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FIRE HAZARD CRITERIA FOR NOISE CONTROL PRODUCTS IN UNDERGROUND COAL MINES

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7. Author(s)
Mark R. Pettitt, R. E. Giuntini, William R. Wessels

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9. Performing Organization Name and Address
Wyle Laboratories
Research & Engineering Division
7800 Governors Drive, West
Huntsville, Alabama 35807

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The development of fire hazard criteria for noise control products in underground coal mines are presented. Qualifying requisites of the criteria include maintaining miners' safety, allowing for maximum use of noise control products, and economic feasibility. The burning process is analyzed for its relationship to fire hazard criteria developed by NASA and the FAA, and the mine environment is analyzed in conjunction with the end-use applications of noise control products. Also, the interim fire hazard specification developed by MSHA is appraised as it applies to end-use applications of noise control products. From these analyses and a literature survey, fire hazard criteria are developed. They include an initial screening procedure that evaluates the level of flammability testing required. Fire tests that may be indicated are the Vertical Flame Test, the Ignition Temperature Test, and the 25-Foot Tunnel Test.

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FOREWORD

This report was prepared by Wyle Laboratories, Research & Engineering Division, Huntsville, Alabama, under USBM Contract number JO395100. The contract was initiated under the Health and Safety Program. It was administered under the technical direction of Pittsburgh Research Center with Messrs Roy Bartholomae and Gerald W. Redmond, Sc. D., acting as Technical Project Officers. Mr. J. Gilchrist 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 September 1979 to May 1983. This report was submitted by the authors on May 1983.

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FIRE HAZARD CRITERIA FOR NOISE CONTROL PRODUCTS IN UNDERGROUND COAL MINES

by

Mark R. Pettitt[1], Ronald E. Guintini[2], and William R. Wessels[3]

ABSTRACT

The development of fire hazard criteria for noise control products in underground coal mines are presented. Qualifying requisites of the criteria include maintaining miners' safety, allowing for maximum use of noise control products, and economic feasibility. The burning process is analyzed for its relationship to fire hazard criteria developed by NASA and the FAA, and the mine environment is analyzed in conjunction with the end-use applications of noise control products. Also, the interim fire hazard specification developed by MSHA is appraised as it applies to end-use applications of noise control products. From these analyses and a literature survey, fire hazard criteria are developed. They include an initial screening procedure that evaluates the level of flammability testing required. Fire tests that may be indicated are the Vertical Flame Test, the Ignition Temperature Test, and the 25-Foot Tunnel Test.

[1,2] Senior Staff Engineer

[3] Senior Engineer

Section 1

EXECUTIVE SUMMARY

1.1 Objective of the Program

The objective of this program was to develop fire hazard criteria based on end-use applications for noise control materials. These criteria must:

1. Ensure that the miners' safety is not compromised by the use of noise control products.
2. Allow maximum use of noise control products.
3. Take into account that the sales volume of most acoustical materials to the mining industry will not be sufficiently large for them to justify an extensive flammability testing program that would qualify their materials only for in-mine use.

1.2 Statement of the Problem

Despite the sweeping provisions of the Federal Coal Mine Health and Safety Act of 1969, underground coal mining continues to be one of the most hazardous occupations in the United States. To minimize the hazards of fire in underground mines, MSHA has adopted interim criteria for the acceptance of products for use in such mines. In other safety and health activities, MSHA has established maximum noise levels permissible for mining personnel. One method of controlling the noise environment is through the use of noise control materials. Many of those materials pose a potential fire hazard. Evaluation of the flammability characteristics of noise control materials with respect to current interim MSHA criteria for flammability could significantly restrict the use of noise control materials in underground mining operations.

One shortcoming of the present interim criteria, as they relate to noise control products, is that they do not consider the unique manner in which these materials are used. The location and use of noise control material, the exposure of the material to the mining environment, and the material-system interface are general factors that should be considered in establishing realistic fire hazard criteria for noise control products.

The objective of this contract was to develop fire hazard criteria that can be adopted in the future as a MSHA specification for noise control products used in underground mines. Under U. S. Bureau of Mines contract No. J0177039, a flammability evaluation of noise control products for use in underground coal mines was performed by the IIT Research Institute. This work was a forerunner to the present program.

1.3 Major Factors to be Considered

1.3.1 End-Use Products

The analysis of the noise control products has been restricted to the end-use products rather than to the basic compounds that constitute an end-use product. From a pragmatic viewpoint, this was essential due to the vast array of compounds available for manufacture of end-use noise control products. Additionally, the reliability of component analysis of an end-use product is suspect. A simple end-use product may manifest a totally different behavior in the presence of flame and heat than the behavior of each of the separate component materials in the presence of flame and heat. Therefore, the recommended approach is to analyze and/or test the end-use products rather than the component materials constituting the end-use products.

1.3.2 Hazard Potential

The hazard potential for a given end-use application of a noise control product is a function of the probability of the occurrence of a fire hazard and the severity profile of the resulting effect of the fire hazard. The use of hazard potential analysis enables a sound, quantitative, comparative analysis of a subjective mine condition. This is accomplished by assigning a value to the severity of the hazard to miner health and system damage and concurrently calculating (or estimating) the probability of occurrence of the specific hazard. The product of the severity and probability yields the hazard potential for the specific hazard.

1.3.3 Excluded or Truncated Testing Equipment for Low Hazard Potential End-Use Products

Some noise control products that have limited end-use applications may manifest a hazard potential so low as to be considered negligible. Because of their limited application and low hazard potential, these specific end-use products should be considered sufficiently safe as to not warrant fire hazard testing. The exemption criteria for these products should be based upon a pass/fail evaluation that is sufficiently rigorous to avoid confusion or contradictory results. That is, two or more independent testors applying the exemption criteria to the same product should yield the same pass/fail evaluation.

1.4 Program Summary

This program was structured in five phases. A summary of each phase of the program follows.

> Phase I, Development of Data Base, initially consisted of a literature search of documented research in flammability testing that would be applicable to acoustical materials, end-use noise control treatments (present and future), and hazards analysis techniques and methodologies. MSHA has an interim criteria for acceptance of products taken into mines. Noise control products are presently subject to this criteria document. As part of this phase, the MSHA criteria was assessed for applicability to noise control products per se. A NASA flammability selection criteria for nonmetallic materials was found to be particularly helpful in formulating a rationale applicable to flammability test selection as well as in stimulating ideas regarding the exemption criteria. Special attention was paid to an examination of the coal mine fire hazard environment within which bounds the noise control products must function.
>
> Phase II, Assessment of Fire Hazards, involved the identification of present end-use applications of noise control treatments employed in underground coal mining and potential future end-use treatments. This was done in a generic sense. Also, flammability tests applicable to noise control products were selected from those presently employed in other industries. A separate task consisted of the development of a fire hazard assessment methodology

having the potential for exempting an end-use product from some testing requirements based upon engineering judgment. This methodology is considered only as an option to the preferred flammability testing and would be recommended only rarely. Two simple scenarios for its application were presented.

Phase III, Development of Fire Hazards Test Specifications, represents the major output of this program. The data base and understanding developed in phases I and II were used in the development of fire hazard criteria that are fully responsive to the goals of the program.

Phase IV, Performance Tests of Fire Hazard Criteria, ran a cross section of noise control materials through the fire hazard test battery to establish an experience base with the procedure.

Section 2 of this report (Factors in the Combustion Process) was an essential prelude to the development of the recommended fire hazard criteria. The burning process identified the nature of the flammability characteristics. Further, the literature search revealed specific generic materials (such as elastomers, plastics, and foams) currently finding usage in noise control applications. These applications led to a review of these generic classifications in somewhat more detail—specifically their flammability and toxicity characteristics. Based upon these characteristics, speculation regarding potential future applications was rendered.

Also, as an essential knowledge base for development of the fire hazard criteria, it was necessary to examine a cross section of mining noise control products and proposed applications. End-use noise control applications have been identified in a generic sense in section 3 (Noise Control Products and Materials).

The coal mine fire hazard environment, noise control product dimensions, expected uses, and feasible material types were important considerations involved in the selection of the recommended flammability tests presented in section 4 (Development of a Fire Hazard Specification).

Section 5 of this report (Proposed Fire Criteria for Acceptance of Noise Control Products for Use in Underground Coal Mines) proposes selection criteria for noise control products on the basis of previously developed philosophies, an appraisal of MSHA interim criteria guidelines, and test selection rationale.

Section 6 (Performance Tests of the Fire Hazard Criteria) details the results of a test program designed to establish an experience base with the proposed fire hazard criteria. This report is concluded with a bibliography contained in section 7.

Section 2

FACTORS IN THE COMBUSTION PROCESS

Several factors affect flammability and combustion of materials. Some of these factors pertain to the chemical and physical characteristics of the individual materials, and others pertain to environmental conditions.

2.1 Physical Form

The influence of physical form on combustion is illustrated by the fact that wood kindling will flame and burn from relatively small heat sources while heavier wood logs show a considerable resistance to ignition. As the size of a particle or material decreases, the ratio of surface area to volume increases. Thus for smaller particles, there is both greater exposure of fuel to air and less mass to conduct heat away from the surface of the particle. Therefore, small, thin forms of combustible solids will continue burning more readily than larger objects of the same material.

Exposed area and density also affect combustion rates. Materials having high thermal conductivity and high heat capacity act as heat sinks to inhibit the onset of the chain reaction mechanism. Materials with large surface area and low density exhibit low thermal conductivity and heat capacity, thus ignite easily.

2.2 Physical Orientation

The orientation of a material with respect to natural or convective air currents governs whether combustion will progress in the direction of the convective currents or in some other direction. The orientation is also important in determining the ultimate combustion rate obtainable for a given material. The greatest combustion rates are obtained when the convective currents flow in the direction of new, unburned materials.

2.3 Flammability Characteristics

Flammability characteristics are properties that define or describe the behavior of a material when exposed to fire. The burning process can be considered as occurring in three stages: pre-ignition, fire buildup, and fully developed fire. Figure 1 shows the burning process. In each stage, the importance of various flammability characteristics varies. An understanding of the role these flammability characteristics play in the burning process is needed in order to be able to develop realistic fire tests for materials. Applicable fire tests and accepted methods of measuring each of these flammability characteristics are discussed in more detail following a brief overview of the flammability characteristics.

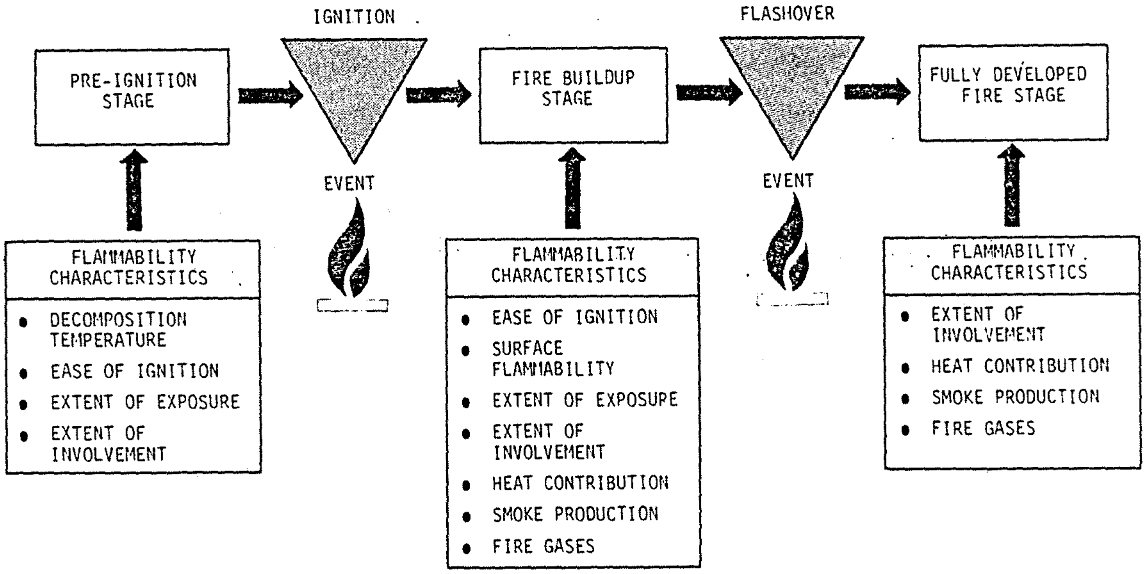

Figure 1. The Burning Process*

2.3.1 **Ease of Ignition** [1, p. 36]

The ignition temperature of a substance, whether solid, liquid, or gas, is the minimum temperature to which the substance must be heated in air in order to initiate or cause self-sustained combustion independently of the heating or heated element. Variables known to affect ignition temperatures are shape and size of the space

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* Information required to construct this figure was taken from refrence 1, pp. 27-41, and personal communication with C. J. Hilado.

where ignition occurs, rate and duration of heating, kind and temperature of the ignition source, and oxygen concentration. The wide variety of test methods used to measure ignition temperatures has resulted in different ignition temperatures being reported for the same material. Ignition temperatures should therefore be looked upon as approximations.

2.3.2 **Surface Flammability** [1, p. 36]

Surface flame spread can be defined as the rate of travel of a flame front under a given set of burning conditions. Surface flame spread provides a measure of fire hazard in that a fire can progress over a material, which in itself contributes very little fuel to the fire, and spread to more flammable materials in the vicinity and thus enlarge the size of the fire.

2.3.3 **Heat Contribution** [1, p. 36]

Heat contribution, or heat release, may be defined as the heat produced by the combustion of a given weight or volume of material. Heat contribution can provide a measure of fire hazard in that a material that burns with the generation of very little heat per unit quantity of material will contribute appreciably less to a fire than a material that generates a large amount of heat per unit quantity burned.

The amount of fuel contributed by a substance is normally measured by its heat contribution or its heat of combustion. The net heat of combustion is the heat released by the combustion reaction minus the amount of heat required to bring the material to the combustion stage. If the net heat of combustion is positive, then the burning material releases an excess of heat that may be used to increase the temperature of adjacent material. The amount of fuel contributed by one combustible versus another, or different forms of the same material, can be used to evaluate the desirability of utilizing the material in a given situation.

2.3.4 **Smoke Density** [1, p. 32]

Smoke density may be defined as the degree of light or sight obscuration produced by smoke from a burning material under given combustion conditions. This characteristic provides a measure of fire hazard in that a person has a better chance of escaping if he can see the way out. In addition, fire fighting efforts are improved if the source of the fire can be located quickly. Smoke density is influenced by the rate of burning and is generally inversely proportional to the degree of ventilation.

2.3.5 Fire Gases and Products of Combustion [1, pp. 34-35]

When a material is heated to its decomposition temperature it begins to evolve one or more of the following products: combustible gases, noncombustible gases, liquids, solids in the form of carbonaceous char, and solid particles entrained in the fire gases (smoke). The toxicity of some gaseous products of combustion is well known. However, the concentration of these gases in an actual fire is not well known. The chemical composition of the materials, the rate of temperature change, and the amount of available oxygen determines what gaseous products of combustion are formed.

Fire fatalities from the inhalation of hot air gases are a significant proportion of fire deaths. Often the minimum survival concentration of oxygen or the maximum survival air temperature is reached before any toxic gases attain lethal concentrations. A breathing level temperature of $300^{\circ}F$ is considered to be the highest level survivable, while an oxygen concentration of ten percent is considered the minimum level for survival. Whether this level is reached and how rapidly it is reached varies with each fire and is affected by the rate of burning, volume of the system, rate of ventilation, and the amount of combustibles present.

2.3.6 Extent of Exposure [1, p. 34]

The extent of exposure of a material differs from the flammability characteristics discussed thus far in that chemical composition of the material is not considered. Rather, the physical orientation of the material affects how the material will react in a fire. Materials presenting an exposed surface are more vulnerable to fire than materials shielded by a coating or covering.

2.3.7 Extent of Involvement [1, p. 35]

The extent of involvement of a material is similar to the extent of exposure of a material in that it is related to physical characteristics. Stated simply, materials present in large quantities are more significant than those present in relatively small amounts. However, since the extent of involvement is a qualitative judgment of the measure of relative fire hazard, it should only be used as a rough approximation to screen obvious fire hazards and not as a fine line of delineation between good and bad.

2.3.8 Summary

If flammability characteristics are considered on the basis of life safety, the material's ease of ignition, surface flame spread, heat contribution, smoke density, and fire gases represent possible hazards to occupants of an area only during the initial fire and fire buildup stages. Chances of survival for occupants who do not escape during these early stages are small because of the high temperatures present in future stages of the burning process. Figure 2 illustrates some obvious threats to human life resulting from the burning process.

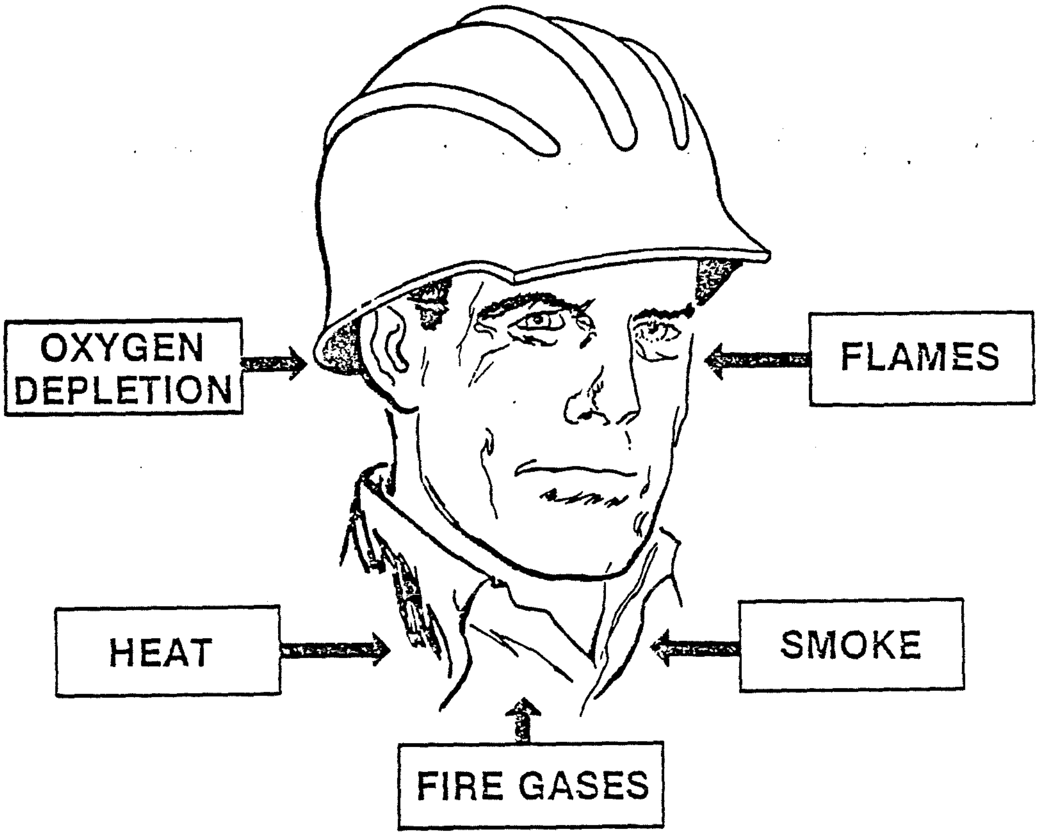

Figure 2. Fire-Related Hazards to Miners

2.4 Ease of Ignition

The first line of defense of any material against fire is its resistance to ignition. Unless ignition occurs, there can be no heat release, no fire spread, and no flash fire. Likewise, without significant combustion reactions there is very little smoke and toxic gas evolution. Tests used to measure ease of ignition usually involve exposure of the material being tested to small, open flames, ranging from a match to a bunsen burner.

Ease of ignition may be defined as the ease with which a material or its pyrolysis products can be ignited under given burning conditions [1, p. 93]. This characteristic provides a measure of fire hazard in that a material that has an ignition temperature much higher than another material is less likely to contribute to a fire, considering all other factors to be the same. Some measures of ease of ignition are auto-ignition temperature, limiting oxygen index, and flash ignition temperature.

Almost any material can be made to ignite, given enough heat, oxygen, and time. Ease of ignition can therefore be measured by holding any two of these three parameters constant.

2.4.1 Methods of Measuring Ease of Ignition

Many tests provide a measure of ease of ignition. Some of the more widely used tests for ease of ignition are discussed in appendix C. These tests include:

- ASTM D 2863-74, Test for Flammability of Plastics Using the Oxygen Index Method
- ASTM D 1929-68, Test for Ignition Properties of Plastics
- ASTM E 136-63, Test for Noncombustibility of Elementary Materials

2.5 Surface Flame Spread

Flame spread defines the amount of material, or surface area, involved in a fire as a function of time. Flame spread is a function not only of the material properties (chemical, physical, and thermal) but of material orientation, ambient temperature, incident heat flux, air velocity, altitude, fire size, and atmospheric oxygen content.

To gain some perspective of the relative importance of the various parameters on flame spread, comparison of test results of several materials is necessary. Results of experiments conducted in five laboratories on flame spread under various conditions have been tabulated (tables 1, 2, and 3).

The effect of surface roughness and exposed edges on flame spread rate is shown in table 1 [3, p. 2]. This table shows that a flame propagates approximately five times faster over a smooth surface when the edges are exposed than when they are inhibited. The rough texture of foamed plastics results in a large increase in propagation rate over smooth plastics with inhibited edges. Thus, the condition of the edges of a material as well as the surface roughness greatly affect flame spread rates.

TABLE 1. Horizontal Flame Spread (In cm/sec)

Smooth polymethylmethacrylate,	
edges inhibited	0.28
edges exposed	1.2
Smooth plastics,	
edges inhibited	0.1-0.2
edges exposed	0.5-0.9
Foamed plastics	32

Table 2 [3, p. 2] shows that there is very little difference between horizontal flame spread rates and vertical downward flame spread rates. However, the upward flame spread rate is much more rapid and very difficult to measure qualitatively. Flame spread rate increases with the angle of upward orientation.

TABLE 2. Vertical Orientation Flame Spread (In cm/sec)

Polymethylmethacrylate (edges inhibited):	
Horizontal	0.28
Vertical downward	0.33
Vertical upward	
Cellulose acetate sheet (edges inhibited):	
Horizontal	0.12-0.14
Vertical downward	0.12-0.15
Vertical upward	

Table 3 [3, p. 3] shows the effect chemical composition has on flame propagation rates.

TABLE 3. Rate of Flame Propagation (In cm/sec)

Teflon	0.00
Polyvinyl chloride	0.04
Delrin	0.04
Nylon	0.05
Polyethylene	0.11
Cellulose acetate	0.13
Do	0.14
Polymethylmethacrylate	0.14
Polystyrene	0.16
Polypropylene	0.18
"Tygon"-plasticized	0.53

Flame spread is a complex phenomenon, and its determination requires recognition and control of a wide variety of influences. Geometrical factors, such as unit surface area and specimen orientation, have much more influence than the material itself in the case of many common materials. Tests performed on a wide variety of materials under several different test atmospheres showed that burn rates which have been normalized to standard atmospheric conditions of percent oxygen, pressure, and thermal conductivity (plotted as a function of the unit surface area, A_s) produced good correlation [4, pp. 7-10]. Very significant departures were observed in a few cases, however. The correlation data obtained indicates that the surface area available for burning per unit weight has a dominant influence on flame spread rates in thin materials.

Orientation is well known to have a very dramatic effect on burn rate. Burning upward vertically is usually avoided by investigators because it is so rapid that accurate tracking of the flame front is difficult. Very often, downward vertical burning is studied because it is slow and easy to observe. Since flame spread is usually upward in any real fire situation, burning upward is a more realistic measure of fire performance. Vertical burning rates are nearly ten times as rapid as horizontal rates. This occurs as a result of the preheating of the material ahead of the flame front by hot gases convecting over the surface. For test purposes, 45 degrees represents a reasonable compromise between the rapid vertical burning and the slower horizontal burning.

2.5.1 Methods of Measuring Flame Spread [1, pp. 96-97]

Surface flame spread may be described as the rate of travel of a flame front under given burning conditions. Surface flame spread can be used as a measure of fire hazard in that flame can spread to more flammable materials in the area of the original fire and thus enlarge a fire. Accepted measures of flame spread are burning rate or combustion rate, distance of flame travel, flame height, and flame spread factor.

Tests for surface flame spread can be numerically described in Cartesian coordinates by the angle formed by the exposed surface angles of 0, 90, 180, and 240 degrees. A zero-degree surface angle is used for testing horizontal flame spread on the upper surface of materials; 90 degrees is used in vertical burning tests; and 180 degrees is used for horizontal burning tests with the flame impinging on the lower side of the material being tested. A 240-degree surface angle gives a measure of flame spread where the lower surface is burned using downward flame front movement. The surface angle determines the extent to which hot combustion gases preheat the area ahead of the flame front. When forced-air ventilation is used rather than natural ventilation, the effect of preheating becomes a function of the direction of forced ventilation rather than surface angle.

There are numerous flame spread tests available that employ methods tailored to both the physical and chemical properties of the materials being tested. Several tests commonly used in determining the relative fire hazards of building materials and plastics that are applicable to noise control products are described in appendix B. These tests include:

- ASTM E 162-73, Test for Surface Flammability of Materials Using a Radiant Heat Energy Source
- ASTM E 84-70, Test for Surface Burning Characteristics of Building Materials
- ASTM E 286-69, Test for Surface Flammability of Building Materials
- ASTM D 635-74, Test for Flammability of Self-Supporting Plastics
- ASTM D 1962-74, Test for Rate of Burning or Extent of Burning of Cellular Plastics Using a Supported Specimen by a Horizontal Screen
- ASTM D 1230-72, Test for Flammability of Clothing Textiles

2.6 Heat Release [1, p. 103]

Heat release may be defined as the heat produced by the combustion of a given weight or volume of material. Heat release may also be considered as a measure of fuel contribution in that a material that burns with the evolution of little heat per unit quantity burned will contribute appreciably less to a fire than a material that generates large amounts of heat per unit quantity burned.

The ignition of materials, their continued burning, and the spread of fire along the surface of materials all involve heat balance relationships. The transfer of heat is responsible for the start and extinguishment of most fires. Heat may be transferred by one or more of the following methods: conduction, radiation, or convection.

Heat is transferred by conduction through direct contact from one body to another or through an intervening solid, liquid, or gaseous heat-conducting medium. The amount of heat transferred by conduction depends upon the thermal conductivity of the materials through which the heat is passing and the cross-sectional area and thickness of the conducting path.

The rate of heat transfer through any material is in direct proportion to the temperature differential between the points of entrance and departure. The most important physical properties of a material, insofar as conduction of heat is concerned, are thermal conductivity, density, and specific heat. The product of the density times the specific heat of a material yields a measure of the amount of heat necessary to raise a volume of a material by a unit of temperature.

The thermal conductivity of a material is a measure of the rate of flow of heat through a unit area of the material with unit temperature gradient. Unit temperature gradient means that in the direction of heat flow, the temperature falls off one degree per unit distance.

An interesting feature of a material is its time constant. If the surface temperature of a material is suddenly increased, then the temperature at a depth x within the material will begin to change substantially at a time (t) according to

$$t = \frac{x^2 \rho c}{K},$$

where ρ = density,
c = specific heat,
K = thermal conductivity.

The application of this can be seen in that, for any given material, the time constant will vary as x^2. This relationship gives an insight as to why a match stick will continue to burn after being subjected to heat for a second or two, while a two-by-four will not. The ratio of the thicknesses of the two-by-four and the match is about 20. This means that the time constants have a ratio of about 400. For this reason, if a two-by-four is subjected to heat for only a few seconds, it will not have been heated at any great depth. The heat applied to or generated at the two-by-four surface will continue to flow inward, and the heat balance will be such that the two-by-four will not continue burning once the ignition source is removed.

The heating of entrained solid particles to incandescence increases heat transfer by radiation, while heating of the solid residue or char increases heat transfer by conduction. Similarly, the expansion of heated gases increases heat transfer by convection.

2.6.1 Tests for Heat Release

Many tests provide a measure of heat release. Some of the more widely used tests are discussed in appendix D. These tests include:

- Factory Mutual Calorimeter Test
- NBS Heat Release Rate Calorimeter Test
- Ohio State University Heat Release Test

2.7 Smoke Evolution

Hilado has defined smoke to be "... the gaseous products of burning inorganic materials in which small, solid, and liquid particles are also dispersed." Any solid material suspended in air as a by-product of burning constitutes smoke.

Ambient conditions render any method of measuring an amount of smoke difficult. Density differentials result in stratification of the suspended particles, most notably the fluids. Agglomeration, a time-dependent variable, further affects the amount of evolving smoke.

The practical application of smoke density measures to miner hazard is predicated upon the obscuration time; that is, the time required to reach the critical smoke density. In a mine passageway, the obscuration time would indicate the time available for a miner to evacuate the affected area before his vision becomes sufficiently obscured by smoke to hinder his escape. Since obscuration time tests have not been made in a mining environment, specific optical density should be used as a measure of smoke obscuration. This enables optical density, the surface area of the smoke-producing material, the volume of the chamber, and the length of the optical path to be taken into consideration.

Emphasis should be directed to the distinction between smoke from fully developed fires and smoke from developing fires. In a developing fire, the smoke density and obscuration time criteria are critical to miners' escape and survival. In a fully developed fire, the smoke density has achieved its maximum value, and the obscuration time has passed. The critical concern becomes maximum smoke produced as a threat to adjacent areas.

2.7.1 Tests for Smoke Evolution

Smoke hazards arise from obscured vision and irritating or toxic gases. The problem of vision obscuration and toxicity are normally measured separately utilizing two different test methods. The determination of relative toxicity is a very complex task and requires much more sophisticated equipment than that needed to measure smoke evolution only.

Tests for smoke evolution generally involve the measurement of the fraction of light absorbed or obstructed by smoke evolved from a burning material. Smoke can vary in appearance, content, and concentration from a light, barely visible gas to a black, sooty, dense smoke. Some measures of smoke density are degree of light absorption, specific optical density, and smoke development factor. Some of the better known tests for measuring smoke evolution include:

- National Bureau of Standards Smoke Density Test
- ASTM D 2843-70, Rohm and Haas XP2 Smoke Density Test
- ASTM E 162-67, Radiant Panel Test
- ASTM E 84-70, 25-foot Tunnel Test

2.7.2 Summary [1, p. 106]

A complete discussion of the various tests for measuring smoke evolution is provided in appendix A. In summary, the XP2 instrument (described in ASTM D 2843-70) is easier to operate than the NBS smoke chamber, does not require daily calibration, and is less costly to purchase and operate. The test results also correlate well with large-scale burning tests. The NBS tester, on the other hand, is more complicated, requires daily calibration of the heat source, and is more versatile and probably more accurate than the XP2. The vertical light path of the NBS eliminates the problem of stratification of smoke, and it can be used under both flaming and nonflaming conditions. The specimen size and holder allows sheeting, coatings, or composites to be evaluated.

The measurement of smoke evolution in the ASTM E 162 test may prove to be an economical advantage in that two flammability characteristics can be measured with one test apparatus. The correlation of laboratory tests with full-scale tests may preclude the combination of the two tests. The ASTM E 84 test has the capability of being the most versatile of all the tests and shows good correlation with full-scale tests, but the amount of sample material required for the test may be prohibitive.

2.8 References

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Section 3

NOISE CONTROL PRODUCTS, MATERIALS, TECHNIQUES, AND END-USE APPLICATIONS

3.1 Plastics

Because of the vast quantity of known plastic materials and the continuing identification of new plastic materials, plastics are becoming accepted noise control materials. As research and development of plastic materials yields more varieties of plastics, the distinction between elastomers and plastics is becoming increasingly difficult to discern.

Although the known variations of available plastic materials are numerous, plastics have been dichotomized as thermoplastic and thermosetting [1, pp. 2-3]. A thermoplastic is characterized as a material that retains its chemical integrity during repeated softening in the heating process and stiffening in the cooling process. This process can be characterized as thermodynamically reversible [2, p. 3.78].

A thermosetting process is not reversible. Upon softening during heating, the material will undergo further chemical reaction [2, p. 3.78]. Figure 3 lists the major types of thermoplastic and thermosetting plastics [1, p. 3].

For each identified type of thermoplastic and thermosetting plastic, many hundred variations have been identified. As should be expected, some variations will have noise control application and others will not. Some polyethylene variations of the olefin type of thermoplastics are currently used as noise control products while polypropylene variations of the olefins are not.

3.1.1 Plastics With Currently Known Noise Control Applications

Variations of two types of thermoplastic and one type of thermosetting plastics have known noise control applications. A brief description of each variation follows.

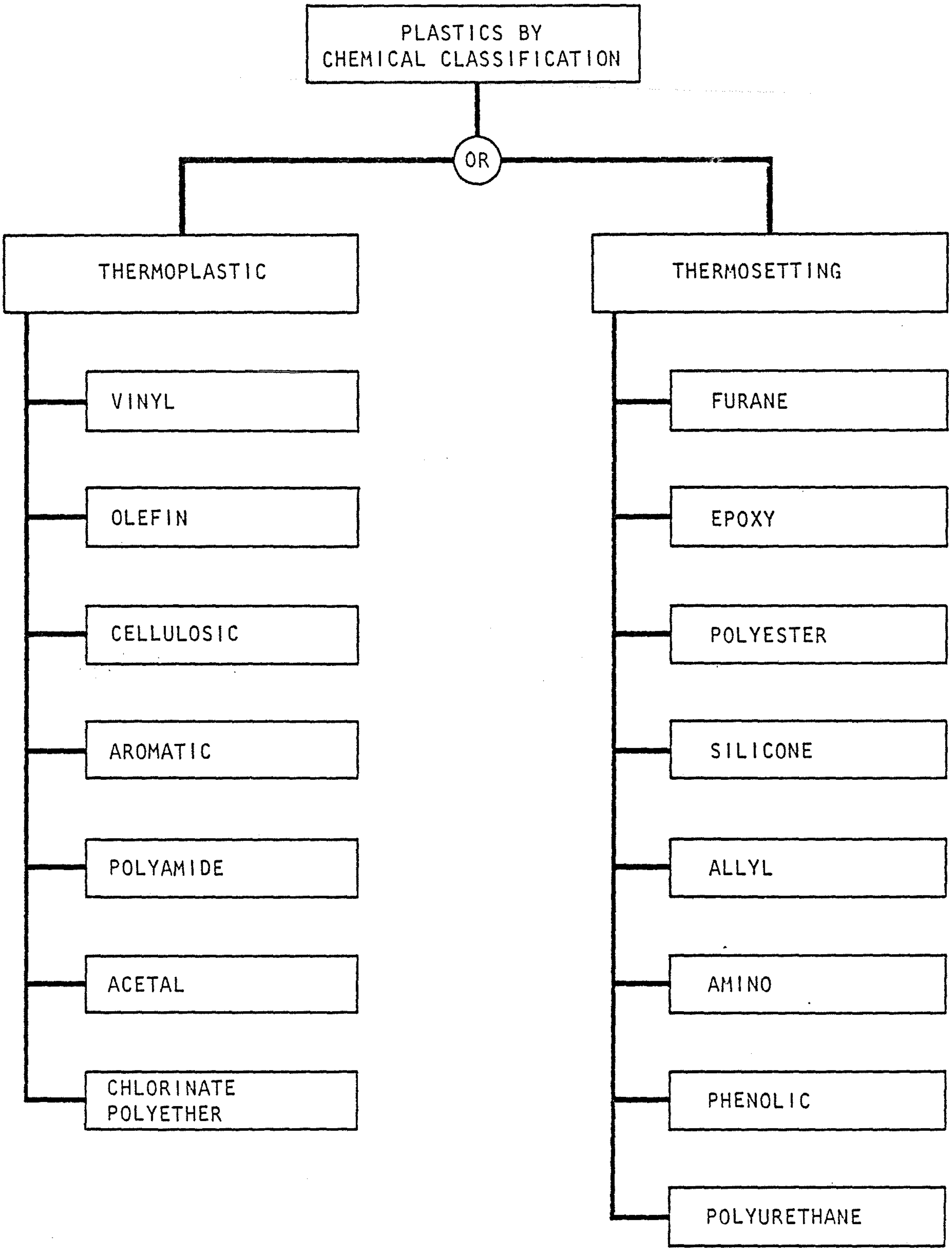


Figure 3. Plastics by Chemical Classification

Vinyl

Some variations of the vinyl type of thermoplastics have been employed as absorptive and barrier materials [2, p. 3.98]. A specific application is lead- or barium-loaded vinyl curtains.

Olefin

Polyethylene variations of the olefin type of thermoplastics have been employed as absorptive and damping materials. A specific application is polyethylene chute liners and resilient screens used in coal preparation.

Polyurethane

Some variations of the polyurethane type of thermosetting plastics have been employed as absorptive and damping materials. A specific application is polyurethane impact pads and resilient screens used in coal preparation.

3.1.2 Plastics With Possible Future Noise Control Applications

The underlying assumption is that all plastic materials with currently known noise control applications must reasonably be considered as having future noise control potential. Based upon current application characteristics, it appears feasible to use these materials. Other possible types of thermoplastic and thermosetting plastics having variations that indicate future noise control applications are described below.

Cellulosic

Rigid foam variations of the cellulosic type of thermoplastics have been employed as the core of sandwich panels [2, p. 3.94].

Silicone

Some variations of the silicone type of thermosetting plastics have been employed as rubber foams and as a grease suitable for high temperature lubrication.

3.1.3 Flame and Smoke Retardants [3, pp. 83-87]

Increasing concern about fire safety has resulted in much attention being focused on plastics. This is because plastics are becoming widely used in homes, vehicles, and factories, and are relatively new arrivals on the materials scene.

Most plastics are organic polymers, containing substantial amounts of carbon and hydrogen and, in their natural state, burn readily. Thus, a great deal of research has been and is continuing to be devoted to modifying the resins with either additives or by changing their basic chemical structure to reduce flammability characteristics.

There are two general types of flame retardants: additive and reactive. An additive is a substance that is mixed with the resin and mechanically held in suspension. A reactive flame retardant is incorporated by chemical reaction so that it becomes a part of the resin. The reactive types are chemically tied into the resin system and cannot bleed or separate from the compound, as can occur with the additive types of flame retardants.

Reactive flame retardants are more commonly used with thermosetting resins, such as epoxies, polyurethanes, and unsaturated polyesters, than with the thermoplastic resins, such as polypropylene, polystyrene, etc. Common reactive types of flame retardants used in unsaturated polyesters include chlorinated and brominated acids. Chlorine, bromine, and/or phosphorus-containing polyols are used to make flame-retardant polyurethane foams and resins.

The development of flame-retardant resin compounds is complex. The effects of the flame retardants on the properties of the end-use plastic must be considered. Some flame retardants soften the resin, others stiffen it. The tensile strength, elongation, flexural strength, modulus, and other properties can be drastically altered. Flame retardants often introduce another problem—smoke. Proprietary smoke suppressants are available for use in some resins to reduce the smoke problem. These additives, however, are expensive and will substantially increase the cost of the end-use plastic.

3.1.4 Summary of Noise Control Applications of Plastics

In the literature search conducted, other types of plastics suitable for current or future noise control applications were identified. A summary of the general applications of these plastics is presented in figure 4. In the right-hand column, under the heading "Noise Control Application," an evaluation was rendered as "definite," "possible," or "remote." "Definite" indicates actual known noise control applications. "Possible" indicates that the potential for future noise control application exists. "Remote" indicates that it is very doubtful that an application exists for this plastic as a future noise control product. The judgments rendered in figure 4 are based upon a knowledge of present applications and general flammability and smoke characteristics of the compositions. The observations and speculations are not all inclusive because many plastic formulations could conceivably become part of a noise control product. Continued research and development will generate increased utility of plastics.

3.2 Elastomers

The term elastomers has come into general use in scientific and technical literature to encompass a wide variety of natural and synthetic products that are elastic or resilient [4, p. 197]. It is becoming increasingly difficult to make a distinction between elastomers and plastics—whether by properties of finished articles, by processing techniques, or by chemical properties. The difference between plastics and elastomers is largely one of definition based on the property of extensibility, or stretching.

The American Society of Testing and Materials defines elastomer as a polymeric material which at room temperature can be stretched to at least twice its original length and upon immediate release of the stress will return quickly to approximately its original length [5, p. 268]. Some plastics, such as the olefins, styrenes, fluoroplastics, and silicones, have elastomer grades.

There are thousands of different elastomer compounds. The many different classes and types of elastomers can be varied or modified by additives, fillers, and reinforcements. Also, curing temperatures, pressures, and processing methods can be varied to produce an almost unlimited variation in the end-use material. Brady and

		OTHER KNOWN APPLICATIONS OF PLASTIC MATERIALS																				
	NOISE CONTROL PRODUCTS	FILMS AND SHEETS	COATINGS AND LAMINATES	TREATMENTS	PIPE, TUBING	WIRE COATING, INSULATORS	FIBERS	CONTAINERS	MOLDED PRODUCTS	LININGS	CANOPIES, SHEETS	FLOORING	ADHESIVES	SEALANTS	DEFOAMER, MOLD RELEASE AGENTS	ABSORPTIVE AND BARRIER MATERIALS	DAMPING MATERIALS	RIGID FOAM	RUBBER FOAM	GREASE LUBRICANTS	POSSIBLE FUTURE NOISE CONTROL PRODUCTS	NOISE CONTROL APPLICATION
THERMOPLASTICS																						
VINYL	●	●	●		●				●		●	●	●			●					●	DEFINITE
OLEFIN	●	●	●	●	●	●	●	●	●	●	●					●	●				●	DEFINITE
CELLULOSIC							●		●									●			●	POSSIBLE
AROMATIC		●	●			●			●				●									REMOTE
POLYAMIDE					●		●		●													REMOTE
ACETAL									●													REMOTE
CHORINATED POLYETHER			●		●		●		●													REMOTE
THERMOSETTING PLASTICS																						
FURANE			●						●				●									REMOTE
EPOXY			●		●								●	●								REMOTE
POLYESTER							●		●		●											REMOTE
SILICONE			●			●								●	●				●	●	●	POSSIBLE
ALLYL			●			●			●					●								REMOTE
AMINO			●				●		●													REMOTE
PHENOLIC			●						●				●									REMOTE
POLYURETHANE	●					●			●				●			●	●	●			●	DEFINITE

Figure 4. Plastics' Application

Clausen [5, pp. 269-274] identify 20 classes of elastomers. Their classification is somewhat different from the chemical categories presented in figure 5. Seven major chemical categories of elastomers and some of the respective subgroupings identified in the literature search [6, pp. 43-49] provide a basic framework for a brief discussion of elastomers.

Most elastomers are compounded with additives, which may be part of the curing system or added for reinforcement or for some other special effects, such as to impart a degree of fire retardancy to the product. Elastomers are used rarely in their pure form but are usually compounded with other materials, often metals and fibers. In general, elastomers burn readily unless compounded with a fire-retardant substance [6, p. 43].

Some desirable characteristics that an elastomer should possess in order to be considered a candidate for a noise control product for use in underground coal mines would be as follows:

- High resistance to hydrocarbons
- High resistance to chemicals
- High fire retardancy
- Low flammability
- Low smoke release
- Present no toxicological hazard due to the release of toxic gases.

Fire retardancy and low flammability are the most important of these characteristics. A material with a high resistivity in these two characteristics would preclude the hazards associated with smoke or toxic gas release. It is virtually impossible to treat the vast array of elastomeric materials in general terms since some of the materials within a single category behave differently, even with respect to each other. Also, their behavior can be altered substantially, depending on the additives incorporated within the compound. Because of these complicating factors, it is desirable to provide some relative general comparison of the seven chemical categories and their behaviors with respect to the aforementioned characteristics. This behavior assessment is of necessity highly subjective since it was based on a limited number of available references as well as the tempered judgment of the researchers on this program. Table 4 provides such an assessment.

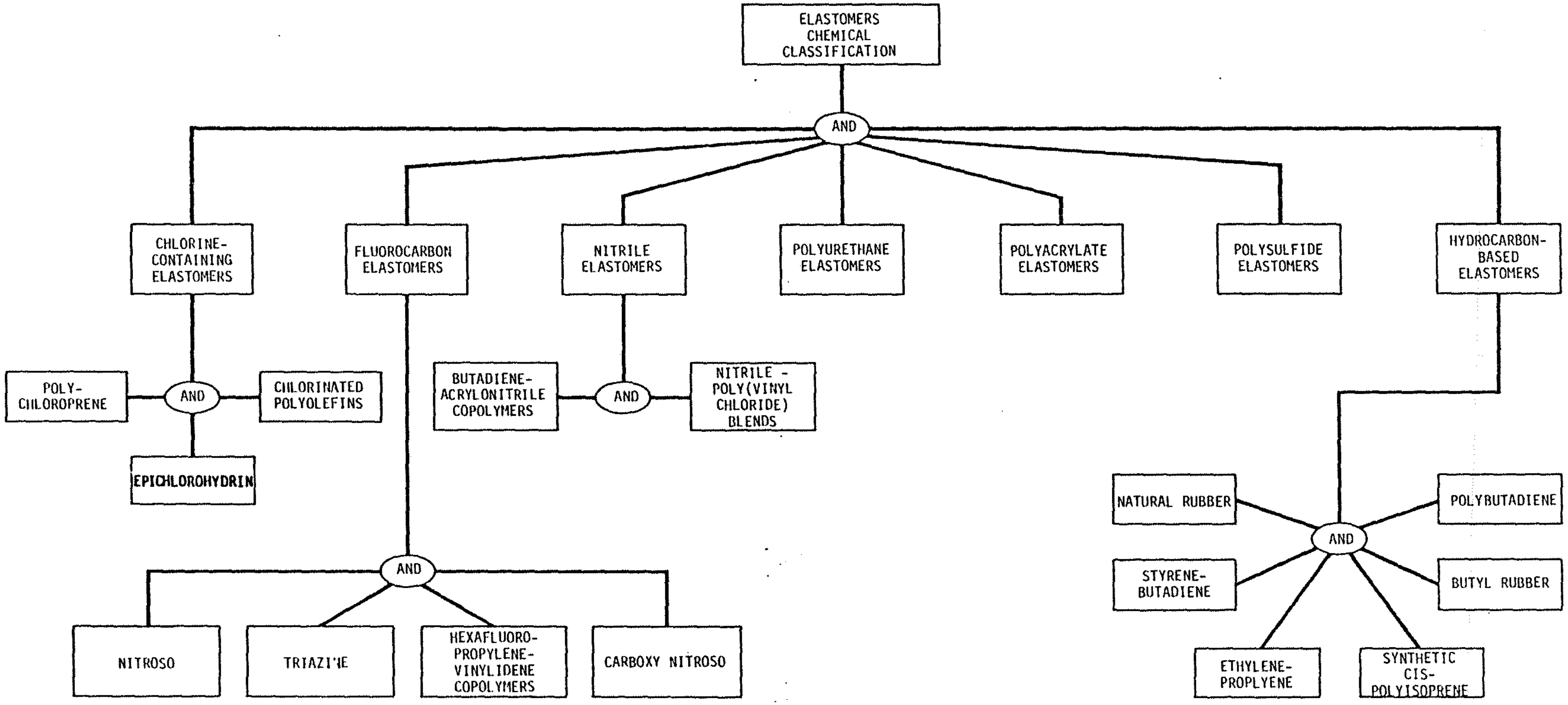


Figure 5. Elastomers' Chemical Classification

TABLE 4. Relative General Comparison of Seven Categories of Elastomers

ELASTOMERS CHEMICAL CLASSIFICATION	CHARACTERISTICS							
						TOXICOLOGICAL HAZARD		
	RESISTANCE TO HYDROCARBONS	RESISTANCE TO CHEMICALS	FIRE RETARDANCY	FLAMMABILITY	SMOKE RELEASE	HYDROGEN CYANIDE RELEASE	HYDROGEN CHLORIDE RELEASE	OTHER
CHLORINE-CONTAINING ELASTOMERS	M	M	H	M	H	NA	●	NA
FLUOROCARBON ELASTOMERS	M	H	H	L	L	NA	NA	●
NITRILE ELASTOMERS	H	M	M	L	M	●	NA	NA
POLYURETHANE ELASTOMERS	H	L	L^{d} M^{a}	M H^{c}	M	●	NA	NA
POLYACRYLATE ELASTOMERS	H	M	L	H	M	NA	NA	NA
POLYSULFIDE ELASTOMERS	H	M	L M^{a}	L M^{a}	M	NA	NA	NA
HYDROCARBON-BASED ELASTOMERS	M	L	L M^{a}	H M^{a}	H	NA	NA	NA

M = medium
H = high
L = low
NA = not applicable
● = presents this type of toxicological hazard
a = with additives (generally bromine and/or phosphorus) unless head source is open flame
b = where chlorine cure is used to reduce flammability
c = in foam form
d = unless heat source is open flame

It is known that the incorporation of halogens as an additive or as an integral part of the molecular structure in natural and synthetic elastomers will decrease its flammability. Examples of these are the chlorine-containing elastomers, such as polychloroprene, chlorinated polyolefins, epichlorohydrin rubbers, the various fluoro and chlorofluoro elastomers, halogen-containing polyurethanes, and the various compositions in which halogenated additives are used [6, pp. 43-44]. Although the halogens possess the capability of rendering an elastomer less susceptible to fire effects, they introduce a potential toxic hazard. Halogen-treated elastomers, upon combustion and/or exposure to an intense fire, give off smoke and toxic hydrogen halides. Also, some elastomers have the potential for generating other specific toxic combustion products. These materials have been identified in table 4 with the black dots, indicating a toxicological hazard. Toxicological hazards analysis, however, is not within the scope of this program. Although a material containing a halogen may pass the proposed flammability tests, in all likelihood it might be excluded due to its toxicological hazard.

Polyurethane elastomers, in addition to presenting toxicological hazards, also present a high flammability hazard. Even the fire-retardant grades (generally based on bromine- and/or phosphorus-containing additives) break down and burn in intense fires. Much has been written recently concerning the potential for flammability hazards based upon emotional appeals surrounding fire involving polyurethane. A $6 million out-of-court settlement was made in 1978 for an Idaho mine fire that killed 91 men [7, p. 3]. Shaw and Gillette provided a condemning report, based upon a four-month investigation, and stated [7, p. 1]:

> Urethane is inherently flammable. Fire investigations call it "solid gasoline." Although its flammability varies from one formulation to another, most formulations burn hotter than wood and twice as fast. Urethane melts and flows as a flamming liquid and generates dense smoke and toxic gas.

Polyacrylate elastomers generally are highly flammable [6, p. 48]. Because of this characteristic and basic mechanical properties, such as low tensile strength and resilience [5, p. 271], it is doubtful that they would be sought in noise control applications.

Polysulfide elastomers generally exhibit a low resistance to flammability unless a halogen-, phosphorus-, or antimony-containing compound has been incorporated [6, pp. 48-49]. The incorporation of the halogen additives would present toxicological hazards unsuitable for the underground mining environment.

Hydrocarbon-based elastomers are low-cost materials with good mechanical properties and are used in large volume throughout industry. However, they do burn readily and give off much smoke. Fire-retardant additives reduce flame spread and ease of ignition from low-energy ignition sources but do not prevent burning in an intense fire situation. Intense study has been underway by a number of manufacturers to reduce the flammability and smoke formulation by the inclusion of alumina trihydrates as a filler.

The comments contained herein are applicable to the elastomer classifications shown in table 4 and are at best general in nature. Since there are possibly thousands of combinations of materials, treatments, additives, and processes available that would render different behavior characteristics, there is no reason to believe that all materials within a given class or category are inherently bad or good. Critical judgment, therefore, should be based upon performance during the recommended tests provided in section 4 of this report.

3.3 Foams

A classification of foams can be structured into two broad categories; that is, natural and synthetic. Naturally occurring foams include meerschaum, cork, pumice, and sponge. Synthetic foams can be made from practically any polymer. Synthetic polymeric foams can further be classified as rigid or flexible types, a distinction paralleling that of unfoamed plastics and elastomers. Rigid foams can be subdivided into thermoplastic and thermosetting foams. Various other subdivisions of these types are shown in figure 6.

Polymeric and natural foams can pose special fire hazards. Some advances in fire retardant treatment of rigid polymeric foams have been made; however, flexible foams burn readily, even when fire retarded. Foams are either blown or syntactic. In blown foams, the cellular structure is formed by a blowing agent, which may be either a liquid that vaporizes during processing, a dissolved gas, or a solid that decomposes to give off gas. Syntactic foams are essentially polymers that contain tiny hollow spheres of another polymer or glass as a filler and have a closed cell

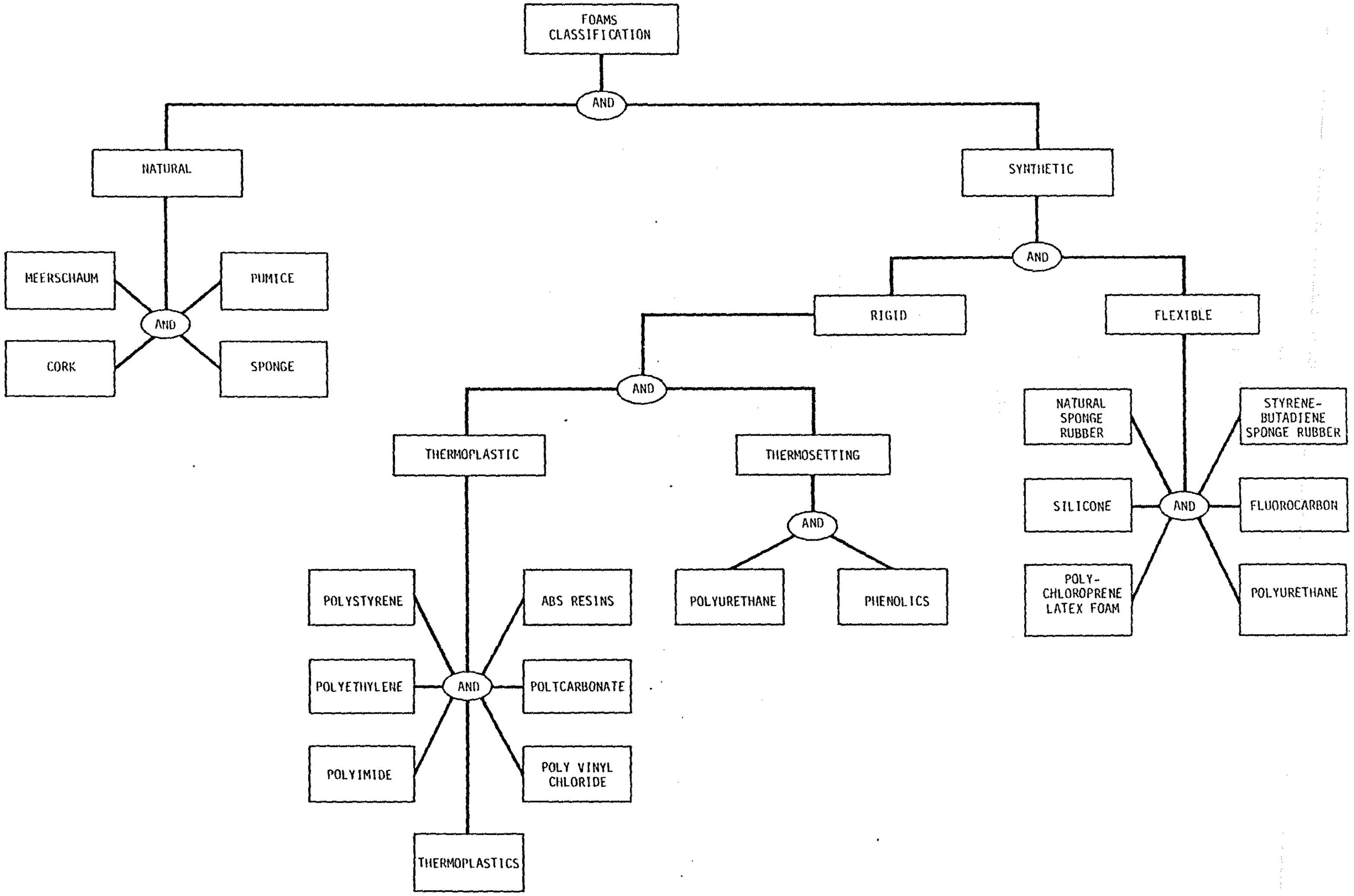


Figure 6. Foams' Classification

structure. Blown foams may be either open cell or closed cell. Flexible foams generally contain an open cell structure, while rigid foams usually have a closed cell structure. The rate of pyrolysis under the impact of a given heat flux, and the heat generated during the subsequent combustion of the volatile pyrolytic gases, are perhaps the most important variables in determining the fire safety characteristics of polymeric solids [8].

Since polymer compositions burn only on their surface, the amount of surface area available for combustion is important in determining the rate of combustion and the intensity of the flame [6, p. 92]. The high surface area per unit weight of material increases the flammability of a foam over that of the polymer composition from which it is made. Burning of polymer foams differs in several respects from the burning of solid polymers. Since many foams have densities of about two pounds per cubic foot, only about three percent of the total volume of the foam is composed of solid polymer. The incorporation of such a high volume of gas into the polymeric structure also affects the burning characteristics of the material. The rate of pyrolysis and burning is increased since a greater surface area is exposed to the oxygen in the air. The high gas content gives foams a low specific heat per unit volume. Their low thermal conductivity tends to concentrate heat on the surface rather than dissipating it to underlying material. This results in a rapid temperature rise and pyrolysis of the surface material when exposed to flame, which often leads to an extremely rapid flame spread rate. The small amount of potentially flammable material per unit volume in foams results in a very small amount of total heat being available per unit area for flame propagation.

A thermoplastic foam, such as polystyrene, melts rapidly when exposed to a flame. The foam adjacent to the flame melts and may recede so fast from the flame front that no ignition occurs. If ignition does occur, the foam may act as an insulator, so that the fire is extinguished when the flaming liquid drops away, carrying the flame front with it. A thermosetting foam acts differently, however, since no melting occurs. The surface of the foam does not recede from the flame front, and the foam is ignited. If the foam is flammable, the fire spreads. Fire-retarded foams pyrolyze rapidly in the vicinity of the flame and form a carbonaceous char on the surface of the material. This char protects the remainder of the material from the flame. Continued impingement of a radiant heat flux can generate continued combustion, but the carbon char is less flammable than the original foam, and the low density of the surface char does not produce sufficient heat to sustain burning in the absence of surface heat radiation.

3.3.1 Rigid Foams

Most thermoplastics can be made into thermoplastic rigid foams, which generally melt or depolymerize in a fire. Examples of thermosetting plastics that are commonly used in foam applications include polystyrene, polyethylene, polycarbonate, ABS resins, and polyvinylchloride.

Some thermosetting foams, such as the phenolics, do not melt or depolymerize, but form a carbonaceous char. Polyurethane foams, however, may depolymerize, melt, and drip like some thermoplastics. Rigid polyurethane foam and expanded polystyrene foam are the volume leaders in the thermosetting and thermoplastic classes, respectively.

Thermoplastic Foams

Polystyrene Foams

Polystyrene has a high heat of combustion and burns rapidly, producing dense smoke [9, p. 289]. Carbon monoxide is the only known highly toxic combustion product of polystyrene. As is the case with elastomers, the fire hazard of polystyrene foam can be reduced by incorporating additives. Fire retardant versions of foamed polystyrene are more difficult to ignite with small ignition sources but burn rapidly with high flame spread rates in the high energy environment of an intense fire [6, p. 98]. Some additives promote molecular weight degradation, softening, and dripping when the foam is heated. The foam retracts from the ignition source and/or drips away, carrying off heat and flame. Flame spread may be reduced under some conditions, but dripping could spread the fire under other conditions. The toxicological factors of smoke originating in polystyrene fires along with the carbon monoxide release would probably rule this material out in a noise control application.

Polyolefin Foams

Low density polyolefin foams having closed-cell structures are produced in a two-step method under pressure. The foaming agents are generally either nitrogen release agents or volatile liquids. Cellular polyolefin plastics, such as polyethylene and polypropylene, show better thermal, acoustical, and electrical insulating properties than their corresponding solid resins. They also have better dielectric properties as well as mechanical damping characteristics and are more flexible.

The flammability performance of polyolefin foams is, for the most part, identical with that of the solid plastics. Flammable blowing agents may increase the fire hazard. Without fire-retardant treatment, polyolefin foams burn cleanly at rates of three to six inches per minute in a horizontal position. Flame spread ratings of 10 to 20, as measured by ASTM Test E 84, are common. Ratings vary as a function of thickness [6, p. 100]. Ranney describes 15 patented processes for improving the flame resistance of polyolefin [10, pp. 223].

Polyvinyl Chloride Foams

The largest use for polyvinyl chloride-based foam is in coated fabrics, where the foam is sandwiched between a supporting fabric and a wear surface. Polyvinyl chloride (PVC) is inherently fire retardant due to its high chlorine content. Flexible PVC foams present increased fire hazards because of the plasticizers they contain. Yehaskel describes a patented German process for making flame-retardant plasticizers for PVC, a Firestone process for using manganese borate as a smoke retardant, and a B. F. Goodrich process whereby copper oxalate and amine molybdates provide an effective combination in vinyl halide polymer compositions to suppress smoke formation [11, pp. 291-296].

Polyimide Foams

Aromatic polyimides demonstrate outstanding thermal stability, low flammability, and high char formation. They are used in a variety of forms, such as films, laminates, compression moldings, coatings, and foams. These polymers have been converted into foams by the liberation of either water or carbon dioxide. Thone-Poulenc Industries in France received a U. S. patent for a process containing red phosphorus that considerably improves the flameproof properties of polyimide with evolution of a toxic gas such as phosphine [11, pp. 318-319].

Thermosetting Foams

Polyurethane Foams

Polyurethane foams are prepared by the controlled introduction of a gas phase during the basic reaction, producing a permanent cellular structure. As stated in the previous section on elastomers, polyurethane presents toxicological hazards and is potentially highly flammable. Even in fire-retardant grades, they break down and burn in intense fires. In application, polyurethane foam fires have been extremely difficult to extinguish. The Tennessee Valley Authority's Brown's Ferry nuclear power plant fire of 1975 strongly pointed out this fact [7, p. 13].

Wismer and LeBras (Pittsburgh Plate Glass Company) received a patent for a process that improves the flame resistance of polyurethane resin foams that does not present a corresponding impairment in other valuable characteristics [10, pp. 54-58].

Phenolic Foams

Phenolic foams are made from one of the oldest synthetic polymers. They are prepared by the condensation of phenol and formaldehyde. Although there has been considerable activity in the area of phenolic foams, they have not received the prominence of polyurethane foams because of their brittleness and open-cell structure. Cured phenolic resins have good thermal stability and high char production in an intense fire. Even after removal of the ignition source, the foams often smolder and char until they are almost completely consumed [6, p. 101].

3.3.2 Flexible Foams

Flexible foams can be made from practically any elastomer. Foam rubber or sponge rubber, as it is generally referred to, is formed when a chemical flowing agent is used in a dry-compounding recipe. The most common type of sponge rubber is made from natural and from styrene-butadiene rubber. Silicone and fluorocarbon sponge rubbers are also available. Polychloroprene latex foam is formed by beating air into compounded rubber latex and then curing.

Little is known about the smoke and toxicity aspects of sponge rubber or latex foams. Flexible slab polyurethane foam accounts for about two-thirds of all flexible foam. Flexible foams burn readily even when fire retarded [6, p. 104].

3.4 Noise Control Technique

In any noise control work, there are three main areas that can be affected. These areas are the source, the path, and the receiver. The source is composed of the various components in the machine that produce the noise. This can be motors, pumps, exhausts, or the tracks. The path is the route the noise travels from the source to the receiver. This route can be through the air or through the machine frame. The receiver is the operator of the machine or persons nearby who hear the noise.

Engineering noise control methods address the source and path elements [12]. There are four basic techniques that can be applied to the source and path elements of engineering noise control: absorption, barrier, vibration damping, and vibration isolation [13].

Absorptive treatments are considered path treatments, and they reduce the reflective component of noise reaching the receiver. Noise control through the use of absorptive treatments alone is relatively ineffective in reducing the overall noise level. Absorptive materials convert acoustic energy into heat, and for this reason, they are often used in combination with barriers to reduce the acoustic energy of the reflected sound wave.

Sound absorbers can be classified as resonant absorbers, porous absorbers, and panel absorbers. Porous absorbers comprise the majority of sound absorbent materials on the market today. Porous absorbers include plastic foams, fibrous glass, mineral wool, and spray-on materials [12].

Barrier treatments are used between the source and receiver and reflect or block the sound transmission path. Barriers are often used in combination with absorptive treatments to increase the efficiency of the barrier. Barriers can be used to isolate the receiver from both direct and reflected sound. When an acoustic wave strikes one side of a barrier, some of the wave's energy is reflected, some is used in moving the barrier, and some is transmitted to the air on the opposite side of the barrier. The ratio of the acoustic energy incident upon one surface of a partition to the energy that is radiated from the opposite surface is called the transmission loss of that barrier [12].

Common barrier materials include common building materials such as steel, wood, concrete, brick, gypsum board, glass, and plaster. Lead is another versatile material used in barrier applications. Lead is used to add mass to loaded plastic and vinyl materials. Common lead composites include foam/lead/foam, foam/leaded vinyl/foam, and glass fiber/lead. Mastic materials used in sound barriers are very densely asphalted products. They are used as cavity fillers in walls or doors [12].

Vibration isolation treatments are source treatments that isolate mechanical components from dynamic driving forces. This has the effect of reducing the sound radiated at the source. The principal function of damping in an isolator is to limit the transmissibility of the isolator at the system resonant frequency [12].

Common materials used for vibration isolators are elastomers, elastomeric foam, cork, felt, steel springs, and steel mesh pads. Selection of isolation materials is usually based on the environment in which they will be used. Design factors that must be considered are load capacity, tear strength, temperature tolerance, resistance to chemicals, and abrasion [12].

Elastomers such as silicone, butyl, natural rubber, and neoprene can be molded in many different configurations with varying load-deflection characteristics and varying degrees of damping. Felt pads have good bonding characteristics and are used when machinery movement must be closely monitored. Cork pads deteriorate slowly and are often used for isolating such things as concrete foundations [12].

Vibration damping techniques constrain the amplitude of mechanical vibrations of source components. Again, this has the effect of reduced sound radiated at the source. Damping reduces structure-borne vibrations by converting a portion of the structural kinetic energy to heat. Reduced vibrational levels results in less sound radiation and reduced structural stress. Vibration damping is very effective when dealing with noise radiated from vibrations associated with impacts between the parts of a structure. Damping efficiency depends on the plastic and elastic properties of the material. High molecular weight polymers (rubbers and plastics) are good vibration damping materials [12].

Viscoelastic materials are usually applied in liquid form (like plaster) on a vibrating surface. The effective damping of these materials can be improved by bonding a solid sheet on top of the material, forming a sandwich or constrained layer. This technique, called constrained-layer damping, shows improved damping with very little additional weight gain [12].

A recent Bureau of Mines contract, JO177039, entitled "Flammability Evaluation of Noise Control Products for Use in Underground Coal Mines," completed by the Illinois Institute of Technology Research Institute (IITRI), requested that a number of acoustic materials be subjected to a specific flammability test. From this study, a representative sample of materials from all four major categories of noise control products (absorption, barrier, vibration damping, and vibration isolation) that might have applications in underground coal mines was obtained.

3.5 End-Use Applications of Acoustical Materials in Underground Coal Mines

Noise surveys have been made in underground coal mines to determine the extent of the noise exposure and to identify the principal noise sources. A study of 21 mines performed by MSHA showed that several problem areas exist. Miners exposed to high noise levels include pneumatic roof bolter operators, continuous miner operators, loading machine operators, and stoper drill operators. Other surveys have shown that longwall mining equipment operators are exposed to high noise levels; however, there has been very little work done in the area of identifying and controlling noise sources associated with longwall mining equipment. Noise sources that have been identified include the winning machine (coal fracturing, cutting pick and pick holder impacts, conveyor noise) and the headgate area (hydraulic/electric motor noise, roof support hydraulic noise, and cutter head assembly vibration) [14, p. 5].

A taxonomy of end-use noise control applications is presented in figure 7. Seven generic categories of machinery and equipment are shown: (1) mantrip vehicles, (2)

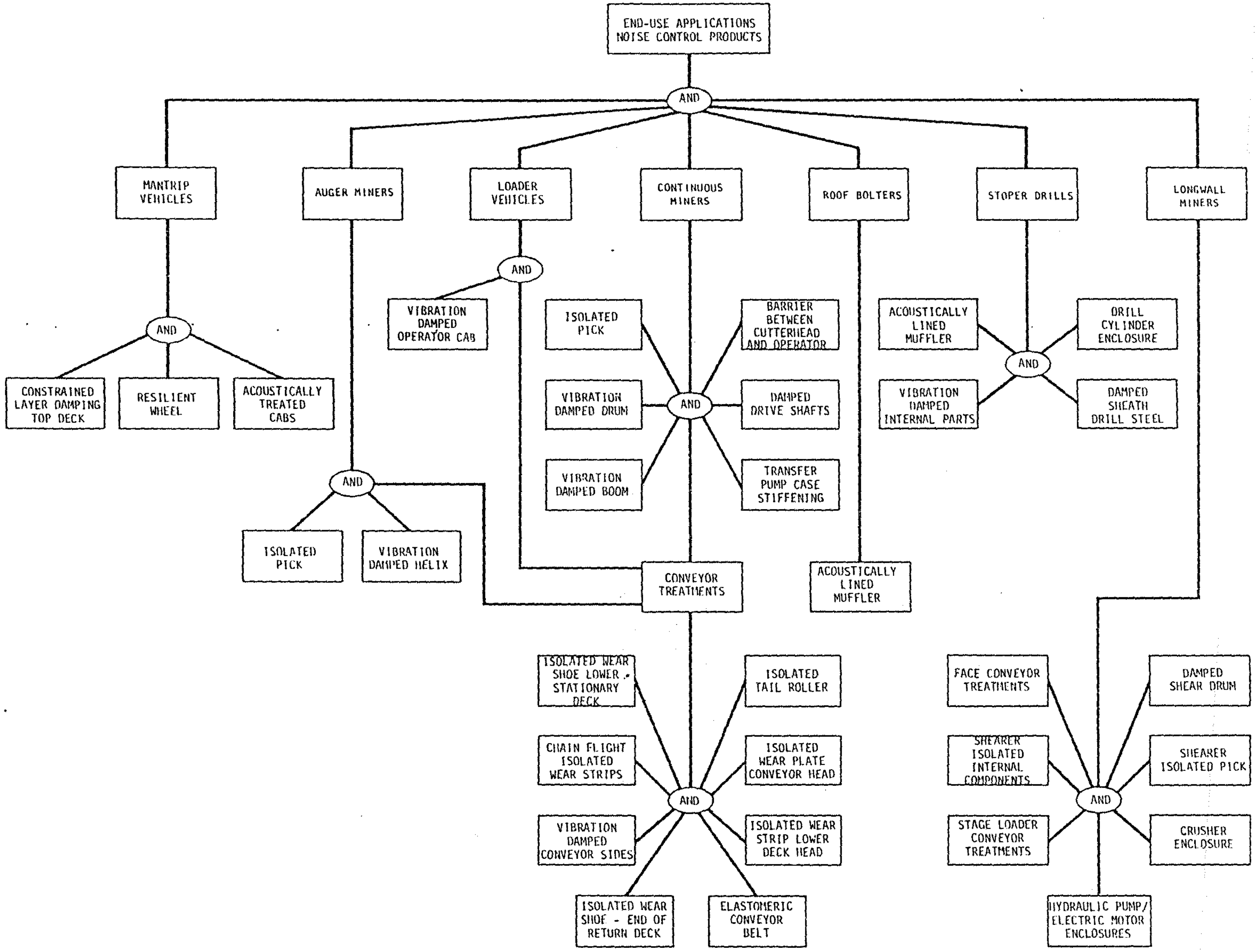


Figure 7. End-Use Applications of Noise Control Products

auger miners, (3) loader vehicles, (4) continuous miners, (5) roof bolters, (6) stoper drills, and (7) longwall miners. For each of these seven categories, further generic delineation of noise control treatments is provided. For the mantrip vehicles, as an example, three broad areas where noise control products are currently being used or conceivably could be adapted in the future are presented. Other areas possibly could have been included. These three, however, are considered the most prominent and fruitful areas for practical treatments. Further delineation of these three types was not warranted since candidate design concepts for constrained layer damping of the top deck and for acoustically treated cabs could be constructed from a large variety of materials (for example, plastics, elastomers, etc.) or structural compositions (for example, sandwich panels, foams, etc.) utilizing various design configurations. Some unique design features for a given concept would be required to enable it to accommodate a specific manufacturer's vehicle. Resilient wheels likewise require design-specific information. The material composition and mechanical characteristics for wheels could also assume a wide range of possibilities, depending upon the designer's tradeoffs. Therefore, for the seven categories of machinery and equipment, their respective areas for noise treatment must remain broadly defined.

Some specific noise control treatments have been studied and tested to determine their noise control characteristics under a number of contracts awarded by the Bureau of Mines. Loader vehicles, stoper drills, continuous miners, auger miners, and others will be briefly discussed in the remainder of this section of the report.

3.5.1 Mantrip Vehicles

Current noise control work on mantrip vehicles has revolved around reducing the transmission of noise through the heavy top plates of the vehicles and thus reducing the amount of noise that reaches the passenger compartments.

Present noise control methods include providing constrained layer damping for the top deck plates. Future noise control methods may include providing vibration isolation mounts for the wheels of the vehicles and providing acoustically treated passenger compartments. Acoustically treated cabs have already been tried in heavy strip-mining equipment with good success [15, p. 85]. A similar application may be feasible for underground mine applications.

The acoustical material used in operator cabs of heavy strip-mining equipment is composed of a high-density plastic sandwiched between two layers of urethane foam. The surface of the material is treated with a vinyl covering as protection against dirt, grease, etc. The acoustical material is installed in the cab by using either an epoxy binder or by spot welding small metal studs on the interior cab surface and then simply pressing the acoustic material onto the studs and using plastic caps to secure the material to the metal studs. Acoustical treatment of a front end loader resulted in a 10-dBA noise reduction. The dBA reduction obtained is critically dependent on the method and thoroughness of application of the material [15, p. 82].

3.5.2 Loader Vehicles

Noise surveys done on loader vehicles have shown that the major source of noise is the conveyor [14, p. 5]. With the gathering arm and conveyor operating, noise levels above 100 dBA have been reported. The specific noise sources of the conveyor are the impact of the chain and flights along the top and return deck and at points of direction change, the impacts of coal and the flights along the sides of the top deck, and the impact and friction of the tail roller and its tension springs [14, p. 6].

Descriptions of Noise Sources

Chain and Flight Impacts

With each impact of the chain or flights, a portion of the kinetic energy stored in the moving chain and flights is transferred into vibrational energy in the conveyor structure at the point of impact. These vibrations propagate through the structure and excite the large plate areas of the conveyor, such as the top and bottom deck plates, side rails, and flexplate. The propagation paths of each impact varies. Each time vibrations cross structural discontinuities, some energy losses occur. An example of this is when tail roller impact vibrations pass through the sliding bearing assembly before reaching the top and bottom deck plates. The points where the chain and flights impact the conveyor structure include the bottom rear deck plate, top deck plate, sidewalls, and leading edges of wear strips and flexplates (see figure 8). Impacts also occur where the returning chain leaves the boom section and enters under the chute in the loader mainframe.

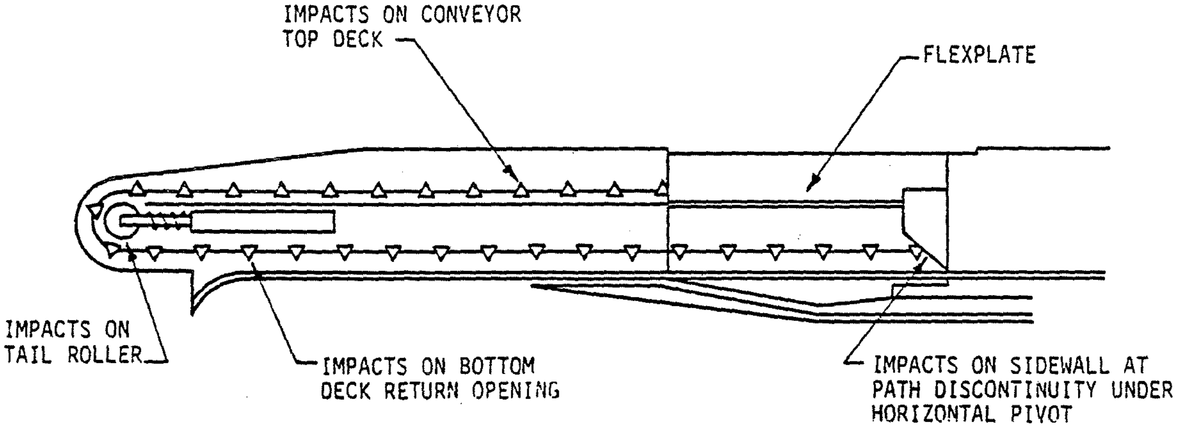


Figure 8. Conveyor Impact Points [14, p. 10]

Noise and vibration studies done recently indicate that acceleration levels measured on the side of the boom were much higher than the levels measured on the main chute. This indicates that the boom section of the conveyor is the larger radiator of the two. The flexplates that link the chute and boom sections of the conveyor walls also radiate the structure-borne noise.

Tail Roller Impacts

At the tail roller, the inability of the chain to smoothly make the speed and direction change results in the chain impacting the tail roller as the chain negotiates the 180-degree turn. These impacts are a function of the size and shape of the chain links in relation to the diameter of the tail roller [14, p. 7]. The condition of the conveyor, the amount of coal in the conveyor, the differences in conveyor sizes, and the different chain-flight configurations can result in wide variations in noise levels generated. However, the major noise sources remain virtually the same.

Noise Control Techniques

The impacts of the chain with the tail roller are controlled by isolating the tail roller from the machine body. Isolation is accomplished by inserting a cylindrical bushing, comprised of three concentric cylinders, around the guide rod. The inner and outer cylinders of the bushing are made of steel, and the middle cylinder is made of some energy-absorbing material or elastomer. The roller is isolated from the tension spring by using a thick washer or energy-absorbing material between two metal spring pressure washers, as shown in figure 9 [14, p. 7].

Impacts of the chain with the tail roller are reduced by making sure the plane of the top deck is tangent to the outer edge of the tail roller where the chain approaches the roller (see figure 10). A steel ramp slightly wider than the chain mounted near the tail roller is usually sufficient. The chain and its flights strike the top deck at three major points; that is, at the ends of the flights and in the center. The chain and flights are isolated from the top deck by installing three-inch-wide steel wear strips along both ends and down the middle of the top deck (see figure 11). The steel wear strips are isolated from the top decks by using 1/4-inch-thick energy-absorbing material. The mounting bolts should be countersunk and isolated from the wear strips and the top deck. At the swivel point of the tail, a solid steel plate isolated with energy-absorbing material is needed to ensure alignment of the chain and flights with the wear strips. The conveyor sides along this plate must be cut out along the bottom edge to give adequate clearance for the isolated plate when the tail is swung left or right. At the conveyor head, the chain and its flights tend to follow around the drive sprocket and impact the top deck [14, p. 13]. An isolated wear plate installed across the conveyor head deck effectively controls this noise source (see figure 12).

The sides of the conveyor top deck are damped by applying sheets of energy-absorbing material to the outer surfaces. These sheets may be epoxied on, and protective edge guards may be installed for increased durability (see figure 13). As the chain leaves the stationary lower deck at the hinge point, to enter the movable-head return deck, the downward movement of the chain causes an impact on the stationary deck. At this point, an isolated wear shoe is installed by cutting out a portion of the stationary deck and welding in a prefabricated wear shoe [14, p. 15]. A similar wear shoe can be installed at the tail end of the return deck to isolate the chain as it leaves the tail roller and enters the return deck on its return path.

If the loader has an operator's cab, damping material can be fastened to the inside of large surfaces to reduce the possibility of the cab becoming a noise radiator.

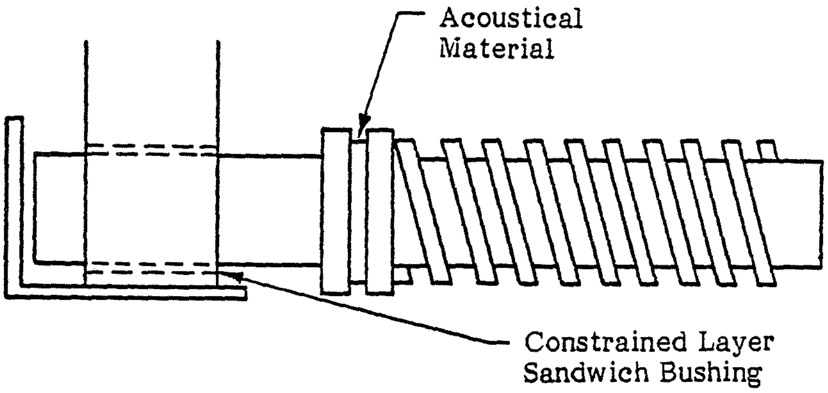


Figure 9. Isolated Tension Spring, Tail Roller Assembly [14, p. 8]

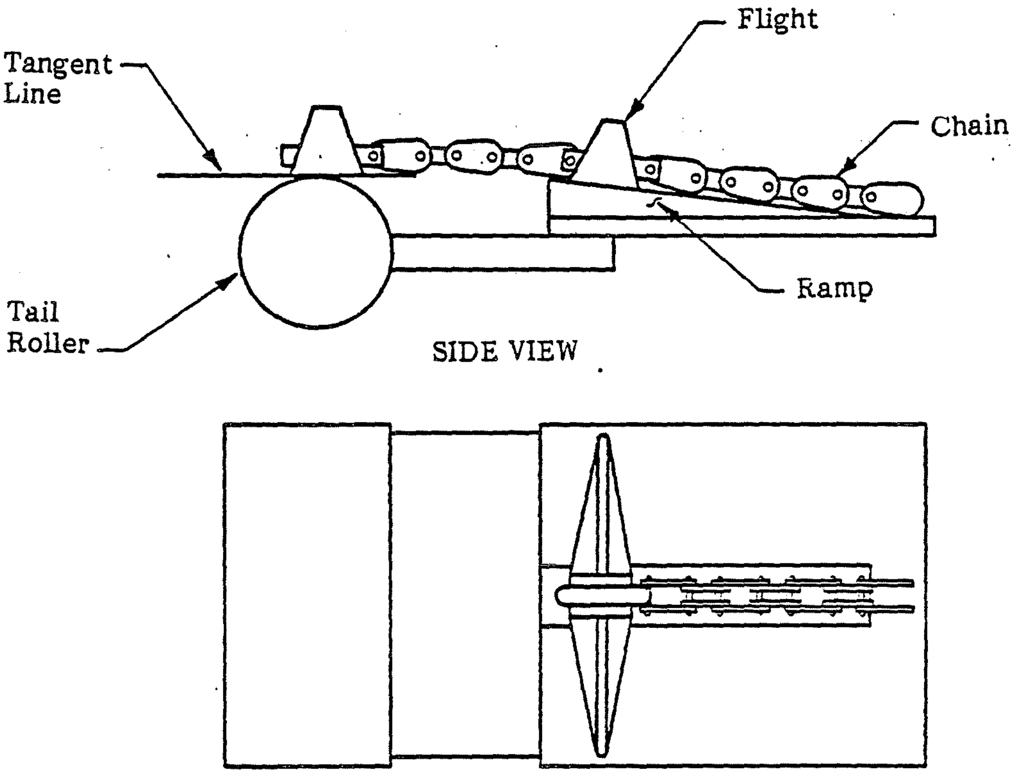
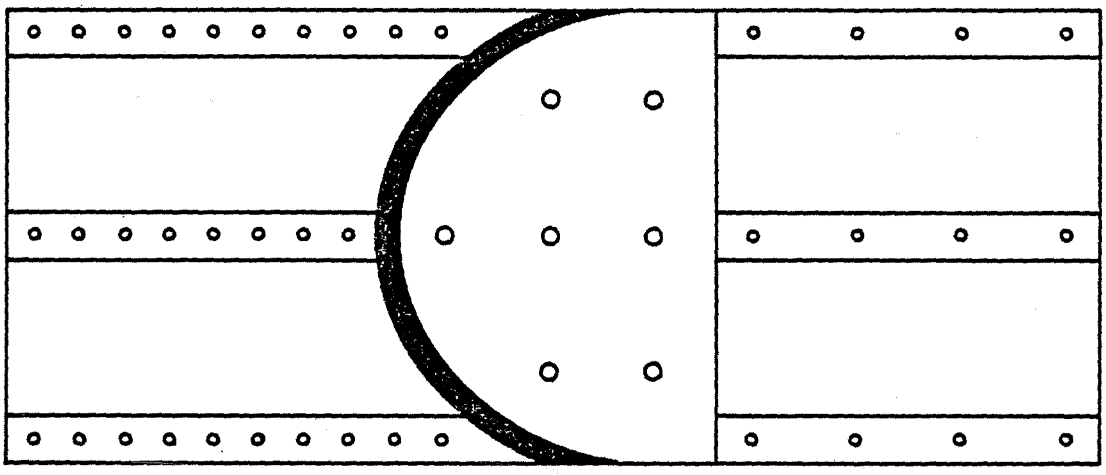
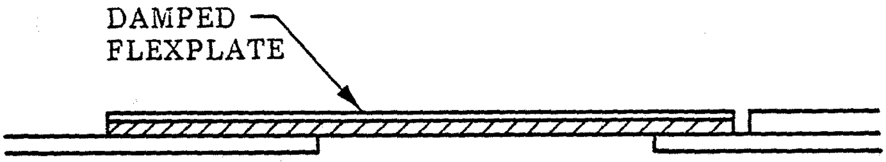


Figure 10. Conveyor Flight and Chain [14, p. 9]



ISOLATED WEAR STRIPS AND FLEXPLATE



SIDE VIEW

Figure 11. Damped Flexplate [14, p. 10]

3.5.3 Pneumatic Stoper Drills

Stoper drills are pneumatic percussion tools used for roof bolting purposes in coal mines. Results of noise surveys conducted in underground coal mines indicate that the noise generated by these drills range from 114 to 120 dBA. There are three main noise sources associated with the stoper drills—exhaust noise, internal mechanical noise, and external mechanical noise. Currently muffling the air exhaust is the major noise control method being attempted (figure 14).

Exhaust Noise

R. E. Manning [16, p. 29] has published several reports describing work completed on the development and testing of mufflers for stoper drills as well as an acoustic enclosure to reduce the mechanical noise emanating from the drill surface. In addition, Manning tested acoustic absorptive units that wrap around the drill steel and attenuate drill steel vibration and percussion noise.

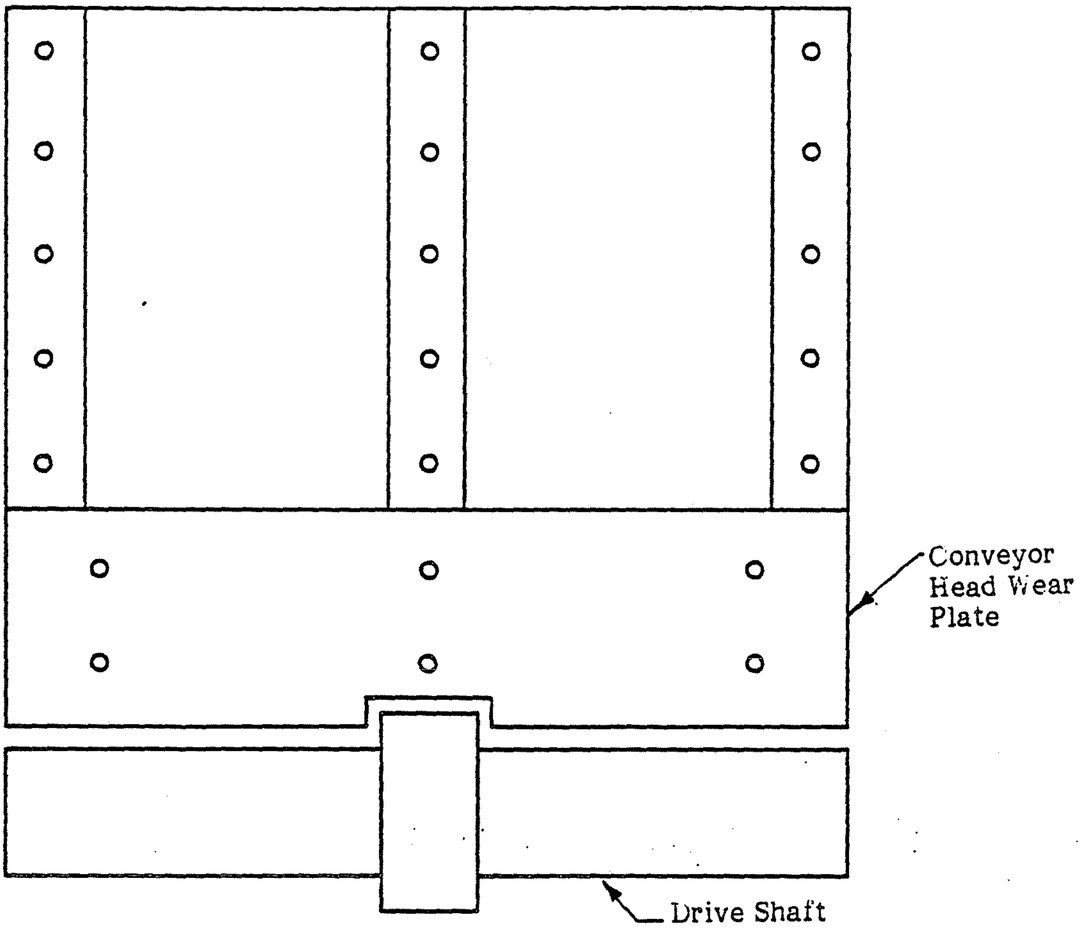


Figure 12. Conveyor Head Wear Plate, Top View [14, p. 13]

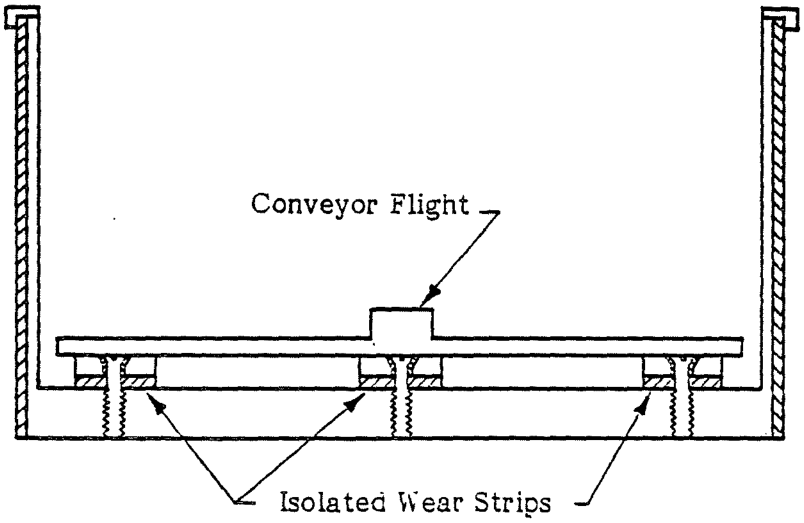


Figure 13. Isolated Conveyor Flight and Chain [14, p. 15]

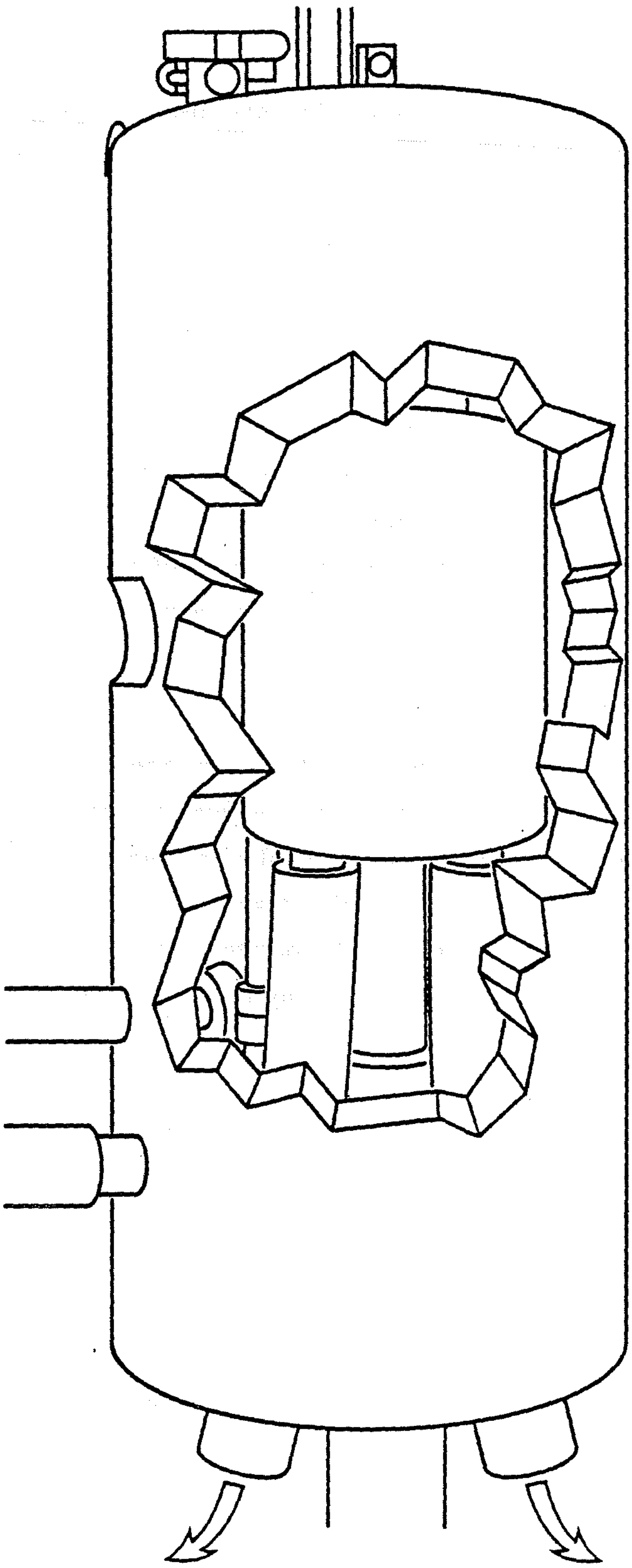


Figure 14. Stoper Drill Treatments (Muffler and Acoustic Enclosure System) [16, p. 59]

Three muffler configurations were tested by Manning [16, pp. 29-30]. All the mufflers were kidney-shaped (figure 15) and used varying amounts of 1/2-inch sheets of neoprene as a liner. The major differences between the three mufflers were internal chamber and tube configurations. Laboratory tests of the three mufflers showed the effect of the design changes on back pressure (a measure of drilling efficiency) and noise reduction and demonstrated the possible tradeoffs between back pressure and noise reduction for different designs. Improved muffler configurations with greater exhaust noise attenuation have been developed. Of the mufflers tested by Manning, the best muffler for noise control had a 34-dBA attenuation for the exhaust air. Field tests of the mufflers revealed that the mufflers attenuated the overall noise level by 6 to 7 dBA and that the drilling rate was essentially the same with or without the mufflers. Another important field test result was that no icing problems occurred with the mufflers tested.

Internal Mechanical Noise

In addition to the noise from the air exhaust, mechanical noise emanates from the drill surface. Three general methods may be used to control this noise [17, p. 69]: (1) Vibration damping materials can be applied to various components of the drill to eliminate excessive body vibration; high transmission loss materials can be used to enclose the drill housing to reduce the outward radiation of the mechanical noise; and (3) vibrationally damped materials may be used to replace internal parts of the drill.

The system encloses and can incorporate air exhaust mufflers like the kidney-shaped mufflers already discussed. One particular mechanical noise enclosure designed by R. E. Manning [16, p. 50] is oval-shaped in cross section and 26 inches long. The top and bottom of the enclosure consists of an external 18-inch-thick sheath made of carbon steel, a layer of 1/4-inch-thick neoprene and a layer of 2-inch-thick neoprene foam. The side of the enclosure is composed of an external 16-gage sheath of carbon steel, a layer of 1/4-inch-thick neoprene, and a layer of 1-inch-thick neoprene foam.

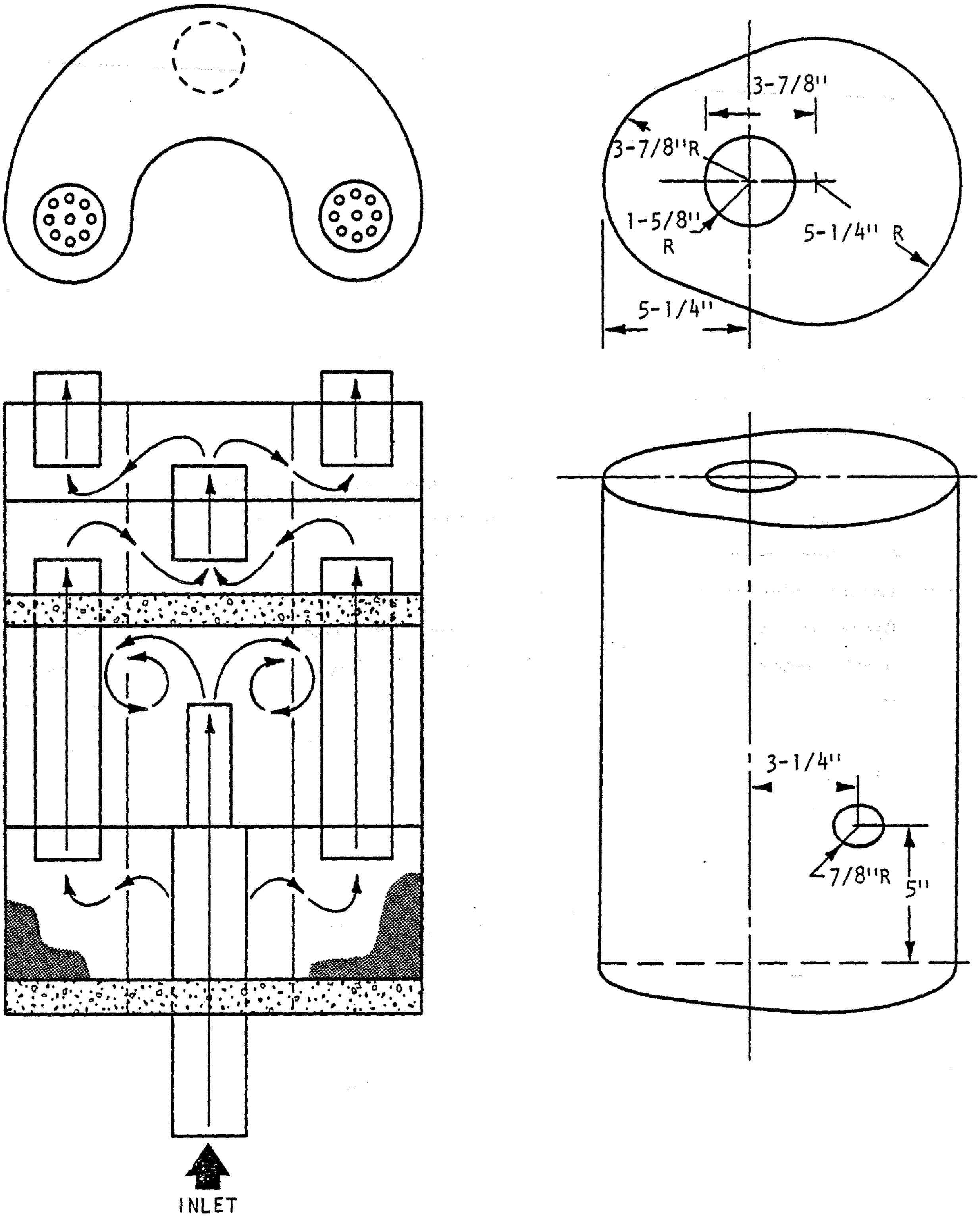


Figure 15. Stoper Muffler and Enclosure [16, pp. 30, 53]

Results of tests on this enclosure show that total noise levels with no muffler or enclosure are 112 dBA. With a muffler, the level was reduced to 106 dBA [16, p. 48]. The total noise level with both a muffler and an acoustic barrier was 93 dBA.

An enclosure similar to the one described above, except that the side of the enclosure was of constrained layer construction, showed no major differences in acoustic performance. Increasing the thickness of the steel sheath for the ends and sides to 16- and 20-gauge carbon steel, respectively, resulted in a total noise level with muffler and acoustic barrier of 90 dBA [16, p. 51].

External Mechanical Noise

Percussion noise is created as the drill steel strikes the hard rock surfaces and when the drill piston strikes the anvil block that holds the drill steel. Attempts have been made to control this percussion noise by wrapping the drill steel with various vibration damping and absorptive materials. Both absorptive elastomer foams and damping sheaths have been developed (figures 16 and 17). The use of partial length constrained layer damped drill steels are effective for controlling the noise from drill steel resonance. One example of this type of damping consists of a six-or seven-inch metal sleeve positioned at the end of the drill steel and then filled with a flexible methane damping material [17, p. 75]. Field tests conducted at the Bureau's experimental research mine at Bruceton, Pa., resulted in the noise levels shown in table 5.

3.5.4 Continuous Miners

The overall noise level of a continuous miner is composed of four major noise sources. These noise sources include the drive train, the hydraulic system, the conveyor, and the cutter head. Of these four, the conveyor and cutter head contribute the most to the overall noise level. The amount of noise contributed by the hydraulic system and the drive train depends almost entirely upon the design and condition of individual machines, whereas conveyor and cutter head noise is associated with all continuous miner equipment.

DRILL ROD

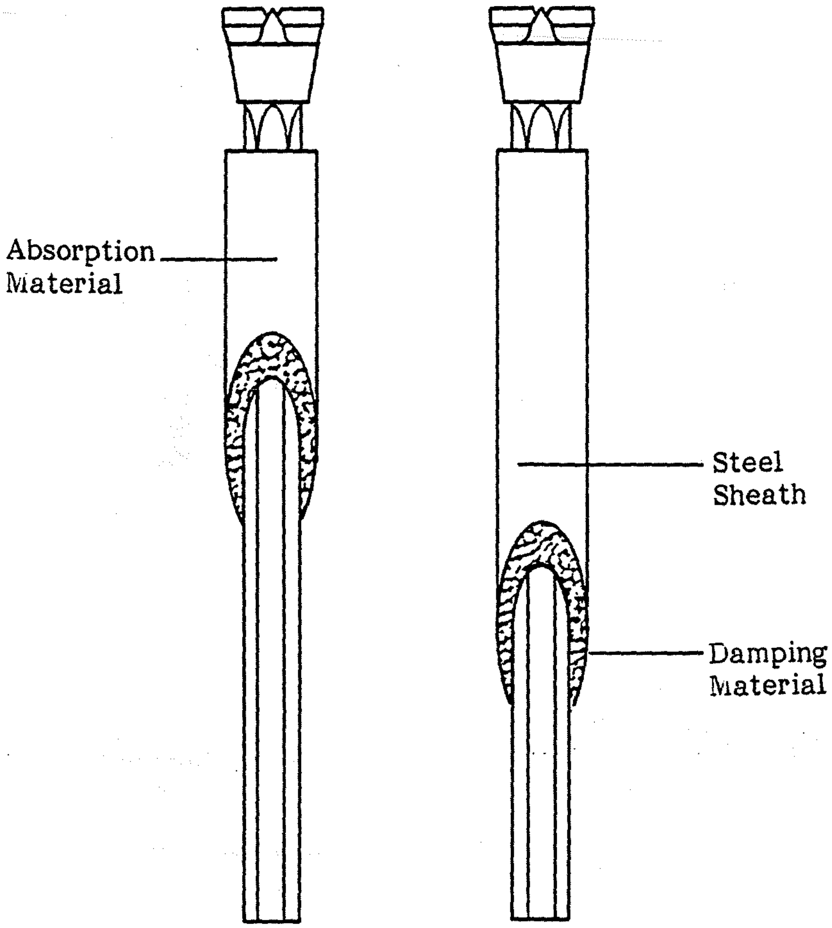


Figure 16. Drill Steel Treatments [16, p. 54]

TABLE 5. Noise Levels for Drill Rod Systems [16, p. 57]

Muffler (inches)	Drill Rod System	Noise Level (dBA)
6	Absorptive foam	96-99
	Damped sheath	94-96
10	Absorptive foam	90-95
	Damped sheath	88-90

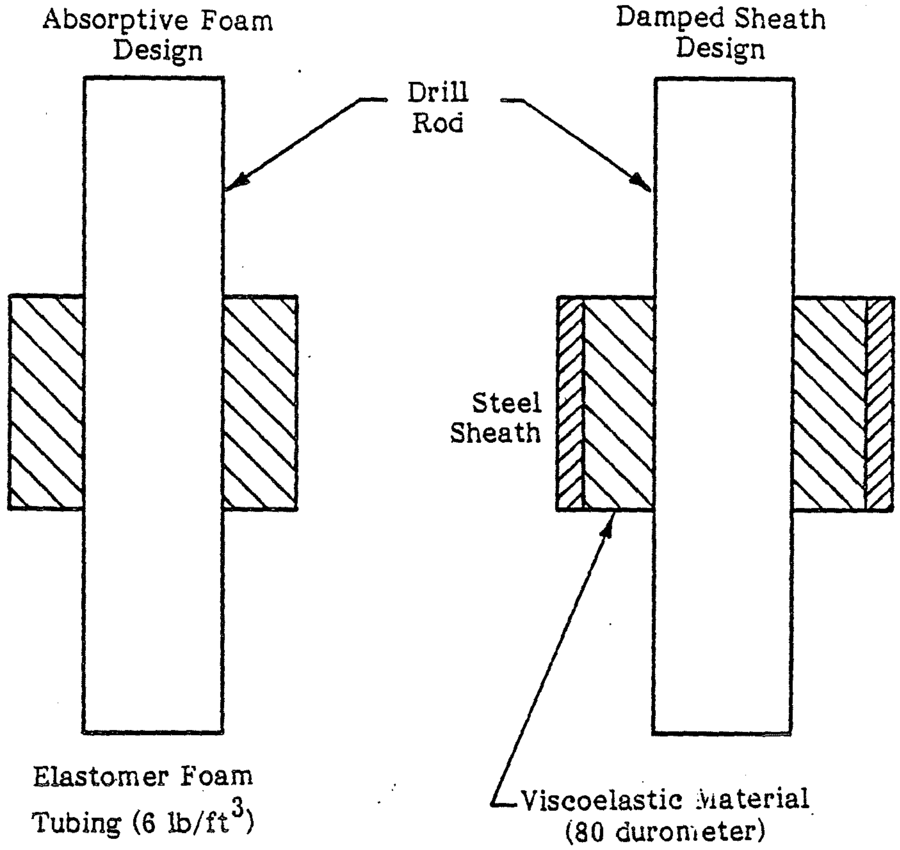


Figure 17. Drill Steel Treatments, Design Details [16, p. 55]

<u>Conveyor Noise</u>

The noise sources and control measures described earlier for loader equipment also apply to continuous mining equipment. Briefly, the conveyor-related noise emanates from points of impact between the chain and flights and the structural members of the conveyor. These points include the tail roller, top deck plate, bottom rear deck plate, sidewalls, conveyor head, lower stationary deck, and lower deck head.

<u>Cutter Head Noise</u> [18]

The noise associated with coal cutting is due to several sources. A typical continuous miner cutting head is composed of a drum containing numerous picks. As the drum rotates and causes each individual pick to engage the coal face, noise is generated as the coal is fractured. The intermittent impacts of the picks also causes coal face vibrations, which result in noise being radiated to the equipment operator.

Impacts of the cutting bit with the bit block produce percussion and impact noise. The cutting forces produced are transmitted to the cutter head, which results in a vibrational response of the drum and produces a structural ringing noise. Vibrations caused by the coal-bit interactions and the bit and bit block interactions can also be transmitted to the equipment operator through the structural components of the continuous miner.

Noise generation in drive trains is usually related to the quality of gears, gear tooth contact rates, the smoothness of drive connections, and the radiation characteristics of the supporting structure. The two mechanisms believed to produce the majority of vibration and noise in the drive train and hydraulic system are (1) gear case response to input forcing, and (2) nonuniform input and output shaft rotation. The most feasible noise control method available for the gear case involves stiffening the gear case to shift the resonance to higher frequencies. Vibration damping is not practical because of problems with heat buildup and because of the physical arrangement of the gear case and its related parts.

Nonuniform input and output shaft rotation can result in gear chatter and can be corrected by replacing standard 90-degree yoke universal joints with constant velocity joints. Noise radiated by the drive shafts can be reduced by damping the drive shafts. Drum vibration noise can be reduced by several methods—stiffening of the drum, isolating the picks, and providing vibration damping for the drum itself.

Acoustical barriers placed between the cutter head and the operator will reduce the amount of cutter head-radiated noise and coal face-radiated noise that reaches the operator. However, the use of barriers is limited because of problems with reduced operator visibility and poor barrier durability. At the operator's station, transmission of structure-borne vibrations originating at the cutter head can be reduced by providing vibration damping treatment of the boom.

Figure 18 depicts an example of the isolated pick concept. A pick assembly as shown in figure 18 was fabricated and tested using 40-60 durometer rubber as isolating material. The tested device provided a 10-dB reduction in noise. For this concept to gain acceptance, it would have to provide sufficient noise reduction at a nominal initial cost while not adversely affecting the amount of cut and not requiring significant replacement time and costs.

3.5.5 **Auger Miner** [19, 20]

There are four systems that have been identified as the major noise sources associated with the auger miner—the cutting heads, the conveyor system, the cutting head drive assembly, and the winch system.

The cutting head noise is created by four major actions: coal fracturing, bit and bit-holder interaction, structural vibrations of the cutting head, and vibrations transmitted to other miner components. The mechanics of both coal fracturing and bit and bit-holder interaction are virtually the same as described for the continuous miner and result in direct sound radiation. The structural vibrations of the cutter head are produced in the same manner as vibrations produced in the continuous miner head, but the physical structure of the auger helix creates a much larger surface area with significantly less stiffness. The sensitivity of the helix plate to transverse forces allows flexural motion of the helix, which results in a ringing noise. The hollow core tube of the helix is also a direct source of ringing noise.

Conveyor noise sources and treatment are virtually the same as those discussed for loader and continuous miner equipment. Noise control methods available for reducing cutter head noise include isolated cutting picks, vibration damped helix, vibration damped core tube, and helix stiffeners. Auger heads treated with vibration damping material are commercially available. Isolated pick mounts and stiffer helix designs, however, are still in the experimental stages.

3.5.6 **Longwall Mining Systems** [12]

Longwall mining systems are composed of four major components: winning machine, roof support system, haulage system, and conveyor system. In addition, each of these major components has several alternative types. For example, the

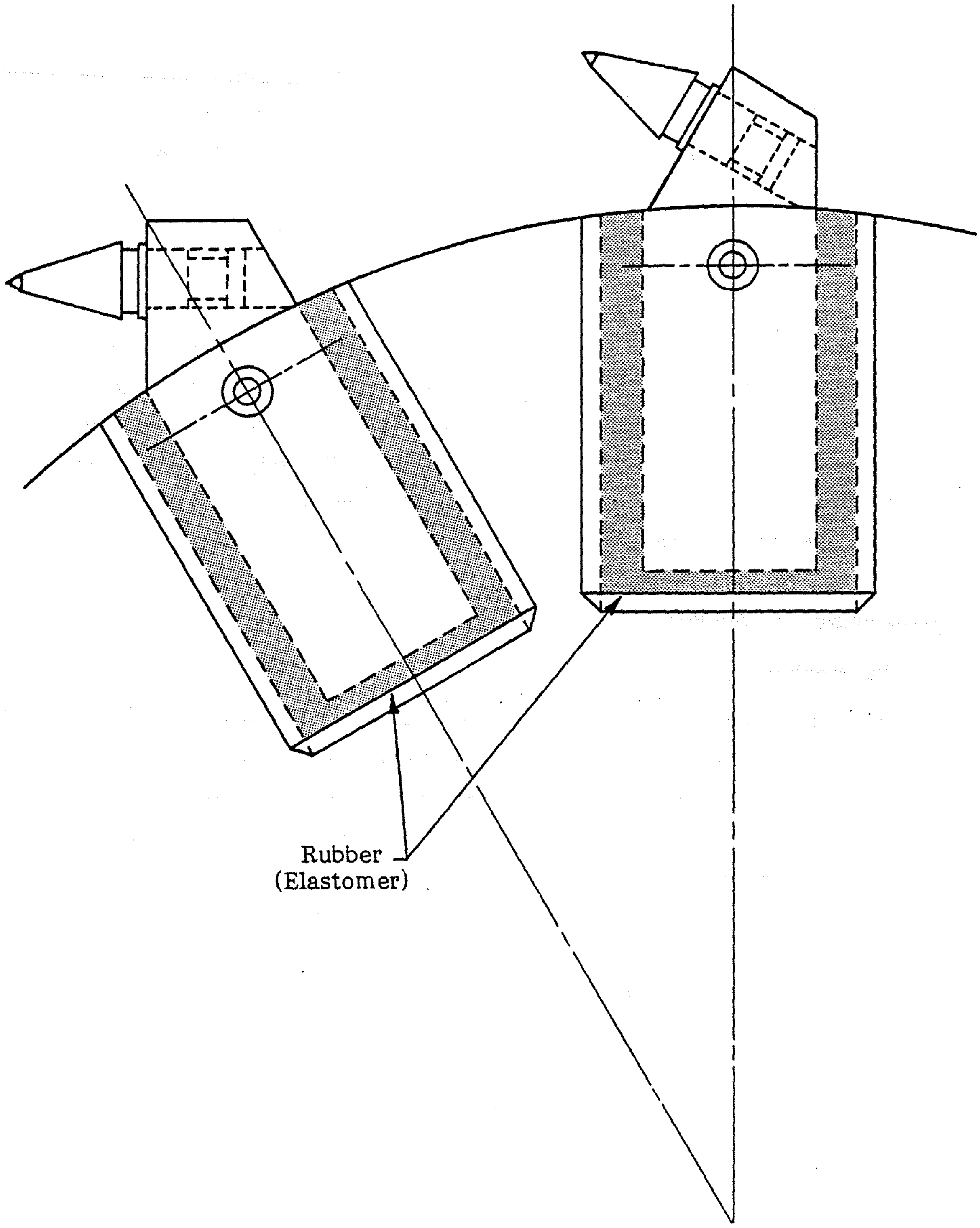


Figure 18. An Isolated Pick Concept (Wyle Laboratories)

winning machine may be either a shearer or a plow. The shearer can be either a single or double drum, and the plow can be one of three types—hook plow, guide-plank plow, or gleithobel. The roof support system may be one of the following types: chock, frame, shield, caliper, or chock shield. The haulage system alternatives are round chain, rack-a-track, track reactive, wedge chain, and ram propulsion. The face conveyor system can be either a gooseneck or a contemporary type.

Personnel who operate the various systems are exposed to different levels of noise. The specific components being used in any particular longwall system will determine not only the overall noise exposure of that system but also what noise control methods may be utilized. For purposes of discussion, the individual noise sources can be divided into two categories: (1) noise sources at the coal face and (2) entry area noise sources.

Noise Sources at the Face [12, section 4.1]

Winning Machine

A noise source common to all winning machines is the fracture of coal. The noise created by rotary cutting (shearers) and by linear cutting (plows) is not identical. Further research is needed to identify the characteristics of each type of cutting before specific noise control methods can be implemented. Technology developed for other mining equipment, such as the continuous miner, may be applicable to longwall systems once these cutting noise characteristics have been identified.

The excitation of the cutting head assembly by cutting forces developed during the removal of coal from the seam is another significant noise source. Cutting pick and pick holder impacts are a source of both structure-borne vibration and percussion noise. Coal striking the surface of the endplates of the bell-shaped shearing head is another source of structure-borne vibration.

Damping and stiffening techniques developed for continuous miner and auger miner cutter heads will, in all probability, play an important role in noise control efforts for longwall shearing heads. Isolated cutting picks are another possibility but will probably not play a big role in the longwall noise control program.

Haulage System Noise [12]

The body of the shearing machine contains electric motors and hydraulic pumps that create various mechanical and hydraulic noise sources. The noise generated by the electric/hydraulic drive system can be substantial while the shearer is in operation. Bearing noise, gear noise, control valve noise, and shearer haulage noise all contribute to the overall noise level.

Vibration damping of the shearing machine body is not very practical. The machine itself is already very massive, and source treatments appear to be a more effective approach to control of these mechanical and hydraulic noise sources.

The conveyor is another major source of noise at the face. The unevenness of the floor causes the different conveyor sections to be misaligned and results in conveyor chain and flight impacts along the leading edges of the various conveyor sections. Structure-borne vibrations are created and travel along virtually the entire length of the coal face conveyor. Other chain and flight impacts identified in loader and continuous miner equipment are possibilities and contribute to the overall noise level at the face.

Roof Support System Noise [12]

The noise associated with the roof support system is composed of hydraulic noise and noise produced as the roof of the previously mined area collapses. The source of hydraulic noise is produced by the flow of hydraulic fluid from high pressure pumps to the support actuators. These actuators and the servo mechanisms that control them generate noise along the face as the hydraulic fluid flows through the labyrinth of pipes and hoses.

Entry Area Noise [12, section 4.2]

Coal is removed from the coal face by the face conveyor and is transported to the headgate entry area where the coal is loaded on a belt conveyor by a stage loader. A crusher may also be located adjacent to the stage loader to provide a more uniform size of coal cuttings. The high pressure hydraulic pumps that operate the roof supports may also be located in the headgate area. The noise produced by the hydraulic components comprises one of the major noise sources in the headgate area.

The crushing machine constitutes the greatest noise source in the headgate entry area. The most effective control measure for this equipment to date has been total enclosure. The hydraulic pump noise can be controlled best by either redesign of the pump or positioning the pumps at a remote location away from operator exposure.

The stage loader is another noise source in the headgate entry area. The stage loader is similar to the face conveyor in construction and has similar noise sources. The motors used to drive the face and stage loader conveyors are located in the headgate area and generate gear and bearing noise as well as noise generated when power is transferred from the motor to the conveyor through some mechanical mechanism.

The specifics of noise sources associated with longwall mining systems has not been defined well enough to date to enable practical and cost-effective application of conventional noise control techniques. There are several potential noise control applications that are possible based on present knowledge of existing noise sources. Face conveyor noise may be controlled by methods similar to conveyor treatments described for loader and continuous miner equipment. Briefly, these applications include vibration damping of conveyor sides, isolated wear strips for conveyor chain and flights and at leading edges of conveyor sections, and tail roller isolation.

Vibration isolation pads may find use in isolating the face conveyor from the coal winning machine. Acoustical barriers and absorption materials may find application in enclosing high pressure hydraulic pumps and electric motors, and limited use at operator stations.

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Section 4

DEVELOPMENT OF A FIRE HAZARDS SPECIFICATION

4.1 Introduction

The program objective requires fire hazard criteria that can be adopted in the future as a Mine Safety and Health Administration (MSHA) specification for noise control products used in underground mines. These criteria must

1. Ensure that the miner's safety is not compromised by the use of noise control products.
2. Allow maximum use of noise control products.
3. Take into account that the volume of most acoustical materials sold to the mining industry will not be sufficiently large for them to justify an extensive flammability testing program that would qualify their materials only for in-mine use.

The classical approach to the development of fire hazard criteria involves the following sequence: Analysis of the history of fire incidents, determination of the most probable types of fire and their characteristics, performance of full-scale fire tests to simulate real-life fires, analysis of parameters in full-scale fire tests, selection of laboratory tests, performance of laboratory tests, correlation of laboratory tests with full-scale fire tests and real-life fires, and selection of acceptance criteria in laboratory tests to define limits of hazards in full-scale fire tests and real-life fires. This approach obviously requires a substantial history of fire incidents and substantial experience in the fire response of the materials involved.

The classical approach has been used, with varying degrees of skill and success, in building environments, home environments, institutional environments, mass transit environments, and aircraft environments. There have been substantial histories of fire incidents and substantial experience in materials response in building fires (both construction and interior finish materials), home fires (primarily furnishings' materials), institutional fires (furnishings' materials), mass transit fires, and aircraft fires (both in-flight and post-crash fires). Fire hazard criteria for materials in these environments, therefore, can be based on statistical and analytical bases of varying degrees of sophistication.

The full classical approach cannot be employed to develop a fire hazard criteria for noise control products used in underground coal mines for two fundamental reasons: There is no substantial history of noise control products' involvement in underground coal mine fires, and there is no substantial experience in the fire response of noise control products. The unique nature of the coal mining environment, however, makes it possible to develop reasonable criteria that are directly related to the significant hazards likely to be posed by a noise control product.

The natural starting point is with an appraisal or assessment of the MSHA interim fire and toxicity criteria. Section 4.2 contains an appraisal of interim criteria. The approach employed in the assessment process was to develop a systematic structuring of each section of the criteria using logic diagrams where possible. The purpose of this technique was to locate ambiguities and missing elements that might lead to errors, erroneous assumptions, or confusion. Since the interim criteria deals with a vast array of products and materials as well as toxicity, noise control products per se were not singled out for special attention. The appraisal of the interim criteria provided valuable insight into the nature of a specific criteria for end-use noise control products by virtue of an understanding of the overall larger problem facing MSHA.

The development of a fire hazards criteria for noise control products used in underground coal mines necessitates a constructive critique of any existing criteria in current use. In essence, a new criteria can be justified only if the existing criteria does not adequately address the full spectrum of the problem. Some aspects of the problem are whether

- An unsafe end-use product will be assumed safe.
- A safe end-use products will be assumed unsafe and its use excluded or restricted.

- An end-use product that is safe for one noise control application will be unsafe for another.
- Testing requirements will be too costly so as to restrict potential manufacturers from entering the noise control products market.
- The test program, and particularly the pass/fail criteria, is commensurate with the level of safety sought.
- The selected tests adequately lead to repeatable results.

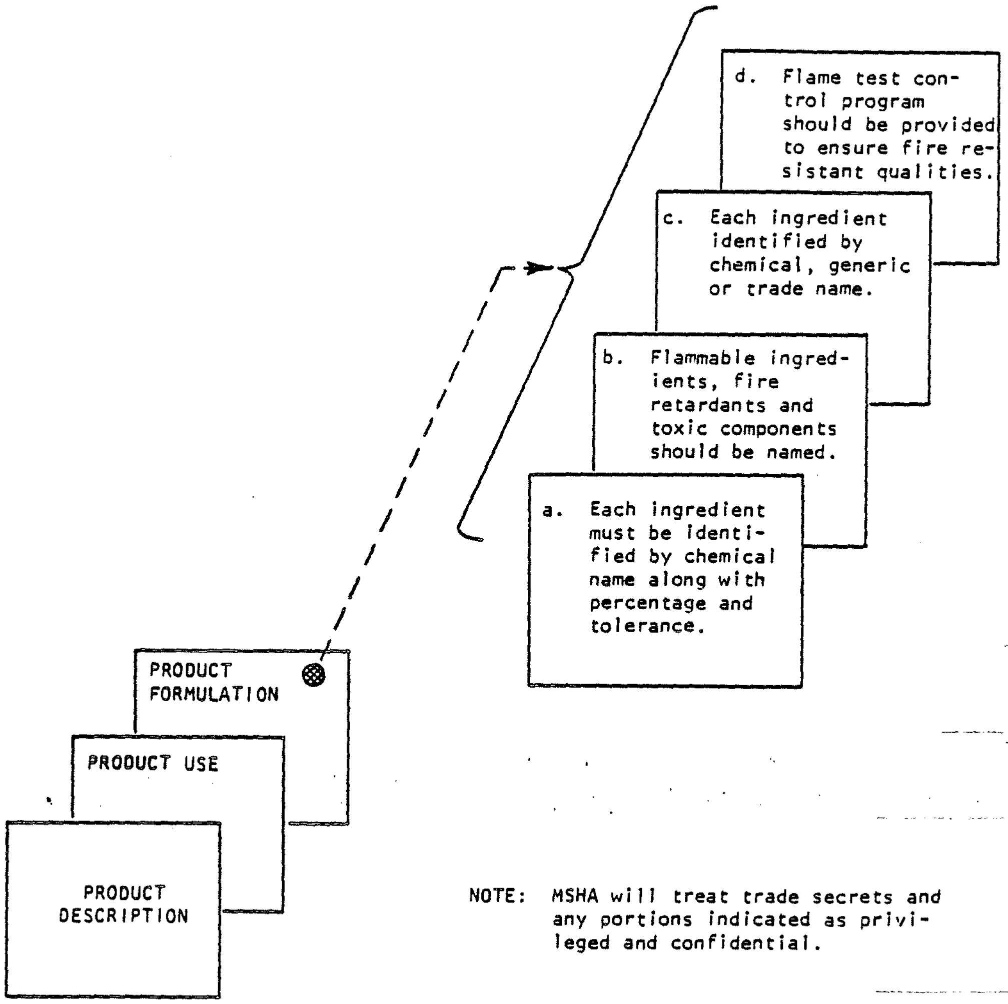
4.2 Appraisal of MSHA Standard for Applicability of Noise Control

4.2.1 Introduction

The initial step in the process of assessing the interim criteria for acceptance of products taken into underground mines was to outline various sections of the criteria by means of logic diagrams. The statements of these sections were diagrammatically structured to indicate the alternative tests, criteria, and limitations of a product or material, both stated and implied. The intent of this task was not to criticize the interim criteria but rather to assess its applicability to noise control products and materials. Sections 1.0 and 2.0 of the MSHA criteria provide the manufacturer with the purpose of the criteria and the process for applying for acceptance. Section 3.0 describes the content of the application as follows:

- Description
- Use
- Formulation

Figure 19 indicates the three parts of the product identification sequence as well as the four elements of the product formulation. The sections of the interim criteria that describe fire tests, criteria, or processes are presented and the relevance to noise control products is discussed.



NOTE: MSHA will treat trade secrets and any portions indicated as privileged and confidential.

Figure 19. Product Identification Sequence

4.2.2 MSHA-Designated Fire Tests

Figure 20 describes sections 4.1 and 5.0 though 5.5. This diagram identifies the appropriate fire test for products taken into underground mines. For a liquid material, two tests have been identified:

- Test for autoignition - ASTM D 2155-66
- Test for flash point temperature - ASTM D 56-70 or D 93-72

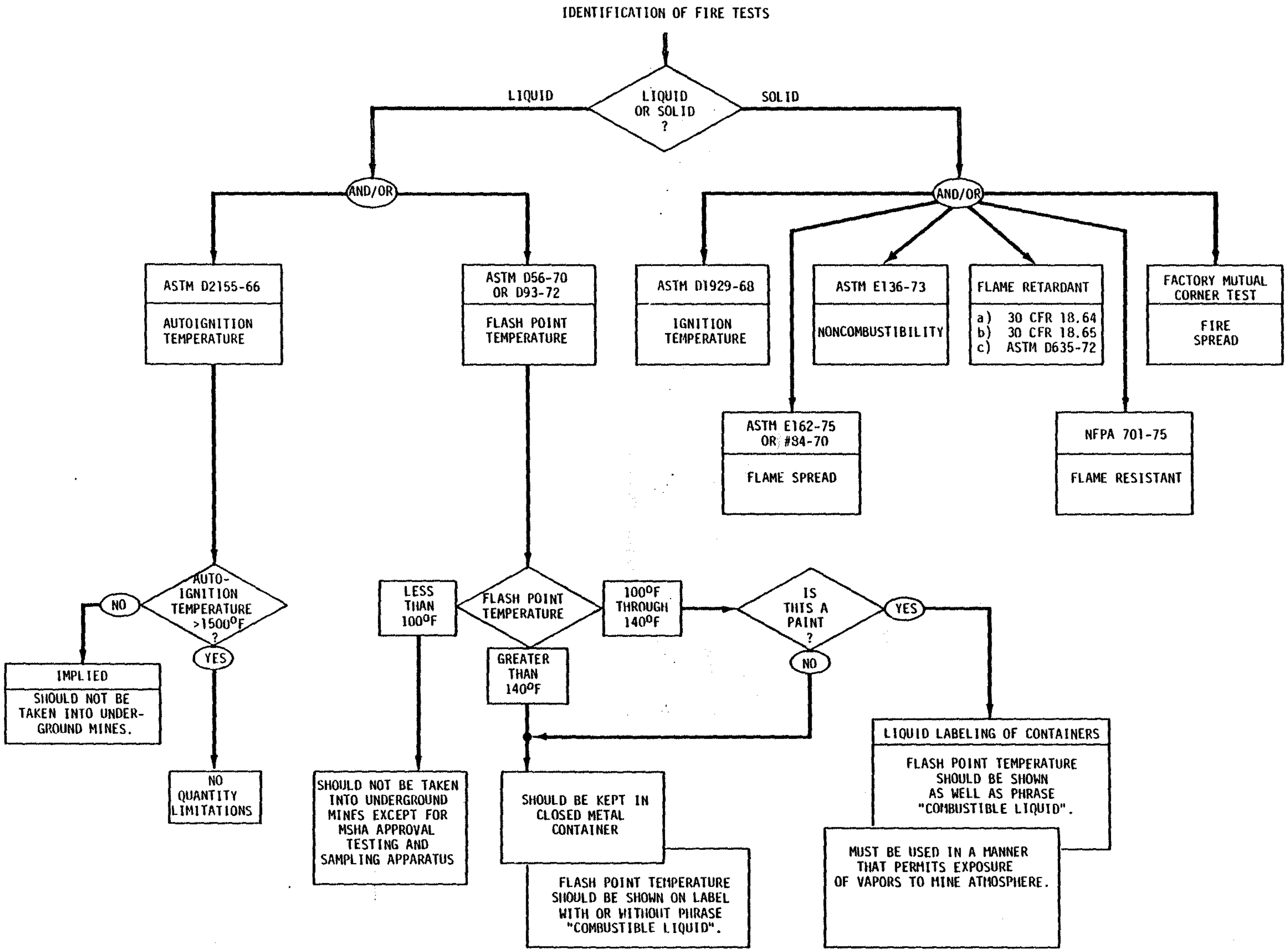


Figure 20. Designated Fire Tests Decision Tree

For a solid material, one or more of the following six tests should be applied:

- Test for ignition temperature - ASTM D 1929-68
- Test for noncombustibility - ASTM E 136-73
- Test for flame retardancy -
  1. 30 CFR 18.64, or
  2. 30 CFR 18.65, or
  3. ASTM D 635-72
- Test for flame spread -
  1. ASTM E 162-75, or
  2. ASTM E 84-70
- Test for flame resistance - NFPA 701-75
- Test for fire spread - Factory Mutual Corner Test

Since the application of liquids for noise control is not considered to be a viable option, that branch of the diagram (figure 20) will not be discussed.

4.2.3 Ignition Temperature Test

If the test to determine the ignition temperature (ASTM D 1929-68) was applied to a solid material and the ignition temperature was found to be less than 300°F, that material should not be taken into underground mines. This is illustrated in figure 21.

4.2.4 Noncombustibility Test

Section 6.2 of the interim criteria pertains to noncombustibility. According to this section, the application of ASTM E 136-73 determines combustibility of a solid. It is then implied that a material that is combustible (by this test) should not be used in underground mines. This section is depicted in the flow diagram of figure 22.

4.2.5 Flame Resistance Test

Section 6.3 discusses the criteria for brattice cloth (including substitutes) and vent tubing in underground mines. It is logically depicted in figure 23. If the material has a flame spread index greater than 25, it should not be taken into underground

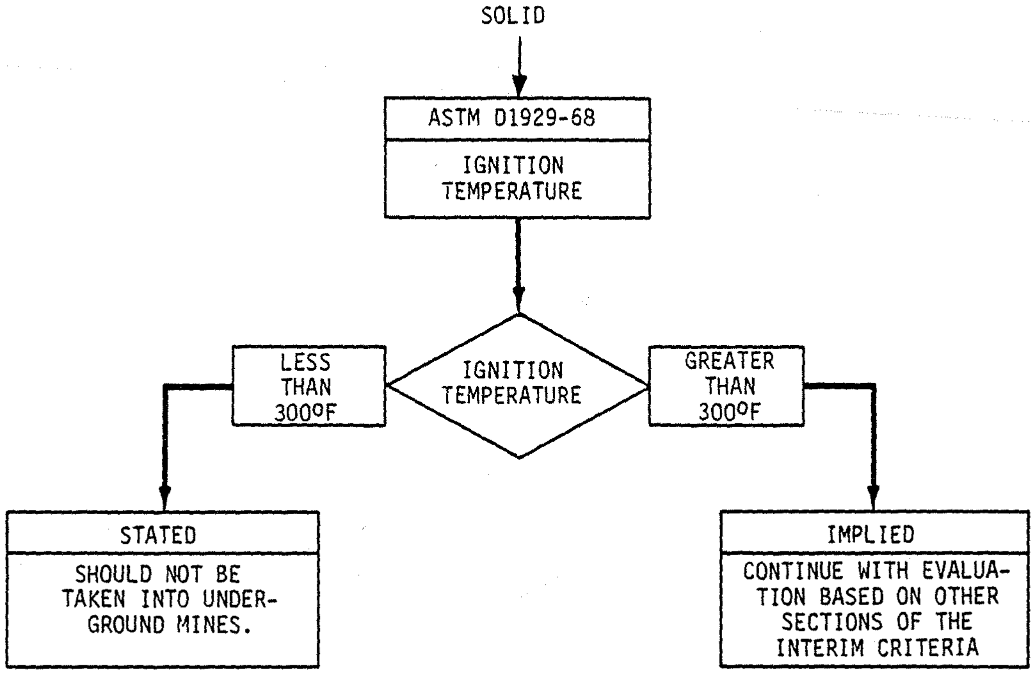


Figure 21. Ignition Temperature Test

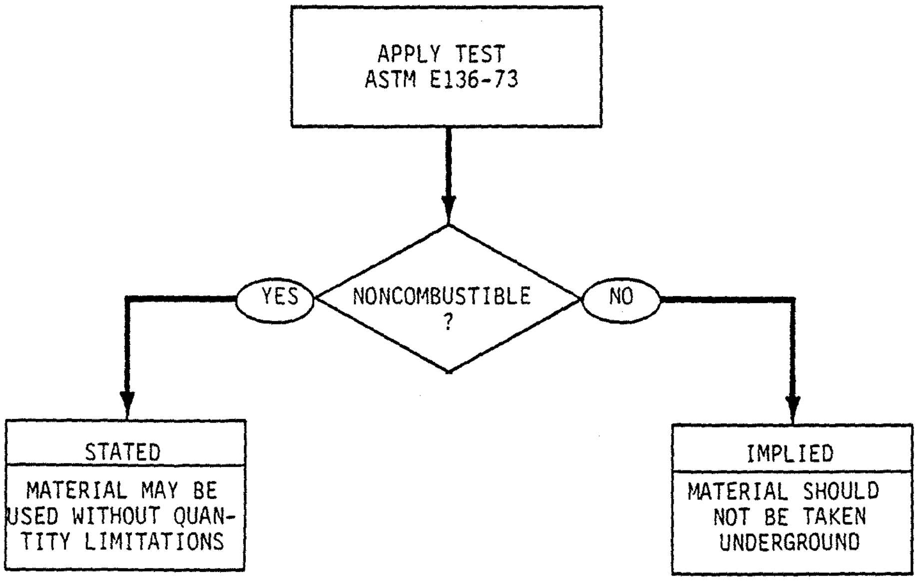


Figure 22. Noncombustibility Test Logic

mines. If the flame spread index is 25 or less, then a second criterion is applied. It must also be flame resistant as determined by NFPA 701-75. Even though it may have a very low flame spread index, unless it also is flame resistant, the material should not be used.

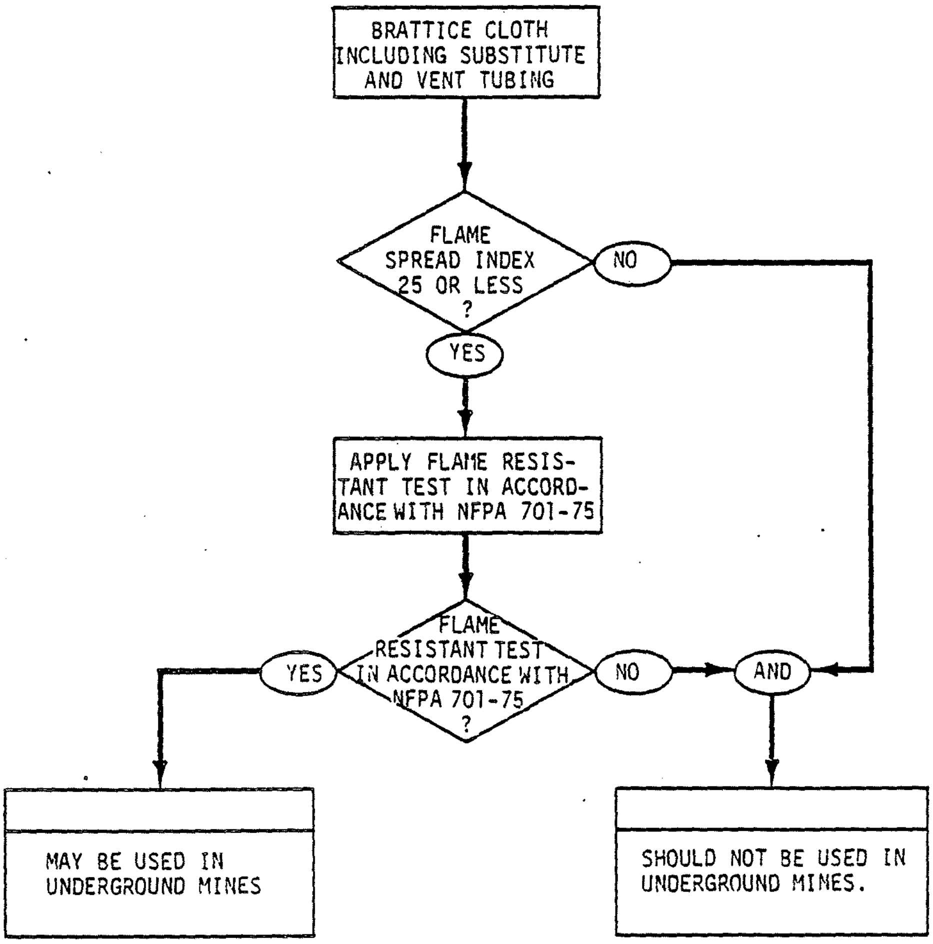


Figure 23. Criteria and Logic for Brattice Cloth

The criteria for determining if a material is flame resistant is discussed in sections 6.3 and 6.3.1 of the interim criteria and is illustrated in the logic diagram of figure 24. As the logic diagram indicates, the material is subjected to NFPA 701-75 test for flame resistance. The conductor of this test must make judgments on three qualitative characteristics in order to determine whether the specimen is flame resistant. The first characteristic is indicated in the first decision box question, "Does specimen continue flamming for more than two seconds after test flame is removed?" If the answer to the question is yes, then the specimen is not flame resistant. If the answer is no, the conductor of the test must address the second characteristic, which is shown by the question in the second decision box of figure 24. The question is, "During or after application of test flame, do portions or residues of textile or flame that break or drip from the specimen continue to flame after reaching the floor of the tester?" If the answer is no, then the question concerning the third characteristic must be examined. This final question is, "Does specimen cloth retain physical integrity when a sample 6 inches wide is maintained at 300 ± 5°F for a period of 5 minutes?" If the answer to this question is no, then the specimen is not flame resistant. If the answer is yes, then the specimen is flame resistant.

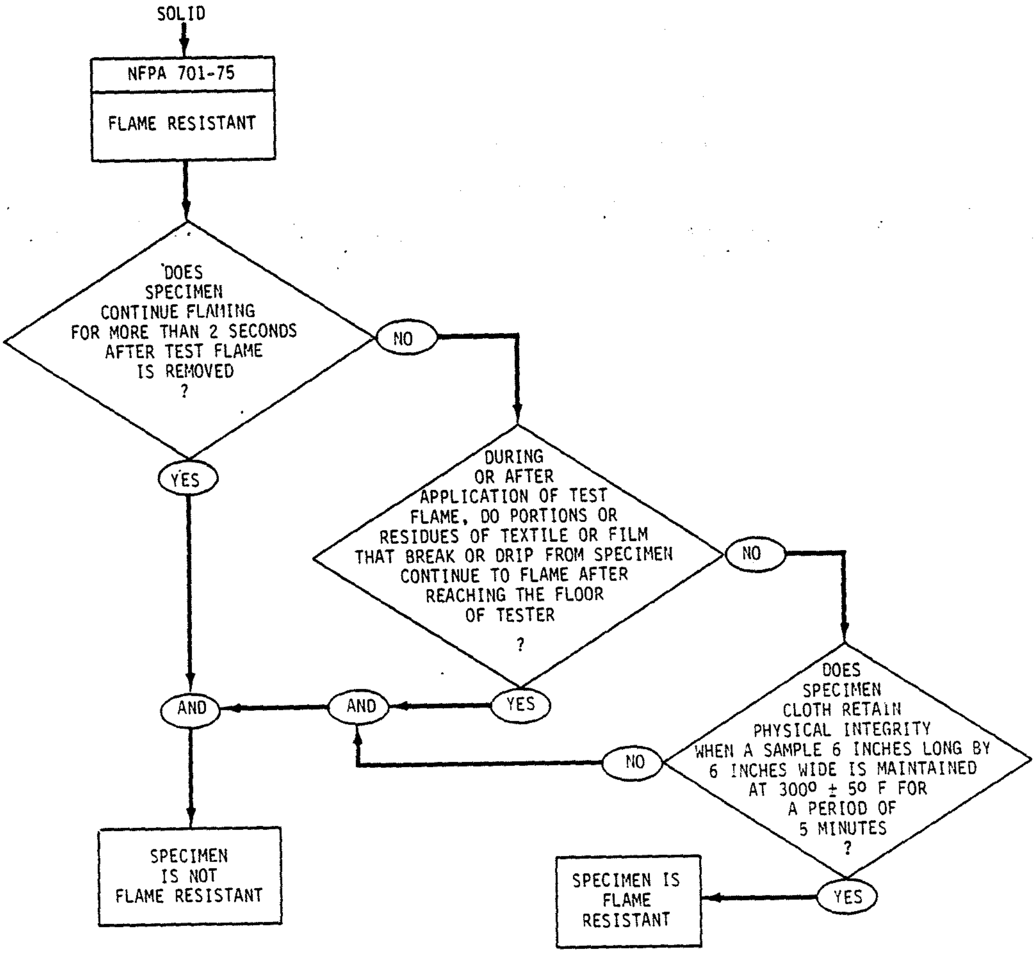


Figure 24. Flame Resistance Criteria and Logic

To pass the NFPA 701-75 test for flame resistance of a solid requires that the specimen successfully meet the requirements for the three characteristics as delineated by the three decision points of figure 24. Failure of the specimen at any one of the three decision points, as determined or judged by the test conductor, will disqualify the material as being flame resistant.

4.2.6 Flame Retardation Tests

Various tests for flame retardation applicable to certain materials are specified in section 6.4 of the MSHA criteria and are shown in figure 25. Since the materials specified were not applicable to noise control, neither they nor their respective tests warrant discussion. Also, flame retardation per se has not been designated as a flammability characteristic for noise control materials.

4.2.7 Products Used on Machines and Equipment

The narrative of sections 6.5, 6.5.1, and 6.5.2 and implications therefrom are presented in the logic diagram of figure 26. The diagram shows that a flame spread test, ASTM E 162-75 or E 84-70, must be performed. Depending on the flame spread index (I_s), other criteria may be required. If the material exhibits I_s less than 25, the product is deemed acceptable and may be used without quantity limitations.

If the I_s is between 25 and 100, then the material must be subjected to a flame retardation test (ASTM D 635-72). Assuming that the material meets the flame retardation test, a fire suppression requirement must be met. That is, the area or location where the material will be used must be protected by a fire suppression system equivalent to 30 CFR 75.1101 or 30 CFR 75.1107. If such a fire suppression system is provided, then the material may be used without quantity limitations. In the absence of the designated type of fire suppression system, the material may be used but the quantity should not exceed an average of five pounds per linear foot of passageway.

As the diagram shows, for materials whose I_s is greater than 100, the user of this product is required to search for a less hazardous substitute, preferably with an I_s less than 100. In the event that a less hazardous substitute product/material is not

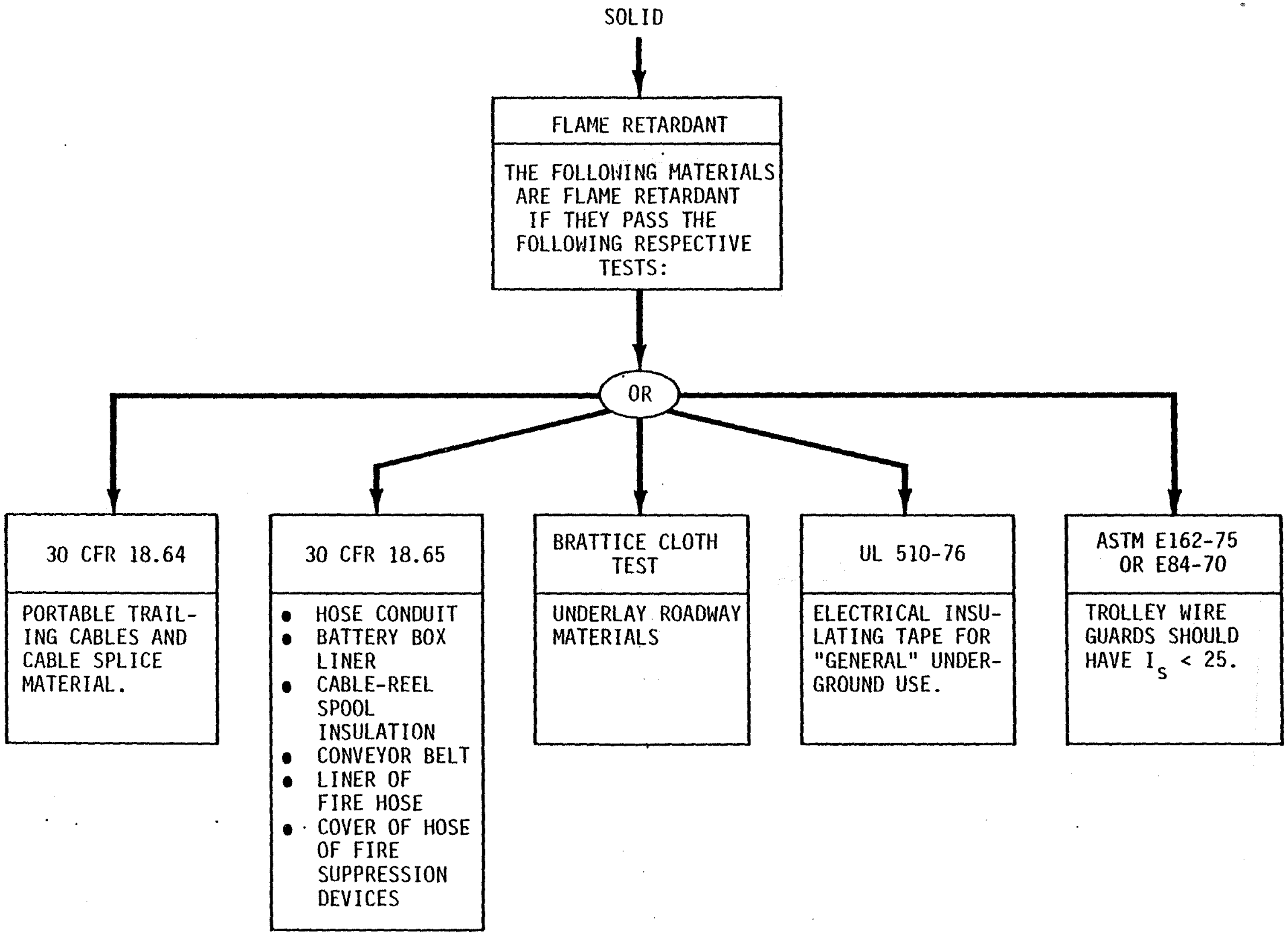


Figure 25. Flame Retardation Tests for Various Materials

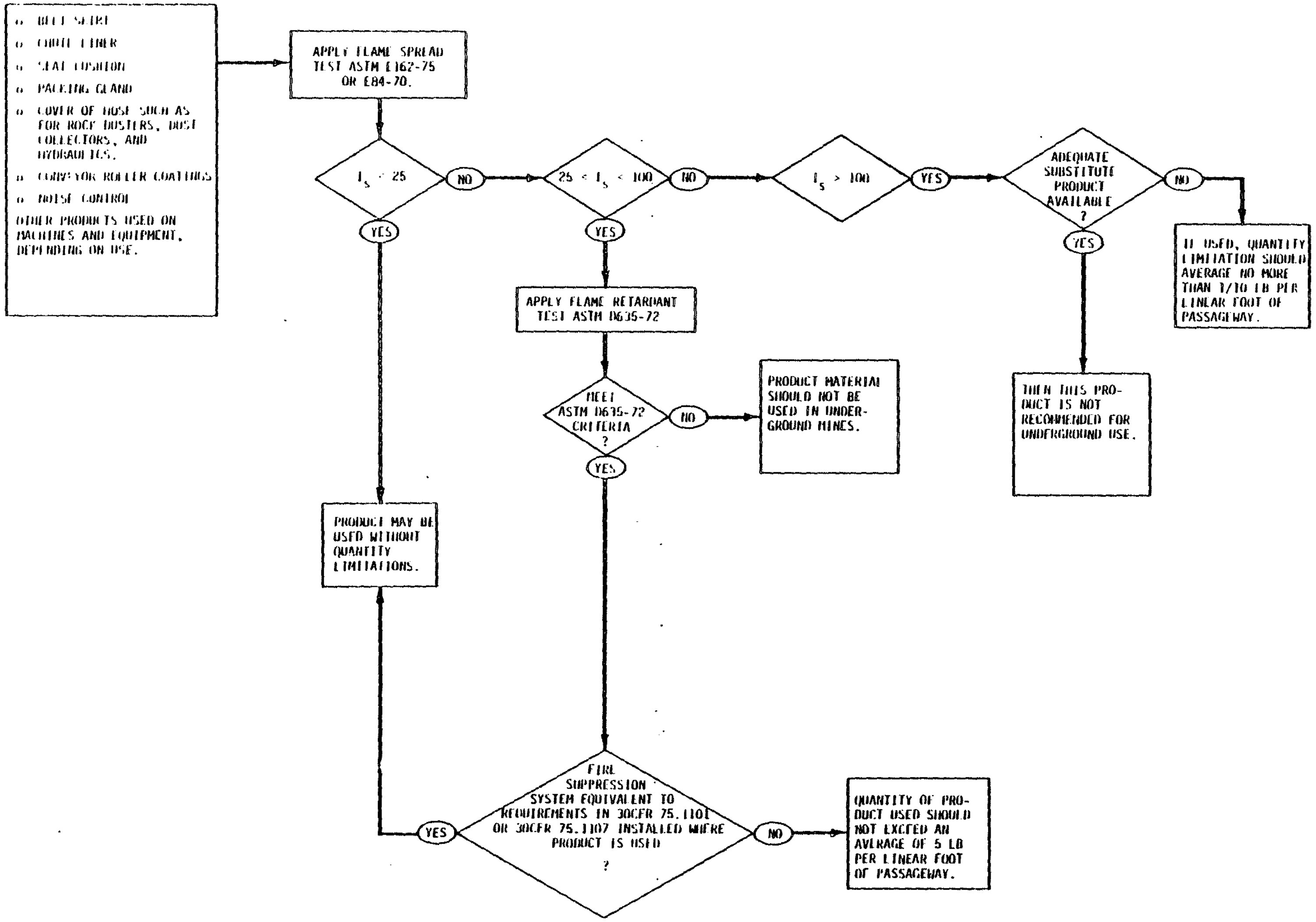


Figure 26. Criteria and Logic for Acceptance of Various End-Use Products

available and this product must be used, then its use must be limited to no more than one-tenth pound per linear foot of passageway.

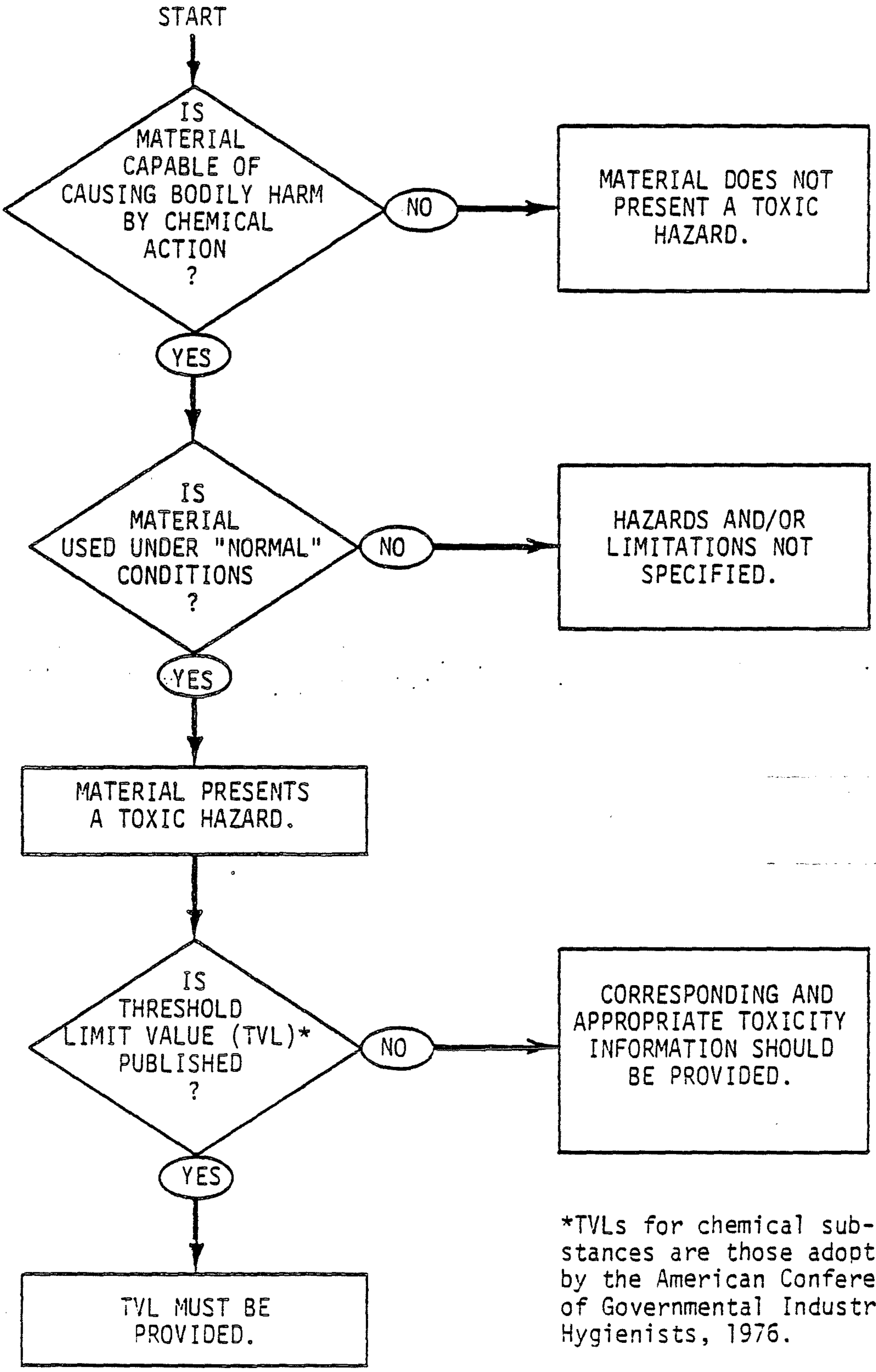
The criteria discussed in this section and presented in figure 26 are applicable to belt skirts, chute liners, seat cushions, packing glands, hose coverings, conveyor roller coatings, noise control, and other products used on machines and equipment.

4.2.8 Toxic Hazard

The problem of toxic hazard is described in sections 7 through 7.8 of the interim criteria and has been presented in the logic diagrams of figures 27 through 29. It should be emphasized that these interim criteria dealt with primary toxicity of material rather than toxicity resulting from combustion products of these materials. The problem of toxic hazards was addressed, but it became too complex an issue, particularly for decomposition products resulting from combustion. Therefore, toxicity requirements are limited to primary toxic effects, which can be evaluated from existing information as per interim MSHA criteria. All materials brought into the mine must meet the primary toxicity requirements in addition to the applicable fire hazard criteria.

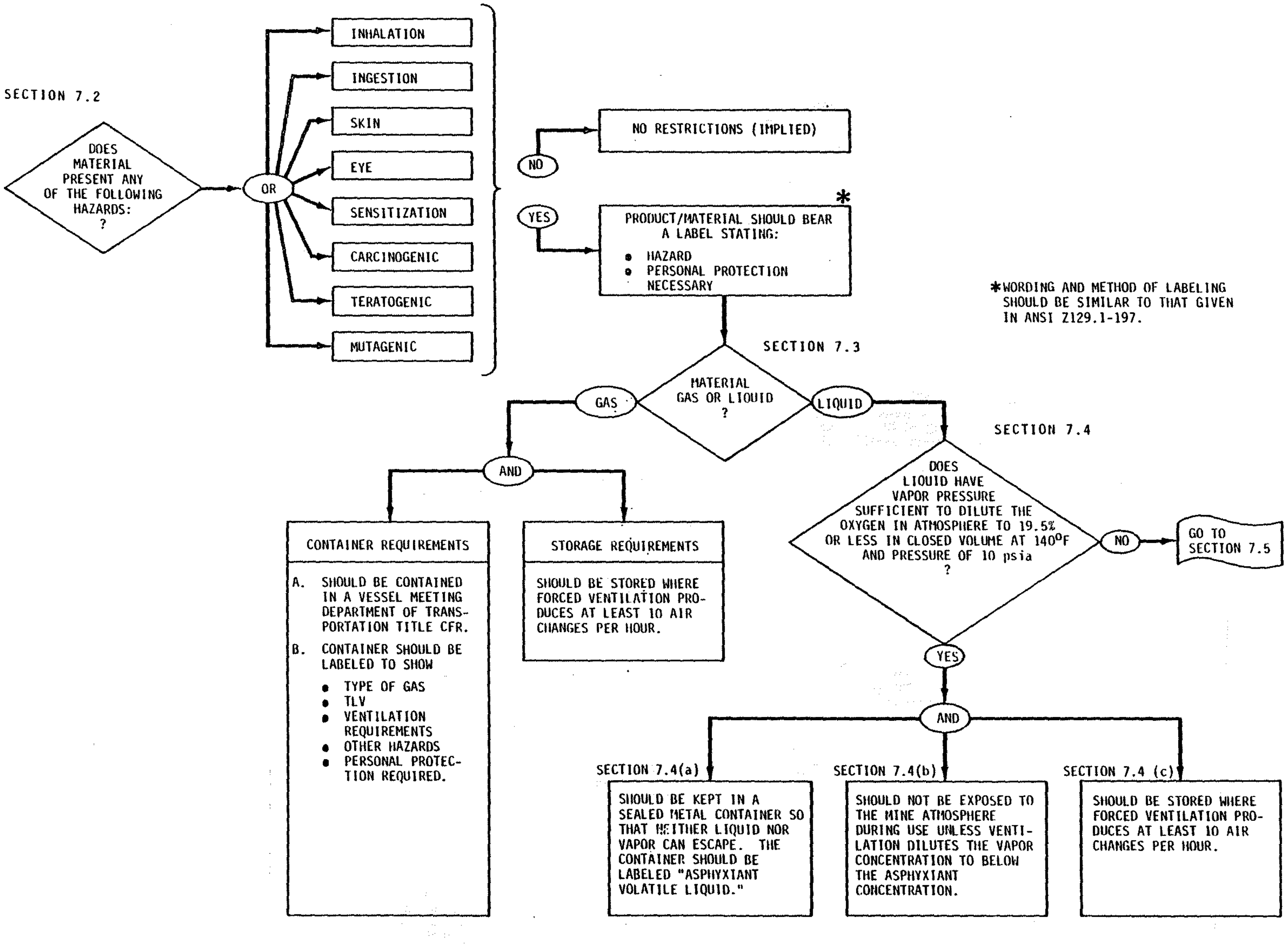
Figure 27 shows that if a material is capable of causing bodily harm by chemical action when used under "normal" conditions, then it presents a toxic hazard. If the material presents no bodily harm, then it is not a toxic hazard. For materials that present toxic hazards, the Threshold Limit Value (TLV), or appropriate corresponding toxicity information, must be provided.

Figure 28 provides the decision points for sections 7.2, 7.3, and 7.4 of the interim criteria. If a material presents an inhalation, ingestion, skin, eye, sensitization, carcinogenic, teratogenic, or mutagenic hazard, it must bear a label stating the nature of the hazard and required personal protection. If the substance is a gas, container requirements and storage requirements must be met. These are indicated on figure 28. If the material is a liquid, other requirements indicated in the logic diagrams of figures 28 and 29 must be satisfied. Further discussion of figures 28 and 29 are not warranted since liquids and gases are not envisioned as being used for noise control in underground mines.



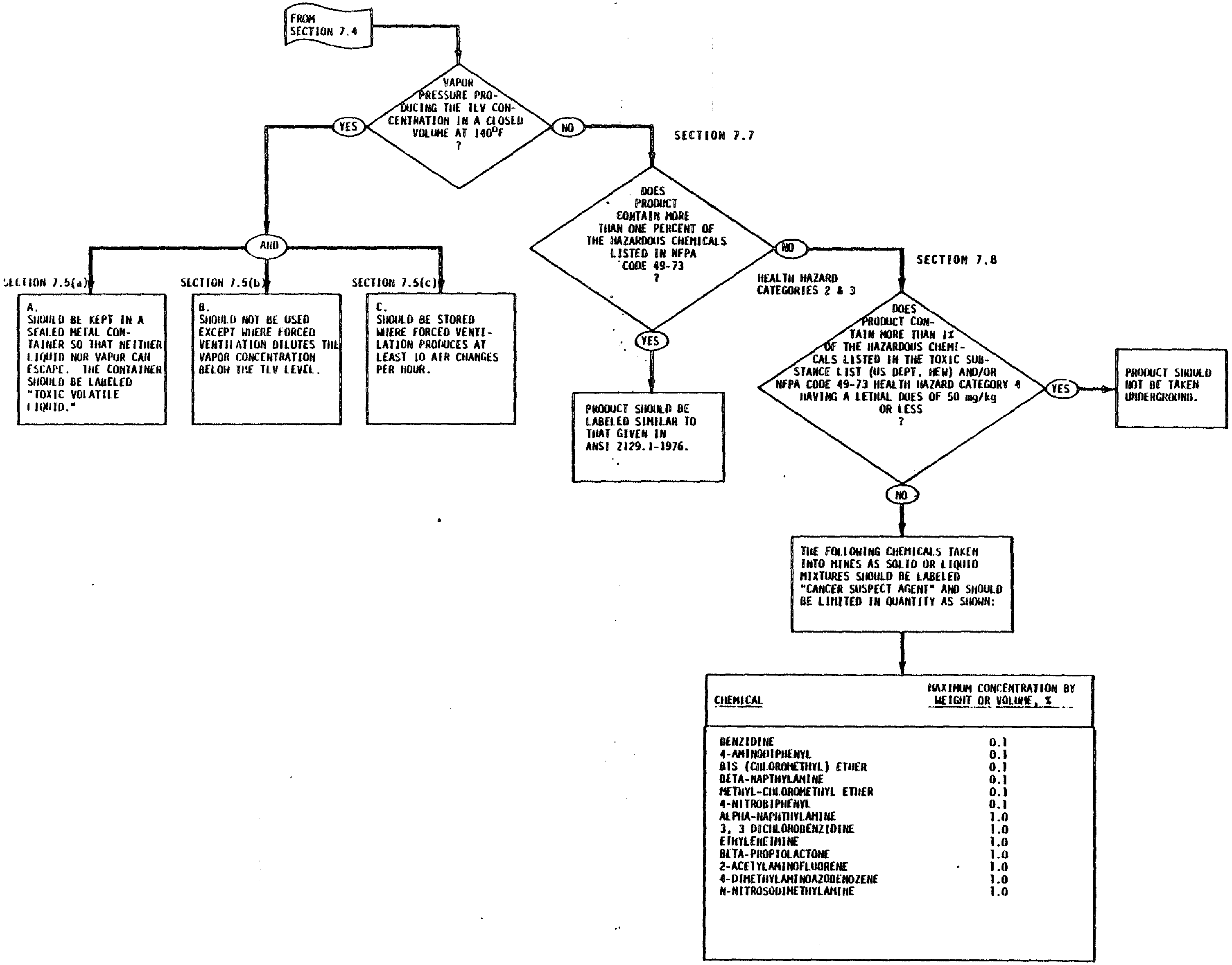
*TVLs for chemical substances are those adopted by the American Conference of Governmental Industrial Hygienists, 1976.

Figure 27. Toxic Hazard Criteria and Logic



*WORDING AND METHOD OF LABELING SHOULD BE SIMILAR TO THAT GIVEN IN ANSI Z129.1-197.

Figure 28. Container and Storage Criteria and Logic for Gases and Liquids



CHEMICAL	MAXIMUM CONCENTRATION BY WEIGHT OR VOLUME, %
BENZIDINE	0.1
4-AMINODIPHENYL	0.1
BIS (CHLOROMETHYL) ETHER	0.1
BETA-NAPTHYLAMINE	0.1
METHYL-CHLOROMETHYL ETHER	0.1
4-NITROBIPHENYL	0.1
ALPHA-NAPHTHYLAMINE	1.0
3, 3 DICHLOROBENZIDINE	1.0
ETHYLENEIMINE	1.0
BETA-PROPIOLACTONE	1.0
2-ACETYLAMINOFLUORENE	1.0
4-DIMETHYLAMINOAZOBENOZENE	1.0
N-NITROSODIMETHYLAMINE	1.0

Figure 29. Container and Storage Criteria and Logic for Gases and Liquids - Concluded

4.2.9 Summary and Conclusions

The interim criteria designated as "Interim Fire and Toxicity Criteria for Acceptance of Products Taken Into Underground Mines," draft No. 2, March 22, 1977, presented by MSHA, applied to organic, inorganic, chemical, or mineral materials or products for an application or use in underground mines. Considering its scope of coverage, the interim criteria provides a general level of assurance that extremely hazardous materials/products are not used in mines; or if used, that their usage be limited or controlled. In the absence of criteria developed for specific materials or materials used for specific purposes, the interim criteria must be used as a basic safeguard. One purpose of this present study is to examine present and future materials that have applicability in end-use noise control products for underground mines and to develop specific fire hazard criteria suitable for these products. It would be highly desirable that these criteria would route a product manufacturer (seeking to gain acceptability for his product) through a designated set of tests that would determine whether or not the product is acceptable as a noise control material for a specific end-use application.

Although the new interim criteria does provide specific tests to determine or measure flame spread, flame resistance, flame retardation, etc, there is some vagueness as to which tests to apply. For instance, the decision logic of figure 20 (derived from sections 4.1 and 5.0 through 5.5 of the interim criteria) designated as "solid" indicates that a product manufacturer has a choice of one or more of several different tests designed to measure different fire characteristics. The implication is that if a product fails one type of test, it may pass one of the others and thus be considered acceptable. Certain designated materials may require two tests--a flame spread test and a flame resistance test--to determine acceptability, as shown in figure 23. Other end-uses or specific products have specific tests called out for flame retardation, as illustrated in figure 25. Figure 26 provides the decision points discussed in sections 6.5, 6.5.1, and 6.5.2 of the interim criteria for the sequence of tests that have been deemed essential for another group of end-use materials. Some paths of this logic are quite complex (that is, $25 < I_s < 100$), requiring that the material satisfy a flame retardation test and a toxicity test, and that a fire suppression system be installed in the area where the material is used or else its use must be limited as shown. It should be noted that noise control materials or products are among those subjected to the criteria for figure 26.

Noise control products cover a wide range of materials, locations, quantities for a given end-use, and interfaces with other systems; therefore, provisions must be made for their unique usages. Clearly, one set of sequence of tests cannot be applicable to all noise control products. Specific test requirements that are a function of a number of factors--such as quantity and location of materials, contributory fire hazards, and interfaces with other systems--must be formulated.

4.3 Guidelines for New Criteria

4.3.1 Introduction

The fire hazard associated with any material can be divided into two categories: (1) ease of ignition and (2) effects of combustion (figure 30). The fire hazard criteria presented in this document is intended to exclude those noise control products from underground use that would increase the hazard to the miner in either of these areas.

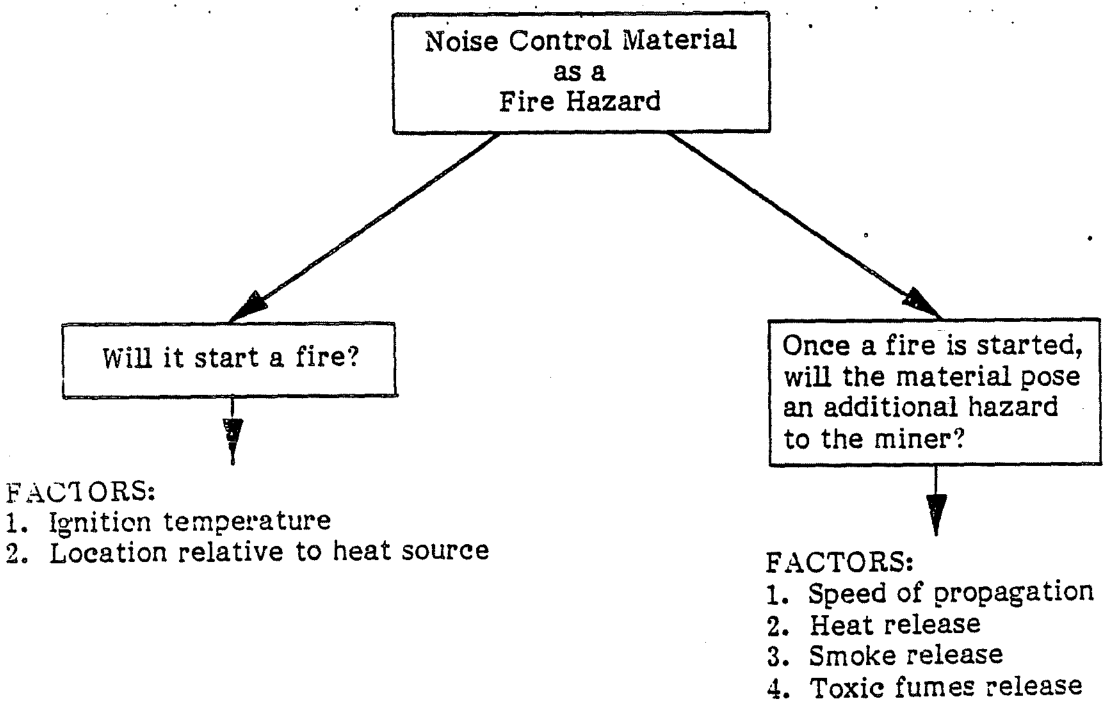


Figure 30. Noise Control Material as a Fire Hazard

The impact that a particular noise control product would have on the fire hazard environment is strongly dependent on the "ambient" situation. The coal mining environment was, therefore, a major consideration in the development of the new criteria. A description of this environment is given in section 4.3.2.

To allow maximum use of noise control products, these criteria were specified for end-use applications rather than for individual materials or components constituting the end-use product. End-use application from a coal mining system perspective provides a means for assessing the nature of the hazard that the product presents where it is used and in the form in which it is used. The various end-use applications are classified in section 4.3.3.

Little data exists to correlate the results of small-scale fire tests to the effects of full-scale mine fire incidents. The tests chosen must, therefore, be capable of evaluating fire response characteristics that relate as directly as possible to the in-mine fire hazard problem posed by the noise control materials. The general rationale behind the fire hazards tests and acceptance criteria are described in section 4.3.4. Sections 4.3.5, 4.3.6, and 4.3.7 detail the rationale for the specific aspects of the proposed fire hazard tests and acceptance criteria.

4.3.2 Coal Mine Fire Hazard Environment

The underground coal mining environment is hostile. Miners face life-threatening dangers daily. Fire is one of the ever-present threats. The mine floor is covered with one to three inches of finely broken coal. Coal dust and fines penetrate to every nook and cranny of the equipment. The ribs and roof are also formed from this material that is mined for its fuel content. These conditions cannot be avoided in practical coal mining operations. Extensive measures must be and are taken to minimize the fire hazards associated with underground coal mining. The presence of coal, however, establishes certain restrictions on the manner in which general mine fire safety assurance can be approached.

A fire must have an ignition source and a fuel. A survey of all reportable mine fires in the years 1953 to 1977 clearly flags the ignition sources of importance (table 6). Coal was the initial burning material in about 30 percent of the fires. Although it was not explicitly stated in the survey, coal was eventually involved in

TABLE 6. Fires by Ignition Source [1, p. 9]

Ignition source	1950-52	1953-55	1956-58	1959-61	1962-64	1965-67	1968-69	1970-71	1972-73	1974-75	1976-77
Electrical	12	60	108	108	101	101	74	18	21	10	12
Friction	5	12	17	21	14	13	8	6	1	1	2
Spontaneous combustion	5	7	11	17	6	7	7	2	5	4	3
Explosives	0	4	2	3	6	1	0	1	0	0	0
Welding and/or cutting	0	3	4	1	8	4	3	2	6	2	1
Vandalism	2	2	1	4	2	0	0	1	0	0	0
Engine or clutch overheat	0	1	0	2	0	1	3	0	3	0	2
Open flame	0	1	3	1	0	2	1	1	0	1	0
Excess cable overheat	0	2	3	6	0	4	0	5	0	0	0
Adjacent or surface fire	1	2	0	3	1	2	0	0	0	0	0
Other	0	1	0	0	0	2	0	3	0	0	0
Unspecified or unknown	3	15	19	18	12	12	5	7	2	2	5
Total	28	110	168	184	150	149	101	46	38	20	25

Ignition source	Major time periods								
	1953-61		1962-69		1970-77		1953-77		
	Total	Pct	Total	Pct	Total	Pct	Total	Pct	χ^2
Electrical	276	59.7	276	69.0	61	47.3	611	61.8	[1]139.49
Friction	50	10.8	35	8.75	10	7.75	95	9.6	[2]21.68
Spontaneous combustion	35	7.6	20	5.0	14	10.9	69	7.0	[1]7.31
Explosives	9	1.95	7	1.75	1	.8	17	1.7	[2]5.43
Welding and/or cutting	8	1.7	15	3.75	11	8.5	34	3.4	[2]1.51
Vandalism	9	1.5	2	.5	1	.8	12	1.7	[1]7.50
Engine or clutch overheat	3	.65	4	1	5	3.9	12	1.2	[2].31
Open flame	5	1.1	3	.75	2	1.6	10	1.0	[1]11.18
Excess cable overheat	11	2.4	4	1	5	3.9	20	2.0	[2]5.40
Adjacent or surface fire	5	1.1	3	.75	0	0	8	.8	[2]4.56
Other	1	.2	2	.5	3	2.3	6	.6	NAp
Unspecified or unknown	52	11.3	29	7.25	16	12.4	97	9.8	NAp
Total	462	100	400	100	129	100	991	100	-

NAp Not applicable.

[1] Statistically significant at the 0.01 level of confidence.

[2] Not statistically significant at the 0.05 level of condifence.

NOTE.--For 1970-77, χ^2 = 149.64 (statistically significant at the 0.01 level of confidence) with electrical fires, and χ^2 = 34.89 (statistically significant at the 0.01 level of confidence) without electrical fires.

at least 88 percent of the reportable fires. This estimate can be deduced from table 7, assuming any fire of over 15-minutes duration must surely have coal as an additional fuel source. Since broken coal on the floor alone can amount to 50-100 kg/m^2, fuel quantity is not a limiting factor. Coal mine fires have been known to burn for years. A coal fire can generate a heat flux of 80 kW/m^2. Prodigious and potentially lethal quantities of smoke and carbon monoxide are also produced.

TABLE 7. Fires by Duration [1, p. 19]

Duration	1953-61		1962-69		1970-77		1953-77		
	Total	Pct	Total	Pct	Total	Pct	Total	Pct	χ^2
0 to 15 min..........	38	8.3	52	13.0	28	21.7	118	12.0	[1]8.37
15 to 30 min..........	31	6.8	40	10.0	12	9.3	83	8.4	[1]14.82
30 min to 1 hr........	53	11.6	36	9.0	11	8.5	100	10.1	[1]22.31
1 to 4 hr.............	87	19.0	91	22.0	28	21.7	206	20.9	[1]33.58
4 to 24 hr............	60	13.1	56	14.0	15	11.6	131	13.3	[1]25.51
Over 24 hr............	35	7.6	23	5.8	28	21.7	86	8.7	[2]1.28
Unspecified or unknown	154	33.6	101	25.3	7	5.4	262	26.6	NAp
Total............	458	100	399	100	129	100	986	100	NAp

NAp Not applicable.

[1] Statistically significant at the 0.05 level of confidence.

[2] Not statistically significant at the 0.05 level of confidence.

All these facts support two intuitively obvious notions about the coal mine fire hazard environment: (1) Coal and the ignition sources are always in proximity, and (2) once started, the severity of coal mine fires is not fuel limited.

In the rock dusted areas of the mine, the fire hazard environment is substantially altered. If the rock dust is applied in the legally required quantities, the coal/rock dust mixture will not sustain combustion. A fire in the rock dusted areas of the mine could involve noise control materials without necessarily igniting coal. The severity of the fire, therefore, could be determined by the combustion properties of the noise control products. These aspects of the underground coal mining environment must be considered when establishing rational and effective fire hazard criteria for noise control products.

4.3.3 End-Use Configuration

As discussed in section 2, the fire properties of a product are both material and form (or configuration) dependent. For example, a foamed plastic burns much more readily than the same plastic in a more solid form. To avoid the confusion that could be caused by this effect, the fire hazard criteria are specified for end-use applications rather than for individual materials constituting the end-use product. End-use application from a coal mining system perspective provides a means for assessing the nature of the hazard that the product presents where and in what form it is used. In the mining environment, material exposure and quantity are the most significant end-use parameters outside the basic form of the material as described above. These aspects strongly affect the hazard potential of the noise control products. If a combustible material is faced on two sides by metal, only the edges exposed to air can burn. If the material is faced on one side by the metal, the heat sink effect makes it less vunerable to ignition. For the purposes of fire hazard specifications, the possible product exposure configurations will be divided into three categories:

1. Material is attached on both faces to metal greater than 1/32 inch thick.
2. Material is attached on one face to metal greater than 1/32 inch thick.
3. Material is not attached on any face to metal greater than 1/32 inch thick.

As will be fully discussed later, only noise control materials that cover very large areas are likely to increase the post-ignition hazards facing the miner in a coal mine fire. By a rather arbitrary process, material quantity will be divided into two categories:

1. Longest dimension is less than 12 feet.
2. Longest dimension is greater than 12 feet.

The fire tests to be required of a noise control product will be a well-defined function of the product's configuration.

4.3.4 Fire Hazard Tests and Acceptance Criteria

The proposed fire hazard tests and acceptance criteria are summarized below.

A. Vertical Flame Test

Affected noise control products: All.

Test conditions:

1. Specimen size is that of end-use configuration or 3 by 12 inches, whichever is smaller.
2. Vertical orientation of longest dimension.
3. Tested in end-use configuration.
4. Flame height - 1.5 inches.
5. Exposure time - 60 seconds.

Test procedure: See appendix E.

Acceptance criteria:

1. Burning extent should not exceed 6 inches.
2. Afterflame should not exceed 2 seconds.
3. Afterglow should not exceed 5 seconds.

B. Ignition Temperature Test

Affected noise control products: All.

Test conditions:

1. Test nonmetallic portion of product only.
2. Piloted ignition.

Test procedure: See appendix F.

Acceptance criteria: The minimum flash ignition temperature will exceed $300^{\circ}C$ ($572^{\circ}F$).

C. Twenty-Five-Foot Tunnel Test

Affected noise control products: All products with longest dimensions greater than 12 feet but not covered on both faces by metal greater than 1/32-inch thickness.

Test conditions:

1. Test nonmetallic portion of product only.
2. Heat flux of 87.9 kW.
3. Air flow rate of 73.2 m/min.

Test procedure: See appendix G.

Acceptance criteria:

1. Flame spread classification should not exceed 25.
2. Smoke-developed classification should not exceed 50.

How does this set of fire hazard criteria assure that coal miner safety is not compromised by the use of noise control products? Figure 30 diagrams the fire hazards associated with a noise control product. The product could provide the fuel needed to start a fire. Once a fire is started, the combustion of the product could speed the propagation of the fire to other parts of the mine, release harmful amounts of heat, release harmful amounts of smoke, release toxic fumes, or seriously deplete the oxygen in the area.

Will the product provide the fuel needed to start a fire? The nonmetallic portion of a noise control product must have a minimum flash ignition temperature of 300°C. This is 50 to 170°C higher than the ignition temperature of the ever-present coal fines [4, p. 15]. An ignition source hot enough to ignite the noise control material would also ignite the coal fines in the area. The afterflame limitation in the Vertical Flame Test (VFT) assures that accidental, short-term application of a torch, spark, or electric arc would not cause the material to achieve self-sustained combustion.

In the fully rock dusted areas of the mine, an ignition source could ignite the product without involving coal. The hazard associated with this possibility will be discussed later.

Will the combustion of the noise control product significantly increase the danger to the miner in the event of a fire? One possible danger is that the noise control product would speed the propagation of the fire to other areas of the mine. If the product's dimensions are reasonably small (less than 12 feet), it cannot be a combustion hazard to other areas of the mine. The very short afterflame limitation in the VFT also demonstrates a high resistance to propagation in the crucial early stages of a fire. The VFT approximates early ignition conditions when the product is initially subjected to an ignition source and has not been fully preheated by a larger fire condition. If the material dimensions are large (greater than 12 feet), propagation along a fully preheated material could speed the spread of the fire over significant areas of the mine. The 25-foot tunnel test criteria effectively screens products with large dimensions that would propagate too quickly in that more serious mine fire condition.

As discussed in detail in section 4.3.2, the severity of coal mine fires in terms of heat, smoke, and toxic combustion gases is not fuel limited in the unrock-dusted areas of the mine. The possible fuel contribution from noise control materials in those areas must, therefore, be of little consequence.

A product with a very short VFT afterflame time can be considered a "secondary" fuel source because severe heat conditions are required to maintain its combustion. In the rock-dusted areas of the mine, the severe heat conditions are only achieved in the immediate area of the ignition source. The material would only burn in that small, local area. Hence, the presence of the material would not be significantly more dangerous than the ignition source itself. If some unforeseen ignition source somehow achieves a larger, more severe fire condition, the 25-foot tunnel test would prevent the use of materials that could accelerate the large-scale propagation of that condition.

Two aspects of the fire hazard problem have not been directly addressed by these criteria. First, toxicity of the combustion products was not examined. The National Bureau of Standards is in the final stages of a five-year, million-dollar development program addressing this important question. This work would provide the basis for any criteria concerning toxicity. There is presently strong evidence, however, that the principal toxicant resulting from the combustion of elastomers (a major noise control material) is carbon monoxide [3]. This being the case, the relative quantity argument (coal versus noise control material) used for heat and smoke release would also apply to toxicity. Secondly, some noise control materials are porous. Porous materials could soak up oil or hydraulic fluid over a period of time and eventually become dangerous. A requirement limiting the porosity of the materials would reduce this hazard. Unfortunately, there is no standard test for the long-term absorption of hydraulic fluid or oil. Further work in this area is required before adequate criteria can be specified.

4.3.5 Justification for the Selection of the Vertical Flame Test, Test Conditions, and Acceptance Criteria

Selection of Test and Test Conditions

Technical Aspects

A. The vertical flame test provides an inexpensive measure of a material's ease of ignition.

B. The burner flame of the specified 1.5-inch height and 60-second application time used in the vertical flame test provides a moderate severity of exposure. This compares favorably with the severity range of the ignition sources that noise control products might be expected to encounter in the underground coal mine.

C. The presence of flame increases the probability of ignition and provides greater reproducibility of test results than does heat flux in the absence of flame.

D. The presence of flame more closely simulates the ignition sources that noise control products would be likely to encounter in underground coal mines. Such heat sources include burning diesel fuel and electrical arcing.

E. The vertical position of the specimen represents more severe exposure than does horizontal or inclined positions.

Practical Aspects

A. The vertical flame test, in various forms, has been used in evaluating many types of materials, including textiles, aircraft interiors, and electrical coverings. The capability for performing this test exists in a majority of testing laboratories.

B. The vertical flame test is generally accepted as a useful first-round screening test, although there may be disagreement about the second-round screening test that is most appropriate for a particular application.

C. The vertical flame test with the specified 1.5-inch flame height and 60-second application time, is cited in many government specifications and regulations. As a result, a substantial base of experience with regard to both operation and results has been established for this test. Citations include Federal Test Method Standard No. 191, Method 5803.2, FF 3-71; California Bulletin 117; and FAR 25.853(a).

D. The vertical flame test requires a minimum of investment in laboratory facilities and personnel training and is, therefore, more amenable for small businesses.

Acceptance Criteria

Technical Aspects

A. A burning extent not exceeding 6 inches in a 12-inch vertical specimen ignited at the bottom by a burner flame indicates a moderate to high degree of resistance to ignition and flame spread.

B. An afterflame not exceeding two seconds is more severe than most other specifications. This stringent requirement assures that the material will not propagate a fire except in very severe situations.

C. An afterglow not exceeding five seconds further attests to the material's high fire ignition and propagation resistance.

Practical Aspects

A. A six-inch burning extent is specified in FAR 25.853(a) and California Bulletin 117.

B. California Bulletin 117 specifies 5 seconds maximum afterflame and 15 seconds maximum afterglow.

C. FAR 25.853(a) specifies 15 seconds maximum afterflame.

4.3.6 Justification for the Selection of the Ignition Temperature Test, Test Conditions, and Acceptance Criteria

Selection of Test and Test Conditions

Technical Aspects

A. Since most ignition sources in the mine will be applied suddenly, accompanied by flame, the flash ignition temperature determined by the step temperature increase method closely approximates those conditions.

B. The flash ignition temperature is lower than the auto- or self-ignition temperature and is more repeatable.

C. The D1929 Ignition Temperature Test gives an accurate measure of a material's temperature tolerance.

Practical Aspects

Many laboratories across the United States can perform the test. As a result, a substantial base of experience with regard to both operation and results has been established for this test.

Acceptance Criteria

Technical Aspects

The minimum flash ignition temperature should exceed 300°C (572°F) so that the noise control material will not ignite before the ever-present coal. The ignition temperature of coal in a similar test (ASTM E 65-9) ranges from 110°C to around 150°C [4, p. 15].

Practical Aspects

A. Many noise control materials meet this high flash ignition temperature requirement.

B. The maximum allowable surface temperature in the mine is 150°C (section 18.23 of Title 30 of the Code of Federal Regulations).

4.3.7 Justification for the Selection of the 25-Foot Tunnel Test, Test Conditions, and Acceptance Criteria

Selection of Test and Test Conditions

Technical Aspects

A. The 25-foot tunnel test simulates fire spread in a horizontal rectangular tunnel and is, therefore, applicable to underground coal mine conditions. Materials in both the tunnel test and the underground coal mine are exposed to heat sources under dynamic air flow conditions with reradiation from the enclosing surfaces.

B. The 25-foot tunnel test simulates fire spread along the ceiling, which represents more severe conditions than fire spread along a wall or along a floor, thus providing the largest safety factor.

C. The 25-foot tunnel test is the only test that is capable of evaluating fire spread over distances exceeding eight feet and has achieved a significant amount of technical acceptance.

D. The 25-foot tunnel test is most relevant to long-dimension noise control products used in underground coal mines.

E. The 25-foot tunnel test is more appropriate to the underground coal mine environment than is the compartment test or the corner-wall test. Both of the latter tests introduce the effects of geometry and dimensions not generally found in underground coal mines.

F. A heat flux of 87.9 kW in a rectangular tunnel measuring 18 by 12 inches is generally accepted to represent a severe exposure. It also approximates heat flux generated by a fully developed coal fire.

G. An air flow rate of 73.2 meters per minute is on the same order of magnitude as the ventilation in underground mines.

Practical Aspects

A. Although the 25-foot tunnel is too costly for most laboratories to install, maintain, and operate in-house, several laboratories in the United States perform tunnel tests under contract.

B. The 25-foot tunnel test is perhaps the most widely recognized and accepted test for noise control products used in building construction.

C. There is effectively no other choice of heat flux or air flow rate. For at least the last 20 years almost all tunnel tests have been performed with these specified conditions. There is almost no experience available for other heat flux levels or air flow rates.

Acceptance Criteria

Technical Aspects

A. A flame spread classification not exceeding 25 indicates that flame spread did not extend farther than 10.5 feet from the end of the specimen (9.5 feet from the fire source) and that flame spread was approximately one-fourth that expected for red oak flooring.

B. A smoke developed classification not exceeding 50 indicates that the effective product of smoke density and time is no more than one-half that for red oak flooring.

Practical Aspects

Many noise control materials intended for use in building construction and interior furnishings meet these severe criteria.

4.4 References

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Section 5

PROPOSED FIRE HAZARD CRITERIA FOR ACCEPTANCE OF NOISE CONTROL PRODUCTS FOR USE IN UNDERGROUND COAL MINES

5.1 Introduction

Section 4 introduced and discussed the philosophies employed as they relate to program objectives. The MSHA interim criteria were appraised as to their applicability to end-use noise control products. In addition, the guidelines for new criteria were set forth, including the rationale for selection of tests and justification of relevant aspects of each test. The salient features of the guidelines criteria have been extracted and framed within the context of a proposed formal criteria document. The content of the proposed document is presented in this section of the report.

5.2 Product Identification

All descriptive literature, vendor data, information restricting or limiting the noise control product, warranty data, brochures advertising or promoting the products's usage, and descriptive information relative to the product's installation and maintenance in the end-use location should be included for review.

5.3 Product Formulation and End-Use Design

The end-use product consists of all elements of the unit as it would be marketed. The product should be identified by its structural composition and physical makeup in its proposed end-use application. If metallic facing on one or more sides is a feature of the end-use product, this should be so stated. A product protected on one side by a metal facing material and attached on the other side to a metallic structural element of considerable mass should be tested in a condition that simulates the installed configuration when specified. Flammable materials contained in the end-use product should be identified by their chemical composition and trade names. Any fire retardants or toxic ingredients, along with their respective percentages and tolerances, should also be identified by chemical composition.

5.4 Laboratory Tests

Flammability tests should have been performed by a certified testing laboratory. Sufficient records of test results, including number of samples and size of samples tested, should be included as part of the documentation for acceptance. All relevant information submitted with the applicant's petition for acceptability should have been reviewed and countersigned by a registered professional engineer or by a person who has the authority to legally commit the petitioning organization.

5.5 Identification of Fire Tests

The potential fire hazard of an end-use noise control product should be determined by one or more of the following fire tests:

	Test Type	Designation
1.	Vertical Flame Test	Federal Test Method Standard No. 191 (Modified for Noise Control Products)
2.	Ignition Temperature Test	American Standard Test Method D 1929-68
3.	25-Foot Tunnel Test	25-Foot Tunnel Test (Unmodified)

5.6 Tests Selection

A test selection matrix, which appears as figure 31, shows possible configurations for an end-use noise control application. The product to be tested must conform to one of these configurations. Once the appropriate product configuration combination has been determined, the required tests are identified by the black dots in the test selection matrix. The testing sequence is arranged in order of increasing test complexity and expense.

As indicated in the test selection matrix, there are a number of end-use product configurations that have been designated for Vertical Flame Tests only. This is because the particular configuration's extremely low hazard potential does not justify further testing from an engineering or economic standpoint.

SPECIFICATION CONDITIONS		CONDITION CONFIGURATION					
		1	2	3	4	5	6
EXPOSURE	Product is attached, both faces, to metal greater than 1/32 inch	●	●				
	Product is attached, one face, to metal greater than 1/32 inch			●	●		
	Product is not attached on any face to metal greater than 1/32 inch					●	●
	Longest dimension is less than 12 feet	●		●		●	
	Longest dimension is greater than 12 feet		●		●		●

REQUIRED TESTING						
Vertical Flame Test (Appendix E)	●	●	●	●	●	●
Ignition Temperature Test (Appendix F)	●	●	●	●	●	●
25-Foot Tunnel Test (Appendix G)				●		●

Figure 31. Test Selection Matrix

5.7 Acceptance Criteria

The individual acceptance criteria for each of the three formal tests are provided herein. These are pass or fail criteria. An end-use noise control product will be deemed acceptable for use in underground coal mines upon successfully completing required testing.

5.7.1 Vertical Flame Test

Affected noise control products: See test selection matrix.

Test procedure: See Vertical Flame Test (Federal Test Method Standard No. 191) procedure in appendix E.

Acceptance criteria:

1. Burning extent should not exceed six inches.
2. Afterflame should not exceed two seconds.
3. Afterglow should not exceed five seconds.

5.7.2 Ignition Temperature Test

Affected noise control products: All nonmetallic materials that make up the end-use configuration.

Test procedure: See Ignition Temperature Test (ASTM D 1929-68) procedure in appendix F.

Acceptance criteria: Minimum flash ignition temperature should exceed 300°C.

5.7.3 25-Foot Tunnel Test

Affected noise control products: See test selection matrix.

Test procedure: See 25-Foot Tunnel Test procedure in appendix G.

Acceptance criteria:

1. Flame spread classification should not exceed 25.
2. Smoke developed classification should not exceed 50.

Section 6

TEST PROGRAM

6.1 Introduction

A test program was conducted to determine how a representative group of noise control products would fair in relation to the proposed fire hazard criteria. Twenty materials were tested in up to six different configurations. The configurations were selected to provide comparative data on the effect of the important parameters identified by the criteria. A full summary of the test materials, configurations, and data is given in section 6.2. In addition to the tests in the proposed criteria, the Ohio State University Rate of Heat Release Test (OSU) was conducted with seven of the materials in up to five configurations to further examine the impact of material thickness and exposure on the short-term combustion characteristics of a material. Analysis of the test results follows in section 6.3.

6.2 Test Results

The following configurations (products) were tested, each with the materials indicated: The results are given in tables 8 through 11.

1. Constrained layer configuration: 1/4-inch steel plate/1/4-inch elastomer/1/4-inch steel plate; elastomer materials: 1, 2, 3, 4, 5*.
2. Constrained layer configuration: 1/4-inch steel plate/1-1/2-inch elastomer/1/4-inch steel plate; elastomer materials: 1, 2, 3, 4, 5*.
3. Free layer configuration: 1/4-inch steel plate/1/4-inch elastomer; elastomer materials: 1, 2, 3, 4, 6*.
4. Free layer configuration: 1/4-inch steel plate/1-1/2-inch elastomer; elastomer materials: 1, 2, 3, 4, 6*.
5. Constrained layer configuration: 15 mil aluminum foil/1/4-inch elastomer/15-mil aluminum foil; elastomer materials: 2*.
6. Material only: 1/4- to 1/2-inch thick material tested without any backing; materials: 1-20*.

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*Material Number	Material Brand Name	Use	Vendor
1.	EAR-C-1002	Damping	EAR Corp., Zionsville, Mo.
2.	EAR-C-2003	Damping	EAR Corp., Zionsville, Mo.
3.	Kennedy Company vinyl	Damping	Kennedy Co., Scottsboro, Ala.
4.	SBR	Damping, isolation	P. I. Mine Service Beckley, W. Va.
5.	ISD-112	Damping	3M Corp., St. Paul, Minn.
6.	Stahlgruber rubber, type A	Damping, isolation	Stahlgruber, West Germany
7.	Stahlgruber rubber, type B	Damping, isolation	Stahlgruber, West Germany
8.	EAR cab liner	Absorption, barrier	EAR Corp., Zionsville, Mo.
9.	EAR cab mat	Absorption, barrier	EAR Corp., Zionsville, Mo.
10.	Hushcloth	Absorption	American Acoustical Products Natick, Mass.
11.	KAC-100	Barrier	Consolidated, Kinetic Corp. Columbus, Ohio
12.	Huych felt	Absorption	BTR Paper Group Reasselaer, N.Y.
13.	Flexane	Isolation	Devcon Co., Manvers, Mass.
14.	Cabfoam	Absorption	Soundcoat Co., Brooklyn, N. Y.
15.	Soundmat-PB/Metal	Absorption, barrier	Soundcoat Co., Brooklyn, N. Y.
16.	Soundmat-LF, 3/4-inch	Absorption, barrier	Soundcoat Co., Brooklyn, N. Y.
17.	GP-2	Damping	Soundcoat Co., Brooklyn, N. Y.
18.	Soundfoam/vinyl	Absorption, barrier	Soundcoat Co., Brooklyn, N. Y.
19.	Soundfluff	Absorption	Soundcoat Co., Brooklyn, N. Y.
20.	Neoprene rubber	Isolation	Goodyear Co., Akron, Ohio

TABLE 8. Vertical Flame Tests

Configuration/ Material	After Flame (Sec)	After Glow (Sec)	Char Length (cm)	Dripping (Yes/No)
Criteria	1	5	15	No
1/1	0	0	N/A	No
1/2	0	0	N/A	No
1/3	0	0	N/A	No
1/4	0	0	N/A	Yes
1/5	59	0	N/A	No
2/1	1	0	N/A	No
2/2	0	0	N/A	No
2/3	0	0	N/A	Yes
2/4	0	0	N/A	No
2/5	1.4	0	N/A	No
3/1	0	0	2.9	No
3/2	0	0	0.5	No
3/3	0	0	3.4	No
3/4	0	7	2.2	No
3/6	46	6	3.0	No
4/1	0	0	0.8	No
4/2	0	0	0.6	No
4/3	0	0	1.2	No
4/4	0	0	0.4	No
4/7	300+	N/A	30.5	No
5/2	NT	NT	NT	NT
6/1	7.4	0	5.7	No
6/2	1.4	0	4.9	No
6/3	0	0	23	No.
6/4	0	458	3.6	No
6/5	114	0	18.9	Yes
6/6	300+	N/A	30.5	Yes
6/7	600+	N/A	30.5	Yes
6/8	7.0	0	13.5	No
6/9	0.8	0	14.3	No
6/10	0	0	0.5	No
6/11	0	1.8	17.0	No
6/12	0	1.0	1.5	No
6/13	0	0	3.5	Yes
6/14	0	0	17.0	No
6/15	0	12.8	12.6	No
6/16	0	0	12.4	No
6/17	16	0	12.4	Yes
6/18	77	0	30.5	No
6/19	0	0	14.1	No
6/20	99	0	7	No

NT = Not Tested
NA = Not Applicable

TABLE 9. Ignition Temperature Tests

Configuration/ Material	Minimum Flash Ignition Temperature (degrees C)
Criteria	300
1/1-5/2	NT
6/1	320
6/2	340
6/3	380
6/4	330
6/5	350
6/6	330
6/7	330
6/8	370
6/9	350
6/10	750+
6/11	350
6/12	490
6/13	340
6/14	360
6/15	380
6/16	425
6/17	440
6/18	340
6/19	430
6/20	340

NT - Not tested

TABLE 10. Twenty-Five-Foot Tunnel Test

Configuration/ Material	Flame Spread Index	Heat Release Index	Smoke Release Index
Criteria	25	50	50
6/1	50	NA	1390
6/2	45	NA	1195
6/8	30	NA	1709
6/10	175	NA	720

NA - Not Available.

TABLE 11. OSU Rate of Heat Release

Configuration/ Material	A*	B	C	D	E	F	G	H
Standard	NS	NS	18.0	NS	80.0	NS	28.0	114.0
1/1	422	600	4.6	-123	44.2	57.5	-38.7	0.0
1/2	NI	NI	0.0	-137.4	8.0	3.3	-43.8	1.4
1/3	NI	NI	-9.8	-139.0	0.0	0.0	-38.7	0.0
1/4	NI	NI	-7.6	-119.5	0.0	0.0	-39.3	0.0
1/6	572	600	5.3	-130.6	39.1	22.7	-45.6	0.0
2/1	460	551	1.2	-137.0	65.5	58.6	-40.8	3.6
2/2	NI	NI	0.0	-150.2	8.0	4.0	-40.3	0.8
2/3	NI	NI	0.0	-137.8	19.8	9.3	-42.4	1.0
2/4	NI	NI	0.0	-137.5	8.0	4.8	-39.9	2.4
2/5	NI	NI	0.0	-148.0	8.0	12.8	-43.5	10.2
3/1	3	50.5	169.0	1113.0	407.0	2077.0	283.6	684.3
3/2	3	271	83.0	606.0	120.0	618.0	101.2	114.4
3/3	3	187	88.0	667.0	592.0	3258.0	133.1	1028.2
3/4	4	174	72.0	479.0	224.0	1027.0	62.15	205.1
3/6	6	62	414.0	1951.0	675.7	1748.3	360.7	416.7
4/1	8	104	132.3	1047.0	367.7	2122.0	182.6	436.7
4/2	5	113	75.5	543.0	135.0	631.0	85.3	126.4
4/3	3	115	81.0	640.0	618.0	3754.0	120.5	1128.4
4/4	2.5	198	57.3	382.5	138.6	612.2	44.8	107.7
4/7	2	37	409.0	3136.0	328.0	2175.0	656.6	596.4
5/2	400	NR	1.1	-30.0	44.1	192.7	-14.5	13.1
6/1 to 6/20 not tested								

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* A = Time to ignition (sec)

B = Total involvement (sec)

C = Heat release rate (kW/m^2)

D = Total heat release ($kW\text{-}min/m^2$)

E = Smoke release rate ($SMOKE/m^2\text{-}min$) maximum

F = Total smoke release ($SMOKE/m^2$)

G = Heat release in 3 minutes (kW/m^2)

H = Smoke release in 3 minutes ($SMOKE/m^2$)

NS = No standard
NI = No ignition
NT = Not tested
NR = Not reached

See appendix J for test procedure.

6.3 Analysis of the Test Results

Material exposure and longest dimension are the only configuration parameters that affect the proposed fire hazard test battery for a given product (see section 5). All products must pass the Vertical Flame Test (VFT) in their end-use configuration. The product's nonmetallic material must meet the Ignition Temperature Test (ITT) criteria. Products with longest dimensions greater than 12 feet must satisfy the 25-foot tunnel test criteria unless the material is covered on two faces by at least 1/32-inch-thick metal. The test program clearly demonstrated the strong effect configuration can have on a material's fire response characteristics. Note, for example, how EAR C1002 (1/4-inch thick) fails the VFT criteria if it is not attached to metal on at least one face. EAR C2003 and other materials exhibited the same sort of behavior.

Material thickness in the range 1/4-inch to 1-1/2-inch does not seem to significantly impact the VFT results, although it is still retained as an implicit aspect of configuration. In the OSU tests, the heat and smoke release from the 1/4-inch-thick material over the 10-minute test period was approximately equal to that of the 1-1/2-inch-thick material. Evidently, thickness in this range and severity of heat application primarily affects fuel loading and not the short-term burning characteristics.

Forty products consisting of various combinations of 20 materials and 6 configurations were subjected to the proposed fire hazard test battery. About 40 percent of these products failed to meet the proposed criteria. The testing laboratory had no difficulty in performing the required tests. Estimated test cost for a single product with longest dimensions less than 12 feet is $300. Products with dimensions greater than 12 feet would also require the six-hundred dollar 25-foot tunnel test. These costs are well within the range of any interested noise control material manufacturer or vendor.

In summary, the test program has shown that the proposed fire hazard criteria adequately satisfies the two secondary goals of the program, which read, (1) Allow maximum use of noise control products, and (2) take into account that the sales volume of most acoustical materials to the mining industry will not be sufficiently large for them to justify an extensive flammability testing program that would qualify their materials only for in-mine use.

Section 7

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The literature search was both automated and manual. Using key words and subject lists, an automated initial search was conducted at the Redstone Scientific Information Center (RSIC) at Redstone Arsenal, Alabama. Applicable flammability and fire hazards literature was selected during the preliminary search phase. This initial set of material was reviewed for relevance within the scope of the program objectives and was further reduced to publications having the highest perceived value. The final review produced this bibliography.

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APPENDIX A

TESTS FOR SMOKE EVOLUTION

NBS Test Method [1, pp. 105-106, or 2]

The National Bureau of Standards smoke test apparatus consists of a chamber three feet high, three feet wide, and two feet deep. A glass door is located on the right-hand side of the front, and an exhaust system is located near the top and to the rear on the left side of the chamber. The test specimen holder is made of stainless steel and measures three inches by three inches. An asbestos board is used as a backing for samples, and a spring-clip is used to hold the samples. To prevent smoke from leaking through the back of the holder, all samples are wrapped in foil, leaving the front surface open. A 500-watt electric heater is used to supply radiant heat and is mounted horizontally, approximately 1½ inches from the face of the sample. The heater is adjusted to yield a flux of 2½ W/cm^2. A small, rotatable gas jet is used to ignite samples for tests requiring flaming conditions. A vertical light beam and a photocell are used to measure the degree of obscuration. The light source is adjusted to 100 percent transmission, and the test is continued until the light transmission reaches a minimum and reverses itself.

The results from the NBS chamber tests are reported in terms of specific optical density (D_s), obscuration time (T_{16}), smoke obscuration index (SOI) and are calculated using

$$D_s = V/AL \log_{10} (100/T).$$

$$\mathrm{SOI} = \frac{D_m^{\,2}}{20 \times 100 \times T_{16}} \left(\frac{1}{t_{90}-t_{70}} + \frac{1}{t_{70}-t_{50}} + \frac{1}{t_{50}-t_{30}} + \frac{1}{t_{30}-t_{10}} \right),$$

T = percent light transmission at any time (t),

D = optical density = $\log_{10}(100/T)$,

V = chamber volume,

A = sample face area,

L = light path through the smoke,

D_s = specific optical density,

D_m = maximum specific optical density (D_s),
T_{16} = time for smoke to reach a critical density (16 percent),
t_{90}, t_{70}, etc = time for D_s to reach 90 percent, 70 percent, etc., of D_m.

The obscuration time is a measure of the time available before a person in a room would find his vision obscured by smoke sufficiently to hinder escape. The value of specific optical density assigned to be critical is 16. This value is arbitrary and is based on 16 percent light transmission over a 10-foot viewing distance in a room measuring 12½ feet by 20 feet by 8 feet in which 10 square feet of the sample was exposed. Using the NBS chamber, specimen size can be varied only in terms of thickness due to the constant size of the specimen holder.

ASTM D 2843-70 [1, p. 106, or 3]

The ASTM D 2843-70 test utilizes a Rohm and Haas XP2 smoke chamber. This apparatus consists of an aluminum box measuring 12x12x31 inches, with a heat-resistant glass door. The chamber is completely enclosed except for one-inch-high ventilation openings at the bottom of the cabinet. The heat source is a propane-air flame and is applied at a 45° angle to the bottom of the horizontally mounted sample.

The photometric system used includes a light source, a photoelectric cell, and a temperature-compensated meter. The light source and photocell are mounted 20 inches above the bottom of the chamber and measure the light absorption across the width of the chamber. The current produced by the photocell is indicated in terms of percent light absorption on a meter. The photocell linearity decreases as the temperature increases, so the meter must compensate for this nonlinearity.

Specimen size can be varied considerably. Itcan range from 1x1x1/4 inch to 2x2x2 inches. This test is not as versatile as the NBS test since flaming and nonflaming conditions cannot be differentiated, and the degree of ventilation is fixed. Two disadvantages of this test method are result variations caused by smoke stratification and the inability to separate the effects of specimen thickness and surface area.

ASTM E 162-73 [1, p. 107, or 4]

This test is primarily used as a measure of surface flammability. A radiant heat source is mounted in front of an inclined sample measuring 6x18 inches. Ignition of the material is made at its upper edge and the flame front progresses downward.

A flame spread index is derived from the rate of progress of the flame front and from the rate of heat release. Provision is also made for measurement of the smoke evolved during the test by collecting the smoke evolved on a piece of glass fiber filter paper using an air pump and a sampling device. The amount of smoke evolved is not presently being used in calculating the flame spread index.

ASTM E 84-70 [1, p. 107, or 5]

Like the ASTM E 162 test, this test is primarily used as a measure of surface flammability; however, smoke density and fuel contributed are recorded in this test. The smoke density is measured using a light source and photoelectric cell placed vertically across the 16-inch-diameter vent pipe. The photoelectric cell is connected to a recording device, which records changes in attenuation of incident light. The products of combustion may also be drawn from the vent pipe during the test and analyzed to determine the degree of toxicity, although this is not presently required as part of this test method.

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APPENDIX B

METHODS OF MEASURING FLAME SPREAD

ASTM E 162-73 [1]

The ASTM E 162-73 radiant panel test uses a vertically mounted, porous refactory panel to heat a 6-inch by 18-inch specimen. The specimen is inclined (lengthwise) 60 degrees from horizontal. A small pilot burner is used to ignite the top of the specimen, which is placed 4-3/4 inches away from the radiant panel. The flame front progresses downward along the bottom side of the specimen, which is also exposed to the radiant panel. Thermocouples are used to monitor the temperature rise in the exhaust stack, and a filter paper sampling device is used to monitor the amount of smoke evolved. Once the specimen is ignited, the time is recorded as the flame front reaches successive 3-inch intervals, until the flame reaches the 15-inch mark. A flame spread index (I_s) is calculated as the product of a flame spread factor (F_s) and a heat evolution factor (Q):

$$I_s = F_s Q,$$

where

$$F_s = 1 + \frac{1}{t_3} + \frac{1}{t_6 - t_3} + \frac{1}{t_9 - t_6} + \frac{1}{t_{12} - t_9} + \frac{1}{t_{15} - t_{12}} \quad \text{, and}$$

$t_3 \ldots t_{15}$ is the time in minutes to the arrival of the flame front at each 3-inch interval,

and $Q = 0.1\ T/\beta$,

0.1 = arbitrary constant,

T = maximum stack temperature,

β = equipment constant.

The test is completed after exposure to the pilot burner and radiant panel for 15 minutes or until the flame reaches the 15-inch mark, whichever is first. The values reported for flame spread indices are an average of four determinations.

ASTM D 2863-74 [2]

This test is used to measure the relative flammability of plastics by measuring the minimum concentration of oxygen that will just support combustion. This minimum concentration of oxygen, expressed as volume percent, is referred to as the oxygen index of the material.

To be truly reproducible, a flammability test procedure must pick a variable to measure that is least affected by other variables, such as temperature, and operator-related factors. The reproducibility of flame tests depends upon control of several parameters: flame temperature, distance from the burner to the specimen, drafts, heat content of the ignitor fuel, and metering of fuel flow. The oxygen index method is designed to eliminate as many of these variables as possible by burning the sample being tested at an equilibrium temperature and rate dependent solely upon the burning characteristics of the material and the concentration of oxygen in the surrounding atmosphere. The variable to be measured, the burning characteristics of the specimen, is related directly to the concentration of oxygen in the surrounding atmosphere. By controlling and precisely measuring the minimum atmospheric concentration of oxygen necessary for combustion of the sample, the relative flammability of a material can be determined.

The minimum concentration of oxygen that will just support combustion is measured under equilibrium conditions of candle-like burning. An equilibrium is established based on the heat of combustion of the specimen and the heat lost to the surroundings. The critical oxygen concentration is approached from both sides in order to establish the oxygen index.

The test apparatus consists of a 75-mm-diameter (minimum) by 450-mm highly heat-resistant glass tube, a specimen holder, a gas supply, a flow measurement control device, an ignition source, and a timer. The bottom of the glass tube contains noncombustible material to mix and evenly distribute the gas mixture entering at the base. The specimen holder can be any small holding device that will support the material at its base and hold it vertically in the center of the column. The gas supply should be commercial grade oxygen and nitrogen. Flow measurement control devices accurate to within one percent should be used in each line to monitor the volumetric flow of each gas. The igniter should be a tube with propane or natural gas flame that can be inserted into the open end of the column to ignite the test specimen. A 10-minute timer accurate to within 5 seconds should be used.

An initial concentration of oxygen is selected, the top of the specimen is ignited, the external flame is removed, and the timer is started. If the specimen burns 3 minutes or longer, to 50 mm, the concentration of oxygen is too high. The oxygen concentration is reduced, and a new sample is tested. This procedure is continued until the limiting oxygen concentration is reached.

The oxygen index, N, of the material is calculated as follows:

$$N, \text{percent} = (100 \text{x} O_2)/(O_2+N_2),$$

where

O_2 = volumetric flow of oxygen in cm^3/sec at the limiting oxygen concentration,

N_2 = corresponding volumetric flow rate of nitrogen in cm^2/sec.

It should be noted that the temperature and method of igniting the sample have virtually no effect on the outcome of the test. The only requirements for ignition of the sample is that it be thoroughly lighted over its entire end.

Differences in thicknesses have an influence on the outcome of the testing, so all materials tested must have the same geometry. The standard sample size is 7 to 15 cm long by 0.64 cm wide by 0.32 cm thick.

ASTM E 84-70 [3]

The ASTM E 84 25-foot tunnel test is perhaps the most widely accepted test for surface flame spread. Sample size is 25 feet long by 20 inches wide. The sample is mounted face down and forms the roof of a 25-foot tunnel, which is 17-1/2 inches wide and 12 inches high. This test method is applicable to any type of material that is capable of supporting itself in position on the test furnace in a thickness comparable to its recommended use.

Fuel contributed and smoke density as well as flame spread rates are recorded in the test. The surface burning characteristics of different materials may be compared, but specific considerations of all the end-use parameters that might affect the surface burning characteristics are not considered. The ignition sources are two gas burners located one foot from the end of the tunnel and positioned 7-1/2 inches below the test specimen.

Flame spread classification is determined by a scale in which asbestos-cement board is zero and select-grade red-oak flooring is 100. Fuel contribution is measured by thermocouple readings, and the results are compared to red oak and asbestos-cement board. Smoke evolution is measured by a photoelectric cell, and the results are compared to red oak and asbestos-cement board.

ASTM E 286-69 [4]

This test covers a procedure for measuring surface flame spread of materials that are capable of being mounted and supported within a 14-inch by 8-foot test tunnel. Provision for measuring heat produced and smoke density are included.

The test frame consists essentially of a gas-heated furnace approximately 10-1/2 feet long with a separate combustion chamber, firebox (which extends the entire length of the furnace), hood, and stack. A 12-gage stainless steel partition is located between the firebox and the combustion chamber. The temperature rise is measured by two thermocouples mounted in the stack and connected in parallel to a potentiometer. Smoke density is determined by using a photoelectric smoke meter, which indicates the reduction in the intensity of a column of light passing horizontally through the stack to a photoelectric cell.

The main burner is located at the front end of the firebox and two inches below the bottom surface of the steel partition. The igniting burner is located 1/2 inch below and parallel to the face of the test specimen and one inch from the lower side of the specimen.

A flame spread index (I_s) is calculated based on red oak (100) and asbestos-cement board (0). For flame spread faster than on red oak,

$$I_s = \frac{T_o}{T_s} \times 100,$$

where

T_o = time to reach end of red oak sample,

T_s = time to reach end of test specimen.

For flame spread slower than on red oak,

$$I_s = \frac{D_s}{D_o} \times 100,$$

where

D_s = distance, in inches, reached on test specimen in test period;

D_o = distance, in inches, reached on red oak in test period.

Similar calculations exist for calculating fuel contributions and smoke density indices.

ASTM D 635-74 [5]

The ASTM D 635 test is one of the most widely used small-scale tests for plastic materials. This test requires a sample 5 inches by 1/2 inch by the supplied thickness at a 45^{o} angle. One end of the sample is contacted for 30-second periods using a 3/8-inch bunsen burner.

ASTM D 1962-74 [6]

This test is widely used as a small-scale test for cellular plastics. Samples tested measure 6 inches by 2 inches by 1/2-inch thick. The sample is mounted horizontally, and one end is contacted for 60 seconds using a bunsen burner. The test chamber measures 300 mm by 600 mm by 760 mm high and has ventilation openings near the bottom of the chamber.

ASTM D 1230-72 [7]

This test for fabrics employs a chamber measuring 14-1/2 inches by 8-1/2 inches by 14 inches high. Test samples measure 2x6 inches and are mounted at a 45° angle. The ignition source is a 5/8-inch flame from a 26-gage hypodermic needle applied for one second.

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APPENDIX C

METHODS OF MEASURING EASE OF IGNITION

ASTM D 1929-68 [1]

The ASTM D 1929 test for ignition properties uses a vertical furnace tube approximately 10 inches long and 4 inches in diameter, heated by electrical current passing through nichrome wire in an asbestos sleeve wound around the tube. A three-inch-diameter inner refractory tube is placed inside the first tube, and the specimen being tested is placed inside this second tube. Air flow is controlled and the temperature of the air is monitored by means of thermocouples. In this test, a three-gram sample is exposed to air at successively higher temperatures until ignition occurs. Self-ignition temperatures are defined as the lowest temperature of air passing around the sample at which, in the absence of an ignition source, the self-heating properties of the sample lead to ignition, explosion, flame, or sustained glow. This test is often referred to as the Setchkin test.

ASTM E 136-72 [2]

This test method uses the same heating element as the Setchkin test. A sample 2 inches long, 1-1/2 inches wide, and 1-1/2 inches thick is heated in a stream of air at 750°C, moving at 10 ft/min. A material is considered noncombustible by this test if specimen temperatures do not increase more than 30°C and there is no flaming after the first 30 seconds.

ASTM D 2863-74 [3]

ASTM D 2863 is also known as the oxygen index test. This test has already been discussed in some detail in appendix B. To recall the nature of the results obtained by using this test, the following definition is sufficient: The limiting oxygen index is the minimum concentration of oxygen in an oxygen-nitrogen mixture that will just permit the sample being tested to burn 3 minutes or 50 mm.

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APPENDIX D

TESTS FOR HEAT RELEASE

Factory Mutual Calorimeter Test [1]

The Factory Mutual Calorimeter Test employs a specimen measuring 4-1/2 feet by 5 feet. Approximately a 4-foot-square area of the sample is exposed and forms the roof of a furnace 17-1/2 feet long, 4 feet wide, and 3-3/4 feet high. Gasoline is used in the main burners, and propane is used as an evaluating fuel. After the specimen is burned using the main burners, a noncombustible cover is inserted and the evaluation burners are adjusted to reproduce the fuel temperature-time curve produced by burning the specimen. The heat added through the evaluation burners is considered to be equal to the heat released by the sample.

National Bureau of Standards [2]

The National Bureau of Standards heat release rate calorimeter uses a combustion chamber lined on three sides with gas-fired radiant panels. The temperature of the panels is varied between 900 and 1300°K. The sample size is 4-1/2 by 6 inches and up to one inch thick. The sample is mounted vertically in the center of the combustion chamber, with only the front surface exposed to the radiant panels. The edges of the samples are shielded by the sample holder, which is insulated. The back surface of the sample is cooled by a water-cooled brass block, which is positioned close to but not touching the sample. Air for combustion passes through a porous plate in the bottom of the combustion chamber.

The combustion chamber is open at the top and allows the hot combustion gases to pass freely into the control chamber above it. The control chamber contains an auxiliary burner to ensure that the average temperature of the gases passing upward remains constant. The heat produced by the burning specimen is reduced by the amount of heat produced by the burner.

Above the auxiliary burner is the mixing chamber. The mixing chamber contains a system of sheet-metal baffles for mixing the combustion gases and four thermocouples to measure an average temperature.

Ohio State University Heat Release [3]

The Ohio State University heat release rate chamber measures 35 inches by 16 inches by 8 inches deep. The top section is pyramid-shaped and connects to an outlet. The chamber contains an electrically heated ceramic radiant panel. The sample size used measures 10 inches square and is normally mounted 3 inches from the radiant panel but may be mounted as far as 8 inches from the panel. The values of heat release rate are calculated in terms of watts per unit surface area exposed.

The ASTM E 84 25-foot tunnel test and the ASTM E 162 radiant panel test are essentially tests for surface flame spread. In addition, these tests enable the measuring of heat release based on the temperature rise in the combustion gases produced.

Refrences

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2. Parker, W. J., and M. E. Long. Development of a Heat Release Rate Calorimeter at NBS. ASTM Special Technical Publication 502, 1972, pp. 135-151.

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APPENDIX E

VERTICAL FLAME TEST

FLAME RESISTANCE OF NOISE CONTROL PRODUCTS (NCP): VERTICAL

E1.0 Scope

This test method is intended to be used in determining the resistance of NCP to flame and flow propagation and tendency to char. It is designated primarily for cellulosic fabrics treated with a flame retardant, but may be utilized in other applications as specified in applicable procurement documents. In addition to the vertical position of the sample and flame exposure conditions common to tests of this type, the method defines gas composition, burner, cabinet, temperature, and humidity test conditions.

E2.0 Test Specimen

The specimen shall be a rectangle of NCP 2-3/4 inches (7.0 cm) by 12 inches (30.5 cm) by end-use thickness.

E3.0 Number of Determinations

Unless otherwise noted in the material specification, five specimens from each of the warp and filling directions shall be tested from each sample unit.

E4.0 Apparatus

E4.1 Cabinet

A cabinet and accessories that is fabricated in accordance with the requirements specified in figures E1, E2, and E3. Galvanized sheet metal or other suitable metal shall be used. The entire inside back wall of the cabinet shall be painted black to facilitate the viewing of the test specimen and pilot flame.

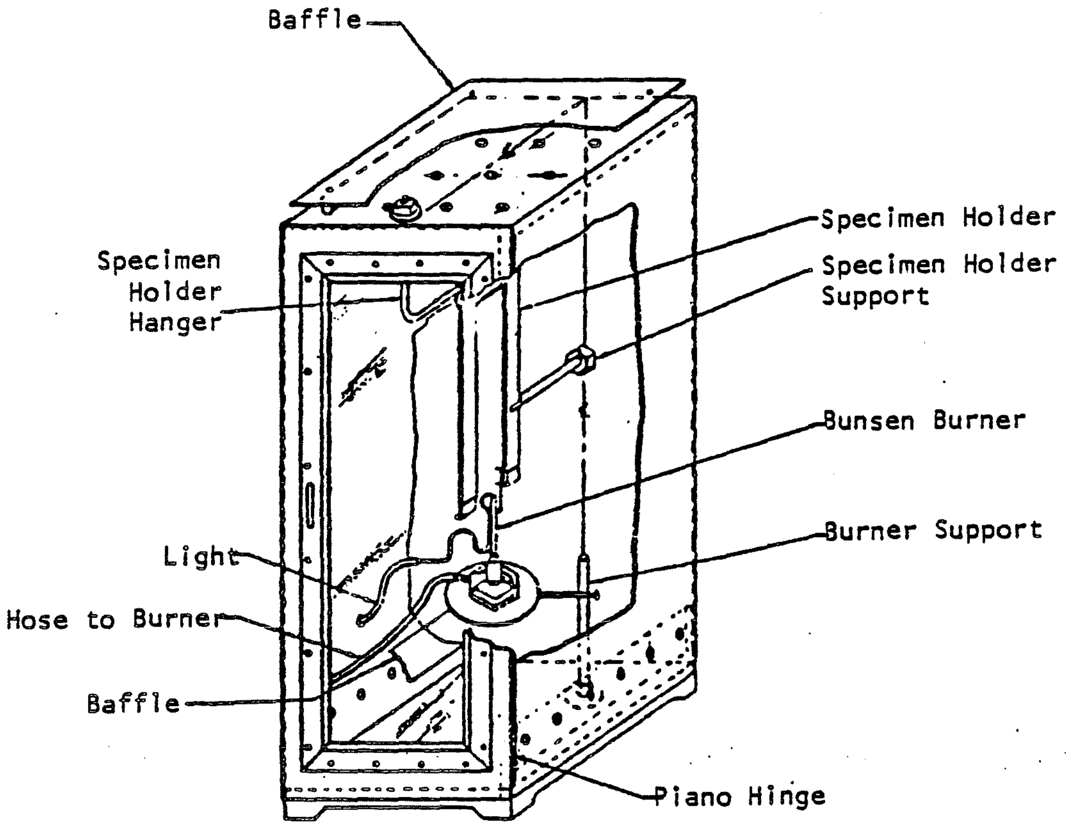
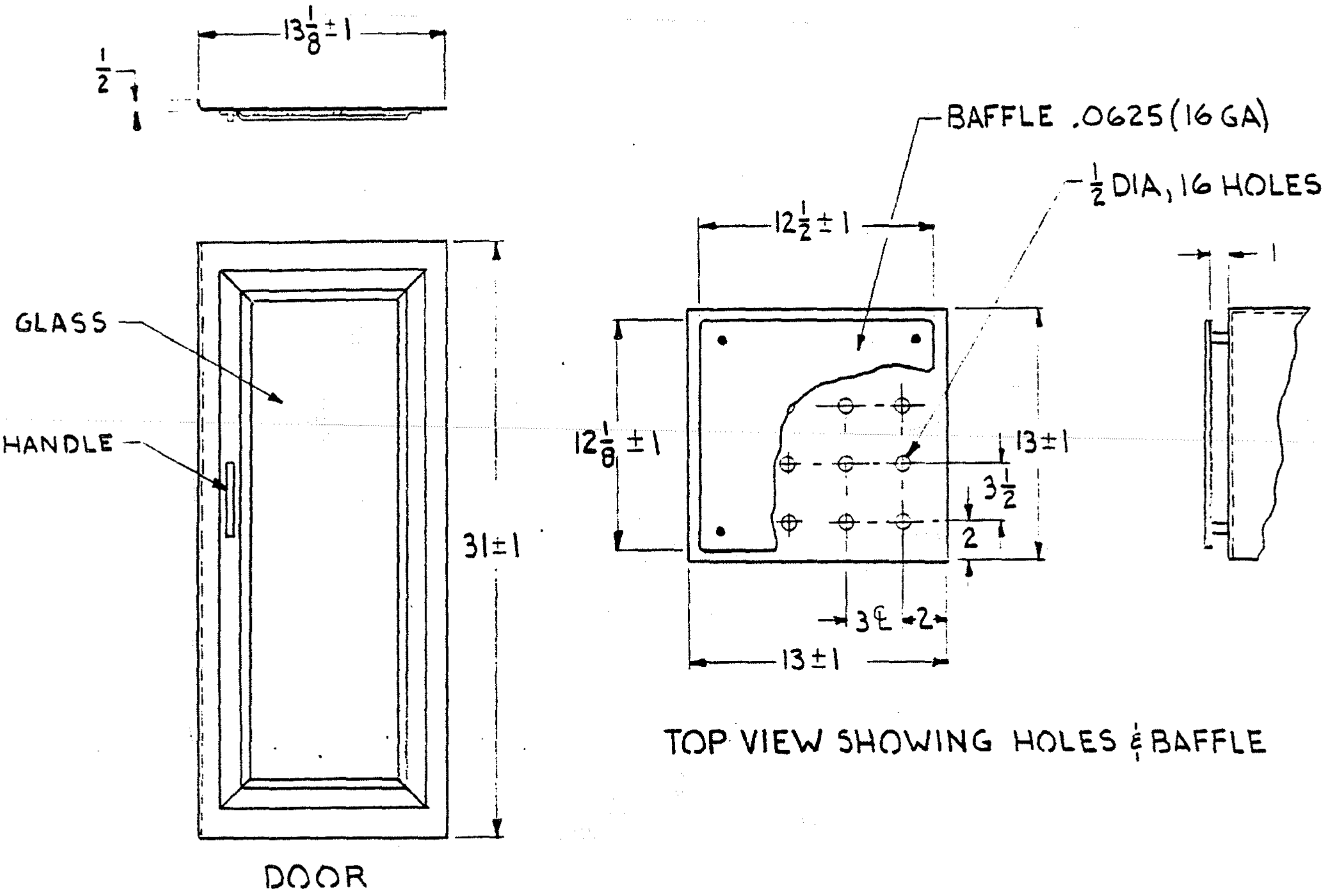


Figure E1. Vertical Flame Apparatus, Perspective



DOOR

TOP VIEW SHOWING HOLES & BAFFLE

Figure E2. Vertical Flame Apparatus, Door and Top View With Baffle

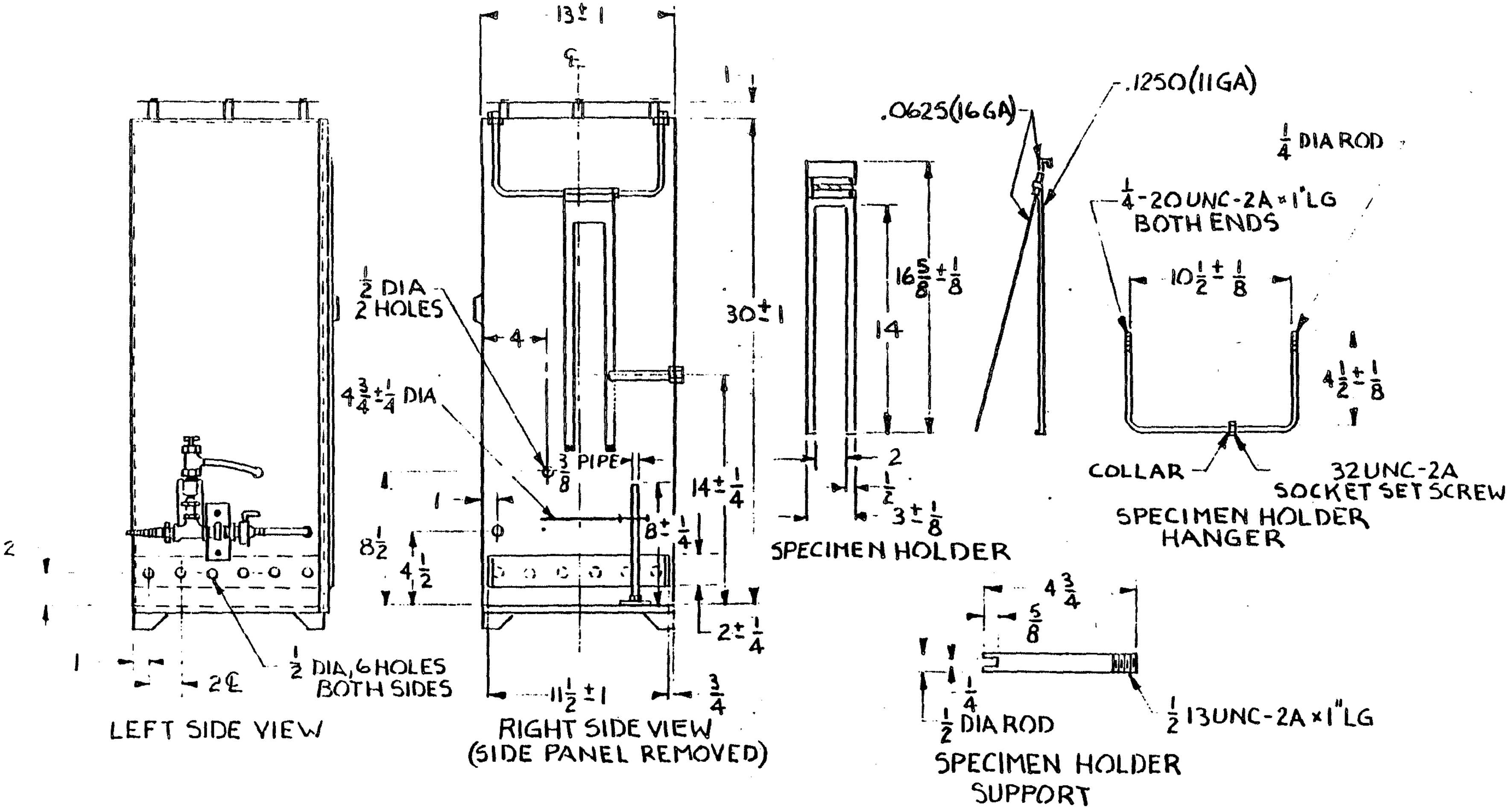


Figure E3. Vertical Flame Apparatus, Views and Details

E4.2 **Burner**

E4.2.1 The burner shall be equipped with a variable orifice to adjust the flame height, a barrel having a 3/8-inch (9.5 mm) inside diameter and a pilot light.

E4.2.2 The burner may be constructed by combining a 3/8-inch (9.5 mm) inside diameter barrel 3 ± 1/4 inches (76.2 ± 6.4 mm) long from a fixed orifice burner with a base from a variable orifice burner.

E4.2.3 The pilot light tube shall have a diameter of approximately 1/16 inch (1.6 mm) and shall be spaced 1/8 inch (3.2 mm) away from the burner edge with a pilot flame 1/8 inch (3.2 mm) long.

E4.2.4 The necessary gas connections and the applicable plumbing shall be as specified in figure E4 except that a solenoid valve may be used in lieu of the stopcock valve to which the burner is attached. The stopcock valve or solenoid valve, whichever is used, shall be capable of being fully opened or fully closed in 0.1 second.

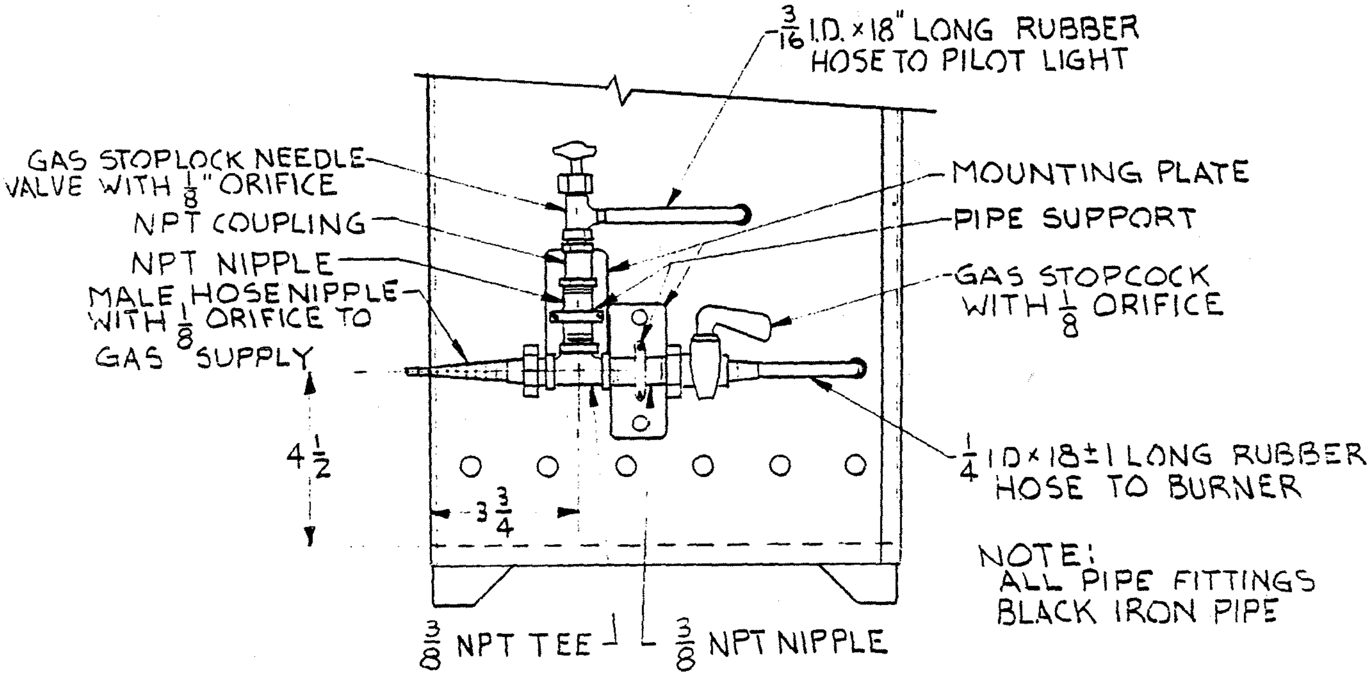


Figure E4. Vertical Flame Apparatus, Side View Showing Gas Hose Connection

E4.2.5 On the side of the barrel of the burner, opposite the pilot light, there shall be a metal rod of approximately 1/8 inch (3.2 mm) diameter spaced 1/2 inch (12.7 mm) from the barrel and extending above the burner. The rod shall have two 5/16-inch (7.9 mm) prongs marking the distances of 3/4 inch (19 mm) and 1-1/2 inches (38.1 mm) above the top of the burner.

E4.2.6 The burner shall be fixed in a position so that the center of the barrel of the burner is directly below the center of the specimen.

E4.3 Control Valve

A control valve system is required with a delivery rate designed to furnish gas to the burner under a pressure of 2-1/2 ± 1/4 pounds (1.1 kg ± 0.1 kg) per square inch at the burner inlet (see E7.1). The manufacturer's recommended delivery rate for the valve system shall include the required pressure.

E4.4 Gas Mixture

A synthetic gas mixture of the following composition within the following limits (analyzed at standard conditions) is required: 55 ± 3 percent hydrogen, 24 ± 1 percent methane, 3 ± 1 percent ethane, and 18 ± 1 percent carbon monoxide, which will give a specific gravity of 0.365 ± 0.018 (air = 1) and a Btu content of 540 ± 20 per cubic foot (dry basis) at 21°C.

E4.5 Specimen Loading

Metal hooks and weights are required to produce a series of total loads to determine length of char. The metal hooks shall consist of No. 19 gauge steel wire or equivalent and shall be made from 3-inch (76.2-mm) lengths of the wire and bent 1/2 inch (12.7 mm) from one end to a 45° hook. One end of the hook shall be fastened around the neck of the weight to be used.

E4.6 Time of Burning

A stopwatch or other device is required to measure the burning time to 0.2 seconds.

E4.7 Length of Char

A scale, graduated in 0.1 inch or 1 mm, must be available to measure the length of char.

E5.0 Procedure

E5.1 The material undergoing test shall be evaluated for the characteristics specified in the applicable procurement document; that is, after-flame time, after-glow time, and char length on each specimen, as applicable.

E5.2 All specimens to be tested shall be at moisture equilibrium under standard atmospheric conditions. Each specimen to be tested shall be exposed to the test flame within 20 seconds after removal from the standard atmospheric conditions.

E5.2.1 In case of dispute, all testing will be conducted under Standard Atmospheric Conditions in accordance with Section 4 of Federal Test Method Standard Number 191 as modified for noise control products.

E5.3 The specimen in its holder shall be suspended vertically in the cabinet in such a manner that the entire length of the specimen is exposed and the lower end is 3/4 inch (19 mm) above the top of the gas burner. The apparatus shall be set up in a draft-free area.

E5.4 Prior to inserting the specimen, the pilot flame shall be adjusted to approximately 1/8 inch (3.2 mm) in height measured from its lowest point to the tip. The burner flame shall be adjusted by means of the needle valve in the base of the burner to give a flame height of 1-1/2 inches (38.1 mm) with the stopcock fully open and the air supply to the burner shut off and taped. The 1-1/2 inch (38.1 mm) flame height is obtained by adjusting the valve so that the uppermost portion (tip) of the flame is level with the tip of the metal prong (see figure E2) specified for adjustment of flame height. It is an important aspect of the evaluation that the flame height be adjusted with the tip of the flame level with the tip of the metal prong. After inserting the specimen, the stopcock shall be fully opened, and the burner flame applied vertically at the middle of the lower edge of the specimen for

12 seconds and the burner turned off. The cabinet door shall remain shut during testing.

E5.5 The after-flame time shall be the time the specimen continues to flame after the burner flame is shut off.

E5.6 The after-glow time shall be the time the specimen continues to glow after it has ceased to flame. If the specimen glows more than 30 seconds, the specimen holder containing the specimen shall be removed from the test cabinet without any unnecessary rate of movement of the specimen (which will fan the glow) and suspended in a draft-free area in the same vertical position as in the test cabinet. When more than one glowing specimen is suspended outside the test apparatus, the specimens shall be spaced at least 6 inches (15.3 cm) apart. The specimens shall not be extinguished even when the after-glow time is not being determined.

E5.7 The after-flame time and after-glow time of the specimen shall be recorded to the nearest 0.2 second.

E6.0 Report

E6.1 The after-flame time, after-glow time, and char length of the sample unit shall be the average of the results obtained from the individual specimens tested. All values obtained from the individual specimens shall be recorded.

E6.2 The after-flame time and after-glow shall be reported to the nearest 0.2 second.

E7.0 Notes

E7.1 The gas mixture described and the regulator valve system, models IL-350 and 70 with hose and fittings connected in series and used in the development of this method may be obtained from Matheson Gas Products, P. O. Box 85, East Rutherford, N. J. 07073.

E7.2 The test cabinet of the type described in this test method may be obtained from U. S. Testing Company, 1941 Park Avenue, Hoboken, N. J. 07030.

APPENDIX F

IGNITION TEMPERATURE TEST*

Designation: D 1929 – 68'

American National Standard K65.111-1971
Approved May 20, 1971
By American National Standards Institute

Standard Method of Test for
IGNITION PROPERTIES OF PLASTICS[1]

This Standard is issued under the fixed designation D 1929; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

' NOTE 1—Editorial changes were made in Fig. 2 in February 1971.

1. Scope

1.1 This method[2] covers a laboratory determination of the self-ignition and flash-ignition temperatures of plastics using a hot-air ignition furnace.

NOTE 1—The values stated in U.S. customary units are to be regarded as the standard.

2. Significance

2.1 Tests made under conditions herein prescribed can be of considerable value in comparing the relative ignition characteristics of different materials. Values obtained represent the lowest ambient air temperature that will cause ignition of the material under the conditions of this test. Test values are expected to rank materials according to ignition susceptibility under actual use conditions.

NOTE 2—Round-robin results from three laboratories indicate an ignition temperature range of 5 to 20 C (9 to 36 F) at the 250 to 350 C (482 to 662 F) level and 20 to 45 C (38 to 81 F) at the 350 to 500 C (662 to 932 F) level.

2.2 This test is not intended to be the sole criterion for fire hazard. In addition to ignition temperatures, fire hazard includes such other factors as burning rate or flame spread, intensity of burning, fuel contribution, products of combustion, and others.

3. Definitions

3.1 *flash-ignition temperature*—the lowest initial temperature of air passing around the specimen at which a sufficient amount of combustible gas is evolved to be ignited by a small external pilot flame.

3.2 *self-ignition temperature*—the lowest initial temperature of air passing around the specimen at which, in the absence of an ignition source, the self-heating properties of the specimen lead to ignition or ignition occurs of itself, as indicated by an explosion, flame, or sustained glow.

3.3 *self-ignition by temporary glow*—In some cases slow decomposition and carbonization of the plastic results only in glow of short duration at various points in the specimen without general ignition actually taking place. This is a special case of self-ignition temperature, defined as "self-ignition by temporary glow."

4. Apparatus

4.1 The apparatus[3] shall be a hot-air ignition furnace as shown in Fig. 1 and shall consist primarily of the following parts:

4.1.1 *Furnace Tube*—A vertical tube with an inside diameter of 100 mm (4 in.) and a length of 210 to 250 mm ($8^1/_2$ to 10 in.), made of a ceramic that will withstand 750 C (1382 F), and with an opening at the bottom fitted with a plug for the removal of accumulated residue.

4.1.2 *Inner Ceramic Tube*—A ceramic tube with inside diameter of 76 mm (3 in.), length

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[1] This method is under the jurisdication of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D-20.30 on Thermal Properties.

Current edition effective Sept. 9, 1968. Originally issued 1962. Replaces D 1929 - 62 T.

[2] The following reference may be of interest in connection with this method:

Setchkin, N. P., "A Method and Apparatus for Determining the Ignition Characteristics of Plastics," *Journal of Research*, Nat. Bureau Standards, Vol 43, No. 6, Dec., 1949, (RP 2052) p. 591.

[3] The apparatus described is commercially available as Model CS-88 from Custom Scientific Instruments, Inc., 13 Wing Drive, Whippany, N. J.

*Reprinted with permission of the American National Standards Institute.

of 210 to 250 mm ($8^1/_2$ to 10 in.), and thickness of about 3.2 mm (0.125 in.); placed inside the furnace tube and positioned 20 mm ($^3/_4$ in.) above the furnace floor on three small spacer blocks. The top shall be covered by a disk of heat-resistant material with a 25.4-mm (1-in.) diameter opening which is used to insert thermocouple leads, for observation, and for passage of smoke and gases. The pilot flame shall be located immediately above the opening.

4.1.3 *Air Source*—An outside air source to admit clean air tangentially near the top of the annular space between the ceramic tubes through a copper tube at a steady and controllable rate. Air shall be heated and circulated in the space between the two tubes and enter the inner furnace tube at the bottom. Air shall be metered by a rotameter or other suitable device; refer to air calibration curves (Fig. 2) for proper furnace air velocities.

4.1.4 *Heating Unit*—An electrical heating unit made of 50 turns of No. 16 B & S wire.[4] The wires, contained within an asbestos sleeve, shall be wound around the furnace tube, and shall be embedded in cement.[5]

4.1.5 *Insulation*, consisting of a layer of asbestos wool approximately 64 mm ($2^1/_2$ in.) thick, and covered by a sheet iron jacket.

4.1.6 *Pilot Flame*, consisting of 1.6-mm ($^1/_{16}$-in.) inside diameter copper tubing attached to a gas supply and placed horizontally 6.4 mm ($^1/_4$ in.) above the top surface of the divided disk. The pilot flame shall be adjusted to 19 mm ($^3/_4$ in.) in length and centered above the opening in the disk.

4.1.7 *Specimen Support and Holder*—A convenient specimen holder, measuring 38 mm ($1^1/_2$ in.) in diameter by 13 mm ($^1/_2$ in.) in depth, is a $^1/_2$-oz metal container of approximately 0.2-mm (5-mil) thick steel.[6] One half of the container shall be used as a specimen holder and shall be held in a ring of 1.6-mm ($^1/_{16}$-in.) stainless steel welding rod. The ring shall be welded to a length of the same type rod extending through the cover of the furnace as shown in Fig. 1. The specimen holder shall be located 180 to 190 mm (7 to $7^1/_2$ in.) down from the top of the furnace.

4.1.8 *Thermocouples*—Chromel-alumel or iron-constantan (0.5-mm or 0.020-in.) thermocouples for temperature measurement. These shall be conveniently connected to a multiple-point recorder and each thermocouple temperature shall be recorded at least every 15 s. Thermocouple No. 1 (T_1) measures the temperature of the specimen. It should be located as near the center of the specimen as possible when the specimen is in place in the furnace. Thermocouple No. 2 (T_2) measures the temperature of the air traveling past the specimen. It shall be located slightly below and to the side of the specimen holder. Thermocouple No. 3 (T_3) measures the temperature of the heating coil. Thermocouple No. 1 is also used for measuring initial air temperature in constant-temperature runs before insertion of the specimen.

NOTE 3—The desired air temperature in the inner tube may be maintained by controlling the electric current supplied to the heating coils through an autotransformer, variable transformer, or equivalent, connected in series with the heating coils. Current adjustment may be made by reference to thermocouple T_3 in the furnace heating coil. This thermocouple is used in preference to the inner-tube thermocouples because of faster response. Constant furnace temperature may also be maintained conveniently by use of an automatic controller.

5. Test Specimens

5.1 Thermoplastic materials may be tested in pellet form normally supplied for molding. Where only sheet samples are available for thermosetting materials, 20 by 20-mm ($^3/_4$ by $^3/_4$-in.) squares of the available sheet or film shall be bound together with fine wire. A specimen weight of 3 ± 0.5 g is required.

6. Conditioning

6.1 *Conditioning*—Condition the test specimens at 23 ± 2 C (73.4 ± 3.6 F) and 50 ± 5 percent relative humidity for not less than 40 h prior to test in accordance with Procedure A of ASTM Methods D 618, Conditioning Plastics and Electrical Insulating Materials for Testing,[7] for those tests where conditioning is required. In cases of disagreement, the tolerances shall be ±1 C (±1.8 F) and ±2 percent

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[4] Nichrome V alloy wire made by the Driver Harris Co., Harrison, N. J., or equivalent, has been found satisfactory for the purpose.

[5] Alundum cement made by the Norton Co., Worchester, Mass., or equivalent, has been found satisfactory for this purpose.

[6] A metal salve container, Style 100, made by the Buckeye Stamping Co., Columbus, Ohio, or equivalent, has been found satisfactory for this purpose.

[7] *1974 Annual Book of ASTM Standards*, Part 35.

relative humidity.

6.2 *Test Conditions*—Conduct tests in the Standard Laboratory Atmosphere of 23 ± 2 C (73.4 ± 3.6 F) and 50 ± 5 percent relative humidity, unless otherwise specified in the test methods or in this specification. In cases of disagreement, the tolerances shall be ±1 C (±1.8 F) and ±2 percent relative humidity.

7. Procedure A

7.1 *First Approximation of Flash-Ignition Temperature* (*Effect of Air Flow Rate*):

7.1.1 *Low Air Flow Determination*—Raise the cup to the cover opening and place the specimen in the furance (Note 4). Set the air flow at 152.4 cm/s (5 ft/min) (Note 5). Adjust the transformer controlling current to the furnace coils to provide a rise in temperature T_2 of approximately 600 C (1080 F)/h (±10 percent). Light the gas pilot flame and place it across the hole in the top of the furnace. Note the air temperature (T_2) at which the combustible gases are ignited. This point is evidenced by a rapid rise in the specimen temperature (T_1). This is an approximation of the flash-ignition temperature.

NOTE 4—The furnace must be cooled to 50 C (122 F) or lower before each rising-temperature run is started.

NOTE 5—At all times the air flow shall be adjusted to the actual rate through the full section of the inner furnace tube. (The actual velocity past the specimen surface is unknown, but the effect of variable air supply through the furnace is resolved by controlling the rate through the unrestricted, and thus measurable, portion of the tube.) Refer to the air calibration curves in Fig. 2 for proper settings at various furnace temperatures. An air flow rate within ±10 percent of the nominal value is suitable.

7.1.2 *Medium Air Flow Determination*—Repeat 7.1.1 but with an air setting of 50.8 mm/s (10 ft/min) (Notes 4 and 5).

7.1.3 *High Air Flow Determination*—Repeat 7.1.1 but with an air setting at 101.6 mm/s (20 ft/min) (Notes 4 and 5).

7.2 *First Approximation of Self-Ignition Temperature* (*Effect of Air Flow Rate*):

7.2.1 Repeat 6.1.1 but without the pilot flame. Note the recorded air temperature (T_2) at which the specimen flames, explodes, or glows.

7.2.2 Repeat 7.1.2 but without the pilot flame. Note the recorded air temperature (T_2) at which the specimen flames, explodes, or glows.

7.2.3 Repeat 7.1.3 but without the pilot flame. Note the recorded air temperature (T_2) at which the specimen flames, explodes, or glows.

7.3 *Second Approximation of Flash-Ignition Temperature*—Choose the air setting from 7.1 that gives the lowest flash temperature, and repeat the appropriate determination, 7.1.1, 7.1.2, or 7.1.3, using a temperature rise of 300 C (540 F)/h (±10 percent).

7.4 *Second Approximation of Self-Ignition Temperature*—Choose the air setting from 7.2 that gives the lowest self-ignition temperature, and repeat the appropriate determination, 7.1.1, 7.1.2, or 7.1.3, using a temperature rise of 300 C (540 F)/h (±10 percent).

7.5 *Constant-Temperature Tests to Determine Minimum Ignition Temperatures:*

NOTE 6—The air temperature of ignition in the constant-temperature determinations is taken with the specimen thermocouple (T_1) before the specimen is inserted. The air temperature thermocouple (T_2) in these runs simply records whether the furnace is running under constant conditions during the time of the test.

7.5.1 *Minimum Flash-Ignition Temperature*—Start the furnace with the air setting used in 7.3. Adjust the transformer setting until the initial air temperature (T_1) stays constant as indicated by the recorded temperature readings for a 15-min period. The initial temperature should be maintained not more than 10 C (18 F) below the flash temperature found in 7.3. Place the specimen in the furnace, ignite the pilot flame, and watch for ignition of gases from the specimen. If ignition occurs, repeat this run with temperature T_1 maintained at a 10 C (18 F) lower setting. Repeat at successively lower temperatures until there is no ignition in 30 min. When temperature T_1 is reached at which no ignition occurs, it is suggested that a second run be made to ensure that this is truly below the self-ignition temperature. Report the lowest air temperature (T_1) setting at which ignition occurred as the minimum flash-ignition temperature.

7.5.2 *Minimum Self-Ignition Temperature* (Notes 7 and 8)—Repeat 7.1 but without the pilot flame. Start with an air temperature 10 C lower than the ignition temperature found in 7.4.

NOTE 7—If no ignition point was found in 7.2 or 7.4, this procedure for minimum self-ignition temperature should be started with a constant air temperature of about 100 C (180 F) above the flash-ignition temperature found in 7.3. This is because some plastics, for example, polystyrene, boil away before self-ignition takes place during the rising-temperature test. However, a self-ignition point can be found in the constant-temperature test if the initial temperature is started high enough. The air flow rate selected for this test should be the same as used in 7.3.

NOTE 8—If a sample does not ignite at 750 C (1382 F) at an air-flow rate of 10 ft/min, reference should be made to ASTM Method E 136, for Determining Noncombustibility of Elementary Materials[*] for the purpose of obtaining a "noncombustible" rating for the test material.

8. Procedure B (Short Method)

8.1 *Minimum Flash-Ignition Temperature:*

8.1.1 Set the air flow rate to provide a velocity of 5 ft/min at 400 C in the test chamber of the furnace. Adjust the current to the heating coil until the initial air temperature, T_2, remains constant at 400 C for 15 min.

NOTE 9—The temperature of 400 C is used where no prior knowledge of the probable ignition temperature range is available. Other starting temperatures may be selected if information about the material indicates a better choice.

8.1.2 Locate thermocouple T_1 centrally in the specimen holder intimately surrounded by the test material and lower the unit into the furnace. Start a timer, ignite the gas pilot flame and watch for ignition. Flash-ignition will be evidenced by a flash or mild explosion of combustible gases which may be followed by continuous burning of the specimen. If the specimen burns, by flaming or glowing, a rapid rise will be observed in the temperature at thermocouple T_1 above that at T_2.

8.1.3 If at the end of 5 min ignition has or has not occurred, lower or raise the temperature (T_2) 50 C as required and repeat the test with a fresh specimen. When the minimum ignition temperature has been bracketed, tests are begun 10 C below the lowest ignition temperature observed and repeated, dropping the temperature in 10 C intervals until the temperature is reached at which there is no ignition during 13 min. A repeat run may be desirable at this temperature using an air velocity of 10 ft/min to verify the use of 5 ft/min as optimum.

NOTE 10—Ordinarily, increasing the air velocity above 5 ft/min does not reduce the minimum ignition temperature in this test. However, if a repeat run at the next higher velocity results in ignition, it will be necessary to determine, by repeat tests at lower temperatures, the optimum air velocity for the material.

8.1.4 The lowest air temperature (T_2) at which a flash is observed is recorded as the minimum flash-ignition temperature.

8.2 *Minimum Self-Ignition Temperature:*

8.2.1 Follow the same procedure as in 8.1 but *without* the gas pilot flame.

8.2.2 Self-ignition will be evidenced by flaming or glowing of the specimen. It may be difficult, with some materials, to detect self-ignition visually when burning is by glowing rather than flaming. In such cases, the rapid rise in temperature at thermocouple T_1 above that at T_2 is the more reliable reference.

8.2.3 The lowest air temperature (T_2) at which the specimen burns is recorded as the minimum self-ignition temperature.

9. Report

9.1 The report shall include the following:

9.1.1 Designation of material, including name of manufacturer, composition, and state of subdivision (granules, sheet, etc.),

9.1.2 Air velocities used. If air velocity is not critical, this should be noted,

9.1.3 Flash-ignition temperature,

9.1.4 Self-ignition temperature, and

9.1.5 Visual observations (melting, bubbling, smoking, etc.).

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[*] *1973 Annual Book of ASTM Standards*, Part 14.

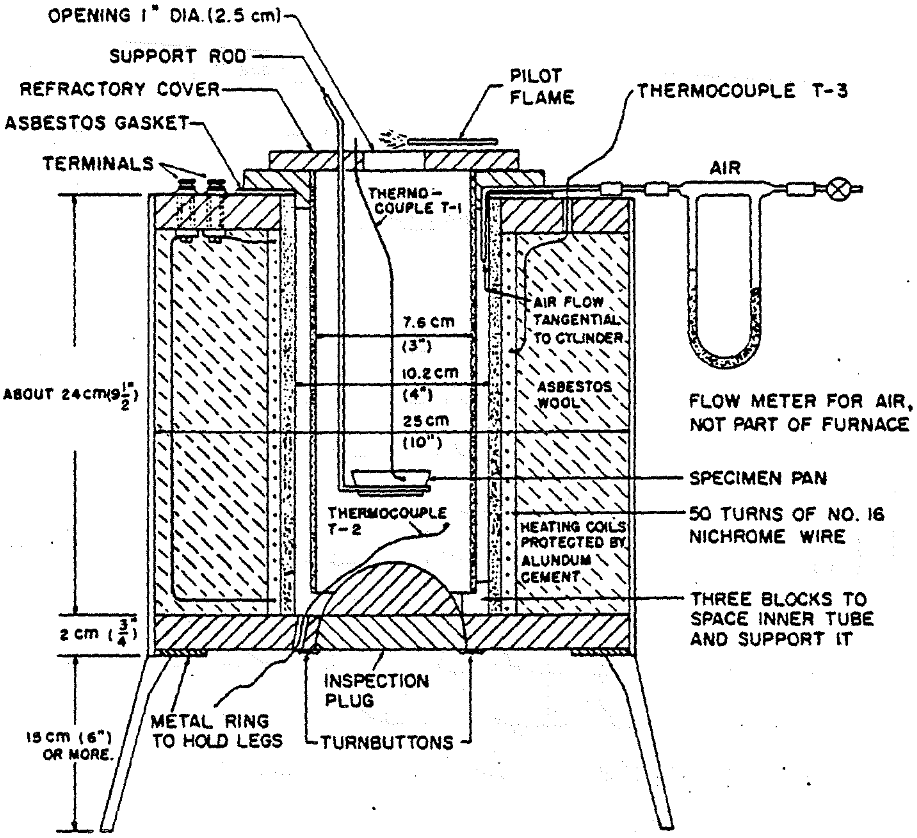

FIG. 1 Cross Section of Hot-Air Ignition Furnace Assembly.

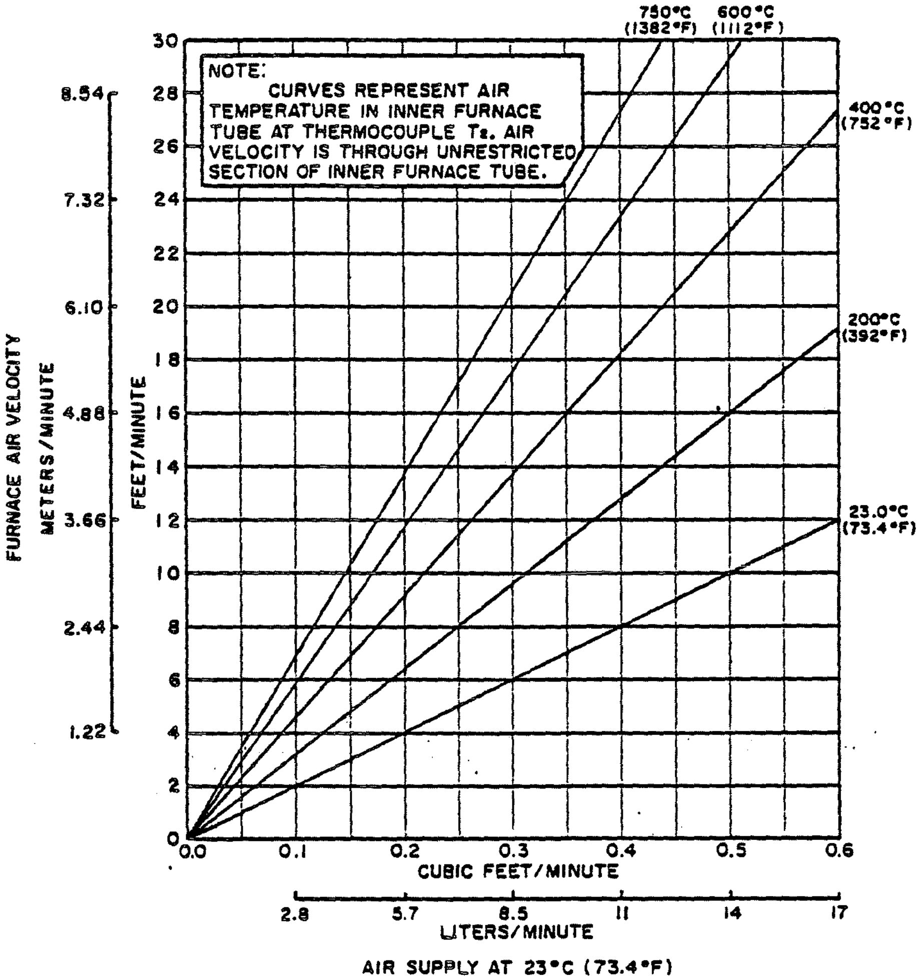

FIG. 2 Air Calibration Curves for Hot-Air Ignition Furnace.

APPENDIX G

25-FOOT TUNNEL TEST

G1.0 Scope

G1.1 This test is intended to be used in determining the surface burning characteristics of noise control products.

G1.2 The purpose of the 25-foot tunnel test is to determine the comparative burning characteristics of the material by evaluating the flame spread over its surface, fuel contributed by its combustion, and the density of the smoke developed when exposed to a fire. The results establish a basis on which surface burning characteristics of different material may be compared, without specific consideration of all the end-use parameters that might affect the surface burning characteristics.

2.0 Fire Test Chamber

G2.1 The fire test chamber, figures G1 and G2, is to consist of a horizontal duct having an inside width of 17-3/4 ± 3/4 inch (451 ± 19.1 mm) measured at a ledge location along side walls and a width of 17-5/8 ± 3/8 inch (448 ± 9.5 mm) at all other points. The chamber duct is to have a depth of 12 ± 1/2 inch (305 ± 12.7 mm) measured from the bottom of the test chamber to the ledge of the inner walls on which the sample is supported [including the 1/8-inch (3.2-mm) thickness of asbestos fabric gasketing tape], and a length of 35 feet (7.6 m). The sides and base of the duct are to be lined with insulating masonry, as illustrated in figure G2, consisting of A. P. Green G-26* refractory fire brick. One side is to be provided with a double-pane observation window wherein the exposed inside glass measures 2-3/4 ± 1/4 by 11 plus 2 minus 1 inch (69.9 ± 6.4 by 278 plus 50.8 minus 25.4 mm). This assures that the glass area is large enough so that the entire length of the test sample may be observed from outside the fire test chamber. The window should be

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*The operation and calibration of this equipment is based on the use of A. P. Green refactories.

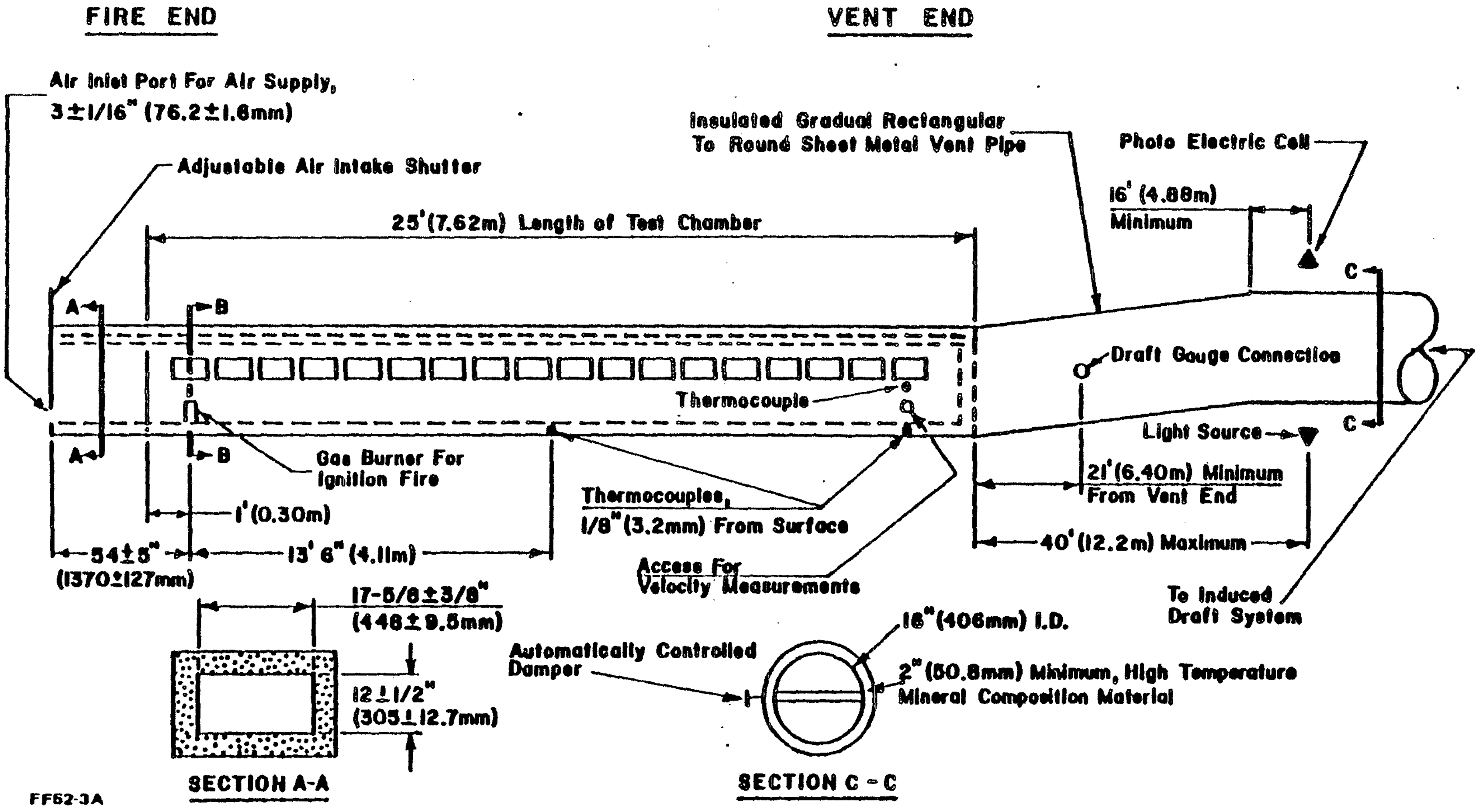

Figure G1. Details of Test Furnace

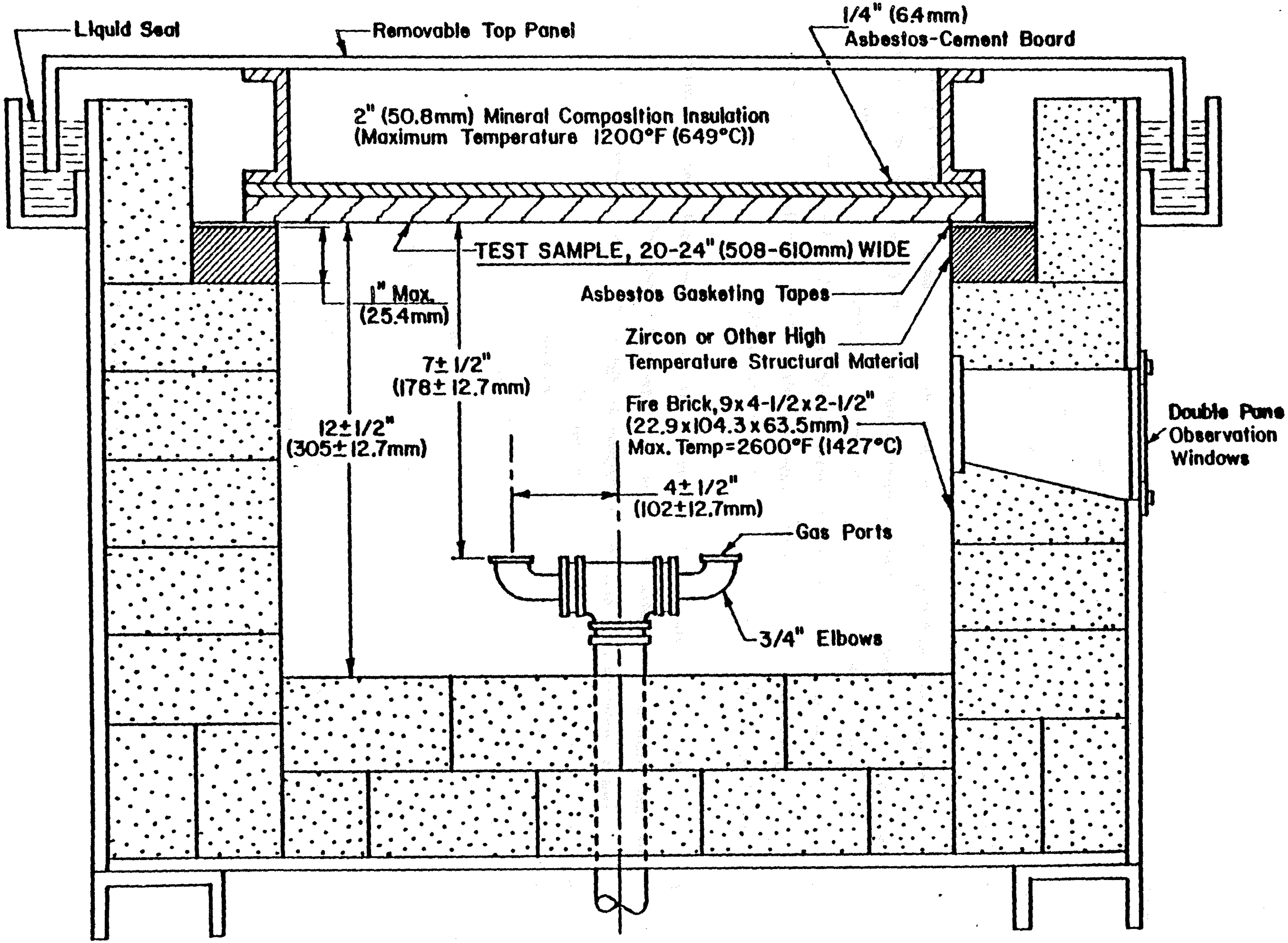

Figure G2. Test Furnace (Section View B-B) pressure tight (as described in paragraphs G4.2 and G4.3) and the inside plane* should be flush-mounted as shown in figure G2.

G2.2 The ledges are to be fabricated of structural material** capable of withstanding the abuse of continuous testing. They should be level with respect to the length and width of the chamber and with each other and should be maintained in a state of repair commensurate with the frequency, volume, and severity of scheduled testing.

G2.3 Turbulence baffling should be provided as necessary to assure proper combustion. This is accomplished by positioning six A. P. Green G-26 refractory fire bricks along the side walls of the chamber at distances of 7, 12, and 20, ±0.5 feet (2.1, 3.6, and 6.1, ±0.15 m) on the window side and 4-1/2, 9-1/2, and 16, ±1/2 feet (1.3, 2.9, and 4.9, ±0.2 m) on the opposite side. Bricks should be placed such that their long dimension, 4-1/2 inches (114 mm), is vertical.

G2.4 The top of the chamber is to consist of a removable, nonflammable (metal and mineral composite) structure, insulated with nominal 2-inch (50.8-mm) thick mineral composition material as shown in figure G2. The mineral composition material shall be of sufficient size to completely cover the chamber and shall have physical characteristics comparable to the following:

Maximum effective temperature - 1200°F (649°C)

Bulk density - 12.5 ± 1.5 lb/ft^3 (196.1 ± 24.0 kg/m^3)

Thermal conductivity - 0.50-0.71 Btu-in/h-ft^2-°F at 300-700°F (0.072-0.102 W/m-°K at 149-371°C)

The entire lid assembly is to be protected with flat sections of high density (nominal 110 lb/ft^3 or 1761 kg/m^3) 1/4-inch (6.4-mm) asbestos-cement board maintained in an unwarped and uncracked condition. The top is to be completely sealed such that air does not leak into the fire test chamber during testing.

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*A glass found suitable for this purpose is Vycor, 100-percent silica glass, nominal 1/4-inch (6.4-mm) thick or equivalent.

**High temperature furnace refactories, such as zircon, has been found suitable for this purpose.

G2.5 One end of the test chamber, designated as "fire end," is to be provided with two gas burners delivering flames upward against the surface of the test sample. The burners are to be spaced 12 inches (305 mm) from the test sample, and 7-1/2 ± 1/2 inches (190.5 ± 12.7 mm) below the under surface of the test sample. The air intake shutter is to be located 54 ± 5 inches (13.7 ± 0.1 m) upstream of the burner, as measured from the burners' center line to the outside surface of the shutter. The burners are to be positioned transversely approximately 4 ± 1/2 inches (102 ± 12.7 mm) on each side of the center line of the furnace so that the flame is evenly distributed over the width of the exposed sample surface (see figure G2). The controls used to assure constant flow of gas to the burners during periods of use are to consist of a pressure regulator, a gas meter calibrated to read in increments of not more than 0.1 ft^3 (2.8 liters), a manometer to indicate gas pressure in inches of water (Pa), a quick-acting gas shutoff valve, a gas metering valve, and an orifice plate in combination with a water manometer to assist in maintaining uniform gas flow conditions. An air intake fitted with a vertically sliding shutter extending the entire width of the test chamber is to be provided at the fire end. The shutter is to be positioned so as to provide an air inlet port 3 ± 1/16 inches (76.2 ± 1.6 mm) high measured from the floor level of the test chamber at the air intake point.

G2.6 The other end of the test chamber, designated as the "vent end," is to be fitted with a square-to-round transition piece, which is in turn fitted to a 16-inch (406-mm) diameter flue pipe. The movement of air by the draft-inducing system should be such that a total draft of at least 0.15-inch (3.8-mm) water column is created with the sample in place, the shutter at the fire end open 3 ± 1/16 inch (76.2 ± 1.6 mm), and the damper in the wide-open position. A draft gauge to indicate static pressure is to be joined with the vent pipe using a surface mounting. The gauge should be placed upstream of the damper and photoelectric cell opening at a location at least 16 diameters (approximately 21 feet or 6.4 mm) from the vent end of the chamber. This corresponds to a point of minimum turbulence in the vent.

G2.7 A light source* is to be mounted on a horizontal section of the 16-inch (406-mm) diameter vent pipe at a point where it will be preceded by a straight run of pipe of at least 12 diameters or 16 feet (4.9 m) and at a location where it will not be affected by flame in the test chamber. The light source should be positioned such that the light beam is directed upward along the vertical axis of the vent pipe. The vent pipe is to be insulated with at least 2 inches (50.8 mm) of high temperature mineral composition material from the vent end of the chamber to the photometer location. A photoelectric cell of which the output is directly proportional to the amount of light received is to be mounted over the light source and connected to a recording device for indicating changes in the attenuation of incident light by passing smoke, particulate, and other effluent.

G2.8 The damper is to be installed in the vent pipe downstream of the smoke-indicating attachment.

G2.9 An automatic draft regulator may be mounted in the vent pipe downstream of the manual damper. Other manual, automatic, or special draft regulation devices may be incorporated to maintain air flow control throughout test periods.

G2.10 A No. 18 AWG (0.83 mm^2) thermocouple, with 3/8 ± 1/8 inch (9.5 ± 3.2 mm) of the junction exposed in the air, is to be inserted through the floor of the test chamber. The tip of the thermocouple is 1 ± 1/32 inch (25.4 ± 0.8 mm) below the top surface of the asbestos gasketing tape and within 1 foot (305 mm) of the vent end of the test sample at the center of its width.

G2.11 A No. 18 AWG (0.82 mm^2) thermocouple is to be embedded 1/8 inch (3.2 mm) below the floor surface of the test chamber in refractory or portland cement at distances of 14 feet (4.3 mm) and 24 feet (7.3 m) from the fire end of the chamber. The cement must be carefully dried to avoid cracking.

G2.12 The room in which the test chamber is located is to provide a free inflow of air so as to maintain atmospheric pressure during testing.

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* A meter found suitable for this purpose is a Weston Instruments No. 856BB, photronic cell and 12-volt sealed beam, clear lens, auto spot lamp, with an overall light-to-cell path length of 36 ± 2 inches (914 ± 50.8 mm).

G3.0 Test Specimen

G3.1 The specimen may consist of continuous, unbroken length, or of sections joined end-to-end. The upstream 12-inch (305-mm) length required to fill the 25-foot (7.6-mm) chamber opening is to consist of a section of mineral or metal material with a zero flame spread classification. Material properties sufficient for positive identification of the test specimen are to be determined and recorded.

G3.2 The test specimen is to be conditioned at a temperature of 70 ± 5°F (21 ± 2.8°C) and at a relative humidity of 35 to 40 percent.

G4.0 Calibration of Test Equipment

G4.1 A 1/4-inch (6.4-mm) asbestos-cement board is to be placed on the ledge of the furnace chamber. The removable top of the test chamber is to be placed in position.

G4.2 A draft is to be established as specified in paragraph G2.6. The fire-end shutter is to be closed and sealed. The manometer reading shall increase to at least 0.375 inch (9.53 mm), indicating that no excessive air leakage exists.

G4.3 In addition, a supplemental leakage test is to be conducted periodically by placing a smoke bomb in the chamber after the fire shutter and exhaust duct has been sealed at a point beyond the differential manometer tube. The bomb is to be ignited and the chamber pressurized to 0.375 ± 0.15 inch (9.53 ± 3.18 mm) water column. All points of leakage, observed in the form of escaping smoke particles, are to be sealed.

G4.4 A draft reading is to be established within the range 0.055-0.085 inch (1.40-2.16 mm) water column. The required draft gauge reading is to be maintained by regulating the manual damper. The air velocity at 7 points, 1 foot (305 mm) from the vent end is to be recorded. These points are to be determined by dividing the width of the tunnel into seven equal sections and recording the velocity at the geometrical center of each section. The average velocity shall be 240 ± 5 fpm (73.2 ± 1.5 m/min).

G4.5 The air supply is to be maintained at 70 ± 5°F (21 ± 2.8°C) and the relative humidity between 35 and 40 percent.

G4.6 The fire test chamber is to be supplied with natural or methane gas of uniform quality and with a nominal heating value of 1000 Btu/ft^3 (37.3 MJ/m^3). The gas supply is to be initially adjusted at approximately 5000 Btu/min (87.9 kW). The gas pressure, the pressure differential across the orifice plate, and the volume of gas used are to be recorded in each test. Unless otherwise corrected for when bottled methane is used, a length of coiled copper tubing is to be inserted into the gas line between the supply and metering connection. This is necessary to compensate for possible errors in the indicated flow due to reductions in gas temperature associated with the pressure drop and expansion across the regulator. With the draft and gas supply adjusted as indicated in paragraphs G4.4 and G4.6, the test flame is to extend downstream a distance of 4-1/2 feet (1.4 m) over the specimen surface, with negligible upstream coverage.

G4.7 The test chamber is to be preheated with the 1/4-inch (6.4 mm) asbestos-cement board and the removable top in place and with the fuel supply adjusted to the required flow. The preheating is to be continued until the temperature indicated by the floor thermocouple at 24 feet (7.3 m) reaches 150 ± 5°F (66 ± 2.8°C). During the preheat test, the temperatures indicated by the thermocouple at the vent end of the test chamber are to be recorded at 15-second intervals and compared to the preheat temperature shown in the time-temperature curve (figure G3). The preheating is for the purpose of establishing the conditions that will exist following successive tests and to verify control of the heat input into the test chamber. If appreciable variation from the temperatures shown in the representative preheat curve is observed, because of variation in the characteristics of the gas used, adjustments in the fuel supply may be made prior to proceeding with the red-oak calibration tests.

G4.8 The furnace is to be allowed to cool after each test. When the floor thermocouple at 14 feet (4.2 m) shows a temperature of 105 ± 5°F (40.5 ± 2.8°C), the next specimen is to be placed in position for test.

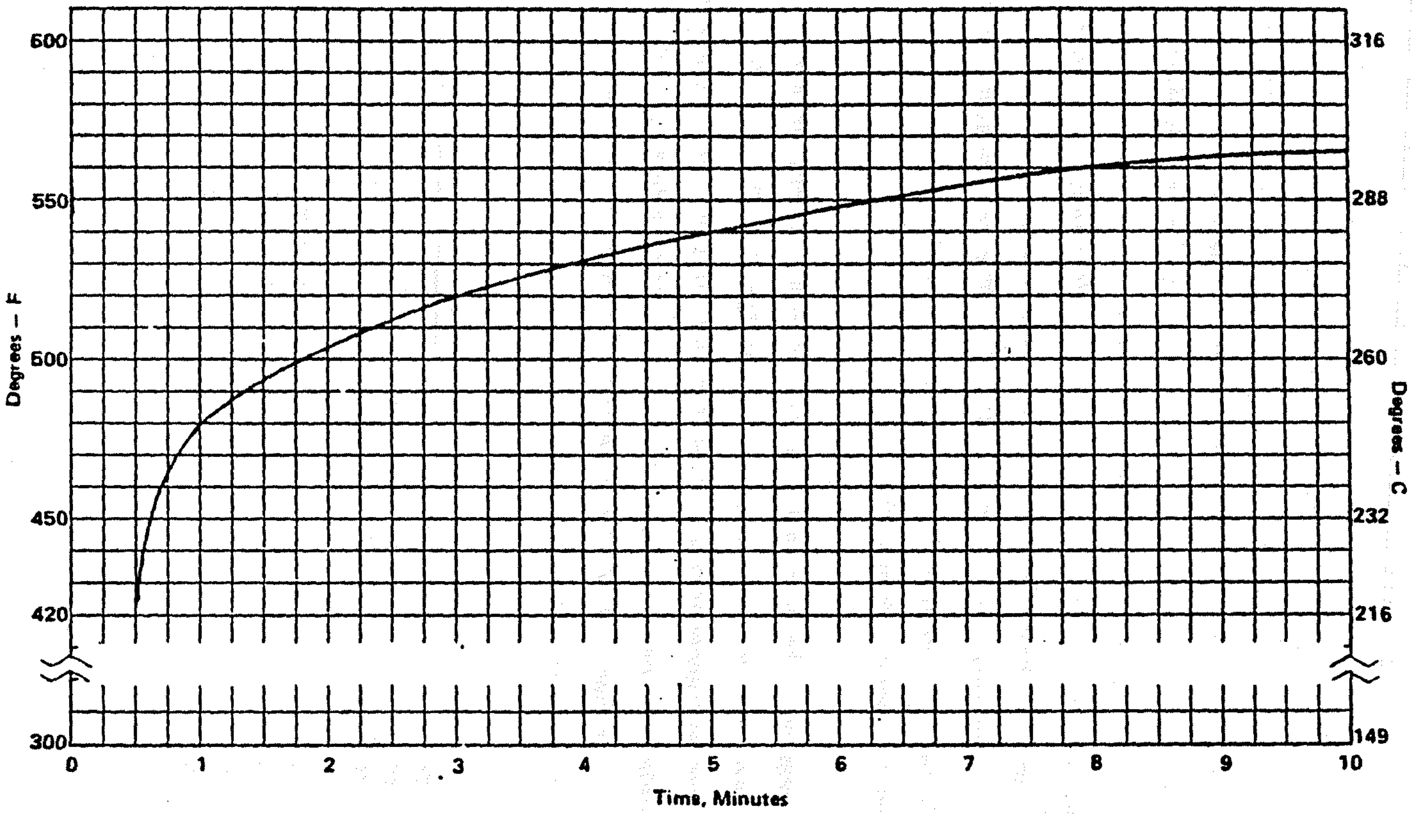

Figure G3. Time-Temperature Curve for Preheat Temperature

G4.9 With the test specimen adjusted and conditioned as described in paragraphs G4.2, G4.4, G4.5, and G4.7, a test or series of tests are to be made. Each test should use nominal 23/32-inch (18.2 mm) select-grade red-oak flooring as the sample after conditioning to 6-8 percent moisture content as determined by the 221°F (105°C) oven-dry method described in ASTM D 2016. Observations are to be made continually, and the time is to be recorded when the flame reaches the end of the specimen; that is, 19-1/2 feet (5.9 m) from the end of the ignition fire. The end of the ignition fire is to be considered as being 4-1/2 feet (1.4 m) from the burners. The flame is to reach the end point in 5-1/2 minutes ± 15 seconds. The flame may be judged to have reached the end point when the vent-end thermocouple registers a temperature of 980°F (527°C). The temperature measured by the thermocouple near the vent end is to be recorded immediately prior to the test and at least every 15 seconds during the test.

G4.10 The results of tests of select-grade red-oak flooring in which the flame spreads 19-1/2 feet (5.9 m) from the end of the igniting flame in 5-1/2 minutes shall be considered as representing a classification of 100. The temperature and change in photoelectric cell readings are to be plotted separately on coordinate paper. Figures G4 through G6 are representative curves for red-oak flame spread, smoke density, and fuel contribution, respectively.

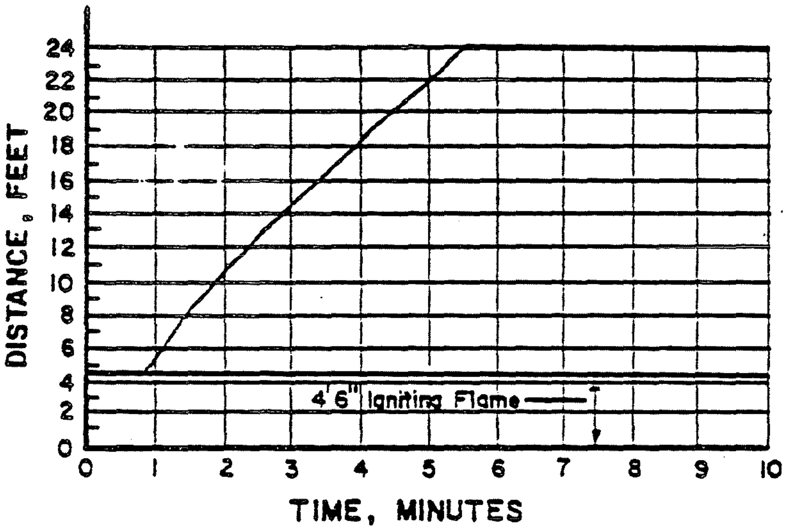

Figure G4. Representative Time-Distance Curve for Flame Spread of Red Oak

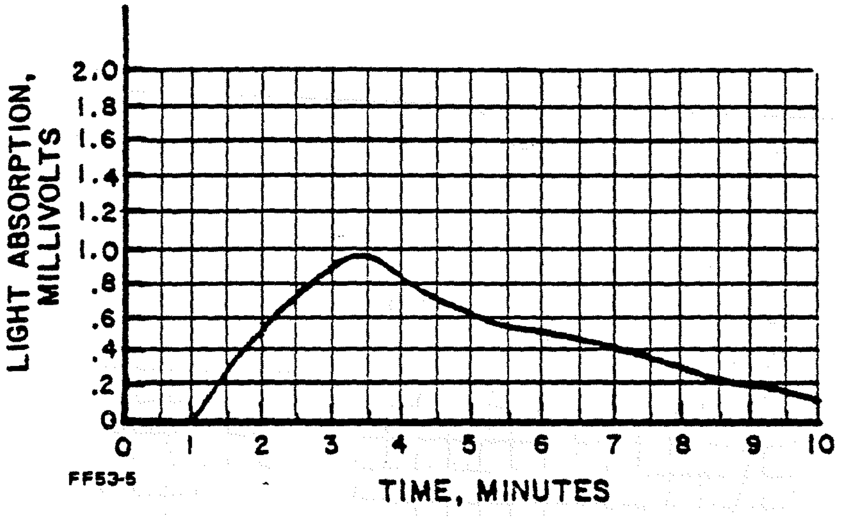

Figure G5. Smoke Density Curve for Red Oak

G4.11 Following the calibration tests for red oak, a similar test(s) is to be conducted on samples of 1/4-inch (6.4 mm) asbestos-cement board. The results are to be considered as representing a classification of zero. The temperature readings are to be plotted separately on coordinate paper. Figure G7 is a representative curve for fuel contribution of asbestos-cement board.

G5.0 Test Procedure

G5.1 The test specimen is to be placed on the test chamber ledges which have been completely covered with nominal 1/8-inch (3.2-mm) thick by 1-1/2-inch (38.1-mm) wide woven asbestos tape. The removable top is to be placed in position over the specimen.

G5.2 The test equipment is to be adjusted and conditioned as described in paragraphs G4.2, G4.4, G4.5, and G4.8 (with test sample in place). The completely mounted specimen is to remain in position in the chamber with the furnace draft operating for 120 ± 15 seconds prior to application of the test flame.

G5.3 The flame is to be ignited and adjusted. The distance and time of maximum flame front travel is to be observed and recorded. The test is to be continued for a 10-minute period unless the sample is completely consumed in less

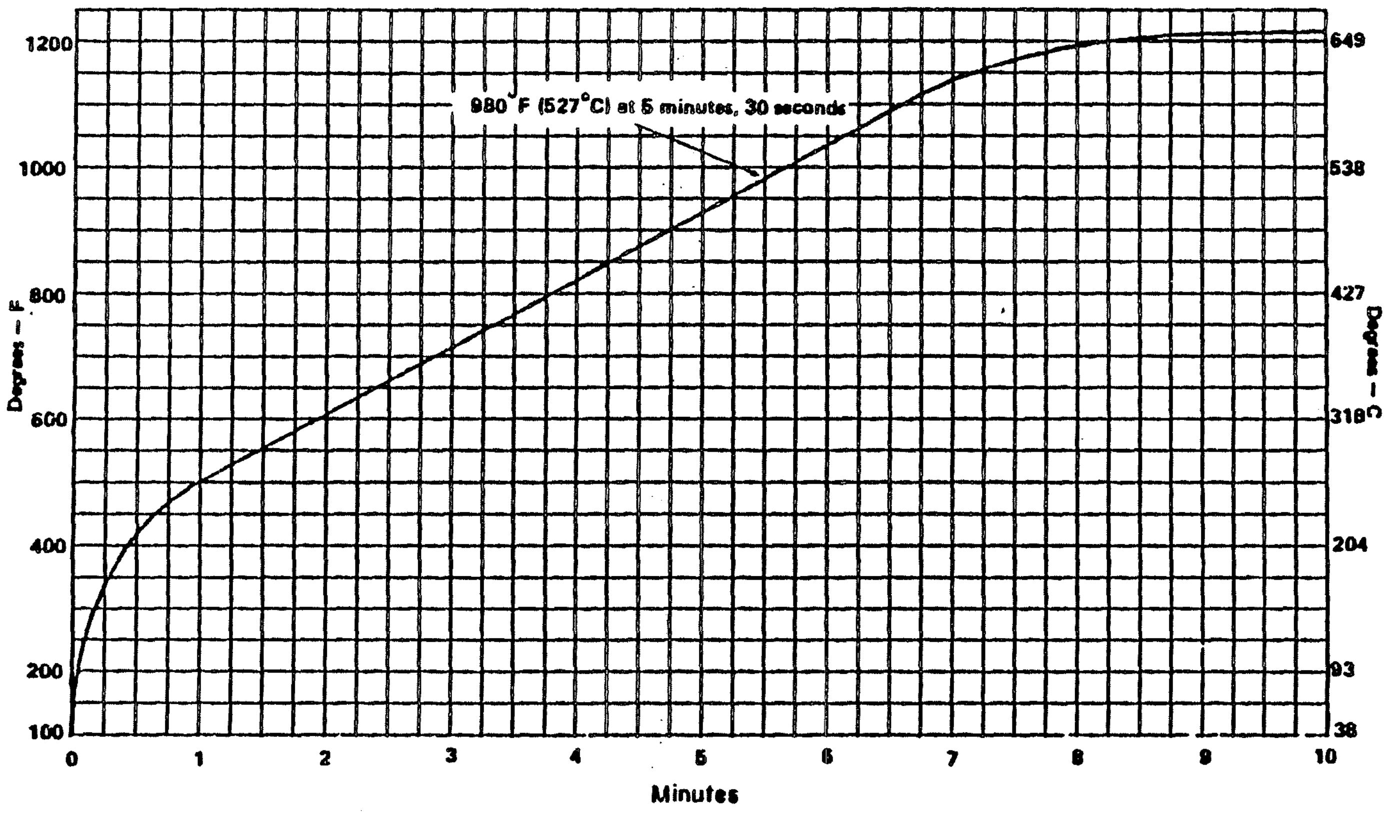

Figure G6. Time-Temperature Curve for Fuel Contribution of Red Oak

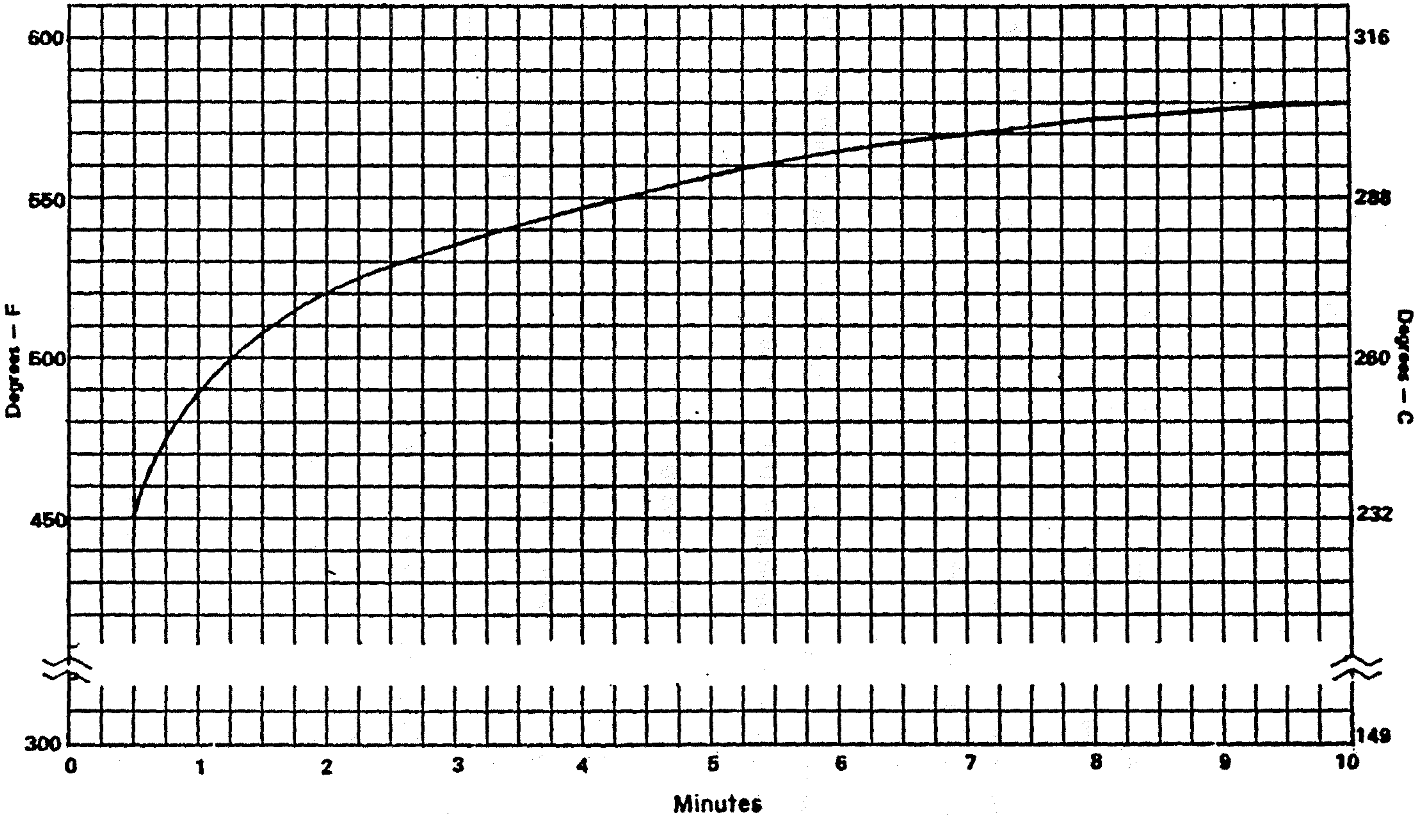

Figure G7. Time-Temperature Curve for Fuel Contribution of Asbestos-Cement Board than 10 minutes. In the latter case, the test is to be ended after complete combustion occurs (that is, smoke development and fuel contribution ceases).

G5.4 The temperature measured by the thermocouple near the vent end is to be recorded at least every 15 seconds. The photoelectric cell output is to be recorded immediately prior to the test and at least every 15 seconds during the test.

G5.5 The gas pressure, the pressure differential across the orifice plate, and the volume of gas used are to be recorded in each test.

G5.6 When the test has been completed, the gas supply is to be shut off, smoldering and other conditions within the test duct are to be observed, and the sample is to be removed for further examination.

G5.7 The temperature and change in photoelectric cell readings are to be plotted separately on the same coordinate paper as specified in paragraph G4.10.

G6.0 Classification

The flame spread classification (FSC) is to be determined as follows:

A. The total area (A_T) under the flame spread time-distance curve is to be determined by ignoring any flame front recession. For example, in figure G8 the flame spreads 10 feet (3.05 m) in 2 minutes and then recedes. The area is calculated as if the flame had spread to 10 feet in 2 minutes and then remained at 10 feet for the remainder of the test or until the flame front again passed 10 feet. This is shown by the dashed line in figure G8. The area (A_T) used for calculating the flame spread classification is the sum of areas A_1 and A_2 as shown in figure G8.

B. If this total area (A_T) is less than or equal to 97.5 min-ft (29.5 m-min), the flame spread classification shall be 0.515 times the total area (FSC = 0.515 A_T).

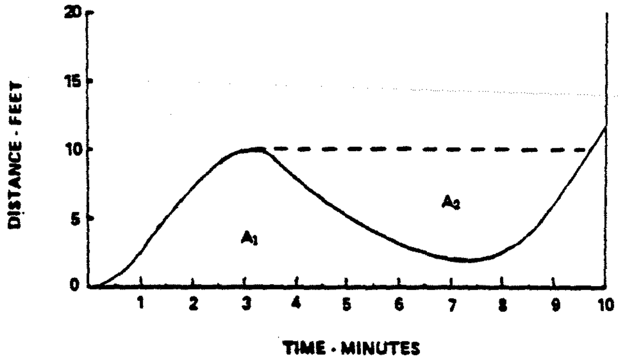

Figure G8. Example of Time-Distance Curve With Flame Front Recession

Note:
1 Foot = .305m

C. If the total area (A_T) is greater than 97.5 min-ft (29.5 m-min), the flame spread classification is to be 4900 divided by 195 minus the total area (A_T) $\left[FSC = 4900/(195-A_T)\right]$.

D. The test results for fuel and smoke contribution are to be plotted using the same coordinates. Comparison of the areas under the respective curves will establish a numerical classification by which the performance of the material may be compared with that of asbestos-cement board and select-grade red-oak flooring, whose flame spread classifications have been arbitrarily established as zero and 100, respectively. Materials of low flame spread classification, having high insulating properties may show an apparent contribution of fuel due to the lessened heat loss through the sample. Allowance should be made for accumulation of soot and dust on the photoelectric cell during the test.

G7.0 Analysis of Products of Combustion

Although not required as a part of this method, products of combustion may be drawn from the test duct during testing. These products can be analyzed to determine specific characteristics that might be of concern considering the intended use of the material undergoing test.

G8.0 Report

The report shall include the following:

- A. A description of the material being tested.
- B. Test results.
- C. Details of the method used in placing the specimen in the test chamber.
- D. Observations of the burning characteristics of the specimen.

APPENDIX H

GUIDE TO MOUNTING METHODS FOR 25-FOOT TUNNEL TEST

H1.0 Scope

H1.1 This guide is intended as an aid in determining the method of mounting various noise control products in the fire test chamber of the furnace. These mounting are described to enhance test method uniformity and convenience. They are not meant to impose restriction in the specific details of field installation.

H1.2 These suggested mounting methods are grouped according to noise control products to be tested, which are broadly described either by usage or by form of the material.

H1.3 For some noise control products, none of the methods described may be applicable. In such cases, other means of support may have to be devised.

H1.4 Whenever asbestos-cement board is specified as a backing, the material shall have a nominal thickness of 1/4 inch (6.4 mm), a density of 110 ± 5 lb/ft (1762 ± 8 kg/m) and be uncoated. When metal rods are specified as supports, 1/4-inch (6.4 mm) rods spanning the width of the tunnel shall be used. Rods should be placed approximately 2 inches (50.8 mm) from each end of each panel. Additional rods shall be placed at approximately 20-foot (0.6 m) intervals starting with the first rod at the fire end of each panel.

H2.0 Asbestos-Cement Boards

H2.1 Flat or corrugated asbestos-cement boards 3/16 inch (4.8 mm) or greater have sufficient structural integrity such that no additional mounting support is required.

H3.0 Batt or Blanket Type of Insulating Materials

H3.1 Batt or blanket materials that do not have sufficient rigidity or strength to support themselves are to be supported by metal rods. The rods shall not be larger than 1/4 inch (6.4 mm) in diameter and shall be inserted through the material in such a way as to span the tunnel width while not actually becoming exposed to the flame.

H3.2 If feasible, materials of other than flat contour are to be flattened to span the tunnel width and, if necessary, supported by metal rods as described in paragraph H3.1.

H4.0 Coating Materials, Cementitious Mixtures, and Sprayed Fibers

H4.1 Coating materials, cementitious mixtures, and sprayed fibers are to be mixed and applied to the substrate in accordance with the thickness, coverage rate, or density recommended by the manufacturer.

H4.2 Materials intended for application to wood surfaces are to be applied to a substrate of 1 by 4 inches (20 by 92 mm) nominal "C" and better VG Douglas fir flooring* (FSC 70 to 90) or to other species for which the surface burning characteristic is to be measured. The pieces shall be placed side by side and secured with four nailing strips spaced approximately 3-1/2 feet (1.1 m) apart, holding the pieces together (see figure H1). Two decks placed end to end shall be used.

H4.3 Coating materials intended for application to particular combustible surfaces, but not wood, are to be applied to the specific surface for which they are intended.

H4.4 Coating materials intended only for field application to nonflammable surfaces are to be applied to 1/4-inch (6.4 mm) asbestos-cement board.

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*Paragraph 104-C of Issue 16 of Standard Grading Rules for West Coast Lumber, published by West Coast Inspection Bureau, shall apply to identifying Douglas fir flooring.

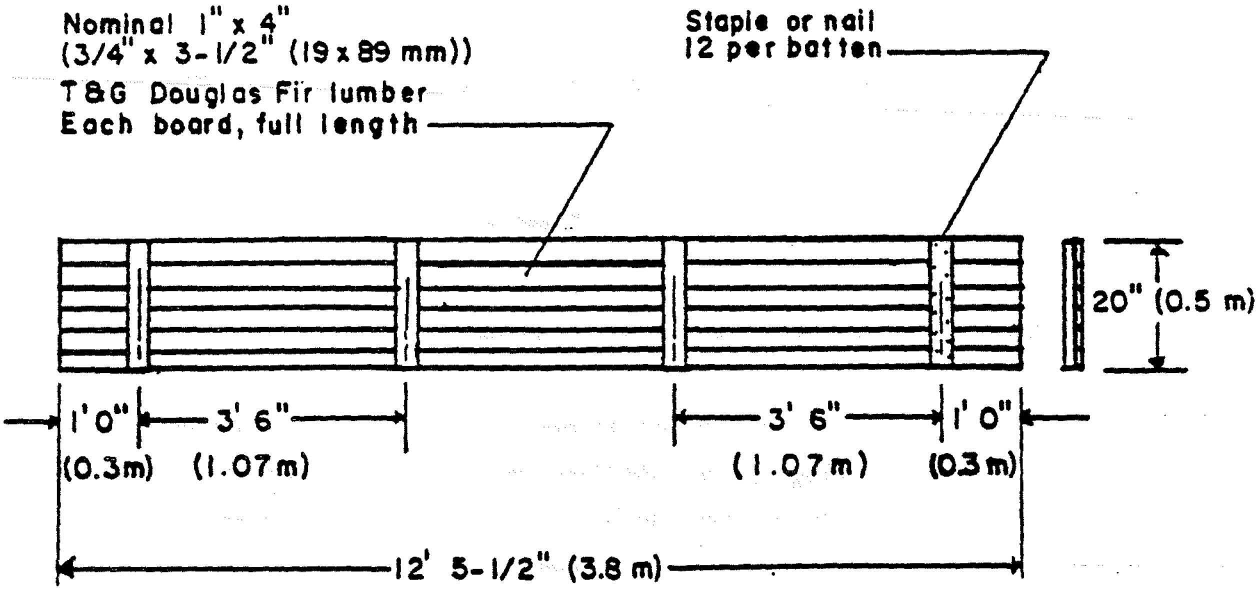

Figure H1. Wood Deck for Coating Materials

H5.0 Honeycomb Panels

Honeycomb type of panels are to be supported for the test on 2-inch (50.8-mm) hexagonal-mesh wire placed on 3/16 by 2-inch (4.8 by 50.8 mm) metal bars or 1/4-inch (6.4-mm) round bars which span the width of the furnace.

H6.0 Mineral Composition Units

Materials falling within this category are primarily inorganic and have sufficient structural integrity such that no additional support is required.

H7.0 Mineral and Fiberboards

Board-like materials consisting of mixtures of organic and inorganic materials fall within this category. These materials usually have sufficient structural integrity such that no additional support is required. If additional support is required, it is to be provided as specified for honeycomb panels.

H8.0 Equipment Coverings

Materials that fall within this category are either to be produced in a flat form or are to be capable of being flattened so that the necessary test samples can be obtained. If necessary, 1/4-inch (6.4-mm) round rods are to be inserted into the material, either to support it or to conform it to a flat contour. The round rods shall not be spaced less than 2 feet (610 mm) apart.

H9.0 Plastics

H9.1 Included within the broad framework of "plastics" are foams, reinforced panels, laminates, grids, and transparent or translucent sheets.

H9.2 If the plastic will remain in position in the furnace during a fire test due to its structural integrity, no additional support will be required. If required, additional support will be provided by 1/4-inch (6.4-mm) round metal rods, or 3/16-inch by 2-inch (4.8- by 50.8-mm) wide bars, or 2-inch (50.8-mm) hexagonal wire mesh placed on metal bars or rods that span the width of the furnace.

H10.0 Protected Metals

Metals that have a decorative or protective coating fall within this category. With few exceptions, these materials have sufficient structural integrity such that no additional support is required. Where additional support is required, it is to be provided in the form of 2-inch (50.8-mm) wide by 3/16-inch (4.8-mm) thick metal bars on 1/4-inch (6.4-mm) round rods that span the width of the tunnel. Rods should not be spaced less than 2 feet (610 mm) apart.

H11.0 Structural Cement Fiber Units

Products in this category are mixes of wood fibers and cementitious binders formed into slabs or boards of various sizes and thicknesses. These materials have sufficient structural integrity such that no additional support is required.

H12.0 Thin Membranes

Single-layer membranes or thin laminates consisting of a limited number of similar or dissimilar layers are considered within this category. These materials are to be supported by 2-inch (50.8-mm) hexagonal-mesh wire placed on 3/16- by 2-inch (4.8- by 50.8-mm) metal bars or 1/4-inch (6.4-mm) round bars that span the width of the tunnel.

APPENDIX I

NASA FLAMMABILITY SELECTION CRITERIA AND REQUIREMENTS FOR NONMETALLIC MATERIALS

I1.0 Introduction

Selection criteria and requirements for nonmetallic materials intended to be used in manned spacecraft were developed by NASA to reduce the potential fire hazards of these materials. The flammability requirements and criteria emphasize acceptance based on the location in the spacecraft, the amount of material used, and the fire-resistant characteristics of the materials.

Based on their end-use application, various flammability screening and application tests were prescribed for materials. Constraints imposed by the spacecraft environment were also considered and include such parameters as weight of the material, volume, performance, location, and the oxygen environment.

Several articles have been written on the NASA flammability selection criteria and requirements for nonmetallic materials. Two articles prepared for the NASA Lyndon B. Johnson Space Center in Houston, Texas, provided a basic understanding of the criteria. They are "Manned Spacecraft Nonmetallic-Materials Flammability Selection Criteria and Requirements," by C. J. Katsikas and J. H. Levine, and "Development of Materials Screening Tests for Oxygen-Enriched Environments," by R. L. Johnston and D. L. Pippen. This appendix summarizes the work of these authors.

I2.0 Historical Evolution

Before 1963 flammability controls for nonmetallic materials were very limited, and the controls that were used were developed by materials specialists on a consultant basis only. In 1964 it was realized that additional requirements were needed to control the flammability aspects of nonmetallic materials. Work done with various Apollo spacecraft contractors helped define the needs and extent of the necessary controls. As a result of this work, several conclusions, which include the following three, were reached.

1. The need for a nonmetallic materials flammability screening specification.
2. The need for a suitable accept/reject criterion.
3. The need for an acceptable/unacceptable nonmetallic materials flammability list.

During 1966 two specifications were prepared, and several nonmetallic materials were tested using one of the specifications. One problem with these earlier specifications was that the applications of the materials were not considered in the development of the acceptable/unacceptable nonmetallic materials list. Consideration was not given to the geometry, the thickness, or the usage of the various materials being tested.

In 1967 a new specification was published in which the actual usage of materials was considered in the overall evaluation. This new specification outlined screening tests to evaluate such items as material quantity, location, area exposed to oxygen, positive ignition sources, possible propagation paths, and the most severe environment the materials are expected to encounter. This new specification also defined specific material categories that accurately defined all the major usages within and outside the crew bay area of the spacecraft. The categories were further defined according to the level of flammability hazard associated with each material usage. This second subdivision encompassing the flammability hazard is needed in order to develop realistic criteria and tests, and it can be illustrated by the following example:

> A small, nonmetallic ink marking does not require the same degree of flammability testing as do large quantities of exposed materials located within the crew bay area.

The new specification also compared the various flammability test ignition sources that were currently in use and concluded that the choice of energy sources used to ignite material samples was critical to the credibility of the materials testing and, therefore, was extremely important in the evaluation of flammability test results.

The end goal of this study of ignition sources was to obtain an ignition system that would be comparable to credible spacecraft ignition sources and that could provide repeatable results. Another requirement of the ignition system was that it could provide relatively good test distribution and time characteristics. The ignition system chosen was a length of silicone rod wrapped with Nichrome wire.

13.0 Materials Usage Classification

As mentioned earlier, a major consideration in the development of the NASA criteria was the actual end use of the material. The different end uses dictate the specific fire test and acceptance criteria to be applied. For example, a large amount of material in a critical area of the crew bay requires more restrictive acceptance criteria and more flammability tests than a minor exposed material. The following categories describe the end uses of materials in the spacecraft:

Category	Materials End-Use Description
A	Major exposed materials in the crew bay atmosphere that are unlimited with respect to quantity, proximity to ignition sources, or exposure cabinet atmosphere, and that are used extensively throughout the spacecraft.
B	Special applications and minor exposed materials in the crew bay atmosphere that are used in discrete locations of the crew bay. The specific amount and arrangement of the materials are shown to prevent propagation. These materials are located such that fire cannot spread to any other nonmetallic materials in the habitable compartment and render nonfunctional other spacecraft systems that are essential for the safe recovery of the crew.
C	Materials in the suit-loop at less than 20 psia of oxygen. Materials that fall into this group include materials within the environmental control system loop that are integral to the space suits, such as hoses, helmets, valve seats, etc. Biomedical harnesses, communications,

Category	Materials End-Use Description
	transducers, and other suit-loop wiring and electrical components are also included in this group.
D	Materials in high pressure oxygen systems greater than 20 psia oxygen pressure applications, such as filters, valve seals, pressure bladders, etc.
E	Material applications in sealed containers for the crew compartment. Includes materials used inside sealed containers that contain an internal ignition source, that are filled with inert gas, air or potting compounds, and that have no means of receiving or backfilling with a supply of oxygen. Electrical wiring, potting compounds and electronic components all fall into this category.
F	Materials in containers vented in the crew compartment and materials used inside unsealed containers with or without an internal ignition source. Foams, wiring, electronic components, personal equipment, food bags, and flight data books fall into this category.
G	Materials used in nonflight equipment during closed-hatch power-on tests. Carry-on ground support equipment, plastic tape, plastic bags, etc, fall into this category.
H	Materials used in uninhabited portions of the spacecraft that are exposed to an atmosphere that will support combustion.

Figure I1 indicates the various materials end-use and associated tests.

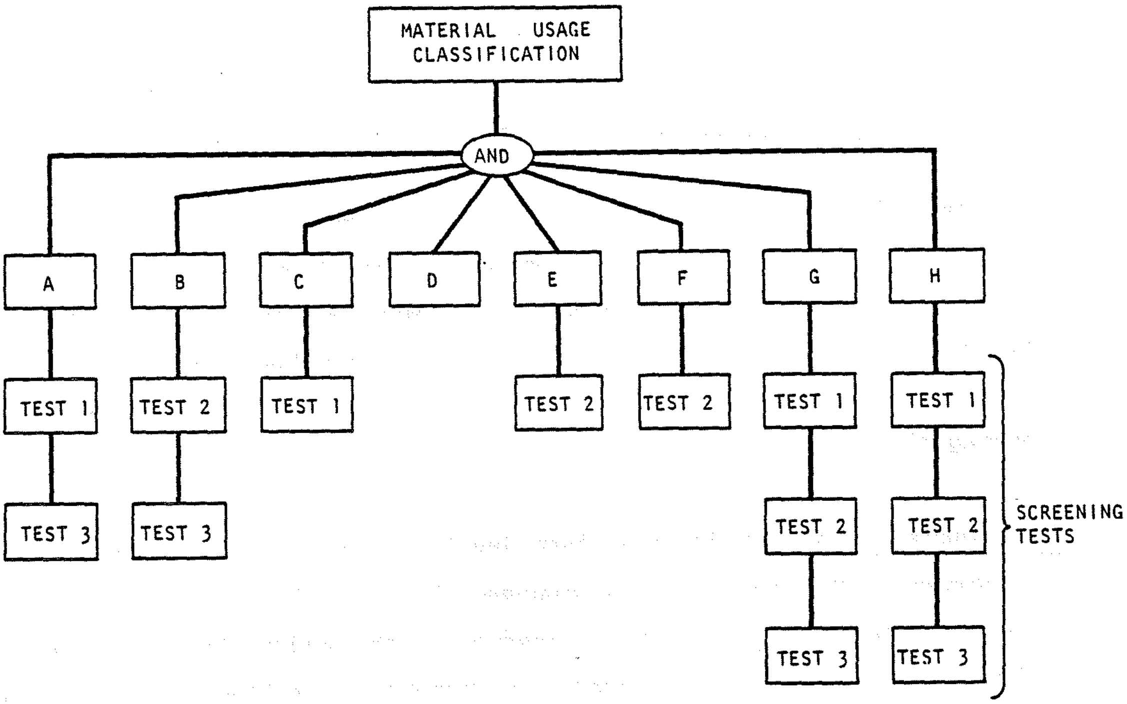

Figure I1. Material Usage Classification and Required Screening Tests

I4.0 Test Requirements

The NASA criteria provides for two types of tests to evaluate nonmetallic materials: screening tests and application tests. Screening tests are used during preliminary design stages to eliminate obvious hazards and to aid in selecting materials with a degree of confidence that they will be acceptable. Currently, there are nine tests used to screen materials for use in manned spacecraft: Upward propagation, downward propagation, combined thermogravimetric analysis and spark ignition, electrical wire insulation and accessory flammability, electrical potting and coating flammability, odor, determination of carbon monoxide and total organics, flash point and fire point determination. The test severity required for a particular material is determined by the end-use of the material in the spacecraft.

Upward propagation, which is the most severe screening test, is used extensively to screen materials that could possibly be used in the crew bay area in large, unrestricted quantities. Materials are acceptable by this test provided they do not ignite under the conditions of the test or provided they self-extinguish before propagating more than three inches along a 5-inch total sample length. Materials that do not self-extinguish are considered to have failed the test. The rate of flame propagation is not used as a criterion because of the nonreproducibility of data.

Downward propagation is used essentially as a measure of the flame propagation rate under the best possible conditions and is considered to be a measure of the in-orbit, zero-convection propagation rate. Materials that are considered to have passed the downward propagation test must be controlled very carefully and used in small quantities in situations where they do not provide a significant flame propagation path.

The current flash and fire point tests involve the use of two separate types of test equipment, a thermogravimetric analyzer (TGA) and a small heating chamber (flash point). The TGA data gives a measure of the weight loss of a material as a function of time as the temperature is increased at a linear rate. Materials that have a flash point of less than 400°F or exhibit charring or pyrolysis at less than 450°F are considered unacceptable.

Determination of a carbon monoxide and total organics and odor tests are used in addition to the flammability tests to determine whether materials are suitable from the standpoint of evolution of potentially toxic products. The determination of carbon monoxide and total organics involves heating a specimen at 200°F in a container with an oxygen pressure of 5 psia for a period of 25 hours. The oxygen in the container is then sampled, and mass spectroscopy, infrared spectrometry, and gas chromatrography are utilized to evaluate and quantify the amount of carbon monoxide and total organics liberated.

In the odor test the samples of material are prepared in essentially the same manner except that they are heated at 155°F for at least 72 hours. A panel of odor consultants sniff the oxygen environment taken from the test specimen and rate it according to a standard subjective scale.

The electrical wire insulation and accessory flammability test is essentially a propagation test conducted on a standard wire bundle. A bundle of seven wires is placed in a test chamber and the center wire is overloaded electrically to the point of fusion or ignition of the insulation. At the time of ignition, current to the current-carrying wire is removed and the specimen is observed to determine if the fire propagates or self-extinguishes. If the test bundle cannot be ignited at the fusion temperature of the conductor or if the simulation ignites but self-extinguishes, the wire is considered acceptable for use.

Electrical potting and flammability tests are quite similar to the wire insulation test. The test criterion is met if the fire will not propagate along the potting compound or if sustained combustion does not occur after removal of the ignition source.

The criteria used for nonmetallic material tests is summarized as follows:

Total organics, ug/g	100
Carbon monoxide, ug/g	25
Odor rating	2.5
Flammability, Category A	Self-extinguishing
Category B	B

Application tests are performed on a worst-case material configuration and environment usage. Both simulated panel/assembly (configuration) and crew bay (system) tests are required (see figure 12). Both internal and external ignition sources are used. Internal sources simulate sources within electrical equipment, and external sources simulate fires that can propagate to the test material but are started in other areas. These tests are used as the final verification and acceptance of nonmetallic materials.

Crew bay tests (system) are performed using the spatial and geometric configuration or worst-case assemblies. The purpose of the test is to define all the worst-case, potential ignition sources to ensure that fires are restricted to well-defined, discrete areas. This is the only type of test that ensures that no propagation path exists between assemblies.

In the Apollo program, full-scale mockup tests were made to investigate basic design approaches, including elimination of long propagation paths, addition of nonflammable coatings and containers, and the use of fire breaks. Deliberate

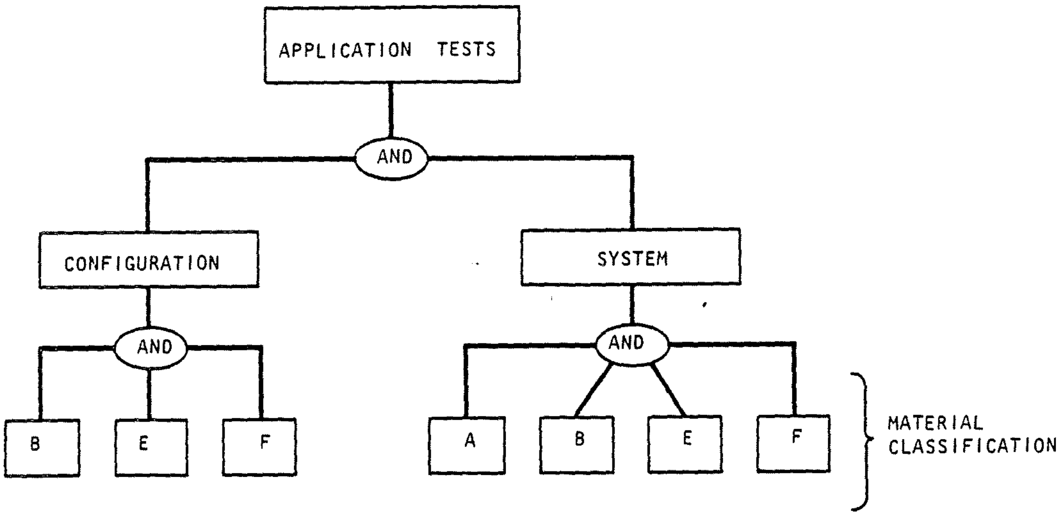

Figure 12. Application Tests

ignitions of materials at various locations within the spacecraft were made under realistic flight conditions. These tests were conducted to determine if the fire would propagate, the magnitude of the fire, the nature of propagation paths, and to identify toxic products resulting from combustion. The NASA acceptance criteria for the application tests are as follows:

Category	Description
A & B	Major and minor materials used in panels, assemblies, etc, in the crew bay when tested according to their application category must be self-extinguishing. They must not propagate to adjacent equipment, and the fire must be restricted to discrete areas.
E & F	Materials used in sealed and vented containers when tested must not rupture these containers or allow flames to be emitted outside.

In many instances a hazardous material was flameproofed by some simple method, such as applying nonflammable tapes, treating with nonflammable coatings, using heat sink devices, etc., to reduce the flammability hazard to an acceptable level.

In summary, there now exists a series of standard tests that have been used for a considerable period of time to evaluate the characteristics of material combustion in oxygen-enriched environments. These tests in the current form are sufficiently reproducible to provide a strong foundation for selection of materials for use in the design of manned spacecraft and, with minor modifications, for direct application to other programs. The proof of the use of any material still is, and must be, passing a verification test in the configuration of intended use.

The overall objectives of fireproofing a spacecraft cabin are similar to those of fireproofing an aircraft interior. Some significant differences exist, however, which must be considered in the final selection of materials. The spacecraft crew bay area contains a closed environment, while an aircraft cabin contains a ventilated, open environment. Consideration of odor and toxic off-gassing are therefore much more critical for spacecraft than for aircraft. Other considerations such as durability, aesthetic value, dyeability, etc., play an important role in the selection of materials for aircraft interiors.

APPENDIX J

OHIO STATE UNIVERSITY RELEASE RATE TEST

J1.0 Scope

J1.1 This test method determines the release rate of heat and visible smoke* from noise control products when exposed to different levels of radiant heat using the test apparatus, configurations, and procedures described by this test method.

J1.2 The method provides for radiant thermal exposure of a specimen, both with and without pilot. For piloted ignition, ignition may be effected by direct flame impingement on the specimen (piloted, point ignition) or by placing the pilot to ignite gases evolved by pyrolysis of the specimen.

J1.3 Heat and smoke release are measured from the moment the specimen is injected into a controlled exposure chamber. The measurements are continued during the period of ignition (and progressive flame involvement of the surface of the case of point ignition), and to such a time the test is terminated.

J1.4 The rate of heat and smoke release is calculated per m^2 of original surface area exposed. If a specimen swells, sags, delaminates or otherwise deforms so that the exposed surface area changes, calculated release rates correspond to the original area, not to the new surface area.

J1.5 The method is limited to specimen sizes of materials described in paragraph J5.1 and to products from which a test specimen can be taken that is representative of the product in actual use. The test is limited to exposure of one surface to radiant flux, wherein the exposed surface can be either vertical or horizontal.

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*Smoke is defined in terms of the obscuration of transmitted light caused by the pyrolysis and combustion products released during the test. The definition is given in paragraph J8.2.1 of this test method.

J1.6 The method tests noise control products under a constant, imposed external heat flux that may be varied from 0 to 10 W/cm^2.

J2.0 Significance

J2.1 The test method provides a description of the behavior of noise control product specimens under a specific fire exposure, in terms of the release rate of heat and visible smoke. The change in behavior of noise control products with change in heat flux exposure can be determined by testing specimens in a series of exposures that cover a range of heat fluxes.

J2.2 The data obtained for a specific test describe the rate of heat and smoke release of the specimen when exposed to the specific environmental conditions and procedures used in performing that test.

J2.3 The entire exposed surface of the specimen will not be burning during the progressive involvement phase when piloted, point ignition (impingement) procedures are used. During the period of progressive surface involvement, release rates of heat and smoke are "per m^2 of exposed surface area," not "per m^2 of flame-involved surface."

J2.4 Heat release values depend on mode of ignition. Gas phase ignition gives a more dimensionally consistent measure of release rate when very rapid or immediate flame involvement of the specimen's surface occurs. However, piloted, point ignition allows release rate information to be obtained at external heat flux from zero up to that required for satisfactory gas phase ignition—usually over two W/cm^2. In many situations the most useful release rate information relative to a developing fire is obtained between zero and two W/cm^2 external exposure. No correlation between the two modes of piloted ignition has been established.

J2.5 Release rates depend on many factors, some of which cannot be controlled. Samples that produce a surface char, layer of adherent ash, or those that are composites or laminates will not attain a steady-state release rate. Thermal thin specimens (that is, specimens whose unexposed surface changes temperature during period of test) will not attain a steady-state release rate.

Therefore, release rates for the same material will not be the same for specimens having a different thickness or method of mounting.

J2.6 For specimens tested in horizontal orientation, the heat release values are for the specific specimen size (exposed area) tested. Results are not directly scaleable to different exposed surface areas for some products.

J2.7 No general relationship between release rate values obtained from horizontally and vertically oriented specimens has been established. Specimens should be tested as the sample is oriented in use. Specimens that melt and drip in vertical orientation should also be tested horizontally.

J3.0 Summary of Method

J3.1 The specimen to be tested is injected into an environmental chamber through which a constant flow of air passes. The specimen's exposure is determined by a radiant heat source adjusted to produce the desired radiant heat flux to the specimen. The specimen may be tested so that the exposed surface is horizontal or vertical. Ignition may be accomplished by autoignition, piloted ignition or evolved gases, or by point ignition of the surface. The change in temperature and optical density of the gas leaving the chamber are monitored, from which data the release rates of heat and visible smoke, as defined in paragraph J8.2.1, are calculated.

J4.0 Apparatus

J4.1 Configuration

A Release Rate Apparatus used to determine release rates of heat and smoke by this test method is shown in figure J1. All exterior surfaces of the apparatus, except the holding chamber, shall be insulated with 25-mm thick, low density, high temperature, fiberglass board insulation. Type 475-FR Owens-Corning flat duct board or equivalent with a density of 65 kg/m^3 (4 lb/ft^3), a thermal conductivity of 0.003 W-cm/m^2-$^\circ$K (0.23 Btu-in/ft^2-$^\circ$F-hr), and a thickness of 1 inch is satisfactory. A gasketed door, through which the sample injection rod slides, forms an airtight closure on the specimen hold chamber.

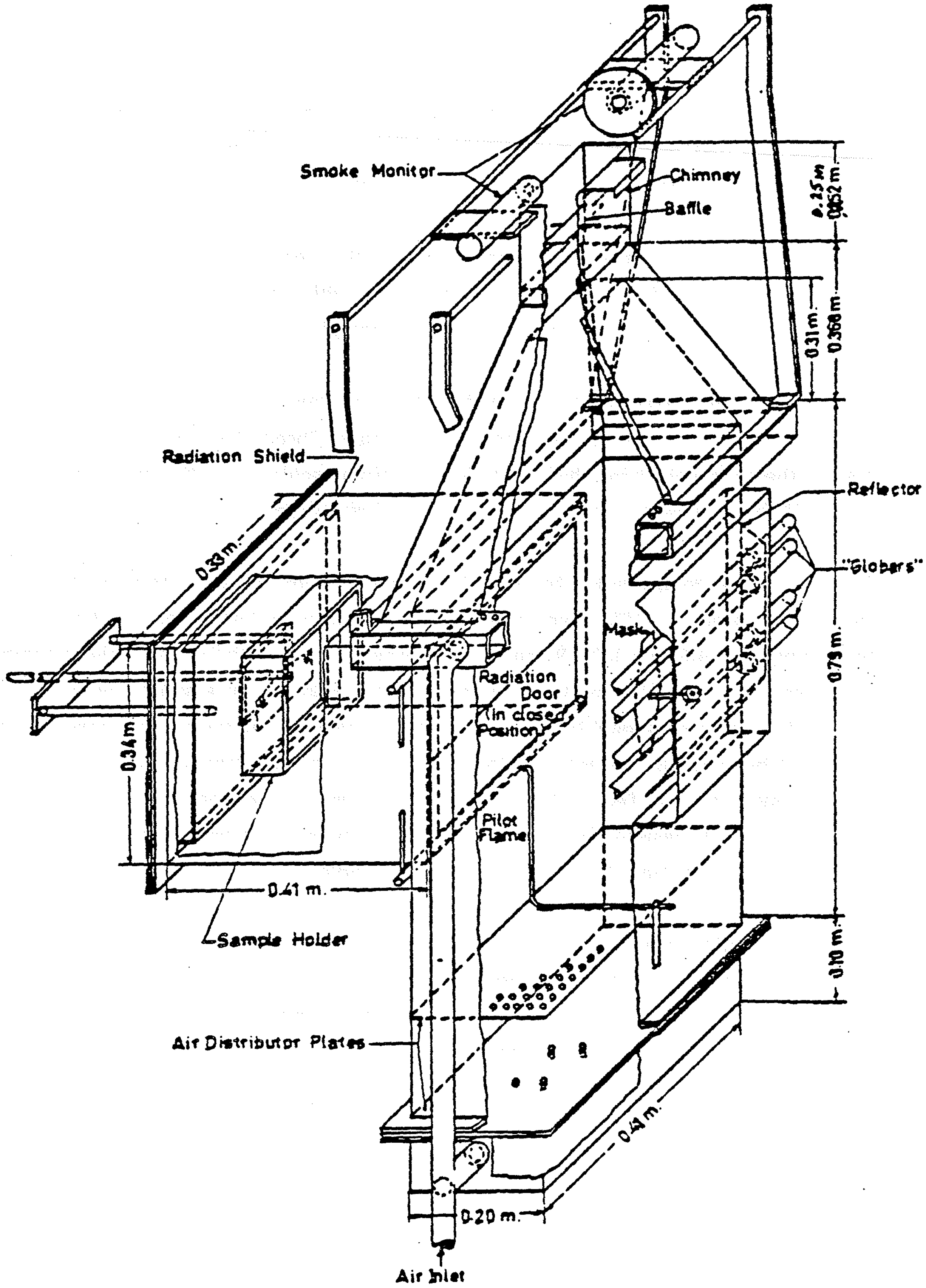


Figure J1. Release Rate Apparatus

J4.2 Thermopile

J4.2.1 The temperature difference between the air entering the environmental chamber and that leaving is monitored by a thermopile having 3 hot and 3 cold 24-gage Chromel-alumel junctions. The hot junctions are spaced across the top of the exhaust stack. Two hot junctions are located 25 mm (1 inch) from each side on diagonally opposite corners, and the third in the center of the chimney's cross section, 10 mm (0.4 inches) below the top of the chimney. The cold junctions are located in the pan below the lower air distribution plate (see paragraph J4.5).

J4.2.2 A compensator tab is made from 0.55 mm (0.022 inch) stainless steel sheet, 10 by 20 mm. An 80-cm length of 24-gage Chromel-alumel glass-insulated duplex thermocouple wire shall be welded or silver-soldered to the tab as shown in figure J2, and the wire bent back so that it is flush against the metal surface.

J4.2.3 The compensator tab shall be mounted on the exhaust stack, as shown in figure J3, using a 6-32 round-head machine screw, 12-mm long. Add small (approximately 4.5 mm I.D., 9 mm O.D.) washers between the head of the machine screw and the compensator tab to give the best response to a square wave input. One or two washers should be adequate. The "sharpness" of the square wave can be increased by changing the ratio of the output from the thermopile and compensator thermocouple that is fed to the recorder. The ratio is changed by adjusting the 1 kilohm variable resistor (R_1) of the thermopile bleeder shown in figure J4. When adjusting compensation, keep R_1 as small as possible.

J4.2.4 Adjust washers and variable resistor (R_1) so that 90 percent full scale response is obtained in 8 to 10 seconds. There shall be no overshoot as shown in figure J5a. If an insufficient number of washers is added or R_1 is too small, the output with a square wave input will look like figure J5b. If too many washers are added and R_1 is too large, the output will look like figure J5a.

J4.2.5 Subtract the output of the compensator from the thermopile. The junctions enclosed in the dotted circle of figure J5 are kept at the same constant temperature by electrically insulating the junctions and placing them on the pipe carrying air to the manifold, then covering them and the pipe with thermal insulation.

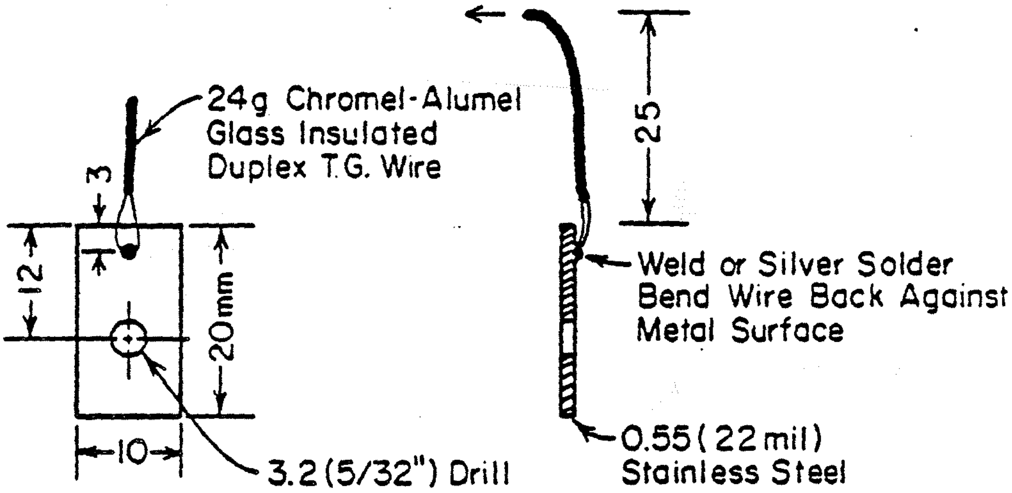


Figure J2. Compensator Tab

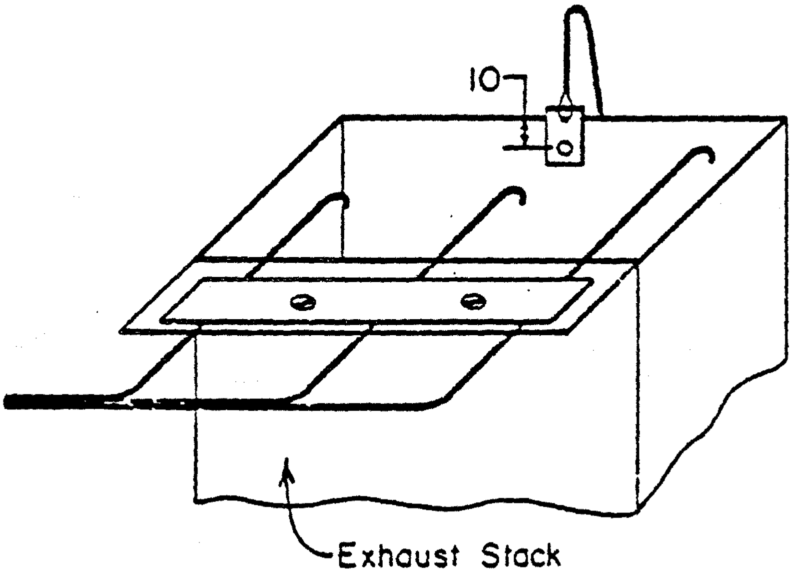


Figure J3. Compensator Tab Mount

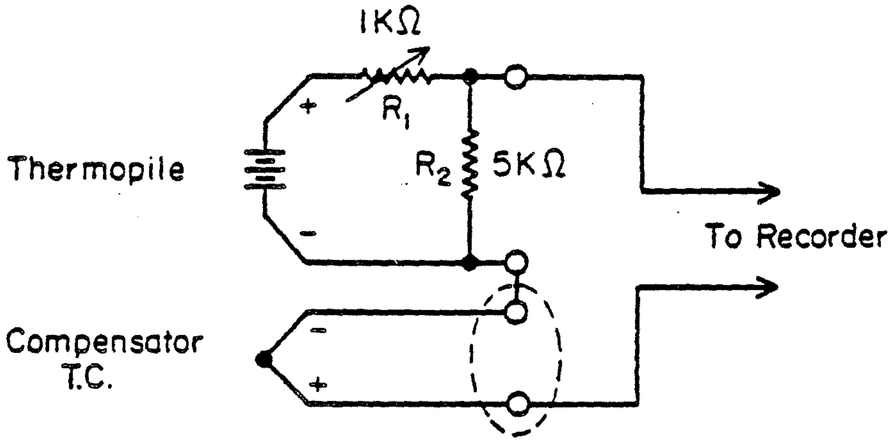
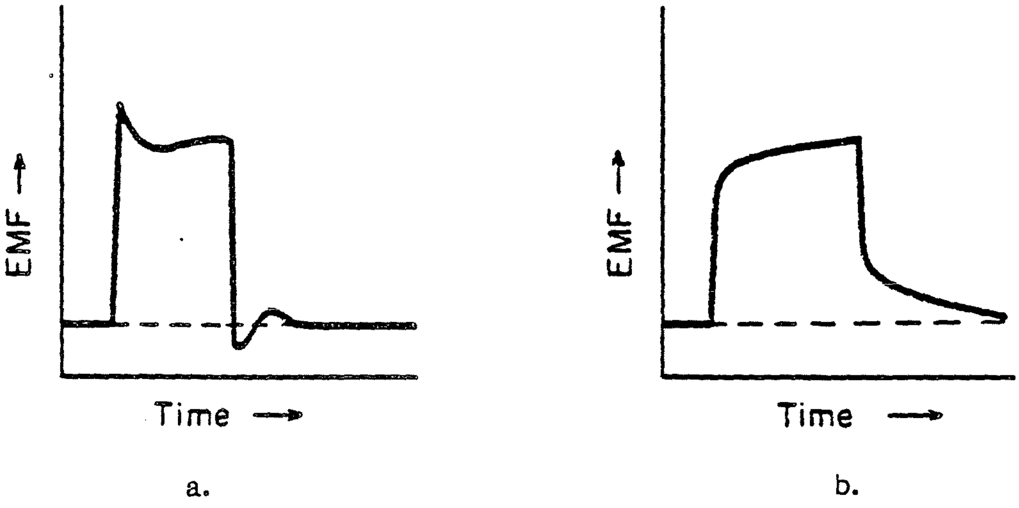


Figure J4. Wiring Diagram



a.

b.

Figure J5. Square Wave Response

J4.3 Smoke Monitor

J4.3.1 A photometer (figure J6) measures the percent of light transmitted through the gases leaving the apparatus. A "Clairex" CL 505 photocell and circuitry, shown in figure J7, shall be used and calibrated as described in section J8.2. The light source shall be a No. 82 miniature incandescent lamp operated at its recommended current of one ampere.

J4.3.2 The smoke monitor apparatus shall be mounted with the centerline 25 mm (1 inch) above the exhaust stack and centered parallel to the length of the opening. The two parts of the optical system shall be 180 mm (7 inches) apart. A continuous flow of constant-temperature air, approximately 0.004 m^3/min shall be maintained to the air lines to prevent smoke from entering the smoke monitor.

J4.4 Radiation Source

A type LL radiant heat source consisting of four silicon carbide elements* (mounted as shown in figures J8a and J8b) with dimensions of 20x12x5/8 inches and a nominal resistance of 1.4 ohm, can be used to generate heat flux up to 10 W/cm^2. The diamond-shaped mask of 24-gage stainless steel is added to provide uniform heat flux over the area occupied by the 150x150-mm vertical sample. A power supply of 12.5 kVA, adjustable from 0 to 270 volts, is required.**

J4.5 Air Distribution System

J4.5.1 The air entering the environmental chamber is distributed by a 6.3-mm (1/4-inch) aluminum plate with eight No. 4 holes spaced 51 mm (2 inches) from one side on 102-mm (4-inch) centers. The plate is mounted at the base of the environmental chamber. A second plate of 18-gage steel having 120 evenly spaced No. 28 holes is mounted 150 mm (6 inches) above the aluminum plate. A well-regulated air supply is required.

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*Available from the Carborundum Company, "Globar" Division, Niagara Falls, N. Y.

**If a heat flux of up to 10 W/cm^2 is desired, a separate power supply for each pair of elements can be used where maximum voltage is less than 270 volts.

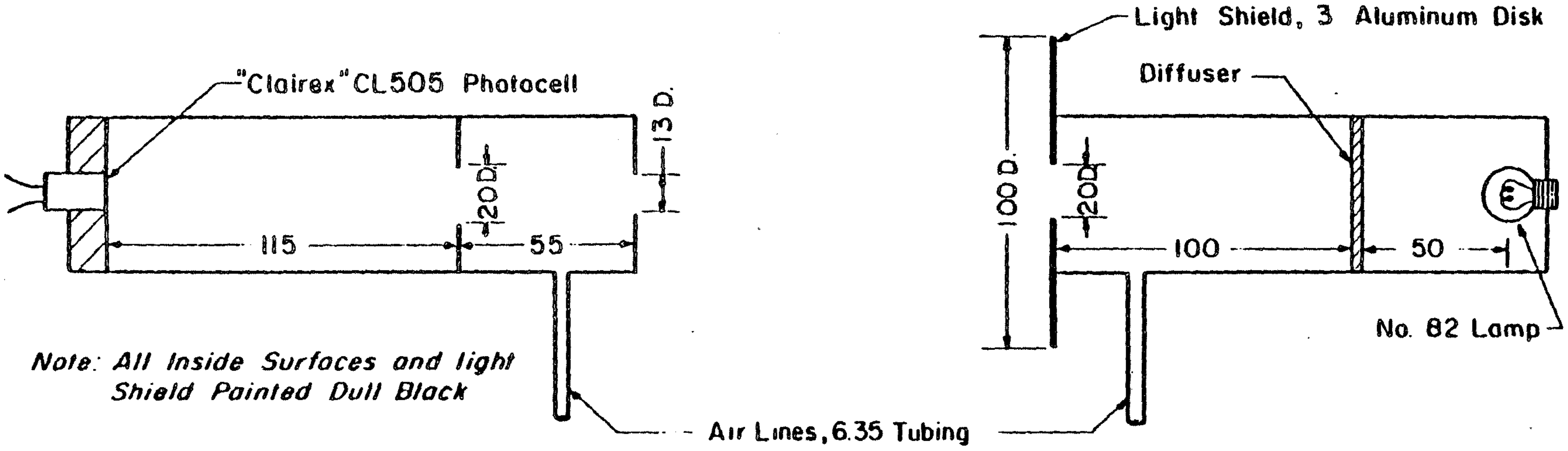

Figure J6. Smoke Monitor

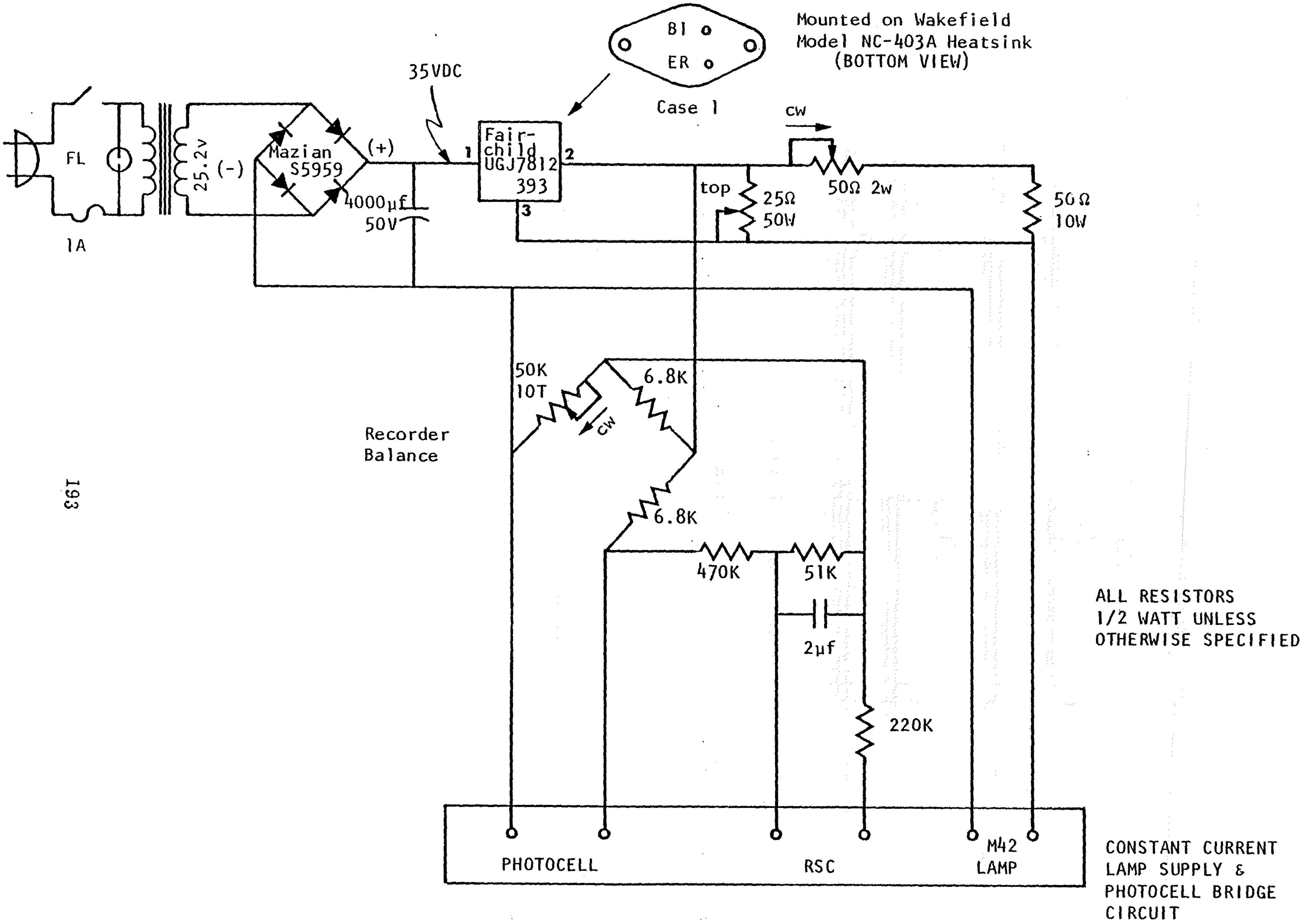

Figure J7. Smoke Monitor Circuit

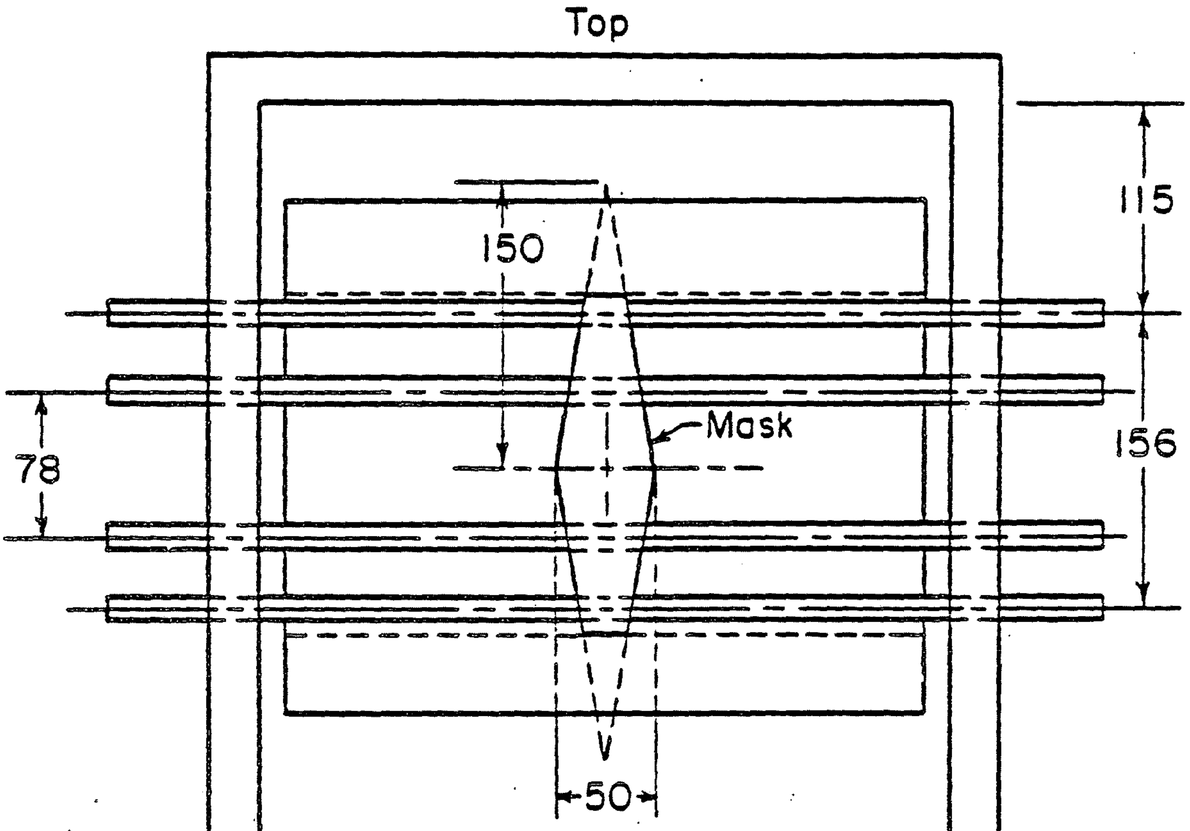

Figure J8a. "Globar" Radiant Panel

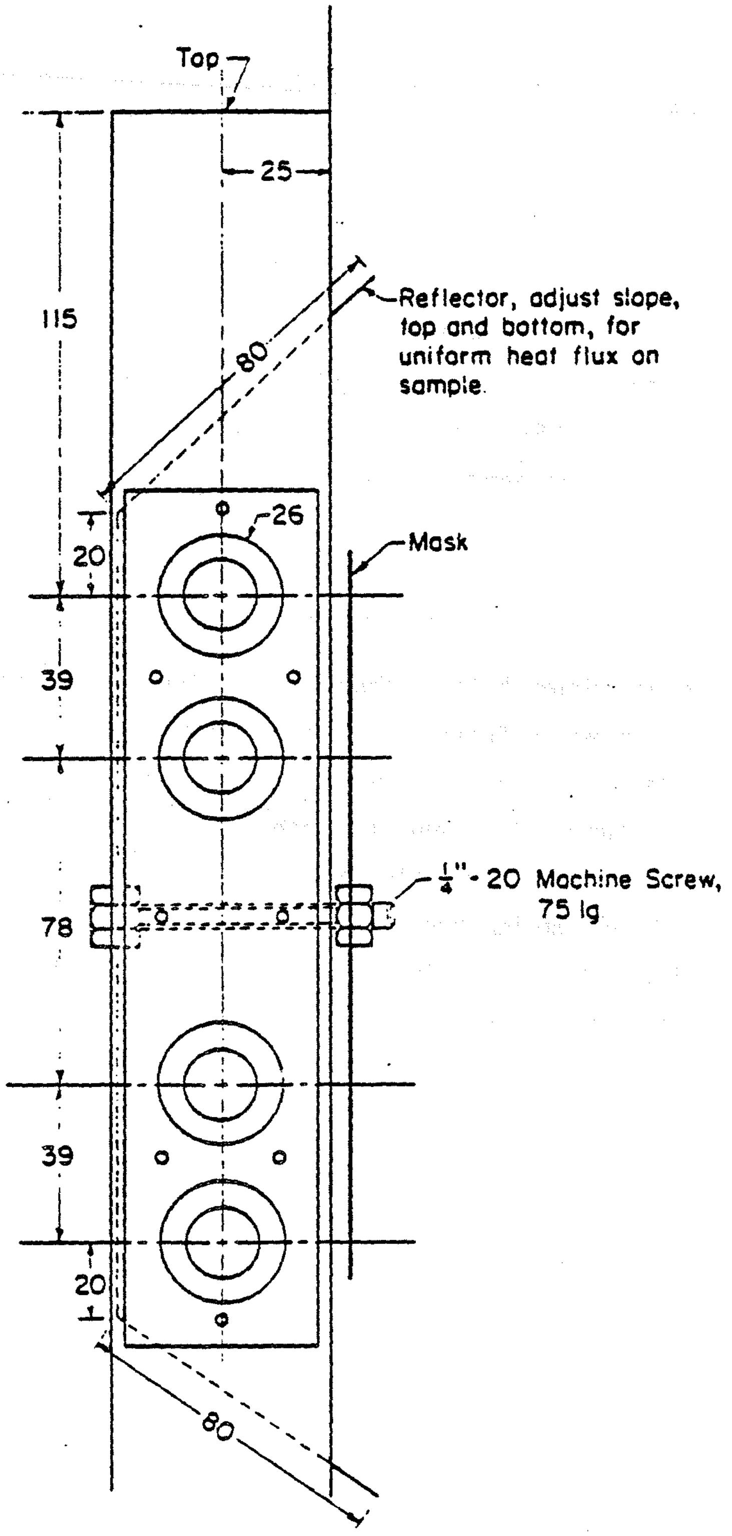

Figure J8b. "Globar" Radiant Panel

J4.5.2 The air supply manifold at the base of the pyramidal section has 48 evenly spaced No. 26 holes 10 mm from the inner edge of the manifold. This assures an air flow of 0.03 m^3/sec (63 ft^3/min) between the pyramidal sections and 0.01 m^3/sec (21 ft^3/min) through the environmental chamber when the total air flow to the apparatus is controlled at 0.04 m^3/sec.

J4.6 Exhaust Stack

An exhaust stack, 133x70 mm (5.25x2.74 inches) in cross section and 254 mm (10 inches) long, fabricated from 28-gage stainless steel is mounted on the outlet of the pyramidal section. A 25x77-mm (1x3-inch) plate of 31-gage stainless steel is centered inside the stack, perpendicular to the air flow, 75 mm (3 inches) above the base of the stack.

J4.7 Specimen Holders

J4.7.1 Vertical specimen holders shall be attached to the injection rod using the vertical support shown in figure J9. Two different types of specimen holders shall be provided, one for 150x150-mm (6x6-inch) specimens to be tested in a vertical orientation (figure J10) and the other for 110x150-mm (4-1/2x6-inch) specimens to be tested in a horizontal orientation (figure J11). Each holder is provided with a v-shaped spring pressure plate and a 12.7-mm (1/2-inch) backing plate of rigid insulation board* having a density of 350 ± 80 kg/m^3 (22 ± 5 lb/ft^3) and a thermal conductivity of 0.008 ± 0.001 W/m-^oK (0.5 ± 0.1 But-in/^oF-ft^2-hr). The position of the spring pressure plate may be changed to accommodate different specimen thicknesses by inserting a retaining rod in different holes of the specimen holder frame.

J4.7.2 The unexposed surfaces of the specimen shall be covered with 2 thicknesses of 0.025-mm aluminum foil pressed tightly to sides and back. This foil shall be carried out and over the lip on the horizontal holder to form a 5-mm-high shield from radiant heat immediately to the side (see figure J11).

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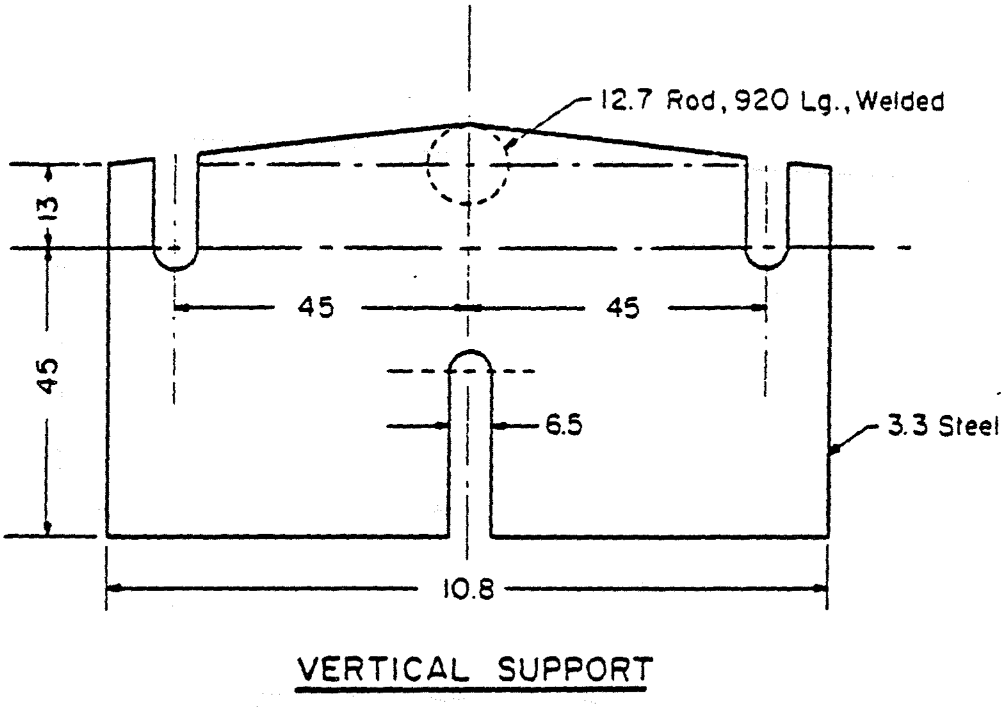
* "Kaowool" Rigidized Mill Board, Babcock Wilcox Refractories, Augusta, Ga., or its equivalent is satisfactory.



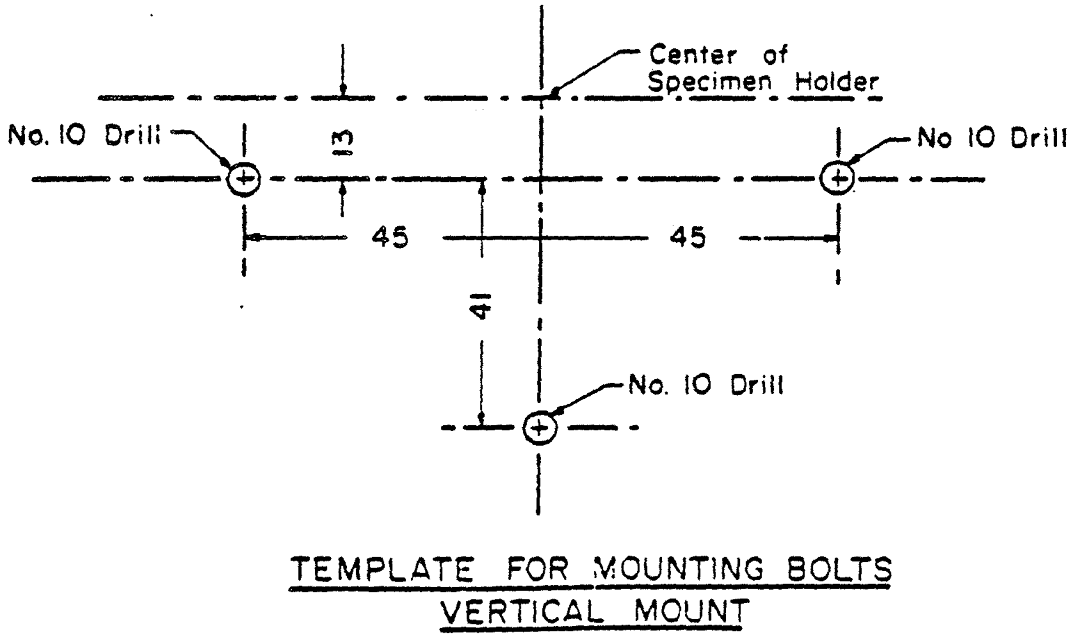
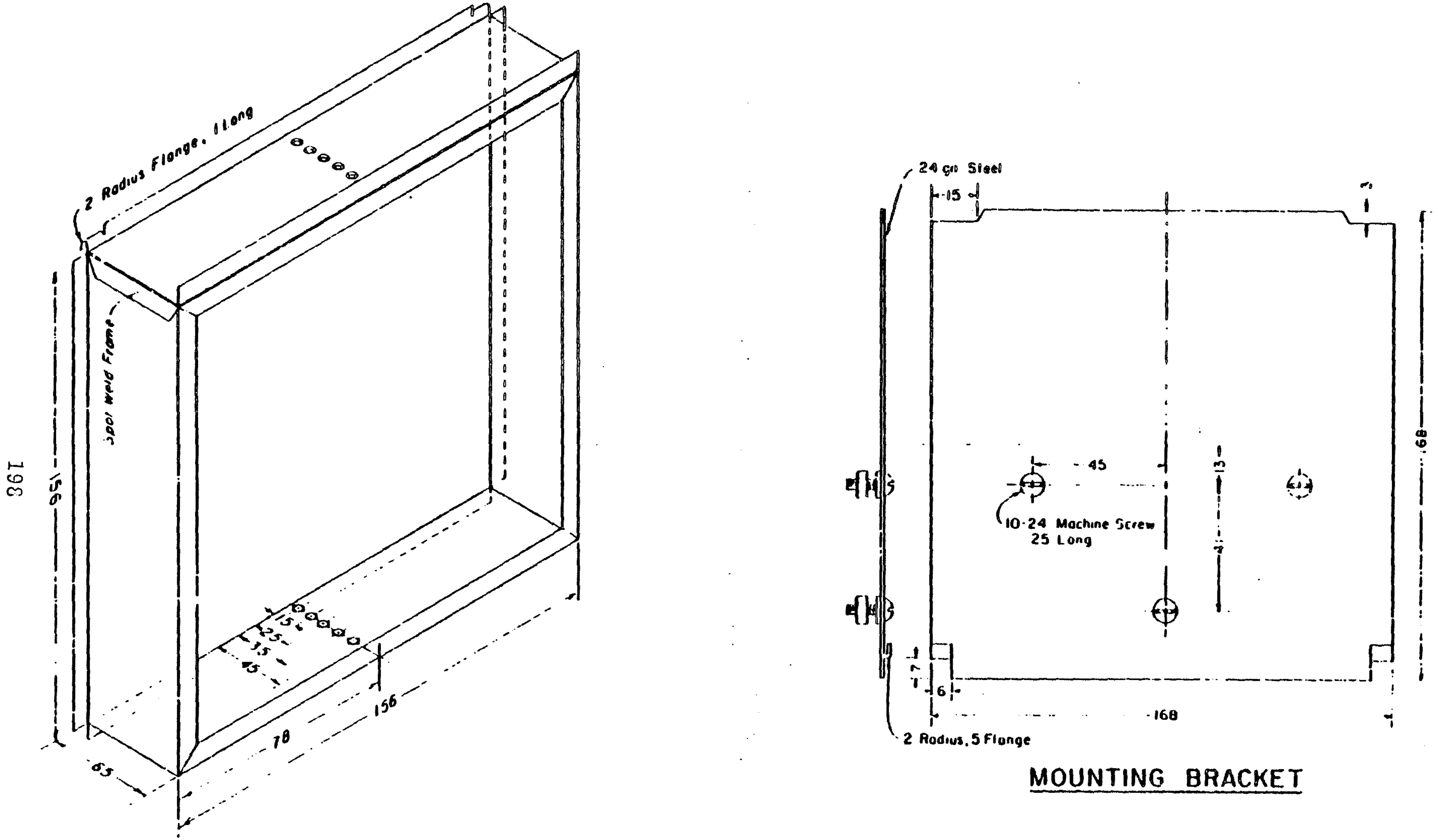


Figure J9. Vertical Holder Mount



MOUNTING BRACKET

Figure J10. Vertical Specimen Holder

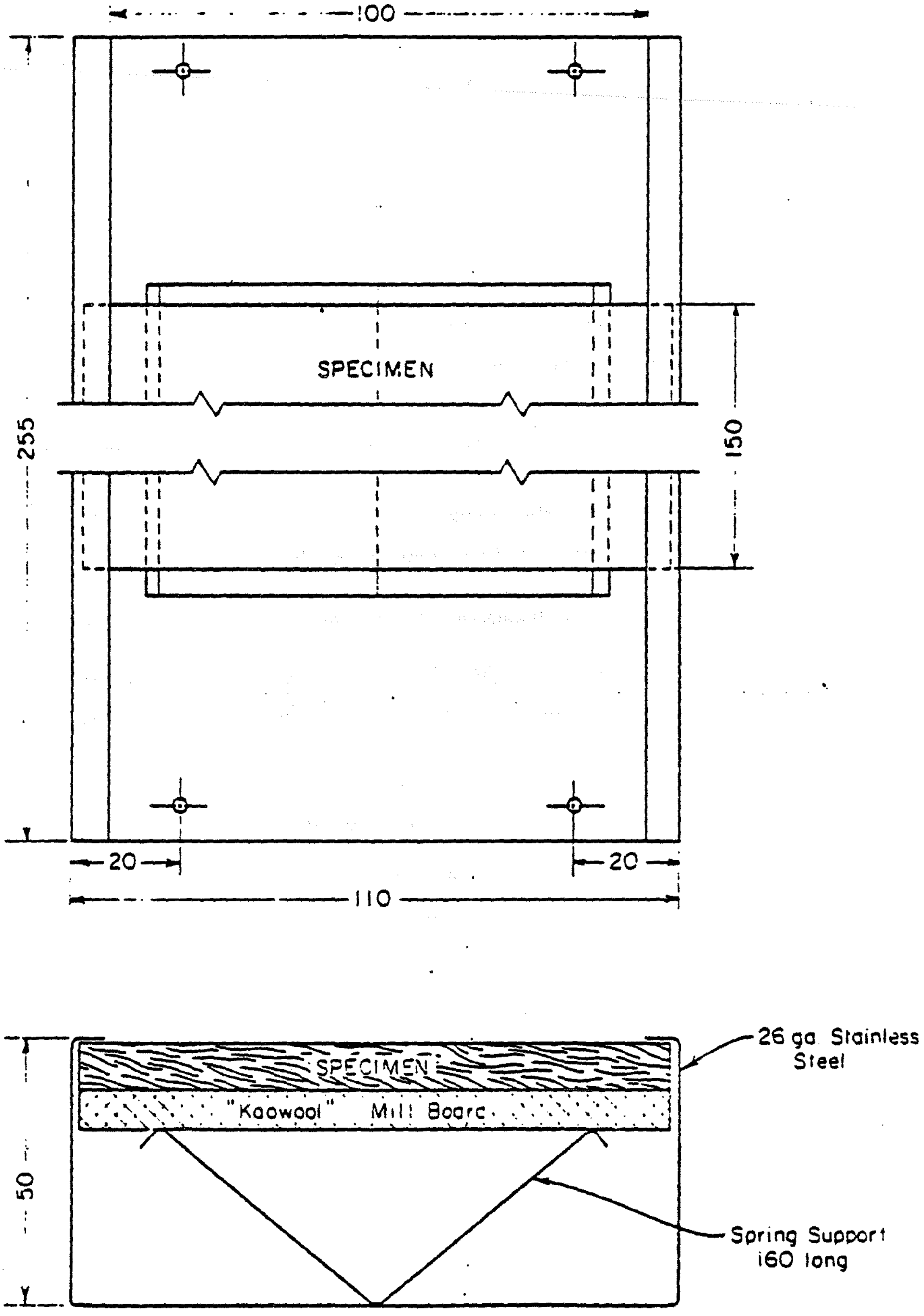


Figure J11. Horizontal Specimen Holder

J4.7.3 Pans or plates for supporting specimens that cannot be mounted in the holders described in paragraph J4.7.1, or are to be tested in an unrestrained condition, shall be constructed so that the weight of the holder is minimized to reduce the heat capacity of the supporting structure. For horizontal specimens that melt, and thermally thin specimens, the aluminum foil "boat" described in paragraph J4.7.2 shall be set on, or backed by, the 12-mm (0.5-inch) rigid insulation board described in paragraph J4.7.1.

J4.7.4 The adjustable radiation shield (figure J1) on the vertical specimen holder, which covers the opening made when the radiation doors are in their open position and the specimen is inserted, is adjusted to position the front surface of the specimen 100 mm (4 inches) from the entrance to the environmental chamber.

J4.7.5 The frame for the horizontal position reflector is shown in figure J12, and the horizontal assembly in burn position is shown in figure J13.

J4.8 Radiation Reflector for Horizontally Mounted Specimen

A new 350x225-mm sheet of 0.025-mm (0.001-inch) aluminum foil shall be placed over the rod supports before each test with the bright side toward the panel. The foil shall be supported by crimping around all edges with a 25-mm (1-inch) overlap.

J4.9 Radiometers

Total flux meters* (calorimeters) shall be used to measure the total heat flux for both horizontal and vertical specimens at the point where the center of the specimen's surface is located at the start of the test. The total flux meters shall have view angles of 180 degrees and be calibrated for incident flux.

J4.10 Pilot Flame

Pilot flame tubing shall be of stainless steel with 6.3-mm (1/4-inch) O.D. and 0.81-mm (0.032-inch) wall thickness. The fuel shall be methane, or natural gas having 90 percent or more methane. A methane-air mixture, 120 cm^3/min gas and 850 cm^3/min air, shall be the fuel mixture fed to the pilot flame burner.

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* A model R-8015-C radiometer for vertical specimens and a model P-8400-J pyroheliometer for horizontal specimens, available from Hy-Cal Engineering, Sante Fe Springs, Cal., or their equivalents, shall be used with water cooling and without quartz window.

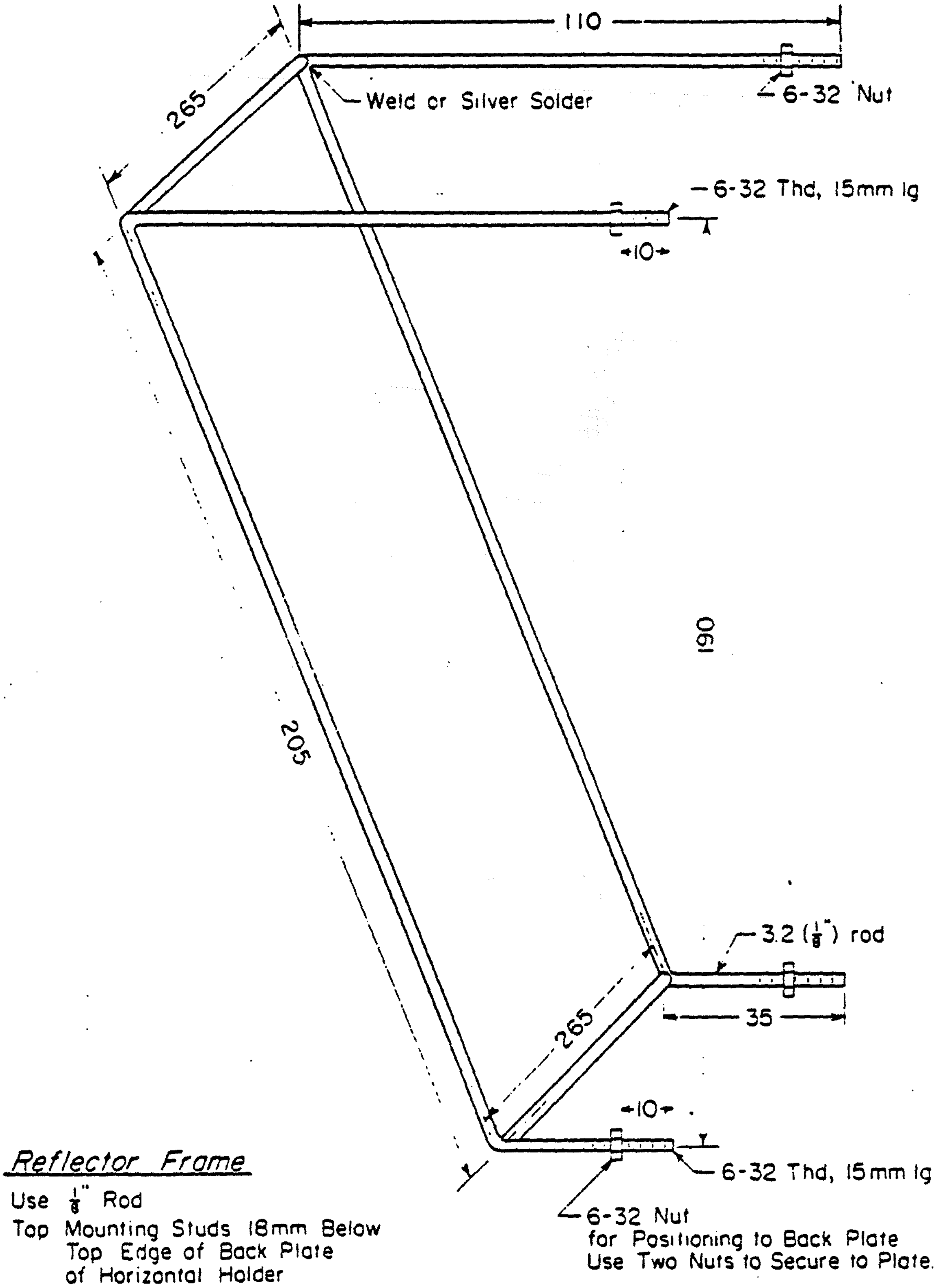

Figure J12. Reflector Frame

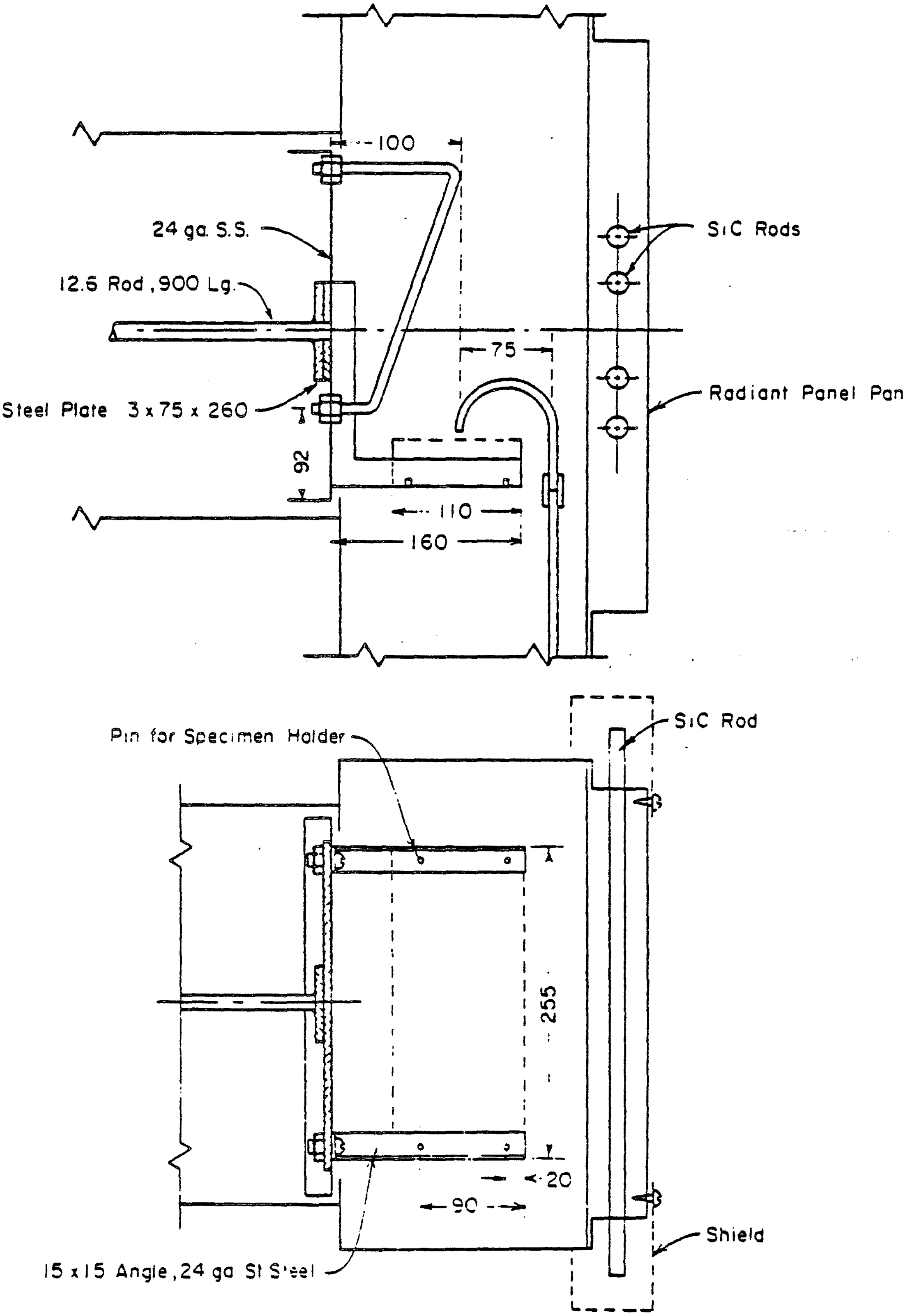

Figure J13. Horizontal Configuration

J4.11 Pilot Flame Positions

J4.11.1 In addition to piloted and nonpiloted modes of operation, piloted ignition of a specimen may be accomplished by locating the pilot flame at a different position relative to the sample surface so that the flame may or may not impinge on the specimen's surface. The location chosen depends on the nature of ignition to be simulated by the test. In all piloted ignitions, pilot flame size shall be that described in section J4.10. Pilot positions are described in paragraphs J4.11.2 through J4.11.4. Piloted ignition by an impinging flame is required when release rate information is required at a heat flux below that at which the pyrolysis rate of the specimen can maintain a combustible gas phase. At heat flux above that producing a combustible gas mixture over the surface of the sample, either piloted point ignition or gas phase (self-) ignition may be used. In gas phase (self-) ignition, surface involvement is usually very rapid, eliminating the progressive involvement phase of the release rate curve. If the rate of surface involvement at a given heat flux is to be observed, piloted point ignition shall be used.

J4.11.2 Piloted Ignition - Vertical Specimen with Impinging Flame. The normal position of the end of the pilot burner tubing is 10 mm from the perpendicular to the exposed vertical surface of the specimen. The centerline at the outlet of the burner tubing shall intersect the vertical centerline of the sample 5 mm above the lower edge of the specimen. An upper, nonimpinging pilot burner shall also be used. The burner and its location is described in paragraph J4.11.4.

J4.11.3 Piloted Ignition - Horizontal Specimen with Impinging Flame. The normal position of the end of the burner tubing is 10 mm above and perpendicular to the exposed horizontal surface of the specimen. The centerline at the outlet of the burner intersects the center of the specimen.

J4.11.4 Piloted Ignition - Vertical Specimen Without Impinging Flame. The pilot burner tubing shall be of stainless steel with 6.3-mm (1/4-inch) O.D., 0.8-mm (0.032-inch) wall thickness, and 360-mm long. One end of the tubing shall be closed, and three No. 40 holes, 60 mm (2.5 inches) apart, all radiating in the same direction shall be drilled into the tubing for gas ports. The first hole shall be 5 mm from the closed end of the tubing. The tube is inserted into the environmental chamber through a 6.6-mm (1/4-inch) hole drilled 10 mm above the upper edge of the window frame. The tube is supported and positioned by an adjustable z-shaped support mounted outside the environmental chamber and above the viewing window. The tube is positioned above and 20 mm behind the exposed upper edge of the specimen. The middle hole shall be in the vertical plane perpendicular to the exposed surface of the specimen. Fuel gas to the burner shall be methane, or natural gas with at least 90 percent methane. Flow of fuel gas shall be adjusted to produce a flame length of 25 mm.

J5.0 Sample Preparation

J5.1 Configuration

The standard size vertically mounted specimen has an exposed surface of 150x150 mm (6x6 inches) and maximum thickness of 100 mm (4 inches). The standard size horizontally mounted specimen has an exposed surface of 100x150 mm (4x6 inches) and a maximum thickness of 45 mm (1-3/4 inches). Thin samples, such as wall or floor coverings, shall be mounted in the same manner as used. For example, a wall covering to be glued to gypsum wallboard shall be tested when glued to a section of gypsum wallboard using the same type of adhesive. The assembly shall be considered the specimen to be tested.

J5.2 Conditioning

Specimens shall be conditioned in a standard laboratory atmosphere ($23^{\circ}C$ and 50 percent relative humidity) as described by Procedure A, ASTM D 618-61, "Standard Methods of Conditioning Plastics and Electrical Insulating Materials for Testing."

J5.3 Mounting

Only one surface of a specimen shall be exposed during a test run. Specimens having a slab geometry shall be insulated on five sides. A double layer of 0.025-mm aluminum foil wrapped tightly on sides and back is satisfactory. For products whose surface is not a plane, the method of mounting and calculating exposed surface areas must be described when reporting results.

J6.0 Procedure

J6.1 If piloted ignition is to be used, the pilot flame is ignited and its position, as described in section J4.11, is checked.

J6.2 The power supply to the radiant panel is set to produce the desired radiant flux. The flux is measured at a point corresponding to the center of the specimen's surface when positioned for testing. The radiant flux is measured with the pilot flame displaced to the side of the environmental chamber and after air flow through the equipment is adjusted to the desired rate.

J6.3 The air flow to the equipment is set at 0.04 ± 0.001 m^3/sec (84 ± 4 ft^3/min) at atmospheric pressure and 23°C. The stop on the vertical specimen holder rod is adjusted so that the exposed surface of the specimen will be positioned in the environmental chamber and 100 mm (4 inches) from the chamber entrance.

J6.4 Steady-state conditions, such that the radiant flux does not change more than 0.5 kW/m^2 (0.045 Btu/ft^2-sec) over a 10-minute period, shall be maintained before the specimen is placed in the environmental chamber.

J6.5 The specimen is placed in the hold chamber with the radiant shield doors closed. The air-tight outer door shall be secured, recording devices started, and output of the thermopile and smoke detector set to "zero" on the recorder. "Zero" conditions are those existing at the time immediately before the sample is injected. The specimen shall be retained in the hold chamber 60 ± 5 seconds before injection.

J6.6 When the specimen is to be injected, the radiation doors are opened, and the sample is injected into the environmental chamber.

J6.7 Injection of the sample occurs at time zero. A continuous record of the output from the photometer circuit and thermopile shall be made during the time the specimen is in the environmental chamber.

J6.8 Normal test duration time is 10 minutes. For specimens that are totally consumed in less than 10 minutes, the test may be terminated when heat and smoke release have ceased.

J6.9 A blank run (baseline) test shall be performed, during which the specimen holder, without specimen, shall be injected and heat release versus time data taken. At low heat fluxes, corrections for heat absorbed by the specimen holder should be negligible, but at a heat flux over 10 kW/m^2, a correction due to the specimen holder may be necessary (see paragraph J8.1.2).

J6.10 At least triplicate determinations shall be made. If the release rate value or values being compared for a given specimen are outside the range described in paragraph J10.1.2, a greater number of replicate determinations are required, as given in paragraph J10.1.3.

J7.0 Calibration of Equipment

J7.1 Heat Release Rate

J7.1.1 A burner, shown in figure J14, shall be placed over the end of the pilot flame tubing using a gas-tight compartment. The gas to the pilot flame shall be accurately metered (for example, by a wet test meter) and set at a low flow rate. The gas shall be at least 90 percent methane and have an accurately known net heating value. After the output of the recorder is "zeroed," the gas flow to the burner shall be increased to a higher preset value and allowed to burn at this steady rate for an accurately measured duration of 4.0 minutes. The flow of gas shall be changed abruptly to its initial low flow, or "zero," rate and continued for 4.0 minutes. At the end of the 4.0 minutes, the baseline shall be adjusted to zero, if necessary, and the gas flow again increased to the higher preset value and allowed to burn for 4.0 minutes, after which the gas flow is again returned to its low flow rate. The sequence is repeated until a constant increase and consistent return to the "zero" baseline is achieved.

J7.1.2 The difference in flow between the low and high settings for gas flow multiplied by its net heating value shall be used as the rate of heat release. The output of the differential temperature recorder, after reaching a steady-state value, is the output corresponding to that heat release rate. At least three levels of heat release shall be used. The heat release rate shall not exceed 7.75 kW (440 Btu/min), nor be less than 1.4 kW (80 Btu/min) when calibrating.

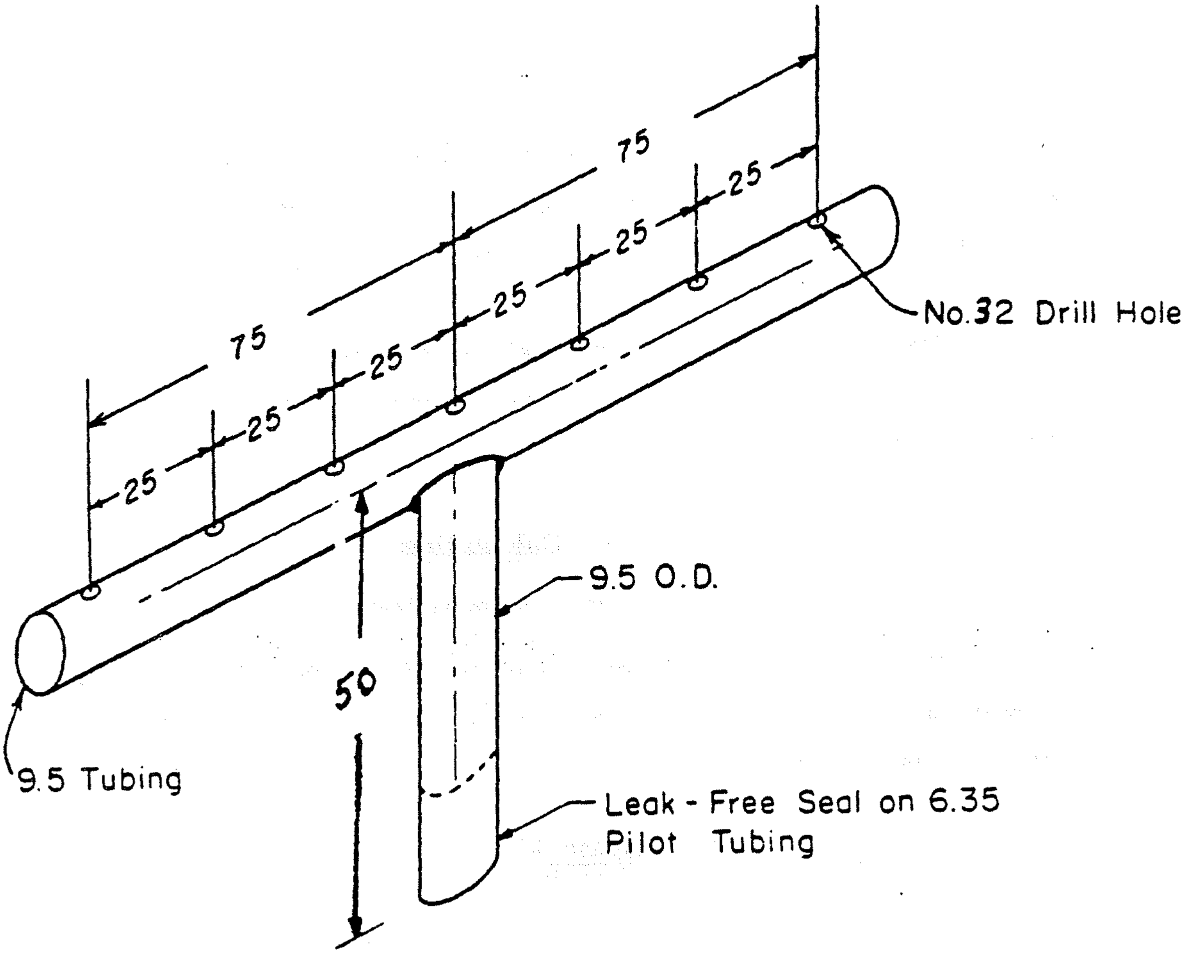

Figure J14. Calibration Burner

J7.2 **Smoke Photometer Calibration**

J7.2.1 Four neutral density filters, having accurately known optical densities of approximately 0.1, 0.2, 0.4, and 1.0, shall be used to calibrate the smoke photometer. The output of the photometer circuit is "zeroed" with no filter or smoke in the light path (zero absorbance). Each of the neutral density filters are alternately placed in the light path, and finally the light path is completely obscured (zero percent transmission). A plot of percent transmission (percent T) versus recorder output is made. For the photometer of section J4.3, this will not be a straight line. Using the relationship, Optical Density = log 100/%T, values of optical density (absorbance) versus recorder output are constructed.

J7.2.2 The optical density of the neutral density filters shall be determined at a wavelength of 580 mm (22.8 inches).

J7.2.3 After the optical density versus recorder output has been determined, minor variations due to aging of the light source or its replacement shall be compensated for by adjusting the 50-ohm, 2-watt resistor to produce the same chart reading for a given neutral density filter.

J7.2.4 The recorder's sensitivity shall be adjusted so that a full scale chart reading is produced by a change in percent transmission of (approximately) 100 percent to 30 percent.

J8.0 Calculations

J8.1 Heat Release Rate

J8.1.1 Heat release rates are calculated from the chart readings of the thermopile output, the exposed surface area of the specimen, and the constant k_H, where, from calibration runs,

$$k_H = \frac{\text{Heat Release (kW)}}{\text{Chart Reading}}$$

Then Heat Release Rate $kW/m^2 = k_H$ (Chart Reading)/A,

where A = exposed surface area of specimen (m^2).

J8.1.2 Heat release rates are determined from chart readings as a function of time. Sufficient points should be taken along the time axis to faithfully reproduce 0.10 cycle/second fluctuations. Smoothed values every five seconds are adequate, and may be taken less frequently when heat release rates change slowly. When blank run corrections (see paragraph J6.9) are greater than three percent of the maximum heat release rates, observed values shall be corrected.

J8.2 Smoke Release Rate

J8.2.1 Using the optical density versus chart reading described in paragraph J7.2.1, values of optical density (D) are calculated at the same elapsed time selected for calculating heat release rates.

J8.2.2 By definition, air having a concentration of one SMOKE (Standard Metric Optical Kinetic Emission) unit per cubic meter (m^3) reduces the percent transmission of light through 1 meter to 10 percent; that is, optical density (absorbance) equals log 100/10 = log 10 = 1.0.

J8.2.3 SMOKE release rate in units of SMOKE per minute per m^2 of the specimen's exposed surface area shall be calculated as follows:

$$\text{SMOKE Release Rate} = \text{SRR} = \frac{D}{K \times L \times A} \, \frac{V_o}{t} ,$$

where K = absorption coefficient = 1.0 m^2/SMOKE

D = optical density (absorbance)

L = light path = 0.134 m = 0.44 ft (stack width)

A = exposed surface area of specimen (m^2)

V_o/t = flow rate of air (m^3/min) leaving apparatus

$$= \frac{V_i}{t} \, \frac{T_o}{T_i}$$

V_i/t = flow rate of air entering apparatus (m^3/min)

T_i, T_o = absolute temperature* of air in and out of apparatus, respectively

t = unit time

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* Major temperature correction (that is, maximum difference in T_i and T_o) occurs when operating at high heat flux and high heat release rates. At conditions of low heat release, an average temperature of effluent air (and therefore constant volumetric flow rate) can be assumed without significant error.

J8.3 Total Heat and Smoke Release

Heat and visible smoke release between any two points in time is given by the area under the respective curves for release rate versus time between those points.

J9.0 Report

J9.1 Description of specimen.

J9.2 Orientation of specimen and detailed description of mounting.

J9.3 Radiant heat flux to specimen, expressed in kW/m^2.

J9.4 Piloted or nonpiloted ignition, location of pilot flame, and type of pilot, if not standard.

J9.5 Data giving release rates of heat (in kW/m^2) and visible smoke (in $SMOKE/m^2$-min) as a function of time, either graphically or tabulated at intervals no greater than 10 seconds.

J9.6 If piloted, point ignition is used, and the time at which total involvement is reached shall be noted.

J9.7 All conditions that alter the exposed surface area of the specimen during tests, such as melting, sagging, or delaminating, shall be described and accurately recorded, including the time at which the condition was observed to occur.

J10.0 Precision

J10.1 The precision of the test method has yet to be finalized, although preliminary round-robin tests indicate the following.

J10.1.1 Precision of data shall be based on the similarity of the release rate versus time curves. Points that may be used in making the comparison are (1) time until a positive rate of heat release is observed (if over 30 seconds), (2) maximum rate of heat release and maximum rate of smoke release and times to maximum,

(3) time to reach selected total heat release and total smoke release values, or total heat and total smoke release after a selected exposure time, depending on the shape of the release rate versus time curve.

J10.1.2 Precision of results varies with the type of specimen tested. For those specimens that burn over a uniform surface area, values for release rates of heat at equivalent times should be within ±12.5 percent (or kW/m^2 for values below 40 kW/m^2). Smoke release rate values for specimens burning over a uniform surface at equivalent exposure times should be within ±12.5 percent (or ±6 SMOKE/m^2-min for values below 48 SMOKE/m^2-min).

J10.1.3 For materials or products that burn over a nonuniform surface (due to warping, slumping, or melting), the release rate for heat and smoke values may vary by ±25 percent at equivalent times. For such samples, at least five specimens shall be tested and the results averaged. If two or more values are outside the limits of ±25 percent of the average, the test condition or sample shall be judged inappropriate for test by this method.

J10.1.4 Because of the baseline "noise" and sensitivity of the sensors, repeatability of baseline setting is no better than ±2.0 kW/m^2 for heat release and ±1.5 SMOKE/m^2-min for smoke release rate. With permissible baseline drift and variation in setting, permissible baseline differences in 3-, 5-, and 10-minute heat and smoke release are ±0.5, ±0.85, and ±1.70 MJ/m^2, and ±5, ±7.5, and ±15 SMOKE/m^2-min, respectively.