# Choice of a test for fire hazard of surfaces: progress to date

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# TECHNICAL NOTE

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PREPARED FOR The Subcommittee on Flame Spread of the Committee on Fire Tests of the CSA

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SUBJECT Choice of a Test for Fire Hazard of Surfaces: Progress to date

Several different standard tests are used in the various fire laboratories of the world to measure flame spread, or fire hazard of surfaces. References to the published descriptions may be found in a previous Technical Note, "Comparison of Flame Spread Tests" (5). The question of which, if any, of these are satisfactory is still open, and the note which follows suggests some arguments which bear on it.

The first part of this note reviews reports of room burnout tests done at four laboratories in recent years, with special reference to the lessons which may be learnt from them regarding the design of a standard flame spread or fire hazard test. The second part suggests certain features to be desired in such a test. The third describes a test under development in the Division of Building Research.

This Note, like its predecessor, was initially written for the information of the Subcommittee on Flame Spread of the Canadian Standards Association.

## Part I: Model Room Burn-out Tests

It may be taken as an axiom that the most useful flame-spread test is the one which ranks wall and ceiling lining materials most nearly in the same order as they are ranked by their performance in real building fires.

There is room for debate, however, on the question of what aspect of the development of a building fire is the important one for this purpose. In this report it will be assumed that the preservation of life is the predominant consideration, and that life safety depends primarily on the amount of time available after the initiation of a fire before escape from any part of the building becomes impossible.

Cases are on record where flame has spread so rapidly that lives have been lost in the room where the fire started though the occupants were conscious and the exits were not blocked. In all such fires studied by the writer the rapid spread can, however, be attributed to neglect of safety principles that are known to everyone (e.g., flammable liquids spilled in kitchens); the wall lining was not primarily responsible for the rapid spread of fire. Here the remedy is well known and the only aspects worthy of study are psychological and social ones with which this report is not concerned. Cases where clothing is the first material ignited are also irrelevant to the study of fire safety of wall linings. Apart from these two groups, people in the room where the fire starts generally escape.

People in other rooms, however, may be trapped by flame or smoke in the corridors and stairwells, even if nothing is burning there. In small buildings, then, where one burning room can render all the corridors impassable, the chance of escape may be governed by the time available for persons to become aware of the fire before being trapped, so that the most important factor appears to be the speed with which fire develops in the room where it starts. This will be shown later in this report to be influenced by the lining of the room; thus the safety of the lining may be assessed in terms of the time from ignition to flashover.

In larger buildings, rate of flame spread in corridors may become the more important factor, but since relatively few lives are lost in large structures it seems reasonable to consider the smaller buildings first. Further, it may turn out that flame spread for a given material in corridors is closely correlated with ignition-to-flashover time in rooms lined with the same material. In this case the ignition-to-flashover time would still be the governing factor.

In any case, for the purpose of the present study, the hypothesis will be adopted that the most important factor is the time from ignition to flashover in the room where the fire starts.

So far as is known, no laboratory anywhere has yet attempted to justify a proposed fire hazard test by relating its results to flashover times in rooms in real buildings. The closest approach to doing this has been a number of burns of full-scale rooms built for the purpose inside suitable enclosures. Here all that is needed is that the rooms should be sufficiently similar to real rooms. Next to these come model tests, i.e., tests on small-scale models of rooms, and for these it is necessary, in addition, to show that the model gives a result which can be related to the full scale by a known "scaling law" and to control the conditions of experiment in whatever manner is necessary to ensure that the law will apply.

Although it has been the Fire Research Section's intention to experiment in this field, shortage of staff has so far prevented this. It seems possible that misleading results might be gained unless the work was done thoroughly.

In recent months a number of test reports have been received which make it possible to compare the approaches used at a number of different laboratories, and a discussion of these follows. This note deals only with the work known to the Section and no disparagement of other work is implied by its omission. Some aspects of these reports are summarized below, in order of report date.

Factory Mutual Laboratories, Boston, Mass. (1)

A full-scale room without furniture was used. A standard crib, $7\frac{1}{2}$ lb.wood ignited from $\frac{3}{4}$ lb.alcohol, was burned in it; this quantity was chosen as being insufficient of itself, when burned in an incombustible room, to make the room untenable, but sufficient to give a severe exposure to a wallboard test piece. Here "untenable" means a temperature of 300°F or over as measured by thermocouples (of unstated gauge) 5 ft. 6 in. above the floor. When the crib was burned in a room lined with a combustible wallboard, it was thought that this lining could be regarded as reasonably safe if the heat released by crib and wallboard together still did not render the room untenable.

It is understood, though not stated in the report, that a subcommittee of the Joint Committee on Building Codes concluded from this work that any material qualifying for "flame spread less than 150" according to Underwriters Laboratories' Fire Hazard Classification was "safe".

Forest Products Laboratory, Madison, Wis. (2)

Full-scale rooms with mock-up furniture were burned. Two walls and the ceiling of the room only were lined with combustible wall linings. In the course of the six experiments conditions were altered so that the individual results are not strictly comparable in all respects. One conclusion reached was that "the nature of the wall ... had ... only small effect on the flashover"; the curves suggest a difference of $1\frac{1}{2}$ or 2 minutes between Douglas fir plywood and insulation board on one hand and plaster and gypsum wallboard on the other.

Joint Fire Research Organization, Boreham Wood, England (3)

A large number of model rooms (scales 1/2, 1/5, 1/10) with mock-up furniture were burned. Full-scale rooms also were burned, and some evidence is given of satisfactory agreement between these and the models. Times from ignition to flashover were measured for different wall lining materials.

One conclusion reached was that boards in Classes 2 to 4 of BS 476, and some of those in Class 1, when applied to both walls and ceiling, "appreciably increase the hazard" compared with a "traditional type room" with plaster linings.

If the threshold of "increased hazard" lies somewhere within Class 1 of BS 476, and if the correspondence table derived in the present author's previous Technical Note, No. 191 (5), may be used, then this threshold may be taken somewhere between Underwriter's Flame Spread 15 and 40; say 30. This is one-fifth of the figure inferred from Factory Mutuals' work to be "safe".

Commonwealth Experimental Building Station, Sydney, Australia (4)

The point of departure of the CEBS investigators was the report of the work of Factory Mutual Laboratories quoted above, and much pains were taken in developing a reproducible gas fire equivalent to the Factory Mutual Laboratories crib fire. This was followed by a number of full-scale room fires, of which some were too mild to affect wall linings and others were so severe that it was considered that the character of the wall lining made little difference to the fire. Accordingly an intermediate size of fire was standardized. An ingenious gas burner was developed which would give the radiative and convective equivalent of the standard fire, but would be repeatable.

No conclusion regarding the relative merits of different wall lining materials had been reached in the report cited.

In comparing these various reports, one point of interest is the apparent lack of agreement between the conclusions drawn from the Factory Mutual Laboratories' work and the findings of the Joint Fire Research Organization. This apparent disagreement is not a positive conflict, since perhaps the hazard with plaster walls may be increased several times before the room ceases to be "safe". Further, the Factory Mutuals seem to be considering the life safety of people in the burning room only, while the JFRO appears to be thinking of the time available for escape from other rooms in the same building. This report will not go into the difficult question of what standard should be set.

In critically comparing these two pieces of work it may be noted that three of the four reports listed above seem to agree that even with incombustible walls and ceilings the combustible contents of the average room are sufficient to produce a burn-out of the room and hence a danger to life in other rooms. In view of this the Factory Mutuals' use of an igniting crib insufficient to produce a burn-out seems to be unrealistic. If they had used a more severe exposure the boards which they classed as safe might have been more thoroughly ignited and a less favourable conclusion on these boards might have been reached.

Perhaps they would have reached the same conclusion as the Forest Products Laboratory, that a realistic exposure to fire is so severe that differences between different wall lining materials are hardly significant. In this connection it should be noted that in the Forest Products Laboratories' work the igniting crib and the group of furniture which it ignited was nowhere less than 18 inches away from the walls. This suggests that it was possible for the fire to become quite severe before reaching the walls at all. Admittedly this could occur in practice, but the opposite is at least as likely, and an incipient fire near a wall seems likely to show a combustible wall lining in a worse light than the Forest Products Laboratories' work would suggest. Two walls and the ceiling only were lined in the FPL tests. It has been shown by the Joint Fire Research Organization workers that partial lining of a room, i.e., walls but not ceiling, or vice versa, makes it possible to meet their safety requirement with a more combustible kind of wall lining.

It would be interesting to know, also, whether the rapid development of the Forest Products Laboratories' test fires owed anything to the finish applied to their mock-up furniture; i.e., "a mahogany water stain, a coat of lacquer, and two coats of pyroxylin lacquer". Certain pyroxylin, or nitrocellulose, lacquers are known to facilitate surface spread of flame (6). It is understood that this type of furniture finish is often used in practice so that it is quite fair to use it in the experiments; but it may be significant that in the FPL's test No. 4, the only one where wooden cribs were used in place of furniture, the development of the fire took almost twice as long as in other tests, and no other reason for this is obvious.

From this discussion there emerge some conclusions which may be worth considering by any laboratory embarking upon a program of test room burns:

(1) There should be as much furniture, or its equivalent, as is found in an average room. (This will be enough to burn out the room even if its linings are incombustible.);

(2) The furniture in which the fire is started should be near enough to a wall to expose that wall early on in the development of the fire;

(3) It should be investigated whether the type of finish on the furniture influences the result of the test.

As regards a standard test for fire hazard of surfaces, the further conclusion may be drawn that, if the object of the test is to classify linings according to how much they will contribute to rapid development of a room fire, then the test should be fairly severe, at least when compared with some of the tests in use at present. For instance, it should be capable of discriminating between the better and the poorer materials in Class 1 of the British test, BS 476, which the British test itself does not do well.

Once a test fire has released the heat of combustion of a certain area of wallboard the interest is in seeing whether this heat will be sufficient to release the heat of combustion of a further area and thus render the fire self-supporting. The test should not contribute so much heat for so long that it is impossible to see whether the fire is self-supporting. But it should be severe enough to give a start to even those materials which are quite hard to ignite, so that it may be seen whether a fire in these is or is not self-supporting.

## Part II: Features desirable in an Ideal Test for Fire Hazard of Wall and Ceiling Linings

1. The most important feature of any test is that it should measure the property on which information is needed. Tests can be devised to measure the radiant intensity for pilot ignition, or the speed of travel of a flame front at a given radiant intensity, or other quantities. But until a precise relationship is found between the tendency of fire to develop rapidly in a building and one or more of these quantities, if it ever is, the best test will be one which ranks materials according to the rapidity with which fire develops in a building lined with a certain material, and a sufficient justification of any proposed test is to show that it does this. This seems to imply that a fire hazard test cannot be fully justified without a program of room burnout tests.

2. In Part I of the present Note a review of published information has suggested that the test needs to be severe, i.e. the initial heat it applies to the test piece should be sufficient to ignite, or release the heat of combustion of, any wallboard which has an appreciable combustible content.

3. The test method should give the fire, once started, enough time and space to show whether it is self supporting, and if so, how vigorously.

4. The apparatus and instrumentation should be fairly simple, so that its use is not restricted to large laboratories specializing in fire testing, and so that it may if desired be set up, for example, in the production control laboratories of materials manufacturers.

5. The cost per test should not be high. If it is more than, say, $100, the bare minimum of tests will be done and the behaviour of a material will not be fully explored. If it is less than, say, $10, it will be practicable to burn sufficient test pieces to explore adequately both variability in performance and the effect of modifications, of conditioning, or retardant treatments, etc.

6. Some tests classify a material in one of a small number of categories, e.g., Class A, Class B, C, or D. Rather than this, it is preferable that the test should give its result in the form of an index or number expressing the merit of the material. This would make it possible to deal separately with what are two distinct problems -- the design of a test, and the fixing of those divisions between categories which are most suitable for a building code. (Underwriters Laboratories' Fire Hazard Classification is a good example of a test which meets this suggested requirement.)

7. The specification for the test should include a formula for calculation of the index or number suggested above from the readings of instruments, or better still, from recorder charts. Tests that depend upon an observer applying a number of criteria are liable to be influenced by misjudgement or by prejudice, especially if the criteria are such that it is difficult to define them briefly and precisely.

8. The test should be repeatable and reproducible.

## Part III: Development Work upon a Tentatively Proposed Test for Fire Hazard of Linings

The initial idea for the test to be described arose from a curiosity of the author to see what would happen if an air duct made of a combustible material became ignited on the inside. A burning duct creates its own draught, which keeps the fire well supplied with air so that it can burn vigorously. On trying this, the idea arose that it might be possible to adapt the experiment to meet many of the requirements of a standard test for fire hazard of surfaces, and further trials were made. The size of duct tried was suggested by consideration of what could safely be burned within rather restricted laboratory space, of the need discussed in Parts I and II for a severe test, and of the standard sizes of materials.

Thus a vertical duct, open at both ends, 4 feet long and 4 inches square in cross-section, was arrived at. Cracks at the joins are sealed with masking tape. After a fair experience with this size, 4 feet still seems a convenient compromise, but the behaviour of some materials suggests that a larger cross-section, say 6 inches square, might have advantages.

An igniter was necessary, and a wide choice of methods existed. A gas flame is a very flexible method, but its effectiveness depends not only upon the amount of heat energy put in but also on the proportion of air, the degree of mixing, turbulence, etc., so that considerable pains might be necessary to find the best combination, and above all to secure that it was accurately repeated in every test. Liquid in a tray could be burned; but liquids have to vaporize before they can burn, so that there is the objection that the rate of boiling off, and hence burning, is dependent on variations in the amount of heat reflected back into the tray.

Accordingly a solid material was used for the igniter-wood fibreboard (which, being a popular building material, might be present in many actual fires). After some trials it was found that a convenient form for the igniter was as a close-fitting lining to the bottom of the test flue, 8 inches high. The material used was half an inch in thickness, so that an opening 3 inches square remained, and into this 2.5 gm. of folded low-ash paper was stuffed. (Though the fibreboard can be directly ignited with a match, the paper assists in securing a uniform start to each test.)

A difficulty met with in the early development of the test was that before the igniter was well alight it induced so much draught that the fire had difficulty in building up. This could be checked by partly blocking either end of the flue; for most rapid burning this blockage had to be gradually removed later in the test as the air requirements of the fire grew, but when this was done manually the development of the fire could, in a large degree, be controlled by the operator. To avoid prejudice some simple method was needed of controlling the draught automatically and impartially in the manner most favourable to the development of the fire.

A simple solution to this problem was found in the "combustible baffle". A piece of stiff brown paper with a hole accurately 1 inch square was fixed with masking tape to stop up the flue partially at a level 16 inches above the base. This checked the draught until the fire was large enough for flame to reach the baffle, when it burned away rapidly and had no further effect.

It was found to be advantageous to have more than one such baffle, and by trial and error, varying the number of baffles, their position and the size of the hole, a combination was arrived at which seemed to be suitable for a wide variety of test materials. The trial and error was not exhaustive, and it may well be possible to improve on this arrangement.

The combination was:

| | | | |
|---|---|---|---|
| Baffle with a | 1-inch square hole | 16 inches | above the base; |
| " " " | 1½-inch " " | 32 inches | " " " ; |
| " " " | 2-inch " " | 48 inches | " " " (i.e. at the top). |

The test may continue until flames appear upon the outside of the flue, or, if this does not occur, until the flue is burnt out and begins to cool of itself. This does not mean that the whole of the record would necessarily be used in interpreting the results of the test.

When flames appear on the outside, the fire is put out by simultaneous application of water spray to the outside and inside. The inside is sprayed by opening a valve and supplying water to a vertical spray-nozzle built into the base of the test stand, and the outside is sprayed manually.

So far a method has been described of applying a severe fire exposure to the surface of a wall lining material. It remains to decide what observation should be taken of the effect of the fire on the test piece.

Two obvious subjects for observation are flame and heat. To the layman flame may seem the more convenient, but in the laboratory it is doubtful if this is so. A flame front is usually unstable and rapidly flickering, and its apparent progress may depend upon the means used to detect it, whether visually, by photocells or by radiation or ionization detectors. On the other hand, the temperature of a thermocouple or of a resistance thermometer is very conveniently measurable as a function of time with an automatic recorder, or a little less conveniently with a potentiometer or millivoltmeter.

In this development work two thermocouples were used. One was a bare chromel-alumel couple, 22-gauge B. & S.; this was held centrally 1 inch below the top of the flue. The other was 14-gauge and was attached internally to a cylinder of solid copper 3 by 3 inches so as to support it with its axis vertical and central and its base 1 inch above the top of the flue. The relationship of the bare thermocouple reading to the gas temperature is no doubt complicated, but the couple gives a rapid indication of temperature rise and fall, and in particular it is easy to see from it when the first and second baffles burn out; this is indicated by the end of a brief hesitation in the rise of temperature.

The large thermal inertia which the copper block gives to the second thermocouple means that the significance of its reading is entirely different. It may be thought of as roughly measuring the time integral of some function of the gas temperature, emissivity, etc. which determines the rate of heat transfer to a blackened copper surface. Compared with the gas temperature, the copper block is at a substantially constant temperature for many materials, and loss of heat from it by radiation to the surroundings might be negligible compared with heat uptake from the combustion gases. Thus the block temperature may serve as a measure of the quantity of heat released by the burning surfaces, and of the rate of release.

The rate of heat transfer from flames and products of combustion is what controls the heating up to ignition of a wall lining, and thus the spread of fire. Hence it would seem reasonable, if this type of test were adopted for classifying wall linings, to base the fire hazard index on some feature of the copper block temperature record.

If the fire hazard index were to be based upon the copper block temperature, then there is still room for discussion of what feature of the temperature record should be used. The maximum of this curve is not suitable, since frequently the test has to be stopped before the maximum is reached. Two possibilities are: firstly, the temperature at a fixed time (say, 4 minutes) after the start of the test; and, secondly, the maximum temperature rise in any 2-minute interval. It does not seem necessary to go into further detail here, as more experimental work is needed upon this question. Whatever feature was chosen could be reduced to a fire hazard index on a scale defined in relation to two materials, just as Underwriters Laboratories' scale is defined against asbestos cement and select grade-A red oak.

The test is still under development, and it is hoped that any interested reader will send in his comments and criticisms.

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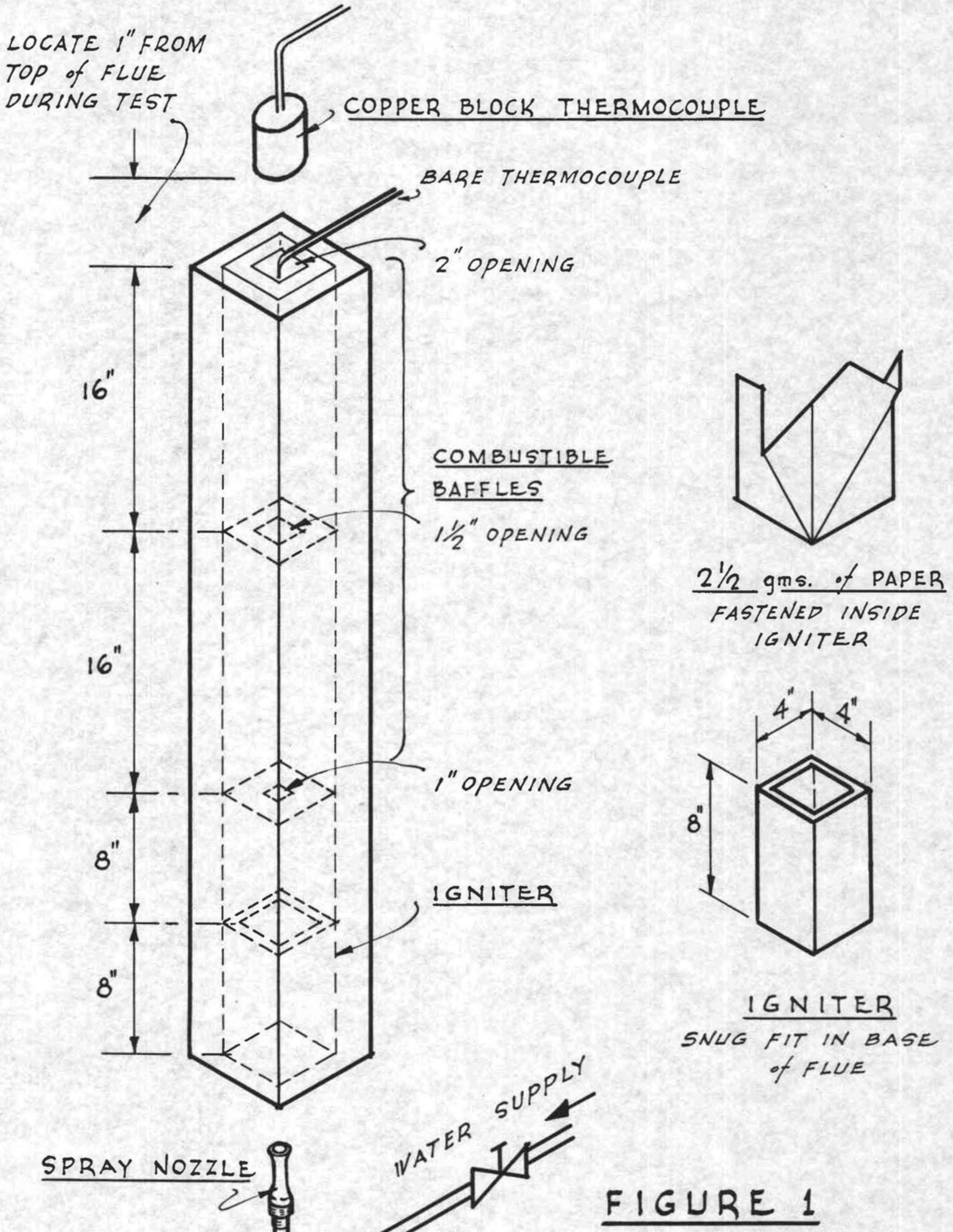


# FIGURE 1

## DIAGRAM of FLUE-BURN APPARATUS

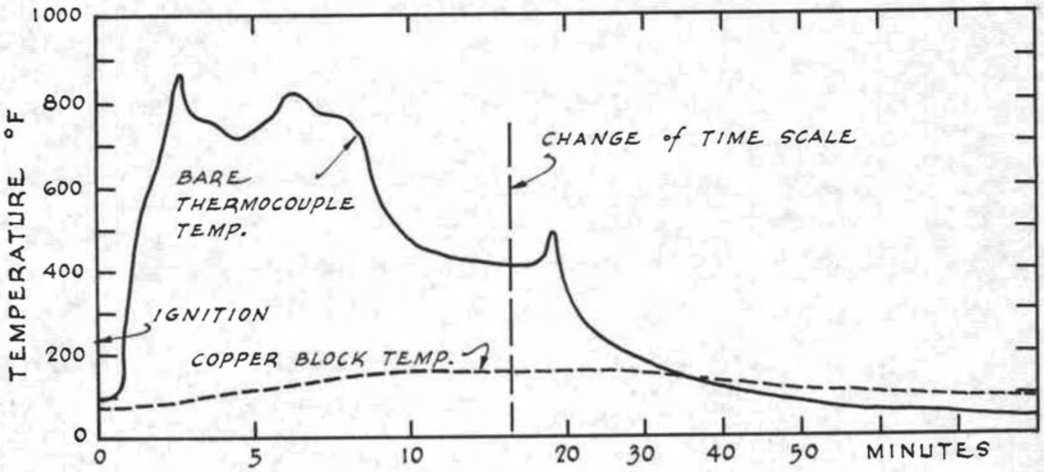


FIGURE 2

RECORDER CHART FOR FLUE-BURN TEST  *TESTPIECE: ASBESTOS WOOD*

BR 917-1  TECH. NOTE 199

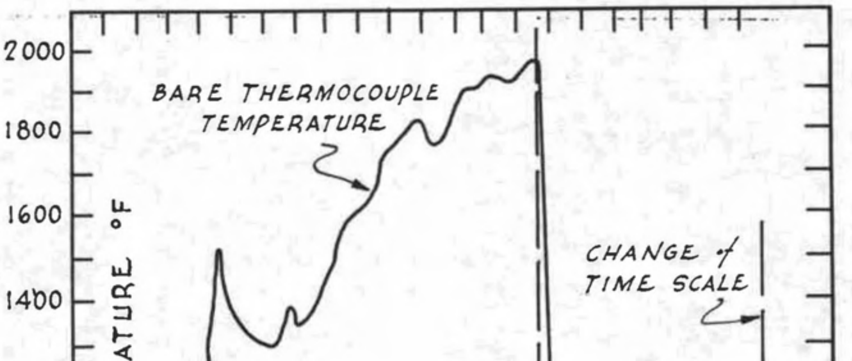


FIGURE 3

RECORDER CHART FOR FLUE-BURN TEST  *TESTPIECE PINE UNTREATED*

BR 917-2  TECH. NOTE 199