listing of the generic foams surveyed and the number of representative manufacturers contacted for each is presented in Table 2.

## Data Solicited

The foam data solicited covered a wide range of properties. An ideal material for constructing and maintaining mine stoppings would be perceived as having the following general characteristics:

1. Good adhesive to the substrate

2. Low air permeability

3. Resistant to heat

4. Resistant to flame penetration

5. Resistant to surface flame spread

6. Resistant to ignition

7. Sufficiently flexible to prevent or reduce cracking

8. Reasonable structural strength

9. Maintenance of structural integrity following exposure to heat and fire.

10. Maintenance of low air permeability following exposure to heat and fire

11. Resistant to deterioration over a period of 10-20 years.

TABLE 1 - Listing of manufacturers contacted

| Generic Type | Company | Generic Type | Company |
|---|---|---|---|
| ABS | Borg-Warner Corporation | Polyimide | Ciba-Geigy Corporation |
| Acetal | Celanese Plastic Materials Co. | | Monsanto Company |
| Cellulose Acetate | American Polymers, Inc. | Polypropylene | Northern Petrochemical Co. |
| | Deltex Associates | | Vantage Products |
| | Eastman Chemical Products, Inc | | Sun Chemical Corporation |
| Epoxy | Bacon Industries, Inc. | Polystyrene | Dow Chemical Company |
| | Isochem Resins Company | | Northern Petrochemical Co. |
| | Shell Chemical Company | Polyurethane | Atlas Minerals and Chemicals |
| | Sika Chemical Company | | Chemetics Systems, Inc. |
| | Emerson and Cumings, Inc. | | Fomo Products, Inc. |
| | Kristal Kraft, Inc. | | Furane Plastics, Inc. |
| | Ren Plastics | | BASF Wyandotte Corporation |
| Ionomer | Gilman Brothers Company | | Cook Paint & Varnish Company |
| | Texas Urethanes | | Freeman Chemical Corporation |
| | Foam Systems Company | | Hastings Plastics Company |
| | Upjohn Company, CPR Division | | Insta-Foam Products, Inc. |
| Melamine-based | American Cyanamid | | Lankro Chemicals, Ltd. |
| Phenolic | Schenectady Chemicals, Inc. | | Kristal Kraft, Inc. |
| | Smithers Company | | M-R Plastics and Coatings |
| Phenylene Oxide-based | General Electric Company | | Magnolia Plastics, Inc. |
| Polyamide-imide | Amoco Chemicals Corporation | | Midwest Manufacturing Corp. |
| | Enplax Corporation | | Olin Chemical Corporation |
| | Allied Chemical Corporation | | Pelron |
| Polybenzimidazole | Celanese Plastic Materials Co. | | Fremont-Hayward |
| Polycarbonate | Armstrong Cork Company | | Reichold Chemicals, Inc. |
| | General Electric Company | | Stepan Chemical Company |
| Polyethylene | Dow Chemical Company | | Hoover Universal |
| | Dynamit Nobel of America, Inc. | | Texas Urethanes |
| | Vantage Products | | United Foam Corporation |
| | Crest Foam, Inc. | | Upjohn Company, CPR Division |
| | Northern Petrochemical Co. | | Urethane Systems Corporation |
| | Rogers Foam Corporation | | Utah Foam Products |
| | United Minerals & Chemicals Corp. | | Witco Chemical Company |
| | | | Ashland Chemical Company |

TABLE 1 - Listing of manufacturers contacted (cont'd)

| Generic Type | Company | Generic Type | Company |
|---|---|---|---|
| Polyurethane (continued) | W. R. Grace and Company | Thermoplastic polyester | General Electric Company |
| | Firestone Corporation | | Celanese Plastic Material Co. |
| | Owens-Corning Company | | Owens-Corning Fiberglass Corp. |
| | Tenneco Chemicals | Urea-formaldehyde | Arrowhead Plastics |
| | Mobay Chemical Company | | Ciba-Geigy Corporation |
| | Cargill, Inc. | | Borden, Inc. |
| | Essex Chemical Corporation | | Rapco, Inc. |
| | Callery Chemical Company | Natural Rubber Material (sprayable) | H. L. Blackford |
| | Diamond Shamrock Corporation | | |
| | Tenneco Chemicals | | |
| | Firestone Plastics Company | | |
| | Colorite Plastics Company | | |
| PVC | Diamond Shamrock Company | | |
| | Caledonia Mining Company, Ltd. | | |
| | Southwest Research Institute | | |
| | Fiberglass Canada, Ltd. | | |
| Silicate | Dow-Corning Corporation | | |
| | General Electric Company | | |
| Silicone | Emerson and Cuming, Inc. | | |

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TABLE 2 - Summary of survey contacts

| Generic foam type | Initial selection | Manufacturers contacted | Candidate data received |
|---|---|---|---|
| ABS | 1 | 1 | 1 |
| Acetal | 1 | 1 | 1 |
| Cellulose-acetate | 1 | 3 | 0 |
| Epoxy | 5 | 7 | 3 |
| Ionomer | 1 | 1 | 1 |
| Isocyanurate | 4 | 4 | 3 |
| Melamine-based | 0 | 1 | 0 |
| Phenolic | 2 | 2 | 1 |
| Phenylene oxide-based | 1 | 1 | 1 |
| Polyamide-imide | 2 | 4 | 3 |
| Polybenzimidazole | 1 | 1 | 0 |
| Polycarbonate | 1 | 1 | 1 |
| Polyethylene | 6 | 7 | 1 |
| Polyimide | 2 | 2 | 1 |
| Polypropylene | 2 | 3 | 0 |
| Polystyrene | 2 | 2 | 0 |
| Polyurethane | 29 | 35 | 34 |
| PVC | 2 | 4 | 0 |
| Silicate | 0 | 4 | 0 |
| Silicone | 3 | 3 | 2 |
| Thermoplastic polyester | 2 | 3 | 3 |
| Urea-formaldehyde | 4 | 4 | 1 |
| Total | 72 | 94 | 57 |

12. Resistant to loss of physical and fire resistant properties following exposure to <u>heat</u> or fire

13. Resistant to loss of physical and fire resistant properties following long-term <u>exposure</u> to ground water

14. <u>Easily</u> transported into mine

15. <u>Easily</u> and <u>rapidly</u> applied by relatively unskilled labor

16. Presents no <u>unreasonable</u> fire or toxic <u>hazards</u> as raw material, finished coating or during application

17. Be <u>economical</u>

18. Be <u>easily</u> repaired.

In compiling the data for each foam, data defining such areas as adhesion, combustibility, permeability, density, shelf life, safety hazards and strength were considered necessary for an objective evaluation of candidate materials. Data concerning application requirements and equipment, costs, maintenance and working life were considered beneficial, but of secondary importance in this initial tabulation of potential candidates. The data received for each material were tabulated in the format shown in Figure 1.

No commercial product was likely to have the desired combination of all 18 general characteristics outlined above. The survey, however, collected data within these 18 general areas to permit the subsequent selection during Phase II of foamed materials providing the best combinations of these characteristics.

## Survey Response

Our initial communications with company representatives indicated that more than 100 products could be considered as candidates for constructing and maintaining mine stoppings. After considering the 18 general "ideal" characteristics or goals, many of the potential sealants were rejected. The survey finally compiled data for 62 products, which the manufacturers considered would be capable of partially fulfilling aforementioned goals.

Thirty-five manufacturers did not wish to participate in this survey. Reasons given were:

1. They had no product line that would fulfill the performance goals,

2. They had no desire to modify or develop their products for this use,

DATE: _____

## FIGURE 1 - Rigid foam survey format

COMPANY_____MSA FILE NO._____

ADDRESS_____TELEPHONE_____

1.  Person Completing Questionnaire_____

                                    Title_____

2.  Foam Product (Name)_____

3.  General Characteristics of Foam:

    a.  Generic type of composition - ABS, Cellulose, Epoxy,

                            Isocyanurate, Phenolic, etc. _____

                                               _____

    b.  Form - rigid, flexible _____

    c.  Shelf life _____

    d.  Density _____

    e.  Closed cell (%) _____

    f.  Adhesion to - wood, rock, coal, metal, etc. _____

    g.  Foam properties:

        Thermal    - 1) Maximum/Minimum Service Temperature _____

                - 2) Flame Spread _____ Test Designation No._____

                - 3) Smoke Developed _____ Test Designation No._____

                - 4) Oxygen Index _____

        Mechanical- 1) Compressive Strength _____

                - 2) Tensile Strength _____

4.  General Foam Preparation Procedures:

    a.  Processing method - (pour, froth, spray)_____

    b.  Mixing conditions:    time_____temperature_____

    c.  Substrate conditions:  wet _____dry_____

    d.  Cure conditions:    time_____temperature_____

    e.  Viscosity of components:    1)_____ 2)_____ 3)_____

    f.  Flash point of components:  1)_____ 2)_____ 3)_____

    g.  Shelf life of components:    1)_____ 2)_____ 3)_____

    h.  Type and costs for application equipment_____

5.  Environmental Factors and Considerations:

    a.  Water absorption

    b.  Water vapor transmission (permeability)

    c.  Effect of water on: fire resistance_____ permeability_____

    d.  Effect of aging on: fire resistance_____ permeability_____

3. They had negative attitudes or opinions concerning the intended use of their product(s),.

4. They lacked interest, or

5. They expressed concern or fear based upon previous exposure to the misunderstandings and harrassment that occurred after the Sunshine mine disaster.

Fortunately, most of the manufacturers responded quickly and thoroughly to the inquiry. Their gracious and prompt response made the survey significantly more meaningful.

DISCUSSION OF SURVEY DATA

Data were compiled on 62 candidate foams. The list of candidates, by manufacturer and product designation, is shown in Table 3. The complete data compilation is included in the Appendix as Table A-2.

The candidate list includes 10 foams for which the manufacturer declined to respond to our survey. The data for these foams were obtained from the reference Desk-Top Data Bank For Foams[1], an essentially complete reference work containing data on about 900 foams. Besides providing a check on the thoroughness of our survey, the reference work allowed us to check the data received from manufacturers of many of our selected foams.

Attempts were made to obtain information on all of the 22 generic types of foam shown in Table 2. However, the final compilation lists only 15 generic types, including nitrile/vinyl blend, which was not included in the original listing. Of the 62 foams identified as being potential candidates, 35 were polyurethane, while 27 were from the remaining 14 generic categories. The heavy emphasis on polyurethane reflects the similarity of the properties of this foam type to the properties of the "ideal" sealant, and also the popularity of this foam type for general commercial use. Manufacturers of the following generic types deemed them unsuitable for use in stoppings:

    a. cellulose acetate
    b. polyimide
    c. polypropylene
    d. polystyrene
    e. PVC (polyvinyl chloride

while no usable information could be obtained on the following:

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[1]Desk-Top Data Bank For Foam, The international Plastics Selector, Cordura Publications, Inc., ISBN 0-8470-6028-4 (1978).

## Table 3 - Listing of potential candidates

| Generic Type | Manufacturer | Product Identity |
|---|---|---|
| ABS | Borg-Warner Corporation | Cyclolax FBK |
| Acetal | Celanese Plastic | Celcon M90 |
| Amide-imide | Allied Chemical | Capron XPN 1173 |
| | Celanese Plastics Co. | Nylon 1503 |
| Epoxy | Ren Plastics | RP 1774 |
| Ionomer | Gilman Brothers | Suryln Softlite |
| Nitrile/vinyl | Armstrong Cork | Armaflex 11 |
| Phenol/formal- | Reichhold Ltd. | Phenolite 1B322/1D644 |
| dehyde | Schenectady Chemicals | HRJ-913 |
| Phenylene Oxide | General Electric | Noryl FN215 |
| Polycarbonate | General Electric | Lexan 1800 |
| Polyethylene | Dow Chemical Company | Ethafoam 222 |
| Urea/formaldehyde | Ciba-Geigy | Aerolite SPE |
| | Raperswill | Rapco-Foam |
| Silicones | Dow-Corning | 3-654BRTV |
| | Emerson & Cuming | Eccofoam SIL |
| | General Electric | RTV 6428 |
| | General Electric | RTV 7403 |
| | General Electric | RTV 850 |
| Thermoplastic | Celanese Plastics Co. | Celanex 3210 |
| Polyesthers | Celanese Plastics Co. | Celanex 3310 |
| | General Electric | Valox FV-600 |
| Isocyanurates | Chemetric Systems | CS1 9575 |
| | Foam Systems | FSC 55 |
| | Insta-Foam Products | ICU Kit |
| | Texas Urethanes | Texthane 333 |
| | Upjohn Co. | Isonate CPR 425 |
| Urethanes | Ashland Chemical | Phenolic Urethane |
| | Atlas Minerals & Chemicals | Urefoam R-02 |
| | Atlas Minerals & Chemicals | Urefoam R-07 |
| | BASF Wyandotte | Pluragard S-602 |
| | CCC/MSA | Rigimix E/F |
| | CCC/MSA | X-156 |
| | Chemetics Systems | CS1 8420 |
| | Chemetics Systems | CS1 9120 |
| | Chemetics Systems | CS1 9152 |
| | Cook Paint and Varnish Co. | Coro-Foam G 325 |
| | Cook Paint and Varnish Co. | Coro-Foam 440 |
| | Emerson & Cuming | Eccooam FPH-FR |
| | Foam Systems Co. | FS 24 |
| | Foam Systems Co. | FS 25 |
| | Foam Systems Co. | FS 234 |
| | Fomo Products, Inc. | Fomospray |

Table 3 - Listing of potential candidates (cont'd)

| Generic Type | Manufacturer | Product Identity |
|---|---|---|
| Urethanes (continued) | Freeman Chemical | Chempol 30-212/30-2038 |
| | Hoover Universal | RU 6100 |
| | Insta-Foam Products, Inc. | FS-75 Kit |
| | Isochem Resins Co. | 9 R 2 |
| | Olin Corp. | Autofroth 7415-02 |
| | Olin Corp. | Polysystem 7622-02 |
| | Olin Corp. | Polysystem 7613-02 |
| | Polymir | FMS-20 |
| | Texas Urethanes | Texthane 220-20 |
| | United Foam | UFC-115 |
| | United Foam | UFC-250 |
| | Upjohn Co. | Isonate CPR 468 |
| | Urethane Systems | USC 230 |
| | Utah Foam Products Co. | FMS 20 |
| | Witco Chemical | SS-0640 |
| | Witco Chemical | SS-0501 |
| | Witco Chemical | SS-0119A/SS-0120B |
| | W. R. Grace | Hypol |

f. melamine based
g. polybenzimidazole
h. silicate

The companies that were involved with silicate foams 10 years ago have all dropped their programs, probably because of lack of acceptance by the market.

Some of the other generic candidates deserve general comments:

- Urea/formaldehyde forms have been marketed widely during the past few years. In the last few months, several manufacturers have taken them off the market; this includes the Ciba-Geigy foam shown in Table 3 (removed 1 April 1980). Thus, this type of foam will not be available in the near future. The reason for the removal of these urea/formaldehyde forms is the reputed release of formaldehyde vapors when the foam is not handled or made properly.

- Phenol/formaldehyde foams have been around for over 10 years, but they have never become very popular. The foaming reaction is catalyzed by strong acids. This causes corrosion problems which are unacceptable in many applications. Nevertheless, there is now a moderate resurgence of interest in these foams.

- Epoxy foams that could be sprayed were marketed by shell 10-15 years ago, but they were dropped. Epoxy foams offered advantages over urethane foams but had several disadvantages, including higher cost.

## CANDIDATE FOAM SELECTION

The information obtained during the foam survey was studied to select approximately 30 foams for testing. The foams were divided into two groups, "potential candidates" and "rejected", based on their apparent suitability for use in constructing and repairing mine stoppings.

### Potential Candidates

The "potential candidate" group, shown in Table 4, totalled 36 foams and consisted of the 27 candidates listed as "yes", and the 9 listed as "maybe" for the assessment "suitability for mine use" in Table A-2 of the Appendix. Foams were listed as "maybe" when the mode of application, strength of the foam, and/or open-celled structure of the foam might create special problems. Most of the "maybe" assessments were for non-urethane foam types. The one "maybe" assessment for the urethane category was for Hypol, a solids-loaded, semi-rigid foam from W.R. Grace, developed as a fire-resistance mattress material for institutions.

The foams listed as potential candidates all met both the combustibility and mode of application criteria. The flame spread ratings were <30 and they could be applied by one of the four common techniques: (1) spraying, (2) frothing, (3) pouring, or (4) with adhesives. Although all techniques are possible for general construction, there are definite preferences for in-mine application. In order of preference:

Spraying is probably the easiest and most satisfactory method of applying foam in mines. Several manufacturers offer equipment for spraying foam iin the $8,000 to $10,000 range. such equipment does require systematic maintenance by trained personnel for satisfactory results. For maximum safety the operators should be properly trained.

Frothing is a close second choice to spraying. Some frothing systems, such as Items 102 and 126 in Table 6, are completely self-contained systems and can be used by people with a minimum of training. Other froth systems require equipment and training similar to that used in spraying.

Pouring is a common way of dispensing foams, but the viscosity of the materials and the rapidity of foaming is not always compatible with mine use. Each system had to be evaluated on its own merits while preparing the samples for testing. The equipment used for pouring may be similar to that used for spraying or it may be more sophisticated and require skilled workers.

# TABLE 4

## Potential foam candidates

| No | Generic type | Foam supplier | Product Identity | Mode of application | Combustibility Smoke | Rating | Method | Maximum Service temp °F | Density pcf | % Closed cell |
|---|---|---|---|---|---|---|---|---|---|---|
| 101 | Isocyanurate | Chemetics Systems | CSI 9575 | Spray | 150 | 25 | E84 | ND | 2.5 | 94 |
| 102 | " | Insta-Foam Products | ICU Kit | Froth | 400 | 25 | E84 | 300 | 2.5 | >90 |
| 103 | " | Texas Urethanes | Texthane 333 | Froth | ND | 25 | E84 | ND | 2.1 | 94 |
| 104 | " | Upjohn Company | Isonate CPR 425 | Spray | 400 | 25 | E84 | ND | 2 | 90 |
| 105 | Nitrile/vinyl | Armstrong Cork | Armaflex II | Glue | 100/150 | 25 | E84 | 220 | 6 | High |
| 106 | Phenol/formaldehyde | Reichhold Ltd. | Phenolite 1B322/10644 | Spray | 0 | 5 | E84 | 400 | 3 | 50 |
| 107 | Silicone | Dow Corning | 3-6548 RTV | Pour | ND | 20 | E84 | High | 17 | >50 |
| 108 | " | General Electric | RTV 6428 | Pour | 54 | 13 | E84 | High | 85 | ND |
| 109 | " | General Electric | RTV 7403 | Pour | ND | 25 | E84 | High | 80 | ND |
| 110 | " | General Electric | RTV 850 | Pour | 204 | 21 | E84 | High | 20-25 | 95 |
| 111 | Urea/formaldehyde | Ciba-Geigy | Aerolite SPE | Pour/Spray | 125/200 | 20 | E84 | 200 | 1 | 1 |
| 112 | " | Raperswill | Rapco Foam | Pour/Spray | 0/5 | 25 | E84 | ND | 0.7 | ND |
| 113 | Urethane | Ashland Chemical | Phenolic Urethane | Pour | 140 | 20 | E84 | 225 | 2 | 90 |
| 114 | " | BASF Wyandotte | Pluragard S-602 | Spray | 350 | 25 | E84 | 250 | 2 | ND |
| 115 | " | CCC/MSA | Rigimix E/F | Spray | 350 | 25 | E84 | 250 | 2 | >90 |
| 116 | " | CCC/MSA | X-156 | Spray | 150 | 20 | E84 | 250 | 2 | >90 |
| 117 | " | Chemetics Systems | CSI 8420 | Froth | 190 | 20 | E84 | ND | 2 | 94 |
| 118 | " | Chemetics Systems | CSI 9120 | Spray | 110 | 20 | E84 | ND | 2 | 96 |
| 119 | " | Chemetics Systems | CSI 9152 | Spray | 305 | 20 | E84 | ND | 2 | 95 |
| 120 | " | Cook Paint & Varnish | Coro-Foam G325 | Spray | 185 | 30 | E84 | ND | 2 | >90 |
| 121 | " | Cook Paint & Varnish | Coro-Foam 440 | Froth | 75 | 25 | E84 | ND | 2 | >90 |
| 122 | " | Foam Systems Company | FS 24 | Spray | 115/450 | 25 | E84 | ND | 2 | 90 |
| 123 | " | Foam Systems Company | FS 25 | Spray | 130/500 | 25-30 | E84 | ND | 2 | 90 |
| 124 | " | Foam Systems Company | FS 234 | Spray | 200/500 | 25 | E84 | ND | 2.2 | 90 |
| 125 | " | Freeman Chemical | Chempol 30-212/30-2038 | Spray | 250/350 | 25 | E84 | ND | 2 | 94 |
| 126 | " | Olin Corporation | Autofroth 7415-02 | Froth | 250 | 20 | E84 | ND | 2.1 | ND |
| 127 | " | Olin Corporation | Polysystem 7622-02 | Spray | 200 | 25 | E84 | ND | 2.2 | ND |
| 128 | " | Polymir | FMS-20 | Spray | 150 | 20 | E84 | ND | 2.1 | 95 |
| 129 | " | Texas Urethanes | Texthane 220-20 | Spray | 175 | 25 | E84 | ND | 2 | 95 |
| 130 | " | United Foam | UFS-250 | Spray | ND | 25 | E84 | ND | 2 | ND |
| 131 | " | Upjohn Company | Isonate CPR 468 | Spray | 350 | 25 | E84 | ND | 2 | 92 |
| 132 | " | Urethane Systems | USC 230 | Spray | 500 | 25 | E84 | ND | 2 | 95 |
| 133 | " | Utah Foam Products Co. | FMS 20 | Spray | 300 | 25 | E84 | ND | 2 | 94 |
| 134 | " | Witco Chemical | SS-0640 | Spray | 450 | 25 | E84 | ND | 2 | >90 |
| 135 | " | Witco Chemical | SS-0501 | Spray | <450 | 25 | E84 | ND | 2 | >90 |
| 136 | " | W. R. Grace | Hypol | Pour/Spray | ND | <25 | E84 | ND | 10-15 | Low |

Note: ND = No data

Adhesives can also be used to affix foam to the substrate, but then the adhesive must also be evaluated. Using adhesives can be slow or fairly fast, but the foam must be carried into the mine and carefully attached. This is probably the least satisfactory mode of application.

## Rejected Candidates

Those foams rejected for use in stoppings are shown in Table 5, along with the key reasons for rejection.

The primary causes for rejection were based on the mode of application and the combustibility of the foams. The key criteria used for rejection were:

a. Flame spread higher than 30 as measured by ASTM E84.

b. Flame spread higher than 25 as measured by ASTM E162.

c. Combustibility greater than VO by UL 94.

d. Self-extinguishing by ASTM D1692.

e. Pass by MV 302.

f. No data (ND) on combustibility.

g. Prepared by molding or extrusion.

Secondary consideration was also given to the maximum service temperature, foam density and the closed cell content. These criteria were as follows:

h. Maximum service temperature below 200°F.

i. Densities greater than 30 lbs/ft$^3$.

j. Closed cell content of less than 80%.

Failure to meet the secondary criteria were not sufficient cause for rejection, but served as a warning sign for careful scrutiny.

A total of 26 candidates were rejected and were excluded from further consideration in the selection process. Fourteen failed because of their mode of application -- they must be molded or extruded; 20 failed because of combustibility; and 9 failed for both reasons. Table 6 summarizes the reasons for rejection for candidates listed in Table 5. Item 215 (isocyanurate) was an exception to the above categories. It failed because the substrate must be heated to at least 100°F prior to

TABLE 5

Foams rejected

| No | Generic type | Foam supplier | Product identity | Mode of appl | Combustibility rating method | | Maximum Service temp °F | Density pcf | % Closed cell |
|---|---|---|---|---|---|---|---|---|---|
| 201 | ABS | Borg-Warner Corporation | Cycolac FBK | Mold | VO/5V | UL94 | 170 | 45 | ND |
| 202 | Acetal | Celanese Plastics Company | Celesn M90 | Mold | Burning | UL94 | 307 | 62 | ND |
| 203 | Amide/imide | Allied Chemical | Capron XPN 1173 | Mold | ND | | 300 | 55 | ND |
| 204 | " | Celanese Plastics Company | Nylon 1503 | Mold | Burning | UL94 | 490 | 60 | 100 |
| 205 | Epoxy | Ren Plastics | RP 1774 | Pour | ND | | 128 | 15 | ND |
| 206 | Ionomer | Gilman Bros. | Surlyn Softlite | Mold | Pass | MV302 | 160 | 3 | ND |
| 207 | Phenolic | Schnectady Chemical | HRJ-913 | Pour | ND | | ND | 3 | ND |
| 208 | Phenylene oxide | General Electric | Noryl FN 215 | Mold | 110 | E162 | 180 | 50 | ND |
| 209 | Polycarbonate | General Electric | Lexan 1800 | Mold | 18 | E162 | 270 | 60 | ND |
| 210 | Polyethylene | Dow Chemical | Ethafoam 222 | Mold | Burning | | 180 | 3 | 100 |
| 211 | Silicone | Emerson & Cuming | Eccofoam SIL | Pour | ND | | 400 | 20 | Closed |
| 212 | Thermoplastic | Celanese Plastics Company | Celanex 3210 | Mold | VO | UL94 | 417 | 68 | ND |
| 213 | polyester | Celanese Plastics Company | Celanex 3310 | Mold | VO | UL94 | 424 | 72 | ND |
| 214 | " | General Electric | Valox FV-600 | Mold | VO | UL94 | 340 | 70 | ND |
| 215 | Isocyanurate | Foam Systems | FSC 55 | Spray | 25 | E84 | ND | 2 | 93 |
| 216 | Urethane | Atlas Minerals & Chem. | Urefoam R-02 | Pour | ND | | 170 | 2 | ND |
| 217 | " | Atlas Minerals & Chem. | Urefoam R-07 | Pour | ND | | 170 | 7 | ND |
| 218 | " | Emerson & Cuming | Eccofoam FPH-FR | Spray | SE | D1692 | 275 | 3 | ND |
| 219 | " | Fomo Products, Inc. | Fomospray | Froth | SE | D1692 | ND | 1.5 | 70 |
| 220 | " | Hoover Universal | RU 6100 | Spray | <75 | E84 | ND | 2 | 90 |
| 221 | " | Insta-Foam Products, Inc. | FS-75 Kit | Froth | 65 | E84 | 250 | 2 | 90 |
| 222 | " | Isochem Resins Company | 9R2 | Pour | SE | D1692 | 165 | 2 | ND |
| 223 | " | Olin Corporation | Polysystem 7613-02 | Spray | 64 | E84 | ND | 2 | ND |
| 224 | " | United Foam | UFC-115 | Spray | <75 | E84 | ND | 2 | 95 |
| 225 | " | Witco Chemical Company | SS-0119A/SS-0120B | Spray | <75 | E84 | ND | 2 | >90 |
| 226 | " | Witco Chemical Company | SS-0715 | Spray | <75 | E84 | ND | 2 | >90 |

Note: ND = No data

## TABLE 6
## Causes for rejection of materials
## listed in Table 5

| Item no | Mode of application | Combustibility | Service temp, max | Density pcf | Closed cell |
|---------|---------------------|----------------|-------------------|-------------|-------------|
| 201 | Fail | Pass | Fail | Fail | ND |
| 202 | Fail | Fail | Pass | Fail | ND |
| 203 | Fail | Fail | Pass | Fail | ND |
| 204 | Fail | Fail | Pass | Fail | Pass |
| 205 | Fail | Fail | Fail | Pass | ND |
| 206 | Fail | Fail | Fail | Pass | ND |
| 207 | Pass | Fail | Fail | Pass | ND |
| 208 | Fail | Fail | Fail | Fail | ND |
| 209 | Fail | Pass | Pass | Fail | ND |
| 210 | Fail | Fail | Fail | Pass | Pass |
| 211 | Pass | Fail | Pass | Pass | Pass |
| 212 | Fail | Pass | Pass | Fail | ND |
| 213 | Fail | Pass | Pass | Fail | ND |
| 214 | Fail | Pass | Pass | Fail | ND |
| 215* | Pass | Pass | ND | Pass | Pass |
| 216 | Fail | Fail | Fail | Pass | ND |
| 217 | Fail | Fail | Fail | Pass | ND |
| 218 | Pass | Fail | Pass | Pass | ND |
| 219 | Pass | Fail | ND | Pass | Fail |
| 220 | Pass | Fail | ND | Pass | Pass |
| 221 | Pass | Fail | Pass | Pass | Pass |
| 222 | Pass | Fail | Fail | Pass | ND |
| 223 | Pass | Fail | ND | Pass | ND |
| 224 | Pass | Fail | ND | Pass | Pass |
| 225 | Pass | Fail | ND | Pass | Pass |
| 226 | Pass | Fail | ND | Pass | Pass |

*Substrate must be heated to at least 100`F prior to application.

Note:  ND = No data

application of the foam. Such a procedure would obviously be impractical in most mines. Isocyanurate would have been a potential candidate in all other respects.

## Candidates Selected for Testing

Selecting the best 30 foams for testing from the 36 candidates in Table 4 proved to be difficult. The data of Table A-2 were evaluated in cooperation with the TPO, and subsequent discussions held with suppliers, resulting in the elimination of several: The nitrile/vinyl candidate (Item 105) comes in sheets and must be glued in place; a urea/formaldehyde (Item 111) was dropped because of a decision by Ciba-Geigy to discontinue its sale in the U.S. because of the formaldehyde vapor con troversy. Since this was likely to be a pattern and the second urea/formaldehyde candidate (Item 112) was also very low density (0.7 pcf),it was also dropped. The two high-density silicone candidates (Items 108 and 109) were dropped in favor of the two lower density foams. Their evaluation properties, in other respects, were similar.

A list of 31 foams remained for laboratory testing. When samples of these foam systems were ordered, however, some had been discontinued. Others had either been assigned new stock numbers or replaced with a similar formulation: Two isocyanurates (Items 101 and 104) and two urethanes (Items 112 and 113) had been discontinued. Item 103 was now called Texthane 301-20; Item 121 was replaced by Coro-Foam C444, and Item 135 was replaced by SS-0768.

Another urethane, Olin's Autofroth 741E-02 (Item 126), was available but could only be obtained by purchasing large quantities of the foam and the mixing equipment at a high cost. The supplier claimed that it was essentially the same material as their Polysystem 7622-02 (Item 127) except for the method of application (froth vs spray). Item 126, therefore, was also rejected.

Later, Foam Systems Company informed us that their FS 55 was an excellent isocyanurate foam that had been used successfully in a number of high temperature applications. Since only two other isocyanurate foams were on the list, FS 55 was also added.

The final list of 27 foam candidates for testing is shown in Table 7. The item number for the candidates shown in the table will be used throughout the remainder of this report for identification, and is cross-referenced to Table 4 by the number in parenthesis and Product Identity.

## CANDIDATE SAMPLE PREPARATION

Twenty-four foam formulations were obtained from the manufacturers or their distributors. A Binks Variable-C pumping unit, coupled to a Binks 18FM gun, was used to prepare 22 foam samples for testing. One of the remaining, the Dow-Corning silicone foam (Item 3, Table 7), was

## TABLE 7

### Identification of foams selected for testing

| Item no | Foam sample 1676- | Generic* type | Product identity | Supplier of foam system |
|---|---|---|---|---|
| 1 (102) | 48-2 | ICU | ICU Kit | Insta-Foam Products |
| 2 (103) | 48-13 | ICU | Texthane 301-20 | Texas Urethanes |
| 3 (107) | 50-1 | Silicone | 3-6548 RTV | Dow-Corning |
| 4 (115) | 48-11 | RUF | RIGIMIX E/F | Callery Chemical/Mine Safety Appl. |
| 5 (116) | 48-12 | RUF | X-156 | Callery Chemical/Mine Safety Appl. |
| 6 (117) | 46-4 | RUF | CSI 8420 | Chemetics Systems |
| 7 (118) | 46-3 | RUF | CSI 9120 | Chemetics Systems |
| 8 (119) | 46-1 | RUF | CSI 9152 | Chemetics Systems |
| 9 (120) | 48-9 | RUF | Coro-Foam G325 | Cook Paint & Varnish |
| 10 (121) | 48-10 | RUF | Coro-Foam C444 | Cook Paint & Varnish |
| 11 (122) | 46-10 | RUF | FS 24 | Foam Systems Co. |
| 12 (123) | 46-11 | RUF | FS 25 | Foam Systems Co. |
| 13 (124) | 46-12 | RUF | FS 234 | Foam Systems Co. |
| 14 (125) | 48-7 | RUF | Chempol 30-2038/30-2124 | Freeman Chemical |
| 15 (127) | 48-6 | RUF | Polysystem 7622 | Olin Corporation |
| 16 (128) | 46-6 | RUF | FMS 20 | Polymir |
| 17 (129) | 48-1 | RIIF | Texthane 220-20 | Texas Urethanes |
| 18 (130) | 48-8 | RUF | UFS 250 | United Foam |
| 19 (131) | 46-5 | RUF | Isonate CPR 468 | Upjohn Company |
| 20 (132) | 46-9 | RUF | USC 230 | Urethane Systems Corp. |
| 21 (133) | 46-13 | RIIF | FMS 20 | Utah Foam Products |
| 22 (134) | 46-8 | RUF | SS-0640 | Witco Chemical |
| 23 (135) | 46-7 | RUF | SS-0768 | Witco Chemical |
| 24 (110) | 50-2** | Silicone | RTV-850 | General Electric |
| 25 (136) | 50-3** | FUF | Hypol RHP 2000 HD | W. R. Grace |
| 26 (106) | 50-5** | Phenolic | 1B-322/1D-644 | Reichhold Chemical, Ltd. |
| 27 (-) | 50-4 | ICU | FS 55 | Foam Systems Company |

Note:  *ICU = Isocyanurate Foam
RUF = Rigid Urethane Foam
FUF = Filled Urethane Foam

**Foam samples prepared by supplier

(xxx) Corresponding Item No. on Table 3

hand mixed and poured, because of its very high viscosity. The other, Insta-Foam ICU Kit (Item 1, Table 7), came complete with its own mixing nozzles, and was used as received. All foam samples were prepared at the recommended ratios.

The three remaining foams of the 27 selected was prepared by the manufacturer. The General Electric Silicone (Item 24, Table 7) was prepared at a General Electric plant using an experimental pumping unit and a static mixer. The foam was poured rather than sprayed because of its high viscosity. General Electric claimed, however, that this formulation has been sprayed using a Binks C pumping unit and a Binks 18 FM gun with no problems.

W.R. Grace's Hypol-based foam (Item 25, Table 7) was prepared at their Research Center using prototype spray equipment. Although the materials were readily sprayed, the slow reactivity of the system made it difficult to prepare foam on a vertical surface.

The phenolic foam (Item 26, Table 7) was supplied as board stock by Reichhold Chemicals, Ltd. It was prepared, not in our presence, using commercial type equipment. Although this foam was designed for pouring on a production line, Reichhold claimed that it could be modified for spraying with conventional urethane spray equipment.

The fact that both the silicone and phenolic foams had to be poured rather than sprayed made them somewhat unsuitable for underground use. Nevertheless, these foams were evaluated because of their unique composition and reputed high resistance to fire.

No difficulties were encountered in preparing the foam samples. Four of the foam systems (Items 6, 8, 16 and 19, Table 7) were slower in reacting than desirable, but this could result from either the design of the formulation or from a short shelf life.

FOAM TESTING

Flame Spread Evaluation

The ability to seal both the face and perimeter of a stopping is an important characteristic of a rigid foam for this proposed use. Equally important, however, is the property to resist flame propagation. The flame spread index ($I_s$) of a foam, as determined by the ASTM E162 test, is an accepted measure of this property.

The candidate foams were subjected to two laboratory-scale flame spread tests: the ASTM E162 test; and a Callery Chemical Company's modification of E162 (designated E162-CCC-2). The results of these tests were used to select 16 of the most promising for further testing.

ASTM E162 Tests - All 27 candidate foam samples were subjected to the ASTM E162 Radiant Panel Test. In the test, one inch thick 6 in. x 18 in. samples of the foam are clamped into the sample holder (Figures 2 and 3) and exposed to a gas-fired radiant panel of a specific heat flux. A pilot flame ignites the upper edge and the flame front progress down the sample is monitored as a function of time. The total test time is 4 minutes.

The sample off-gas captured in the exhaust stack is also monitored for temperature and smoke content (by light obscuration). The peak temperature is compared to a baseline temperature to obtain a temperature rise ($\Delta T$) for the sample, and is combined with the burning rate data to calculate the flame spread index ($I_s$). Both a peak and an integrated (total) smoke content are recorded for comparison.

The flame spread index ($I_s$) is the product of the heat evolution factor (Q) and the flame spread factor (F).

$$I_s = FQ$$

The heat evolution (Q) is the increase in stack temperature multiplied by 0.1 and divided by a constant $\beta$, which is the thermocouple response to a known but varied range of heat inputs in btu's. Hence,

$$Q = \frac{0.1 \Delta T}{\beta}$$

The flame spread (F) is a function of the speed with which the flame front advances between three-inch-spaced bench marks. Mathematically, the flame spread factor may be expressed as:

$$F = 1 + \frac{1}{t_6 - t_3} + \frac{1}{t_9 - t_6} + \frac{1}{t_{12} - t_9} + \frac{1}{t_{15} - t_{12}}$$

where t.....equals the time in minutes that the flame reaches the 3, 6, 9, 12 and 15 inch marks.

The percent obscuration caused by generated smoke was measured by a photoelectric device as it passed through the vent stack of the hood. The peak recorded smoke datum was 3 times the percent obscuration. The smoke area datum was the area under the smoke curve (3 x percent obscuration x minutes).

Most of the rigid foam samples for testing were prepared by spraying the materials on large cardboard sheets and sawing to size. The flexible or semi-rigid foams (Items 3, 24 and 25, Table 7) were prepared on cement asbestos board so that they would not fall out of the holders during the radiant panel tests. Four samples of each foam were tested except for Reichhold Chemicals phenolic foam (Item 26). Only two samples of this foam were used due to a short supply.
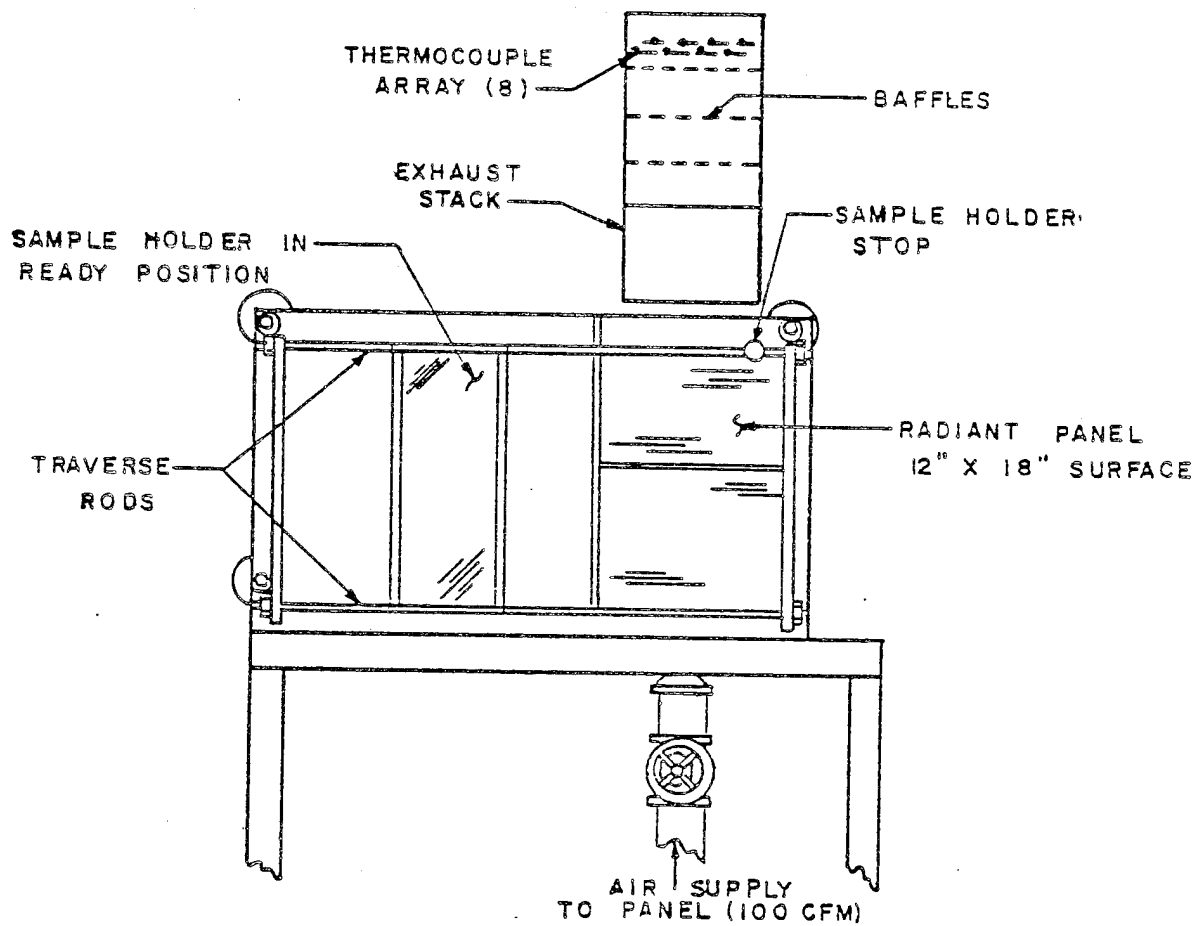
FIGURE 2 - E162 Radiant panel test facility (front view)
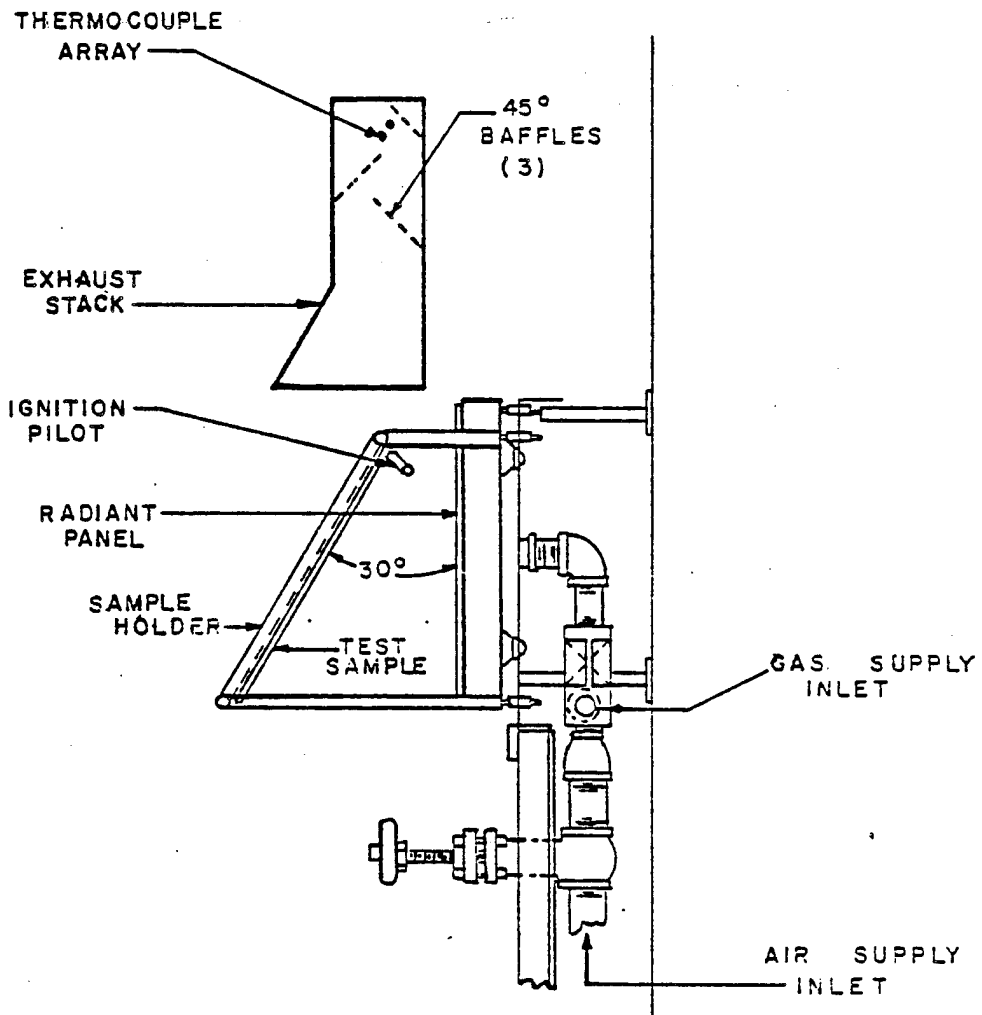
FIGURE 3 - E162 Radiant panel test facility (side view)

The data obtained in the E162 tests are shown in Table 8 along with the averge and standard deviation.

E162-CCC-2 Tests - The E162-CCC-2 test is a more severe variation of the ASTM E162 test. The changes, and comparison with the conventional test facility, are illustrated in Figures 2, 3 and 4.

The front view (Figure 2) of both the ASTM E162 and E162-CCC-2 test facility is identical. Figure 3 shows a side view of the standard E162 test facility, while Figure 4 is a similar view of the modified version. The basic changes made were:

1. The angle of the test sample in relation to the radiant panel was reversed, with the bottom of the test sample placed at the same distance from the radiant panel as the top was in the ASTM E162. The angle at the bottom of the sample away from the panel is set at 25°.

2. The ignition pilot was moved from the top to the bottom of the sample.

3. The exhaust stack was moved back from the panel and essentially centered over the sample to collect the heat and smoke.

The data collected and calculations are the same as in the ASTM E162 test.

Four samples of each of the 27 foams were subjected to the E162-CCC-2 modified radiant panel test (only two samples of Item 26 (1676-50-5) were used due to a limited supply of the foam). The data are shown in Table 9 along with the averages and standard deviation.

Flame Spread Index ($I_s$) - The flame spread index is a function of the rate and distance of flame propagation and heat of reaction. The data for both radiant panel tests are summarized in Table 10. These data may be conveniently grouped into five ranges. These groups and ranges are shown in Table 11, with Group A being best and Group E the poorest. Items 4, 5, 9, 11, 14, 15, 17, 22, 23, 24, 25, 26 and 27 appear in Groups A, B and C by both tests. Items 2, 3, 7, 13, 18, 19 and 21 fit into these three groups by one of the test methods. Those foams falling into Groups D and E by both tests include Items 1, 6, 8, 10, 12, 16 and 20.

The silicone and Hypol-based foams (Items 3, 24 and 25) deserve special comment. All three of these foams are properly classed as "flexible" or "semi-rigid" rather than rigid foams. When flexible or semi-rigid foams are exposed to the heat of the radiant panel test, they tend to distort and in so doing move closer to the heat source and increase the radiant heat to which they are subjected. Wire mesh is often used to prevent this distortion, but that effectively alters the foam exposure and introduces unknown errors. This happened with Item 3.

## TABLE 8

## ASTM E162 Radiant panel data on virgin foams

| Sample 1676- | Q | F | Is | In burned | Smoke* Peak | Area |
|---|---|---|---|---|---|---|
| 46-1 Item 8 | 13.0 | 64.3 | 834 | 17 | 58.5 | 6765 |
|  | 12.5 | 58.3 | 727 | 17 | 46.5 | 6356 |
|  | 8.1 | 64.7 | 522 | 17 | 39.5 | 4440 |
|  | 8.9 | 58.7 | 523 | 17 | 42.0 | 8860+ |
| Avg | 10.6 | 61.5 | 651 | 17 | 46.6 | 6605 |
| Std dev | 2.5 | 3.5 | 155 | 0 | 8.4 | 1813 |
| 46-3 Item 7 | 8.4 | (106) | (889) | 9 | 25.0 | 3040 |
|  | 7.7 | 31.3 | 241 | 9 | 25.5 | 3200 |
|  | 8.6 | 21.6 | 185 | 9 | 21.5 | 2660 |
|  | 7.5 | 6.3 | 47 | 6 | 22.5 | 2640 |
| Avg | 8.0 | 19.7 | 158 | 8.3 | 23.6 | 2885 |
| Std dev | 0.6 | 12.6 | 100 | 1.5 | 1.9 | 279 |
| 46-4 Item 6 | 5.8 | 95.7 | 550 | 18 | 28.5 | 3080 |
|  | 6.2 | 119 | 734 | 18 | 29.0 | 2310 |
|  | 4.9 | 94.9 | 469 | 17 | ND | ND |
|  | 4.6 | 80.9 | 374 | 18 | 20.0 | 2940 |
| Avg | 5.4 | 97.5 | 532 | 17.8 | 25.8 | 2777 |
| Std dev | 0.7 | 15.6 | 153 | 0.5 | 5.1 | 410 |
| 46-5 Item 19 | 5.4 | 6.1 | 33 | 3 | 13.0 | 2040 |
|  | 5.6 | 10.5 | 59 | 3 | 15.0 | 1580 |
|  | 5.4 | 8.0 | 43 | 3 | 14.5 | 1660 |
|  | 5.9 | 4.9 | 29 | 3 | 13.0 | 1985 |
| Avg | 5.6 | 7.4 | 41 | 3 | 13.9 | 1816 |
| Std dev | 0.2 | 2.5 | 13 | 0 | 1.0 | 230 |

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Area |
|---|---|---|---|---|---|---|
| 46-6 Item 16 | 17.5 | 23.3 | 407 | 15 | 41.5 | 8380 |
|  | 13.0 | 31.9 | 413 | 17 | 49.0 | 6950 |
|  | 13.8 | 20.5 | 282 | 13 | 49.5 | 7210 |
|  | 11.0 | 18.7 | 206 | 13 | 36.5 | ND |
| Avg | 13.8 | 23.6 | 327 | 14.5 | 44.1 | 7513 |
| Std dev | 2.7 | 5.9 | 101 | 1.9 | 6.3 | 762 |
| 46-7 Item 23 | 4.5 | 2.9 | 13 | 3 | 9.5 | 1232 |
|  | 4.6 | 3.0 | 14 | 3 | 12.5 | 1570 |
|  | 4.3 | 2.4 | 10 | 3 | 12.5 | 1440 |
|  | 6.2 | 2.5 | 16 | 3 | 13.5 | 1890 |
| Avg | 4.9 | 2.7 | 13 | 3 | 12.0 | 1533 |
| Std dev | 0.9 | 0.3 | 2 | 0 | 1.7 | 276 |
| 46-8 Item 22 | 4.7 | 34.1 | 161 | 10 | 24.5 | 1950 |
|  | 4.3 | 37.0 | 159 | 9 | 26.0 | 2210 |
|  | 5.8 | 35.5 | 207 | 11 | 27.0 | 2500 |
|  | 7.9 | (115) | (905) | 10 | 31.5 | 2210 |
| Avg | 5.7 | 35.5 | 176 | 10.0 | 27.3 | 2218 |
| Std dev | 1.6 | 1.5 | 27 | 0.8 | 3.0 | 225 |
| 46-9 Item 20 | 5.7 | 141 | 801 | 18 | 41.5 | 4880 |
|  | 5.8 | 156 | 897 | 18 | 55.0 | 6560 |
|  | 5.9 | 114 | 673 | 18 | 44.0 | 3850 |
|  | 6.9 | 109 | 755 | 18 | 63.5 | 4740 |
| Avg | 6.1 | 130 | 782 | 18 | 51.0 | 5008 |
| Std dev | 0.6 | 22 | 94 | 0 | 10.2 | 1131 |

TABLE 8 (cont)

ASTM E162 Radiant panel data on virgin foams

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 46-10 Item 11 | 4.1 | 15.0 | 62 | 6 | 16.5 | 2110 |
|  | 3.6 | 17.4 | 63 | 6 | 19.0 | 2385 |
|  | 2.8 | 22.0 | 60 | 6 | 21.5 | 2660 |
|  | 3.4 | 25.0 | 85 | 8 | 18.0 | 2160 |
| Avg | 3.5 | 19.8 | 68 | 6.5 | 18.8 | 2329 |
| Std dev | 0.6 | 4.5 | 12 | 1.0 | 2.1 | 251 |
| 46-11 Item 12 | 7.7 | 14.9 | 114 | 8 | 11.5 | 1930 |
|  | 6.3 | 136 | 862 | 16 | 25.5 | 2250 |
|  | 5.3 | 134 | 707 | 16 | 25.0 | 2910 |
|  | 3.8 | 122 | 469 | 9.5 | 26.5 | 3030 |
| Avg | 5.8 | 102 | 538 | 12.0 | 22.1 | 2530 |
| Std dev | 1.6 | 58 | 326 | 4.0 | 7.1 | 527 |
| 46-12 Item 13 | 3.7 | 113 | 423 | 17 | 34.0 | 3050 |
|  | 4.1 | 56.5 | 229 | 17 | 56.5 | 2910 |
|  | 4.4 | 77.4 | 338 | 15.5 | 37.0 | 3140 |
|  | 4.9 | 76.8 | 373 | 9 | 36.5 | 2170 |
| Avg | 4.3 | 80.9 | 341 | 14.6 | 41.0 | 2818 |
| Std dev | 0.5 | 23.5 | 82 | 3.8 | 10.4 | 442 |
| 46-13 Item 21 | 6.3 | 10.8 | 68 | 5 | 14.0 | 1920 |
|  | 4.8 | 16.4 | 78 | 5 | 14.0 | 1840 |
|  | 5.4 | 14.1 | 76 | 5 | 12.0 | 1750 |
|  | 5.5 | 20.1 | 111 | 7 | 12.5 | 1930 |
| Avg | 5.5 | 15.4 | 83 | 5.5 | 13.1 | 1860 |
| Std dev | 0.6 | 3.9 | 19 | 1.0 | 1.0 | 84 |

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 48-1 Item 17 | 4.7 | 13.0 | 61 | 3 | 15.0 | 1890 |
|  | 5.8 | 13.9 | 81 | 3 | 14.5 | 1510 |
|  | 5.1 | 10.2 | 52 | 4 | 11.5 | 1910 |
|  | 4.9 | (103) | (507) | 6 | 11.0 | (1050+) |
| Avg | 5.1 | 12.4 | 65 | 4.0 | 13.0 | 1770 |
| Std dev | 0.5 | 1.9 | 15 | 1.4 | 2.0 | 225 |
| 48-2 Item 1 | 6.8 | 57.5 | 393 | 15 | 62.5 | 4420 |
|  | 6.2 | 56.0 | 349 | 14 | 58.0 | 3565 |
|  | 4.5 | 61.1 | 278 | 14 | 57.5 | 3770 |
|  | 5.3 | 64.8 | 343 | 17 | 58.5 | 4130 |
| Avg | 5.7 | 59.9 | 341 | 15.0 | 59.1 | 3971 |
| Std dev | 1.0 | 3.9 | 47 | 1.4 | 2.3 | 380 |
| 48-6 Item 15 | 5.4 | 2.3 | 12 | 3 | 15.5 | (1100+) |
|  | 5.8 | 2.1 | 12 | 3 | 18.0 | 1725 |
|  | 5.8 | 2.2 | 12 | 3 | 16.5 | 1870 |
|  | 5.8 | 2.2 | 13 | 3 | 14.5 | 1190 |
| Avg | 5.7 | 2.2 | 12 | 3 | 16.1 | 1595 |
| Std dev | 0.2 | 0.1 | 0 | 0 | 1.5 | 358 |
| 48-7 Item 14 | 4.6 | 2.6 | 12 | 4 | 12.5 | 1515 |
|  | 3.5 | 2.5 | 9 | 4 | 10.5 | 1502 |
|  | 4.2 | 2.1 | 9 | 3 | 11.5 | 1330 |
|  | 4.5 | 2.6 | 12 | 3 | ND | ND |
| Avg | 4.2 | 2.5 | 10 | 3.5 | 11.5 | 1449 |
| Std dev | 0.5 | 0.2 | 2 | 0.6 | 1.0 | 103 |

TABLE 8 (cont)

ASTM E162 Radiant panel data on virgin forma

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 48-8 Item 18 | 6.2 | 8.1 | 50 | 4 | 11.5 | 2067 |
| | 7.2 | 7.3 | 53 | 4 | 10.5 | ND |
| | 8.1 | (113) | (912) | 5 | 10.5 | 1750 |
| | 7.5 | 12.7 | 95 | 5 | 13.5 | 1920 |
| Avg | 7.3 | 9.4 | 66 | 4.5 | 11.5 | 1912 |
| Std dev | 0.8 | 2.9 | 25 | 0.6 | 1.4 | 159 |
| 48-9 Item 9 | 1.8 | 51.0 | 91 | 9 | 21.0 | 1330 |
| | 2.9 | 57.9 | 169 | 10 | 22.0 | 1930 |
| | 1.5 | 54.5 | 80 | 9 | 23.5 | 1570 |
| | 1.5 | 75.5 | 110 | 17 | 22.0 | 2395 |
| Avg | 1.9 | 59.7 | 112 | 11.3 | 22.1 | 1806 |
| Std dev | 0.7 | 10.9 | 40 | 3.9 | 1.0 | 464 |
| 48-10 Item 10 | 14.1 | 47.7 | 673 | 18 | 53.0 | 7840 |
| | 12.6 | 47.0 | 594 | 18 | 55.0 | 8070 |
| | 10.2 | 39.3 | 401 | 18 | 63.0 | 7900 |
| | 13.0 | 38.7 | 502 | 18 | 51.0 | ND |
| Avg | 12.5 | 43.2 | 543 | 18 | 55.5 | 7937 |
| Std dev | 1.6 | 4.9 | 118 | 0 | 5.3 | 119 |
| 48-11 Item 4 | 5.2 | 33.8 | 175 | 11.0 | 21.0 | 2510 |
| | 5.4 | 27.5 | 149 | 11.5 | 27.5 | 3210 |
| | 3.9 | 34.1 | 134 | 12.0 | 24.0 | 2795 |
| | 4.6 | 25.9 | 118 | 11.0 | 26.0 | 2741 |
| Avg | 4.8 | 30.3 | 144 | 11.4 | 24.6 | 2814 |
| Std dev | 0.7 | 4.2 | 24 | 0.5 | 2.8 | 292 |

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 48-12 Item 5 | 1.4 | 1.0 | 1 | 1 | 10.5 | 1100 |
| | 1.9 | 1.0 | 2 | 1 | 12.0 | 1060 |
| | 2.8 | 1.0 | 3 | 1 | 10.0 | 1390 |
| | 2.0 | 1.0 | 2 | 1 | 11.5 | 850 |
| Avg | 2.4 | 1.0 | 2 | 1 | 11.0 | 1100 |
| Std dev | 0.9 | 0 | 1 | 0 | 0.9 | 222 |
| 48-13 Item 2 | 7.3 | 102 | 747 | 7.5 | 27.5 | 2760 |
| | 6.3 | 103 | 648 | 6 | 19.5 | 2100 |
| | 5.0 | 6.1 | 31 | 6 | 16.5 | 1660 |
| | 6.3 | 18.7 | 118 | 9 | 20.5 | 2200 |
| Avg | 6.2 | 57.4 | 386 | 7.1 | 21.0 | 2180 |
| Std dev | 0.9 | 52.4 | 364 | 1.4 | 4.7 | 452 |
| 50-1 Item 3 | 34.3 | 9.6 | 329 | 14 | 23.5 | 12140 |
| | 55.1 | 10.2 | 559 | 14 | 35.5 | 15500 |
| | 28.7 | 10.6 | 305 | 14 | 13.0 | 12680 |
| | 30.0 | 10.4 | 311 | 15 | 12.5 | 10510 |
| Avg | 37.0 | 10.2 | 376 | 14.3 | 21.1 | 12708 |
| Std dev | 12.3 | 0.5 | 122 | 0.5 | 10.8 | 2078 |
| 50-2** Item 24 | 8.9 | 9.1 | 81 | 14 | 9 | ND |
| | 8.4 | 8.1 | 68 | 14 | 7 | 8670 |
| | 8.6 | 9.2 | 79 | 14 | 5 | 5290 |
| | 7.8 | 9.0 | 70 | 14 | 8 | 8320 |
| Avg | 8.4 | 8.9 | 75 | 14 | 7.3 | .7427 |
| Std dev | 0.5 | 0.5 | 6 | 0 | 1.7 | 1859 |

# TABLE 8 (cont)

## ASTM E162 Radiant panel data on virgin foams

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 50 - 3** Item 25 | 5.7 | 2.7 | 15 | 3 | 5 | 2550 |
|  | 5.8 | 2.4 | 14 | 3 | 4 | 2650 |
|  | 4.9 | 2.4 | 12 | 3 | 1 | 3300 |
|  | 10.2 | 2.3 | 23 | 3 | 2 | 4050 |
| Avg | 6.6 | 2.4 | 16 | 3 | 3.0 | 3138 |
| Std dev | 2.4 | 0.2 | 5 | 0 | 1.8 | 693 |
| 50 - 4 Item 27 | 6.0 | 13.6 | 82 | 9 | 24.0 | 3000 |
|  | 7.3 | 15.9 | 116 | 9 | 34.0 | 3260 |
|  | 7.3 | 14.4 | 105 | 9 | 40.0 | ND |
|  | 7.0 | 12.3 | 86 | 10 | 30.0 | 4420 |
| Avg | 6.9 | 14.0 | 97 | 9.3 | 32.0 | 3560 |
| Std dev | 0.6 | 1.5 | 16 | 0.5 | 6.7 | 756 |
| 50 - 5 Item 26 | 3.2 | 1 | 3 | <3 | 0 | 0 |
|  | 1.6 | 1 | 2 | <3 | 0 | 0 |
| Avg | 2.4 | 1 | 3 | <3 | 0 | 0 |
| Std dev | 0.9 | 0 | 1 | 0 | 0 | 0 |

Notes: *Peak smoke = 3 x % Obscuration

*Smoke area = Area under smoke curve
(3 x % Obscuration x Minutes)

**Prepared on cement asbestos board

(-) These numbers were not used in the calculations. They seemed to be incomplete or spurious.

ND = No data

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THERMOCOUPLE
ARRAY

45°
BAFFLES
(3)

EXHAUST
STACK

RADIANT
PANEL

65°
TEST
SAMPLE

SAMPLE
HOLDER

IGNITION
PILOT

GAS SUPPLY
INLET

AIR SUPPLY
INLET
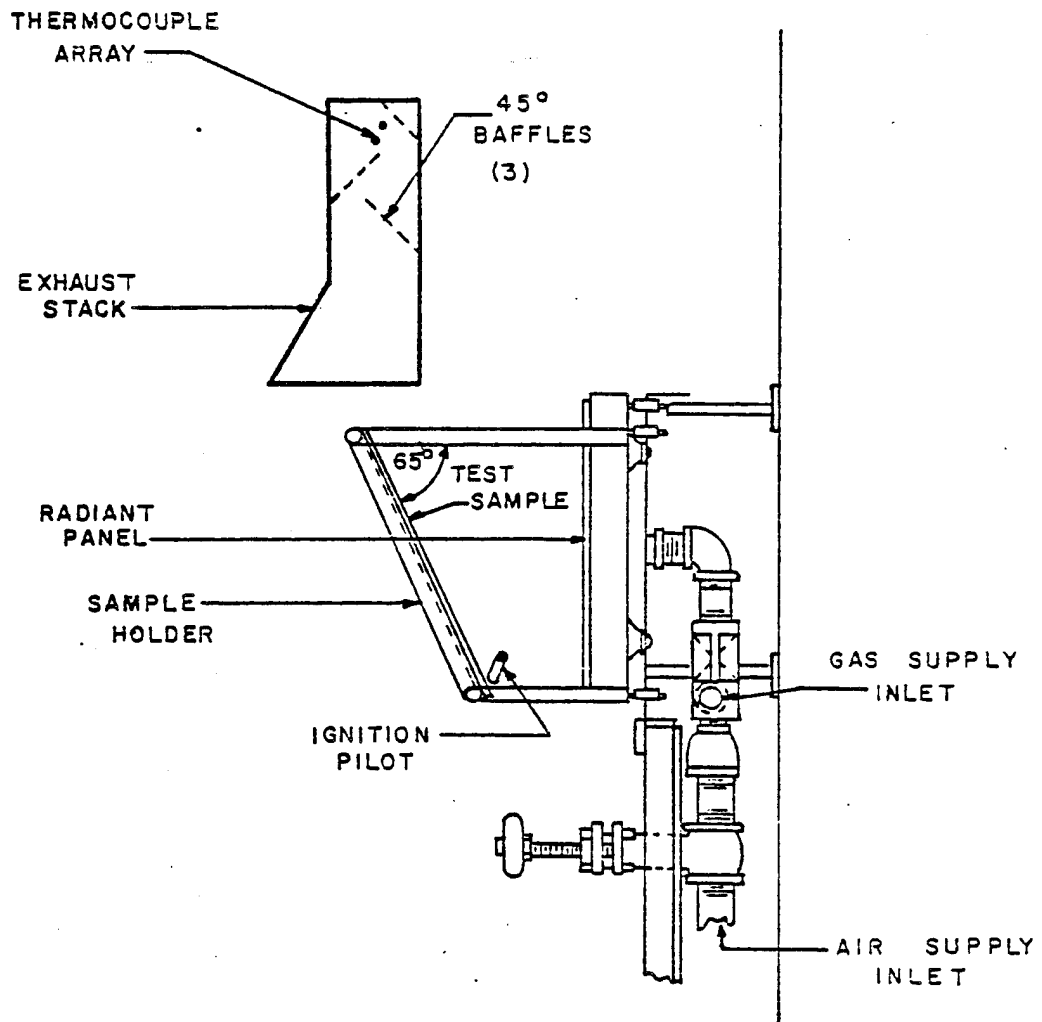
FIGURE 4 - E162-CCC-2 Modified radiant panel test facility (side view)

TABLE 9

E162-CCC-2 Modified radiant panel data on virgin foams

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 46-1 Item 8 | 20.7 | 251 | 5196 | 18 | 89 | 6300 |
|  | 27.4 | 251 | 6877 | 18 | 90 | (13110) |
|  | 15.3 | 251 | 3840 | 18 | 94 | 7600 |
|  | 14.9 | 251 | 3740 | 18 | 93 | 6660 |
| Avg | 19.6 | 251 | 4913 | 18 | 91.5 | 6853 |
| Std dev | 5.8 | 0 | 1468 | 0 | 2.4 | 671 |
| 46-3 Item 7 | 10.2 | 284 | 2905 | 18 | 75 | 7130 |
|  | 7.5 | 284 | 2118 | 18 | 76 | 7740 |
|  | 10.2 | 284 | 2905 | 18 | 67 | ND |
|  | 6.4 | 284 | 1825 | 18 | 73 | 8150 |
| Avg | 8.6 | 284 | 2438 | 18 | 72.8 | 7673 |
| Std dev | 1.9 | 0 | 552 | 0 | 4.0 | 513 |
| 46-4 Item 6 | 13.4 | 251 | 3371 | 18 | 29.5 | 2690 |
|  | 13.9 | 251 | 3481 | 18 | 25 | 4000 |
|  | 14.2 | 209 | 2964 | 18 | 26.5 | 4510 |
|  | 9.9 | 209 | 2076 | 18 | 34.5 | 4400 |
| Avg | 12.9 | 230 | 2973 | 18 | 28.9 | 3900 |
| Std dev | 2.0 | 24 | 638 | 0 | 4.2 | 836 |
| 46-5 Item 19 | 10.1 | 351 | 3545 | 18 | 54 | 4340 |
|  | 9.2 | 351 | 3229 | 18 | 54 | 4620 |
|  | 9.1 | 351 | 3159 | 18 | 53 | 3740 |
|  | 8.0 | 351 | 2808 | 18 | 54 | ND |
| Avg | 9.1 | 351 | 3185 | 18 | 53.8 | 4233 |
| Std dev | 0.9 | 0 | 302 | 0 | 0.5 | 450 |

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 46-6 Item 16 | 21.5 | 134 | 2882 | 18 | 94 | 10900 |
|  | 30.5 | 134 | 4097 | 18 | 100+ | 9560+ |
|  | 24.5 | 134 | 3294 | 18 | 100+ | 1080+ |
|  | 27.3 | 134 | 3666 | 18 | 75 | 9350 |
| Avg | 26.0 | 134 | 3485 | 18 | 92+ | 10223+ |
| Std dev | 3.8 | 0 | 519 | 0 | 12+ | 893+ |
| 46-7 Item 23 | 6.0 | 351 | 2102 | 18 | 46.5 | 3290 |
|  | 5.8 | 351 | 2050 | 18 | 44 | 3260 |
|  | 5.6 | 251 | 1393 | 18 | 39 | 3230 |
|  | 5.8 | 251 | 1448 | 18 | 45.5 | 3230 |
| Avg | 5.8 | 301 | 1748 | 18 | 43.8 | 3253 |
| Std dev | 0.2 | 58 | 380 | 0 | 3.3 | 29 |
| 46-8 Item 22 | 9.5 | 103 | 975 | 18 | 78 | 5990 |
|  | 8.8 | 109 | 951 | 18 | 68 | 5390 |
|  | 10.5 | 94 | 983 | 18 | 77.5 | 5600 |
|  | 10.2 | 99 | 1013 | 18 | 79 | 5420 |
| Avg | 9.7 | 101 | 981 | 18 | 75.6 | 5600 |
| Std dev | 0.8 | 6 | 26 | 0 | 5.1 | 276 |

TABLE 9 (cont)

E162-CCC-2 Modified radiant panel data on virgin foams

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 46-9 Item 20 | 13.4 | 351 | 4703 | 18 | 94 | ND |
|  | 13.0 | 351 | 4563 | 18 | 90 | 7700 |
|  | 11.7 | 351 | 4107 | 18 | 92 | 8280 |
|  | 11.7 | 351 | 4100 | 18 | 91 | 8690 |
| Avg | 12.5 | 351 | 4368 | 18 | 91.8 | 8223 |
| Std dev | 0.9 | 0 | 311 | 0 | 1.7 | 497 |
| 46-10 Item 11 | 4.4 | 148 | 647 | 18 | 50.5 | 3630 |
|  | 4.7 | 234 | 1094 | 18 | 56.5 | 4200 |
|  | 5.0 | 130 | 646 | 18 | 56.5 | 7160 |
|  | 4.4 | 168 | 735 | 18 | 49.5 | 3335 |
| Avg | 4.6 | 170 | 781 | 18 | 53.5 | 4581 |
| Std dev | 0.3 | 45 | 213 | 0 | 3.8 | 1756 |
| 46-11 Item 12 | 9.5 | 268 | 2540 | 18 | 58 | 3580 |
|  | 9.5 | 268 | 2540 | 18 | 60.5 | 3760 |
|  | 8.3 | 268 | 2227 | 18 | 63 | 3950 |
|  | 9.8 | 268 | 2618 | 18 | 60.5 | 3640 |
| Avg | 9.3 | 268 | 2481 | 18 | 60.5 | 3733 |
| Std dev | 0.6 | 0 | 173 | 0 | 2.0 | 163 |
| 46-12 Item 13 | 4.2 | 309 | 1287 | 18 | 60 | 4330 |
|  | 4.7 | 309 | 1445 | 18 | 61 | 2890 |
|  | 4.1 | 309 | 1265 | 18 | 58 | 2825 |
|  | 4.1 | 276 | 1129 | 18 | 53 | 3160 |
| Avg | 4.3 | 301 | 1282 | 18 | 58.0 | 3301 |
| Std dev | 0.2 | 17 | 129 | 0 | 3.6 | 701 |

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 46-13 Item 21 | 6.6 | 351 | 2331 | 18 | 58 | 3540 |
|  | 5.6 | 351 | 1948 | 18 | 52 | 3020 |
|  | 6.4 | 351 | 2253 | 18 | 61 | 3230 |
|  | 6.1 | 351 | 2127 | 18 | 55 | 3550 |
| Avg | 6.2 | 351 | 2165 | 18 | 56.5 | 3335 |
| Std dev | 0.5 | 0 | 167 | 0 | 3.9 | 257 |
| 48-1 Item 17 | 8.5 | 201 | 1702 | 18 | 58 | 5320 |
|  | 8.5 | 201 | 1702 | 18 | 66.5 | ND |
|  | 8.0 | 184 | 1480 | 18 | 60 | 5180 |
|  | 7.2 | 184 | 1318 | 18 | 59 | 5340 |
| Avg | 8.0 | 193 | 1551 | 18 | 60.9 | 5280 |
| Std dev | 0.6 | 10 | 187 | 0 | 3.8 | 87 |
| 48-2 Item 1 | 12.9 | 168 | 2155 | 18 | 90 | 4920 |
|  | 11.4 | 168 | 1910 | 18 | 85 | 4730 |
|  | 12.0 | 168 | 2007 | 18 | 98 | 5250 |
|  | 15.2 | 168 | 2546 | 18 | 85.5 | 4550 |
| Avg | 12.9 | 168 | 2155 | 18 | 89.6 | 4863 |
| Std dev | 1.7 | 0 | 280 | 0 | 6.0 | 299 |

## TABLE 9 (cont)

### E162-CCC-2 Modified radiant panel data on virgin foams

| Sample 1676- | Q | F | Is | Inches burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 48-6 Item 15 | 6.1 | 218 | 1326 | 18 | 36.5 | 3715 |
| | 5.6 | 218 | 1208 | 18 | 39 | 3700 |
| | 5.7 | 218 | 1239 | 18 | 40 | 3855 |
| | 5.6 | 218 | 1208 | 18 | 36 | 3680 |
| Avg | 5.7 | 218 | 1245 | 18 | 37.9 | 3738 |
| Std dev | 0.3 | 0 | 56 | 0 | 1.9 | 80 |
| 48-7 Item 14 | 4.3 | 143 | 608 | 18 | 42.5 | 2860 |
| | 4.1 | 143 | 584 | 18 | 41 | ND |
| | 4.4 | 168 | 745 | 18 | 44.5 | 3480 |
| | 5.0 | 168 | 842 | 18 | 44.5 | 3290 |
| Avg | 4.5 | 156 | 696 | 18 | 43.1 | 3210 |
| Std dev | 0.4 | 14 | 122 | 0 | 1.7 | 318 |
| 48-8 Item 18 | 9.1 | 301 | 2724 | 18 | 71 | 4340 |
| | 9.5 | 301 | 2856 | 18 | 71 | 4460 |
| | 9.5 | 301 | 2856 | 18 | 69 | ND |
| | 9.8 | 301 | 2944 | 18 | 59 | 4960 |
| Avg | 9.5 | 301 | 2845 | 18 | 67.5 | 4587 |
| Std dev | 0.3 | 0 | 91 | 0 | 5.7 | 329 |
| 48-9 Item 9 | 2.5 | 171 | 424 | 18 | 32.5 | 2920 |
| | 5.2 | 171 | 886 | 18 | 35.5 | 3020 |
| | 4.1 | 143 | 585 | 18 | 35.5 | 3630 |
| | 4.1 | 168 | 686 | 18 | 35.5 | 2900 |
| Avg | 4.0 | 163 | 645 | 18 | 34.8 | 3118 |
| Std dev | 1.1 | 14 | 193 | 0 | 1.5 | 346 |

| Sample 1676- | Q | F | Is | Inches burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 48-10 Item 10 | 20.9 | 168 | 3502 | 18 | 68 | 6540 |
| | 18.3 | 301 | 5493 | 18 | 74.5 | 6130 |
| | 20.2 | 151 | 3043 | 18 | 70 | ND |
| | 14.6 | 151 | 2205 | 18 | 86.5 | 5920 |
| Avg | 18.5 | 193 | 3561 | 18 | 74.8 | 6197 |
| Std dev | 2.8 | 73 | 1396 | 0 | 8.3 | 315 |
| 48-11 Item 4 | 9.1 | 171 | 1547 | 18 | 72 | 6440 |
| | 7.6 | 171 | 1298 | 18 | 62 | 6370 |
| | 7.3 | 171 | 1248 | 18 | 61 | 5560 |
| | 8.0 | 171 | 1373 | 18 | 78.5 | 6830 |
| Avg | 8.0 | 171 | 1367 | 18 | 68.4 | 6300 |
| Std dev | 0.8 | 0 | 131 | 0 | 8.4 | 533 |
| 48-12 Item 5 | 0.5 | 101 | 52 | 3 | 30 | 2420 |
| | 0.2 | 101 | 15 | 3 | 34 | 2500 |
| | 0.4 | 101 | 44 | 3 | 32 | 2620 |
| | 0.4 | 101 | 44 | 3 | 32.5 | 2330 |
| Avg | 0.4 | 101 | 39 | 3 | 32.1 | 2468 |
| Std dev | 0.1 | 0 | 16 | 0 | 1.7 | 123 |

TABLE 9 (cont)

E162-CCC-2 Modified radiant panel data on virgin foams

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 48-13 Item 2 | 5.5 | 163 | 890 | 18 | 52 | 3630 |
| | (12.0) | 159 | (1907) | 18 | (82) | (6250) |
| | 5.1 | 146 | 746 | 18 | 55 | 4210 |
| | 5.8 | 133 | 766 | 18 | 51 | 4630 |
| Avg | 5.5 | 150 | 801 | 18 | 52.7 | 4157 |
| Std dev | 0.3 | 14 | 78 | 0 | 2.1 | 502 |
| 50-1 Item 3 | (71.8) | (18.3) | (1314) | (18) | (24) | (17620) |
| | 11.0 | 11.8 | 129 | 15 | 7 | 9490 |
| | 11.0 | 11.5 | 126 | 15 | 4.5 | 4740 |
| | 9.5 | 11.8 | 112 | 15 | 6.5 | 4230 |
| Avg | 10.5 | 11.7 | 122 | 15 | 6.0 | 6153 |
| Std dev | 0.9 | 0.2 | 9 | 0 | 1.3 | 2901 |
| 50-2* Item 24 | 43.2 | 12.6 | 542 | 12 | 7.0 | 5860 |
| | 30.1 | 11.7 | 351 | 12 | 6.5 | 7590 |
| | 41.8 | 12.7 | 529 | 12 | 5.0 | 7380 |
| | 45.9 | 15.1 | 692 | 12 | 8.0 | 11270 |
| Avg | 40.2 | 13.0 | 529 | 12 | 6.6 | 8025 |
| Std dev | 6.9 | 1.5 | 140 | 0 | 1.3 | 2297 |
| 50-3* Item 25 | -2.7 | 1 | -3 | 1 | 4 | (4010+) |
| | -1.4 | 1 | -1 | 1 | 7 | 8260 |
| | -1.4 | 1 | -1 | 1 | 0 | 9110 |
| | 8.2 | 1 | 8 | 1 | 0 | 7830 |
| Avg | 0.7 | 1 | 1 | 1 | 5.5 | 8400 |
| Std dev | 5.1 | 0 | 5 | 0 | 1.5 | 651 |

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 50-4 Item 27 | 11.7 | 152 | 1772 | 15 | 75 | 5370 |
| | 11.8 | 113 | 1333 | 15 | 69 | 5190 |
| | 8.0 | 113 | 905 | 15 | 71 | 5180 |
| | 8.5 | 102 | 865 | 15 | 72 | 5230 |
| Avg | 10.0 | 120 | 1219 | 15 | 71.8 | 5243 |
| Std dev | 2.0 | 22 | 425 | 0 | 2.5 | 88 |
| 50-5 Item 26 | 2.5 | 1 | 3 | <3 | 2 | (5380) |
| | 3.0 | 1 | 3 | <3 | 2 | 4570 |
| Avg | 2.8 | 1 | 3 | <3 | 2 | 4970+ |
| Std dev | 0.4 | 0 | 0 | 0 | 0 | NM |

Note: (-) These numbers were not used in the calcula-
tions. They seemed to be incomplete or spurious.

ND = No data

NM = Not meaningful

*Prepared on cement asbestos board.

TABLE 10

Summary of radiant panel data on virgin foams

Standard ASTM E162 & modified E162-CCC-2

| Item no | Foam sample 1676- | Q | | F | | Is | | In burned | | Smoke | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Peak | | Area | |
| | | Std | Mod | Std | Mod | Std | Mod | Std | Mod | Std | Mod | Std | Mod |
| 1 | 48-2 | 5.7 | 12.9 | 59.9 | 168 | 341 | 2155 | 15.0 | 18 | 59.1 | 89.6 | 3971 | 4863 |
| 2 | 48-13 | 6.2 | 5.5 | 57.4 | 150 | 386 | 801 | 7.1 | 18 | 21.0 | 52.7 | 2180 | 4157 |
| 3 | 50-1 | 37.0 | 10.5 | 10.2 | 11.7 | 376 | 122 | 14.3 | 15 | 21.1 | 6.0 | 12708 | 6153 |
| 4 | 48-11 | 4.8 | 8.0 | 30.3 | 171 | 144 | 1367 | 11.4 | 18 | 24.6 | 68.4 | 2814 | 6300 |
| 5 | 48-12 | 2.4 | 0.4 | 1 | 101 | 2 | 39 | 1 | 3 | 11.0 | 32.1 | 1100 | 2468 |
| 6 | 46-4 | 5.4 | 12.9 | 97.5 | 230 | 532 | 2973 | 17.8 | 18 | 25.8 | 28.9 | 2777 | 3900 |
| 7 | 46-3 | 8.0 | 8.6 | 19.7 | 284 | 158 | 2438 | 8.3 | 18 | 23.6 | 72.8 | 2885 | 7673 |
| 8 | 46-1 | 10.6 | 19.6 | 61.5 | 251 | 651 | 4913 | 17 | 18 | 46.6 | 91.5 | 6605 | 6853 |
| 9 | 48-9 | 1.9 | 4.0 | 59.7 | 163 | 112 | 645 | 11.3 | 18 | 22.1 | 34.8 | 1806 | 3118 |
| 10 | 48-10 | 12.5 | 18.5 | 43.2 | 193 | 543 | 3561 | 18 | 18 | 55.5 | 74.8 | 7937 | 6197 |
| 11 | 46-10 | 3.5 | 4.6 | 19.8 | 170 | 68 | 781 | 6.5 | 18 | 18.8 | 53.5 | 2329 | 4581 |
| 12 | 46-11 | 5.8 | 9.3 | 102 | 268 | 538 | 2481 | 12.0 | 18 | 22.1 | 60.5 | 2530 | 3733 |
| 13 | 46-12 | 4.3 | 4.3 | 80.9 | 301 | 341 | 1282 | 14.6 | 18 | 41.0 | 58.0 | 2818 | 3301 |
| 14 | 48-7 | 4.2 | 4.5 | 2.5 | 156 | 10 | 696 | 3.5 | 18 | 11.5 | 43.1 | 1449 | 3210 |
| 15 | 48-6 | 5.7 | 5.7 | 2.2 | 218 | 12 | 1245 | 3 | 18 | 16.1 | 37.9 | 1595 | 3738 |
| 16 | 46-6 | 13.8 | 26.0 | 23.6 | 134 | 327 | 3485 | 14.5 | 18 | 44.1 | 92+ | 7513 | 10223+ |
| 17 | 48-1 | 5.1 | 8.0 | 12.4 | 193 | 65 | 1551 | 4.0 | 18 | 13.0 | 60.9 | 1770 | 5280 |
| 18 | 48-8 | 7.3 | 9.5 | 9.4 | 301 | 66 | 2845 | 4.5 | 18 | 11.5 | 67.5 | 1912 | 4587 |
| 19 | 46-5 | 5.6 | 9.1 | 7.4 | 351 | 41 | 3185 | 3 | 18 | 13.9 | 53.8 | 1816 | 4233 |
| 20 | 46-9 | 6.1 | 12.5 | 130 | 351 | 782 | 4368 | 18 | 18 | 51.0 | 91.8 | 5008 | 8223 |
| 21 | 46-13 | 5.5 | 6.2 | 15.4 | 351 | 83 | 2165 | 5.5 | 18 | 13.1 | 56.5 | 1860 | 3335 |
| 22 | 46-8 | 5.7 | 9.7 | 35.5 | 101 | 176 | 981 | 10.0 | 18 | 27.3 | 75.6 | 2218 | 5600 |
| 23 | 46-7 | 4.9 | 5.8 | 2.7 | 301 | 13 | 1748 | 3 | 18 | 12.0 | 43.8 | 1533 | 3253 |
| 24 | 50-2 | 8.4 | 40.2 | 8.9 | 13.0 | 75 | 529 | 14 | 12 | 7.3 | 6.6 | 7427 | 8025 |
| 25 | 50-3 | 6.6 | 0.7 | 2.4 | 1 | 16 | 1 | 3 | 1 | 3.0 | 5.5 | 3138 | 8400 |
| 26 | 50-5 | 2.4 | 2.8 | 1 | 1 | 3 | 3 | <3 | <3 | 0 | 2 | 0 | 4970+ |
| 27 | 50-4 | 6.9 | 10.0 | 14.0 | 120 | 97 | 1219 | 9.3 | 15 | 32.0 | 71.8 | 3560 | 5243 |
| Avg | | 7.3 | 10.2 | 34.9 | 192 | 229 | 1821 | 9.5 | 14.9 | 24.6 | 55.4 | 3464 | 5060 |
| Std dev | | 6.9 | 8.5 | 38.9 | 104 | 249 | 1394 | 5.7 | 6.0 | 16.2 | 25.5 | 2807 | 1999 |

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TABLE 11

Flame spread index ($I_S$) ranges

| | ASTM E162 | | | E162-CCC-2 | | |
|---|---|---|---|---|---|---|
| Group | Range | No | Item nos | Range | No | Item nos |
| A | 2-16 | 6 | 5, 14, 15, 23, 25 & 26 | 1-122 | 4 | 3, 5, 25 & 26 |
| B | 41-112 | 8 | 9, 11, 17, 18, 19, 21, 24 & 27 | 529-981 | 6 | 2, 9, 11, 14, 22 & 24 |
| C | 144-176 | 3 | 4, 7 & 22 | 1219-1748 | 6 | 4, 13, 15, 17, 23 & 27 |
| D | 327-386 | 5 | 1, 2, 3, 13 & 16 | 2155-2481 | 4 | 1, 7, 12 & 21 |
| E | 532-782 | 5 | 6, 8, 10, 12 & 20 | 2845-4913 | 7 | 6, 8, 10, 16, 18, 19 & 20 |

To prevent this from happening to Items 24 and 25, the samples were pre-pared directly on a section of cement asbestos board. This arrangement more nearly represents a real life situation in which the foam will be attached to its substrate. The strategy seemed to work quite satisfac-torily.

In general, comparisons of the data obtained from tests ASTM E162 and E162-CCC-2 produced similar groupings of the candidate mate-rials. Forty-four percent were in the same group in Table 11 and 74% were no more than one group apart. Only three foams (11%) were three or more groups apart. The more severe E162-CCC-2 increased the $I_S$ values by a little less than an order of magnitude. In our opinion, this method is a useful tool for separating foams having lower flame spread values by ASTM E162 test.

Distances Burned - The flame spread index ($I_s$) is a function of the distance burned and the rate at which it burns. It seems reasonable to expect that the shorter the distance that the flame propagates, the safer the foam. The test data averages for distances burned, shown in Table 10, may be arranged into five groups, with A being the best and E the poorest. These groups and their ranges are shown in Table 12.

TABLE 12

Ranges of flame spread distances

| | ASTM E162 | | | E162-CCC-2 | | |
|---|---|---|---|---|---|---|
| Group | Range( in) | No | Item nos | Range( in) | No | Item nos |
| A | 1-3 | 6 | 5, 15, 19, 23, 25 & 26 | 1-3 | 3 | 5, 25 & 26 |
| B | 3.5-7.1 | 6 | 2, 11, 14, 17, 18 & 21 | 4-11 | 0 | - |
| C | 8.3-12.0 | 6 | 4, 7, 9, 12, 22 & 27 | 12 | 1 | 24 |
| D | 14-15 | 5 | 1, 3, 13, 16 & 24 | 15 | 2 | 3 & 27 |
| E | 17-18 | 4 | 6, 8, 10 & 20 | 18 | 21 | 1, 2, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 & 23 |

These data show the differences in the distance of flame propagation between the two radiant panel tests. Only six foams failed to burn the entire length of the sample (18 inches) by E162-CCC-2 while six burned three inches or less by ASTM E162.

A correlation of the performances measured for candidate foams by the two test methods was not particularly useful. The increased severity of the E162-CCC-2 test was sufficient to cause most of the foams to burn the entire 18 inches. The 3 foams (Items 5, 25 and 26) in Group A by E162-CCC-2 clearly demonstrated their superior resistance to flame propagation in face of the higher heat flux.

<u>Peak Smoke</u> - The peak smoke values used for comparison were read directly from a chart of percent light obscuration recorded at 30 percent equals full-scale. Absolute values for percent light obscuration, if they are desired, are 30 percent of the recorded number.

The test data average results, shown in Table 10, may be conveniently divided into five groups with A being the best and E the poorest. These groupings are shown in Table 13.

TABLE 13

Ranges of peak smoke values

| | ASTM E162 | | | E162-CCC-2 | | |
|---|---|---|---|---|---|---|
| Group | Range | No | Item nos | Range | No | Item nos |
| A | 0-7.3 | 3 | 24, 25 & 26 | 2-6.6 | 4 | 3, 24, 25 & 26 |
| B | 11-13.9 | 7 | 5, 14, 17, 18, 19, 21 & 23 | 28.9-37.9 | 4 | 5, 6, 9 & 15 |
| C | 16.1-32 | 11 | 2, 3, 4, 6, 7, 9, 11, 12, 15, 22 & 27 | 43.1-60.9 | 9 | 2, 11, 12, 13, 14, 17, 19, 21 & 23 |
| D | 41-46.6 | 3 | 8, 13 & 16 | 67.5-75.6 | 6 | 4, 7, 10, 18, 22 & 27 |
| E | 51-59.1 | 3 | 1, 10 & 20 | 89.6-92+ | 4 | 1, 8, 16 & 20 |

This general comparison of the data generated by the two test methods shows: 33% are in the same groups by both methods, 92% are no more than one group apart and none are over two groups apart.

<u>Smoke Area</u> - The area under the smoke obscuration curve plotted over time is a measure of the total amount of smoke evolved during the test. Some foams evolve smoke at a low, but fairly continuous level and the result is a large smoke area. Other foams evolve larger amounts of smoke for a very short time (high peak smoke) but return to essentially no smoke, resulting in a small smoke area. The E162-CCC-2 test method gives higher smoke areas due to the increased severity of the test.

The test data average smoke area results, shown in Table 10, can be conveniently arranged into five groups with A being best and E the poorest. These groups are shown in Table 14. A total of 44% falls into

the same group and 92% fall no more than one group apart. No samples were more than two groups apart.

## TABLE 14

### Ranges of smoke areas

| | ASTM E162 | | | E162-CCC-2 | | |
|---|---|---|---|---|---|---|
| Group | Range | No | Item nos | Range | No | Item nos |
| A | 0 | 1 | 26 | 2468-2497 | 2 | 5 & 26 |
| B | 1100-1912 | 9 | 5, 9, 14, 15, 17, 18, 19, 21, & 23 | 3118-3900 | 8 | 6, 9, 12, 13, 14, 15, 21 & 23 |
| C | 2180-3138 | 9 | 2, 4, 6, 7, 11, 12, 13, 22 & 25 | 4157-5600 | 8 | 1, 2, 11, 17, 18, 19, 22 & 27 |
| D | 3560-3971 | 2 | 1 & 27 | 6153-6853 | 4 | 3, 4, 8 & 10 |
| E | 5008-12708 | 6 | 3, 8, 10, 16, 20 & 24 | 7673-10223 | 5 | 7, 16, 20, 24 25 |

Selection of Candidates for Further Evaluation - Sixteen (16) of the 27 foams screened by the two radiant panel tests were selected for further evaluation by water immersion. They included the 13 foams found in Groups A, B and C of Table 11 by both tests (Items 4,5,9,11,14,15,17,22, 23,24,25,26 and 27) olus Items 18, 19 and 21 which were in Group B by ASTM E162, although the final three foams were found in Groups D and E by E162-CCC-2, the standard ASTM test value was used for the selection process.

The foams were selected solely on the basis of their flame spread values. Although the smoke values were not considered, the foams selected for further evaluation were among those having the best smoke ratings (Tables 13 and 14.)

Selection of the borderline foams was arbitrary. However, to make certain that no really promising foam was eliminated this early in the selection process, these marginally-performing products were included.

Comments - Although a primary basis for the initial selection of all of the foam candidates was good flame-resistant properties, the ASTM E162 flame spread data showed wide variation. The flame spread indices varied

from a low of 2 to a high of 782 with a mean value of 229. Only six foams had a flame spread index below 25, and about one-half the foams had $I_S$ values of 144 or higher.

These foams constitute a fair representation of the best commercial foams available, and all were reported to have a flame spread rating of 30 or less by the ASTM E84 test (25-foot tunnel). The ASTM E84 test is the standard in the construction industry and is considered to be equivalent to the ASTM E162 test by MSHA. The MSAR data does not support this assumption, and it leaves unanswered the question of which test, E84 or E162, more closely compares with the flame spread of foams under actual mine fire conditions.

Water Immersion Tests

Foam used in mines is usually subjected to both high relative humidity and water; therefore moisture and water must have no deleterious effect. Possible undesirable effects include (1) structural weakening and increased combustibility due to the loss or hydrolysis of flame retardant or other materials from the foam, or (2) increased air permeability due to a reduction of the closed cell content.

The effect of water was determined by immersing 6 inch by 18 inch by 1 inch thick samples of foam in distilled water for a period of 96 hours. After the samples were removed from the water, the drained weight was determined. The samples were then allowed to dry to a constant weight and weight loss, dimension changes, flame spread by E162 and E162-CCC-2, compressive strength and closed cell content were measured. These results were compared with untreated samples.

Nine samples of each formulation (a total of one-half cubic foot) were subjected to water immersion. Each sample was separated with a wire mesh divider for good exposure, and each formulation was tested in separate water chambers to prevent undesirable component interaction or exchange. The phenolic foam candidate (Item 26) was the only exception to this procedure because of a shortage of sample.

ASTM E162 Tests - Four samples of each of the candidate foams were subjected to the ASTM E162 radiant panel test after water immersion. The results obtained are shown in Table 15 along with the mean and standard deviation. The average results are summarized in Table 16 where they are compared with the averages of previous data on virgin foams.

In general, the flame spread index, the inches burned, and peak smoke values did not change significantly. The smoke area values did increase slightly for eight of the 16 foams (Items 11, 19, 21, 22, 23, 24, 25 and 26), but the reasons for the smoke area increase are not clear, nor is the magnitude of the increase considered significant.

TABLE 15

ASTM E162 Radiant panel data after water immersion

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 46 – 5 / Item 19 | 4.9 | 22.3 | 108 | 6 | 13 | 2720 |
| | 5.7 | 7.2 | 41 | 7 | ND | ND |
| | 4.9 | 6.1 | 30 | ND | 12 | 2200 |
| | 6.2 | 5.5 | 34 | 6 | 11 | 2230 |
| Avg | 5.4 | 10.2 | 53 | 6.3 | 12.0 | 2383 |
| Std dev | 0.6 | 8.0 | 37 | 0.6 | 1.0 | 292 |
| 46 – 7 / Item 23 | 4.7 | 3.7 | 17 | 4 | 13 | ND |
| | 4.5 | 10.3 | 47 | 6 | 13 | 2550 |
| | 3.7 | 9.3 | 35 | 6 | 12 | 2230 |
| | 3.9 | 8.7 | 34 | 6 | 14 | 2240 |
| Avg | 4.2 | 8.0 | 33 | 5.5 | 13.0 | 2340 |
| Std dev | 0.5 | 2.9 | 12 | 1.0 | 0.8 | 182 |
| 46 – 8 / Item 22 | 5.7 | 32.7 | 185 | 11 | 28 | 2880 |
| | 10.7 | 47.4 | 507 | 10 | 30 | 3570 |
| | 5.3 | 35.1 | 187 | 11 | 25 | 2250 |
| | 3.7 | 27.1 | 101 | 11 | 29 | 3560 |
| Avg | 6.4 | 35.6 | 245 | 10.8 | 28.0 | 3065 |
| Std dev | 3.0 | 8.6 | 179 | 0.5 | 2.2 | 632 |
| 46 –10 / Item 11 | 4.9 | 11.4 | 55 | 6 | 16 | 3280 |
| | 4.4 | 53.1 | 232 | 6 | 19 | 3380 |
| | 5.2 | 19.8 | 102 | 6 | 16 | 3440 |
| | 5.4 | 10.0 | 54 | 7 | 19 | 2900 |
| Avg | 4.9 | 23.6 | 111 | 6.3 | 17.5 | 3250 |
| Std dev | 0.4 | 20.1 | 84 | 0.5 | 1.7 | 242 |

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 46 – 13 / Item 21 | 5.3 | 9.2 | 49 | 7 | 11 | ND |
| | 4.9 | 8.4 | 41 | 7 | 11 | 2550 |
| | 4.9 | 11.3 | 55 | 8 | 13 | 2400 |
| | 5.0 | 7.4 | 37 | 8 | 9 | 2150 |
| Avg | 5.0 | 9.1 | 46 | 7.5 | 11.0 | 2367 |
| Std dev | 0.2 | 1.6 | 8 | 0.6 | 1.6 | 202 |
| 48-1 / Item 17 | 7.6 | 12.5 | 95 | 8 | 12 | 1880 |
| | 5.7 | 1.7 | 11 | 5 | 12 | 1270 |
| | 5.4 | 13.2 | 71 | 7 | 13 | 2050 |
| | 5.7 | 8.4 | 47 | 8 | 11 | 1800 |
| Avg | 6.1 | 8.9 | 56 | 7.0 | 12.0 | 1750 |
| Std dev | 1.0 | 5.3 | 36 | 1.4 | 0.8 | 337 |
| 48 – 6 / Item 15 | 6.3 | 1.9 | 12 | 4 | 11 | ND |
| | 5.7 | 1.7 | 9 | 3 | 14 | 1630 |
| | 5.0 | 1.6 | 8 | 3 | 40 | 3030 |
| | 5.7 | 1.7 | 10 | 3 | 11 | 1740 |
| Avg | 5.7 | 1.7 | 10 | 3.3 | 19.0 | 2133 |
| Std dev | 0.5 | 0.2 | 2 | 0.5 | 14.1 | 778 |
| 48 – 7 / Item 14 | 4.1 | 2.0 | 8 | 3 | 10 | 1330 |
| | 4.5 | 1.7 | 8 | 3 | 14 | 1790 |
| | 4.1 | 8.9 | 36 | 6 | 12 | 1740 |
| | 4.4 | 2.3 | 10 | 3 | 13 | 2300 |
| Avg | 4.3 | 3.7 | 15 | 3.8 | 12.3 | 1790 |
| Std dev | 0.2 | 3.5 | 14 | 1.5 | 1.7 | 398 |

## TABLE 15 (cont)

### ASTM E162 Radiant panel data after water immersion

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Area |
|---|---|---|---|---|---|---|
| 48 - 8 Item 18 | 6.0 | 7.7 | 46 | 8 | 11 | 1320 |
|  | 4.9 | 7.0 | 34 | 7 | 9 | 1660 |
|  | 5.0 | 12.0 | 60 | 9 | 12 | 2170 |
|  | 6.5 | 33.2 | 215 | 9 | 14 | 2240 |
| Avg | 5.6 | 15.0 | 89 | 8.3 | 11.5 | 1848 |
| Std dev | 0.8 | 12.4 | 85 | 1.0 | 2.1 | 436 |
| 48 - 9 Item 9 | 3.9 | 42.0 | 163 | 9 | 24 | 2400 |
|  | 2.9 | 56.4 | 165 | 17 | 27 | 2560 |
|  | 3.2 | 52.1 | 169 | 17 | 26 | 2030 |
|  | 3.2 | 63.7 | 206 | 17 | 27 | 2440 |
| Avg | 3.3 | 53.5 | 176 | 15.0 | 26.0 | 2358 |
| Std dev | 0.4 | 9.1 | 20 | 4.0 | 1.4 | 229 |
| 48 - 11 Item 4 | 5.7 | 22.4 | 127 | 11 | 18 | 2730 |
|  | 4.9 | 25.7 | 125 | 10 | 26 | 2640 |
|  | 5.7 | 32.3 | 183 | 11 | 23 | 2880 |
|  | 5.7 | 30.4 | 172 | 10 | 24 | 1540 |
| Avg | 5.5 | 27.7 | 152 | 10.5 | 22.8 | 2448 |
| Std dev | 0.4 | 4.5 | 30 | 0.6 | 3.4 | 613 |
| 48 - 12 Item 5 | 2.3 | 1.0 | 2 | 0 | 8 | 1270 |
|  | 2.4 | 1.0 | 2 | 1 | 8 | 1400 |
|  | 2.3 | 1.0 | 2 | 1 | 8 | 1290 |
|  | 2.9 | 1.0 | 3 | 1 | 17 | 2000 |
| Avg | 2.5 | 1.0 | 3 | 0.8 | 10.3 | 1490 |
| Std dev | 0.3 | 0.0 | 0 | 0.5 | 4.5 | 345 |

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Area |
|---|---|---|---|---|---|---|
| 50 - 2 Item 24 | 9.2 | 9.6 | 89 | 14 | 7 | 8490 |
|  | 8.1 | 9.8 | 79 | 14 | 6 | 7290 |
|  | 9.7 | 10.4 | 101 | 15 | 7 | 10,010 |
|  | 6.5 | 10.9 | 71 | - | 9 | 13,300 |
| Avg | 8.4 | 10.2 | 85 | 14.3 | 7.3 | 9773 |
| Std dev | 1.4 | 0.6 | 13 | 0.6 | 1.3 | 2602 |
| 50 - 3 Item 25 | 4.9 | 1.0 | 5 | 0 | - | 3950 |
|  | 4.1 | 1.0 | 4 | 0 | - | 5290 |
|  | 6.8 | 1.0 | 7 | 0 | 1 | 3620 |
|  | 4.1 | 1.0 | 4 | 0 | 4 | 6320 |
| Avg | 4.9 | 1.0 | 5 | 0 | 2.5 | 4795 |
| Std dev | 1.3 | 0.0 | 1 | 0 | 2.1 | 1247 |
| 50 - 4 Item 27 | 7.0 | 11.5 | 80 | 9 | 30 | 4700 |
|  | 6.8 | 7.9 | 54 | 7 | 20 | 2710 |
|  | 5.4 | 7.2 | 38 | 6 | 13 | 2440 |
|  | 5.7 | 7.5 | 43 | 7 | 21 | 4650 |
| Avg | 6.2 | 8.5 | 54 | 7.3 | 21.0 | 3625 |
| Std dev | 0.8 | 2.0 | 19 | 1.3 | 7.0 | 1218 |
| 50 - 5 Item 26 | 3.2 | 1.5 | 5 | 3 | 1.5 | 2975 |
| Avg | 3.2 | 1.5 | 5 | 3 | 1.5 | 2975 |
| Std dev | NM | NM | NM | NM | NM | NM |

Note: NM = Not meaningful

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TABLE 16

Comparison of test data for virgin (before) and water-immersed (after) samples by ASTM E162

| Item no | Sample 1676- | Q Before | Q After | F Before | F After | Is Before | Is After | In burned Before | In burned After | Peak smoke Before | Peak smoke After | Smoke area Before | Smoke area After |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 48-11 | 4.8 | 5.5 | 30.3 | 27.5 | 144 | 152 | 11.4 | 10.5 | 24.6 | 22.8 | 2814 | 2448 |
| 5 | 48-12 | 2.4 | 2.5 | 1.0 | 1.0 | 2 | 3 | 1.0 | 0.8 | 11.0 | 10.3 | 1100 | 1490 |
| 9 | 48-9 | 1.9 | 3.3 | 59.7 | 53.5 | 112 | 176 | 11.3 | 15.0 | 22.1 | 26.0 | 1806 | 2358 |
| 11 | 46-10 | 3.5 | 4.9 | 19.8 | 23.6 | 68 | 111 | 6.5 | 6.3 | 18.8 | 17.5 | 2329 | 3250 |
| 14 | 48-7 | 4.2 | 4.3 | 2.5 | 3.7 | 10 | 15 | 3.5 | 3.8 | 11.5 | 12.3 | 1449 | 1790 |
| 15 | 48-6 | 5.7 | 5.7 | 2.2 | 1.7 | 12 | 10 | 3.0 | 3.3 | 16.1 | 19.0 | 1595 | 2133 |
| 17 | 48-1 | 5.1 | 6.1 | 12.4 | 8.9 | 65 | 56 | 4.0 | 7.0 | 13.0 | 12.0 | 1770 | 1750 |
| 18 | 48-8 | 7.3 | 5.6 | 9.4 | 15.0 | 66 | 89 | 4.5 | 8.3 | 11.5 | 11.5 | 1912 | .1848 |
| 19 | 46-5 | 5.6 | 5.4 | 7.4 | 10.2 | 41 | 53 | 3.0 | 6.3 | 13.9 | 12.0 | 1816 | 2383 |
| 21 | 46-13 | 5.5 | 5.0 | 15.4 | 9.1 | 83 | 46 | 5.5 | 7.5 | 13.1 | 11.0 | 1860 | 2367 |
| 22 | 46-8 | 5.7 | 6.4 | 35.5 | 35.6 | 176 | 245 | 10.0 | 10.8 | 27.3 | 28.0 | 2218 | 3065 |
| 23 | 46-7 | 4.9 | 4.2 | 2.7 | 8.0 | 13 | 33 | 3.0 | 5.5 | 12.0 | 13.0 | 1533 | 2340 |
| 24 | 50-2 | 8.4 | 8.4 | 8.9 | 10.2 | 75 | 85 | 14.0 | 14.3 | 7.3 | 7.3 | 7427 | 9773 |
| 25 | 50-3 | 6.6 | 4.9 | 2.4 | 1.0 | 16 | 5 | 3.0 | 0 | 3.0 | 2.5 | 3138 | 4795 |
| 26 | 50-5 | 2.4 | 3.2 | 1.0 | 1.5 | 3 | 5 | <3 | 3 | 0 | 1.5 | 0 | 2975 |
| 27 | 50-4 | 6.9 | 6.2 | 14.0 | 8.5 | 97 | 54 | 9.3 | 7.3 | 32.0 | 21.0 | 3560 | 3625 |

TABLE 17

E162-CCC-2 Modified radiant panel data after water immersion

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Area |
|---|---|---|---|---|---|---|
| 46 - 5 / Item 19 | 8.8 | 251 | 2199 | 18 | 65 | 4720 |
|  | 8.2 | 251 | 2052 | 18 | 60 | 5800 |
|  | 7.4 | 251 | 1867 | 18 | 65 | 4520 |
|  | 9.1 | 251 | 2271 | 18 | 60 | 4940 |
| Avg | 8.4 | 251 | 2097 | 18 | 62.5 | 4995 |
| Std dev | 0.7 | 0 | 179 | 0 | 2.9 | 563 |
| 46 - 7 / Item 23 | 5.3 | 251 | 1319 | 18 | 53 | 5050 |
|  | 7.6 | 251 | 1905 | 18 | 56 | 6080 |
|  | 6.1 | 251 | 1539 | 18 | 62 | 5790 |
|  | 7.7 | 218 | 1684 | 18 | 52 | 5040 |
| Avg | 6.7 | 243 | 1612 | 18 | 56.0 | 5490 |
| Std dev | 1.2 | 17 | 246 | 0 | 4.5 | 527 |
| 46 - 8 / Item 22 | 12.7 | 251 | 3188 | 18 | 74 | 6450 |
|  | 10.2 | 251 | 2560 | 18 | 74 | 7210 |
|  | 10.6 | 168 | 1777 | 18 | 81 | 6770 |
|  | 10.8 | 159 | 1721 | 18 | 73 | 6670 |
| Avg | 11.1 | 207 | 2312 | 18 | 75.5 | 6775 |
| Std dev | 1.1 | 51 | 699 | 0 | 3.7 | 319 |
| 46 -10 / Item 11 | 9.8 | 218 | 2129 | 18 | 50 | 5000 |
|  | 6.4 | 218 | 1398 | 18 | 46 | (3330+) |
|  | 8.0 | 168 | 1346 | 18 | 49 | 4270 |
|  | 9.8 | 168 | 1640 | 18 | 57 | 5130 |
| Avg | 8.5 | 193 | 1628 | 18 | 50.5 | 4867 |
| Std dev | 1.6 | 29 | 358 | 0 | 4.7 | 350 |

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Area |
|---|---|---|---|---|---|---|
| 46 - 13 / Item 21 | 9.1 | 279 | 2688 | 18 | 64 | (3200+) |
|  | 8.6 | 301 | 2592 | 18 | 54 | 3890 |
|  | 8.8 | 301 | 2637 | 18 | 66 | (2990+) |
|  | 10.1 | 301 | 3031 | 18 | 63 | 5380 |
| Avg | 9.2 | 296 | 2737 | 18 | 61.8 | 4635 |
| Std dev | 0.7 | 11 | 200 | 0 | 5.3 | 1054 |
| 48-1 / Item 17 | 9.1 | 201 | 1810 | 18 | 60 | 4550 |
|  | 10.2 | 201 | 2044 | 18 | 55 | 4770 |
|  | 9.3 | 201 | 1869 | 18 | 55 | 4420 |
|  | 8.6 | 201 | 1723 | 18 | 55 | 4500 |
| Avg | 9.3 | 201 | 1862 | 18 | 56.3 | 4560 |
| Std dev | 0.7 | 0 | 136 | 0 | 2.5 | 150 |
| 48 - 6 / Item 15 | 5.6 | 251 | 1392 | 18 | 44 | ND |
|  | 6.1 | 251 | 1539 | 18 | 44 | 5560 |
|  | 6.6 | 251 | 1649 | 18 | 43 | (3920+) |
|  | 5.6 | 251 | 1392 | 18 | 44 | 5560 |
| Avg | 6.0 | 251 | 1493 | 18 | 43.8 | 5560 |
| Std dev | 0.5 | 0 | 125 | 0 | 0.5 | 0 |
| 48 - 7 / Item 14 | 6.9 | 251 | 1722 | 18 | 55 | 4460 |
|  | 6.7 | 168 | 1125 | 18 | 51 | 3960 |
|  | 6.7 | 251 | 1684 | 18 | 56 | 4730 |
|  | 6.9 | 251 | 1722 | 18 | 50 | ND |
| Avg | 6.8 | 230 | 1563 | 18 | 53.0 | 4383 |
| Std dev | 0.1 | 42 | 293 | 0 | 2.9 | 391 |

TABLE 17 (cont)

E162-CCC-2 Modified radiant panel data after water immersion

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 48 - 8 Item 18 | 11.7 | 351 | 4100 | 18 | 61 | 3970 |
|  | 13.1 | 351 | 4612 | 18 | 64 | (3850+) |
|  | 11.5 | 351 | 4048 | 18 | 61 | 5500 |
|  | 11.3 | 351 | 3946 | 18 | 63 | 5580 |
| Avg | 11.9 | 351 | 4177 | 18 | 62.3 | 5017 |
| Std dev | 0.8 | 0 | 297 | 0 | 1.5 | 907 |
| 48 - 9 Item 9 | 6.1 | 151 | 926 | 18 | 27 | ND |
|  | 5.3 | 128 | 675 | 18 | 30 | 3340 |
|  | 5.1 | 159 | 814 | 18 | 31 | 3390 |
|  | 5.4 | 159 | 860 | 18 | 29 | 3680 |
| Avg | 5.5 | 149 | 819 | 18 | 29.3 | 3470 |
| Std dev | 0.5 | 15 | 106 | 0 | 1.7 | 184 |
| 48 - 11 Item 4 | 9.5 | 226 | 2145 | 18 | 65 | 6930 |
|  | 9.3 | 204 | 1909 | 18 | 70 | 6660 |
|  | 10.8 | 168 | 1811 | 18 | 72 | 7070 |
|  | 8.3 | 168 | 1395 | 18 | 68 | 7350 |
| Avg | 9.5 | 192 | 1815 | 18 | 68.8 | 7003 |
| Std dev | 1.0 | 29 | 313 | 0 | 3.0 | 287 |
| 48 - 12 Item 5 | 0.4 | 101 | 37 | 3 | 44 | 4340 |
|  | 0.9 | 101 | 88 | 3 | 45 | 3860 |
|  | 0.7 | 101 | 74 | 3 | 33 | 3510 |
|  | 0.4 | 101 | 44 | 3 | 42 | 2650 |
| Avg | 0.6 | 101 | 61 | 3.0 | 41.0 | 3590 |
| Std dev | 0.2 | 0 | 24 | 0 | 5.5 | 713 |

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 50 - 2 Item 24 | 9.0 | 11.5 | 104 | 12 | 6 | 6350 |
|  | 8.5 | 11.4 | 96 | 12 | 7 | 7300 |
|  | 10.7 | 11.6 | 124 | 12 | 7 | 6280 |
|  | 6.6 | 13.5 | 88 | 12 | 6 | 3400 |
| Avg | 8.7 | 12.0 | 103 | 12 | 6.5 | 5833 |
| Std dev | 1.7 | 1.0 | 15 | 0 | 0.6 | 1087 |
| 50 - 3 Item 25 | 1.0 | 6.5 | 7 | 7 | 9 | 6370 |
|  | 1.2 | 6.5 | 8 | 7 | 8 | 7400 |
|  | 2.2 | 4.7 | 10 | 7 | 6 | 6270 |
|  | 2.6 | 5.3 | 14 | 7 | 8 | 6350 |
| Avg | 1.8 | 5.8 | 9 | 7 | 7.8 | 6598 |
| Std dev | 0.8 | 0.9 | 3 | 0 | 1.3 | 537 |
| 50 - 4 Item 27 | 7.7 | 115 | 894 | 18 | 73 | (3540+) |
|  | 11.7 | 286 | 3340 | 18 | 82 | 7110 |
|  | 8.8 | 168 | 1469 | 18 | 85 | 8580 |
|  | 11.7 | 154 | 1796 | 18 | 59 | (3430+) |
| Avg | 10.0 | 181 | 1875 | 18 | 74.8 | 7845 |
| Std dev | 2.0 | 74 | 1046 | 0 | 11.7 | 1039 |
| 50 - 5 Item 26 | 2.2 | 1.0 | 2 | 3 | 0 | 4090 |
| Avg | 2.2 | 1.0 | 2 | 3 | 1.5 | 4090 |
| Std dev | NM | NM | NM | NM | NM | NM |

Note: ND = No data
NM = Not meaningful

## TABLE 18

Comparison of test data for virgin (before) and water-immersed samples by E162-CCC-2

| Item no | Sample 1676- | Q Before | Q After | F Before | F After | Is Before | Is After | In burned Before | In burned After | Peak smoke Before | Peak smoke After | Smoke area Before | Smoke area After |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 48-11 | 8.0 | 9.5 | 171 | 192 | 1367 | 1815 | 18 | 18 | 68.4 | 68.8 | 6300 | 7003 |
| 5 | 48-12 | 0.4 | 0.6 | 101 | 101 | 39 | 61 | 3 | 3 | 32.1 | 41.0 | 2468 | 3590 |
| 9 | 48-9 | 4.0 | 5.5 | 163 | 149 | 645 | 819 | 18 | 18 | 34.8 | 29.3 | 3118 | 3470 |
| 11 | 46-10 | 4.6 | 8.5 | 170 | 193 | 781 | 1628 | 18 | 18 | 53.5 | 50.5 | 4581 | 4867 |
| 14 | 48-7 | 4.5 | 6.8 | 156 | 230 | 696 | 1563 | 18 | 18 | 43.1 | 53.0 | 3210 | 4383 |
| 15 | 48-6 | 5.7 | 6.0 | 218 | 251 | 1245 | 1493 | 18 | 18 | 37.9 | 43.8 | 3738 | 5560 |
| 17 | 48-1 | 8.0 | 9.3 | 193 | 201 | 1551 | 1862 | 18 | 18 | 60.9 | 56.3 | 5280 | 4560 |
| 18 | 48-8 | 9.5 | 11.9 | 301 | 351 | 2845 | 4177 | 18 | 18 | 67.5 | 62.3 | 4587 | 5017 |
| 19 | 46-5 | 9.1 | 8.4 | 351 | 251 | 3185 | 2097 | 18 | 18 | 53.8 | 62.5 | 4233. | 4995 |
| 21 | 46-13 | 6.2 | 9.2 | 351 | 296 | 2165 | 2737 | 18 | 18 | 56.5 | 61.8 | 3335 | 4635 |
| 22 | 46-8 | 9.7 | 11.1 | 101 | 207 | 981 | 2312 | 18 | 18 | 75.6 | 75.5 | 5600 | 6775 |
| 23 | 46-7 | 5.8 | 6.7 | 301 | 243 | 1748 | 1612 | 18 | 18 | 43.8 | 56.0 | 3253 | 5490 |
| 24 | 50-2 | 40.2 | 8.7 | 13 | 12 | 529 | 103 | 12 | 12 | 6.6 | 6.5 | 8025 | 5833 |
| 25 | 50-3 | 0.7 | 1.8 | 1 | 6 | 1 | 9 | 1 | 7 | 5.5 | 7.8 | 8400 | 6598 |
| 26 | 50-5 | 2.8 | 2.2 | 1 | 1 | 3 | 2 | <3 | 3 | 2 | 0 | 4970+ | 4090 |
| 27 | 50-4 | 10.0 | 10.0 | 120 | 181 | 1219 | 1875 | 15 | 18 | 71.8 | 74.8 | 5243 | 7845 |

<u>E162-CCC-2 Tests</u> - Four samples of each candidate foam were also tested by the E162-CCC-2 radiant panel after being thoroughly dried. These data are shown in Table 17 along with the mean and standard deviation. The data are summarized in Table 18 and compared with the values obtained with virgin foam.

The flame spread index values for Items 11, 14, and 18 seemed to have increased significantly after the water immersion. The precision of the Is values is less at the higher values, so the significance of these higher values is not clear. It may indicate, however, the beginning of a harmful effect. Certainly these foams should be viewed with suspicion. The results for Item 24, which decreased significantly, cannot be explained and are suspect.

The increase in some of the peak smoke values was also rather large, but once again it is hard to properly evaluate these high smoke values. In general, these changes in the smoke are not deemed to be critical.

<u>Changes in Weight</u> - The foam samples were weighed prior to the 96 hour immersion in water, and then reweighed 15-30 minutes and 48 hours after removing them from the water. Initially, a 96 hour weighing was also made, but was abandoned when it routinely showed no additional weight loss.

The 15-30 minute weight gives a picture of how much water was actually absorbed/adsorbed by the foam. The 48 hour weight was designed to show if any significant amount of material was extracted. The data, along with the mean and standard deviation, are shown in Table 19 and are summarized in Table 20.

Most of the foams showed a 20-47 gram weight gain at the 15-30 minutes weighing. This is equivalent to a 39-72% increase in weight. Since the silicone and Hypol foams (Items 24 and 25) were attached to cement asbestos boards, the % increase is not meaningful.

The silicone foam (Item 24) picked up about twice the weight of water as most of the other foams. The Hypol-based foam (Item 25) and the phenolic foam (Item 26) picked up over 600 grams of water. These two foams are open celled and apparently hydrophilic. Furthermore, both the Hypol and phenolic foams seemed to be much weaker when wet. The Hypol foam could hardly be removed from the water without tearing. Whether the apparent weakness when they are wet is structural or due to the weight of the large pickup of water is not certain, but the loss in weight of the Hypol upon drying suggests that its weakness might be due to removal of material from the foam.

TABLE 19

Effect of water immersion on weight

| Sample 1676- | Before | Weight, g | | | | | |
|---|---|---|---|---|---|---|---|
| | | 15-30 min after | | | 48 hr after | | |
| | | After | Gain | % | After | Gain | % |
| 46-5* Item 19 | 57.8 | 97.2 | 39.4 | 68.2 | 57.7 | -0.1 | -0.17 |
| | 57.5 | 98.3 | 40.8 | 71.0 | 57.2 | -0.3 | -0.52 |
| | 58.3 | 93.6 | 35.3 | 60.5 | 58.1 | -0.2 | -0.34 |
| | 58.1 | 101.0 | 42.9 | 73.8 | 58.0 | -0.1 | -0.17 |
| | 57.8 | 97.5 | 39.7 | 68.7 | 57.5 | -0.3 | -0.52 |
| | 57.2 | 97.2 | 40.0 | 69.9 | 57.0 | -0.2 | -0.34 |
| | 58.4 | 99.9 | 41.5 | 71.1 | 58.2 | -0.2 | -0.34 |
| | 57.5 | 99.7 | 42.2 | 73.4 | 57.0 | -0.5 | -0.87 |
| | 59.4 | 111.0 | 51.6 | 86.7 | 59.1 | -0.3 | -0.51 |
| Avg | NM | NM | 41.5 | 71.5 | NM | -0.2 | -0.42 |
| Std dev | NM | NM | 4.4 | 7.0 | NM | 0.1 | 0.21 |
| 46-7 Item 23 | 50.8 | 80.3 | 29.5 | 58.1 | 50.9 | 0.1 | 0.20 |
| | 55.2 | 90.0 | 34.8 | 63.0 | 55.2 | 0.0 | 0.00 |
| | 56.7 | 90.0 | 33.3 | 58.7 | 56.8 | 0.1 | 0.18 |
| | 56.7 | 87.2 | 30.5 | 53.8 | 56.9 | 0.2 | 0.35 |
| | 56.5 | 89.3 | 32.8 | 58.1 | 56.4 | -0.1 | -0.18 |
| | 58.7 | 92.6 | 33.9 | 57.8 | 58.9 | 0.2 | 0.34 |
| | 57.2 | 90.8 | 33.6 | 58.7 | 57.5 | 0.3 | 0.52 |
| | 56.0 | 89.8 | 33.8 | 60.4 | 55.9 | -0.1 | -0.18 |
| | 64.6 | 109.2 | 44.6 | 69.0 | 64.9 | 0.3 | 0.46 |
| Avg | NM | NM | 34.1 | 59.7 | NM | 0.1 | 0.19 |
| Std dev | NM | NM | 4.3 | 4.3 | NM | 0.2 | 0.26 |

| Sample 1676- | Before | Weight, g | | | | | |
|---|---|---|---|---|---|---|---|
| | | 15-30 min after | | | 48 hr after | | |
| | | After | Gain | % | After | Gain | % |
| 46-8* Item 22 | 51.6 | 71.5 | 19.9 | 38.6 | 51.6 | 0.0 | 0.00 |
| | 56.2 | 78.5 | 22.3 | 39.7 | 56.2 | 0.0 | 0.00 |
| | 55.7 | 83.3 | 27.6 | 49.6 | 55.7 | 0.0 | 0.00 |
| | 54.7 | 82.2 | 27.5 | 50.3 | 54.8 | 0.1 | 0.18 |
| | 51.5 | 79.5 | 28.0 | 54.4 | 51.5 | 0.0 | 0.00 |
| | 51.9 | 76.8 | 24.9 | 48.0 | 52.0 | 0.1 | 0.19 |
| | 49.9 | 71.8 | 21.9 | 43.9 | 49.9 | 0.0 | 0.00 |
| | 58.1 | 81.2 | 23.1 | 39.8 | 58.3 | 0.2 | 0.34 |
| | 63.5 | 90.0 | 26.5 | 41.7 | 63.4 | -0.1 | -0.15 |
| Avg | NM | NM | 24.6 | 45.1 | NM | 0.0 | 0.06 |
| Std dev | NM | NM | 2.9 | 5.6 | NM | 0.1 | 0.15 |
| 46-10 Item 11 | 57.1 | 88.1 | 31.0 | 54.3 | 56.9 | -0.2 | -0.35 |
| | 55.5 | 80.1 | 24.9 | 45.1 | 55.2 | 0.0 | 0.00 |
| | 55.5 | 85.5 | 30.0 | 54.1 | 55.3 | -0.2 | -0.36 |
| | 53.8 | 86.6 | 32.8 | 61.0 | 53.5 | -0.3 | -0.56 |
| | 55.1 | 84.1 | 29.0 | 52.6 | 54.8 | -0.3 | -0.54 |
| | 52.0 | 80.0 | 28.0 | 53.8 | 51.8 | -0.2 | -0.38 |
| | 58.4 | 86.2 | 27.8 | 47.6 | 58.0 | -0.4 | -0.68 |
| | 54.9 | 80.0 | 25.1 | 45.7 | 54.8 | -0.1 | -0.18 |
| | 64.8 | 102.9 | 38.1 | 58.8 | 64.5 | -0.3 | -0.46 |
| Avg | NM | NM | 29.6 | 52.6 | NM | -0.2 | -0.39 |
| Std dev | NM | NM | 4.1 | 5.5 | NM | 0.1 | 0.21 |

TABLE 19 (cont)

Effect of water immersion on weight

| Sample 1676- | Before | 15-30 min after After | Gain | % | 48 hr after After | Gain | % |
|---|---|---|---|---|---|---|---|
| 46-13 Item 21 | 61.7 | 97.0 | 35.3 | 57.2 | 61.8 | 0.1 | 0.16 |
|  | 53.9 | 89.9 | 36.0 | 66.8 | 54.1 | 0.2 | 0.37 |
|  | 60.6 | 96.0 | 35.4 | 58.4 | 60.7 | 0.1 | 0.17 |
|  | 56.8 | 92.5 | 35.7 | 62.9 | 57.0 | 0.2 | 0.35 |
|  | 50.3 | 87.0 | 36.7 | 73.0 | 50.4 | 0.1 | 0.20 |
|  | 58.2 | 95.0 | 36.8 | 63.2 | 58.3 | 0.1 | 0.17 |
|  | 50.7 | 88.0 | 37.3 | 73.6 | 50.8 | 0.1 | 0.20 |
|  | 53.8 | 88.5 | 34.7 | 64.5 | 53.7 | -0.1 | -0.19 |
|  | 72.7 | 122.0 | 49.3 | 67.8 | 72.9 | 0.2 | 0.28 |
| Avg | NM | NM | 37.5 | 65.3 | NM | 0.1 | 0.19 |
| Std dev | NM | NM | 4.5 | 5.7 | NM | 0.1 | 0.16 |
| 48-1 * Item 17 | 54.7 | 77.8 | 23.1 | 42.2 | 54.5 | -0.2 | -0.37 |
|  | 51.4 | 73.7 | 22.3 | 43.4 | 51.0 | -0.4 | -0.78 |
|  | 51.0 | 73.8 | 22.8 | 44.7 | 51.0 | 0.0 | 0.00 |
|  | 54.9 | 75.6 | 20.7 | 37.7 | 54.8 | -0.1 | -0.18 |
|  | 53.8 | 77.3 | 23.5 | 43.7 | 53.5 | -0.3 | -0.56 |
|  | 53.4 | 73.3 | 19.9 | 37.3 | 53.1 | -0.3 | -0.56 |
|  | 51.4 | 70.5 | 19.1 | 37.2 | 51.3 | -0.1 | -0.19 |
|  | 52.0 | 70.6 | 18.6 | 35.8 | 52.0 | 0.0 | 0.00 |
|  | 61.7 | 80.0 | 18.3 | 29.7 | 61.6 | -0.1 | -0.16 |
| Avg | NM | NM | 20.9 | 39.1 | NM | -0.2 | -0.31 |
| Std dev | NM | NM | 2.0 | 4.9 | NM | 0.1 | 0.27 |

| Sample 1676- | Before | 15-30 min after After | Gain | % | 48 hr after After | Gain | % |
|---|---|---|---|---|---|---|---|
| 48-6 Item 15 | 73.7 | 101.8 | 28.1 | 38.1 | 73.7 | 0.0 | 0.00 |
|  | 73.7 | 100.6 | 26.9 | 36.5 | 73.7 | 0.0 | 0.00 |
|  | 76.7 | 105.9 | 29.2 | 38.1 | 76.4 | -0.3 | -0.39 |
|  | 70.1 | 96.4 | 26.3 | 37.5 | 70.0 | -0.1 | -0.14 |
|  | 70.6 | 98.8 | 28.2 | 39.9 | 70.6 | 0.0 | 0.00 |
|  | 72.9 | 104.0 | 31.1 | 42.7 | 72.9 | 0.0 | 0.00 |
|  | 72.9 | 100.4 | 27.5 | 37.7 | 73.0 | 0.1 | 0.14 |
|  | 71.5 | 97.9 | 26.4 | 36.9 | 71.6 | 0.1 | 0.14 |
|  | 73.3 | 113.3 | 40.0 | 54.6 | 73.6 | 0.3 | 0.41 |
| Avg | NM | NM | 29.3 | 40.2 | NM | 0.0 | 0.02 |
| Std dev | NM | NM | 4.3 | 5.7 | NM | 0.2 | 0.22 |
| 48-7 Item 14 | 56.2 | 80.0 | 23.8 | 42.3 | 56.0 | -0.2 | -0.36 |
|  | 53.7 | 81.0 | 27.3 | 50.8 | 53.7 | 0.0 | 0.00 |
|  | 58.0 | 84.8 | 26.8 | 46.2 | 58.0 | 0.0 | 0.00 |
|  | 56.4 | 85.0 | 28.6 | 50.7 | 56.3 | -0.1 | -0.18 |
|  | 56.2 | 84.6 | 28.4 | 50.5 | 56.0 | -0.2 | -0.36 |
|  | 53.6 | 80.5 | 26.9 | 50.2 | 53.6 | 0.0 | 0.00 |
|  | 54.3 | 81.5 | 27.2 | 50.1 | 54.3 | 0.0 | 0.00 |
|  | 54.0 | 82.8 | 28.8 | 53.3 | 53.8 | -0.2 | -0.37 |
|  | 60.4 | 99.2 | 38.8 | 64.2 | 60.4 | 0.0 | 0.00 |
| Avg | NM | NM | 28.5 | 50.9 | NM | -0.1 | -0.14 |
| Std dev | NM | NM | 4.1 | 5.9 | NM | 0.1 | 0.18 |

TABLE 19 (cont)

Effect of water immersion on weight

| Sample 1676- | Weight, g | | | | | | |
|---|---|---|---|---|---|---|---|
| | Before | 15-30 min after | | | 48 hr after | | |
| | | After | Gain | % | After | Gain | % |
| 48-8 Item 18 | 58.6 | 101.0 | 42.4 | 72.4 | 58.4 | -0.2 | -0.34 |
| | 65.0 | 108.0 | 43.0 | 66.2 | 64.7 | -0.3 | -0.46 |
| | 65.1 | 107.6 | 42.5 | 65.3 | 65.2 | 0.1 | 0.15 |
| | 64.5 | 106.3 | 41.8 | 64.8 | 64.5 | 0.0 | 0.00 |
| | 57.3 | 100.0 | 42.7 | 74.5 | 57.2 | -0.1 | -0.18 |
| | 52.4 | 90.5 | 38.1 | 72.7 | 52.3 | -0.1 | -0.19 |
| | 59.6 | 104.8 | 45.2 | 75.8 | 59.3 | -0.3 | -0.50 |
| | 58.4 | 102.8 | 44.4 | 76.0 | 58.3 | -0.1 | -0.17 |
| | 66.1 | 115.3 | 49.2 | 74.4 | 66.1 | 0.0 | 0.05 |
| Avg | NM | NM | 43.3 | 71.3 | NM | -0.1 | -0.15 |
| Std dev | NM | NM | 3.0 | 4.6 | NM | 0.1 | 0.25 |
| 48-9 Item 9 | 64.8 | 117.2 | 52.4 | 80.9 | 64.2 | -0.6 | -0.93 |
| | 65.9 | 117.5 | 51.6 | 78.3 | 65.3 | -0.6 | -0.91 |
| | 67.8 | 122.2 | 54.4 | 80.2 | 67.0 | -0.8 | -1.18 |
| | 67.7 | 110.0 | 42.3 | 62.5 | 66.6 | -1.1 | -1.62 |
| | 66.5 | 104.5 | 38.0 | 57.1 | 65.6 | -0.9 | -1.35 |
| | 63.2 | 104.0 | 40.8 | 64.6 | 62.1 | -1.1 | -1.74 |
| | 65.1 | 119.4 | 54.3 | 83.4 | 64.7 | -0.4 | -0.61 |
| | 66.2 | 101.7 | 35.5 | 53.6 | 65.5 | -0.7 | -1.06 |
| | 65.3 | 117.7 | 52.4 | 80.2 | 64.4 | -0.9 | -1.38 |
| Avg | NM | NM | 46.9 | 71.2 | NM | -0.8 | -1.20 |
| Std dev | NM | NM | 7.6 | 11.6 | NM | 0.2 | 0.36 |

| Sample 1676- | Weight, g | | | | | | |
|---|---|---|---|---|---|---|---|
| | Before | 15-30 min after | | | 48 hr after | | |
| | | After | Gain | % | After | Gain | % |
| 48-11 Item 4 | 56.1 | 88.3 | 32.2 | 57.4 | 56.4 | 0.3 | 0.53 |
| | 58.1 | 95.4 | 37.3 | 64.2 | 58.1 | 0.0 | 0.00 |
| | 60.5 | 97.4 | 36.9 | 61.0 | 60.3 | -0.2 | -0.33 |
| | 56.5 | 91.8 | 35.3 | 62.5 | 56.6 | 0.1 | 0.18 |
| | 57.0 | 90.8 | 33.8 | 59.3 | 56.8 | -0.2 | -0.35 |
| | 56.5 | 87.2 | 30.7 | 54.3 | 56.5 | 0.0 | 0.00 |
| | 58.5 | 89.8 | 31.3 | 53.5 | 58.3 | -0.2 | -0.34 |
| | 58.3 | 93.5 | 35.2 | 60.4 | 58.2 | -0.1 | -0.17 |
| | 51.7 | 84.3 | 32.6 | 63.1 | 51.6 | -0.1 | -0.19 |
| Avg | NM | NM | 33.9 | 59.5 | NM | 0.0 | -0.08 |
| Std dev | NM | NM | 2.4 | 3.8 | NM | 0.2 | 0.29 |
| 48-12 Item 5 | 52.4 | 78.0 | 25.6 | 48.9 | 52.2 | -0.2 | -0.38 |
| | 52.1 | 83.0 | 30.9 | 59.3 | 52.0 | -0.1 | -0.19 |
| | 55.5 | 83.8 | 28.3 | 51.0 | 55.5 | 0.0 | 0.00 |
| | 52.8 | 82.0 | 29.2 | 55.3 | 52.6 | -0.2 | -0.38 |
| | 54.7 | 84.0 | 29.3 | 53.6 | 54.6 | -0.1 | -0.18 |
| | 51.6 | 77.5 | 25.9 | 50.2 | 51.2 | -0.4 | -0.78 |
| | 53.1 | 79.7 | 26.6 | 50.1 | 52.9 | -0.2 | -0.38 |
| | 45.5 | 68.0 | 22.5 | 49.5 | 45.4 | -0.1 | -0.22 |
| | 58.2 | 95.8 | 37.6 | 64.6 | 57.9 | -0.3 | -0.52 |
| Avg | NM | NM | 28.4 | 53.6 | NM | -0.2 | -0.34 |
| Std dev | NM | NM | 4.2 | 5.3 | NM | 0.1 | 0.22 |

TABLE 19 (cont)

Effect of water immersion on weight

**Left table**

| Sample 1676- | Weight, g | | | | | | |
|---|---|---|---|---|---|---|---|
| | Before | 15-30 min after | | | 48 hr after | | |
| | | After | Gain | % | After | Gain | % |
| 50-2** Item 24 | 800 | 880 | 80 | | 797 | -3 | |
| | 805 | 892 | 87 | | 804 | -1 | |
| | 747 | 832 | 85 | | 744 | -3 | |
| | 793 | 876 | 83 | Not meaningful | 791 | -2 | Not meaningful |
| | 789 | 879 | 90 | | 788 | -1 | |
| | 748 | 829 | 81 | | 748 | 0 | |
| | 785 | 870 | 85 | | 784 | -1 | |
| | 728 | 805 | 77 | | 727 | -1 | |
| Avg | NM | NM | 83.5 | Not meaningful | NM | -1.5 | Not meaningful |
| Std dev | NM | NM | 4.1 | | NM | 1.1 | |
| 50-3*** Item 25 | 761 | 1400 | 639 | Not meaningful | 734 | -27 | Not meaningful |
| | 787 | 1484 | 697 | | 758 | -29 | |
| | 843 | 1605 | 762 | | 806 | -37 | |
| | 932 | 1884 | 952 | | 887 | -45 | |
| | 855 | 1645 | 790 | | 821 | -34 | |
| | 942 | 1873 | 931 | | 903 | -39 | |
| | 1016 | 2054 | 1038 | | 973 | -43 | |
| | 940 | 1848 | 908 | | 901 | -39 | |
| Avg | NM | NM | 840 | | NM | -37 | |
| Std dev | NM | NM | 138 | | NM | 6.3 | |

**Right table**

| Sample 1676- | Weight, g | | | | | | |
|---|---|---|---|---|---|---|---|
| | Before | 15-30 min after | | | 48 hr after | | |
| | | After | Gain | % | After | Gain | % |
| 50-4 Item 27 | 67.7 | 100.9 | 33.2 | 49.0 | 67.1 | -0.6 | -0.89 |
| | 64.7 | 94.0 | 29.3 | 45.3 | 64.4 | -0.3 | -0.46 |
| | 57.8 | 87.8 | 30.0 | 51.9 | 57.4 | -0.4 | -0.69 |
| | 61.0 | 95.9 | 34.9 | 57.2 | 60.2 | -0.8 | -1.31 |
| | 61.7 | 97.2 | 35.5 | 57.5 | 61.0 | -0.7 | -1.13 |
| | 58.6 | 88.9 | 30.3 | 51.7 | 58.2 | -0.4 | -0.68 |
| | 57.5 | 88.9 | 31.4 | 54.6 | 57.0 | -0.5 | -0.87 |
| | 59.5 | 92.1 | 32.6 | 54.8 | 59.3 | -0.2 | -0.34 |
| | 63.3 | 108.2 | 44.9 | 70.9 | 62.8 | -0.5 | -0.79 |
| Avg | NM | NM | 33.6 | 54.8 | NM | -0.5 | -0.80 |
| Std dev | NM | NM | 4.8 | 7.2 | NM | 0.2 | 0.30 |
| 50-5 Item 26 | 24.0 | 455.0 | 431.0 | 1796 | 165.0 | 141.0 | 588 |
| | 76.7 | 779.0 | 702.3 | 916 | 340.0 | 263.3 | 474 |
| | 56.4 | 809.0 | 752.6 | 1334 | 347.5 | 291.1 | 516 |
| | | | 24 hr drying time | | | 96 hr drying time | |
| Avg | NM | NM | 628.6 | 1349 | NM | 231.8 | 526 |
| Std dev | NM | NM | 173.0 | 440 | NM | 79.9 | 58 |
| | 24.0 | 25.0 | 1.0 | 104 | 19.3 | -4.7 | -20 |
| | 76.7 | 127.4 | 50.7 | 166 | 63.4 | -13.3 | -17 |
| | 56.4 | 129.9 | 73.5 | 230 | 50.3 | -6.1 | -11 |
| | | | 24 hr drying time | | | 1 mo drying time | |
| Avg | NM | NM | 41.7 | 167 | NM | -8.0 | -16 |
| Std dev | NM | NM | 37.1 | 63 | NM | 4.6 | 5 |

*   24 Hr drying time
**  Foam samples or cement asbestos board
*** Sample still wet at 48 hr.

Note: NM = Not meaningful

-60-

## TABLE 20

### SUMMARY – Effect of water immersion on weight

| Item no | Sample 1676- | Weight increase, g | | Weight increase, % | |
|---|---|---|---|---|---|
| | | 15–30 min After | 48 hr After | 15–30 min After | 48 hr After |
| 4 | 48-11 | 33.9 | 0.0 | 59.5 | -0.08 |
| 5 | 48-12 | 28.4 | -0.2 | 53.6 | -0.34 |
| 9 | 48-9 | 46.9 | -0.8 | 71.2 | -1.20 |
| 11 | 46-10 | 29.6 | -0.2 | 52.6 | -0.39 |
| 14 | 48-7 | 28.5 | -0.1 | 50.9 | -0.14 |
| 15 | 48-6 | 29.3 | 0.0 | 40.2 | 0.02 |
| 17* | 48-1 | 20.9 | -0.2 | 39.1 | -0.31 |
| 18 | 48-8 | 43.3 | -0.1 | 71.3 | -0.15 |
| 19* | 46-5 | 41.5 | -0.2 | 71.5 | -0.42 |
| 21 | 46-13 | 37.5 | 0.1 | 65.3 | 0.19 |
| 22* | 46-8 | 24.6 | 0.0 | 45.1 | 0.06 |
| 23 | 46-7 | 34.1 | 0.1 | 59.7 | 0.19 |
| 24** | 50-2 | 83.5 | -1.5 | NM | NM |
| 25**,*** | 50-3 | 840 | -37 | NM | NM |
| 26 | 50-5 | 629 | 232 (96 hr) -8.0 (1 mo) | 1349 | 526 (96 hr) -16 (1 mo) |
| 27 | 50-4 | 33.6 | -0.5 | 54.8 | -0.80 |

Notes:
* 24 hour drying time
** Sample on cement asbestos board
*** Sample still wet after 48 hours
NM Not meaningful

The phenolic foam (Item 26) not only picked up a lot of water, but it was also difficult to dry. It was still wet after 10 days, so the one month weight was taken as the final dry weight.

A slight gain in weight from adsorbed or absorbed moisture would not appear to cause any practical problems in the use of the foam as a sealant unless the increase in weight caused the foam to lose its adhesion to the substrate. The importance of adhesion is even more critical if the moisture pick-up weakens the foam as it apparently does with the Hypol foam (Item 25). Thus, the effect of water pick-up on the adhesion and strength of Hypol and phenolic foams should be checked further before using them in mines.

The urethane foams showed little weight loss on drying, indicating no significant leaching of material. The final weights were usually within one gram of the original weight. The silicone foam (Item 24) lost a bit more weight than did most urethane foams. The phenolic foam (Item 26) lost about 16% of its weight, suggesting that something was removed. The Hypol foam (Item 25) lost the most weight, indicating the probable loss of some of the solids with which this foam is loaded. Foams losing a significant amount of weight should be checked for even longer range effects on their ability to seal a stopping and resist flame propagation.

Surface Area - The surface area of the foams was measured before and after the water immersion test. No measurements were made on Items 24 and 25 because their movements were restricted by the cement asbestos board to which they were attached. The data obtained are shown in Table 21 along with the average and standard deviations of the change in area. These data are summarized in Table 22.

The % area changes were negligible for all but Items 11 and 26. The unusually high shrinkage of Item 11 might lead to ultimate failure by splitting on a substrate. This can only be determined by an actual field test. Item 26 might also suffer the same fate because the phenolic is more brittle than the urethane foams.

Effect on Closed Cell and Foam Density - The % closed cell and densities were determined on foam samples both before and after water immersion. These data are shown in Table 23 along with the average and standard deviation. The data are summarized in Table 24.

Most of the foams are essentially closed cell. The range of 88-99% is typical of what one would expect to find. The low closed cell content of the silicone and Hypol samples, (Items 24 and 25) are typical of flexible foams. If a flexible foam contains a high percentage of closed cells, it is likely to shrink at or below room temperature. The open-celled nature of Item 26 is historically typical of flexible and phenolic foams, but both W. R. Grace and Reichhold claim they can make their foam closed cell.

TABLE 21

Effect of water immersion on surface area

| Sample 1676- | Area, in² Before | After | Area Increase in² | % |
|---|---|---|---|---|
| 46 - 5 Item 19 | 106.94 | 107.67 | 0.73 | 0.68 |
| | 106.39 | 107.49 | 1.10 | 1.03 |
| | 106.39 | 107.12 | 0.73 | 0.69 |
| | 106.94 | 107.67 | 0.73 | 0.68 |
| | 106.94 | 107.68 | 0.74 | 0.69 |
| | 107.85 | 108.41 | 0.56 | 0.52 |
| | 107.30 | 107.85 | 0.55 | 0.51 |
| | 107.68 | 107.12 | -0.56 | -0.52 |
| | 108.61 | 108.96 | 0.35 | 0.32 |
| Avg | NM | NM | 0.55 | 0.51 |
| Std dev | NM | NM | 0.46 | 0.43 |
| 46 - 7 Item 23 | 112.87 | 113.24 | 0.37 | 0.33 |
| | 110.64 | 112.49 | 1.85 | 1.67 |
| | 112.11 | 112.87 | 0.76 | 0.68 |
| | 112.87 | 112.87 | 0.00 | 0.00 |
| | 112.87 | 112.87 | 0.00 | 0.00 |
| | 111.00 | 111.00 | 0.00 | 0.00 |
| | 112.87 | 113.24 | 0.37 | 0.33 |
| | 112.87 | 112.87 | 0.00 | 0.00 |
| | 112.87 | ND | ND | ND |
| Avg | NM | NM | 0.42 | 0.38 |
| Std dev | NM | NM | 0.64 | 0.58 |
| 46 - 8 Item 22 | 108.41 | 108.04 | -0.37 | -0.34 |
| | 106.76 | 106.58 | -0.18 | -0.17 |
| | 109.52 | 110.25 | 0.73 | 0.67 |
| | 108.77 | 108.22 | -0.55 | -0.51 |
| | 110.25 | 110.25 | 0.00 | 0.00 |
| | 107.13 | 107.86 | 0.73 | 0.68 |
| | 108.04 | 108.59 | 0.55 | 0.51 |
| | 108.22 | 108.22 | 0.00 | 0.00 |
| | 109.14 | 109.70 | 0.56 | 0.51 |
| Avg | NM | NM | 0.16 | 0.15 |
| Std dev | NM | NM | 0.49 | 0.45 |

| Sample 1676- | Area, in² Before | After | Area Increase in² | % |
|---|---|---|---|---|
| 46 - 10 Item 11 | 111.60 | 108.04 | -3.56 | -3.19 |
| | 111.60 | 108.81 | -2.79 | -2.50 |
| | 109.74 | 108.25 | -1.49 | -1.36 |
| | 109.74 | 108.44 | -1.30 | -1.18 |
| | 111.60 | 108.04 | -3.56 | -3.19 |
| | 112.50 | 109.40 | -3.10 | -2.76 |
| | 111.60 | 109.00 | -2.60 | -2.33 |
| | 111.60 | 109.00 | -2.60 | -2.33 |
| | 112.20 | 108.81 | -3.39 | -3.02 |
| Avf | NM | NM | -2.71 | -2.43 |
| Std dev | NM | NM | 0.83 | 0.74 |
| 46 - 13 Item 21 | 108.22 | 107.49 | -0.73 | -0.67 |
| | 109.33 | 109.52 | 0.19 | 0.17 |
| | 108.23 | 107.31 | -0.92 | -0.85 |
| | 109.15 | 109.15 | 0.00 | 0.00 |
| | 109.87 | 110.25 | 0.38 | 0.35 |
| | 108.22 | 108.41 | 0.19 | 0.18 |
| | 108.22 | 107.49 | -0.73 | -0.67 |
| | 107.86 | 107.68 | -0.18 | -0.17 |
| | 111.56 | 110.82 | -0.74 | -0.66 |
| Avg | NM | NM | -0.28 | -0.26 |
| Std dev | NM | NM | 0.50 | 0.46 |
| 48 - 1 Item 17 | 106.58 | 106.76 | 0.18 | 0.17 |
| | 106.01 | 106.19 | 0.18 | 0.17 |
| | 106.03 | 106.03 | 0.00 | 0.00 |
| | 106.93 | 107.09 | 0.16 | 0.15 |
| | 107.30 | 107.49 | 0.19 | 0.18 |
| | 106.35 | 106.16 | -0.19 | -0.18 |
| | 108.41 | 108.41 | 0.00 | 0.00 |
| | 105.12 | 105.49 | 0.37 | 0.35 |
| | 107.49 | 107.86 | 0.37 | 0.35 |
| Avg | NM | NM | 0.14 | 0.13 |
| Std dev | NM | NM | 0.18 | 0.17 |

| Sample 1676- | Area, in² Before | After | Area Increase in² | % |
|---|---|---|---|---|
| 48 - 6 Item 15 | 110.45 | 111.00 | 0.55 | 0.50 |
| | 109.34 | 110.08 | 0.74 | 0.68 |
| | 109.70 | 110.07 | 0.37 | 0.34 |
| | 109.72 | 110.26 | 0.54 | 0.49 |
| | 109.88 | 110.25 | 0.37 | 0.34 |
| | 109.72 | 111.00 | 1.28 | 1.17 |
| | 109.70 | 110.25 | 0.55 | 0.50 |
| | 109.72 | 110.62 | 0.90 | 0.82 |
| | 111.81 | ND | ND | ND |
| Avg | NM | NM | 0.66 | 0.61 |
| Std dev | NM | NM | 0.31 | 0.28 |
| 48 - 7 Item 14 | 111.75 | 112.87 | 1.12 | 1.00 |
| | 110.82 | 111.37 | 0.55 | 0.50 |
| | 110.54 | 110.82 | 0.28 | 0.25 |
| | 112.49 | 112.87 | 0.38 | 0.34 |
| | 110.35 | 111.00 | 0.65 | 0.59 |
| | 111.37 | 112.87 | 1.50 | 1.35 |
| | 112.49 | 112.87 | 0.38 | 0.34 |
| | 111.00 | 111.37 | 0.37 | 0.33 |
| | 109.72 | ND | ND | ND |
| Avg | NM | NM | 0.65 | 0.59 |
| Std dev | NM | NM | 0.43 | 0.39 |
| 48 - 8 Item 18 | 111.60 | 111.00 | 0.00 | 0.00 |
| | 111.00 | 111.00 | 0.00 | 0.00 |
| | 108.56 | 109.15 | 0.59 | 0.54 |
| | 108.56 | 110.40 | 1.84 | 1.69 |
| | 111.00 | 111.60 | 0.60 | 0.55 |
| | 111.60 | 111.60 | 0.00 | 0.00 |
| | 111.00 | 109.15 | -1.85 | -1.67 |
| | 111.00 | 111.00 | 0.00 | 0.00 |
| | 111.00 | 108.56 | -2.44 | -2.20 |
| Avg | NM | NM | -0.14 | -0.12 |
| Std dev | NM | NM | 1.29 | 1.17 |

TABLE 21 (cont)

Effect of water immersion on surface area

| Sample 1676- | Area, in² Before | Area, in² After | Area Increase in² | Area Increase % |
|---|---|---|---|---|
| 48 - 9 Item 9 | 106.02 | 106.12 | 0.10 | 0.09 |
|  | 107.68 | 107.77 | 0.09 | 0.08 |
|  | 107.13 | 107.13 | 0.00 | 0.00 |
|  | 107.13 | 106.95 | -0.18 | -0.17 |
|  | 107.49 | 106.95 | -0.54 | -0.50 |
|  | 105.67 | 106.03 | 0.36 | 0.34 |
|  | 106.76 | 106.76 | 0.00 | 0.00 |
|  | 107.67 | 107.67 | 0.00 | 0.00 |
|  | 108.60 | 108.50 | -0.10 | -0.09 |
| Avg | NM | NM | -0.03 | -0.03 |
| Std dev | NM | NM | 0.24 | 0.23 |
| 48 - 11 Item 4 | 106.38 | 105.80 | -0.58 | -0.55 |
|  | 106.38 | 105.45 | -0.93 | -0.87 |
|  | 106.38 | 105.80 | -0.58 | -0.55 |
|  | 106.38 | 106.38 | 0.00 | 0.00 |
|  | 106.38 | 105.80 | -0.58 | -0.55 |
|  | 106.38 | 105.80 | -0.58 | -0.55 |
|  | 106.38 | 106.38 | 0.00 | 0.00 |
|  | 106.38 | 105.80 | -0.58 | -0.55 |
|  | 89.36 | 88.87 | -0.49 | -0.55 |
| Avg | NM | NM | -0.48 | -0.46 |
| Std dev | NM | NM | 0.30 | 0.28 |
| 48 - 12 Item 5 | 109.15 | 109.33 | 0.18 | 0.16 |
|  | 108.04 | 108.23 | 0.19 | 0.18 |
|  | 107.86 | 108.05 | 0.19 | 0.18 |
|  | 109.52 | 109.71 | 0.19 | 0.17 |
|  | 109.15 | 109.15 | 0.00 | 0.00 |
|  | 108.05 | 108.41 | 0.36 | 0.33 |
|  | 108.23 | 108.41 | 0.18 | 0.17 |
|  | 109.15 | 109.33 | 0.18 | 0.16 |
|  | 108.96 | 109.15 | 0.19 | 0.17 |
| Avg | NM | NM | 0.18 | 0.17 |
| Std dev | NM | NM | 0.09 | 0.08 |

| Sample 1676- | Area, in² Before | Area, in² After | Area Increase in² | Area Increase % |
|---|---|---|---|---|
| 50 - 4 Item 27 | 103.30 | 102.24 | -1.06 | -1.03 |
|  | 102.41 | 101.53 | -0.88 | -0.86 |
|  | 102.77 | 102.60 | -0.17 | -0.17 |
|  | 102.51 | 102.87 | 0.36 | 0.35 |
|  | 103.12 | 102.96 | -0.16 | -0.16 |
|  | 102.33 | 101.99 | -0.34 | -0.33 |
|  | 104.40 | 103.68 | -0.72 | -0.69 |
|  | 102.60 | 102.78 | 0.18 | 0.18 |
|  | 103.53 | 103.50 | -0.03 | -0.03 |
| Avg | NM | NM | -0.31 | -0.30 |
| Std dev | NM | NM | 0.48 | 0.47 |
| 50 - 5 Item 26 | 42.05 | 41.83 | -0.22 | -0.52 |
|  | 83.67 | 82.30 | -1.37 | -1.64 |
|  | 88.82 | 88.35 | -0.47 | -0.53 |
| Avg | NM | NM | -0.69 | -0.90 |
| Std dev | NM | NM | 0.60 | 0.64 |

Note:  ND = No data
       NM = Not meaningful

# TABLE 22

## Summary

## effect of water immersion on surface area

| Item no | Sample 1676- | Area Increase | |
|---|---|---|---|
| | | $In^2$ | % |
| 4 | 48-11 | -0.48 | -0.46 |
| 5 | 48-12 | 0.18 | 0.17 |
| 9 | 48-9 | -0.03 | -0.03 |
| 11 | 46-10 | -2.71 | -2.43 |
| 14 | 48-7 | 0.65 | 0.59 |
| 15 | 48-6 | 0.66 | 0.61 |
| 17 | 48-1 | 0.14 | 0.13 |
| 18 | 48-8 | -0.14 | -0.12 |
| 19 | 46-5 | 0.55 | 0.51 |
| 21 | 46-13 | -0.28 | -0.26 |
| 22 | 46-8 | 0.16 | 0.15 |
| 23 | 46-7 | 0.42 | 0.38 |
| 26 | 50-5 | -0.69 | -0.90 |
| 27 | 50-4 | -0.31 | -0.30 |

The foam densities were also typical of what we would expect. The density of Item 24 is higher, but seems to be typical of silicone foams. The high density of Item 25 is a result of the high loading of solids in the foam. The foam almost acts as a carrier for the fire resistant additives.

The most important finding was the fact that water immersion had no significant effect upon either the closed cell content or the density, except for the phenolic foam (Item 26). The decrease in density of the phenolic foam correlates with the weight loss (Table 20). Neither the loss in weight nor the corresponding loss in density altered the excellent flame spread properties of the phenolic foam, however, as was shown in Tables 16 and 18.

Effect On Compressive Properties - The compressive strength at 10% deflection was measured and the modulus was calculated both before and after water immersion. The results are shown in Table 25 along with the average values and the standard deviation. Table 26 summarizes the data.

The compressive strength of Items 4, 11, 17, 18 and 21 decreased slightly, but these changes are relatively minor and of no importance for this foam application.

The low compressive strengths shown for the silicone and Hypol samples (Items 24 and 25) are typical of flexible foams. The low value for phenolic (Item 26) is indicative of a weak foam.

Foams to be used as sealants for stoppings have no fixed requirement for compressive properties, but the general requirement is that the foam have sufficient strength to endure the conditions it will encounter. The compressive properties of all these foams are likely adequate for use on stoppings.

Summary of Effect of Water Immersion - In general, the foams withstood the effects of 96 hour water immersion very well. Most of the observed changes were relatively minor and not sufficient to cause rejection of the foam. Some of the changes, however, might indicate that longer periods of water immersion could cause greater changes. The pertinent data for all tests are summarized in Table 27.

The data do show a few things that concern us, but at this time their significance is not clear. They include:

a) low closed cell contents for Items 24, 25 and 26
b) high weight loss values for Items 25 and possibly 26
c) poor wet strength for Item 25 and possibly 26
d) an increase in the flame spread index for Items 11, 14, 18 and 22 by E162-CCC-2
e) decreased compressive strength for Items 11, 17, 18 and 21.

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TABLE 23

Effect of water immersion on closed cell and density

| Sample 1676- | % Closed cell Before | After | Density, lbs/ft Before | After |
|---|---|---|---|---|
| 46-5 Item 19 | 88.6 | 92.1 | 2.05 | 2.02 |
|  | 92.0 | 91.1 | 2.04 | 2.01 |
|  | 89.2 | 92.2 | 2.04 | 2.03 |
|  | 87.8 | 91.3 | 2.03 | 2.02 |
|  | 88.6 | 91.7 | 2.03 | 2.01 |
| Avg | 89.2 | 91.7 | 2.04 | 2.02 |
| Std dev | 1.6 | 0.5 | 0.01 | 0.01 |
| 46-7 Item 23 | 93.1 | 91.7 | 2.12 | 2.10 |
|  | 92.9 | 89.9 | 2.12 | 2.11 |
|  | 92.2 | 94.5 | 2.12 | 2.12 |
|  | 92.1 | 95.2 | 2.14 | 2.12 |
|  | 94.6 | 92.7 | 2.14 | 2.08 |
| Avg | 93.0 | 92.8 | 2.13 | 2.11 |
| Std dev | 1.0 | 2.1 | 0.01 | 0.02 |
| 46-8 Item 22 | 86.3 | 93.9 | 2.13 | 2.21 |
|  | 90.4 | 93.2 | 2.15 | 2.20 |
|  | 89.9 | 93.3 | 2.17 | 2.21 |
|  | 90.8 | 90.2 | 2.14 | 2.19 |
|  | 90.3 | 93.7 | 2.19 | 2.23 |
| Avg | 89.5 | 92.9 | 2.16 | 2.21 |
| Std dev | 1.8 | 1.5 | 0.02 | 0.01 |

| Sample 1676- | % Closed cell Before | After | Density, lbs/ft Before | After |
|---|---|---|---|---|
| 46-10 Item 11 | 95.3 | 89.5 | 2.12 | 2.06 |
|  | 95.3 | 91.5 | 2.12 | 2.14 |
|  | 95.5 | 91.9 | 2.08 | 2.08 |
|  | 95.8 | 88.9 | 2.17 | 2.14 |
|  | 94.0 | 91.6 | 2.13 | 2.18 |
| Avg | 95.2 | 90.7 | 2.11 | 2.12 |
| Std dev | 0.7 | 1.4 | 0.02 | 0.05 |
| 46-13 Item 21 | 91.0 | 93.9 | 2.39 | 2.34 |
|  | 89.9 | 91.2 | 2.36 | 2.30 |
|  | 94.2 | 90.4 | 2.38 | 2.30 |
|  | 94.2 | 91.2 | 2.34 | 2.31 |
|  | 92.0 | 84.1 | 2.37 | 2.31 |
| Avg | 92.3 | 90.2 | 2.37 | 2.31 |
| Std dev | 1.9 | 3.6 | 0.02 | 0.02 |
| 48-1 Item 17 | 88.6 | 94.5 | 2.17 | 2.26 |
|  | 87.2 | 91.2 | 2.15 | 2.30 |
|  | 89.2 | 94.5 | 2.27 | 2.23 |
|  | 98.5 | 91.5 | 2.19 | 2.21 |
|  | 92.4 | 96.0 | 2.23 | 2.25 |
| Avg | 91.2 | 93.5 | 2.20 | 2.25 |
| Std dev | 4.5 | 2.1 | 0.05 | 0.03 |

| Sample 1676- | % Closed cell Before | After | Density, lbs/ft Before | After |
|---|---|---|---|---|
| 48-6 Item 15 | 91.8 | 91.8 | 2.41 | 2.33 |
|  | 93.1 | 92.2 | 2.35 | 2.36 |
|  | 93.1 | 91.4 | 2.33 | 2.33 |
|  | 93.6 | 91.3 | 2.36 | 2.38 |
|  | 98.3 | 90.3 | 2.53 | 2.41 |
| Avg | 94.0 | 91.4 | 2.40 | 2.36 |
| Std dev | 2.5 | 0.7 | 0.08 | 0.03 |
| 48-7 Item 14 | 90.0 | 97.0 | 2.02 | 2.03 |
|  | 91.0 | 95.1 | 2.03 | 2.02 |
|  | 91.7 | 93.9 | 2.02 | 2.03 |
|  | 93.2 | 99.4 | 2.04 | 2.04 |
|  | 94.7 | 93.4 | 2.01 | 1.99 |
| Avg | 92.1 | 95.8 | 2.02 | 2.02 |
| Std dev | 1.9 | 2.5 | 0.01 | 0.02 |
| 48-8 Item 18 | 97.5 | 97.2 | 2.20 | 2.20 |
|  | 94.3 | 97.0 | 2.21 | 2.21 |
|  | 93.8 | 97.0 | 2.28 | 2.15 |
|  | 93.7 | 97.0 | 2.19 | 2.21 |
|  | 94.5 | 97.0 | 2.24 | 2.22 |
| Avg | 94.8 | 97.0 | 2.22 | 2.20 |
| Std dev | 1.6 | 0.1 | 0.04 | 0.03 |

TABLE 23 (cont)

Effect of water immersion on closed cell and density

| Sample 1676- | % Closed cell Before | After | Density, lbs/ft Before | After |
|---|---|---|---|---|
| 48-9 Item 9 | 87.4 | 85.1 | 2.20 | 2.15 |
|  | 87.0 | 85.8 | 2.19 | 2.15 |
|  | 88.1 | 88.9 | 2.20 | 2.15 |
|  | 92.0 | 89.8 | 2.26 | 2.17 |
|  | 89.3 | 89.8 | 2.26 | 2.16 |
| Avg | 88.8 | 87.9 | 2.22 | 2.16 |
| Std dev | 2.0 | 2.3 | 0.03 | 0.01 |
| 48-11 Item 4 | 98.4 | 96.9 | 2.18 | 2.23 |
|  | 98.7 | 97.0 | 2.23 | 2.20 |
|  | 100 | 97.0 | 2.20 | 2.19 |
|  | 98.3 | 97.0 | 2.18 | 2.18 |
|  | 97.8 | 97.0 | 2.20 | 2.20 |
| Avg | 98.6 | 97.0 | 2.20 | 2.20 |
| Std dev | 0.8 | 0.0 | 0.02 | 0.02 |
| 48-12 Item 5 | 89.8 | 87.1 | 2.05 | 1.94 |
|  | 93.2 | 91.5 | 2.02 | 1.94 |
|  | 94.8 | 91.1 | 2.02 | 1.96 |
|  | 89.8 | 92.6 | 2.04 | 1.94 |
|  | 96.4 | 89.0 | 2.00 | 1.93 |
| Avg | 92.8 | 90.3 | 2.03 | 1.94 |
| Std dev | 3.0 | 2.2 | 0.02 | 0.01 |

| Sample 1676- | % Closed cell Before | After | Density, lbs/ft Before | After |
|---|---|---|---|---|
| 50-2 Item 24 | 13.9 | No Samples | 26.0 | No Samples |
|  | 23.9 |  | 26.5 |  |
|  | 23.1 |  | 27.2 |  |
|  | 28.5 |  | 27.1 |  |
|  | 26.6 |  | 27.4 |  |
| Avg | 23.2 |  | 26.8 |  |
| Std dev | 5.6 |  | 0.6 |  |
| 50-3 Item 25 | 8.7 | 12.7 | 14.2 | 15.4 |
|  | 9.9 | 16.7 | 13.1 | 14.6 |
|  | 9.8 | 9.0 | 14.0 | 15.1 |
|  | 9.9 | 9.2 | 13.4 | 14.5 |
|  | 8.8 | 13.0 | 13.1 | 14.3 |
| Avg | 9.4 | 12.1 | 13.6 | 14.8 |
| Std dev | 0.6 | 3.1 | 0.5 | 0.5 |
| 50-5 Item 26 | 1.1 | 0.0 | 2.37 | 2.39 |
|  | 0.3 | 1.2 | 2.50 | 1.48 |
|  | 0.8 | 1.2 | 2.45 | 1.54 |
|  | 0.5 | 0.2 | 2.34 | 2.25 |
|  | 0.4 | 1.2 | 2.51 | 1.57 |
| Avg | 0.6 | 0.8 | 2.43 | 1.85 |
| Std dev | 0.4 | 0.6 | 0.08 | 0.44 |

# TABLE 24

## Summary

## effect of water immersion on closed cell and foam density

| Item no | Sample 1676- | % Closed cell Before | After | Density, pcf Before | After |
|---------|--------------|----------------------|-------|---------------------|-------|
| 4 | 48-11 | 98.6 | 97.0 | 2.20 | 2.20 |
| 5 | 48-12 | 92.8 | 90.3 | 2.03 | 1.94 |
| 9 | 48-9 | 88.8 | 87.9 | 2.22 | 2.16 |
| 11 | 46-10 | 95.2 | 90.7 | 2.11 | 2.12 |
| 14 | 48-7 | 92.1 | 95.8 | 2.02 | 2.02 |
| 15 | 48-6 | 94.0 | 91.4 | 2.40 | 2.36 |
| 17 | 48-1 | 91.2 | 93.5 | 2.20 | 2.25 |
| 18 | 48-8 | 94.8 | 97.0 | 2.22 | 2.20 |
| 19 | 46-5 | 89.2 | 91.7 | 2.04 | 2.02 |
| 21 | 46-13 | 92.3 | 90.2 | 2.37 | 2.31 |
| 22 | 46-8 | 89.5 | 92.9 | 2.16 | 2.21 |
| 23 | 46-7 | 93.0 | 92.8 | 2.13 | 2.11 |
| 24 | 50-2 | 23.2 | No Sample | 26.8 | No Sample |
| 25 | 50-3 | 9.4 | 12.1 | 13.6 | 14.8 |
| 26 | 50-5 | 0.6 | 0.8 | 2.43 | 1.85 |

TABLE 25

Effect of water immersion on compressive properties

| Sample 1676- | 10% Compressive Before | After | Modulus, psi Before | After |
|---|---|---|---|---|
| 46 – 5 Item 19 | 29.0 | 28.2 | 787 | 567 |
| | 28.0 | 28.5 | 756 | 561 |
| | 27.8 | 29.8 | 564 | 794 |
| | 27.3 | 29.1 | 562 | 671 |
| | 27.9 | 28.4 | 561 | 807 |
| Avg | 28.0 | 28.8 | 646 | 680 |
| Std dev | 0.6 | 0.7 | 115 | 118 |
| 46 – 7 Item 23 | 24.0 | 23.4 | 367 | 398 |
| | 23.0 | 22.3 | 581 | 392 |
| | 22.6 | 23.9 | 333 | 370 |
| | – | 22.7 | 245 | 551 |
| | 22.0 | 22.5 | 541 | 320 |
| Avg | 22.9 | 23.0 | 413 | 406 |
| Std dev | 0.8 | 0.7 | 143 | 87 |
| 46 – 8 Item 22 | 25.9 | 28.8 | 786 | 798 |
| | 24.5 | 26.8 | 830 | 637 |
| | 27.0 | 26.7 | 441 | 677 |
| | 26.1 | 26.1 | 542 | 687 |
| | 28.0 | 27.2 | 804 | 722 |
| Avg | 26.3 | 27.1 | 681 | 704 |
| Std dev | 1.3 | 1.0 | 177 | 61 |

| Sample 1676- | 10% Compressive Before | After | Modulus, psi Before | After |
|---|---|---|---|---|
| 46 – 10 Item 11 | 20.4 | 18.5 | 477 | 425 |
| | 19.8 | 17.7 | 396 | 449 |
| | 21.8 | 19.0 | 622 | 414 |
| | 23.1 | 20.2 | 513 | 433 |
| | 19.3 | 19.3 | 442 | 483 |
| Avg | 20.9 | 18.9 | 490 | 441 |
| Std dev | 1.6 | 0.9 | 86 | 27 |
| 46 – 13 Item 21 | 28.4 | 26.9 | 656 | 542 |
| | 27.6 | 27.0 | 643 | 435 |
| | 27.1 | 24.7 | 550 | 716 |
| | 28.0 | 23.5 | 579 | 589 |
| | 27.1 | 25.0 | 523 | 372 |
| Avg | 27.6 | 25.4 | 590 | 531 |
| Std dev | 0.6 | 1.5 | 58 | 134 |
| 48 – 1 Item 17 | 23.7 | 17.4 | 643 | 422 |
| | 22.0 | 17.4 | 686 | 251 |
| | 22.5 | – | 645 | – |
| | 21.4 | 20.4 | 662 | 555 |
| | 23.1 | 19.0 | 775 | 313 |
| Avg | 22.5 | 18.6 | 682 | 385 |
| Std dev | 0.9 | 1.4 | 55 | 133 |

| Sample 1676- | 10% Compressive Before | After | Modulus, psi Before | After |
|---|---|---|---|---|
| 48 – 6 Item 15 | 28.5 | 32.0 | 410 | 817 |
| | 30.8 | 32.1 | 538 | 855 |
| | 32.4 | 30.5 | 635 | 980 |
| | 33.0 | 31.6 | 750 | 956 |
| | 29.8 | 31.9 | 726 | 733 |
| Avg | 30.9 | 31.6 | 612 | 868 |
| Std dev | 1.8 | 0.7 | 140 | 102 |
| 48 – 7 Item 14 | 23.0 | 23.2 | 600 | 602 |
| | 22.3 | 22.5 | 379 | 523 |
| | 22.3 | 21.7 | 332 | 419 |
| | 23.8 | 22.2 | 625 | 548 |
| | 24.1 | 21.6 | 648 | 394 |
| Avg | 23.1 | 22.2 | 517 | 497 |
| Std dev | 0.8 | 0.7 | 149 | 88 |
| 48 – 8 Item 18 | 28.1 | 26.0 | 487 | 500 |
| | 28.5 | 25.0 | 659 | 510 |
| | 30.7 | 24.5 | 710 | 451 |
| | 30.5 | 25.5 | 663 | 519 |
| | 28.5 | 26.7 | 639 | 532 |
| Avg | 29.3 | 25.5 | 632 | 502 |
| Std dev | 1.2 | 0.9 | 85 | 31 |

## TABLE 25 (cont)

### Effect of water immersion on compressive properties

| Sample 1676- | 10% Compressive Before | After | Modulus, psi Before | After |
|---|---|---|---|---|
| 48 – 9 Item 9 | 30.9 | 31.3 | 624 | 651 |
| | 29.6 | 29.5 | 468 | 671 |
| | 29.4 | 29.5 | 547 | 603 |
| | 33.4 | 30.7 | 733 | 583 |
| | 33.2 | 30.9 | 837 | 709 |
| Avg | 31.3 | 30.4 | 642 | 643 |
| Std dev | 1.9 | 0.8 | 147 | 51 |
| 48 – 11 Item 4 | 43.6 | 40.7 | 928 | 1048 |
| | 43.0 | 38.0 | 962 | 625 |
| | 39.9 | 39.0 | 725 | 658 |
| | 40.5 | 31.3 | 881 | 451 |
| | 40.8 | 38.0 | 909 | 816 |
| Avg | 41.6 | 37.4 | 881 | 720 |
| Std dev | 1.6 | 3.6 | 92 | 225 |
| 48 – 12 Item 5 | 21.6 | 22.6 | 608 | 624 |
| | 21.1 | 23.6 | 720 | 639 |
| | 20.4 | 22.6 | 575 | 414 |
| | 22.3 | 23.6 | 498 | 647 |
| | 25.4 | 22.5 | 571 | 381 |
| Avg | 22.2 | 23.0 | 594 | 541 |
| Std dev | 1.9 | 0.6 | 81 | 132 |

| Sample 1676- | 10% Compressive Before | After | Modulus, psi Before | After |
|---|---|---|---|---|
| 50 – 2* Item 24 | 1.7 | No | 10.0 | No |
| | 1.7 | Sample | 8.4 | Sample |
| | 1.4 | " | 10.8 | " |
| | 1.6 | " | 10.1 | " |
| | 1.8 | " | 10.4 | " |
| Avg | 1.6 | " | 9.9 | " |
| Std dev | 0.2 | " | 0.9 | " |
| 50 – 3** Item 25 | 2.8 | 2.5 | 36.8 | 31.9 |
| | 1.9 | 1.9 | 41.6 | 25.2 |
| | 2.7 | 2.2 | 70.9 | 33.1 |
| | 2.1 | 2.7 | 50.8 | 32.7 |
| | 1.8 | 2.2 | 40.5 | 29.9 |
| Avg | 2.3 | 2.3 | 48.1 | 30.6 |
| Std dev | 0.5 | 0.3 | 13.7 | 3.2 |
| 50 – 5 Item 26 | 6.3 | 12.3 | 178 | 643 |
| | 8.7 | 5.8 | 196 | 196 |
| | 5.4 | 8.0 | 118 | 296 |
| | 6.5 | 11.2 | 215 | 464 |
| | 6.0 | 7.0 | 202 | 234 |
| Avg | 6.6 | 8.9 | 182 | 367 |
| Std dev | 1.2 | 2.8 | 38 | 185 |

*  Compressive at 30% deflection; flexible foam.
** Compressive at 20% deflection; flexible foam.

## TABLE 26

### Summary

### effect of water immersion on compressive properties, psi

| Item no | Sample 1676- | 10% Compressive | | Modulus | |
|---|---|---|---|---|---|
| | | Before | After | Before | After |
| 4 | 48-11 | 41.6 | 37.4 | 881 | 720 |
| 5 | 48-12 | 22.2 | 23.0 | 594 | 541 |
| 9 | 48-9 | 31.3 | 30.4 | 644 | 643 |
| 11 | 46-10 | 20.9 | 18.9 | 490 | 441 |
| 14 | 48-7 | 23.1 | 22.2 | 517 | 497 |
| 15 | 48-6 | 30.9 | 31.6 | 612 | 868 |
| 17 | 48-1 | 22.5 | 18.6 | 682 | 385 |
| 18 | 48-8 | 29.3 | 25.5 | 632 | 502 |
| 19 | 46-5 | 28.0 | 28.8 | 646 | 680 |
| 21 | 46-13 | 27.6 | 25.4 | 590 | 531 |
| 22 | 46-8 | 26.3 | 27.1 | 681 | 704 |
| 23 | 46-7 | 22.9 | 23.0 | 413 | 406 |
| 24* | 50-2 | 1.6 | No Sample | 9.9 | No Sample |
| 25** | 50-3 | 2.3 | 2.3 | 48.1 | 30.6 |
| 26 | 50-5 | 6.6 | 8.9 | 182 | 367 |

*Flexible Foam - compressive at 30% deflection
**Flexible Foam - compressive at 20% deflection

TABLE 27

Summary - effect of 96 hours water immersion on foam properties

| Item no | Sample 1676- | Radiant panel, Is E162 Before | E162 After | E162 - CCC-2 Before | CCC-2 After | Radiant panel, smoke area E162 Before | E162 After | E162 - CCC-2 Before | CCC-2 After | % Closed cell Before | After | 10% Compressive strength, psi Before | After | Foam area Increase % | Weight Increase, g 15-30 min | 48 hr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 48-11 | 144 | 152 | 1367 | 1815 | 2814 | 2448 | 6300 | 7003 | 99 | 97 | 42 | 37 | -0.5 | 34 | 0.0 |
| 5 | 48-12 | 2 | 3 | 39 | 61 | 1100 | 1490 | 2468 | 3590 | 93 | 90 | 22 | 23 | 0.2 | 28 | -0.2 |
| 9 | 48-9 | 112 | 176 | 645 | 819 | 1806 | 2358 | 3118 | 3470 | 89 | 88 | 31 | 30 | -0.0 | 47 | -0.8 |
| 11 | 46-10 | 68 | 111 | 781 | 1628 | 2329 | 3250 | 4581 | 4867 | 95 | 91 | 21 | 19 | -2.4 | 30 | -0.2 |
| 14 | 48-7 | 10 | 15 | 696 | 1563 | 1449 | 1790 | 3210 | 4383 | 92 | 96 | 23 | 22 | 0.6 | 29 | -0.1 |
| 15 | 48-6 | 12 | 10 | 1245 | 1493 | 1595 | 2133 | 3738 | 5560 | 94 | 91 | 31 | 32 | 0.6 | 29 | 0.0 |
| 17 | 48-1 | 65 | 56 | 1551 | 1862 | 1770 | 1750 | 5280 | 4560 | 91 | 94 | 23 | 19 | 0.1 | 21 | -0.2 |
| 18 | 48-8 | 66 | 89 | 2845 | 4177 | 1912 | 1848 | 4587 | 5017 | 95 | 97 | 29 | 26 | -0.1 | 43 | -0.1 |
| 19 | 46-5 | 41 | 53 | 3185 | 2097 | 1816 | 2383 | 4233 | 4995 | 89 | 92 | 28 | 29 | 0.5 | 42 | -0.2 |
| 21 | 46-13 | 83 | 46 | 2165 | 2737 | 1860 | 2367 | 3335 | 4635 | 92 | 90 | 28 | 25 | -0.3 | 38 | 0.1 |
| 22 | 46-8 | 176 | 245 | 981 | 2312 | 2218 | 3065 | 5600 | 6775 | 90 | 93 | 26 | 27 | 0.2 | 25 | 0.0 |
| 23 | 46-7 | 13 | 33 | 1748 | 1612 | 1533 | 2340 | 3253 | 5490 | 93 | 93 | 23 | 23 | 0.4 | 34 | 0.1 |
| 24 | 50-2 | 75 | 85 | 529 | 103 | 7427 | 9773 | 8025 | 5833 | 23 | ND | 2 | ND | ND | 84 | -1.5 |
| 25 | 50-3 | 16 | 5 | 1 | 9 | 3138 | 4795 | 8400 | 6598 | 9 | 12 | 2 | 2 | ND | 840 | -37 |
| 26 | 50-5 | 3 | 5 | 3 | 2 | 0 | 2975 | 4970+ | 4090 | 1 | 1 | 7 | 9 | -0.9 | 629 | -8 (1 mo) |
| 27 | 50-4 | 97 | 54 | 1219 | 1875 | 3560 | 3625 | 5243 | 7845 | ND | ND | ND | ND | -0.3 | 34 | -0.5 |

Note: ND = No data

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## Dry Aging Tests

Dry-aging tests were conducted to determine if the flame retardants for the candidates were volatile or fugitive. The dry-aging was conducted by storing nine, 6 inch by 18 inch by 1 inch thick samples of each candidate foam in an air circulating oven for 28 days at 100°C. After aging, the samples were removed, allowed to equilibrate at room temperature, weighed and subjected to comparison testing.

Flame spread by the two radiant panel tests and flame penetration tests were used for the comparison. Significant changes in either test values could be considered cause for rejection.

ASTM E162 Tests - Four specimens of the dry aged foam samples were subjected to the ASTM E162 radiant panel test. The results are shown in Table 28 along with the average and standard deviation. The data are summarized and compared with virgin foam in Table 29.

The data show that dry aging did not have much effect on most of the foams. The flame spread properties of Items 18, 22 and 27 deteriorated slightly, and the smoke areas of Items 9, 22, 24 and 26 increased moderately. None of the changes were felt to be significant.

E162-CCC-2 Tests - Four of the dry-aged foam samples were also subjected to the modified radiant panel test. The results are shown in Table 30 along with the average and standard deviation. These data are summarized and compared with the virgin foam samples in Table 31.

The flame spread index of Item 22 increased greatly, and that of Item 24 actually decreased as did the smoke area. The reason for this improvement in properties for the latter candidate is not known. Item 21 was the only foam showing an increase in smoke area. In general; however, the effect of dry aging upon the flame spread properties was negligible.

Changes in Weight - The effect of 28 days dry aging at 100°C on the sample weight is shown in Table 32 along with the average and standard deviation. These data are summarized in Table 33.

The weight loss was relatively low for all but Items 24, 25 and 26, for which the weight loss was excessive. It is likely that 100°C was close to the thermal decomposition temperature of the Hypol-based foam (Item 25), which is basically a flexible foam loaded with mostly inorganics. The reason(s) for the high weight loss for Items 24 and 26 is not at all clear, but since the loss in weight at these elevated temperatures was not accompanied by a significant loss of flame retardancy, the weight loss is probably of no consequence.

Flame Penetration - In the event of a fire near a stopping, it is highly desirable that the stopping maintain its seal as long as possible. In order to maintain the seal, the foam must not only resist ignition and

TABLE 28

ASTM E162 Radiant panel data after dry aging

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 46 - 5 Item 19 | 8.4 | 14.8 | 124 | 6 | 11 | 1940 |
|  | 7.0 | 12.4 | 87 | 7 | 14 | 2450 |
|  | 4.5 | 13.8 | 63 | 7 | 10 | 1560 |
|  | 5.4 | 23.5 | 126 | 9 | 20 | 2520 |
| Avg | 6.3 | 16.1 | 100 | 7.3 | 13.8 | 2118 |
| Std dev | 1.7 | 5.0 | 31 | 1.3 | 4.5 | 453 |
| 46 - 7 Item 23 | 2.8 | 2.4 | 7 | 3 | 18 | (5280) |
|  | 3.9 | 2.5 | 10 | 3 | 13 | 1710 |
|  | 2.8 | 2.5 | 7 | 3 | 12 | 2220 |
|  | 3.2 | 2.7 | 9 | 4 | 11 | 1850 |
| Avg | 3.2 | 2.5 | 8 | 3.3 | 13.5 | 1927 |
| Std dev | 0.5 | 0.1 | 2 | 0.5 | 3.1 | 264 |
| 46 - 8 Item 22 | 7.3 | 88.5 | 645 | 11 | 40 | ND |
|  | 7.3 | 48.5 | 354 | 12 | 40 | 3770 |
|  | 6.0 | 38.8 | 232 | 12 | 36 | 3120 |
|  | 9.2 | 28.5 | 263 | 10 | 36 | 2820 |
| Avg | 7.5 | 51.1 | 374 | 11.3 | 38.0 | 3237 |
| Std dev | 1.3 | 26.3 | 188 | 1.0 | 2.3 | 486 |
| 46 - 10 Item 11 | 8.1 | 11.6 | 94 | 8 | 17 | 2270 |
|  | 8.9 | 102.5 | (913) | 8 | 19 | 2670 |
|  | 6.5 | 22.8 | 148 | 8 | 21 | 2920 |
|  | 6.8 | 9.2 | 62 | 8 | 17 | 2360 |
| Avg | 7.6 | 36.5 | 101 | 8 | 18.5 | 2555 |
| Std dev | 1.1 | 44.4 | 43 | 0 | 1.9 | 298 |

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 48 - 8 Item 18 | 6.8 | 104.3 | 709 | 10 | 21 | 2850 |
|  | 4.7 | 102.8 | 483 | 9 | 13 | 2720 |
|  | 8.1 | 7.0 | 57 | 8 | 10 | 2430 |
|  | 6.0 | 6.4 | 39 | 8 | 7 | 1590 |
| Avg | 6.4 | 55.1 | 322 | 8.8 | 12.8 | 2398 |
| Std dev | 1.4 | 55.9 | 330 | 1.0 | 6.0 | 566 |
| 48 - 9 Item 9 | 2.1 | 60.2 | 127 | 17 | 25 | 2780 |
|  | 2.3 | 63.8 | 145 | 17 | 27 | 3490 |
|  | 4.1 | 58.3 | 236 | 17 | 21 | 1820 |
|  | 4.1 | 61.0 | 247 | 17 | 23 | 2820 |
| Avg | 3.1 | 60.8 | 189 | 17.0 | 24.0 | 2728 |
| Std dev | 1.1 | 2.3 | 62 | 0 | 2.6 | 687 |
| 48 - 11 Item 4 | 4.9 | 50.1 | 243 | 12 | 25 | 2770 |
|  | 4.1 | 32.6 | 132 | 11 | 28 | 2610 |
|  | 4.1 | 38.7 | 157 | 10 | 20 | 2680 |
|  | 5.4 | 28.7 | 153 | 11 | 27 | 3600 |
| Avg | 4.6 | 37.5 | 171 | 11.0 | 25.0 | 2915 |
| Std dev | 0.6 | 9.3 | 49 | 0.8 | 3.6 | 461 |
| 48 - 12 Item 5 | 2.9 | 1.0 | 3 | <3 | 14 | 1750 |
|  | 1.6 | 1.0 | 2 | <3 | 10 | (980+) |
|  | 2.9 | 1.0 | 3 | <3 | 9 | 890 |
|  | 2.1 | 1.0 | 2 | <3 | 10 | 1080 |
| Avg | 2.4 | 1.0 | 2 | <3 | 10.8 | 1240 |
| Std dev | 0.6 | 0.0 | 1 | 0 | 2.2 | 452 |

TABLE 28 (cont)

ASTM E162 Radiant panel data after dry aging

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 46 - 13 Item 21 | 7.3 | 9.0 | 66 | 7 | 8 | 1520 |
|  | 7.3 | 5.5 | 40 | 7 | 10 | 2020 |
|  | 8.3 | 9.6 | 79 | 7 | 8 | (900+) |
|  | 5.4 | 19.6 | 105 | 9 | 20 | 2320 |
| Avg | 7.0 | 10.9 | 73 | 7.5 | 11.5 | 1953 |
| Std dev | 1.2 | 6.0 | 27 | 1.0 | 5.7 | 404 |
| 48 - 1 Item 17 | 6.7 | 6.3 | 42 | 7 | 9 | 790 |
|  | 6.5 | 5.7 | 37 | 7 | 9 | 1470 |
|  | 5.2 | 22.3 | 116 | 7 | 9 | 1230 |
|  | 5.7 | 7.7 | 43 | 7 | 8 | 1380 |
| Avg | 6.0 | 10.5 | 59 | 7.0 | 8.8 | 1218 |
| Std dev | 0.7 | 7.9 | 38 | 0.0 | 0.5 | 302 |
| 48 - 6 Item 15 | 3.2 | 1.9 | 6 | 5 | 10 | 1500 |
|  | 5.7 | 1.7 | 9 | 3 | 11 | 2060 |
|  | 6.2 | 2.3 | 14 | 3 | 10 | 1420 |
|  | 4.9 | 2.2 | 11 | 4 | 11 | 1300 |
| Avg | 5.0 | 2.0 | 10 | 3.8 | 10.5 | 1570 |
| Std dev | 1.3 | 0.3 | 3 | 1.0 | 0.6 | 337 |
| 48 - 7 Item 14 | 3.2 | 2.1 | 7 | 3 | 12 | 1990 |
|  | 4.9 | 2.7 | 13 | 5 | 18 | (900+) |
|  | 7.3 | 3.0 | 22 | 5 | 11 | (800+) |
|  | 5.2 | 2.3 | 12 | 5 | 10 | 1870 |
| Avg | 5.1 | 2.5 | 14 | 4.5 | 12.8 | 1930 |
| Std dev | 1.7 | 0.4 | 6 | 1.0 | 3.6 | 85 |

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 50 - 2 Item 24 | 9.7 | 10.0 | 96 | 14 | 6 | 8920 |
|  | 10.0 | 10.1 | 101 | 14 | 7 | 10,920 |
|  | 9.3 | 10.9 | 100 | 14 | 7 | 9990 |
|  | 11.7 | 9.7 | 113 | 14 | 9 | 14,430 |
| Avg | 10.2 | 10.1 | 103 | 14.0 | 7.3 | 11,065 |
| Std dev | 1.1 | 0.5 | 7 | 0 | 1.3 | 2388 |
| 50 - 3 Item 25 | 4.9 | 1.0 | 5 | <3 | 3 | 3090 |
|  | 5.4 | 1.0 | 5 | <3 | 4 | 5170 |
|  | 5.4 | 1.0 | 5 | <3 | 3 | 3240 |
|  | 3.7 | 1.0 | 4 | <3 | 2 | 1730 |
| Avg | 4.8 | 1.0 | 5 | <3 | 3.0 | 3308 |
| Std dev | 0.8 | 0 | 1 | - | 0.8 | 1415 |
| 50 - 4 Item 27 | 9.7 | 32.5 | 316 | 9 | 23 | 2250 |
|  | 8.1 | 10.5 | 85 | 8 | 24 | 3430 |
|  | 8.3 | 52.4 | 433 | 8 | 31 | 4260 |
|  | 8.4 | 55.6 | 468 | 8 | 32 | 2910 |
| Avg | 8.6 | 37.8 | 326 | 8.3 | 27.5 | 3213 |
| Std dev | 0.7 | 20.9 | 173 | 0.5 | 4.7 | 849 |
| 50 - 5 Item 26 | 2.8 | 1.0 | 3 | 0 | 1.8 | 1230+ |
| Avg | 2.8 | 1.0 | 3 | 0 | 1.8 | 1230+ |
| Std dev | NM | NM | NM | NM | NM | NM |

Note: ND = No data
NM = Not meaningful

-76-

## TABLE 29

### ASTM E162 Radiant panel - summary of effect of dry aging

| Item no | Sample 1676- | O Before | O After | F Before | F After | Is Before | Is After | In burned Before | In burned After | Peak smoke Before | Peak smoke After | Smoke area Before | Smoke area After |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 48-11 | 4.8 | 4.6 | 30.3 | 37.5 | 144 | 171 | 11.4 | 11.0 | 24.6 | 25.0 | 2814 | 2915 |
| 5 | 48-12 | 2.4 | 2.4 | 1.0 | 1.0 | 2 | 2 | 1.0 | <3 | 11.0 | 10.8 | 1100 | 1240 |
| 9 | 48-9 | 1.9 | 3.1 | 59.7 | 60.8 | 112 | 189 | 11.3 | 17.0 | 22.1 | 24.0 | 1806 | 2728 |
| 11 | 46-10 | 3.5 | 7.6 | 19.8 | 36.5 | 68 | 101 | 6.5 | 8.0 | 18.8 | 18.5 | 2329 | 2555 |
| 14 | 48-7 | 4.2 | 5.1 | 2.5 | 2.5 | 10 | 14 | 3.5 | 4.5 | 11.5 | 12.8 | 1449 | 1930 |
| 15 | 48-6 | 5.7 | 5.0 | 2.2 | 2.0 | 12 | 10 | 3.0 | 3.8 | 16.1 | 10.5 | 1595 | 1570 |
| 17 | 48-1 | 5.1 | 6.0 | 12.4 | 10.5 | 65 | 59 | 4.0 | 7.0 | 13.0 | 8.8 | 1770 | 1218 |
| 18 | 48-8 | 7.3 | 6.4 | 9.4 | 55.1 | 66 | 322 | 4.5 | 8.8 | 11.5 | 12.8 | 1912 | 2398 |
| 19 | 46-5 | 5.6 | 6.3 | 7.4 | 16.1 | 41 | 100 | 3.0 | 7.3 | 13.9 | 13.8 | 1816 | 2118 |
| 21 | 46-13 | 5.5 | 7.0 | 15.4 | 10.9 | 83 | 73 | 5.5 | 7.5 | 13.1 | 11.5 | 1860 | 1953 |
| 22 | 46-8 | 5.7 | 7.5 | 35.5 | 51.1 | 176 | 374 | 10.0 | 11.3 | 27.3 | 38.0 | 2218 | 3237 |
| 23 | 46-7 | 4.9 | 3.2 | 2.7 | 2.5 | 13 | 8 | 3.0 | 3.3 | 12.0 | 13.5 | 1533 | 1927 |
| 24 | 50-2 | 8.4 | 10.2 | 8.9 | 10.1 | 75 | 103 | 14.0 | 14.0 | 7.3 | 7.3 | 7427 | 11,065 |
| 25 | 50-3 | 6.6 | 4.8 | 2.4 | 1.0 | 16 | 5 | 3.0 | <3 | 3.0 | 3.0 | 3138 | 3308 |
| 26 | 50-5 | 2.4 | 2.8 | 1.0 | 1.0 | 3 | 3 | <3 | 0 | 0 | 1.8 | 0 | 1230+ |
| 27 | 50-4 | 6.9 | 8.6 | 14.0 | 37.8 | 97 | 326 | 9.3 | 8.3 | 32.0 | 27.5 | 3560 | 3213 |

TABLE 30

E162-CCC-2 Modified radiant panel data after dry aging

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 46 - 5 Item 19 | 9.9 | 251 | 2485 | 18 | 50 | 3930 |
|  | 8.3 | 251 | 2083 | 18 | 48 | 3800 |
|  | 8.0 | 251 | 2008 | 18 | 47 | 4010 |
|  | 8.5 | 234 | 1992 | 18 | 48 | 3430 |
| Avg | 8.7 | 247 | 2142 | 18 | 48.3 | 3793 |
| Std dev | 0.8 | 9 | 232 | 0 | 1.3 | 257 |
| 46 - 7 Item 23 | 4.5 | 193 | 867 | 18 | 45 | 3860 |
|  | 4.6 | 193 | 886 | 18 | 48 | 3120 |
|  | 5.2 | 193 | 1002 | 18 | 40 | 3100 |
|  | 5.4 | 193 | 1040 | 18 | 43 | 3130 |
| Avg | 4.9 | 193 | 949 | 18 | 44.0 | 3303 |
| Std dev | 0.4 | 0 | 85 | 0 | 3.4 | 372 |
| 46 - 8 Item 22 | 15.3 | 218 | 3337 | 18 | 60 | 4990 |
|  | 14.6 | 218 | 3178 | 18 | 64 | 4940 |
|  | 13.3 | 218 | 2895 | 18 | 62 | 3900 |
|  | 13.1 | 218 | 2851 | 18 | 61 | 5470 |
| Avg | 14.1 | 218 | 3065 | 18 | 61.8 | 4825 |
| Std dev | 1.1 | 0 | 232 | 0 | 1.7 | 661 |
| 46 -10 Item 11 | 6.6 | 150 | 987 | 15 | 49 | 3860 |
|  | 6.3 | 150 | 943 | 15 | 52 | 4040 |
|  | 7.6 | 150 | 1140 | 15 | 50 | 3720 |
|  | 10.5 | 150 | 1578 | 15 | 50 | 3920 |
| Avg | 7.8 | 150 | 1162 | 15 | 50.3 | 3885 |
| Std dev | 1.9 | 0 | 290 | 0 | 1.3 | 133 |
| 46 - 13 Item 21 | 8.5 | 234 | 1985 | 18 | 52 | 4370 |
|  | 7.3 | 251 | 1832 | 18 | 47 | 4840 |
|  | 10.2 | 251 | 2565 | 18 | 51 | 6000 |
|  | 9.9 | 251 | 2492 | 18 | 50 | 5290 |
| Avg | 9.0 | 247 | 2219 | 18 | 50.0 | 5125 |
| Std dev | 1.4 | 9 | 365 | 0 | 2.2 | 694 |
| 48 - 1 Item 17 | 10.4 | 251 | 2603 | 18 | 56 | 5190 |
|  | 11.0 | 201 | 2201 | 18 | 56 | 5360 |
|  | 11.0 | 251 | 2748 | 18 | 63 | 4770 |
|  | 7.7 | 251 | 1943 | 18 | 56 | 4390 |
| Avg | 10.0 | 239 | 2374 | 18 | 57.8 | 4928 |
| Std dev | 1.5 | 25 | 369 | 0 | 3.5 | 436 |
| 48 - 6 Item 15 | 5.8 | 168 | 979 | 18 | 32 | 3850 |
|  | 5.8 | 168 | 979 | 18 | 29 | 3330 |
|  | 6.6 | 168 | 1101 | 18 | 34 | 3555 |
|  | 6.3 | 168 | 1053 | 18 | 34 | 3615 |
| Avg | 6.1 | 168 | 1028 | 18 | 32.3 | 3588 |
| Std dev | 0.4 | 0 | 60 | 0 | 2.4 | 214 |
| 48 - 7 Item 14 | 6.6 | 188 | 1233 | 18 | 50 | ND |
|  | 6.1 | 188 | 1150 | 18 | 41 | 3550 |
|  | 7.0 | 188 | 1314 | 18 | 42 | 4530 |
|  | 6.1 | 188 | 1150 | 18 | ND | 3860 |
| Avg | 6.5 | 188 | 1212 | 18 | 44.3 | 3980 |
| Std dev | 0.4 | 0 | 79 | 0 | 4.9 | 501 |

TABLE 30 (cont)

E162-CCC-2 Modified radiant panel data after dry aging

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 50 - 2 Item 24 | 7.2 | 13 | 92 | 12 | 7 | 2440 |
| | 8.9 | 13 | 114 | 12 | 11 | 4000 |
| | 7.7 | 13 | 103 | 12 | 7 | 2250 |
| | 6.1 | 13 | 78 | 12 | 12 | 1810 |
| Avg | 7.5 | 13 | 97 | 12 | 9.3 | 2625 |
| Std dev | 1.2 | 0.3 | 15 | 0 | 2.6 | 954 |
| 50 - 3 Item 25 | 5.7 | 4 | 25 | 3 | - | 2060 |
| | 0.9 | 4 | 4 | 3 | 9 | 7020 |
| | 0.3 | 4 | 1 | 3 | 7 | 5580 |
| | 0.2 | 4 | 1 | 3 | 9 | 9970 |
| Avg | 1.8 | 4 | 8 | 3 | 8.3 | 6158 |
| Std dev | 2.6 | 0 | 11 | 0 | 1.2 | 3286 |
| 50 - 4 Item 27 | 14.6 | 129 | 1888 | 18 | 73 | 4520 |
| | 10.2 | 126 | 1288 | 18 | 48 | 3420 |
| | 13.9 | 134 | 1863 | 18 | 77 | 4820 |
| | 10.1 | 133 | 1336 | 18 | 62 | 5030 |
| Avg | 12.2 | 131 | 1594 | 18 | 65.8 | 4448 |
| Std dev | 2.4 | 4 | 326 | 0 | 13.7 | 716 |
| 50 - 5 Item 26 | 8.0 | 1.0 | 8 | <3 | 3.0 | 5430 |
| Avg | 8.0 | 1.0 | 8 | <3 | 3.0 | 5430 |
| Std dev | NM | NM | NM | NM | NM | NM |

| Sample 1676- | Q | F | Is | In burned | Smoke Peak | Smoke Area |
|---|---|---|---|---|---|---|
| 48 - 8 Item 18 | 8.0 | 218 | 1748 | 18 | 48 | 3070 |
| | 11.4 | 218 | 2479 | 18 | 53 | 6560 |
| | 13.1 | 251 | 3298 | 18 | 53 | 3750 |
| | 11.4 | 168 | 1898 | 18 | 49 | 3370 |
| Avg | 11.0 | 214 | 2356 | 18 | 50.8 | 4188 |
| Std dev | 2.1 | 34 | 703 | 0 | 2.6 | 1606 |
| 48 - 9 Item 9 | 6.0 | 168 | 1004 | 18 | 23 | 3670 |
| | 8.0 | 134 | 1079 | 18 | 26 | (2570+) |
| | 6.0 | 176 | 1054 | 18 | 23 | 3080 |
| | 8.0 | 134 | 1079 | 18 | 23 | 2870 |
| Avg | 7.0 | 153 | 1054 | 18 | 23.8 | 3207 |
| Std dev | 1.2 | 22 | 35 | 0 | 1.5 | 415 |
| 48 - 11 Item 4 | 8.0 | 176 | 1413 | 18 | 24 | 4390 |
| | 8.0 | 176 | 1413 | 18 | 30 | 5500 |
| | 8.0 | 176 | 1413 | 18 | 27 | 5460 |
| | 7.9 | 176 | 1387 | 18 | ND | 6290 |
| Avg | 8.0 | 176 | 1407 | 18 | 27.0 | 5410 |
| Std dev | 0.1 | 0 | 13 | 0 | 3.0 | 780 |
| 48 - 12 Item 5 | 0.6 | 1 | 0.6 | <3 | 29 | 2500 |
| | 0.4 | 1 | 0.6 | <3 | 32 | 2100 |
| | 0.4 | 1 | 0.4 | <3 | 30 | 2140 |
| | 0.6 | 1 | 0.6 | <3 | 31 | 2440 |
| Avg | 0.5 | 1 | 0.5 | <3 | 30.5 | 2295 |
| Std dev | 0.1 | 0 | 0.1 | 0 | 1.3 | 204 |

Note:   ND = No data
        NM = Not meaningful

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TABLE 31

E162-CCC-2 Modified radiant panel – Summary of effect of dry aging

| Item no | Sample 1676- | Q | | F | | Is | | In burned | | Peak smoke | | Smoke area | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After |
| 4 | 48-11 | 8.0 | 8.0 | 171 | 176 | 1367 | 1407 | 18 | 18 | 68.4 | 27.0 | 6300 | 5410 |
| 5 | 48-12 | 0.4 | 0.5 | 101 | 1 | 39 | 1 | 3 | <3 | 32.1 | 30.5 | 2468 | 2295 |
| 9 | 48-9 | 4.0 | 7.0 | 163 | 153 | 645 | 1054 | 18 | 18 | 34.8 | 23.8 | 3118 | 3207 |
| 11 | 46-10 | 4.6 | 7.8 | 170 | 150 | 781 | 1162 | 18 | 15 | 53.5 | 50.3 | 4581 | 3885 |
| 14 | 48-7 | 4.5 | 6.5 | 156 | 188 | 696 | 1212 | 18 | 18 | 43.1 | 44.3 | 3210 | 3980 |
| 15 | 48-6 | 5.7 | 6.1 | 218 | 168 | 1245 | 1028 | 18 | 18 | 37.9 | 32.3 | 3738 | 3588 |
| 17 | 48-1 | 8.0 | 10.0 | 193 | 239 | 1551 | 2374 | 18 | 18 | 60.9 | 57.8 | 5280 | 4928 |
| 18 | 48-8 | 9.5 | 11.0 | 301 | 214 | 2845 | 2356 | 18 | 18 | 67.5 | 50.8 | 4587 | 4188 |
| 19 | 46-5 | 9.1 | 8.7 | 351 | 247 | 3185 | 2142 | 18 | 18 | 53.8 | 48.3 | 4233 | 3793 |
| 21 | 46-13 | 6.2 | 9.0 | 351 | 247 | 2165 | 2219 | 18 | 18 | 56.5 | 50.0 | 3335 | 5125 |
| 22 | 46-8 | 9.7 | 14.1 | 101 | 218 | 981 | 3065 | 18 | 18 | 75.6 | 61.8 | 5600 | 4825 |
| 23 | 46-7 | 5.8 | 4.9 | 301 | 193 | 1748 | 949 | 18 | 18 | 43.8 | 44.0 | 3253 | 3303 |
| 24 | 50-2 | 40.2 | 7.5 | 13 | 13 | 529 | 97 | 12 | 12 | 6.6 | 9.3 | 8025 | 2625 |
| 25 | 50-3 | 0.7 | 1.8 | 1 | 4 | 1 | 8 | 1 | 3 | 5.5 | 8.3 | 8400 | 6158 |
| 26 | 50-5 | 2.8 | 8.0 | 1 | 1 | 3 | 8 | <3 | <3 | 2 | 3.0 | 4970+ | 5430 |
| 27 | 50-4 | 10.0 | 12.2 | 120 | 131 | 1219 | 1594 | 15 | 18 | 71.8 | 65.8 | 5243 | 4448 |

flame spread, but it must also resist flame penetration. There is no direct correlation between flame spread and flame penetration.

Flame penetration testing was conducted according to procedures developed by the Bureau.[2] Four sample specimens, 6 inches square and 1 inch thick, (from foam 3 to 7 days old) were cut parallel to the rise without the dense foam skin. Weight and size measurements were accurately determined for density calculations.

The test apparatus (Figure 5) consists of the sample holder and flame burner equipment. The equipment is placed in a hood maintained at $75° \pm 2°F$. The fuel source is propane gas. The mirror at the base of the apparatus is used to observe the flame penetration through the sample being tested.

The procedure is as follows:

The pencil-flame burner head is placed vertically above the axis of the hole in the Transite and adjusted to be $2.0 \pm 0.25$ inches from the face of a foam specimen when inserted in place. Before the specimen is inserted, the burner is lit and adjusted to produce a steady test flame with a 1.5 inch-long center blue cone. The test flame temperature measured by a thermocouple $2.0 \pm 0.25$ inches below the burner head was $2,150° \pm 25°F$ for a period of not less than 5 minutes, without a foam specimen in place.

The foam specimen is positioned as quickly as possible on the sample holder, and a timer started. The test continues until flame penetration is observed, or 1000 seconds, at which time the specimen is removed and the flame temperature measured again as described above.

Flame penetration tests were run on both virgin and dry-aged foam samples. These data are shown in Table 34 along with the averages and standard deviation. A summary of the data is shown in Table 35.

Items 18 and 26 have low flame penetration times. Item 26 is highly fire resistant, but upon application of a flame, the foam erodes and shrinks to form a "star" crack or hole. This behavior is typical of many isocyanurate foams. Item 9, 11 and 14 also showed low flame penetration times but it was discovered that the temperature was much higher than standard. Upon retesting the foams at 2150°F, they were found to have good flame penetration times. Unfortunately, we could not retest the dry aged samples, but we would expect them to be satisfactory based upon the mode of failure.

[2]Mitchell, D. W., Murphy, E. M. and Nagy, J. Fire Hazard of Urethane Foam in Mines. BuMines RI 6837, 1968, pp 5-7.
Mitchell, D. W., Nagy and Murphy, E. M. Rigid Foam for Mines. BuMines RI 6366, 1964, pp 16-8.

TABLE 32

Effect of dry aging on weight

| Sample 1676- | Weight Before | After | Weight loss g | % |
|---|---|---|---|---|
| 46 - 5 Item 19 | 56.2 | 54.4 | 1.8 | 3.2 |
| | 59.7 | 58.3 | 1.4 | 2.3 |
| | 60.3 | 58.7 | 1.6 | 2.7 |
| | 56.0 | 54.4 | 1.6 | 2.9 |
| | 60.0 | 58.5 | 1.5 | 2.5 |
| | 60.0 | 58.7 | 1.3 | 2.2 |
| | 57.3 | 55.7 | 1.6 | 2.8 |
| | 55.2 | 54.0 | 1.2 | 2.2 |
| Avg | NM | NM | 1.5 | 2.6 |
| Std dev | NM | NM | 0.2 | 0.4 |
| 46 - 7 Item 23 | 52.8 | 51.5 | 1.3 | 2.5 |
| | 51.7 | 50.1 | 1.6 | 3.1 |
| | 52.7 | 51.2 | 1.5 | 2.8 |
| | 49.0 | 48.0 | 1.0 | 2.0 |
| | 53.0 | 52.9 | 0.1 | 0.2 |
| | 50.7 | 50.0 | 0.7 | 1.4 |
| | 52.0 | 50.6 | 1.4 | 2.7 |
| | 53.8 | 52.8 | 1.0 | 1.9 |
| Avg | NM | NM | 1.1 | 2.1 |
| Std dev | NM | NM | 0.5 | 0.9 |
| 46 - 8 Item 22 | 51.8 | 49.6 | 2.2 | 4.2 |
| | 53.4 | 50.9 | 2.5 | 4.7 |
| | 53.3 | 50.3 | 3.0 | 5.6 |
| | 53.5 | 50.0 | 3.5 | 6.5 |
| | 54.9 | 52.0 | 2.9 | 5.3 |
| | 51.3 | 48.0 | 3.3 | 6.4 |
| | 54.9 | 51.5 | 3.4 | 6.2 |
| | 53.8 | 50.7 | 3.1 | 5.8 |
| Avg | NM | NM | 3.0 | 5.6 |
| Std dev | NM | NM | 0.4 | 0.8 |

| Sample 1676- | Weight Before | After | Weight loss g | % |
|---|---|---|---|---|
| 46 - 10 Item 11 | 54.5 | 52.2 | 2.3 | 4.2 |
| | 53.4 | 51.0 | 2.4 | 4.5 |
| | 48.4 | 46.0 | 2.4 | 5.0 |
| | 53.3 | 50.9 | 2.4 | 4.5 |
| | 51.3 | 48.9 | 2.4 | 4.7 |
| | 52.0 | 49.6 | 2.4 | 4.6 |
| | 46.5 | 44.1 | 2.4 | 5.2 |
| | 56.6 | 54.3 | 2.3 | 4.1 |
| Avg | NM | NM | 2.4 | 4.6 |
| Std dev | NM | NM | 0.0 | 0.4 |
| 46 - 13 Item 21 | 57.0 | 56.0 | 1.0 | 1.8 |
| | 59.5 | 58.8 | 0.7 | 1.2 |
| | 57.0 | 56.2 | 0.8 | 1.4 |
| | 56.0 | 55.0 | 1.0 | 1.8 |
| | 55.6 | 54.7 | 0.9 | 1.6 |
| | 57.9 | 57.0 | 0.9 | 1.6 |
| | 55.6 | 54.9 | 0.7 | 1.3 |
| | 55.4 | 54.5 | 0.9 | 1.6 |
| Avg | NM | NM | 0.9 | 1.5 |
| Std dev | NM | NM | 0.1 | 0.2 |
| 48 - 1 Item 17 | 58.8 | 57.6 | 1.2 | 2.0 |
| | 59.0 | 58.1 | 0.9 | 1.5 |
| | 60.0 | 59.1 | 0.9 | 1.5 |
| | 55.2 | 54.3 | 0.9 | 1.6 |
| | 53.5 | 52.5 | 1.0 | 1.9 |
| | 53.3 | 52.3 | 1.0 | 1.9 |
| | 49.9 | 48.6 | 1.3 | 2.6 |
| | 64.9 | 64.0 | 0.9 | 1.4 |
| Avg | NM | NM | 1.0 | 1.8 |
| Std dev | NM | NM | 0.2 | 0.4 |

| Sample 1676- | Weight Before | After | Weight loss g | % |
|---|---|---|---|---|
| 48 - 6 Item 15 | 62.0 | 60.7 | 1.3 | 2.1 |
| | 61.3 | 59.8 | 1.5 | 2.4 |
| | 62.2 | 61.1 | 1.1 | 1.8 |
| | 62.0 | 60.9 | 1.1 | 1.8 |
| | 63.0 | 61.8 | 1.2 | 1.9 |
| | 59.1 | 58.0 | 1.1 | 1.9 |
| | 54.7 | 52.8 | 1.9 | 3.5 |
| | 62.3 | 60.6 | 1.7 | 2.7 |
| Avg | NM | NM | 1.4 | 2.3 |
| Std dev | NM | NM | 0.3 | 0.6 |
| 48 - 7 Item 14 | 60.6 | 59.5 | 1.1 | 1.8 |
| | 61.1 | 60.0 | 1.1 | 1.8 |
| | 58.7 | 57.4 | 1.3 | 2.2 |
| | 58.5 | 57.5 | 1.0 | 1.7 |
| | 58.2 | 56.9 | 1.3 | 2.2 |
| | 58.7 | 57.6 | 1.1 | 1.9 |
| | 55.5 | 54.3 | 1.2 | 2.2 |
| | 61.0 | 60.3 | 0.7 | 1.1 |
| Avg | NM | NM | 1.1 | 1.9 |
| Std dev | NM | NM | 0.2 | 0.4 |
| 48 - 8 Item 18 | 52.3 | 51.7 | 0.6 | 1.1 |
| | 53.8 | 53.2 | 0.6 | 1.1 |
| | 59.9 | 59.7 | 0.2 | 0.3 |
| | 62.8 | 62.6 | 0.2 | 0.3 |
| | 63.8 | 63.6 | 0.2 | 0.3 |
| | 62.6 | 62.2 | 0.4 | 0.6 |
| | 64.8 | 64.3 | 0.5 | 0.8 |
| | 60.0 | 59.3 | 0.7 | 1.2 |
| Avg | NM | NM | 0.4 | 0.7 |
| Std dev | NM | NM | 0.2 | 0.4 |

TABLE 32 (cont)

Effect of dry aging on weight

| Sample 1676- | Weight Before | After | Weight loss g | % |
|---|---|---|---|---|
| 48 - 9 Item 9 | 58.0 | 54.0 | 4.0 | 6.9 |
| | 54.7 | 51.0 | 3.7 | 6.8 |
| | 58.6 | 55.3 | 3.3 | 5.6 |
| | 62.2 | 59.5 | 2.7 | 4.3 |
| | 55.4 | 51.8 | 3.6 | 6.5 |
| | 60.0 | 56.3 | 3.7 | 6.2 |
| | 59.4 | 56.1 | 3.3 | 5.6 |
| | 58.7 | 55.1 | 3.6 | 6.1 |
| Avg | NM | NM | 3.5 | 6.0 |
| Std dev | NM | NM | 0.4 | 0.8 |
| 48 - 11 Item 4 | 58.6 | 58.9 | -0.3 | -0.5 |
| | 55.9 | 56.0 | -0.1 | -0.2 |
| | 58.5 | 58.7 | -0.2 | -0.3 |
| | 55.5 | 55.8 | -0.3 | -0.5 |
| | 56.0 | 55.9 | 0.1 | 0.2 |
| | 60.2 | 60.6 | -0.4 | -0.7 |
| | 56.2 | 56.9 | -0.7 | -1.2 |
| | 53.0 | 53.0 | 0.0 | 0.0 |
| Avg | NM | NM | -0.2 | -0.4 |
| Std dev | NM | NM | 0.3 | 0.4 |
| 48 - 12 Item 5 | 51.4 | 48.8 | 2.6 | 5.1 |
| | 54.2 | 51.6 | 2.6 | 4.8 |
| | 50.6 | 47.9 | 2.7 | 5.3 |
| | 50.5 | 47.9 | 2.6 | 5.1 |
| | 52.6 | 50.2 | 2.4 | 4.6 |
| | 46.2 | 43.9 | 2.3 | 5.0 |
| | 47.1 | 44.9 | 2.2 | 4.7 |
| | 51.8 | 49.2 | 2.6 | 5.0 |
| Avg | NM | NM | 2.5 | 4.9 |
| Std dev | NM | NM | 0.2 | 0.3 |

| Sample 1676- | Weight Before | After | Weight loss g | % |
|---|---|---|---|---|
| 50 - 2 Item 24 | 780 | 762 | 18 | NM* |
| | 768 | 750 | 18 | NM |
| | 802 | 783 | 19 | NM |
| | 733 | 713 | 20 | NM |
| | 761 | 744 | 17 | NM |
| | 804 | 786 | 18 | NM |
| | 783 | 764 | 19 | NM |
| | 759 | 741 | 18 | NM |
| Avg | NM | NM | 18.4 | NM* |
| Std dev | NM | NM | 0.9 | NM |
| 50 - 3 Item 25 | 831 | 812 | 19 | NM* |
| | 834 | 814 | 20 | NM |
| | 854 | 833 | 21 | NM |
| | 836 | 817 | 19 | NM |
| | 888 | 868 | 20 | NM |
| | 920 | 898 | 22 | NM |
| | 856 | 835 | 21 | NM |
| | 860 | 840 | 20 | NM |
| Avg | NM | NM | 20.3 | NM* |
| Std dev | NM | NM | 1.0 | NM |
| 50 - 4 Item 27 | 60.0 | 57.8 | 2.2 | 3.7 |
| | 60.4 | 58.3 | 2.1 | 3.5 |
| | 59.1 | 56.7 | 2.4 | 4.1 |
| | 53.5 | 51.2 | 2.3 | 4.3 |
| | 55.3 | 53.1 | 2.2 | 4.0 |
| | 56.6 | 54.1 | 2.5 | 4.4 |
| | 59.4 | 56.8 | 2.6 | 4.4 |
| | 52.6 | 48.8 | 3.8 | 7.2 |
| Avg | NM | NM | 2.5 | 4.4 |
| Std dev | NM | NM | 0.5 | 1.2 |

| Sample 1676- | Weight Before | After | Weight loss g | % |
|---|---|---|---|---|
| 50 - 5 Item 26 | 87.6 | 71.5 | 16.1 | 18.4 |
| | 75.3 | 62.4 | 12.9 | 17.1 |
| | 37.1 | 32.1 | 5.0 | 13.5 |
| Avg | NM | NM | 11.3 | 16.3 |
| Std dev | NM | NM | 5.7 | 2.5 |

*Not meaningful

# TABLE 33

## Summary of effect of dry aging on weight

| Item no | Sample 1676- | Weight loss | |
| --- | --- | --- | --- |
| | | g | % |
| 4 | 48-11 | -0.2 | -0.4 |
| 5 | 48-12 | 2.5 | 4.9 |
| 9 | 48-9 | 3.5 | 6.0 |
| 11 | 46-10 | 2.4 | 4.6 |
| 14 | 48-7 | 1.1 | 1.9 |
| 15 | 48-6 | 1.4 | 2.3 |
| 17 | 48-1 | 1.0 | 1.8 |
| 18 | 48-8 | 0.4 | 0.7 |
| 19 | 46-5 | 1.5 | 2.6 |
| 21 | 46-13 | 0.9 | 1.5 |
| 22 | 46-8 | 3.0 | 5.6 |
| 23 | 46-7 | 1.1 | 2.1 |
| 24 | 50-2 | 18.4 | NM* |
| 25 | 50-3 | 20.3 | NM* |
| 26 | 50-5 | 11.3 | 16.3 |
| 27 | 50-4 | 2.5 | 4.4 |

*Not meaningful

Smoke baffle

Pencil-flame
burner head

1.5" blue
cone

Thermocouple

0.5"

Foam specimen
6" X6"

1"

Transite

1.5" diam

SECTION A-A'

Gas torch

3" diam
smoke baffle

Foam specimen

Pencil-flame
burner head

Thermocouple

Transite

A'

Mirror
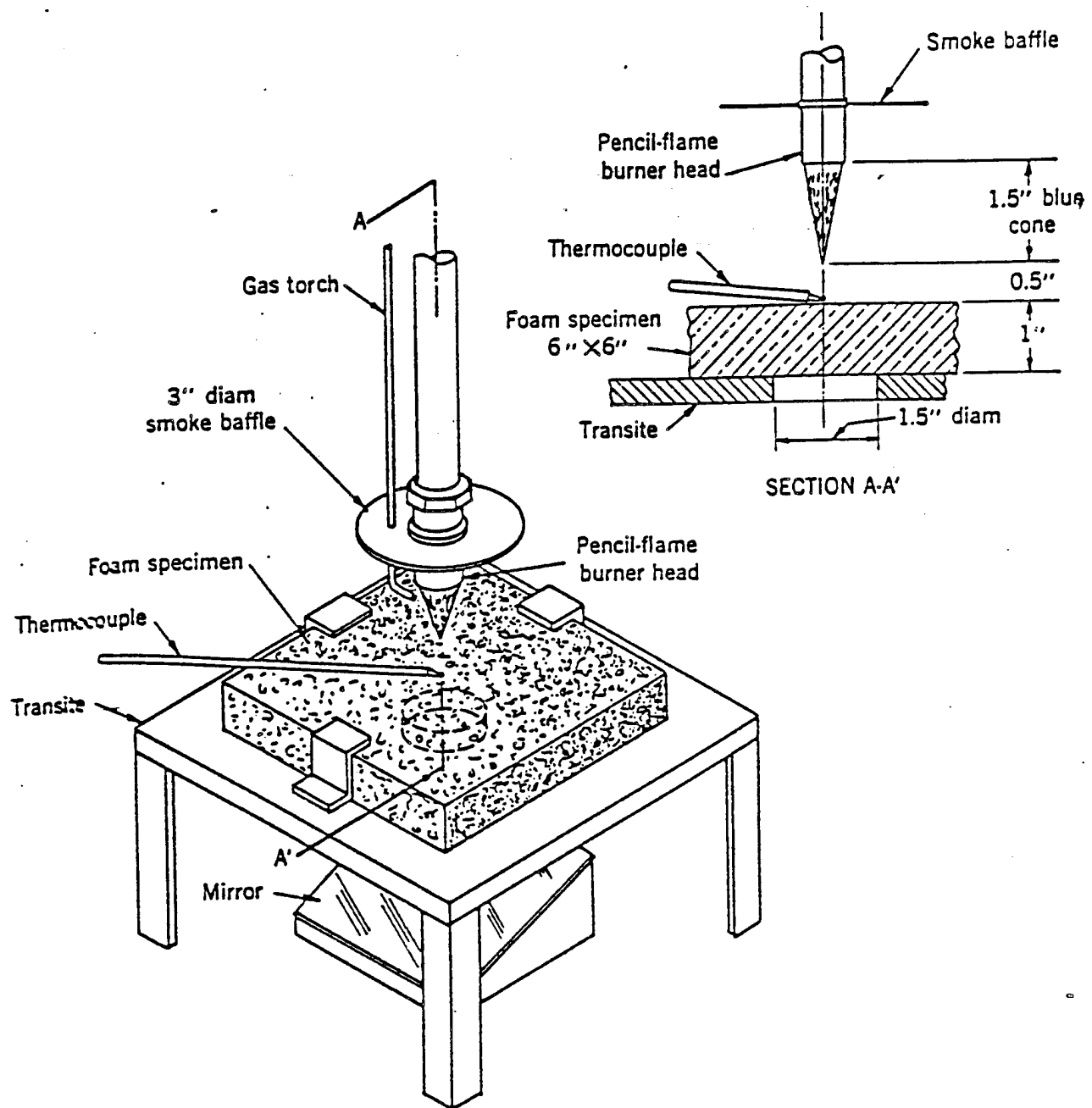
FIGURE 5 - General arrangement of flame-endurance test

TABLE 34

Effect of dry aging on flame penetration

| Sample 1676- | Penetration time, sec Before | After |
|---|---|---|
| 46 - 5 / Item 19 | 1000+ | 868 |
| | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| Avg | 1000+ | 967+ |
| Std dev | NM | NM |
| 46 - 7 / Item 23 | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| Avg | 1000+ | 1000+ |
| Std dev | NM | NM |
| 46 - 8 / Item 22 | 568 | 354 |
| | 258 | 867 |
| | 281 | 1000 |
| | 750 | 150 |
| Avg | 464 | 593 |
| Std dev | 237 | 406 |
| 46 - 10 / Item 11 | 8( 205) | 7 |
| | 12( 851) | 6 |
| | 7(1000+) | 6 |
| | 7( 915) | 6 |
| Avg | 9(743+) | 6? |
| Std dev | 2(364+) | 1 |

| Sample 1676- | Penetration time, sec Before | After |
|---|---|---|
| 46 - 13 / Item 21 | 667 | 1000 |
| | 1000+ | 870 |
| | 716 | 794 |
| | 1000 | 875 |
| Avg | 846+ | 885 |
| Std dev | 179+ | 85 |
| 48 - 1 / Item 17 | 944 | 885 |
| | 862 | 1000+ |
| | 1000 | 1000+ |
| | 226 | 334 |
| Avg | 758 | 805+ |
| Std dev | 359 | 318+ |
| 48 - 6 / Item 15 | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| Avg | 1000+ | 1000+ |
| Std dev | NM | NM |
| 48 - 7 / Item 14 | 297(1000+) | 293 |
| | 340(1000+) | 1000 |
| | 82(1000+) | 636 |
| | 91(1000+) | 1000 |
| Avg | 203(1000+) | 732 |
| Std dev | 135(NM) | 339 |

| Sample 1676- | Penetration time, sec Before | After |
|---|---|---|
| 48 - 8 / Item 18 | 253 | 179 |
| | 176 | 215 |
| | 176 | 192 |
| | 129 | 203 |
| Avg | 184 | 197 |
| Std dev | 51 | 15 |
| 48 - 9 / Item 9 | 8(624) | 6 |
| | 9(1000+) | 7 |
| | 9(1000+) | 6 |
| | 8(ND) | 9 |
| Avg | 9(875+) | 7 |
| Std dev | 1(217+) | 1 |
| 48 - 11 / Item 4 | 991 | 725 |
| | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| | 1000+ | 810 |
| Avg | 998+ | 884+ |
| Std dev | 5+ | 139+ |
| 48 - 12 / Item 5 | 1000+ | 970 |
| | 1000+ | 1000+ |
| | 1000+ | 794 |
| | 1000+ | 1000+ |
| Avg | 1000+ | 941+ |
| Std dev | NM5+ | 99+ |

| Sample 1676- | Penetration time, sec Before | After |
|---|---|---|
| 50 - 2 / Item 24 | 1000+ | 640 |
| | 1000+ | 531 |
| | 931 | 678 |
| | 724 | 500 |
| Avg | 914+ | 587 |
| Std dev | 131 | 85 |
| 50 - 3 / Item 25 | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| Avg | 1000+ | 1000+ |
| Std dev | NM | NM |
| 50 - 4 / Item 27 | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| | 1000+ | 1000+ |
| Avg | 1000+ | 1000+ |
| Std dev | NM | NM |
| 50 - 5 / Item 26 | 82 | 73 |
| | 150 | 153 |
| Avg | 116 | 113 |
| Std dev | 48 | 57 |

Note: Figures inside ( ) indicate retest data.
NM = Not meaningful
ND = No data

## TABLE 35

### Summary of effect of dry aging on flame penetration

| Item no | Sample 1676- | Flame penetration time, sec | |
| --- | --- | --- | --- |
| | | Before | After |
| 4 | 48-11 | 998+ | 884+ |
| 5 | 48-12 | 1000+ | 941+ |
| 9 | 48-9 | 9* (875+) | 7* |
| 11 | 46-10 | 9* (743+) | 6* |
| 14 | 48-7 | 203* (1000+) | 732 |
| 15 | 48-6 | 1000+ | 1000+ |
| 17 | 48-1 | 758 | 805+ |
| 18 | 48-8 | 184 | 197 |
| 19 | 46-5 | 1000+ | 967+ |
| 21 | 46-13 | 846+ | 885 |
| 22 | 46-8 | 464 | 593 |
| 23 | 46-7 | 1000+ | 1000+ |
| 24 | 50-2 | 914+ | 587 |
| 25 | 50-3 | 1000+ | 1000+ |
| 26 | 50-5 | 116 | 113 |
| 27 | 50-4 | 1000+ | 1000+ |

*Flame temperatures were believed to be high during these tests. Figures inside ( ) indicate retest data.

Summary of Dry-Aging Tests - In general, dry aging did not seriously effect the important properties of the foam such as flame spread and flame penetration. The better foams withstood dry aging in good shape.

Selection of the "10 Best" Candidate Foams for Further Evaluation - The program called for the selection of 10 foam candidates for further testing from those having undergone the water immersion testing and evaluation. The immersion tests, however, produced no results for any of the candidates that on their own were cause for rejection. Consequently, the selection of the "10 Best" was made on the flame spread data for the virgin samples.

Although somewhat arbitrary, in order to include the full spectrum of formulations for additional testing, the "10 Best" selected foams, by item number and source, were as follows:

| Item no | Source |
|---------|--------|
| 5 | Callery Chemical/Mine Safety Appliances Co. |
| 9 | Cook Paint & Varnish |
| 11 | Foam Systems Co. |
| 14 | Freeman Chemical |
| 15 | Olin Corporation |
| 17 | Texas Urethanes |
| 23 | Witco Chemical |
| 24 | General Electric |
| 25 | W. R. Grace |
| 26 | Reichhold Chemical, Ltd. |

This group was subjected to advanced testing to gather additional data for the final selection process. The tests were:
- flash and self-ignition temperature
- air permeability
- adhesion to common mine substrates.

Item 4, Callery Chemical Companys Rigimix E/F foam, did not rank sufficiently high to be selected as one of the "10 best foams". It has had widespread use in mines over the past 15 years, however, and was included in the advanced testing as an eleventh material, to be used as a comparison standard for the "10 best".

Ignition Temperatures

Organic materials have rather definite flash and self ignition temperatures. Ideally, foams used on stoppings should have as high ignition temperatures as possible. The lower the ignition temperature, the easier it should be to ignite the foams.

The ignition temperatures of the "10 best" foams were determined using ASTM Method D1929-77, Procedure B. The apparatus essentially consists of a vertical tube furnace containing an inner ceramic tube with an inside diameter of 3" and a length of 10". Heated air is passed up through the inner tube at a velocity of .5ft/min. The foam sample is

lowered into the furnace at various temperatures and the sample observed for evidence of ignition for 5 minutes.

The lowest furnace temperature at which ignition occurs is called the self ignition temperature. To determine the flash ignition temperature, a small pilot flame is located at the exit of the furnace; the minimum temperature at which the gases ignite and flash back to the sample is called the flash ignition temperature.

The ASTM method was not designed for cellular plastics so certain modifications in the sample size were made. Normally, a 3/4" x 3/4" cubical sample weighing $3 \pm 0.5$ g is used. This is not possible with foams, so a sample 3/4" x 3/4" x 1 1/2" was used without reference to weight. In this technique, equal volumes of foam were compared. This is reasonable when it is apparent that essentially equal volumes of foam would be used on stoppings.

The ignition temperatures are shown in Table 36. The self ignition temperatures of all the urethanes were between 500-525°C. The silicone (Item 24) was only 460°C while the phenolic (Item 26) was 600°C. Our previous experience had indicated that the self ignition temperature depended more upon the generic type of foam than upon the actual composition; these data tend to confirm this.

TABLE 36 - Flash and self ignition temperatures
of "10 best" foams

| Item no | Foam 1676- | Ignition temperatures, °C | |
|---|---|---|---|
| | | Flash | Self |
| 4 | 48-11 | 400 | 525 |
| 5 | 48-12 | 525 | 525 |
| 9 | 48-9 | 445 | 525 |
| 11 | 46-10 | 445 | 525 |
| 14 | 48-7 | 435 | 500 |
| 15 | 48-6 | 445 | 500 |
| 17 | 48-1 | 445 | 525 |
| 23 | 46-7 | 445 | 500 |
| 24 | 50-2 | 420 | 460 |
| 25 | 50-3 | 525 | 525 |
| 26 | 50-5 | 600 | 600 |

The flash ignition temperatures were more varied than the self ignition temperatures. Most of the flash ignition temperatures were below 450°C, but Items 5, 25 and 26 were significantly higher. Those foams having flash ignition temperatures above 500°C were also those having a flame spread index by the modified radiant panel (see Table 37) of less than 100. These data show that a flash ignition temperature in excess of 500°C is highly desirable and indicative of a low flame spread index.

TABLE 37 - Ignition temperatures and flame
spread indexes

| Item | Foam | Ignition temperatures, °C | | Radiant panel flame spread index | |
|------|------|-------|------|------|-------|
| no | 1676- | Flash | Self | E162 | CCC-2 |
| 4 | 48-11 | 400 | 525 | 144 | 1367 |
| 5 | 48-12 | 525 | 525 | 2 | 39 |
| 9 | 48-9 | 445 | 525 | 112 | 645 |
| 11 | 46-10 | 445 | 525 | 68 | 781 |
| 14 | 48-7 | 435 | 500 | 10 | 696 |
| 15 | 48-6 | 445 | 500 | 12 | 1245 |
| 17 | 48-1 | 445 | 525 | 65 | 1551 |
| 23 | 46-7 | 445 | 500 | 13 | 1748 |
| 24 | 50-2 | 420 | 460 | 75 | 529 |
| 25 | 50-3 | 525 | 525 | 16 | 1 |
| 26 | 50-5 | 600 | 600 | 3 | 2 |

## Air Permeability

A foam must be capable of stopping the flow of air to be suit-
able for use on stoppings. To determine its permeability to air, the
leak rate of the candidate foams, applied to a porous backing, was meas-
ured at test air pressures of 1, 5 and 10 inches W.G.

One-half inch building insulation board (Celotex) was used as
the porous substrate. Tests had shown that a 2' x 2' sample of uncoated
Celotex had a leak rate of over 2 CFM at 0.4" W.G., well in excess of any
values expected in our tests.

The test apparatus is shown in Figure 6. The top and bottom
framework are fabricated of aluminum, with flanges at the seal surfaces
1/4" thick and 5/8" wide. The outside dimensions of the flanges, and
thus the sample, are 2' x 2'. The samples were sealed in the 1 1/2"
angle iron frame and the frame clamped in between the top and bottom
framework.

Two samples of each foam candidate were prepared on the porous
substrate--one at a nominal 1" thickness, and one somewhat thicker. For

Clamp - all 4 sides

Silicone caulking

Foam sample

Porous substrate

Top frame

Magnehelic
gauge (0-10 in. W.G.)

Gasket

Sample
frame

Bottom
frame

Flow rators

Air supply
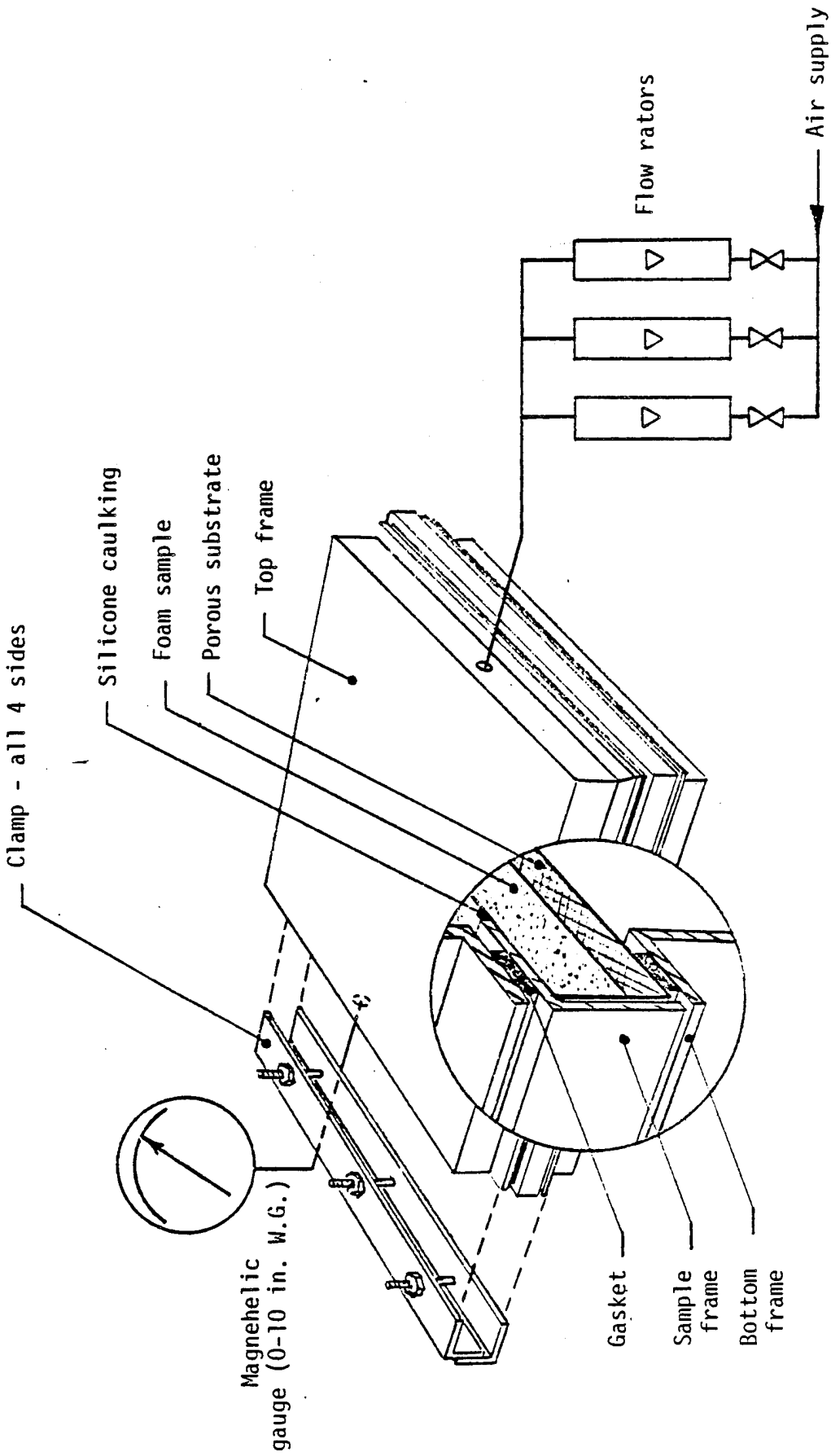
FIGURE 6 - Schematic of air permeability apparatus

the initial test, the 1" sample was sealed into the frame using silicone caulking on the edges and around the face. Total sample surface area exposure was 3.06 sq. ft. For most of the candidates, the leak rate was so low for this sample that the thicker sample was not tested. For those with a significant leak rate on the 1" sample, the thicker sample was also tested.

The results of the air permeability tests are shown in Table 38, and a comparison of the air permeability and closed cell content in Table 39. Most of the foams have very low air permeability and high closed cell content.

We expected the air permeability, for the most part, to be a direct function of the closed cell content. We would expect a closed cell foam to have very low permeability unless the cell walls were very weak and apt to rupture upon the application of pressure. Conversely, a low closed cell content was expected to have high permeability. We could not, however, predict the effect of the surface skin.

Items 25 and 26 had very low closed cell contents and very high air permeability. Item 24 had a low closed cell content and low but variable air permeability. The flexibility and high density may render this foam partially self-sealing. The low and variable permeability of Items 9 and 14 may indicate minor imperfections or a few weak membranes.

The high air permeability of Items 25 and 26 discourages their use on mine stoppings; they would not make adequate seals.

Adhesion Testing

Adhesion test samples of 9 of the "10 best" foams were prepared on the selected substrates by spraying or pouring. Five solid substrates (coal, wood, rock, concrete block and plastic coated brattice cloth) were used under four conditions: (1) dry, (2) dry and coated with rockdust, (3) wet and (4) wet, coated with rockdust. Three metal substrates were also used (1/2 inch hardware cloth, expanded metal lath and Truss Loop*. Originally, 1/2 inch, 1-inch and 2-inch wire screens were to be used as substrates, but it was soon obvious that foam samples could not be built up on the 1-inch and 2-inch screens. Expanded metal lath and Truss Loop were substituted for the 1-inch and 2-inch screens because they seemed to be practical metal backings for use in mines. Later both 3/16 inch and 1/4 inch Arco Durathene polyolefin diamond mesh net were evaluated with one foam system. No tests were conducted on the tenth sample, the phenolic foam (Item 26) due to the lack of a suitable sample. Also, its air permeability essentially excluded it from further consideration.

*Truss loop - a perforated metal lath manufactured by Bostwick Steel Lath Company, Niles Ohio - used as backing for ceramic tile, gunnite, concrete decking, etc.

# TABLE 38 - Air permeability of foams

| Item no | Sample 1676- | Sample thickness, in | Permeability (SCFM/100 ft$^2$) at P of | | |
|---------|--------------|----------------------|-----------|---------|-----------|
|         |              |                      | 1" $H_2O$ | 5" $H_2O$ | 10" $H_2O$ |
| Control | Celotex | 0.5 | 121 | ND | ND |
|         |         | 0.5 | 121 | ND | ND |
| 4 | 48-11 | 0.9 | <.05 | <.05 | <.05 |
| 5 | 48-12 | 0.8 | <.05 | <.05 | <.05 |
| 9 | 48-9 | 1.0 | <.05 | 0.22 | 0.32 |
|   |      | 1.0 | <.05 | <.05 | <.05 |
| 11 | 46-10 | 0.6 | <.05 | <.05 | <.05 |
| 14 | 48-7 | 0.5 - 0.8 | <.05 | 0.05 | 0.11 |
|    |      | 1.0 | <.05 | <.05 | <.05 |
| 15 | 48-6 | 0.5 | <.05 | <.05 | <.05 |
| 17 | 48-1 | 0.8 | <.05 | <.05 | <.05 |
| 23 | 46-7 | 0.8 | <.05 | <.05 | <.05 |
| 24 | 50-2 | 0.3 - 0.5 | <.05 | 0.54 | 0.81 |
|    | —    | 0.5 - 0.8 | <.05 | <.05 | <.05 |
|    |      | 1.0 | <.05 | 0.11 | 0.22 |
| 25 | 50-3 | 1.4 | 65 | 194 | 283 |
|    |      | 1.5 | 89 | 242 | 299 (8"$H_2O$) |
| 26* | 50-5 | 1.0 | 16 | 95 | 181 |

Note: *Single 16.9 in$^2$ sample used
ND = No data

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TABLE 39 - Comparison of closed cell content and
air permeability

| Item no | Sample 1676- | % Closed cell | Thickness, in (Avg) | Air permeability SCFM/100 ft$^2$ at | | P of |
| | | | | 1" H$_2$O | 5" H$_2$O | 10" H$_2$O |
|---|---|---|---|---|---|---|
| 4 | 48-11 | 98 | 0.9 | <.05 | <.05 | <.05 |
| 5 | 48-12 | 93 | 0.8 | <.05 | <.05 | <.05 |
| 9 | 48-9 | 89 | 1.0 | <.05 | .22 | .32 |
| | | | 1.0 | <.05 | <.05 | <.05 |
| 11 | 46-10 | 95 | 0.6 | <.05 | <.05 | <.05 |
| 14 | 48-7 | 92 | 0.5 - 0.8 | <.05 | <.05 | .11 |
| | | | 1.0 | <.05 | <.05 | <.05 |
| 15 | 48-6 | 94 | 0.5 | <.05 | <.05 | <.05 |
| 17 | 48-1 | 91 | 0.8 | <.05 | <.05 | <.05 |
| 23 | 46-7 | 93 | 0.8 | <.05 | <.05 | <.05 |
| 24 | 50-2 | 23 | 0.3 - 0.5 | <.05 | .54 | .81 |
| | | | 0.5 - 0.8 | <.05 | <.05 | <.05 |
| | | | 1.0 | <.05 | .11 | .22 |
| 25 | 50-3 | 9 | 1.4 | 65 | 194 | 283 |
| | | | 1.5 | 89 | 242 | 299 (8"H$_2$O) |
| 26* | 50-5 | 1 | 1.0 | 16 | 95 | 181 |

Note:  *Single 16.9 in$^2$ sample used

The rockdusted substrates were prepared by sprinkling a thin uniform layer of rockdust on the horizontal substrate until the substrate was completely hidden from view. The wet substrates were prepared by hand spraying water onto the horizontal substrates (clean or rockdusted) until the surface was saturated but not pooled with water.

The adhesion samples were prepared by spraying or pouring about one inch of foam onto the substrate and foaming a metal pull tab in place with about one inch of foam (Figure 7). The pull tabs consisted of 4-inch square perforated metal sheets with an attached eyebolt. This is basically the procedure described in the Bureau of Mines Report of Investigation 6366[2] on "Rigid Foam in Mines."

The samples were pulled on an Instron Tensile Testing machine with the foamed substrate mechanically held to the machine. The crosshead was then attached to the eyebolt and the sample pulled to failure. To make the sample size uniform, a die was prepared which cut a circle six inches in diameter while using the eyebolt as the center. Excess foam was cut from around the six inch circle to make certain the foam sample was free from the adjacent foam.

The adhesion data are shown in Table 40 along with the average values for the duplicate samples and the estimated percent of substrate exposed following the pull test. The average adhesion values are shown in Table 41 as a function of the substrate type along with the median and standard deviation. The data in Table 41 are summarized in Table 42. These data show the best adhesion was to metals, followed by concrete. The lowest adhesion was to brattice cloth. (The data for the plastic mesh are not comparable since it is only for one foam.)

These same adhesion averages are also shown in Table 43 as a function of the condition of the substrate along with the median values and standard deviation. These data are summarized in Table 44, which show the adhesion to be much better to dry than to wet substrates. This is what one would expect since the water prevents the foam from effectively reaching and adhering to the substrate.

The presence of rockdust did not adversely effect the adhesion to dry substrates. The adhesion to wetted and rockdusted substrates, on the other hand, was the poorest of all. The foams showing the best adhesion were Items 11 and 4; Item 24 showed the poorest adhesion.

Ideally, the foam should not only adhere to the substrate, but any failure in tension should be within the foam rather than at the substrate. The data in Tables 45 and 46 summarize the mode of failure as a function of both substrate (Table 45) and substrate condition (Table 46). The table notes the percent of substrate exposed at the break. Thus, the lower results indicate a desirable foam-to-foam failure rather than a foam-substrate failure. As with the actual adhesion numbers, the best adhesion (lowest percent substrate exposed) was to metal and concrete block, with plastic brattice cloth being the poorest. Similarly, the
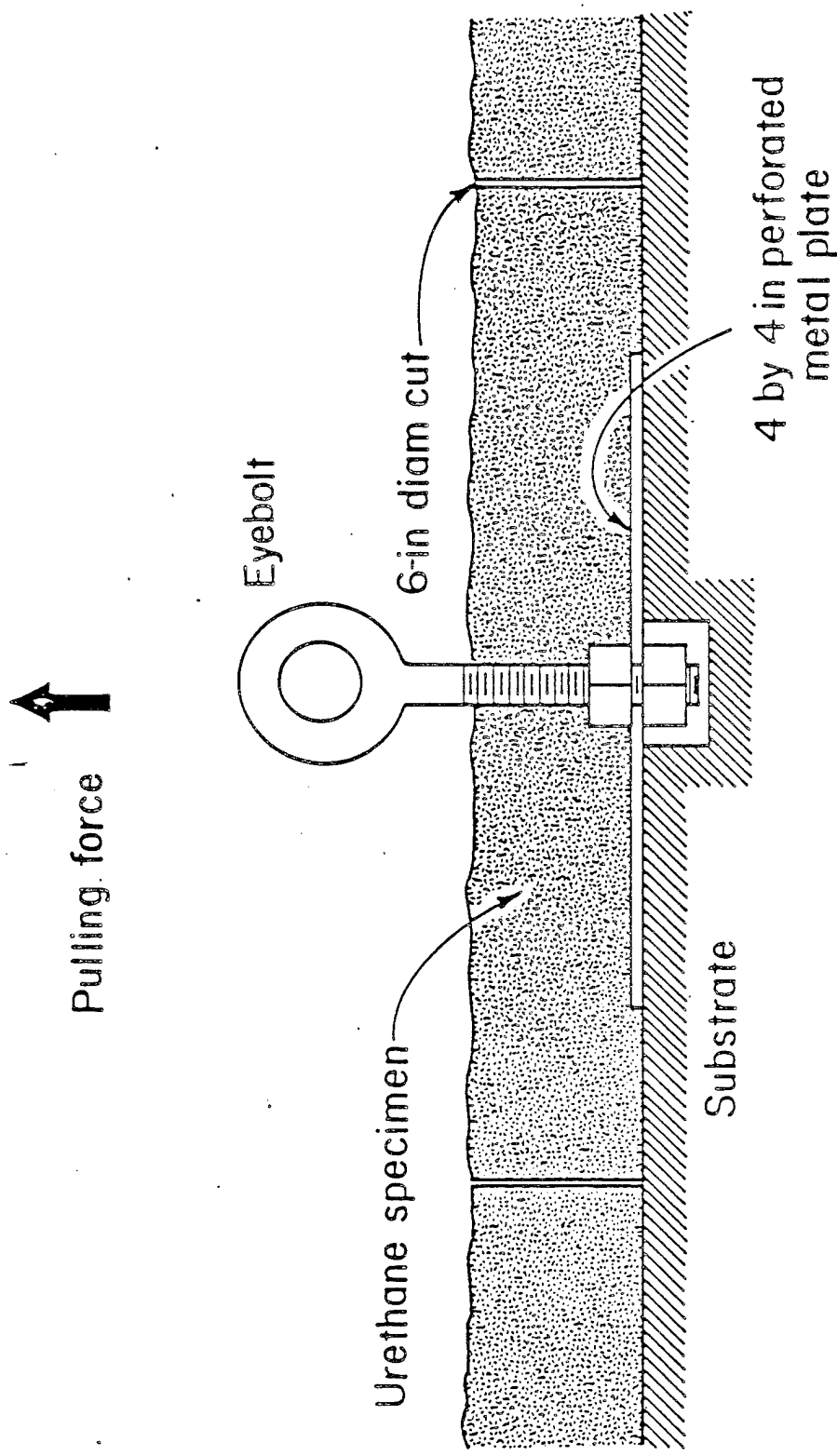
Pulling force



Eyebolt

6-in diam cut

Urethane specimen

4 by 4 in perforated metal plate

Substrate

FIGURE 7 - Pull tab set up for adhesion testing

TABLE 40 – Foam adhesion test data

| Item no | 4 | | | 5 | | | 9 | | | 11 | | | 14 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample 1676- | 48-11(1) | | (3) | 48-12 | | | 48-9 | | | 46-10 | | | 48-7 | | |
| | (2) | | | | | | | | | | | | | | |
| Substrate | lbs | avg | % | lbs | avg | % | lbs | avg | % | lbs | avg | % | lbs | avg | % |
| **Coal** | | | | | | | | | | | | | | | |
| Clean & dry | 248 | 268 | 100 | 100 | 105 | 0 | 128 | 143 | 0 | 190 | 289 | 100 | 254 | 188 | 70(4) |
| Clean & dry | 288 | | 0 | 110 | | 0 | 158 | | 0 | 388 | | 0 | 121 | | 100 |
| Wet | 40 | 40 | 100 | 37 | 44 | 100 | 156 | 136 | 0 | 190 | 205 | 100 | 85 | 69 | 100 |
| Wet | 39 | | 100 | 50 | | 30 | 116 | | 60 | 220 | | 0 | 53 | | 100 |
| Rockdust dry | 296 | 255 | 0 | 110 | 115 | 0 | 110 | 109 | 0 | 324 | 272 | 75 | 190 | 138 | 0 |
| Rockdust dry | 212 | | 50 | 120 | | 0 | 108 | | 0 | 220 | | 90 | 85 | | 100 |
| Rockdust wet | 10 | 8 | 100 | 31 | 16 | 100 | 38 | 66 | 100 | 56 | 48 | 100 | 20 | 21 | 100 |
| Rockdust wet | 5 | | 100 | 0 | | 100 | 94 | | 100 | 40 | | 100 | 21 | | 100 |
| **Rock** | | | | | | | | | | | | | | | |
| Clean & dry | 292 | 246 | 90 | 110 | 112 | 0 | 122 | 132 | 0 | 308 | 328 | 100 | 94 | 104 | 100 |
| Clean & dry | 200 | | 0 | 114 | | 0 | 142 | | 0 | 348 | | 0 | 114 | | 0 |
| Wet | 84 | 72 | 100 | 36 | 18 | 100 | 144 | 88 | 0 | 130 | 141 | 100 | 0 | 7 | 100 |
| Wet | 59 | | 100 | 0 | | 100 | 32 | | 100 | 152 | | 100 | 14 | | 100 |
| Rockdust dry | 190 | 187 | 90 | 108 | 125 | 0 | 126 | 143 | 0 | 264 | 300 | 100 | 163 | 82 | 0 |
| Rockdust dry | 184 | | 100 | 142 | | 100 | 160 | | 0 | 336 | | 0 | 0 | | 100 |
| Rockdust wet | 13 | 92 | 100 | 28 | 21 | 100 | 76 | 61 | 100 | 36 | 34 | 100 | 55 | 42 | 100 |
| Rockdust wet | 170 | | 100 | 13 | | 100 | 46 | | 100 | 32 | | 100 | 28 | | 100 |

TABLE 40 - Foam adhesion test data (cont)

| Item no | 4 | | | 5 | | | 9 | | | 11 | | | 14 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample 1676- | 48-11 (1)(2)(3) | | | 48-12 | | | 48-9 | | | 46-10 | | | 48-7 | | |
| Substrate | lbs | avg | % | lbs | avg | % | lbs | avg | % | lbs | avg | % | lbs | avg | % |
| **Concrete block** | | | | | | | | | | | | | | | |
| Clean & dry | 192 | 236 | 0 | 132 | 127 | 0 | 144 | 156 | 0 | 324 | 352 | 0 | 186 | 183 | 0 |
| Clean & dry | 280 | | 0 | 122 | | 0 | 168 | | 0 | 380 | | 0 | 180 | | 50 |
| Wet | 212 | 246 | 0 | 66 | 83 | 90 | 146 | 144 | 100 | 158 | 160 | 100 | 71 | 66 | 100 |
| Wet | 280 | | 0 | 100 | | 0 | 142 | | 0 | 162 | | 100 | 60 | | 100 |
| Rockdust dry | 352 | 292 | 0 | 134 | 145 | 0 | 118 | 130 | 0 | 420 | 408 | 0 | 276 | 278 | 0 |
| Rockdust dry | 232 | | 0 | 156 | | 0 | 142 | | 0 | 396 | | 0 | 280 | | 0 |
| Rockdust wet | 208 | 181 | 20 | 36 | 35 | 100 | 108 | 114 | 0 | 104 | 117 | 100 | 0 | 0 | 100 |
| Rockdust wet | 154 | | 100 | 34 | | 100 | 120 | | 0 | 130 | | 100 | 0 | | 100 |
| **Wood (oak)** | | | | | | | | | | | | | | | |
| Clean & dry | 208 | 208 | 0 | 100 | 121 | 100 | 122 | 128 | 100 | 316 | 304 | 0 | 0 | 0 | 100 |
| Clean & dry | 208 | | 0 | 142 | | 0 | 134 | | 0 | 292 | | 0 | 0 | | 100 |
| Wet | 80 | 81 | 100 | 34 | 20 | 100 | 164 | 108 | 0 | 288 | 270 | 100 | 62 | 41 | 100 |
| Wet | 82 | | 100 | 6 | | 100 | 52 | | 100 | 252 | | 100 | 20 | | 100 |
| Rockdust dry | 312 | 292 | 0 | 122 | 124 | 0 | 170 | 151 | 0 | 260 | 274 | 100 | 80 | 103 | 100 |
| Rockdust dry | 272 | | 0 | 126 | | 100 | 132 | | 0 | 288 | | 0 | 126 | | 100 |
| Rockdust wet | 51 | 57 | 100 | 0 | 0 | 100 | 118 | 83 | 0 | 126 | 126 | 100 | 0 | 0 | 100 |
| Rockdust wet | 63 | | 100 | 0 | | 100 | 48 | | 100 | 126 | | 100 | 0 | | 100 |

TABLE 40 - Foam adhesion test data (cont)

| Item no | 4 | | | 5 | | | 9 | | | 11 | | | 14 | | |
| Sample 1676- | 48-11(1) | | | 48-12 | | | 48-9 | | | 46-10 | | | 48-7 | | |
| Substrate | lbs | avg(2) | %(3) | lbs | avg | % | lbs | avg | % | lbs | avg | % | lbs | avg | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Brattice cloth** | | | | | | | | | | | | | | | |
| Clean & dry | 130 | 124 | 75 | 81 | 71 | 100 | 92 | 97 | 70 | 132 | 133 | 75 | 73 | 69 | 100 |
| Clean & dry | 118 | | 75 | 61 | | 100 | 101 | | 60 | 134 | | 80 | 64 | | 100 |
| Wet | 78 | 73 | 100 | 24 | 22 | 100 | 48 | 37 | 100 | 46 | 46 | 100 | 0 | 0 | 100 |
| Wet | 67 | | 100 | 19 | | 100 | 25 | | 100 | 46 | | 100 | 0 | | 100 |
| Rockdust dry | 148 | 145 | 75 | 65 | 63 | 100 | 72 | 85 | 90 | 102 | 101 | 100 | 56 | 58 | 100 |
| Rockdust dry | 142 | | 75 | 60 | | 80 | 97 | | 60 | 100 | | 100 | 59 | | 100 |
| Rockdust wet | 80 | 51 | 100 | 0 | 0 | 100 | 56 | 45 | 100 | 36 | 35 | 100 | 0 | 0 | 100 |
| Rockdust wet | 22 | | 100 | 0 | | 100 | 34 | | 100 | 34 | | 100 | 0 | | 100 |
| 1/2" Hardware cloth | 198 | 205 | 0 | 111 | 109 | 100 | 118 | 110 | 0 | 204 | 228 | 80 | 118 | 138 | 90 |
| 1/2" Hardware cloth | 212 | | 66 | 107 | | 100 | 102 | | 0 | 255 | | 80 | 158 | | 20 |
| Expanded metal lath | 192 | 182 | 66 | 122 | 123 | 60 | 126 | 133 | 0 | 312 | 348 | 75 | 204 | 208 | 50 |
| Expanded metal lath | 172 | | 50 | 124 | | 60 | 140 | | 60 | 384 | | 70 | 212 | | 60 |
| Truss loop | 118 | 107 | 100 | 114 | 103 | 100 | 101 | 106 | 80 | 116 | 146 | 100 | 84 | 96 | 85 |
| Truss loop | 96 | | 100 | 91 | | 100 | 110 | | 70 | 176 | | 100 | 108 | | 85 |
| 3/16" Plastic mesh | 166 | 171 | 70 | ND | ND | ND | ND | ND | ND | ND. | ND | ND | ND | ND | ND |
| 3/16" Plastic mesh | 176 | | 95 | ND | | ND | ND | | ND | ND | | ND | ND | | ND |
| 1/4" Plastic mesh | 124 | 135 | 100 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| 1/4" Plastic mesh | 146 | | 90 | ND | | ND | ND | | ND | ND | | ND | ND | | ND |

Notes:  (1) For information only; not included in "10 best" selection.

(2) Total pounds on 6" circle (28.3 in).

(3) % of substrate surface exposed during test.

(4) Lifted layer of substrate.

ND = No data

TABLE 40 - Foam adhesion test data (cont)

| Item no | 15 | | | 17 | | | 23 | | | 24 | | | 25 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample 1676- | 48-6 | | | 48-1 | | | 46-7 | | | 50-2 | | | 50-3 | | |
| Substrate | lbs | avg | % | lbs | avg | % | lbs | avg | % | lbs | avg | % | lbs | avg | % |
| **Coal** | | | | | | | | | | | | | | | |
| Clean & dry | 116 | 92 | 0 | 190 | 172 | 100 | 67 | 112 | 100 | 71 | 62 | 70 | 120 | 96 | 0(4) |
| Clean & dry | 68 | | 100 | 154 | | 100 | 156 | | 100 | 52 | | 100 | 72 | | 60 |
| Wet | 118 | 113 | 100 | 82 | 94 | 100 | 71 | 111 | 95 | 3 | 15 | 100 | 124 | 124 | 0 |
| Wet | 108 | | 100 | 105 | | 100 | 150 | | 80 | 27 | | 100 | 124 | | 0 |
| Rockdust dry | 172 | 206 | 0 | 70 | 172 | 50 | 196 | 158 | 0 | 73 | 48 | 70 | 140 | 140 | 0 |
| Rockdust dry | 240 | | 0 | 274 | | 0 | 120 | | 0 | 22 | | 90 | ND | | ND |
| Rockdust wet | 31 | 23 | 100 | 43 | 55 | 100 | 86 | 66 | 100 | 5 | 7 | 100 | 70 | 103 | 100 |
| Rockdust wet | 15 | | 100 | 67 | | 100 | 46 | | 100 | 8 | | 100 | 136 | | 0 |
| **Rock** | | | | | | | | | | | | | | | |
| Clean & dry | 87 | 88 | 100 | 172 | 141 | 0 | 208 | 147 | 10 | 77 | 126 | 80 | 100 | 97 | 0 |
| Clean & dry | 88 | | 0 | 110 | | 0 | 86 | | 0 | 174 | | 10 | 94 | | 0 |
| Wet | 0 | 0 | 100 | 103 | 83 | 100 | 88 | 82 | 100 | 260 | 130 | 50 | 104 | 92 | 0 |
| Wet | 0 | | 100 | 62 | | 100 | 75 | | 100 | 0 | | 100 | 80 | | 0 |
| Rockdust dry | 186 | 194 | 0 | 208 | 155 | 100 | 160 | 165 | 100 | 220 | 110 | 10 | 120 | 95 | 0 |
| Rockdust dry | 202 | | 0 | 102 | | 100 | 170 | | 0 | 0 | | 100 | 70 | | 0 |
| Rockdust wet | 30 | 28 | 100 | 45 | 44 | 100 | 0 | 0 | 100 | 45 | 23 | 100 | 104 | 107 | 0 |
| Rockdust wet | 26 | | 100 | 43 | | 100 | 0 | | 100 | 0 | | 100 | 110 | | 0 |

TABLE 40 – Foam adhesion test data (cont)

| Item no 1676- Sample Substrate | 15 48-6 lbs | avg | % | 17 48-1 lbs | avg | % | 23 46-7 lbs | avg | % | 24 50-2 lbs | avg | % | 25 50-3 lbs | avg | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Concrete block** | | | | | | | | | | | | | | | |
| Clean & dry | 140 | 169 | 0 | 188 | 195 | 100 | 172 | 198 | 0 | 115 | 113 | 100 | 86 | 119 | 0 |
| Clean & dry | 198 | | 0 | 202 | | 100 | 224 | | 0 | 110 | | 100 | 152 | | 0 |
| Wet | 102 | 108 | 100 | 155 | 125 | 100 | 136 | 79 | 100 | 25 | 43 | 100 | 0 | 0 | 100 |
| Wet | 114 | | 100 | 95 | | 0 | 21 | | 100 | 61 | | 100 | 0 | | 100 |
| Rockdust dry | 256 | 240 | 0 | 292 | 308 | 0 | 264 | 228 | 0 | 0 | 0 | 100 | 6 | 21 | 100 |
| Rockdust dry | 224 | | 0 | 324 | | 0 | 192 | | 0 | 0 | | 100 | 35 | | 100 |
| Rockdust wet | 46 | 59 | 100 | 102 | 95 | 100 | 0 | 0 | 100 | 0 | 0 | 100 | 68 | 34 | 100 |
| Rockdust wet | 72 | | 100 | 87 | | 100 | 0 | | 100 | 0 | | 100 | 0 | | 100 |
| **Wood (oak)** | | | | | | | | | | | | | | | |
| Clean & dry | 198 | 153 | 100 | 140 | 110 | 100 | 244 | 230 | 0 | 134 | 136 | 0 | 152 | 146 | 0 |
| Clean & dry | 108 | | 100 | 79 | | 100 | 216 | | 100 | 138 | | 0 | 140 | | 0 |
| Wet | 116 | 122 | 100 | 77 | 74 | 100 | 20 | 44 | 100 | 27 | 48 | 100 | 88 | 120 | 0 |
| Wet | 128 | | 100 | 70 | | 100 | 68 | | 100 | 68 | | 100 | 152 | | 0 |
| Rockdust dry | 166 | 239 | 100 | 272 | 252 | 60 | 220 | 203 | 0 | 3 | 29 | 100 | 160 | 163 | 0 |
| Rockdust dry | 312 | | 0 | 232 | | 60 | 186 | | 100 | 54 | | 100 | 166 | | 0 |
| Rockdust wet | 0 | 0 | 100 | 0 | 0 | 100 | 0 | 0 | 100 | 0 | 0 | 100 | 140 | 107 | 0 |
| Rockdust wet | 0 | | 100 | 11 | | 100 | 0 | | 100 | 0 | | 100 | 74 | | 0 |

TABLE 40 - Foam adhesion test data (cont)

| Item no 1676- Sample Substrate | 15 (48-6) lbs | avg | % | 17 (48-1) lbs | avg | % | 23 (46-7) lbs | avg | % | 24 (50-2) lbs | avg | % | 25 (50-3) lbs | avg | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Brattice cloth** | | | | | | | | | | | | | | | |
| Clean & dry | 140 | 140 | 60 | 160 | 122 | 100 | 142 | 140 | 70 | 0 | 0 | 100 | 180 | 172 | 0 |
| Clean & dry | 140 | | 70 | 83 | | 70 | 138 | | 75 | 0 | | 100 | 164 | | 0 |
| Wet | 42 | 39 | 100 | 41 | 37 | 100 | 26 | 27 | 100 | 0 | 0 | 100 | 154 | 144 | 0 |
| Wet | 35 | | 100 | 33 | | 100 | 28 | | 100 | 0 | | 100 | 134 | | 0 |
| Rockdust dry | 130 | 119 | 100 | 92 | 89 | 0 | 136 | 126 | 60 | 0 | 0 | 100 | 56 | 72 | 100 |
| Rockdust dry | 108 | | 100 | 85 | | 0 | 116 | | 50 | 0 | | 100 | 87 | | 100 |
| Rockdust wet | 0 | 0 | 100 | 0 | 0 | 100 | 0 | 0 | 100 | 0 | 0 | 100 | 0 | 0 | 100 |
| Rockdust wet | 0 | | 100 | 0 | | 100 | 0 | | 100 | 0 | | 100 | 0 | | 100 |
| 1/2" Hardware cloth | 150 | 229 | 90 | 246 | 235 | 75 | 224 | 220 | 70 | 85 | 81 | 100 | 98 | 105 | 0 |
| 1/2" Hardware cloth | 448 | | 0 | 224 | | 0 | 216 | | 70 | 77 | | 100 | 112 | | 0 |
| Expanded metal Lath | 224 | 222 | 10 | 260 | 291 | 0 | 260 | 215 | 50 | 132 | 128 | 0 | 140 | 136 | 0 |
| Expanded metal Lath | 220 | | 70 | 322 | | 0 | 170 | | 70 | 124 | | 0 | 132 | | 0 |
| Truss loop | 132 | 146 | 90 | 234 | 216 | 80 | 152 | 158 | 100 | 61 | 58 | 100 | 154 | 145 | 0 |
| Truss loop | 162 | | 90 | 198 | | 80 | 164 | | 90 | 55 | | 100 | 136 | | 0 |

TABLE 41 - Foam adhesion data as a
function of substrate

| Item no | | 4 | 5 | 9 | 11 | 14 | 15 | 17 | 23 | 24 | 25 | | Std |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample-1676 | | 48-11 | 48-12 | 48-9 | 46-10 | 48-7 | 48-6 | 48-1 | 46-7 | 50-2 | 50-3 | Avg | dev |
| Substrate | Condition | | | | | | | | | | | | |
| Brattice cloth | Clean & dry | 124 | 71 | 97 | 133 | 69 | 140 | 122 | 140 | 0 | 172 | 107 | 50 |
| | Rockdust & dry | 145 | 63 | 85 | 101 | 58 | 119 | 89 | 126 | 0 | 72 | 86 | 41 |
| | Wet | 73 | 22 | 37 | 46 | 0 | 39 | 37 | 27 | 0 | 144 | 42 | 41 |
| | Rockdust & wet | 51 | 0 | 45 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 23 |
| | Avg | 98 | 39 | 66 | 79 | 32 | 74 | 62 | 73 | 0 | 97 | 62 | NA |
| | Std dev | 44 | 32 | 29 | 43 | 34 | 62 | 54 | 65 | 0 | 72 | 54 | 54 |
| Coal | Clean & dry | 268 | 105 | 143 | 289 | 188 | 92 | 172 | 112 | 62 | 96 | 153 | 87 |
| | Rockdust & dry | 255 | 115 | 109 | 272 | 138 | 206 | 172 | 158 | 48 | 140 | 162 | 83 |
| | Wet | 40 | 44 | 136 | 205 | 69 | 113 | 94 | 111 | 15 | 124 | 95 | 56 |
| | Rockdust & wet | 8 | 16 | 66 | 48 | 21 | 23 | 55 | 66 | 7 | 103 | 41 | 35 |
| | Avg | 142 | 70 | 114 | 204 | 104 | 109 | 123 | 112 | 33 | 112 | 112 | NA |
| | Std dev | 130 | 46 | 38 | 118 | 82 | 74 | 78 | 52 | 29 | 29 | 83 | 83 |
| Concrete block | Clean & dry | 236 | 127 | 156 | 352 | 183 | 169 | 195 | 198 | 113 | 119 | 185 | 73 |
| | Rockdust & dry | 292 | 145 | 130 | 408 | 278 | 240 | 308 | 228 | 21 | 21 | 205 | 129 |
| | Wet | 246 | 83 | 144 | 160 | 66 | 108 | 125 | 79 | 43 | 0 | 105 | 71 |
| | Rockdust & wet | 181 | 35 | 114 | 117 | 0 | 59 | 95 | 0 | 0 | 34 | 63 | 62 |
| | Avg | 239 | 98 | 136 | 259 | 132 | 144 | 181 | 126 | 39 | 43 | 140 | NA |
| | Std dev | 62 | 47 | 19 | 133 | 114 | 75 | 90 | 106 | 50 | 55 | 104 | 104 |
| Rock | Clean & dry | 246 | 112 | 132 | 328 | 104 | 88 | 141 | 147 | 126 | 97 | 152 | 81 |
| | Rockdust & dry | 187 | 125 | 143 | 300 | 82 | 194 | 155 | 165 | 110 | 95 | 156 | 79 |
| | Wet | 72 | 18 | 88 | 141 | 7 | 0 | 83 | 82 | 130 | 92 | 71 | 67 |
| | Rockdust & wet | 92 | 21 | 61 | 34 | 42 | 28 | 44 | 0 | 23 | 107 | 45 | 42 |
| | Avg | 149 | 69 | 106 | 201 | 59 | 77 | 106 | 98 | 97 | 98 | 106 | NA |
| | Std dev | 90 | 55 | 48 | 130 | 60 | 80 | 59 | 77 | 106 | 16 | 84 | 84 |

TABLE 41 - Foam adhesion data as a
function of substrate
(cont)

| Item no | | 4 | 5 | 9 | 11 | 14 | 15 | 17 | 23 | 24 | 25 | Avg | Std. dev |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample 1676- | | 48-11 | 48-12 | 48-9 | 46-10 | 48-7 | 48-6 | 48-1 | 46-7 | 50-2 | 50-3 | | |
| Substrate | Condition | | | | | | | | | | | | |
| Wood | Clean & dry | 208 | 121 | 128 | 304 | 0 | 153 | 110 | 230 | 136 | 146 | 154 | 81 |
| | Rockdust & dry | 292 | 124 | 151 | 274 | 103 | 239 | 252 | 203 | 29 | 163 | 183 | 87 |
| | Wet | 81 | 20 | 108 | 270 | 41 | 122 | 74 | 44 | 48 | 120 | 93 | 74 |
| | Rockdust & wet | 57 | 0 | 83 | 126 | 0 | 0 | 6 | 0 | 0 | 107 | 38 | 52 |
| | Avg | 160 | 66 | 118 | 244 | 36 | 129 | 110 | 119 | 53 | 134 | 117 | NA |
| | Std dev | 103 | 62 | 46 | 75 | 48 | 102 | 98 | 107 | 57 | 34 | 67 | 67 |
| Hardware cloth | dry | 205 | 109 | 110 | 228 | 138 | 299 | 235 | 220 | 81 | 105 | 173 | 87 |
| Metal lath | dry | 182 | 123 | 133 | 348 | 208 | 222 | 291 | 215 | 128 | 136 | 199 | 76 |
| Truss loop | dry | 107 | 103 | 106 | 146 | 96 | 146 | 216 | 158 | 58 | 145 | 128 | 45 |
| 3/16" Plast. mesh | dry | 171 | ND | ND | ND | ND | ND | ND | ND | ND | ND | 171 | ND |
| 1/4" Plast. mesh | dry | 135 | ND | ND | ND | ND | ND | ND | ND | ND | ND | 135 | ND |
| | Avg | 160 | 112 | 116 | 241 | 147 | 223 | 247 | 198 | 89 | 129 | 167 | NA |
| | Std dev | 38 | 12 | 15 | 97 | 53 | 117 | 42 | 42 | 32 | 20 | 76 | 76 |
| All | Avg | 158 | 74 | 109 | 208 | 82 | 122 | 133 | 118 | 50 | 101 | 115 | NA |
| | Std dev | 89 | 49 | 40 | 116 | 81 | 93 | 90 | 84 | 63 | 51 | 89 | 89 |

Note: NA = Not applicable
ND = No data

TABLE 42

Summary - foam adhesion based on substrate (lbs)

| Item no | Sample 1676- | Brattice cloth | Coal | Concrete block | Rock | Wood | Metal | Plastic | Avg |
|---|---|---|---|---|---|---|---|---|---|
| 4* | 48-11 | 98 | 142 | 239 | 149 | 160 | 165 | 153 | 158 |
| 5 | 48-12 | 39 | 70 | 98 | 69 | 66 | 112 | ND | 74 |
| 9 | 48-9 | 66 | 114 | 136 | 106 | 118 | 116 | ND | 109 |
| 11 | 46-10 | 79 | 204 | 259 | 201 | 244 | 241 | ND | 208 |
| 14 | 48-7 | 32 | 104 | 132 | 59 | 36 | 147 | ND | 82 |
| 15 | 48-6 | 74 | 109 | 144 | 77 | 129 | 223 | ND | 122 |
| 17 | 48-1 | 62 | 123 | 181 | 106 | 110 | 247 | ND | 133 |
| 23 | 46-7 | 73 | 112 | 126 | 98 | 119 | 198 | ND | 118 |
| 24 | 50-2 | 0 | 33 | 39 | 97 | 53 | 89 | ND | 50 |
| 25 | 50-3 | 97 | 112 | 43 | 98 | 134 | 129 | ND | 101 |
| Avg | | 62 | 112 | 140 | 106 | 117 | 167 | 153 | 115 |

Note: *For information only; not included in "10 best" selection.
ND = No data

TABLE 43 - Foam adhesion data as a function
of substrate condition

| Item no | 4 | 5 | 9 | 11 | 14 | 15 | 17 | 23 | 24 | 25 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample 1676- | 48-11 | 48-12 | 48-9 | 46-10 | 48-7 | 48-6 | 48-1 | 46-7 | 50-2 | 50-3 | Avg | Std dev |
| Condition / Substrate | | | | | | | | | | | | |
| **Clean & dry** | | | | | | | | | | | | |
| Brattice cloth | 124 | 71 | 97 | 133 | 69 | 140 | 122 | 140 | 0 | 172 | 107 | 50 |
| Coal | 268 | 105 | 143 | 289 | 188 | 92 | 172 | 112 | 62 | 96 | 153 | 87 |
| Concrete block | 236 | 127 | 156 | 352 | 183 | 169 | 195 | 198 | 113 | 119 | 185 | 73 |
| Rock | 246 | 112 | 132 | 328 | 104 | 88 | 141 | 147 | 126 | 97 | 152 | 81 |
| Wood | 208 | 121 | 128 | 304 | 0 | 153 | 110 | 230 | 136 | 146 | 154 | 81 |
| Avg | 216 | 107 | 131 | 281 | 109 | 128 | 148 | 165 | 87 | 126 | 150 | NM |
| Std dev | 61 | 24 | 24 | 95 | 81 | 44 | 44 | 59 | 58 | 37 | 78 | 78 |
| Hardware cloth | 205 | 109 | 110 | 228 | 138 | 299 | 235 | 220 | 81 | 105 | 173 | 87 |
| Metal lath | 182 | 123 | 133 | 348 | 208 | 222 | 291 | 215 | 128 | 136 | 199 | 76 |
| Truss loop | 107 | 103 | 106 | 146 | 96 | 146 | 216 | 158 | 58 | 145 | 128 | 45 |
| Plastic mesh | 153 | ND | ND | ND | ND | ND | ND | ND | ND | ND | 153 | 23 |
| Avg | 160 | 112 | 116 | 241 | 147 | 223 | 247 | 198 | 89 | 129 | 166 | NM |
| Std dev | 38 | 12 | 15 | 97 | 53 | 117 | 42 | 42 | 32 | 20 | 76 | 76 |
| **Rockdust & dry** | | | | | | | | | | | | |
| Brattice cloth | 145 | 63 | 85 | 101 | 58 | 119 | 89 | 126 | 0 | 72 | 86 | 41 |
| Coal | 255 | 115 | 109 | 272 | 138 | 206 | 172 | 158 | 48 | 140 | 162 | 83 |
| Concrete block | 292 | 145 | 130 | 408 | 278 | 240 | 308 | 228 | 0 | 21 | 205 | 129 |
| Rock | 187 | 125 | 143 | 300 | 82 | 194 | 155 | 165 | 110 | 95 | 156 | 79 |
| Wood | 292 | 124 | 151 | 274 | 103 | 239 | 252 | 203 | 29 | 163 | 183 | 87 |
| Avg | 234 | 114 | 124 | 271 | 132 | 200 | 195 | 176 | 37 | 93 | 158 | NM |
| Std dev | 72 | 31 | 29 | 108 | 95 | 61 | 98 | 46 | 69 | 57 | 96 | 96 |
| **All dry** | | | | | | | | | | | | |
| Avg | 203 | 111 | 125 | 268 | 126 | 178 | 189 | 177 | 68 | 115 | 156 | NM |
| Std dev | 65 | 24 | 23 | 98 | 80 | 80 | 78 | 50 | 62 | 44 | 94 | 94 |

TABLE 43 - Foam adhesion data as a function
of substrate condition
(cont)

| Item no | 4 | 5 | 9 | 11 | 14 | 15 | 17 | 23 | 24 | 25 | | Std |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample 1676- | 48-11 | 48-12 | 48-9 | 46-10 | 48-7 | 48-6 | 48-1 | 46-7 | 50-2 | 50-3 | Avg | dev |
| Condition — Substrate | | | | | | | | | | | | |
| **Clean & wet** | | | | | | | | | | | | |
| Brattice cloth | 73 | 22 | 37 | 46 | 0 | 39 | 37 | 27 | 0 | 144 | 42 | 41 |
| Coal | 44 | 44 | 136 | 205 | 69 | 113 | 94 | 111 | 15 | 124 | 95 | 56 |
| Concrete block | 246 | 83 | 144 | 160 | 66 | 108 | 125 | 79 | 43 | 0 | 105 | 71 |
| Rock | 72 | 18 | 88 | 141 | 7 | 0 | 83 | 82 | 130 | 92 | 71 | 67 |
| Wood | 81 | 20 | 108 | 270 | 41 | 122 | 74 | 44 | 48 | 120 | 93 | 74 |
| Avg | 103 | 37 | 103 | 164 | 37 | 76 | 82 | 68 | 47 | 96 | 81 | NM |
| Std dev | 78 | 29 | 56 | 79 | 33 | 51 | 33 | 47 | 79 | 56 | 66 | 66 |
| **Rockdust & wet** | | | | | | | | | | | | |
| Brattice cloth | 51 | 0 | 45 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 23 |
| Coal | 8 | 16 | 66 | 48 | 21 | 23 | 55 | 66 | 7 | 103 | 41 | 35 |
| Concrete block | 181 | 35 | 114 | 117 | 0 | 59 | 95 | 0 | 0 | 34 | 63 | 62 |
| Rock | 92 | 21 | 61 | 34 | 42 | 28 | 44 | 0 | 23 | 107 | 45 | 42 |
| Wood | 57 | 0 | 83 | 126 | 0 | 0 | 6 | 0 | 0 | 107 | 38 | 52 |
| Avg | 78 | 14 | 74 | 72 | 12 | 22 | 40 | 13 | 6 | 70 | 40 | NM |
| Std dev | 74 | 16 | 34 | 44 | 19 | 24 | 37 | 29 | 14 | 54 | 47 | 47 |
| **All wet** | | | | | | | | | | | | |
| Avg | 90 | 26 | 88 | 118 | 24 | 49 | 61 | 41 | 26 | 83 | 61 | NM |
| Std dev | 75 | 26 | 48 | 78 | 29 | 48 | 41 | 47 | 59 | 55 | 61 | 61 |
| **All** | | | | | | | | | | | | |
| Avg | 158 | 74 | 109 | 208 | 82 | 122 | 133 | 118 | 50 | 101 | 115 | NM |
| Std dev | 93 | 49 | 40 | 116 | 81 | 93 | 90 | 84 | 63 | 51 | 89 | 89 |

Note: ND = No data
NM = Not meaningful

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TABLE 44

Summary - foam adhesion based on condition (lbs)

| Item no | Sample 1676- | Clean dry | Dusty dry | All dry | Clean wet | Dusty wet | All wet | Avg |
|---------|--------------|-----------|-----------|---------|-----------|-----------|---------|-----|
| 4 | 48-11 | 197 | 234 | 203 | 103 | 78 | 90 | 158 |
| 5 | 48-12 | 109 | 114 | 111 | 37 | 14 | 26 | 74 |
| 9 | 48-9 | 126 | 124 | 125 | 103 | 74 | 88 | 109 |
| 11 | 46-10 | 266 | 271 | 268 | 164 | 72 | 118 | 208 |
| 14 | 48-7 | 123 | 132 | 126 | 37 | 12 | 24 | 82 |
| 15 | 48-6 | 164 | 200 | 178 | 76 | 22 | 49 | 122 |
| 17 | 48-1 | 185 | 195 | 189 | 82 | 40 | 61 | 133 |
| 23 | 46-7 | 177 | 176 | 177 | 68 | 13 | 41 | 118 |
| 24 | 50-2 | 88 | 37 | 68 | 47 | 6 | 26 | 50 |
| 25 | 50-3 | 127 | 93 | 115 | 96 | 70 | 83 | 101 |
| Avg | | 156 | 158 | 156 | 81 | 40 | 61 | 115 |

## TABLE 45

### Summary - % substrate exposed as a function of substrate

| Item no | Sample 1676- | Brattice cloth | Coal | Concrete block | Rock | Wood | Metal | Plastic | Avg |
|---------|--------------|----------------|------|----------------|------|------|-------|---------|-----|
| 4       | 48-11        | 88             | 69   | 15             | 85   | 50   | 64    | 90      | 64  |
| 5       | 48-12        | 98             | 41   | 36             | 63   | 75   | 87    | ND      | 66  |
| 9       | 48-9         | 85             | 33   | 13             | 38   | 38   | 35    | ND      | 40  |
| 11      | 46-10        | 94             | 71   | 50             | 75   | 63   | 84    | ND      | 72  |
| 14      | 48-7         | 100            | 84   | 56             | 75   | 100  | 65    | ND      | 81  |
| 15      | 48-6         | 91             | 63   | 50             | 63   | 88   | 58    | ND      | 69  |
| 17      | 48-1         | 71             | 81   | 63             | 75   | 90   | 39    | ND      | 71  |
| 23      | 46-7         | 82             | 72   | 50             | 64   | 75   | 75    | ND      | 69  |
| 24      | 50-2         | 100            | 91   | 100            | 69   | 75   | 67    | ND      | 84  |
| 25      | 50-3         | 50             | 20   | 75             | 0    | 0    | 0     | ND      | 25  |
| Avg     |              | 86             | 62   | 51             | 61   | 65   | 43    | 90      | 64  |

Note: ND = No data

TABLE 46

Summary - % substrate exposed as a function of substrate condition

| Item no | Sample 1676- | Clean dry | Dusty dry | All dry | Clean wet | Dusty wet | All wet | Avg |
|---------|--------------|-----------|-----------|---------|-----------|-----------|---------|-----|
| 4 | 48-11 | 55 | 39 | 49 | 80 | 92 | 86 | 64 |
| 5 | 48-12 | 51 | 38 | 46 | 82 | 100 | 91 | 66 |
| 9 | 48-9 | 28 | 15 | 23 | 56 | 70 | 63 | 40 |
| 11 | 46-10 | 54 | 57 | 55 | 90 | 100 | 95 | 72 |
| 14 | 48-7 | 69 | 60 | 66 | 100 | 100 | 100 | 81 |
| 15 | 48-6 | 55 | 30 | 45 | 100 | 100 | 100 | 69 |
| 17 | 48-1 | 63 | 37 | 53 | 90 | 100 | 95 | 71 |
| 23 | 46-7 | 57 | 31 | 47 | 98 | 100 | 99 | 69 |
| 24 | 50-2 | 66 | 87 | 74 | 95 | 100 | 98 | 84 |
| 25 | 50-3 | 4 | 44 | 18 | 20 | 50 | 35 | 25 |
| Avg | | 50 | 44 | 48 | 81 | 91 | 86 | 64 |

adhesion to dry substrates was better than to wet. Although Item 4 gave high pull test values with plastic mesh, the actual adhesion to the plastic surface was poor, as evidenced by the 90 percent surface exposed. The high pull test values were obviously due to interlocking of the cured foam around the plastic-coated wires of the substrate.

The adhesive properties of the foams were arranged into groups such that Group A was the best and Group E the poorest. These results are shown in Table 47.

While these data are interesting, the important point to keep in mind is that the foam need only to maintain adhesion to the substrate to be an effective sealant. To our knowledge, the "pull" value that is

TABLE 47
Ranking of adhesive values by item number
as function of substrates

| Group | Dry substrates | Wet substrates | Dry metal substrates | All substrates |
|-------|------------|------------|--------------|------------|
| A | 11 | 11 | 11<br>17 | 11 |
| B | 4 | 4<br>9<br>25 | 15 | 4<br>17 |
| C | 15<br>17<br>23 | 15<br>17 | 4<br>14<br>23 | 9<br>15<br>23<br>25 |
| D | 5<br>9<br>14<br>25 | 23 | 5<br>9<br>25 | 5<br>14 |
| E | 24 | 5<br>14<br>24 | 24 | 24 |

adequate to maintain adhesion has not been properly defined. Mitchell,[3] suggested 200 lbs for dry surfaces and 100 lbs for wet surfaces with no

[3]Mitchell, D. W., Nagy, J. and Murphy, E. M. Rigid Foam for Mines. BuMines RI 6366, pp 12-3.

failure at the foam-substrate interface. Mitchell's data, however, were obtained with a spring scale on a pull tab with an undefined pull area and not limited to a 6" diameter circle.

Our data show that a pull of 20 lbs or less was obtained with about 16% of the samples, of which only 23% were dry substrates. Thus, most of the low pulls were on the wet substrates. Moreover, most of the candidates are polyurethanes, and it is characteristic of polyurethanes in general to have low adhesion to wet substrates. This is not only caused by the barrier formed by the water but also by the water reacting with the isocyanate component of the system to release carbon dioxide which tends to blow the foam off the substrate.

Theoretically, the foam needs only sufficient adhesion to support its own weight. Even a pull of 1 lb should be more than sufficient. Thus, although the data can be used to compare adhesion of the candidates with the various substrates, we conclude that all of the foams showed adequate adhesion except to wet substrates and plastic coated brattice cloth.

## SAFETY

The application of an organic foam can produce hazardous vapor concentrations of raw or unreacted components, solvents, catalysts, etc., irritating to the eyes and respiratory tract, or result in minor or severe skin irritations from contacts with liquids or sprays. The use of protective goggles, rubber aprons and gloves and organic cartridge vapor respirators is generally recommended. The application of some foams present greater hazards than others. This section reviews the hazards of those foam types being considered.

### Rigid Polyurethane Foams

Twenty of the 27 foams evaluated, and seven of the "10 best" foams were conventional rigid polyurethane spray foams. These foams are prepared by mixing two liquid materials commonly called the "A" and "B" components. The "A" component contains a polymeric isocyanate. The "B" component contains polyalcohols (polyols), blowing agent, catalyst, surfactant, and perhaps, a fire retardant additive.

"A" Component - The "A" component is a mixture of polymeric isocyanates. NIOSH has recommended that all isocyanates have a TLV of 0.02 ppm and a TWA of 0.005 ppm in air. With respect to polymeric isocyanates, their data was obtained using polymethylene diisocyanate (MDI). Actually, MDI comprises about 50% of the isocyanate; the remainder consists of higher molecular weight polyisocyanates having lower vapor pressure than MDI. This reduces the vapor hazard.

Tests have shown that the TLV level above an open container of polymeric isocyanate is not reached until it is heated to 110-120°F. Such temperatures are seldom reached in mine working areas.

The oral and dermal toxicity of the polymeric isocyanate is also low (LD$_{50}$ = >10 g/kg).

Tests have usually not detected isocyanate vapors in the vicinity of a spray operation when polymeric isocyanates were used. They did, however, find small droplets of polyisocyanates. These settled out or reacted with the moisture vapor to form solid ureas in about three minutes.

"B" Component - The "B" component contains monofluorotrichloromethane (CCl$_3$F, Fluorocarbon-11) as the blowing agent, which is a low boiling liquid (75°F) comprising about 25% of the component. It has a TLV of 1000 ppm. The catalyst may contain a tertiary amine and/or a small mount of metal catalyst (typically an organo-tin or organo-lead compound). The amines may be slightly irritating to eyes and respiratory tract. The metal catalysts are usually present at such low levels that they can hardly be detected.

The polyol itself is generally not considered to be a hazard. The surfactant is usually a high molecular weight silicone-based block copolymer, which is considered non-toxic.

Summary - Only the polyisocyanate and the blowing agent of the polyurethane foam formulations have been assigned TLV's. All other ingredients are considered to be nontoxic but could cause an allergic reaction to spray.

Industry-wide experience in spraying millions of pounds of polyurethane foam has shown that no particular toxicity hazard exists when the spray operator and people in the vicinity of the spray operation are wearing appropriate breathing apparatuses; normally, supplied-air masks are used. Simple protective clothing and safety glasses usually serve to protect the operators from contact. Foams cure within a few minutes, and once cured, emit no significant vapors.

Protection for mine personnel downstream of a spraying operation is dependent on the magnitude of the spray operation, amount of ventilation air and proximity of personnel. Spraying a stooping several crosscuts back from the face, in most mine ventilation would sufficiently dilute component vapors to a safe level. Where this is to be a routine operation, however, vapor concentrations should be checked to determine protection requirements.

Isocyanurate Foams

Three of the candidate foams were isocyanurate foams. They are prepared from an excess of polymeric isocyanate reacted with a small amount of polyol. The safety hazards of these foams are the same as for the rigid polyurethane foams.

## Flexible Polyurethane Foam

One candidate foam was a highly solids-loaded, flexible polyurethane-based foam (Hypol, Item 25). The isocyanate component is a Toluene diisocyanate (TDI) prepolymer which has a vapor pressure about that of pure MDI. However, the TDI prepolymer is very viscous and must be heated to be suitable for spraying. At the elevated temperatures, the isocyanate component could be above the TLV in the vapor phase. This is uncertain and was not measured.

The other component of the Hypol foam is an aqueous suspension of mainly inorganic solids. None of these components are hazardous.

Overall, the TDI prepolymer for the Hypol candidate is slightly more hazardous than the polymeric isocyanates used in the rigid polyurethane and isocyanurate foams. The added risk, however, is minor.

## Silicone Foams

Two foam candidates were silicone based (Items 3 and 24). No known hazards are associated with their use.

## Phenolic Foam

One candidate foam (Item 26), a rigid phenolic, was supplied to us as boardstock without any information relative to its liquid precursors.

In the past, one component of the phenolics has been a phenol-formaldehyde prepolymer, which was reacted with an acidic material to form the foam. The phenolic prepolymers are not usually hazardous. The catalyst may be somewhat corrosive due to its acidic properties.

The candidate phenolic foam appears to be a new type, and thus the older stereotypes may not apply. We do not, however, expect the components to have any particularly hazardous properties.

## Summary

The information available about the potentially hazardous materials present in the foams tested are summarized in Table 48. While this list looks rather formidable, experience has shown that the foams can be prepared without any significant hazards, when reasonable precautions are taken.

## SELECTION OF "FINAL 2" FOAMS FOR IN-MINE TESTING

The objective of Phase II of this program was to select two foam candidates considered the best of the group for in-mine testing as stopping sealants. Twenty-seven candidates were initially selected from an industry-wide survey of promising foams and through a series of tests

## TABLE 48
## Hazardous components of foam systems

| Item no | Foam 1676- | Isocyanate | CFCl₃ | Catalysts | |
| --- | --- | --- | --- | --- | --- |
| | | | | Amines | Heavy metals |
| 1 | 48-2 | Polymeric | Yes | Probable | Probable |
| 2 | 48-13 | Polymeric | Yes | Probable | Probable |
| 3 | 50-1 | None | None | ND | ND |
| 4 | 48-11 | Polymeric | Yes | Yes | Yes |
| 5 | 48-12 | Polymeric | Yes | Yes | Yes |
| 6 | 46-4 | Polymeric | Yes | Yes | ND |
| 7 | 46-3 | Polymeric | Yes | Yes | Yes |
| 8 | 46-1 | Polymeric | Yes | Yes | Yes |
| 9 | 48-9 | Polymeric | Yes | ND | ND |
| 10 | 48-10 | Polymeric | Yes | Yes | ND |
| 11 | 46-10 | Polymeric | Yes | Probable | ND |
| 12 | 46-11 | Polymeric | Yes | Probable | ND |
| 13 | 46-12 | Polymeric | Yes | Probable | ND |
| 14 | 48-7 | Polymeric | Yes | Yes | ND |
| 15 | 48-6 | Polymeric | Yes | Probable | Yes |
| 16 | 46-6 | Polymeric | Yes | Probable | ND |
| 17 | 48-1 | Polymeric | Yes | Probable | ND |
| 18 | 48-8 | Polymeric | Yes | Probable | ND |
| 19 | 46-5 | Polymeric | Yes | Probable | ND |
| 20 | 46-9 | Polymeric | Yes | Probable | ND |
| 21 | 46-13 | Polymeric | Yes | Probable | ND |
| 22 | 46-8 | Polymeric | Yes | Probahle | ND |
| 23 | 46-7 | Polymeric | Yes | Probable | ND |
| 24 | 50-2 | None | None | ND | ND |
| 25 | 50-3 | TDI prepolymer | None | Yes | No |
| 26 | 50-5 | None | ND | ND | ND |
| 27 | 50-4 | Polymeric | Yes | Probable | Probable |

Note:  ND = No data

narrowed to 16, and finally to the "10 best". These 10 were then sub-jected to further testing and evaluation, including possible application problems or hazards, and the final 2 candidates selected for testing.

The initial selection of the "Final 2" candidates was based on the merits of the foams. Before the in-mine tests were conducted, how-ever, the commercial availability of the majority of top candidates became questionable when the manufacture of a component, common to the five leading urethane formulations, was discontinued on a large scale because of insufficient sales. This necessitated a reevaluation and reselection. Both selections and the logic behind them are presented for the record.

The data used for selecting the "Final 2" from the list of the "10 best" candidates are summarized in Table 49. The table does not include data from all tests conducted on the program, but includes only data from those tests which proved to be definitive; that is from which a merit ranking could be established.

## Initial Selection of "Final 2" Candidates

Item 5, Callery's X-156, and item 15, were initially selected from the "10 best" for in-mine testing. Three candidates, Items 5, 25, and 26, stand out on the basis of exceptionally low flame spread index values by both the ASTM E162 and the more severe E162-CCC-2 test. Of these, however, Items 25, the Hypol-based foam, and Item 26, the phe-nolic, have high air permeability values, which make them unsuitable as air stopping sealants. Their high weight loss following water immersion and dry-aging may also portend problems for long-term stability. Item 5, therefore, was selected from this group.

Three more candidates, Items 14, 15 and 23, are grouped together as having lower flame spread values than the remaining, and since most all other test values are equivalent, the selection of the other candi-date for the "Final 2" should logically come from one of these.

These three candidates are essentially equivalent and the selec-tion of one for in-mine testing does not necessarily mean an apparent superiority for it over the others. Item 15 was selected on the basis of (1) overall low flame spread values even after water immersion, a condi-tion likely prevalent in mines, and (2) lower viscosities for the compo-nents, which may make for easier application under all mine conditions.

## Secondary Selection of "Final 2" Candidates

The unavailability of a polyol used in the formulation of the leading candidates, including the two initially selected for in-mine testing, resulted in the selection of Item 11 to replace Item 15. Because of insufficient market potential, Olin Corporation, the supplier of Thermolin RF 230, decided to stop production. If available at all in limited production, the polyol would be significantly more expensive, probably more than doubling the cost of the formulation.

TABLE 49
Summary of essential foam data

| Item no | 5 | 9 | 11 | 14 | 15 | 17 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample 1676- | 48-12 | 48-9 | 46-10 | 48-7 | 48-6 | 48-1 | 46-7 | 50-2 | 50-3 | 50-5 |
| **Tests** | | | | | | | | | | |
| **1. Flame spread index** | | | | | | | | | | |
| a.  E162, Virgin | 2 | 112 | 68 | 10 | 12 | 65 | 13 | 75 | 16 | 3 |
| , After H2O immersion | 3 | 176 | 111 | 15 | 10 | 56 | 33 | 85 | 5 | 5 |
| , After dry aging | 2 | 189 | 101 | 14 | 10 | 59 | 8 | 103 | 5 | 3 |
| b.  E162-CCC-2, Virgin | 39 | 645 | 781 | 696 | 1245 | 1551 | 1748 | 529 | 1 | 3 |
| , After H2O immersion | 61 | 819 | 1628 | 1563 | 1493 | 1862 | 1612 | 103 | 9 | 2 |
| , After dry aging | 1 | 1054 | 1162 | 1212 | 1028 | 2374 | 949 | 97 | 8 | 8 |
| **2. Flame penetration time** | | | | | | | | | | |
| a.  Virgin | 1000+ | 875+ | 743 | 1000+ | 1000+ | 758 | 1000+ | 914+ | 1000+ | 116 |
| b.  After dry aging* | 941+ | 7? | 6? | 732 | 1000+ | 805+ | 1000+ | 587 | 1000+ | 113 |
| **3. Ignition, °C (D-1929)** | | | | | | | | | | |
| a.  Flash | 525 | 445 | 445 | 435 | 445 | 445 | 445 | 420 | 525 | 600 |
| b.  Self | 525 | 525 | 525 | 500 | 500 | 525 | 500 | 460 | 525 | 600 |
| **4. Permeability, SCFM/100 Ft² @ 10" H2O** | <0.05 | 0.32 | <0.05 | 0.11 | <0.05 | <0.05 | <0.05 | 0.81 | 299 | 181 |
| **5. Adhesion, lbs pull** | 74 | 109 | 208 | 82 | 122 | 133 | 118 | 50 | 101 | ND |
| **6. Density, lbs/Ft²** | 2.03 | 2.22 | 2.11 | 2.02 | 2.40 | 2.20 | 2.13 | 26.8 | 13.6 | 2.43 |
| **7. Compressive, psig @ 10%** | 22 | 31 | 21 | 23 | 31 | 23 | 23 | 2 | 2 | 7 |
| **8. Weight change, g.** | | | | | | | | | | |
| a.  After H2O immersion | -0.2 | -0.8 | -0.2 | -0.1 | 0.0 | -0.2 | 0.1 | -1.5 | -37 | -8 |
| b.  After dry aging | -2.5 | -3.5 | -2.4 | -1.1 | -1.4 | -1.0 | -1.1 | -18.4 | -20.3 | -11.3 |
| **9. Area change, %** | | | | | | | | | | |
| After H2O immersion | 0.2 | 0.0 | -2.4 | 0.6 | 0.6 | 0.1 | 0.4 | ND | ND | -0.9 |
| **10. Closed cell, %** | 93 | 89 | 95 | 92 | 94 | 91 | 93 | 23 | 9 | 1 |
| Reason for rejection, test | None | 1,4 | 1 | 2b,4 | None | 1 | 1 | 1,2b,4,8b,10 | 4,8,10 | 4,8,10 |

Note:  *Values having ? after them are believed to be grossly erroneous; they were ignored.
ND = No data

Olin's Thermolin RF 230 is used in Callery Chemical Company's X-156. Moreover, a survey of suppliers of the remaining six urethane candidates showed that it was also a component in four of these. Those candidates containing the polyol ranked 1 through 5 by our testing, which says something for the fire retarding property contribution by the polyol. Since the candidate formulations were not known prior to the testing, the fact that the five candidates containing this polyol were the top five ranked also says something for the validity of the selection process and testing procedures.

Since material had already been purchased for the in-mine testing of X-156, this candidate (Item 5) was retained in the "Final 2". For the second candidate, Item 11 (Foam Systems' FS-24), which was sixth ranked of the urethanes, was selected. Although lower ranked than the candidates bypassed by E162, it did show more favorable data than three of these by E162-CCC-2, and had excellent adhesion test data.

FOAM COSTS

As previously stated, estimating the total "in-place" cost of a foam stopping is extremely difficult. The cost is much more dependent upon the frequency and the timing of the foaming operation than upon the cost of the chemicals and equipment. Hence, our discussion will be limited primarily to those predictable costs.

Chemicals

The chemicals from which the foam is made varied in price from $0.56 to $9.30 per pound (as of summer 1980). These costs are shown in Table 50 along with the estimated chemical cost per square foot of foam. The $9.30 cost of Item 1 seems high, but it is unique in that it is a completely self-contained unit requiring no equipment; one person can both transport and operate the unit containing this foam. If the unit is not completely used (100-120 board feet), the cost would naturally increase.

Items 3 and 24 are rather expensive silicone foams. Their high density also raises the cost of material needed. The other "10 best" foams cost from $0.59 to $2.00 per pound or $0.10 to $0.67 per square foot.

The two foams selected for field testing (Items 5 and 15) cost $1.11 to $2.00 per pound, or $0.22 to $0.33 per square foot of one inch thick foam.

Equipment

All but Item 1 require some sort of pumping, metering and mixing equipment. The high viscosity components (Items 3, 24 and 25) would probably require heated equipment. The highly-filled foam (Item 25) would require extra equipment to make certain the solids were uniformly

## TABLE 50
## Material costs of applied foams

| Item no | Cost,* $/lb | Use density,* lb/cu ft | Thickness used, in | Theoretical cost, $/ft |
|---|---|---|---|---|
| 1 | 9.30 | (2.2) | 1.0 | 1.71 |
| 2 | 1.75 | (2.2) | 1.0 | 0.32 |
| 3 | 5.15 | (20) | 1.0 | 8.58 |
|   |      |       | 0.5 | 4.29 |
|   |      |       | 0.25 | 2.15 |
| 4 | 1.35 | 2.2 | 1.0 | 0.25 |
| 5 | 2.00 | 2.0 | 1.0 | 0.33 |
| 6 | 1.18 | (2.2) | 1.0 | 0.22 |
| 7 | 1.18 | (2.2) | 1.0 | 0.22 |
| 8 | 1.13 | (2.2) | 1.0 | 0.21 |
| 9 | 1.01 | 2.2 | 1.0 | 0.19 |
| 10 | 0.95 | (2.2) | 1.0 | 0.17 |
| 11 | 1.24 | 2.1 | 1.0 | 0.22 |
| 12 | 1.18 | (2.2) | 1.0 | 0.22 |
| 13 | 1.21 | (3.0) | 1.0 | 0.30 |
| 14 | 1.10 | 2.0 | 1.0 | 0.18 |
| 15 | 1.11 | 2.4 | 1.0 | 0.22 |
| 16 | 1.06 | (2.2) | 1.0 | 0.19 |
| 17 | 1.75 | 2.2 | 1.0 | 0.32 |
| 18 | 1.20 | 2.2 | 1.0 | 0.22 |
| 19 | 1.16 | 2.0 | 1.0 | 0.19 |
| 20 | 0.88 | (2.2) | 1.0 | 0.16 |
| 21 | 1.07 | 2.4 | 1.0 | 0.21 |
| 22 | 1.14 | 2.2 | 1.0 | 0.21 |
| 23 | 1.16 | 2.1 | 1.0 | 0.20 |
| 24 | 4.50 | 26.8 | 1.0 | 10.05 |
|   |      |       | 0.5 | 5.03 |
|   |      |       | 0.25 | 2.51 |
| 25 | 0.59 | 13.6 | 1.0 | 0.67 |
|   |      |       | 0.5 | 0.33 |
|   |      |       | 0.25 | 0.17 |
| 26 | (1.00) | 2.2 | 1.0 | (0.10) |
| 27 | 1.25 | (2.5) | 1.0 | 0.26 |

Note:  *Figure in brackets are estimated.

dispersed. All other foams should be handled with moderately priced equipment using air-operated, double-acting piston pumps for both pumping and metering in conjuction with a suitable internally mixed spray gun. Such equipment is available at a cost varying from about $8000-$10,000.

The suggested equipment can be operated by one man, but the bulk and weight require extra manpower for handling and transporting. It also requires a certain amount of maintenance in order to prevent the isocyanate component from hardening in the pumps, lines, and gun. A few minutes a day is adequate for equipment that is used properly and fairly often. If the equipment is to be used infrequently, it must be cleaned out completely after each session. Hence, the more the equipment is used, the lower the maintenance costs per stopping. With proper care, a spray unit should last for over 10 years with only routine cleaning and packing replacement.

## Manpower

This is the hardest cost to estimate. As mentioned previously, one person can operate the unit, but other manpower will be required to move the equipment and liquid components in the mine unless the unit and chemicals are mounted on a mechanized or motorized unit.

A stopping can be sealed in 5-10 minutes, but the time required to move the equipment to and from the work site must also be included.

Normal maintenance on a frequently used unit may require only about 30 minutes per day. Maintenance activties and clean out of an infrequently used unit may require one man day. Overhaul and major repairs should not be frequent if the equipment is properly maintained. Poor maintenance will cause the cost to escalate rapidly.

## IN-MINE TESTING

The "final 2" foam candidates selected on the basis of all previous testing were used as stopping sealant materials for an in-mine test program. The contract requirements were for the design, construction, and testing of 20 stoppings--ten using foam as the main air barrier, and ten in which foam is the joint and perimeter seal for another barrier material. Foam was also to be used to repair 10 existing stoppings. Once constructed, the stoppings were to be tested for leaks, and evaluated and tested again after 6 and 12 month periods.

Unexpected program delays and higher-than-anticipated material and construction costs allowed for the completed construction of only 12 stoppings, and most of these were destroyed completely or partially before leak testing could be conducted. These in-mine problems prevented the completion of the total program. The program did, however, produce information of value on the utility of the final foam candidates as stopping sealants. In addition, performance as well as problems on new stopping construction techniques were evaluated.

## DESCRIPTION OF TEST MINE

The in-mine tests were conducted in FMC's Trona mine at Green River, WY, during the period 7 to 16 June 1982. This mine is one of four Trona mines in the area, all of which have squeeze problems because of floor heaving. FMC and Texasgulf Chemical, an adjacent Trona mine, both are conducting in-house evaluations of stopping construction techniques to minimize the problem. FMC uses urethane foam as the final sealant on their stoppings and, therefore, had both basic equipment and personnel for the application of our foam candidates.

The FMC mine has conventional, continuous and longwall sections all in operation. Because of the blasting and subsequent squeeze, their greatest need for a flexible sealant is in the conventional sections. They are conducting their own, in-house stopping development efforts in these areas.

The mine uses a standard room and pillar panel development with entries and crossouts approximately 7 to 8 feet high by 15 to 18 feet wide. Their conventional stoppings for this area are constructed with wood blocks measuring 4" x 8" x 24". The blocks are laid up in a staggered joint pattern on a 2" x 8" plank footer and then wedged securely all around. Because of the blasting, the openings are rough and irregular requiring extensive fitting of blocks, and a large number of wedges to effect closure. A nominal 1" layer of polyurethane foam is sprayed on for the final seal.

Stoppings constructed of 8" x 12" x 42" polystyrene foam block, dry stacked to give both 8" and 12" thick walls, have been a more recent innovation. The joints were sealed with urethane foam. These, too, are

laid on a 2" x 8" or 2" x 12" plank footer and wedged. These stoppings lay up fast and are easily sealed. The materials handling and erection labor are significantly less than the block, but the materials themselves, are expensive.

FMC likes the polystyrene block stoppings even if costs are only comparable to the wooden block stoppings. The lightweight, larger pieces and easy fitting make for rapid construction.

Polystyrene foam stoppings blow out more readily than the wood stoppings during blasting. One or two pieces of lagging placed diagonally across the stoppings and sealed to the polystyrene with the urethane foam improve their stability.

PROPOSED TEST PROGRAM

MSAR proposed a program in which the foam candidates would be tested as the main air barrier on stoppings constructed on metal framing, using a coated brattice as the backing, and as a joint and perimeter seal for the polystyrene foam block stoppings. We believed that the new stopping design, using the light metal framework and coated brattice as a backing for a urethane foam stopping, would effect a significant improvement in materials handling labor over both the conventional wooden and the new polystyrene foam block stoppings. Stopping construction labor could be less than that for the wooden stoppings, but likely more than that for the polystyrene block. Material costs should be comparable.

Prior approval of the plan was obtained from local MSHA inspectors by the mine. The program outline was to install 10 stoppings using the metal framework and brattice cloth combination as backing, and 10 sealing the perimeter and joints of the polystyrene foam block stoppings. The two selected foams would be used on 5 of each type.

The test stoppings were to be placed about 10 feet in front of previously-placed wood block stoppings. This procedure insured ventilation, and allowed better scheduling during the construction of the test stoppings. Once the test stoppings were in place, the wood stoppings would then have a hole punched through them to expose the test stoppings to normal mine ventilation conditions. The enclosed volume between the two would later serve as an enclosed volume for leak testing with the Bureau's SF$_6$ leak test technique.

Metal Frame Stopping Design

The metal frame backed stopping design was patterned after work being conducted by Ned Miles at U.S. Steel for their coal mines, in which squeezing is also a problem. In this approach, Miles used a prefabricated framework of galvanized steel channel to support expanded metal lath. The vertical supports were built in two sections that telescope within one-another to accommodate variable mine heights. A cement-based sealant trowelled to the lath formed the final air seal.

Our approach employed smaller metal frame members and jute-backed brattice cloth, vinyl coated one side to support the sprayed urethane foam sealant. The frame was constructed of 1-5/8" track and frame members of 20 gauge galvanized steel from Bostwick Steel Lath Company, Niles, OH. The components and assembly technique are shown in Figure 8.

The erection technique consisted of the pre-assembly of 8' sections of the metal framework without those telescoping stud sections that would overlap at the center. The telescoping stud sections were fastened to the top and bottom track on 18" centers by punching a tap hole in the jointing members using a modified vise-grip tool, and installing hex-head, self-tapping screws. The section was then erected in the opening and the top and sides fastened to the rock roof and ribs. After all sections were in place, the bottom track was forced to the floor and nailed with 30 or 40 D spikes and a hose clamp securely fastened around the overlapping sections of the metal studs.

Fastening the track to roof and ribs was done with pop rivets. Initially, rivets were installed by drilling a hole with a small hand drill to about a 3/4 inch depth. The task was laborious. Later, power was tapped off of the battery-powered jeeps to do the job.

The brattice was installed by overlapping and prefastening extra long 6 ft. wide strips to the top track with the self tapping screws, and pulling it tight under the base before fastening the base to the mine floor. The strips were overlapped several inches on the edges on a stud, and the lapped edges wired tightly to the backing stud at several places. Sequential photos of a stopping erection in the mine is shown in Figures 9 and 10.

The vinyl-coated burlap brattice was installed with the burlap exposed to the fresh air entry, with the studs behind. The burlap provided the rough surface for the urethane foam. It was later suggested that a more rigid seal might be made by fastening the brattice with the studding in front so that the subsequent foaming process would envelope the studding and fasten each to the brattice over its entire length.

## Polystyrene Foam Block Stoppings

Polystyrene foam block stoppings were used by FMC to construct permanent stoppings. MSAR's plan was to test the two foam candidates as joint and perimeter sealants by spraying the foam directly on the polystyrene.

In the course of our work, however, we made one contribution to the company's design that appeared to be a definite improvement in providing additional strength against blast shockwaves. It was the mine's practice to place one or two 2" x 8" lagging members across the face of the stopping and seal them to the foam with the subsequent foam application. While helping rebuild one such large stopping that had been blown out, MSAR personnel suggested installing a parallel lagging

METAL TRACK, 8' LG.

SELF-TAPPING HEX HD. SHEET
METAL SCREW

1 5/8 IN. SQUARE INTERLOCKING
METAL STUDS, 5' LG.

#28 ADJUSTABLE METAL HOSE
CLAMPS - APPROX. 2' APART

METAL TRACK

METAL TRACK
AT RIB
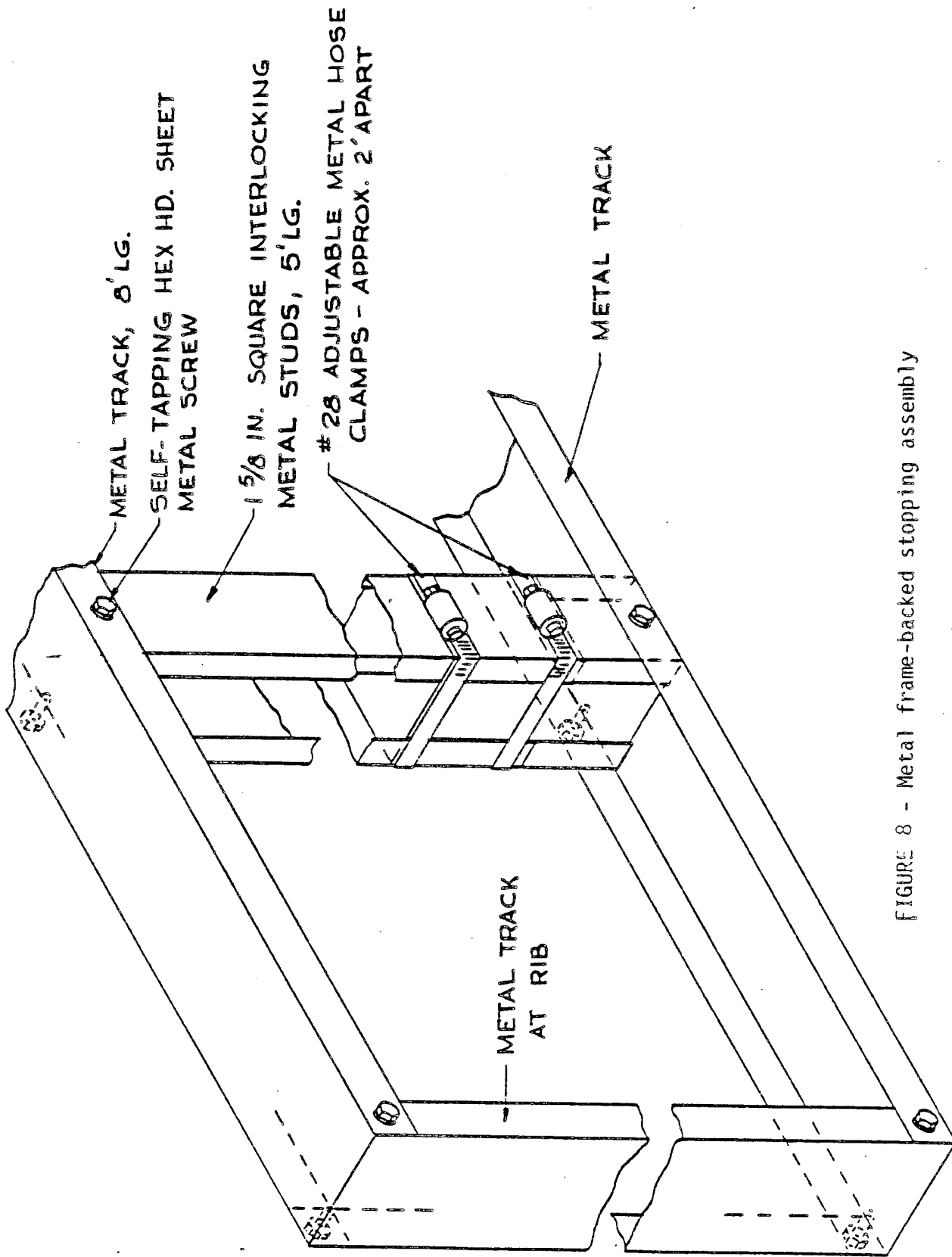
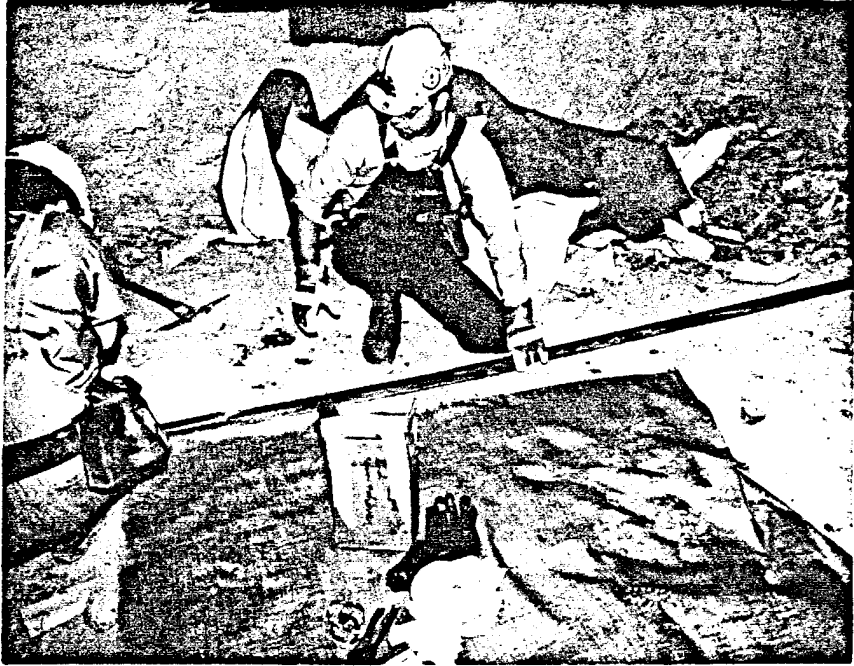FIGURE 8 - Metal frame-backed stopping assembly

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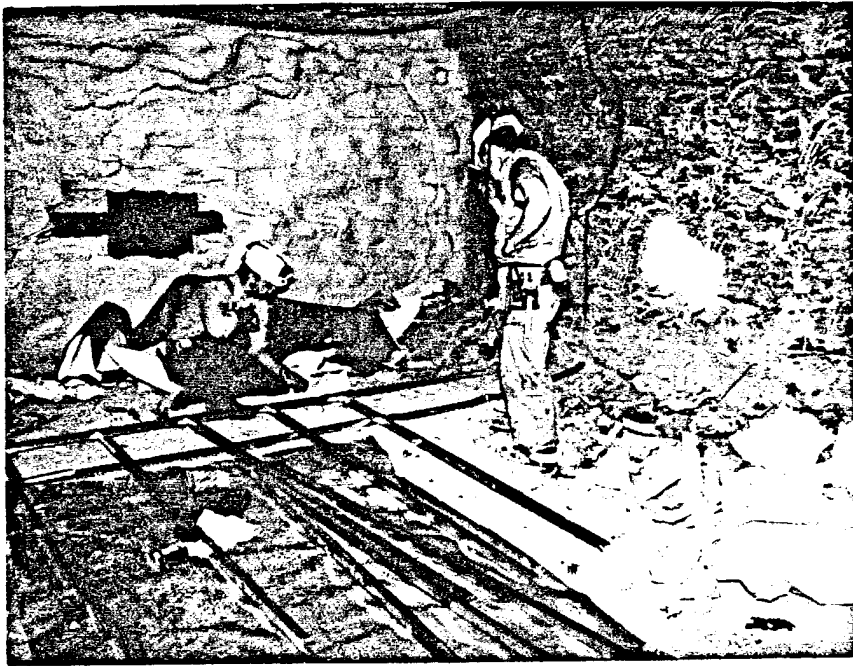
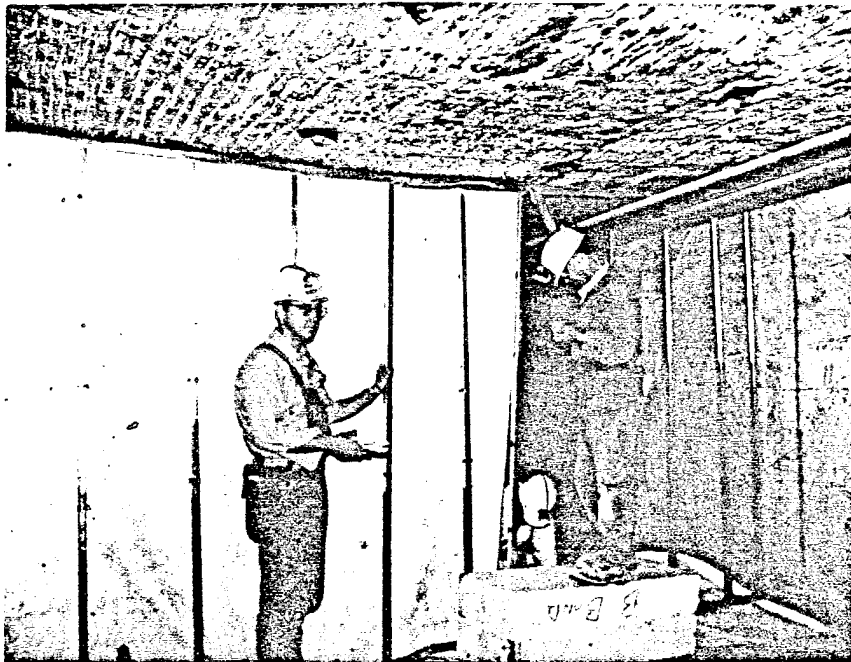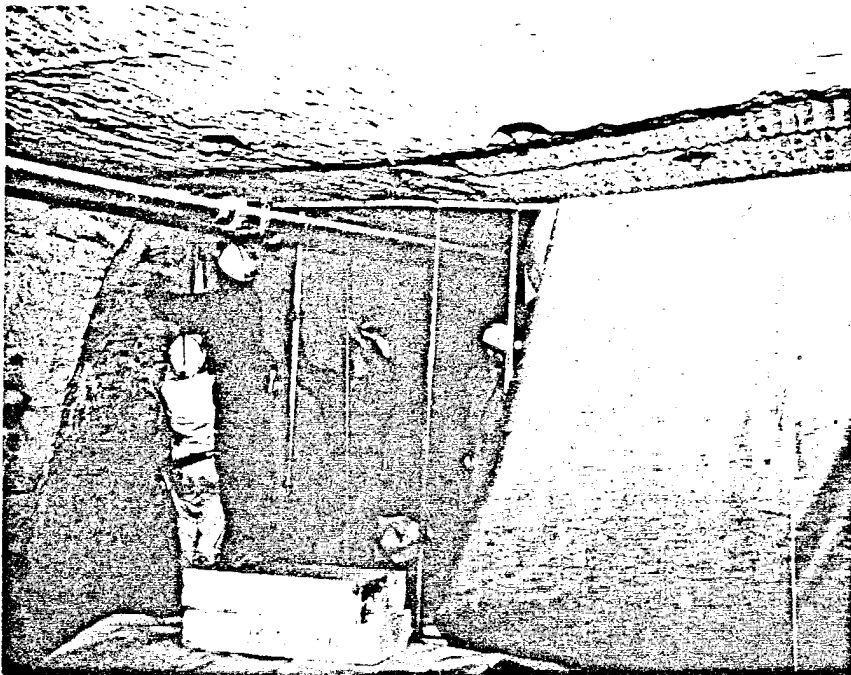FIGURE 9 - Metal frame-backed stoppings under construction

FIGURE 10 - Metal frame-backed stoppings under construction

member on the back side of the stopping and binding the two together tightly with wires.

The binding wires were easily pushed through the polystyrene block stoppings, and when twisted tight with a wood or metal member, sandwiched the foam blocks tightly between the lagging. The urethane foam was applied on the surface as before. This technique would tend to distribute any potentially rupturing force more evenly over the full face of the stopping.

TEST SUMMARY

A summary of the test stopping construction is shown in Table 51. The stopping sizes were nominal 8' H x 16' W, with variances running to 10' high and 19' wide. The problems involved and status approximately one month after installation are included in the comments. A summary of the test follows:

The test program called for the installation of 10 metal frame stoppings and 10 in which urethane was the sealant on new polystyrene foam block stoppings. The 10 foam block test stoppings were installed. However, severe shock waves set up by either exceptionally heavy charges or improper timing sequences during production blasting caused considerable damage not only to the test stoppings, but to the mine's normal wooden and polystyrene stoppings. In one case, the first day's construction effort, consisting of 2 each of the foam block and metal-backed stoppings placed alternately, were destroyed overnight. Two of those destroyed were in the 6th and 7th crosscuts from the face, demonstrating the extreme force of the shock waves. The foam stoppings were salvable. The metal stoppings were completely demolished.

This pattern was repeated with later test efforts. In another panel, two foam block stoppings placed in crosscuts 5 and 6 back from the face were blown out after being foamed. Subsequent test stoppings, placed 16 and 20 cross cuts from the face, also suffered blast damage. This damage was unusually severe, according to the mine ventilation personnel. These problems severely hampered our efforts. Before and after photos of both types of stoppings are shown in Figures 11 and 12. Because of the heavy blast over-pressures, only two metal/brattice stoppings were able to be completed in the time allotted.

TABLE 51 - Summary of test stopping program at FMC mine,
Green River, WY

| Stopping no. | Type | Foam identification | Comments |
|---|---|---|---|
| 8 Panel - Face at Crosscut 30 | | | |
| 26 | Foam block | X-156 | Installed completely; blast damage showing 8 sq. ft. missing and perimeter cracking |
| 25 | " | X-156 | Installed completely; blast damage bowed and cracked perimeter. |
| 15 | " | X-156 | Installed completely; blast damage showed cracks on perimeter |
| 12 | " | X-156 | Installed completely; intact |
| 11 | " | X-156 | Installed completely; intact |
| 9 | " | FS-24 | Installed completely; intact |
| 7 | " | FS-24 | Installed completely; intact |
| 5 | " | FS-24 | Installed completely; intact |
| 10 Panel - Face at Crosscut 7 | | | |
| 2 | Foam block | FS-24 | Blown out before foaming; repaired and sprayed; intact |
| 1 | Metal frame | FS-24 | Blown out before foaming; repaired and blown out 2nd time; removed |
| Haulage 2 | Foam block | -- | Blown out before foaming; repaired and sprayed; intact |
| Haulage 1 | Metal frame | FS-24 | Buckled during blasting; repaired and sprayed; blown out subsequently |
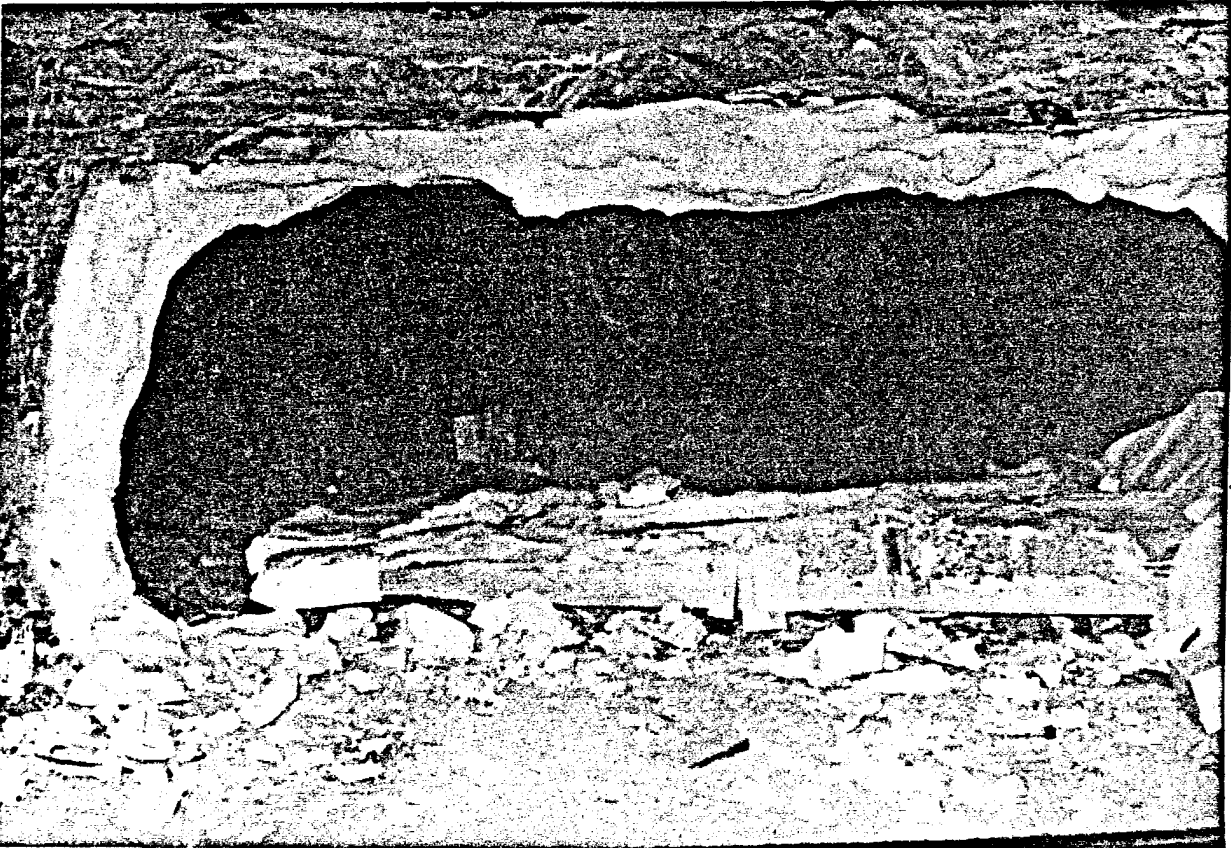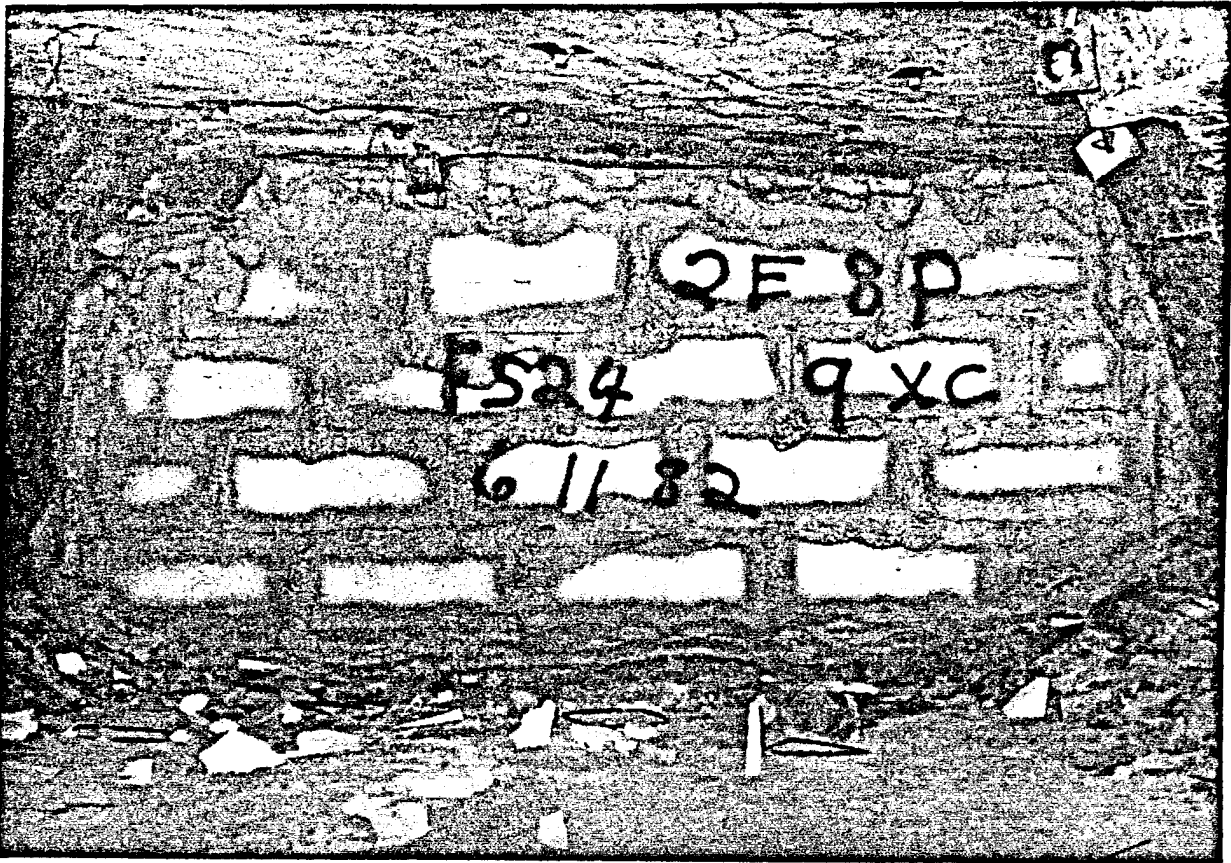
FIGURE 11 - Before and after photos of polystyrene
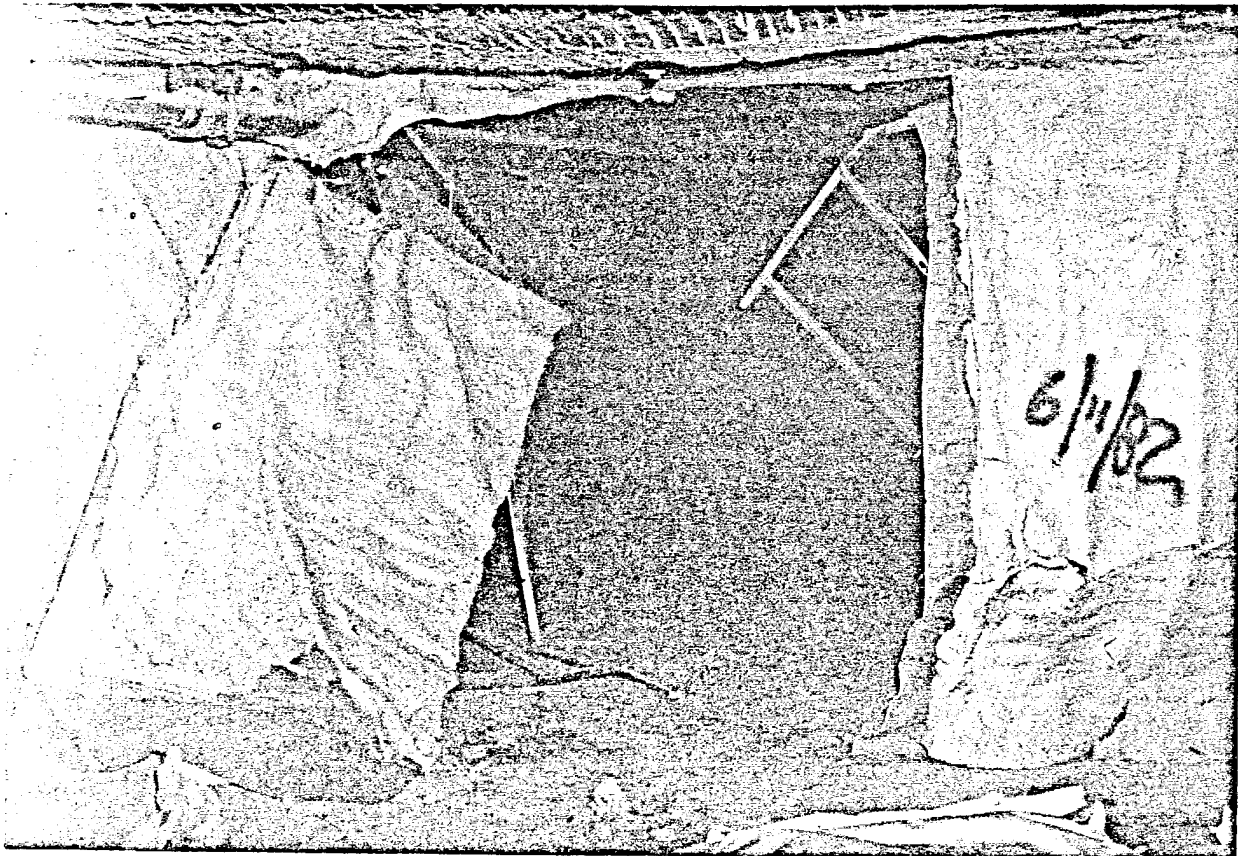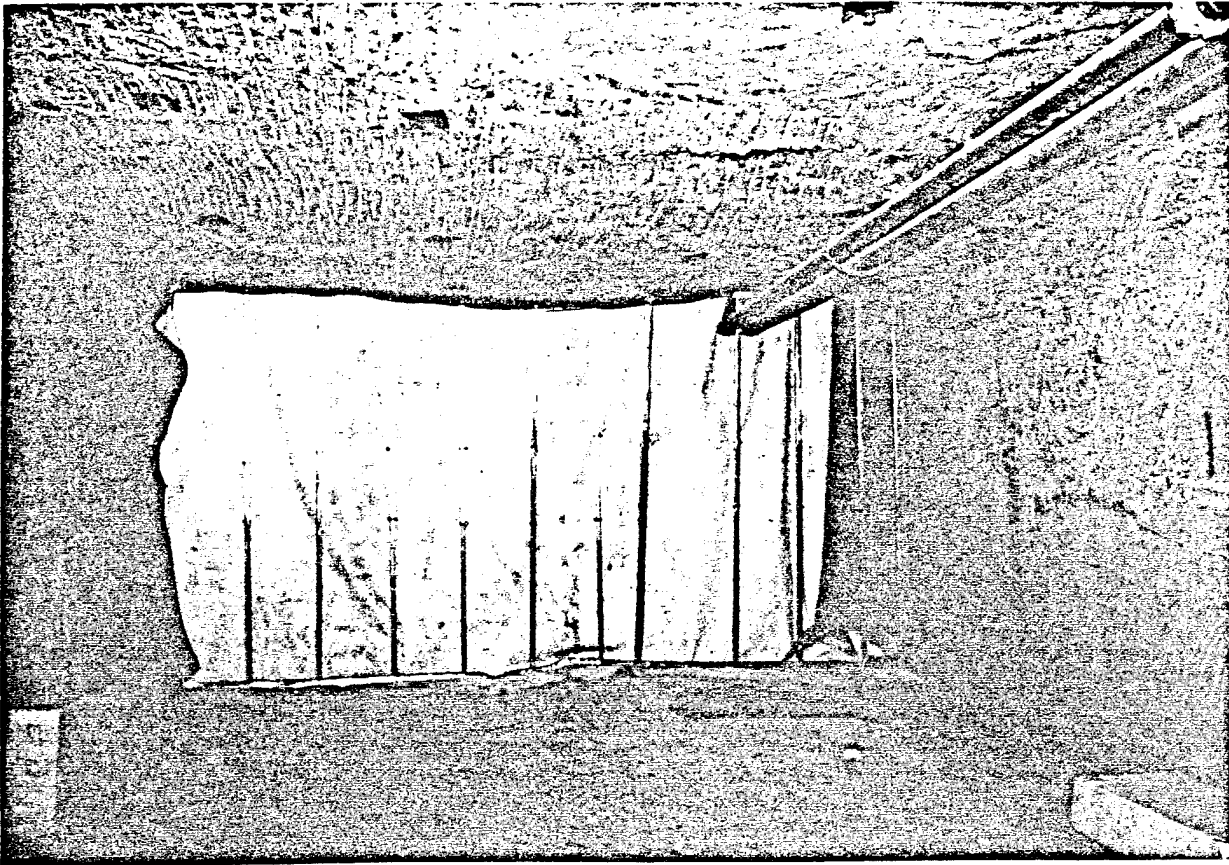block stoppings showing effects of blasting

FIGURE 12 - Before and after photos of metal frame-
backed stoppings showing effects of blasting

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## SUMMARY

A total of 27 foams representing 5 generic types of foam were selected from an industry-wide survey and evaluated for use as a sealant for mine stoppings.

Flame spread data, used in the evaluations of this program, were obtained by ASTM-E162 tests and a modification, signified as E162-CCC-2. These data differed significantly from manufacturer's published results of the ASTM-E84, 25 ft. tunnel test. No adequate correlations of these data became apparent during this investigation.

The general quality and fire-resistance of rigid foams have improved considerably over the years. The best of the earliest candidates entering the market is now about equal to the average product performance in these two areas.

Ten to fifteen of representative foam materials selected for evaluation were considered to have generally "good" properties. Three of these had "outstanding" flame spread indices and three others were considered "good". However, two that were "outstanding" had high air permeability and were thus unsuitable for stoppings.

The best foam clearly was Item 5, X-156, offered by Callery Chemical Company/Mine Safety Appliances Company. It ranked at the top by flame spread testing and equivalent in all of the remaining tests, except adhesion to wet surfaces.

The second foam, initially selected was Item 15, Olin Chemical's Poly System 7622-02. It was grouped closely with foam candidates from the Freeman and Witco Chemical Companies, either of which could just as well have been selected.

The unavailability of a polyol used in the formulation of these leading candidates, however, caused all of them to be dropped from consideration. Because of insufficient market potential, Olin Corporation, the supplier of Thermolin RF230, decided to stop production.

Foam System's FS-24 (Item 11), was selected as the replacement for Olin's Poly System 7622-02. Although lower ranked than the bypassed candidates by E162, it had excellent adhesion test data.

In-mine test of the "final 2" candidate foams were conducted in FMC's Trona mine at Green River, Wyoming, in a conventional mining section subjected to squeeze conditions. The foams were employed as joint and perimeter seals for polystyrene foam block stoppings under test by FMC, and as a face sealant for a light metal framework/brattice stopping.

The metal framework/brattice combination as backing for the urethane foam sealant proved to be unsuitable for the conventional mining section. The openings were too irregular to allow for convenient erection and the type construction ultimately too flimsy to withstand the blasting shockwaves. Attempts to install this type even at considerable distances from the face were soon abandoned because of the problems of erection in the rough openings. We feel, however, that this design would be suitable for continuous miner sections where the openings are more regular and blasting nonexistent.

Both the X-156 and FS-24 foams applied readily with the foam applicator equipment. Subsequent shockwaves proved the FS-24, however, to be superior to X-156 in adhesion to foam, wood and stone surfaces. The more brittle X-156 cracked under load and released significantly from the substrates. This was particularly noticeable on the polystyrene foam where, if failure occurred, with X-156 a urethane/foam substrate break occurred, whereas with FS-24 the break occurred in the polystyrene.

Although an indictment against X-156, these results should be reviewed in context. X-156 demonstrates that foams far superior to FS-24 on flame properties are possible, but may have to trade off other properties (such as adhesion) to achieve the high flame resistance. Under less extreme circumstances, however, where disruptive blasting shockwaves are not present, the adhesion of such foams may prove to be more than adequate.

APPENDIX

Table A-1 is a detailed listing of Manufacturers contacted during our survey for foamed materials candidates in Phase I of the program. Table A-2 is a listing of the foams that resulted from the survey, their properties as obtained from the manufacturer or published literature, and our assessment as to their suitability for mine use. A code sheet and comments on property designations are included to assist in the interpretation of the table.

TABLE A-1 - Manufacturers contacted in survey of foamed materials

| Generic foam type | Company | Generic foam type | Company |
|---|---|---|---|
| ABS | Borg-Warner Corporation<br>Borg-Warner Chemicals & Plastics<br>International Center<br>Parkersburg, WV 26101 | Epoxy (cont) | Emerson and Cumings, Inc.<br>869 Washington Street<br>Canton, MA 02021 |
| Acetal | Celanese Plastic Materials Co.<br>26 Main Street<br>Chatham. NJ 07925 | | Ren Plastics<br>5656 South Cedar Street<br>Lansing, MI 48909 |
| Cellulose<br>acetate | American Polymers, Inc.<br>50 California Avenue<br>Paterson, NJ 07503 | | Kristal Kraft, Inc.<br>P.O. Box 787<br>Palmetto, FL 33561 |
| | Deltex Associates<br>122 Lowell Street<br>Carterette, NJ 07008 | Ionomer | Gilman Brothers Company<br>102 Main Street<br>Gilman, CT 06336 |
| | Eastman Chemical Products, Inc.<br>P.O. Box 331<br>Kingsport, TN 37662 | Isocyanurate | Chemetics Systems, Inc.<br>2006 Gladwick Street<br>Compton, CA 90220 |
| Epoxy | Bacon Industries, Inc.<br>192 Pleasant Street<br>Watertown, MA 02172 | | Texas Urethanes<br>10137 Highway 290 East<br>Austin, TX 78766 |
| | Isochem Resins Company<br>Cook Street<br>Lincoln, RI 02865 | | Foam Systems Company<br>3640 Chicago Avenue<br>Riverside, CA 92507 |
| | Shell Chemical Company<br>One Shell Plaza<br>Houston, TX 77002 | | Upjohn Company, CPR Division<br>555 Alaska Avenue<br>Torrance, CA 90503 |
| | Sika Chemical Company<br>631 Idlewood Avenue<br>Carnegie, PA 15106 | Melamine-based | American Cyanamid<br>Chemical Research Division<br>1937 West Main Street<br>Stamford, CT 06904 |

TABLE A-1 - Manufacturers contacted in survey of foamed materials (cont)

| Generic foam type | Company | Generic foam type | Company |
|---|---|---|---|
| Phenolic | Schenectady Chemicals, Inc.<br>P.O. Box 1046<br>Schenectady, NY 12301 | Polycarbonate | General Electric Company<br>Engineering Structural Foam Resins<br>Plastics Division<br>One Plastics Avenue<br>Pittsfield, MA 01201 |
| | Smithers Company<br>Oasis Division<br>919 Marvin Avenue<br>Kent. OH 44240 | Polyethylene | Dow Chemical Company<br>2020 Dow Center<br>Midland, MI 48640 |
| Phenylene<br>oxide-based | General Electric Company<br>Plastics Division<br>One Plastics Avenue<br>Pittsfield, MA 01201 | | Dynamit Nobel of America, Inc.<br>105 Stonehurst Ct.<br>Northvale, NJ 07647 |
| Polyamide-imide | Amoco Chemicals Corporation<br>200 East Randolf Street<br>Chicago, IL 60601 | | Vantage Products<br>Conyers, GA 30207 |
| | Enplax Corporation<br>P.O. Box 22<br>234 Franklin Avenue<br>Nutley, NJ 07110 | | Crest Foam, Inc.<br>100 Carol Place<br>Moonachie, NJ 07075 |
| | Allied Chemical Corporation<br>Fibers and Plastics Company<br>P.O. Box 2332R<br>Morristown, NJ 07960 | | Northern Petrochemical Co.<br>Nortech Division<br>830 Main Street<br>Clinton, MA 01510 |
| | Celanese Plastic Materials Co.<br>26 Main Street<br>Chatham, NJ 07928 | | Rogers Foam Corporation<br>20 Vernon Street<br>Somerville, MA 02145 |
| Polybenzimidazole | Armstrong Cork Company<br>1010 Concord Street<br>Lancaster, PA 17603 | | United Minerals and<br>Chemicals Corp.<br>129 Hudson Street<br>New York, NY 10013 |

TABLE A-1 - Manufacturers contacted in survey of foamed materials (cont)

| Generic foam type | Company | Generic foam type | Company |
|---|---|---|---|
| Polyimide | Ciba-Geigy Corporation<br>SPE Aerolite Division<br>8025 Dixie Highway<br>Florence, KY 41042 | Polyurethane<br>(cont) | Chemetics Systems, Inc.<br>2006 Gladwick Street<br>Compton, CA 90220 |
| | Monsanto Company<br>800 N. Linbergh Boulevard<br>St. Louis, MO 63166 | | Fomo Products, Inc.<br>1090 Jacoby Road<br>Akron, OH 44321 |
| Polypropylene | Northern Petrochemical Co.<br>Nortech Division<br>830 Main Street<br>Clinton, MA 01510 | | Furane Plastics, Inc.<br>5121 San Fernando Road<br>Los Angeles, CA 90039 |
| | Vantage Products<br>Conyers, GA 30207 | | BASF Wyandotte Corporation<br>Wyandotte, MI 48192 |
| | Sun Chemical Corporation<br>Facile Division<br>185 Sixth Avenue<br>Paterson, NJ 07524 | | Cook Paint & Varnish Company<br>P.O. Box 389<br>Kansas City, MO 64141 |
| | | | Freeman Chemical Corporation<br>P.O. Box 247<br>Port Washington, WI 53074 |
| Polystyrene | Dow Chemical Company<br>202 Dow Center<br>Midland, MI 48640 | | Hastings Plastics Company<br>1704 Colorado Avenue<br>Santa Monica, CA 90404 |
| | Northern Petrochemical Co.<br>Nortech Division<br>830 Main Street<br>Clinton, MA 01510 | | Insta-Foam Products, Inc.<br>2050 N. Broadway<br>Joliet, IL 60435 |
| Polyurethane | Atlas Minerals and Chemicals<br>Farmington Road<br>Merztown, PA 19539 | | Lankro Chemicals, Ltd.<br>P.O. Box 1<br>Eccles, Manchester<br>England M30 OBH |

TABLE A-1 - Manufacturers contacted in survey of foamed materials (cont)

| Generic foam type | Company | Generic foam type | Company |
|---|---|---|---|
| Polyurethane (cont) | Kristal Kraft, Inc.<br>P.O. Box 787<br>Palmetto, FL 33561 | Polyurethane (cont) | Hoover Universal<br>Chemical Specialties Division<br>P.O. Box 1424<br>Ann Arbor, MI 48106 |
| | M-R Plastics and Coatings<br>11460 Dorsett Road<br>Maryland Heights, MO 63043 | | Texas Urethanes<br>10137 Highway 290 East<br>Austin, TX 78766 |
| | Magnolia Plastics, Inc.<br>5547 Peachtree Ind. Pk. Blvd.<br>Chamble, GA 30341 | | United Foam Corporation<br>2626 Vista Industria<br>Compton, CA 90221 |
| | Midwest Manufacturing Corp.<br>Oak Street at Bluff Road<br>Burlington, IA 52601 | | Upjohn Company, CPR Division<br>555 Alaska Drive<br>Torrance, CA 90503 |
| | Olin Chemical Corporation<br>120 Long Ridge Road<br>Stamford, CT 06904 | | Urethane Systems Corporation<br>109 West 134th Street<br>Los Angeles, CA 90061 |
| | Pelron<br>7847 West 47th Street<br>Lyons, IL 60534 | | Utah Foam Products<br>572 South 2165 West<br>Salt Lake City, UT 84104 |
| | Fremont-Hayward<br>California | | Witco Chemical Company<br>Isocyanate Products Division<br>900 Wilmington Road<br>New Castle, DE 19720 |
| | Reichold Chemicals, Inc.<br>525 North Broadway<br>White Plains, NY 10603 | | Ashland Chemical Company<br>P.O. Box 2219<br>Columbus, OH 43216 |
| | Stepan Chemical Company<br>Urethane Department<br>Northfield, IL 48106 | | W. R. Grace and Company<br>Chemical Foam Systems<br>Columbia, MD 21044 |

TABLE A-1 - Manufacturers contacted in survey of foamed materials (cont)

| Generic foam type | Company | Generic foam type | Company, |
|---|---|---|---|
| Polyurethane (cont) | Firestone Corporation<br>Urethane Foam Division<br>Foam Products Company<br>823 Waterman Avenue, Box 4159<br>East Providence, RI 02914 | PVC (cont) | Tenneco Chemicals<br>Foam Division<br>Valmont Industrial Avenue<br>West Hazelton, PA 18201 |
| | Owens-Corning Company<br>Fiberglass Tower<br>Toledo, OH 43659 | | Firestone Plastics Company<br>P.O. Box 699<br>Pottstown, PA 19464 |
| | Tenneco Chemicals<br>Foam Division<br>Valmont Industrial Park<br>West Hazelton, PA 18201 | | Colorite Plastics Company<br>101 Railroad Avenue<br>Ridgefield, NJ 07657 |
| | Mobay Chemical Company<br>Parkway West<br>Pittsburgh, PA 15235 | Silicate | Diamond Shamrock Company<br>Technical Center<br>Box 191<br>Painesville, OH 44077 |
| | Cargill, Inc.<br>15407 McGinty Road<br>Minneapolis, MN | | Caledonia Mining Company, Ltd.<br>Carlton-on-Trent (Newark)<br>Nottinghamshire<br>England NG236NT |
| | Essex Chemical Corporation<br>1-T Crossman Road, S<br>Sayreville, NJ 08872 | | Southwest Research Institute<br>6220 Culebra<br>San Antonia, TX 78228 |
| | Callery Chemical Company<br>Evans City, PA 16033 | | Fiberglass Canada, Ltd.<br>Box 3005<br>Sarnia, Ontario<br>Canada N7T7M6 |
| PVC | Diamond Shamrock Corporation<br>1110 Superior Avenue<br>Cleveland, OH 44114 | Silicone | Dow-Corning Corporation<br>P.O. Box 1767<br>Midland, MI 48640 |

TABLE A-1 - Manufacturers contacted in survey of foamed materials (cont)

| Generic foam type | Company | Generic foam type | Company |
|---|---|---|---|
| Silicone | General Electric Company<br>Silicone Products Department<br>Mechanicville Road<br>Waterford, NY 12188 | Urea-formaldehyde<br>(cont) | Rapco, Inc.<br>518 South Eleventh Street<br>Richmond, CA 94804 |
| | Emerson and Cuming, Inc.<br>869 Washington Street<br>Canton, MA 02021 | Also, for a natural rubber blended material which is sprayable: | |
| Thermoplastic polyester | General Electric Company<br>Plastics Division<br>One Plastics Avenue<br>Pittsfield, MA 01201 | | H. L. Blackford, Ltd.<br>2323 Royal Windsor Drive<br>Mississauga, Ontario<br>Canada L5J1K5 |
| | Celanese Plastic Material Co.<br>26 Main Street<br>Chatham, NJ 07928 | | |
| | Owens-Corning Fiberglass Corp.<br>Fiberglass Tower<br>Toledo, OH 43659 | | |
| Urea-formaldehyde | Arrowhead Plastics<br>Engineering, Inc.<br>P.O. Box 412<br>Muncie, IN 47305 | | |
| | Ciba-Geigy Corporation<br>Plastics Division<br>Saw Mill River Boulevard<br>Ardsley, NY 10502 | | |
| | Borden, Inc.<br>180 E. Broad Street<br>Columbus, OH 43215 | | |

TABLE A-2 - Properties of foams surveyed

| Generic type | ABS | Acetal | Amide/Imide | | Epoxy | Ionomer | Nitrile/vinyl |
|---|---|---|---|---|---|---|---|
| Supplier | Borg-Warner Corporation | Celanese Plastics Co. | Allied Chemical | Celanese Plastics Co. | Ren Plastics | Gilman Brothers | Armstrong Cork |
| Product Identity | Cycolac FBK | Celcon M90 | Capron XPN 1173 | Nylon 1503 | RP 1774 | Surlyn Softlite | Armaflex II |
| Type of foam | Rigid | Rigid | Rigid | Rigid | Rigid | Semi-rigid | Flexible |
| Density, lb/ft$^3$ | 45 | 62 | 55 | 60 | 15 | 3 | 6 |
| Comp strength, psi* | 3000 | ND | ND | ND | 450 | 2 | 3 |
| Tensile strength, psi* | 2000 | 5400 | 9000 | 13,400 | ND | 100 | ND |
| Combustibility, rating* | VO/5V | HB | (14) | HB | (14) | Pass | 25 |
| , method | UL94 | UL94 | ND | UL94 | ND | M.V. 302 | E84 |
| , smoke | ND | ND | ND | ND | ND | ND | 100/150 |
| Water absorption, lbs/ft$^2$* | ND | ND | ND | ND | ND | ND | ND |
| , % | 0.3 | ND | 1.6 | ND | ND | 0.1 | 6 |
| Moisture vapor transmission,* perm in | ND | ND | ND | ND | ND | ND | 0.17 |
| Maximum service temp, °F* | 170 | 307 | 300 | 490 | 128 | 160 | 220 |
| Commercial use* | (1) | (1) | (1) | (1) | (1) | (2) | (4) |
| Mode of preparation* | (5) | (5) | (5) | (5) | Pour | (5) | (5) |
| Equipment costs, $1000 | 50-250 | 50-250 | 50-250 | 50-250 | 10 | 50-250 | None |
| Stopping cost/100 ft$^2$, $ | 115 | 185 | 185 | 185 | 115 | 45 | 115 |
| at thickness, in | 0.25 | 0.25 | 0.25 | 0.25 | 0.5 | 1.0 | 0.25 |
| Unusual positive properties* | (6) | (6) | (6) | (6) | None | None | None |
| Unusual negative properties* | (13) | (13,14) | (13,14) | (13,14) | (14,20) | (13,14) | (13) |
| Suitable for mine use? | | | | | | | |
| As to mode of production? | No | No | No | No | No | No | Maybe |
| As to combustibility? | No | No | No | No | Maybe | No | Maybe |
| | Maybe | No | No | No | No | No | Yes |

*Refer to code sheet at end of table

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TABLE A-2 - Properties of foams surveyed (cont)

| Generic type | Phenol/formaldehyde | Phenol/formaldehyde | Phenylene Oxide | Polycarbonate | Poly-ethylene | Urea/formaldehyde | Urea/formaldehyde |
|---|---|---|---|---|---|---|---|
| Supplier | Reichhold Ltd. | Schenectady Chemicals | General Electric | General Electric | Dow Chemical | Ciba-Gelgy | Rapersw111 |
| Product Identity | Phenolite 1B322/1D644 | HRJ-913 | Noryl FN215 | Lexan 1800 | Ethafoam 222 | Aerolite SPE | Rapco-Foam |
| Type of foam | Rigid | Rigid | Rigid | Rigid | Rigid | Rigid | Rigid |
| Density, lb/ft³ | 3 | 3 | 50 | 60 | 3 | 1 | 0.7 |
| Comp strength, psi* | 20 | ND | ND | ND | 6 – 12 | 1.5 | ND |
| Tensile strength, psi* | ND | ND | 3600 | 6300 | 100 | ND | ND |
| Combustibility, rating* | 5 | (14) | 110 | 18 | Burning | 20 | 25 |
| , method | E84 | ND | E162 | E162 | ND | E84 | E84 |
| , smoke | 0 | ND | ND | ND | ND | 125-200 | 0 - 5 |
| Water absorption, lbs/ft²* | ND | ND | ND | ND | ND | ND | ND |
| , % | 25 | ND | 0.07 | ND | 0.2 | 15 | 2.2 |
| Moisture vapor transmission,* perm in | ND | ND | ND | ND | 0.3 | 20 | 35 |
| Maximum service temp, °F* | 400 | ND | 180 | 270 | 180 | 200 | ND |
| Commercial use* | (4) | (4) | (1) | (1) | (2,4) | (4) | (4) |
| Mode of preparation* | Pour/Spray | Pour | (5) | (5) | (5) | Pour/Spray | Pour/Spray |
| Equipment costs, $1000 | 10 | 10 | 50-250 | 50-250 | None | 6 | 6 |
| Stopping cost/100 ft², $ | 45 | 45 | 115 | 185 | 45 | 45 | 45 |
| at thickness, in | 1.0 | 1.0 | 0.25 | 0.25 | 1.0 | 1.0 | 1.0 |
| Unusual positive properties* | (10,11) | None | (6) | (6) | None | None | (11) |
| Unusual negative properties* | (15,18) | (14,18) | (13,14) | (13) | (13,14) | (15,17) | (15,17,22,23) |
| Suitable for mine use? | | | | | | | |
| As to mode of production? | Maybe | No | No | No | No | Maybe | Maybe |
| As to combustibility? | Yes | No | No | No | No | Yes | Yes |
| | Yes | No | No | Yes | No | Yes | Yes |

*Refer to code sheet at end of table

TABLE A-2 - Properties of foams surveyed (cont)

| Generic type | Silicones | | | | | Thermoplastic polyesters | | |
|---|---|---|---|---|---|---|---|---|
| Supplier | Dow-Corning | Emerson & Cuming | General Electric | General Electric | General Electric | Celanese Plastics Co. | Celanese Plastics Co. | General Electric |
| Product Identity | 3-6548RTV | Eccofoam SIL | RTV 6428 | RTV 7403 | RTV 850 | Celanex 3210 | Celanex 3310 | Valox FV-600 |
| Type of foam | Flexible | Flexible | Flexible | Elastomer | Semi-rigid | Rigid | Rigid | Rigid |
| Density, lb/ft$^3$ | 17 | 20 | 85 | 80 | 20 - 25 | 68 | 72 | 70 |
| Comp strength, psi* | 5 | 5 | ND | ND | ND | ND | ND | ND |
| Tensile strength, psi* | 33 | 100 | 400 | 25 | ND | 9000 | 10,200 | 7000 |
| Combustibility, rating* | 20 | (14) | 13 | 25 | 21 | VO | VO | VO |
| , method | E84 | ND | E84 | E84 | UL94 | UL94 | UL94 | ND |
| , smoke | ND | ND | 54 | ND | 204 | ND | ND | ND |
| Water absorption, lbs/ft$^2$* | ND | ND | ND | ND | ND | ND | ND | ND |
| , % | ND | 0.1 | ND | ND | ND | ND | ND | 0.26 |
| Moisture vapor transmission,* perm in | ND | ND | ND | ND | ND | ND | ND | ND |
| Maximum service temp, °F* | High | 400 | High | High | High | 417 | 424 | 340 |
| Commercial use* | (3) | (3) | (3) | (3) | (3) | (1) | (1) | (1) |
| Mode of preparation* | Pour | Pour | Pour | Pour | Pour | (5) | (5) | (5) |
| Equipment costs, $1000 | 10 | 6-10 | 10+ | 10+ | 10+ | 50-250 | 50-250 | 50-250 |
| Stopping cost/100 ft$^2$, $ | 485 | 485 | 485 | 485 | 485 | 185 | 185 | 185 |
| at thickness, in | 0.5 | 0.5 | 0.15 | 0.15 | 0.5 | 0.25 | 0.25 | 0.25 |
| Unusual positive properties* | (9) | (9) | (9) | (9) | (9) | (6,9) | (6,9) | (6) |
| Unusual negative properties* | (16,20) | (14,16,20) | (16,20) | (16,20) | (16,20) | (13) | (13) | (13) |
| Suitable for mine use? | Maybe | No | Maybe | Maybe | Maybe | No | No | No |
| As to mode of production? | Maybe | Maybe | Maybe | Maybe | Maybe | No | No | No |
| As to combustibility? | Yes | No | Yes | Yes | Yes | Maybe | Maybe | Maybe |

*Refer to code sheet at end of table

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TABLE A-2 - Properties of foams surveyed (cont)

| Generic type | Isocyanurates | | | | | | Urethanes | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Atlas Minerals and Chemicals | |
| Supplier | Chemetics Systems | Foam Systems | Insta-Foam Products | Texas Urethanes | UpJohn Co. | Ashland Chemical | Urefoam R-02 | Urefoam R-07 |
| Product Identity | CSI 9575 | FSC 55 | ICU Kit | Texthane 333 | Isonate CPR425 | Phenolic Urethane | | |
| Type of foam | Rigid | Rigid | Rigid | Rigid | Rigid | Rigid | Rigid | Rigid |
| Density, lb/ft$^3$ | 2.5 | 2 | 2.5 | 2.1 | 2 | 2 | 2 | 7 |
| Comp strength, psi* | 40 | 30 | 20 | 27 | 26 | 35 | 5 | 80 |
| Tensile strength, psi* | 75 | 45 | 40 | ND | 50 | ND | 13 | 65 |
| Combustibility, rating* | 25 | 25 | 25 | 25 | 25 | 20 | ND | ND |
| , method | E84 | E84 | E84 | E84 | E84 | E84 | ND | ND |
| , smoke | 150 | 250-450 | 400 | ND | 400 | 140 | ND | ND |
| Water absorption, lbs/ft$^2$* | ND | ND | ND | ND | ND | ND | ND | ND |
| , % | ND | ND | 3 | ND | ND | ND | 0.11 | 0.05 |
| Moisture vapor transmission,* perm in | ND | ND | 3 | ND | 2.5 | ND | ND | ND |
| Maximum service temp, °F* | ND | ND | 300 | ND | ND | 225 | 170 | 170 |
| Commercial use* | (4) | (4) | (4) | (4) | (4) | (4) | (4) | (4) |
| Mode of preparation* | Spray | Spray | Froth | Froth | Spray | Pour | Pour | Pour |
| Equipment costs, $1000 | 6 | 6 | None | 10 | 6 | 6 | 6 | 6 |
| Stopping cost/100 ft$^2$, $ | 45 | 45 | 300 | 45 | 45 | 60 | 45 | 90 |
| at thickness, in | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Unusual positive properties* | None | None | None | None | None | None | None | None |
| Unusual negative properties* | (22) | (21) | None | (22,23) | (22,23) | None | (14,15) | (14) |
| Suitable for mine use? | Yes | No | Yes | Yes | Yes | Yes | No | No |
| As to mode of production? | Yes | Yes | Yes | Yes | Yes | Maybe | No | No |
| As to combustibility? | Yes | Yes | Yes | Yes | Yes | Yes | No | No |

*Refer to code sheet at end of table

## TABLE A-2 - Properties of foams surveyed (cont)

| Generic type | Urethanes | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Supplier | BASF Wyandotte | CCC/MSA | CCC/MSA | Chemetics Systems | Chemetics Systems | Chemetics Systems | Cook Paint and Varnish Co. | Cook Paint and Varnish Co. |
| Product Identity | Pluragard S-602 | Rigimix E/F | X-156 | CSI 8420 | CSI 9120 | CSI 9152 | Coro-Foam G 325 | Coro-Foam 440 |
| Type of foam | Rigid | Rigid | Rigid | Rigid | Rigid | Rigid | Rigid | Rigid |
| Density, lb/ft³ | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Comp strength, psi* | 30 | 30 | 30 | 33 | 29 | 35 | 27 | 25 |
| Tensile strength, psi* | 40 | 40 | 40 | 38 | 27 | 40 | ND | ND |
| Combustibility rating* | 25 | 25 | 20 | 20 | 20 | 20 | 30 | 25 |
| , method | E84 | E84 | E84 | E84 | E84 | E84 | E84 | E84 |
| , smoke | 350 | 350 | 150 | 190 | 110 | 305 | 185 | 75 |
| Water absorption, lbs/ft²* | ND | ND | ND | ND | ND | ND | ND | ND |
| , % | ND | ND | ND | 0.1 | 0.03 | 0.03 | 0.06 | 0.06 |
| Moisture vapor transmission,* perm in | ND | 2.5 | 2.5 | 2 | 2 | 2 | 2.5 | 2.5 |
| Maximum service temp, °F* | 250 | 250 | 250 | ND | ND | ND | ND | ND |
| Commercial use* | (4) | (4) | (4) | (4) | (4) | (4) | (4) | (4) |
| Mode of preparation* | Spray | Spray | Spray | Froth | Spray | Spray | Spray | Froth |
| Equipment costs, $1000 | 6 | 6 | 6 | 10 | 6 | 6 | 6 | 10 |
| Stopping cost/100 ft², $ | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 |
| at thickness, in | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Unusual positive properties* | None | None | (11) | None | (11) | None | None | (11) |
| Unusual negative properties* | (22) | None | None | None | (22) | None | None | None |
| Suitable for mine use? | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| As to mode of production? | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| As to combustibility? | Yes | Yes | Yes | Yes | Yes | Yes | Maybe | Yes |

*Refer to code sheet at end of table

| Generic type | Urethanes | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Supplier | Emerson & Cuming | Foam Systems Co. | Foam Systems Co. | Foam Systems Co. | Fomo Products, Inc. | Freeman Chemical | Hoover Universal | Insta-Foam Products, Inc. |
| Product Identity | Eccofoam FPH-FR | FS 24 | FS 25 | FS 234 | Fomospray | Chempol 30-212/30-2038 | RU 6100 | FS-75 Kit |
| Type of foam | Rigid | Rigid | Rigid | Rigid | Semi-rigid | Rigid | Rigid | Rigid |
| Density, lb/ft³ | 3 | 2 | 2 | 2.2 | 1.5 | 2 | 2 | 1.8 |
| Comp strength, psi* | 30 | 33 | 25 | 40 | 10 | 25 | 29 | 17 |
| Tensile strength, psi* | 40 | 53 | 40 | 50 | 12 | 40 | ND | 35 |
| Combustibility rating* , method | SE D1692 | 25 E84 | 25-30 E84 | 25 E84 | SE D1692 | 25 E84 | <75 ND | 65 E84 |
| , smoke | ND | 115-500 | 135-500 | 200-500 | ND | 250-350 | <250 | 400 |
| Water absorption, lbs/ft²* , % | ND 3 | ND ND | ND ND | ND ND | ND ND | ND ND | ND ND | ND 5 |
| Moisture vapor transmission,* perm in | ND | ND | ND | ND | ND | ND | 1.7 | 3 |
| Maximum service temp, °F* | 275 | ND | ND | ND | ND | ND | ND | 250 |
| Commercial use* | (4) | (4) | (4) | (4) | (4) | (4) | (4) | (4) |
| Mode of preparation* | Spray | Spray | Spray | Spray | Froth | Spray | Spray | Froth |
| Equipment costs, $1000 | 6 | 6 | 6 | 6 | None | 6 | 6 | None |
| Stopping cost/100 ft², $ | 60 | 45 | 45 | 45 | 300 | 45 | 45 | 300 |
| at thickness, in | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Unusual positive properties* | None | None | None | None | (7,8) | None | None | (8) |
| Unusual negative properties* | (17) | None | None | None | (14,15) | None | None | (14) |
| Suitable for mine use? | No | Yes | Yes | Yes | No | Yes | No | No |
| As to mode of production? | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| As to combustibility? | No | Yes | Maybe | Yes | No | Yes | No | No |

*Refer to code sheet at end of table

TABLE A-2 - Properties of foams surveyed (cont)

| Generic type | | Urethanes | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Supplier | Isochem Resins Co. | Olin Corp. | Olin Corp. | Olin Corp. | Polymir | Texas Urethanes | United Foam | United Foam |
| Product Identity | 9 R 2 | Autofroth 7415-02 | Polysystem 7622-02 | Polysystem 7613-02 | FMS-20 | Texthane 220-20 | UFC-115 | UFC-250 |
| Type of foam | Rigid | Rigid | Rigid | Rigid | Rigid | Rigid | Rigid | Rigid |
| Density, $lb/ft^3$ | 2 | 2.1 | 2.2 | 2.2 | 2.1 | 2 | 2 | 2 |
| Comp strength, psi* | ND | 30 | 27 | 30 | 33 | 27 | 33 | ND |
| Tensile strength, psi* | ND | 40 | ND | ND | 58 | 40 | 47 | ND |
| Combustibility, rating* | SE | 20 | 25 | 64 | 20 | 25 | <75 | 25 |
| , method | D1692 | E84 | E84 | E84 | E84 | E84 | E84 | E84 |
| , smoke | ND | 250 | 200 | 440 | 150 | 175 | <450 | ND |
| Water absorption, $lbs/ft^2$* | ND | ND | ND | ND | ND | ND | ND | ND |
| , % | 0.75 | ND | ND | ND | 0.04 | ND | ND | ND |
| Moisture vapor transmission,* perm in | ND | ND | ND | ND | ND | 2.4 | ND | ND |
| Maximum service temp, °F* | 165 | ND | ND | ND | ND | ND | ND | ND |
| Commercial use* | (4) | (4) | (4) | (4) | (4) | (4) | (4) | (4) |
| Mode of preparation* | Pour | Froth | Spray | Spray | Spray | Spray | Spray | Spray |
| Equipment costs, $1000 | 6 | ND | 6 | 6 | 6 | 6 | 6 | 6 |
| Stopping cost/100 $ft^2$, $ | 45 | 75 | 45 | 45 | 45 | 45 | 45 | 45 |
| at thickness, in | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Unusual positive properties* | None | None | None | None | None | None | None | None |
| Unusual negative properties* | (14,15) | (19,22) | None | (14) | (22,23) | None | (14) | None |
| Suitable for mine use? | No | Yes | Yes | No | Yes | Yes | No | Yes |
| As to mode of production? | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| As to combustibility? | No | Yes | Yes | No | Yes | Yes | No | Yes |

*Refer to code sheet at end of table

TABLE A-2 - Properties of foams surveyed (cont)

| | | | | Urethanes | | | | |
|---|---|---|---|---|---|---|---|---|
| Generic type | | | | | | | | |
| Supplier | UpJohn Co. | Urethane Systems | Utah Foam Products Co. | Witco Chemical | Witco Chemical | Witco Chemical | Witco Chemical | W. R. Grace |
| Product Identity | Isonate CPR 468 | USC 230 | FMS 20 | SS-0640 | SS-0501 | SS-0119A/SS-0120B | SS-0715 | Hypol |
| Type of foam | Rigid | Rigid | Rigid | Rigid | Rigid | Rigid | Rigid | Semi-rigid |
| Density, lb/ft$^3$ | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 10-15 |
| Comp strength, psi* | 28 | 25 | 26 | 32 | 30 | 32 | 27 | ND |
| Tensile strength, psi* | 40 | 40 | 52 | ND | ND | ND | ND | ND |
| Combustibility, rating* | 25 | 25 | 25 | 25 | 25 | <75 | <75 | <25 |
| , method | E84 | E84 | E84 | E84 | E84 | E84 | E84 | E84 |
| , smoke | 350 | 500 | 300 | 450 | <450 | <450 | <450 | ND |
| Water absorption, lbs/ft$^2$* | ND | ND | ND | ND | ND | ND | ND | ND |
| , % | ND | 2.2 | 0.08 | ND | ND | ND | ND | ND |
| Moisture vapor transmission,* perm in | ND | ND | 1.8 | ND | ND | ND | ND | ND |
| Maximum service temp, °F* | ND | ND | ND | ND | ND | ND | ND | ND |
| Commercial use* | (4) | (4) | (4) | (4) | (4) | (4) | (4) | ND |
| Mode of preparation* | Spray | Spray | Spray | Spray | Spray | Spray | Spray | Spray/Pour |
| Equipment costs, $1000 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 10 |
| Stopping cost/100 ft$^2$, $ | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 115 |
| at thickness, in | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Unusual positive properties* | None | None | None | None | None | None | None | (12) |
| Unusual negative properties* | (22,23) | None | (22,23) | None | None | None | None | (17) |
| Suitable for mine use? | Yes | Yes | Yes | Yes | Yes | No | No | Maybe |
| As to mode of production? | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Maybe |
| As to combustibility? | Yes | Yes | Yes | Yes | Yes | No | No | Yes |

*Refer to code sheet at end of table

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## Code for TABLE A-2

Code

(1)   Cabinets for small equipment, appliances, tooling, etc.

(2)   Packaging or cushioning

(3)   Potting, casting, sealing

(4)   . Thermal insulation

(5)   Injection molding or extrusion

(6)   Strong

(7)   1-component system

(8)   Self-contained unit - no equipment needed

(9)   Usable at higher temperatures

(10)  Very low flame spread

(11)  Low smoke evolution

(12)  Can be applied to wet surface

(13)  Foam must be transported into mine and applied with adhesives

(14)  High or unknown flame spread

(15)  Very friable or weak

(16)  Contains fillers which can settle to bottom

(17)  Contains free TDI or formaldehyde

(18)  Short shelf life of components

(19)  3-component system

(20)  Pour-in-place; may need partial mold

(21)  Requires warm substrate

(22)  Data obtained from literature

(23)  Company does not want to participate

ND    No data

## Comments on Table 3 Performance Entries

Some of the information shown in Table 3 is discussed below:

a) Combustibility - The general trade policy about combustibility information is to use the best data available. No information usually means that the material will burn rapidly. Data obtained using ASTM Method D1692 (which has been discontinued because of its ambiguity) indicates minimal resistance to fire. The high density foams which are usually molded or extruded are typically rated by the UL94 procedure with VO/5V being the best rating. The UL94 results do not correlate with E84 or E162 data. We would anticipate that only foams having VO/5V ratings have sufficient resistance to fire to be safe for mine use. A UL94 rating can be obtained only from UL (Underwriters Laboratories).*

Many foam manufacturers had ASTM E84 data on their foams. Sometimes called the 25 ft. or Steiner tunnel test, ASTM E84 is a fairly severe test although its correlation with mine conditions is doubtful. E84 tests are invariably run by independent laboratories only, such as Underwriters Laboratories, Factory Mutual, U.S. Testing, and Southwest Research Institute. Several building codes and insurance underwriters require that foams be "listed" or certified. After initial certification, UL and FM have a policy of periodically checking on the quality and/or composition of the foam. Although the foam may have been "certified" several years ago, it has usually been checked and confirmed during the last year. UL guards its certification marks zealously.

b) Solubility in Water - All the foams listed in Table A-2 are primarily organic in nature. All have very low solubilities in water. In fact, the solubility is so low that it is almost never determined. A few foams contain fillers that are also insoluble in water. Probably none of these foams or their fillers would have sufficient solubility in water to exclude them from mine applications. The leaching tests in this study would identify any foams which would be unsuited for mine use.

c) Toxicity - None of the foams in Table A-2 are themselves toxic. Some raw materials can be hazardous and these should be listed by generic type.

\* Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding, and does not imply endorsement by the Bureau of Mines.

(1) <u>Epoxy Foams</u> - Some unreacted epoxides are known to be skin sensitizers on certain people. The catalysts are usually either strong primary amines (vesicants) or boron trifluoride complexes. Their suitability for mine use must be determined for each specific system.

(2) <u>Phenol/formaldehyde and Urea/formaldehyde</u> - The resins may be slightly alkaline, but the catalysts are usually strongly acidic, which might create some problems. Safety and handling procedures will have to be determined for each individual system. Furthermore, formaldehyde vapors can be evolved during foaming.

(3) <u>Isocyanurate and Urethane Foams</u> - These foams all use polymeric isocyanates as one of the main components. The isocyanate TLV is 0.02 ppm. Experience in mines has indicated that the isocyanate vapors react out in 2-3 minutes to form polyureas.

d) <u>Effects of Temperature and Humidity</u> - Only limited data were available. These data concerned water absorption, moisture vapor transmission, and usable temperature range. How this information relates to the suitability of various forms for stoppings is not clear.

e) <u>Application Equipment</u> - Basically, the foams are prepared by (1) molding, (2) extrusion, (3) pouring, (4) frothing, or (5) spraying. Equipment costs for any individual type of foam reflect the degree of sophistication and capacity of the equipment. Molders and extruders are expensive; they run from $50,000 to $250,000 and more. The froth, pour and spray equipment can usually be purchased in the $5,000 to $10,000 range. The cost figures shown in Table 3 are reasonable estimates.

f) <u>Costs of Stoppings</u> - The exact cost of labor and materials for a 100 ft² stopping varies with the material and method of application. Most of the raw materials cost from $0.50 to $1.50 per pound; the silicones are in the $4 to $7 per pound range. Labor was estimated at $16 per man-hour. The calculated cost varied from $15 to $540 for a stopping.

The cost figures fell into rather well-defined ranges and these were averaged and used in Table A-2. While these are not exact, the orders of magnitude and the relative costs should remain valid.

Equipment costs are not included except for the 3 foams marketed in self-contained disposable units. Many mines prefer the disposable units because they reduce labor and maintenance costs and delays. It is difficult to quantify these

costs; however the overall costs of using foam from a self-contained unit are about 10 times that of using a typical froth or spray applied foam. Spray equipment is not overly expensive ($8,000), but it must be moved to the site. Moving such equipment requires considerable expense in a mine situation.

While molding machines and extruders are expensive, the mines could probably purchase the foam from a manufacturer just as they do concrete blocks. This procedure would avoid the capital investment and maintenance costs.

g) Positive and Negative Foam Properites - Most of the foams in Table 3 are probably capable of making a stopping. The unusual positive properties are numbers 6 through 12 of the Table 3 code. Numbers 13 through 23 were considered to be unusual negative properties.

h) Suitability for Mine Use - This was decided primarily on the basis of the mode of production and the combustibility of the foams. Being unsatisfactory in either respect makes these unsuitable for mine use.

Foams were listed in Table A-2 as "maybe" when the mode of application, strength of the foam, and/or open-celled structure of the foam might create special problems.