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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20386799
Report (National Research Council of Canada. Division of Building Research); no. DBR-R-43, 1955-07-01

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CANADA

DIVISION OF BUILDING RESEARCH

COMPARISON OF COMBUSTIBILITY TEST PROCEDURES

by

K. Sumi

Report No. 43

of the

Division of Building Research

Ottawa
July 1955

Preface

This report describes the results from work undertaken by the Fire Research Section of the Division of Building Research to assist the Sub-Committee of the Canadian Standards Association charged with the preparation of a new combustibility test specification for Canada. The results of further studies, together with recommendations on testing procedures and apparatus will be presented in subsequent reports.

The author, Mr. Kik Sumi, left for Great Britain to begin a year study in fire research before the report could be completed. Credit is due, therefore, to his colleagues in the Fire Research Section, particularly Mr. G. Williams-Leir and Mr. J. R. Jutras, who have spent much time on revisions to the first draft report prepared by Mr. Sumi.

N. B. Hutcheon,
Assistant Director.

Ottawa
June, 1955.

COMPARISON OF COMBUSTIBILITY TEST PROCEDURES

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The words "incombustible"(or noncombustible) and "combustible" are used in building codes, specifications, and other regulations often without being adequately defined. As used in such documents, an incombustible material means a material which will not burn under conditions of exposure which the user of the word has in mind. It will not necessarily have the same meaning to others unless those conditions are specified. This is often true in building code work in classifying combustibility of a material containing minor amounts of combustible constituents in an otherwise incombustible material. Thus there seems to be need for a suitable performance test with reference to a well defined testing procedure.

Since the withdrawal of Specification A54-1940 by the Canadian Standards Association a new specification has been needed. The work which this report describes was done at the instigation and for the guidance of the sub-committee charged with preparing the part of the new specification dealing with combustibility tests.

The purpose of this investigation was to compare the merits of the combustibility test procedure of the British Standards Institution with certain procedures suggested by the writer using a furnace essentially the same as the one described in a previous report (2).

Seven different building materials were tested. The procedure used with the apparatus of the American Society for Testing Materials was based largely on the decisions made by Sub-Committee V of ASTM Committee E-5 on Fire Tests of Building Materials and Construction when the investigation reported herein was initiated. The procedure used with the British furnace was in accordance with "Combustibility Test of Materials" described in British Standard 476:1953, "Fire Tests on Building Materials and Structures" (1).

PREVIOUS WORK

The need for a suitable performance test for classifying combustibility of building materials led the British Standards Institution to the adoption of the "Incombustibility Test of Materials" described in British Standard 476-1932 (3). In this method a specimen is suspended in an electrically heated tubular furnace and heated gradually for 1½ hours to a temperature of 1382°F. (750°C), while observations are made of flaming or glow of the specimen.

Investigations made by N. P. Setchkin and S. H. Ingberg of the U.S. National Bureau of Standards and reported to the American Society for Testing Materials in 1945 (4) led to a number of conclusions, one of which was that the British incombustibility test could be improved by setting the furnace at the final temperature of 1382°F. before inserting the specimen instead of raising the temperature gradually with the specimen in. This makes a more severe test.

In February 1952 the author was co-author of a report "ASTM Combustibility Tests" (2). The work reported was the Fire Research Section's contribution to a program of tests in co-operation with other laboratories. This program was organized by the American Society for Testing Materials; its purpose was to assist in the studies undertaken by Sub-Committee V of ASTM Committee E-5 on the development of a standard method of test for defining the incombustibility of building materials. Samples of forty-seven different building materials were distributed to the Fire Research Section and four American laboratories. The furnace used was patterned on the British apparatus described in B.S. 476: 1932 which in turn is apparently related to the 1915 design of Prince (5). Provision was made for a regulated flow of air through the furnace. After the temperature in the furnace was stabilized at 1382°F. with air-flow of 2.0 c.f.m., the specimen was inserted. The test was continued for 15 minutes unless the specimen ignited or disintegrated during that interval of time.

In 1953, the British Standards Institution issued a revision of the British Standard (1). In this the above-mentioned conclusion of Setchkin and Ingberg seems to have been adopted, and the procedure as regards setting the furnace temperature is similar to theirs.

EXPERIMENTAL DETAILS

The experimental details apply to tests carried out in both furnaces unless otherwise stated.

Apparatus

ASTM furnace. - A furnace similar to the one used for the "ASTM Combustibility Tests" but with minor modifications was constructed as shown in Fig. 2. A fused-alumina refractory tube of 3-inch inside diameter and 1/8-inch wall thickness was used as the inner wall of the furnace. A 4-inch inside diameter tube of the same material of 3/8-inch wall thickness, with spiral grooves for winding the heating element was arranged coaxially so that the annular space between the tubes would serve as a preheater for the incoming air. Nickel-chrome wire of 18-gauge Brown and Sharpe with a total resistance of 15.5 ohms was used as the heating element. This wire was embedded in a refractory cement. The cover was made in two semi-circular parts with a circular opening 1 sq. in. in area at the centre. The furnace had an outside diameter of 10 inches. Other details are as shown in Fig. 2.

BSI Furnace. - The second furnace constructed was made as alike as possible in all relevant details to that described in B.S. 476:1953 (1). Like the latter, it had an observation window in the lower brass cylinder though this has been omitted from Fig. 1 as no use was made of it. A fused-alumina refractory tube of 3-inch inside diameter and 3/8-inch wall thickness was used as the inner wall of the furnace. Nickel-chrome wire of 18-gauge B & S with a total resistance of 14.0 ohms was used as the heating element.

Each furnace was heated by passing an electric current through the heating wires. A variable auto-transformer connected to the 220-volt mains was used for regulating the temperature in the furnace. A pilot gas flame, 5/8 to 7/8 inch in height, fed through a 0.04-inch port in the wall of a copper tube, 1/8 inch inside diameter, was located immediately above the furnace opening.

Temperature Distribution

In order to increase knowledge about the experimental conditions of the tests, the temperature profile of each furnace was determined, temperatures being measured at points one inch apart along the axis of the refractory tubes in the absence of a test specimen. In the case of the ASTM furnace, this was done with zero and 0.5 c.f.m. air-flow. Results from these determinations are shown graphically in Fig. 19.

Since the operating temperature of 1382°F. is based, in the ASTM furnace, on a thermocouple at a point $\frac{1}{4}$ inch below the specimen and, in the BSI furnace, on a thermocouple at the level of the centre of the specimen, it can be readily seen from Fig. 19 that the thermal environment of the specimen is more rigorous when using the ASTM furnace, particularly so under zero air-flow conditions. For example, comparing the BSI conditions with the ASTM furnace without air-flow, the specimen base is 90°F cooler in the former and the specimen top 108°F cooler.

Thermocouples

The thermocouples were made of 22 B & S gauge chromel-alumel wires welded at the junction. A multi-channel, self-balancing, recording potentiometer was used in conjunction with the thermocouples for measuring the temperatures.

a) ASTM furnace.- Four thermocouples were used: T_1 on the heating element; T_2 about $\frac{1}{4}$-inch below the bottom of the specimen; T_3 on the surface of one of the sides of the specimen; and T_4 in the centre of the specimen. The latter was omitted in tests on cinder block.

b) BSI furnace.- The furnace temperature was taken as that of a thermocouple situated at the level of the centre of the specimen and 3/8-inch from the internal wall of the heating tube.

Air-flow

For the ASTM furnace the air was supplied from the laboratory compressed air line and its flow rate was measured with a rotameter gauge of the float-in-conical-tube type. Two series of tests were carried out with air flowing at 0.5 c.f.m. and two with no air-flow.

For the BSI furnace air-flow was produced by natural convection and governed by the nine 1/8-inch diameter holes provided in the base of the observation chamber. Under normal operating conditions, the air-flow was about 0.2 c.f.m. as described in Appendix A.

Size of Specimen

The specimen size was $1\frac{1}{2}$ by $1\frac{1}{2}$ by 2 inches. Materials with normal thickness less than $1\frac{1}{2}$ inches were built up of sufficient layers to achieve a final thickness of $1\frac{1}{2}$ inches. Accordingly three layers of $\frac{1}{2}$-inch wood fibreboard and four layers of 3/8-inch plasterboard were used in building up specimens. White pine, mineral wool, glass wool, wood-cement block, and cinder block were cut to the prescribed size.

Conditioning of the Specimen

Prior to being thermally tested in either furnace, the specimen was conditioned as follows:

a) Using ASTM furnace

(i) oven-dried at 100°C. ± 5°C. (212°F. ± 9°F.) for 24 hours; or

(ii) maintained at 68°F. ± 2°F. and 60% ± 5% relative humidity to constant weight.

b) Using BSI furnace

(i) oven-dried at 100°C. ± 5°C. (212°F. ± 9°F.) for 6 hours; or

(ii) dried in desiccator over calcium chloride to constant weight (i.e. approximately seven days).

Suspension of the Specimen

A wire screen basket of nickel-chrome wire was made for holding the specimen. The same type of wire was used for suspending the specimen. The basket is shown in Fig. 1, as is the stand used to position the specimen.

Position of Specimen

The specimen was suspended in either furnace with its long axis vertical along the vertical axis of the furnace.

a) For ASTM furnace.- The specimen was located with its top end 4½ inches from the top of the furnace.

b) For BSI furnace.- The specimen was located with its top end 2 inches from the top of the furnace.

Numbering of Materials

The building materials tested were numbered as follows:

1. wood fibreboard;
2. white pine;
3. plasterboard;
4. glass wool (without paper back);
5. mineral wool (with paper back);
6. wood-cement block;
7. cinder block

Test Procedure

The temperature in either furnace was first stabilized at 1382°F. ± 10°F. by using a fixed setting on the auto-transformer and checking by observation. For the ASTM furnace, the temperature at thermocouple T_2, just below the specimen, was used as a measure of the furnace temperature. This temperature was stabilized with the air-flow adjusted at the rate at which tests were subsequently to be carried out.

The pilot flame was then lit and the specimen lowered into the furnace where it was held for a period of 15 minutes. Visual observation of the specimen was made by the use of a mirror inclined at an angle above the furnace aperture.

With some types of material the products formed early in the test extinguished the pilot flame. It was found best in these cases to postpone attempting to relight it until one minute from the start of the tests. On relighting the pilot, specimens of certain materials burst into flame immediately and the procedure described ensured that all such materials were ignited at the same stage in the test. If the flame was extinguished after the first minute it was ignited as soon as this became possible.

Program of Tests

The various combinations of conditions used will be referred to as "series". There were six series in all, as summarized in Table 1. Thus there were six different tests on each of the seven materials, and each of these was repeated so that there were 2, 3, or 4 identical tests for each series with each material.

TABLE I

SYNOPSIS OF TEST PROCEDURE

Series	Furnace	Air-flow (c.f.m.)	Conditioning
I	ASTM	0	212°F. for 24 hours
II	ASTM	0.5	212°F. for 24 hours
III	ASTM	0	68°F., 60% R.H.
IV	ASTM	0.5	68°F., 60% R.H.
V	BSI	0.2	212°F. for 6 hours
VI	BSI	0.2	in desiccator over $CaCl_2$

RESULTS

The progress of each test was followed by recording the temperatures at the thermocouples at regular time intervals and by observing visually the physical phenomena occurring during the test.

Visual Observations

Visual observations will not be reported fully but instead only for one of the series (Series V) for each of the seven materials (Table 2). This information is typical for each of the materials since it was affected very little by changes in conditioning and air-flow. It concerns mainly the existence and duration of flaming, smoke generation, and variations in the pilot flame.

It was noted that the pilot flame was often extinguished when the specimen contained combustible constituents. At times it was difficult or impossible to reignite it. This characteristic was usually more pronounced when the air-flow was low. In many of the tests, as the pilot flame was reignited as soon as possible after the end of the first minute of test, the combustible gases that were being generated from the specimen ignited and the flame flashed from the pilot flame back to the specimen leading to more rapid burning of the specimen.

Temperature Records

Temperatures at the thermocouples were automatically recorded by the potentiometer. The readings at each minute mark were averaged over two to four repeat tests and the means were transferred to series of graphs where they were plotted against time. The curves in Fig. 3, show the relation between T_2, T_3, and T_4 for one case. Means of four repeat tests were used for this purpose. Figures 4 to 17 include a curve for each series of tests performed on each material and, in the case of the first four series, for each of the three thermocouples T_2, T_3, T_4. These are means of the individual tests. To show the variability between individual tests on the same material, results of three repeat tests are presented in Fig. 18 for three materials. The variations do not appear to be excessive.

Criteria of Combustibility

One possible criterion of combustibility that has been used (1) is the maximum temperature rise. In Table 3 the range of variation of the maxima over two to four repeat tests is given for each series and for each material, expressed in terms of temperature rise (in °F.) above the initial furnace temperature.

TABLE 2

VISUAL OBSERVATIONS FOR SERIES V

WOOD FIBREBOARD

Specimen ignited and started generating smoke almost immediately when inserted in furnace. Pilot flame was extinguished. When pilot flame was reignited at 1-minute mark, the flame from the specimen suddenly increased in size. Flaming of the specimen ceased at about the 4-minute mark.

MINERAL WOOL

Specimen flamed and started generating black smoke almost as soon as it was inserted in furnace. Flaming ceased in about 1-minute 15 seconds. Impossible to reignite pilot flame until after flaming ceased. Specimen glowed during test.

WHITE PINE

Specimen ignited and started generating smoke almost as soon as it was inserted in furnace. Pilot flame was extinguished. When pilot flame was reignited at the 1-minute mark, the flame from the specimen suddenly increased in size. Flaming of the specimen ceased at about the 7-minute mark.

WOOD CEMENT BLOCK

Specimen ignited almost as soon as it was inserted in furnace. Pilot flame was extinguished. Flaming ceased in about 7 minutes. Impossible to reignite pilot flame until flaming ceased. Specimen glowed until end of test.

PLASTERBOARD

Paper covering ignited and started generating smoke almost immediately when specimen was inserted in furnace. Pilot flame was extinguished. Flaming of specimens ceased at about 1-minute mark. Impossible to reignite pilot flame until about 4-minute mark.

CINDER BLOCK

Pilot flame had blue tinge and was about 1 inch at 3-minute mark. Specimen started flaming at about 3-minute mark and continued to do so until about 7-minute mark. Pilot flame was normal when flaming ceased. Specimen glowed during remainder of test.

GLASS WOOL

At 15-second mark pilot flame was about one inch. Pilot flame was back to normal in about one minute. Specimen glowed and shrank gradually during test.

TABLE 3

RANGE OF MAXIMUM TEMPERATURE RISE IN THE FURNACE ABOVE THE STABILIZED FURNACE TEMPERATURE (°F.)

MATERIAL	SERIES					
	I.	II	III	IV	V	VI
Wood fibreboard	202-394	172-396	102-234	282-390	366-386	308-366
White pine	318-394	402-568	202-348	370-42[illegible]	314-382	400-438
Plasterboard	64-118	94-178	50-102	2-44	216-306	150-194
Glass wool	4-14	8-26	6-26	14-26	42-50	30-58
Mineral wool	98-122	58-90	134-144	46-90	160-228	270-294
Wood-cement block	148-170	138-186	126-150	88-196	262-278	190-262
Cinder block	62-68	94-110	58-102	46-98	114-126	102-114

An alternative criterion of combustibility is the area under the time-temperature curve. In Table 4 the areas under the mean curve for the reference thermocouple only (T_2 in the ASTM furnace) are given for each series and for each material. This area corresponds to the excess of temperature over the initial furnace temperature, integrated with respect to time from when it first becomes positive until time 15 minutes. Accordingly, any area between the curve and 1382°F. is left out of the calculation where the curve lies below this figure, and is not treated as a negative contribution to the area above. It may be noted that this substantially affects the results for cinder block.

TABLE 4

AREA UNDER TIME-TEMPERATURE CURVE ABOVE STABILIZED FURNACE TEMPERATURE (MINUTE °F.)

MATERIAL	SERIES						MEAN
	I	II	III	IV	V	VI	
Wood fibreboard	2580	2080	1480	2890	2690	2700	2403
White pine	2630	4110	2020	3860	2690	3030	3057
Plasterboard	922	796	686	216	1070	939	772
Glass wool	103	165	139	174	210	222	169
Mineral wool	400	262	548	261	723	1000	532
Wood-cement block	1850	1830	1450	1440	2730	2240	1923
Cinder block	219	570	255	264	858	467	439

DISCUSSION OF RESULTS

The results of the tests reported in the present report are of three different types:

1) Visual observations: flaming, smoke generation, glow and production of flammable gases;

2) Temperature records;

3) Particular data obtained from the time-temperature graphs: temperature maxima and areas under curves.

The temperature records as such are not of any particular significance in the combustibility rating of materials and will not be considered further.

The visually observed events, particularly flaming and production of ignitable gases, have been and are still used (1,3) as combustibility standards but need not be discussed here since they are in most cases clearly perceptible phenomena. It is worth noting, however, that these can only determine whether a particular material is combustible or incombustible under the conditions of the test. In order to obtain information about the relative degree of combustibility of building materials, other characteristics which lend themselves to easy and accurate evaluation, need be considered. These are the maximum temperature rise and the integrated area under the time-temperature curve.

Temperature Maxima

The observed values of maximum temperature rise given in Table 3 show variations in individual tests on one material which are not small compared with the variations noted between different materials. Thus it would be difficult to classify building materials for combustibility by means of these maxima. If this type of criterion were to be used, as is done in the revised British standard (1), it might be better to compare the means, over a number of tests, of the maximum temperature rise values obtained under the conditions of the tests, than to take the overall maximum rise value for all the tests.

A study of the data in Table 5 where maximum ranges of variation of temperature maxima (obtained from Table 3) are listed and averaged for each series and for each material, shows that the greatest variations are found in the series of tests made with the ASTM furnace and that the variations are generally smaller with the least combustible materials. This seems to indicate that the positioning of the reference thermocouple relative to the specimen might be of great importance in defining a standard procedure of testing.

It was also believed that the reproducibility of the temperature maxima might be influenced by the behaviour of the pilot flame during tests, and that means of standardizing further the procedure for reigniting the flame when extinguished should thus be sought. The use of a secondary pilot flame, located on the same level as the first and about 3/4 inch away from it, is being studied.

Areas under Time-temperature Curves

The use of the areas under time-temperature curves as a standard in the combustibility rating of materials is seriously being considered. The values obtained from the present tests, which are listed in Table 4, lead to classification of the materials in an order that seems consistent with experience. This order is: white pine, wood fibreboard, wood-cement block, plasterboard, mineral wool, cinder block, and glass wool. Of these, the first three and the last four could reasonably be treated as separate classes at least for the purpose of analysis of the results here presented.

TABLE 5

MAXIMUM RANGES OF VARIATION OF TEMPERATURE RISE

(Materials classified in decreasing order of combustibility as determined by time-temperature data from Table 4)

MATERIALS	SERIES I	II	III	IV	V	VI	MEAN
White pine	76	166	146	58	68	38	92
Wood fibreboard	192	224	132	108	20	58	122
Wood-cement block	22	48	24	108	16	72	48
Plasterboard	54	84	52	42	90	44	61
Mineral wool	24	32	10	44	68	24	34
Cinder block	6	16	44	52	12	12	24
Glass wool	10	18	20	12	8	28	16
Averages	55	84	61	61	40	39	

Statistical Analysis of Results

A systematic analysis of the numerical results, of which the details are given in Appendix B, leads to conclusions best summarized by the figures in Table 6 (extracted from Table B-14).

TABLE 6

CONSISTENCY INDICES FOR EACH SERIES

Series	I		II		III		IV		V	VI
Thermocouples	T_2	T_3	T_2	T_3	T_2	T_3	T_2	T_3		
Consistency index	0.97	0.83	0.95	0.94	0.91	0.49	0.96	0.93	0.94	0.99

The "consistency indices" are measures of how closely the results of experiments under each set of experimental conditions agree with the overall results obtained when all the sets of conditions tried are averaged. They are all numbers less than unity; unity would signify perfect agreement.

The validity of this approach is discussed in Appendix B. Insofar as it may be acceptable, certain conclusions may be drawn from it.

a) ASTM Furnace (Series I - IV)

Firstly, T_2 always gives better consistency than T_3 (both are shown in Appendix B to be better than T_4).

The next conclusion will be more clearly seen if we repeat Table 6, this time giving a mean consistency index for thermocouples T_2 and T_3 taken together:

TABLE 6A

CONSISTENCY INDEX ACCORDING TO CONDITIONING OF SPECIMEN FOR TESTS WITH ASTM FURNACE

Series	I	II	III	IV
Conditions	(no air-flow, drier)	(airflow, drier)	(no air-flow, moister)	(air-flow, moister)
Consistency Index	0.90	0.94	0.70	0.94

Thus air-flow seems to be desirable and the dried condition is better, though the differences in each respect are less when T_2 only is considered.

One explanation of the second observation might be that the materials which were arbitrarily chosen for this experimental work were such that the more combustible were on the whole also the more hygroscopic, so that when tested under the moister condition the extra water they held tended to conceal their higher combustibility.

This argument seems only to apply, however, when there is no air-flow. With air-flow, better, i.e. more consistent, results are obtained than without, regardless of whether the moister or the drier condition is used. This suggests that when vapours or gases produced by the specimen under test are continuously carried away and there is a steady supply of oxygen, a material has a better chance to show whether it is combustible or not, and this seems reasonable.

If the choice of the best procedure to standardize were to be based on these conditions, series II and thermocouple T_2 would be indicated. It should be noted that this combination is not the one which would be arrived at by simply taking the highest consistency index in the first eight columns of the information tabulated previously. It is believed, however, that the weight of the evidence is in favour of it.

b) BSI Furnace

The consistency indices given for series V and VI in Table 6 are for each of the two conditioning procedures laid down in B.S. 476:53. These permit a fair comparison of the merits of the ASTM and BSI procedures.

CONCLUSIONS

In this comparative analysis of the combustibility test procedure specified in BSI 476:1953 and that based largely on proposals of ASTM Committee E-5, seven different building materials have been tested under various sets of experimental conditions. An analysis of the results obtained has led to some definite conclusions which are briefly summarized as follows:

(a) The maximum temperature rise above the furnace temperature of 1382°F. should not be used as a basis for classifying materials until the cause of its variability is found and counteracted;

(b) The fact that the areas under the mean time-temperature curves above 1382°F. lead to a classification of the materials tested in an order that seems consistent with experience, would justify its tentative use as a standard in the combustibility rating of materials;

(c) When using the ASTM furnace:

(i) Thermocouples T_2, T_3, T_4 give consistency of results in that order with T_4 giving the greatest inconsistency.

(ii) Consistency of results seems to improve slightly when an air-flow is introduced;

(iii) When air-flow is introduced, conditioning does not appreciably affect the consistency.

(d) When using the BSI furnace the mean of the results obtained with the two standard procedures laid down in British Standard 476 (1) differs very little from the best of eight possible combinations of experimental procedures using the ASTM furnace.

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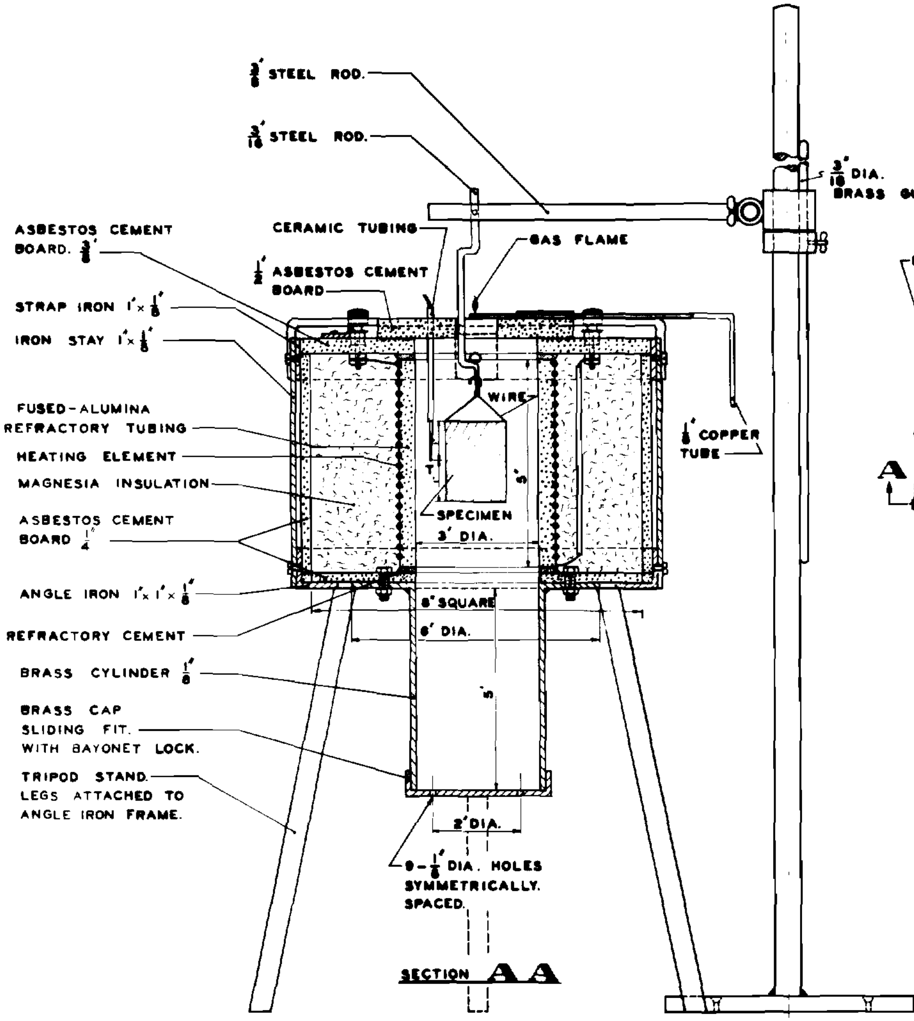

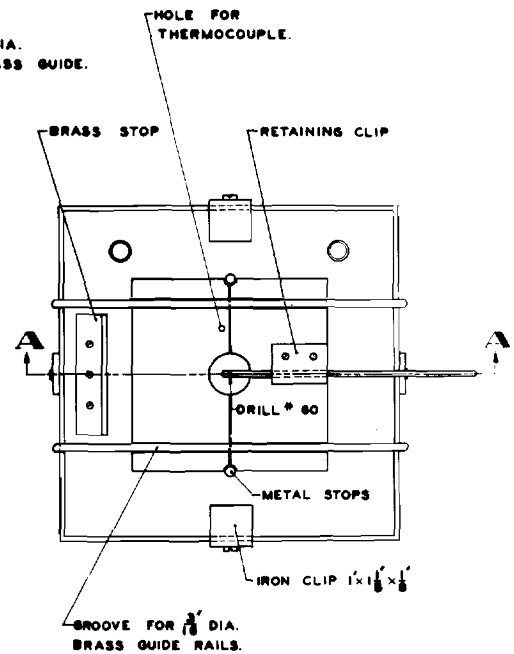

FIGURE 1. APPARATUS FOR COMBUSTIBILITY TEST.

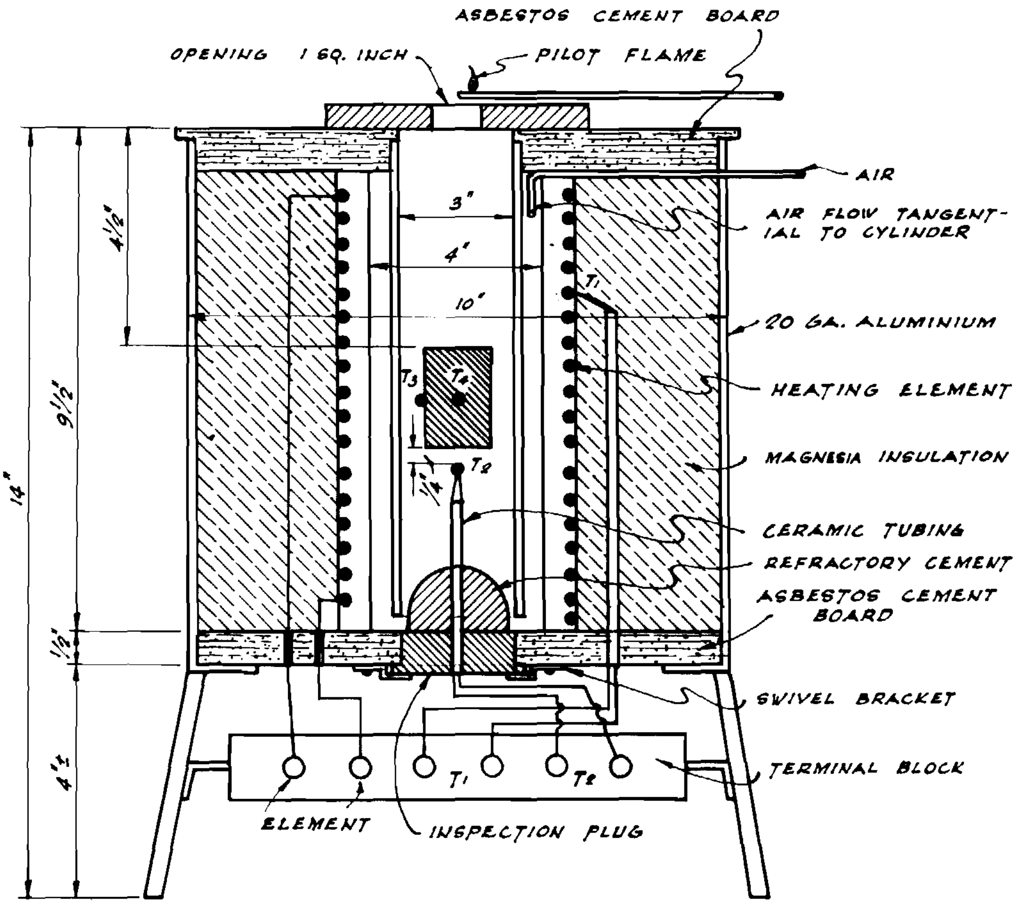

FIGURE 2

APPARATUS FOR COMBUSTIBILITY TEST

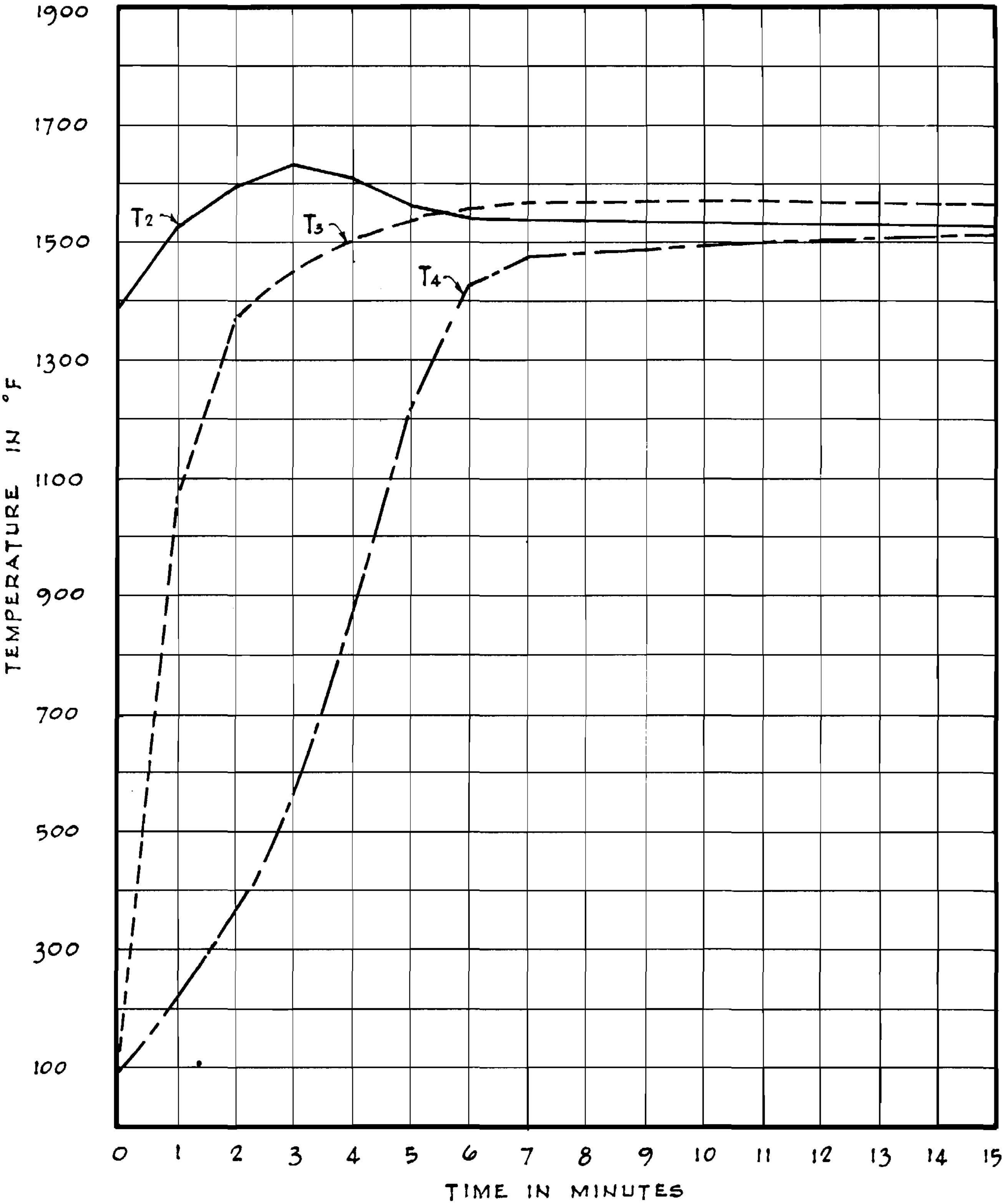

FIGURE 3

EXAMPLE FOR COMPARISON OF READINGS OF THE THREE THERMOCOUPLES

(AVERAGE OF FOUR REPEAT TESTS ON WOOD FIBREBOARD)
SERIES I

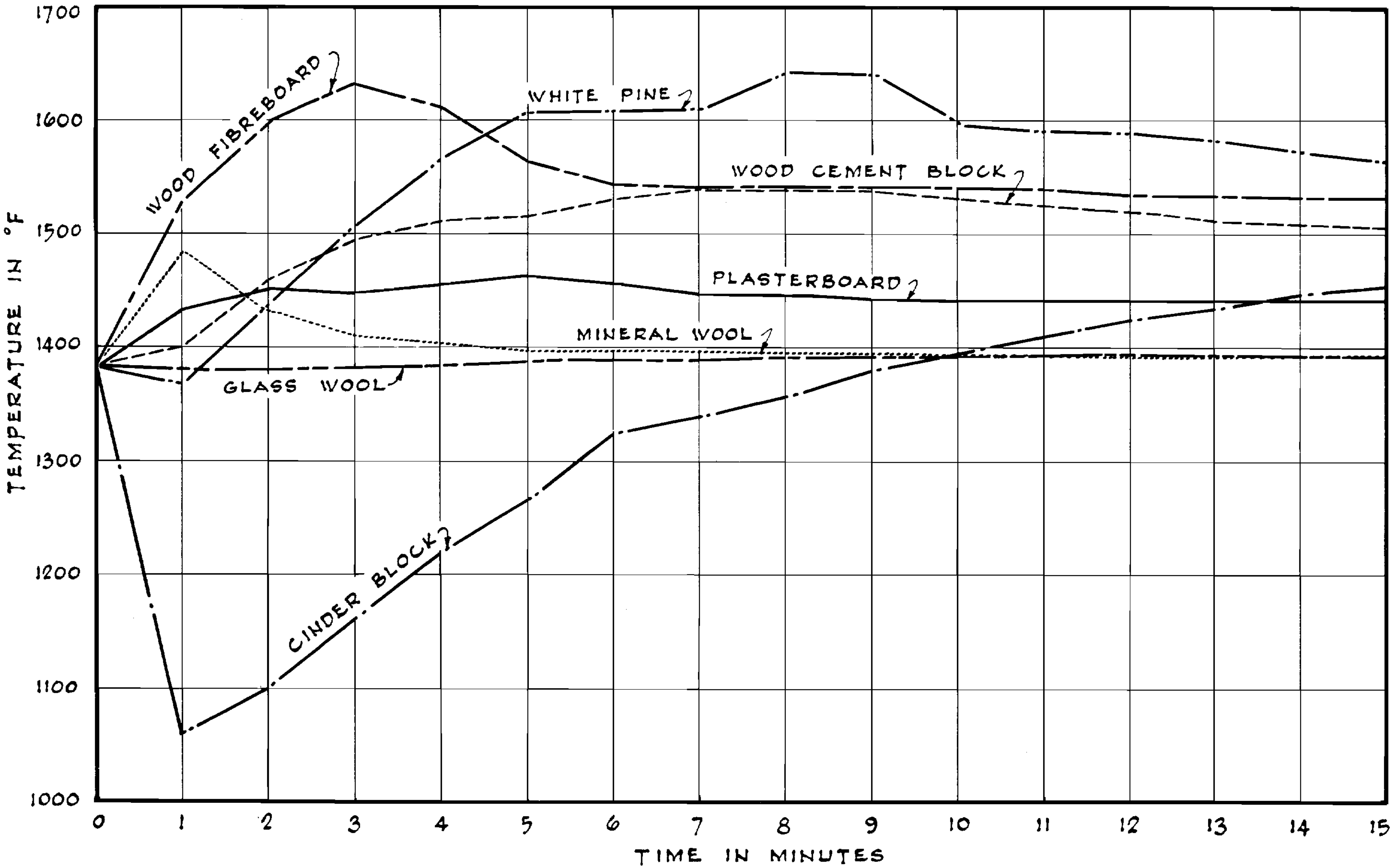

FIGURE 4

READINGS ON THERMOCOUPLE T_2 FOR SEVEN MATERIALS (SERIES I)

(AVERAGE OF TWO, THREE OR FOUR REPEAT TESTS)

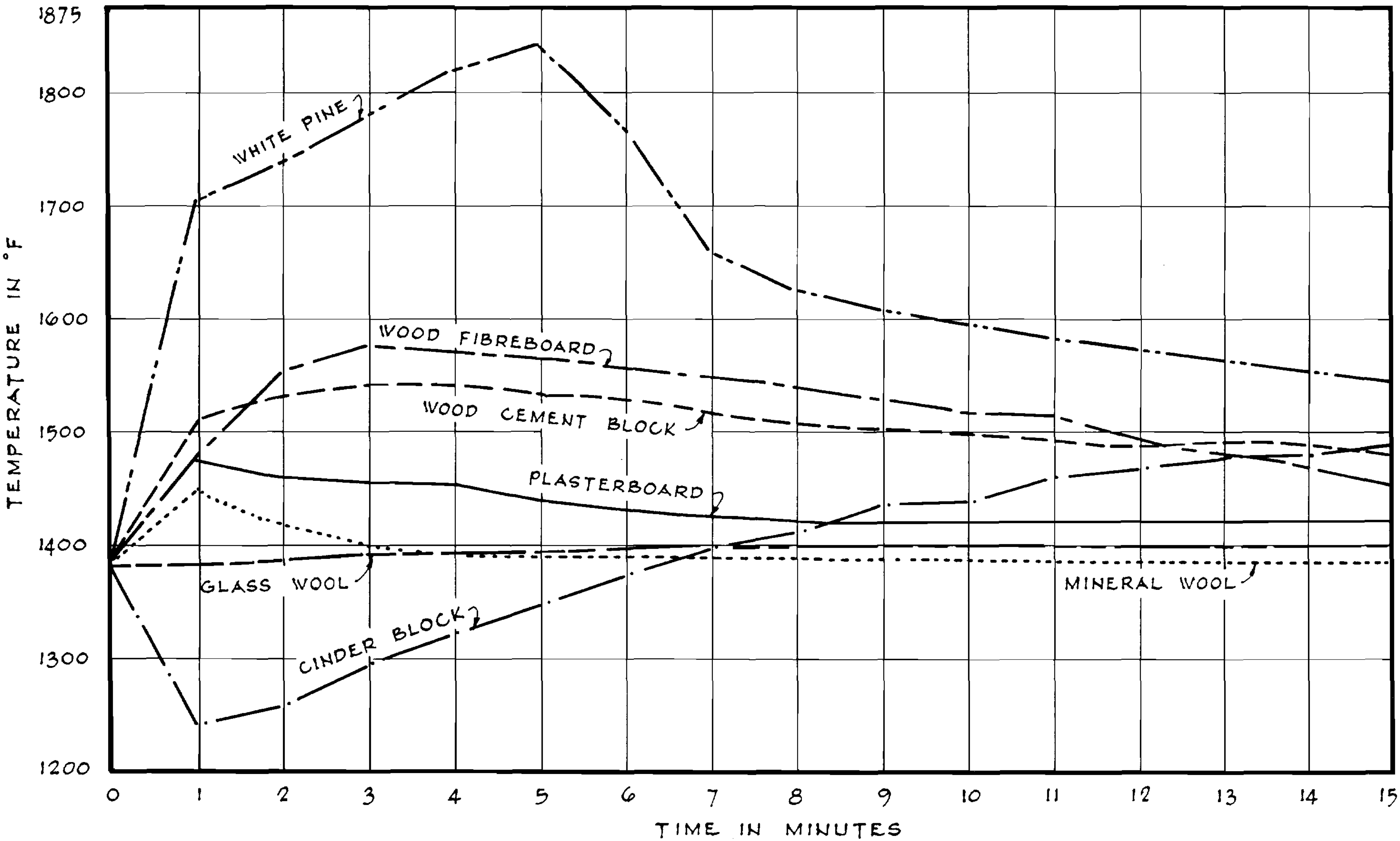

FIGURE 5

SERIES II READINGS ON THERMOCOUPLE T_2 FOR SEVEN MATERIALS

(AVERAGE OF TWO, THREE OR FOUR REPEAT TESTS)

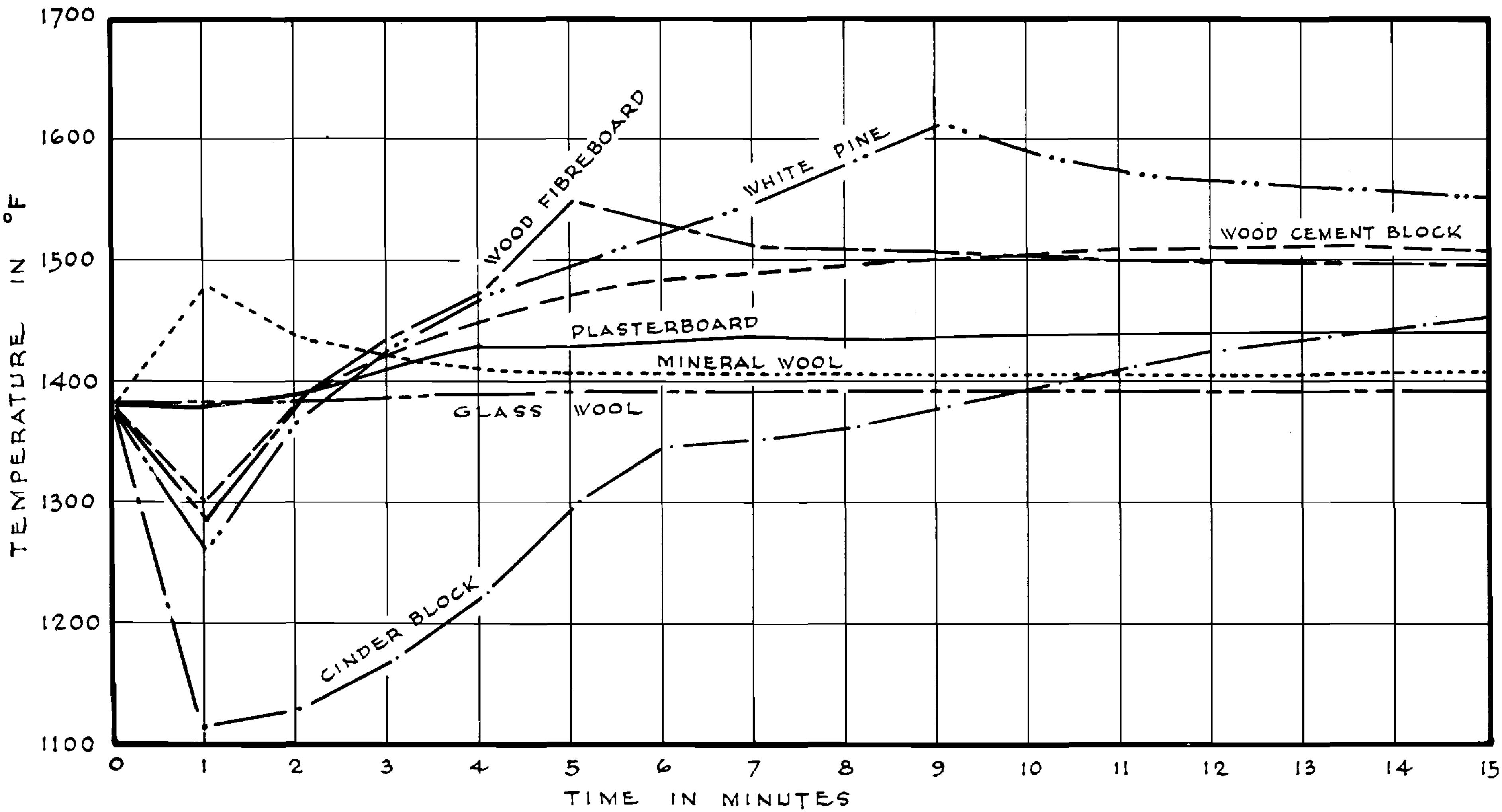

FIGURE 6

SERIES III READINGS ON THERMOCOUPLE T_2 FOR SEVEN MATERIALS

(AVERAGE of TWO, THREE OR FOUR REPEAT TESTS)

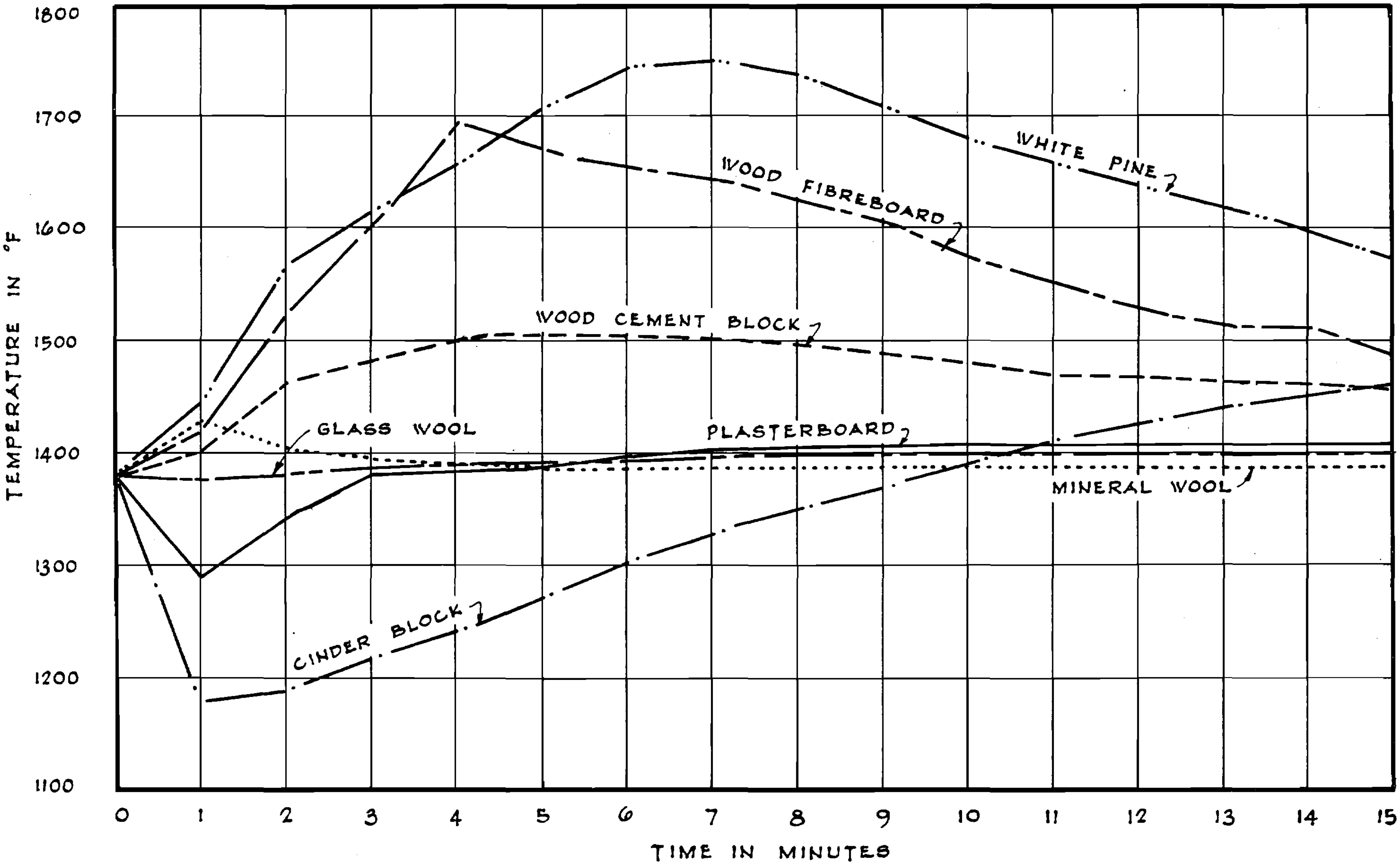

FIGURE 7

SERIES IV READINGS ON THERMOCOUPLE T_2 FOR SEVEN MATERIALS

(AVERAGE OF TWO, THREE OR FOUR REPEAT TESTS)

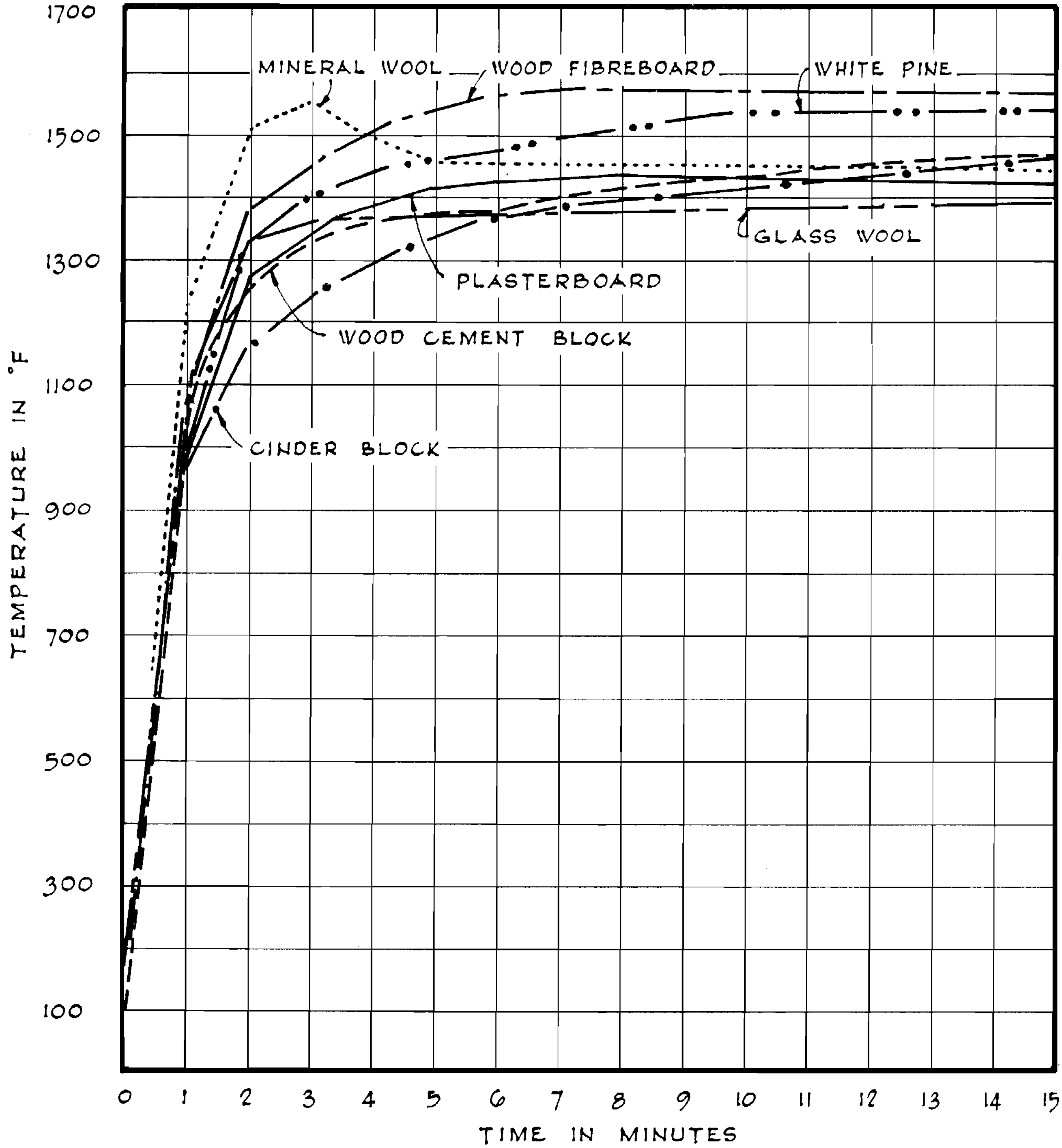

FIGURE 8

SERIES I READINGS ON THERMOCOUPLE T_3 FOR SEVEN MATERIALS

(AVERAGE OF TWO, THREE OR FOUR REPEAT TESTS)

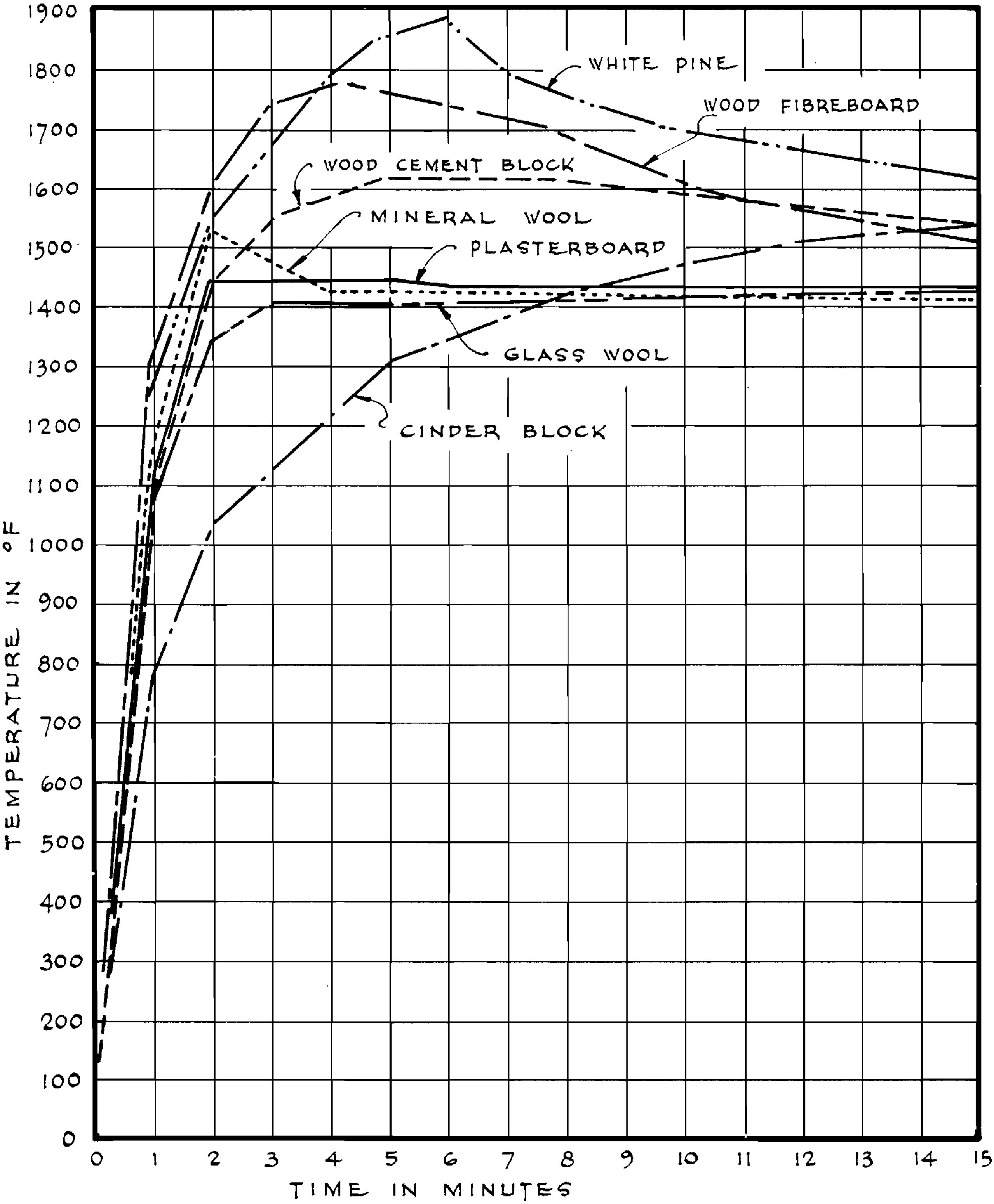

FIGURE 9

SERIES II READINGS ON THERMOCOUPLE T_3 FOR SEVEN MATERIALS

(AVERAGE of TWO, THREE OR FOUR REPEAT TESTS)

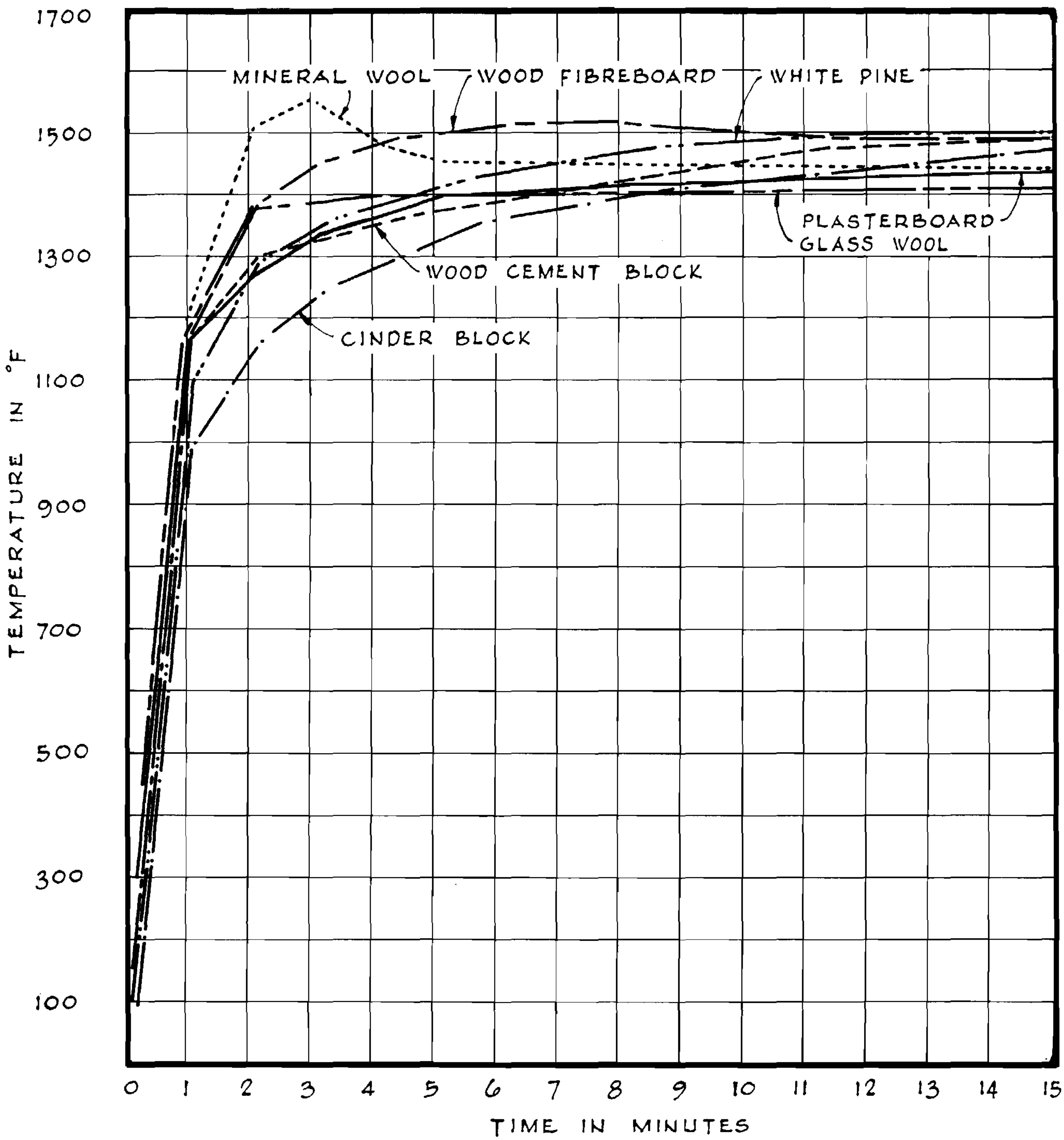

FIGURE 10

SERIES III READINGS ON THERMOCOUPLE T_3 FOR SEVEN MATERIALS

(AVERAGE OF TWO, THREE OR FOUR REPEAT TESTS)

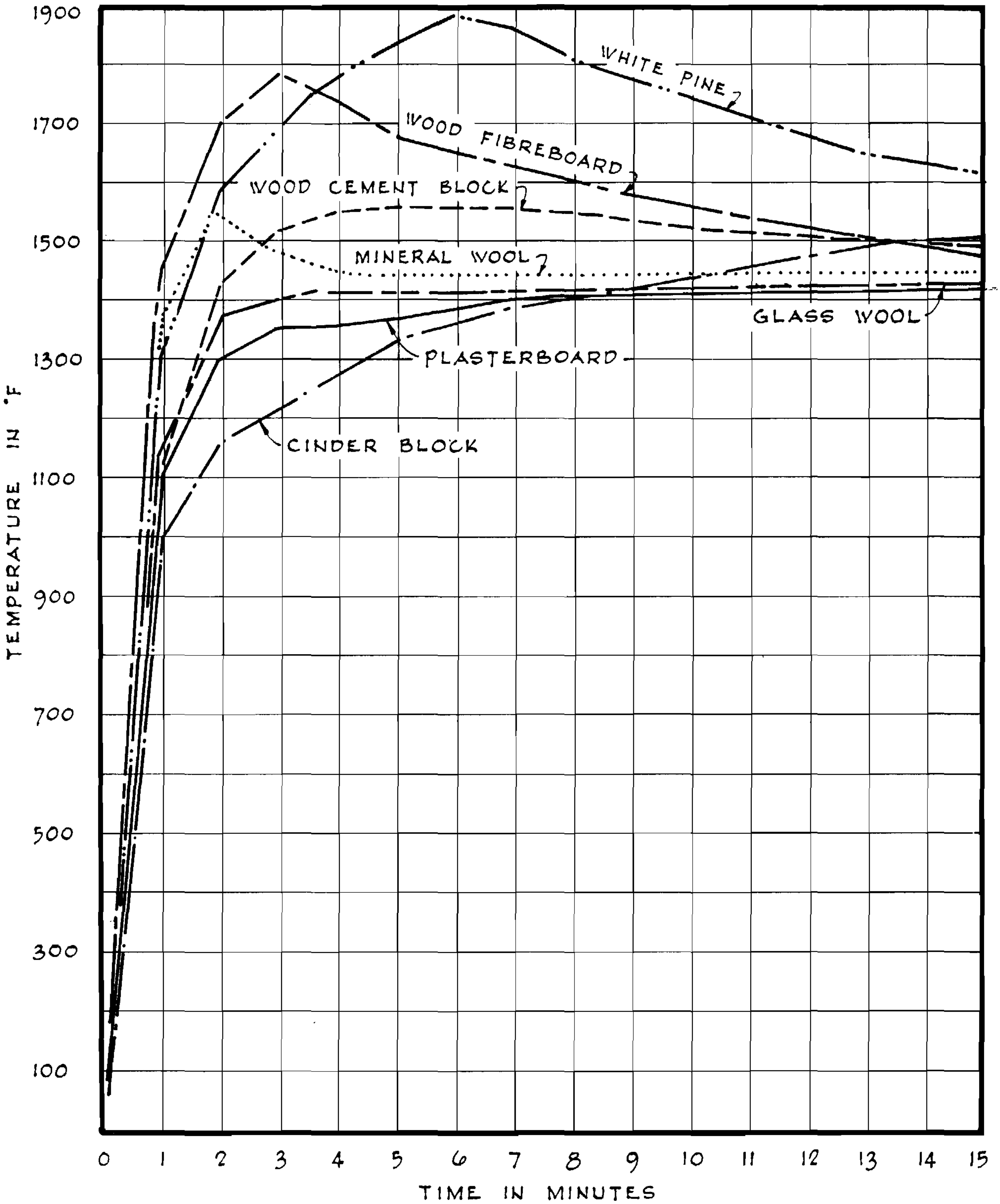

FIGURE 11

SERIES IV READINGS ON THERMOCOUPLE T_3 FOR SEVEN MATERIALS

(AVERAGE OF TWO, THREE OR FOUR REPEAT TESTS)

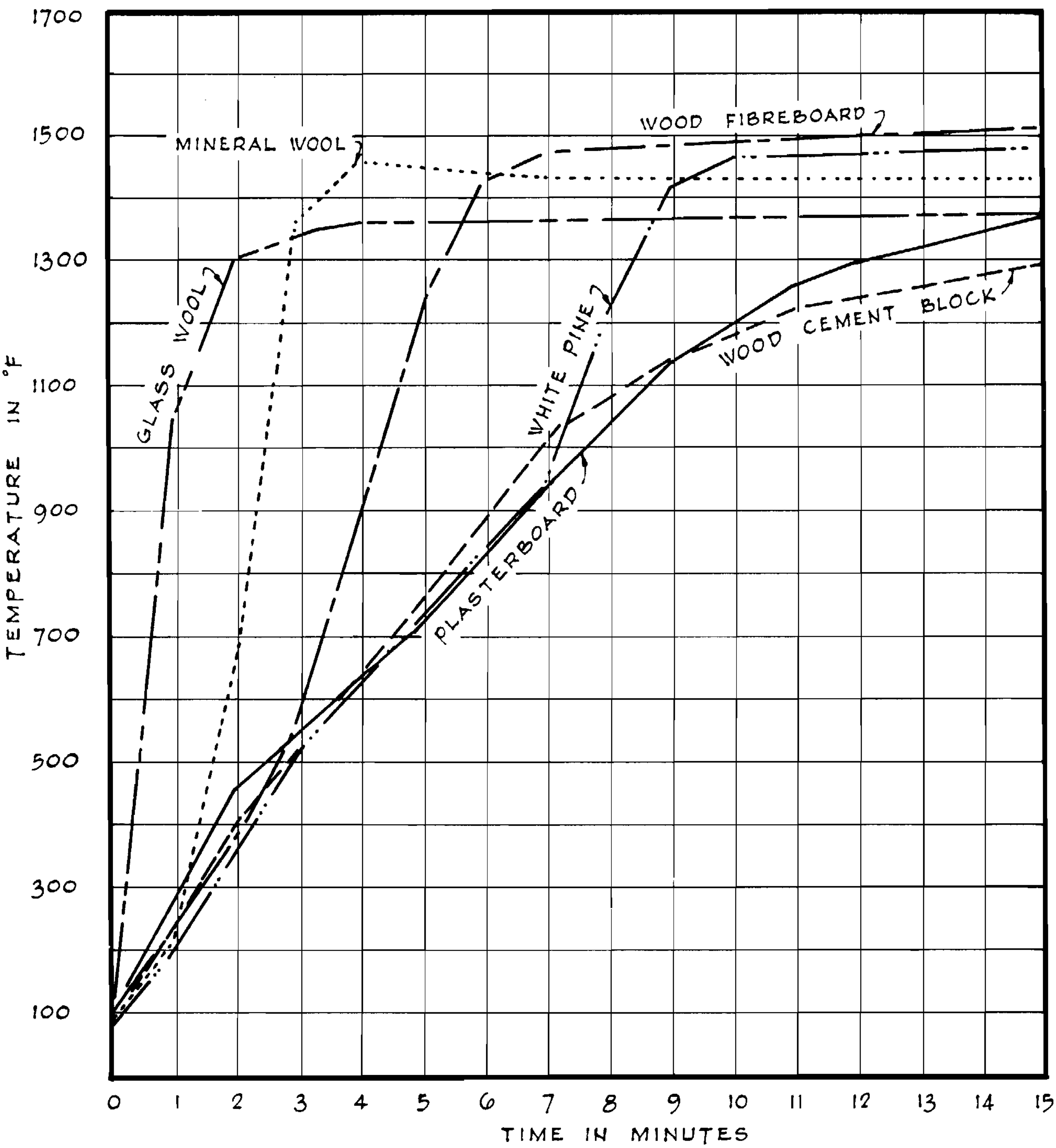

FIGURE 12

SERIES I READINGS ON THERMOCOUPLE T_4 FOR SIX MATERIALS

(AVERAGE OF TWO, THREE OR FOUR REPEAT TESTS)

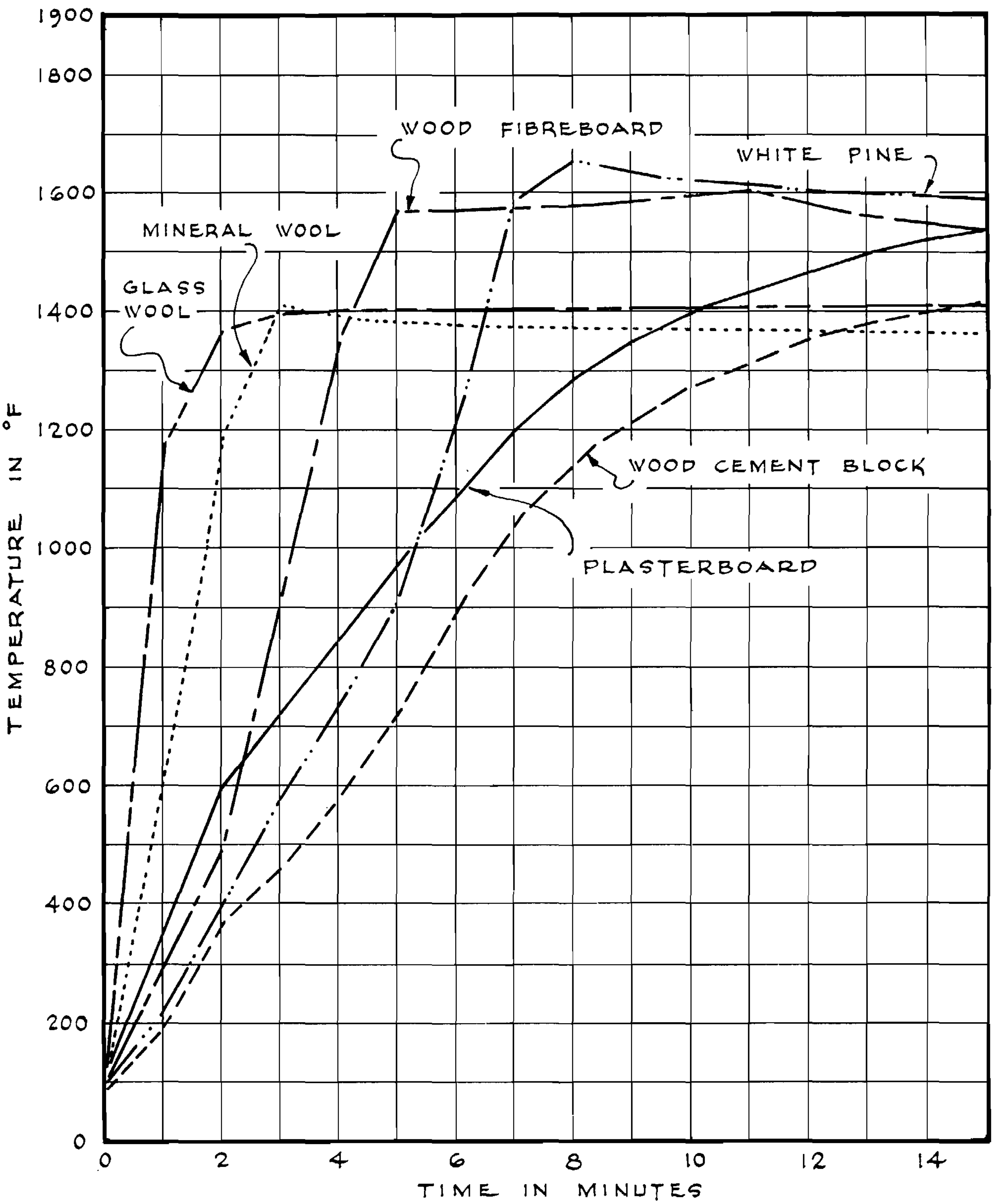

FIGURE 13

SERIES II READINGS ON THERMOCOUPLE T_4 FOR SIX MATERIALS

(AVERAGE of TWO, THREE OR FOUR REPEAT TESTS)

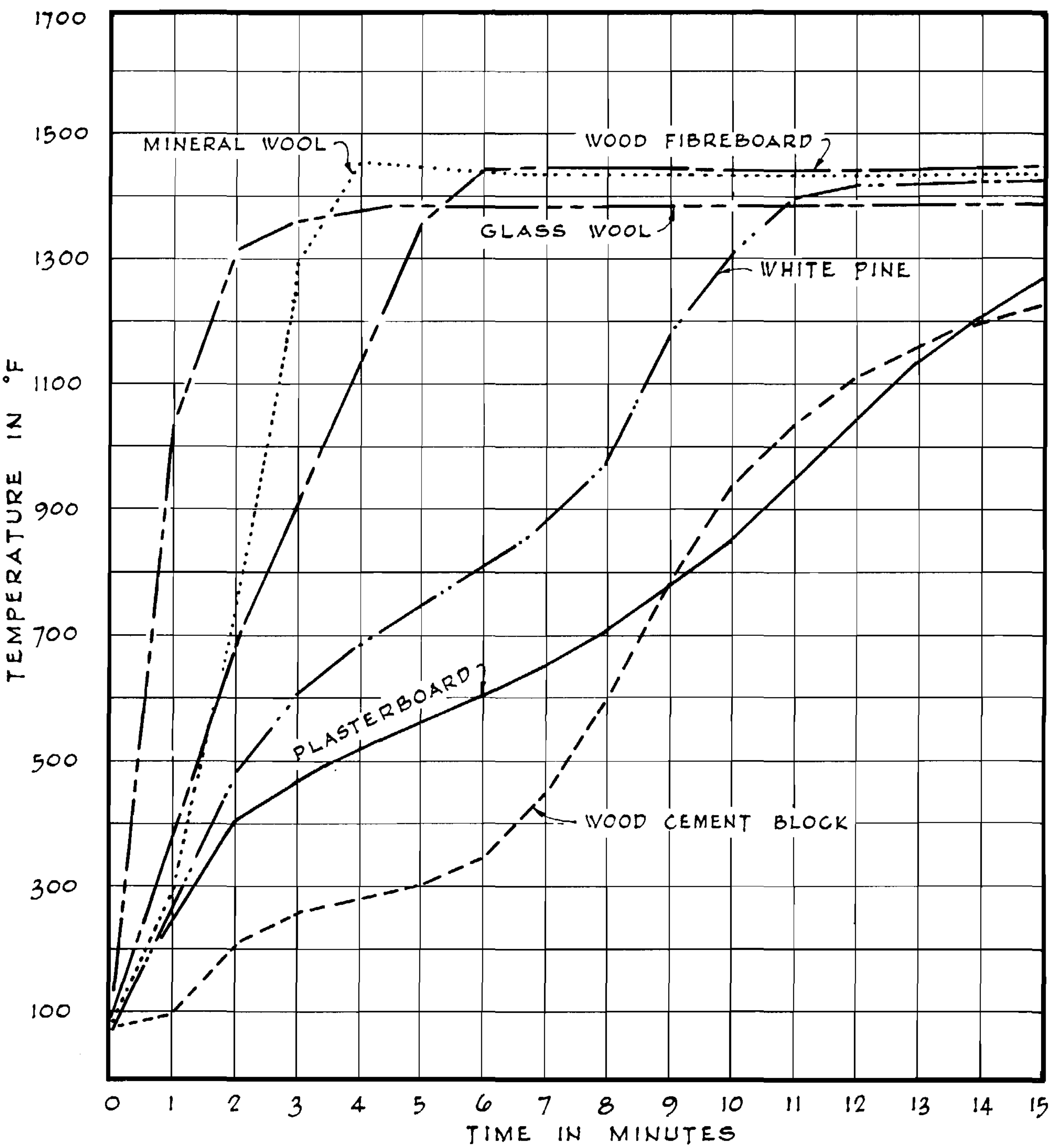

FIGURE 14

SERIES III READINGS ON THERMOCOUPLE T_4 FOR SIX MATERIALS

(AVERAGE OF TWO, THREE OR FOUR REPEAT TESTS)

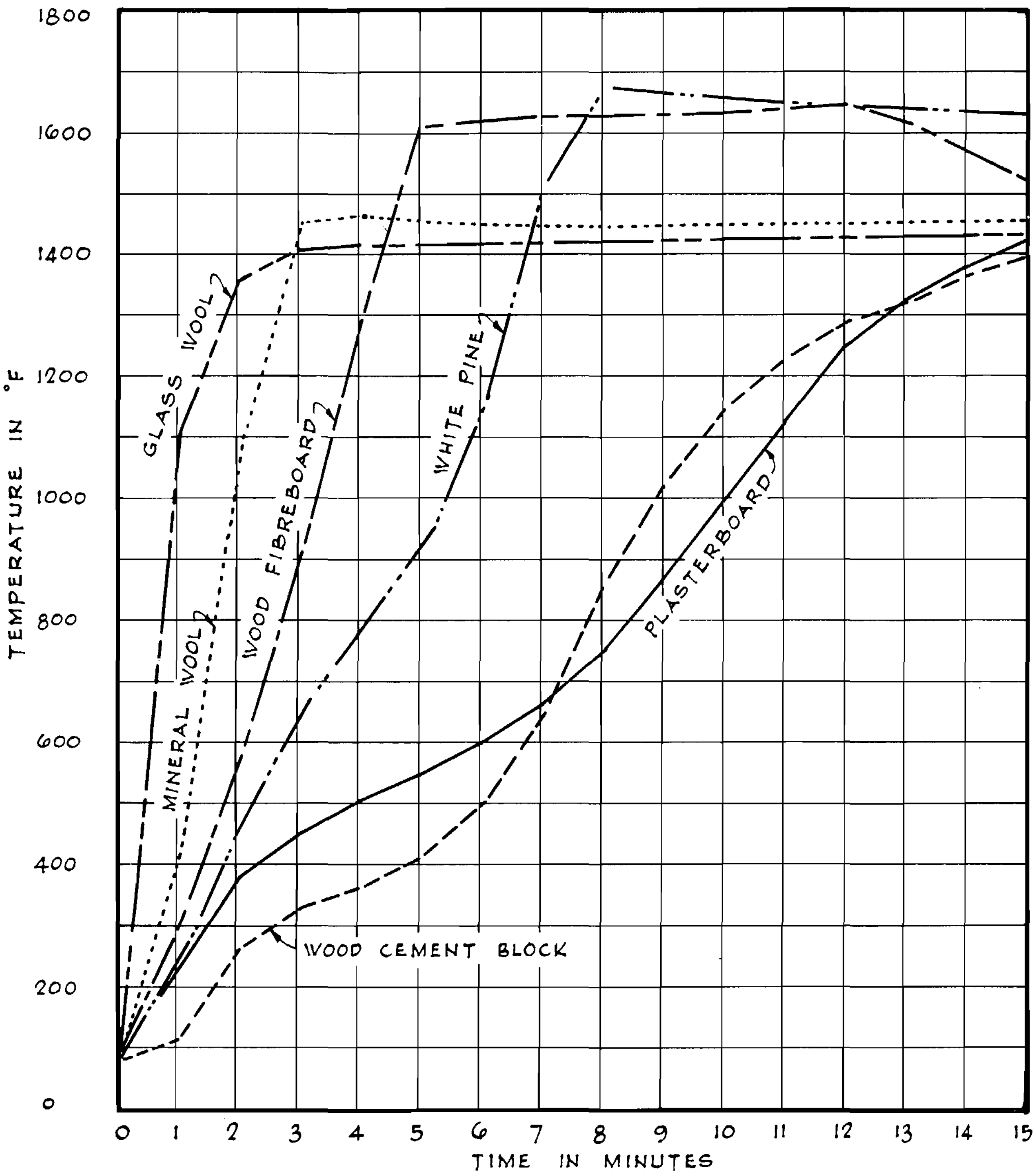

FIGURE 15

SERIES IV READINGS ON THERMOCOUPLE T_4 FOR SIX MATERIALS

(AVERAGE OF TWO, THREE OR FOUR REPEAT TESTS)

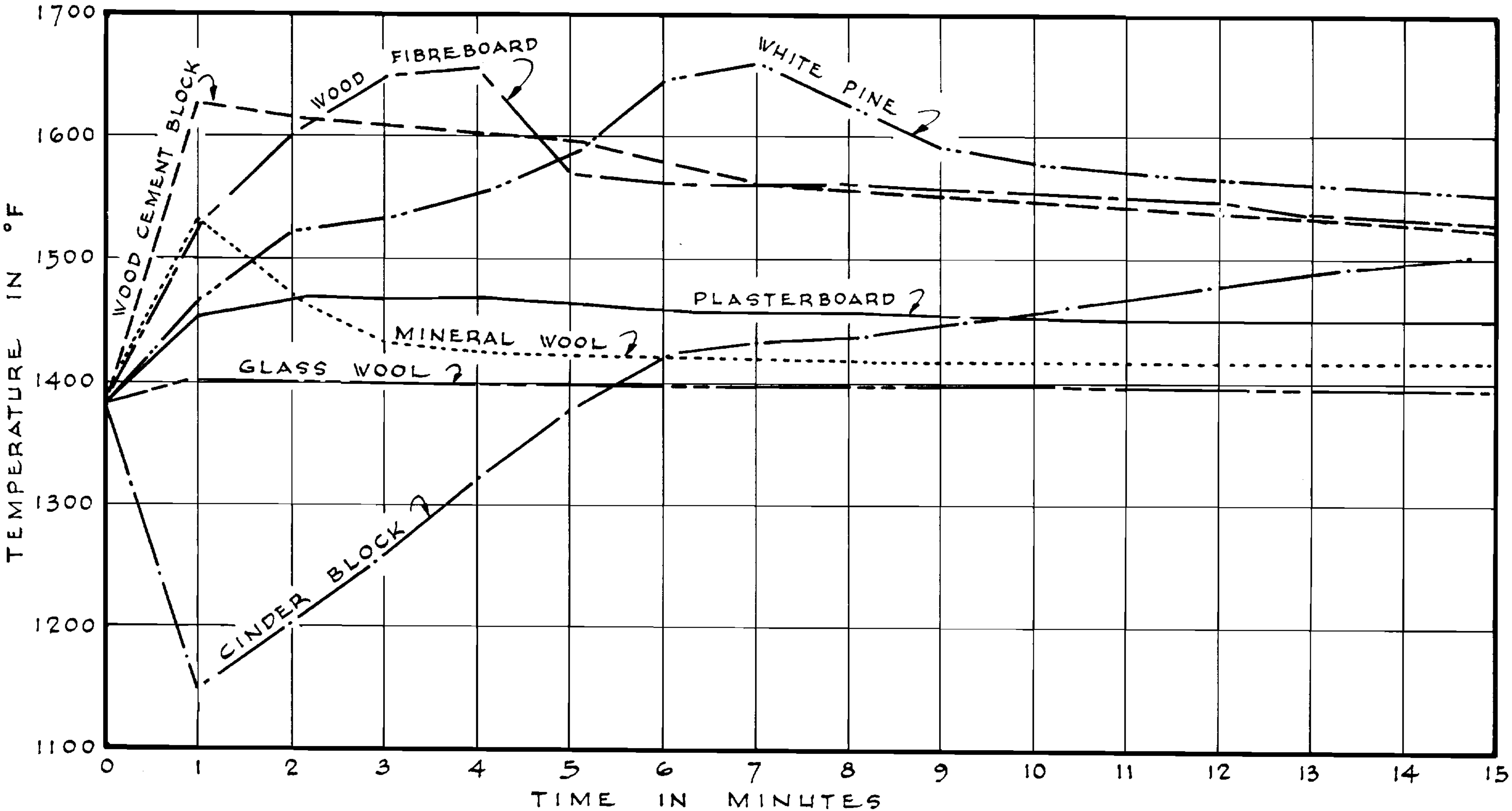

FIGURE 16

SERIES V READINGS ON THERMOCOUPLE FOR SEVEN MATERIALS

(AVERAGE of TWO, THREE OR FOUR REPEAT TESTS)

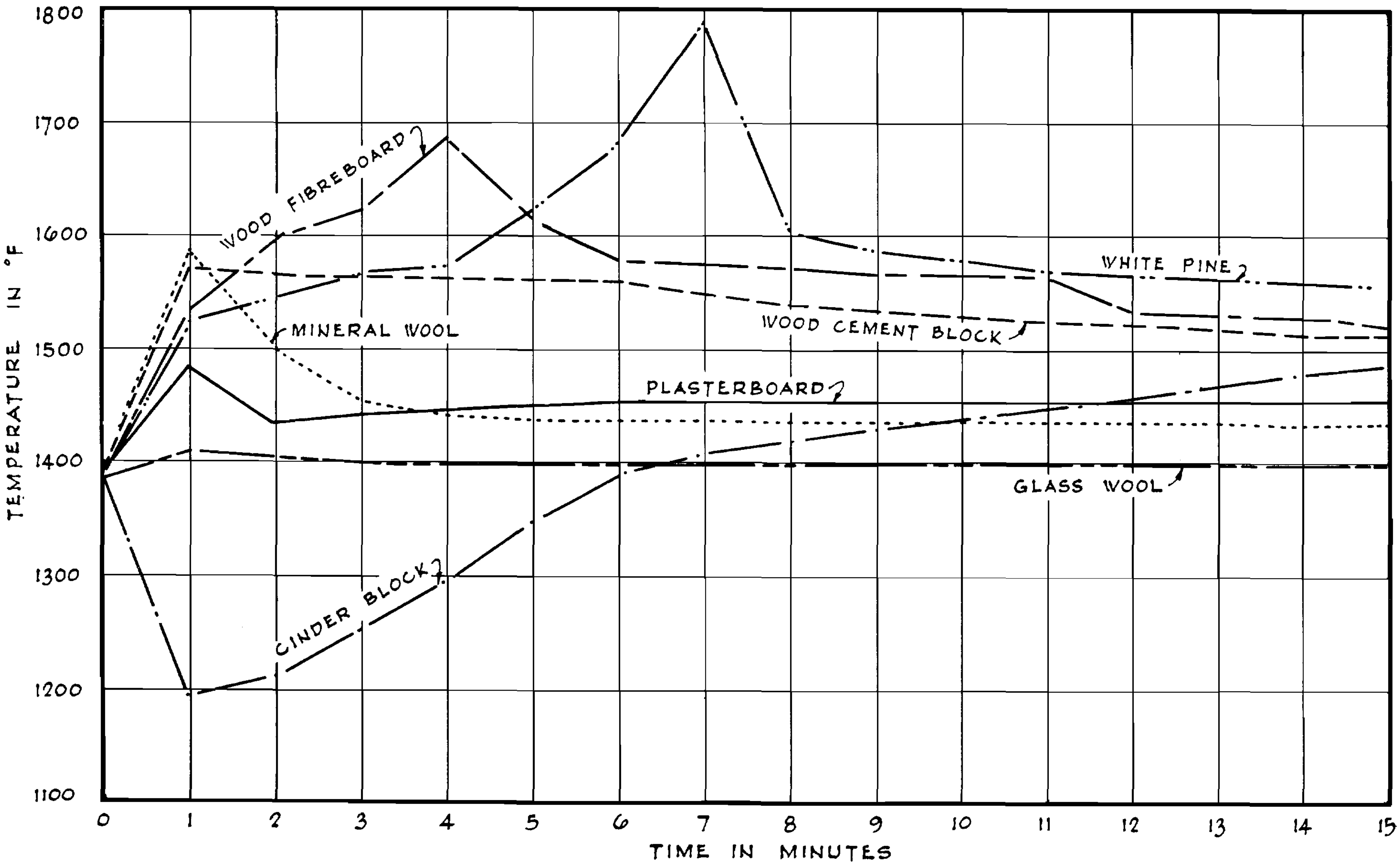

FIGURE 17

SERIES VI READINGS ON THERMOCOUPLE FOR SEVEN MATERIALS

(AVERAGE OF TWO, THREE OR FOUR REPEAT TESTS)

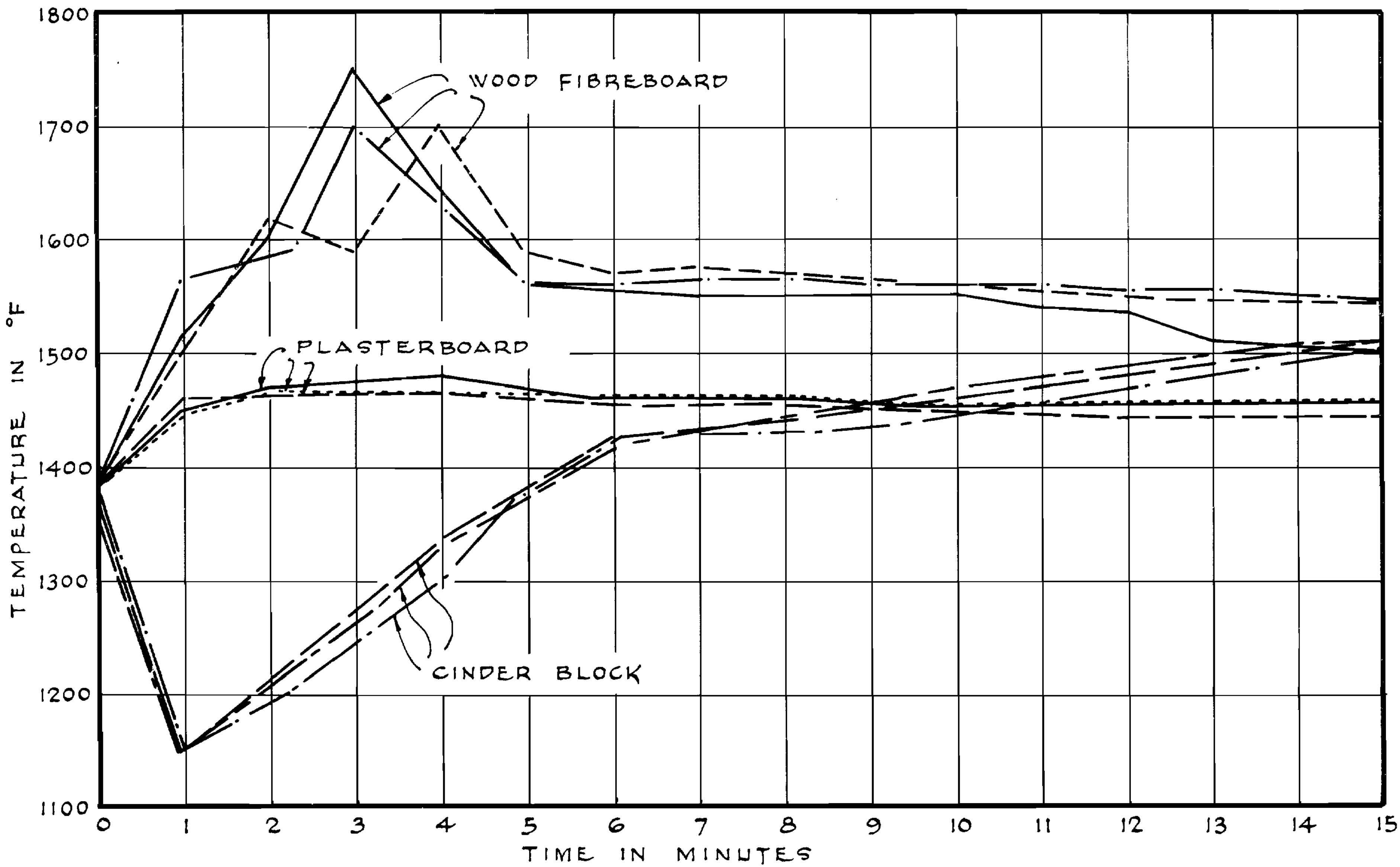

FIGURE 18

SERIES V INDIVIDUAL TESTS ON THREE MATERIALS TO SHOW VARIABILITY.

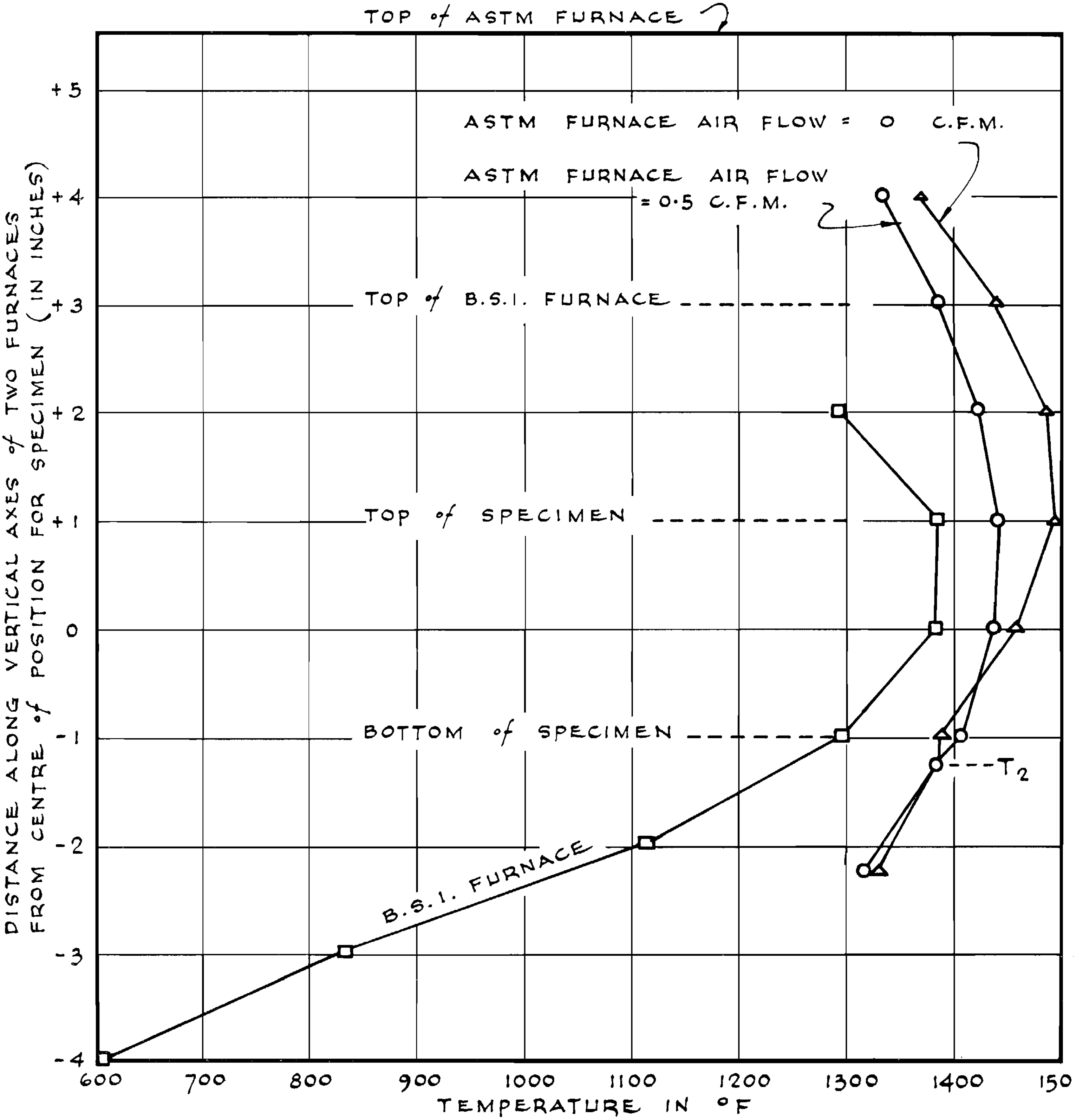

FIG. 19 TEMPERATURE GRADIENT IN FURNACES

APPENDIX A

Determination of the Flow of Air Through the BSI Furnace

The air-flow through the BSI furnace cannot be manually preset prior to individual tests, nor be measured during operation, but is defined by the design and the procedure for use of the furnace. To permit comparison between test results obtained from the two furnaces used in the present study, it was found desirable to determine the value of this flow rate under the normal operating conditions of the BSI furnace. This has been achieved in two ways: by calculation and by experimental determination.

Calculation of Flow Rate

Let z be the altitude above a datum level, this being at the base of the furnace;

Let p, ρ, T be respectively the pressure, density, and temperature of the air at any point, and

Let P_o, ρ_o, T_o refer to the base of the furnace (outside),

P_f, T_f refer to the base of the furnace (inside),

P_1, ρ_1, z_1 refer to the top of the furnace (outside);

Let K be the gas constant per gram (=R/m) (2.87×10^6 cm.gm./sec. work units),

g be the acceleration due to gravity,

x be the linear velocity of flow, and

A be the aggregate area of the holes in the furnace base (9 holes, 1/8" diam.)

Thus; according to Boyle's law,

$$p = K \rho T$$

whereas:

$$\frac{dp}{dz} = -\rho g$$

whence:

$$\log P_1/P_o = -\frac{g}{K}\int_0^1 dz / T$$

Then, if the outside temperature is constant at T_o and the inside temperature at T_f,

$$P_1/P_o = e^{-gz_1/KT_o}$$
$$P_1/P_f = e^{-gz_1/KT_f}$$
$$\therefore \quad P_o - P_f = P_1 \left(e^{gz_1/KT_o} - e^{gz_1/KT_f}\right)$$

and since the exponents are both much less than unity:

$$P_o - P_f = P_1 \left(\frac{gz_1}{KT_o} - \frac{gz_1}{KT_o} \right)$$
$$= \frac{P_1 g z_1}{K} \cdot \frac{T_f - T_o}{T_o T_f}$$
$$= \frac{g z_1 \rho_1}{T_f} \left(T_f - T_o \right)$$

If the work done by this pressure in accelerating air through the holes in the furnace base is equal to the kinetic energy given to the air, then:

$$A.x.(P_o - P_f) = \frac{1}{2} A.x.\rho.x^2.$$

So that:

$$x^2 = \frac{2}{\rho_o} (P_o - P_f)$$
$$= 2\, gz_1 \, (T_f - T_o/T_f)$$

neglecting the difference between ρ_1 and ρ_o.

So the volume rate of flow may be expressed as follows:

Volume rate of flow $= A.x$

$$= A \sqrt{2\, gz_1 \, (T_f - T_o/T_f)}$$

Then if $A = .713 \text{ cm}^2$

$g = 981 \text{ cm.sec}^{-2}$

$z_1 = 28.0 \text{ cm.}$

$T_o = 293^oK$

$T_f = 1023^oK$

the volume rate of flow should then be 141 cm^3 /sec., i.e., 0.299 c.f.m. The actual flow will probably be less than this, because the average air temperature is below 1382°F. and because of friction. The latter factor may be allowed for by means of a coefficient of discharge, which for these orifices is estimated at 0.62 (see Perry: "Chemical Engineers Handbook", p. 405). This would make the gas flow 0.19 c.f.m.

Experimental check of air-flow calculation

The air-flow calculated above has been determined experimentally by J. R. Jutras, using a method suggested by G. Williams-Leir.

A pressure tap was made near the base of the furnace, and connected to a sloping tube water draught gauge calibrated to 0.005 in. H_2O. The top of the (cold) furnace was plugged and connection made through a rotameter to a vacuum pump. Flow was plotted against pressure drop. Then the unplugged furnace was heated to the standard temperature of 1382°F; the draught gauge read 0.01 inch H_2O, corresponding to a rate of flow of 0.30 c.f.m. This in turn corresponds to a linear flow past the specimen of 9.0 ft. per minute, which is close to the value of "about 10 ft. per minute" which is recommended for tests of this nature (see S.H. Ingberg: "Specifying Flame Resistance", The Construction Specifier, October 1954, p. 33).

APPENDIX B

Analysis of Results

The results with the ASTM furnace were analysed as follows. First the mean temperatures of each thermocouple in the repeated tests were plotted (Figs. 4 to 15). Then from each graph the 3-minute reading was taken and tabulated in twelve columns (there being three thermocouple readings for each of the four series) and in seven rows (for the seven materials Table B-1). This was repeated for the 5-minute readings and the 15-minute readings. (Tables B-2 and B-3).

Next the means for the seven materials were calculated. The letter "a" was placed under each of the values 50F. degrees or more above the mean and "b" similarly placed below each value 50F. degrees or more below the mean.

Table 4 suggests an hypothesis, which will be further justified later, that the combustible materials are Nos. 1, 2, and 6 and that the others are of low combustibility. If every thermocouple and every series agreed with this, all the "a's" would be in rows 1, 2, and 6 and all the "b's" in the other four. It will be seen that in fact, this is not the case; an X has been placed against every "b" in rows 1, 2, and 6 and against every "a" in the other four. ("X" may be regarded as an abbreviation meaning: "inconsistency", or: "this figure is inconsistent with the above hypothesis as to the grouping of the seven materials".)

The X's have been totalled in the bottom row of each table. The total X's for the three tables are then a measure of the discordancy between the indications of each series and of each thermocouple and the hypothesis above (Table B-4).

From this table of total "X's" certain conclusions might possibly be drawn; but since a more detailed study presented later in this appendix will reveal them better, only one will be pointed out here. This is that there are many more inconsistencies with thermocouple T_4 than with T_2 and T_3. This is individually true at each time, 3, 5 and 15 minutes, as the tables show. Thus if our hypothesis is correct, T_4 is a poor guide to combustibility. As a consequence, in the further analysis which follows, the readings of T_4 have been omitted.

A second analysis will now be made, omitting T_4, but now including series V and VI, i.e., the results from the BSI furnace. This will be done more thoroughly than before, taking all the temperatures at 2 minute intervals throughout (Tables B-5 to B-12.).

The technique is exactly as before and will not be described again. The results are given in Table B-13. From this table it may be inferred, firstly, as regards the ASTM furnace, that:

	"inconsistencies"
T_2 is slightly to be preferred over T_3	7 to 11
Air flow is desirable	3 to 15
The drier condition is slightly preferable	7 to 11

Secondly, considering both furnaces together, series V and VI are comparable with the other series. These may be regarded as provisional conclusions, since the further analysis which follows may throw further light upon the same questions.

A further step will now be taken which was not attempted in the first analysis. The total number of "a's" over all the times from 1 minute to 15 minutes have been entered in Table B-14 for each series and for each material. For this purpose the number of "b's" is subtracted from the number of "a's" (so that if the "b's" exceed the "a's" a negative quantity is entered in the appropriate space). In the last column on the right a mean is given of all the figures in each row.

The figures in Table B-14 thus obtained are an indication of the trend of the temperature readings. A large positive figure means that under the conditions in question the material under consideration regularly gives a higher temperature than the mean of the other materials tested under the same conditions, and a large negative figure indicates the reverse.

Looking first at the means column on the right of the table, the ranking of materials there given is in effect a mean ranking for all the different conditions of test. It will be seen that the seven materials are ranked in exactly the same order as provisionally derived earlier from the right-hand column of Table 4, and this may be taken as permitting greater confidence in the ranking, which from here on will be treated as a "standard" ranking.

(It should be noted that though the mean result of all the tests done may seem to carry some weight, the decision to treat it as "standard" is still an arbitrary one. Arguments might well be put forward that any one of the series is more correct than the others, or even that conditions outside those covered by the work described should have been chosen. In particular it will be noted that the mean is weighted in favour of the ASTM furnace in the ratio 8:2.

Agreement between Table B-14 and Table-4 should not be regarded as independent confirmation, since both derive from the same data by analogous method.)

One of the principal aims of this report is to find which of the conditions of test gives the most reliable ranking of materials, and the data of Table B-14 make it possible to apply a test to this. If, for instance, any one column of this table coincided exactly with the mean column, then the corresponding conditions would be the best possible and could be regarded as being as satisfactory as this analysis could indicate. However, the verdict of "satisfactory"need not be restricted to this case, since (for example) if in one column each figure was two units greater than that in the mean, or if it was twice as great as the mean, the rankings of the materials would be unaltered and the intervals between them would be proportional to those in the standard ranking.

By inspection, or by plotting graphs, it may easily be shown that no one condition gives a result exactly the same as the standard ranking. A measure of how closely each condition attains to this is given, however, by computing the correlation coefficient between each of the first ten columns and the right-hand column. Since it is doubtful whether the result is a correlation coefficient in the strict statistical sense it will be referred to here as the "consistency index" because it measures how closely each column comes to giving the standard ranking of materials.

The consistency indices thus arrived at are given in the bottom row of Table B-14. They are all numbers less than unity; unity would indicate complete consistency. From this it could be said, for instance, that series VI gives a good result, as do also series I, II, and IV on thermocouple T_2 (but not on T_3). Series III and V are less satisfactory, and thermocouple T_3 is in all cases less reliable than T_2.

If a speculative interpretation of these results may be permitted, it could be said as between series I to IV, (i.e. for the ASTM furnace) that the oven-dry condition gives better reliability than the 60% RH when there is no air-flow, but when there is flow of air, results are obtained which are not significantly less reliable, and the preconditioning of the samples then makes negligible difference to reliability.

These results are based on a fairly elaborate mass of computation and some comments upon their reliability will not be out of place.

Firstly, it should be noted, if it is not obvious, that any other assumed ranking of materials would have led to a different set of consistency indices, so that everything hangs on the standard ranking being correct.

Secondly, the impression may have been given that this ranking has been fed into the calculation and that the ranking which came out has been prejudiced thereby. This is not correct. The first division of materials into two groups was based on the areas under T_2 curves, but this was used only in the first analysis and the only use of the results of this was the rejection of T_4. With T_4 rejected, the second analysis was made, and this led in a purely mechanical and systematic manner to the so-called "standard" ranking, which in fact turned out to agree with the first ranking on the area basis.

TABLE B-1

AVERAGE TEMPERATURES (°F) AT THREE THERMOCOUPLES FOR TIME THREE MINUTES

MATERIAL No.	I			II			III			IV		
	T_2	T_3	T_4	T_2	T_3	T_4	T_2	T_3	T_4	T_2	T_3	T_4
1	1630 a	1455 a	550 bX	1575 a	1735 a	890	1435 a	1445 a	915 a	1605 a	1790 a	890
2	1505 a	1400	510 bX	1780 a	1675 a	575 bX	1430	1345	615 bX	1615 a	1700 a	645 bX
3	1445	1345	550 b	1455	1445	725 b	1415	1330	475 b	1380 b	1360 b	450 b
4	1380 b	1355	1345 aX	1390 b	1395 b	1385 aX	1390	1390	1365 aX	1385 b	1405 b	1395 aX
5	1430	1550 aX	1360 aX	1400 b	1470	1410 aX	1425	1530 aX	1295 aX	1395	1485	1445 aX
6	1495 a	1330 bX	505 bX	1540 a	1540 a	460 bX	1425	1335	265 bX	1490	1520	325 bX
7	1160 b	1240 b	-	1290 b	1130 b	-	1170 b	1235 b	-	1220 b	1220 b	-
TOTAL	10045	9675	4820	10430	10390	5445	9690	9610	4930	10090	10480	5150
MEAN	1435	1382	803	1490	1484	908	1384	1373	822	1441	1497	858
X's	0	2	5	0	0	4	0	1	4	0	0	4

TABLE B-2

AVERAGE TEMPERATURES (°F) AT THREE THERMOCOUPLES FOR TIME FIVE MINUTES

MATERIAL No.	I			II			III			IV		
	T_2	T_3	T_4	T_2	T_3	T_4	T_2	T_3	T_4	T_2	T_3	T_4
1	1665 a	1535 a	1230 a	1565 a	1765 a	1565 a	1550 a	1495 a	1160 a	1670 a	1680 a	1610 a
2	1605 a	1460	730 bX	1840 a	1860 a	905 bX	1495 a	1415	755 bX	1705 a	1840 a	915 bX
3	1460	1410	715 b	1440 b	1445 b	970 b	1430	1395	565 b	1390 b	1375 b	545 b
4	1385 b	1375	1365 aX	1395 b	1420 b	1400 aX	1395	1405	1395 aX	1395 b	1415 b	1415 aX
5	1395 b	1460	1455 aX	1390 b	1420 b	1380 aX	1410	1455	1455 aX	1390 b	1450 b	1450 aX
6	1515	1360 bX	755 bX	1530	1615 a	725 bX	1475	1370	310 bX	1505	1565	405 bX
7	1265 b	1345 b	-	1340 b	1300 b	-	1295 b	1320 b	-	1270 b	1340 b	-
TOTAL	10290	9945	6250	10500	10825	6945	10050	9855	5640	10325	10665	6340
MEAN	1470	1421	1042	1500	1546	1158	1436	1408	940	1475	1524	1057
X's	0	1	4	0	0	4	0	0	4	0	0	4

TABLE B-3

AVERAGE TEMPERATURES (°F) AT THREE THERMOCOUPLES FOR TIME FIFTEEN MINUTES

MATERIAL No.	I			II			III			IV		
	T_2	T_3	T_4	T_2	T_3	T_4	T_2	T_3	T_4	T_2	T_3	T_4
1	1525 a	1570 a	1515 a	1450	1505	1540 a	1495	1495	1455 a	1465	1485	1515
2	1560 a	1540 a	1480 a	1545 a	1615 a	1595 a	1565 a	1495	1435 a	1575 a	1625 a	1625 a
3	1440	1425	1370	1415	1430 b	1535 aX	1440	1435	1275 b	1410	1420 b	1415 b
4	1395 b	1385 b	1375	1395 b	1415 b	1410 b	1395 b	1405 b	1395	1400 b	1425 b	1425
5	1390 b	1445	1435	1380 b	1410 b	1370 b	1405 b	1445	1445 aX	1390 b	1450	1450
6	1505	1470	1295 bX	1480	1545 a	1410 bX	1510	1495	1235 bX	1460	1495	1395 bX
7	1455	1465	-	1485	1535	-	1455	1475	-	1460	1515	-
TOTAL	10270	10300	8470	10150	10455	8860	10265	10245	8240	10160	10415	8825
MEAN	1467	1471	1412	1450	1494	1477	1466	1464	1373	1451	1488	1471
X's	0	0	1	0	0	2	0	0	2	0	0	1

TABLE B-4

TOTAL "X's" FROM TABLES B-1 TO B-3

TIME (MINUTES)	I			II			III			IV		
	T_2	T_3	T_4	T_2	T_3	T_4	T_2	T_3	T_4	T_2	T_3	T_4
3	0	2	5	0	0	4	0	1	4	0	0	4
5	0	1	4	0	0	4	0	0	4	0	0	4
15	0	0	1	0	0	2	0	0	2	0	0	1
TOTAL	0	3	10	0	0	10	0	1	10	0	0	9

TABLE B-5

AVERAGE TEMPERATURES (°F) OF REPEAT TESTS
FOR TIME ONE MINUTE

MATERIAL No.	I		II		III		IV		V	VI	a's	b's
	T_2	T_3	T_2	T_3	T_2	T_3	T_2	T_3	T	T		
1	1525 a	1045	1475	1300 a	1290	1165	1420 a	1450 a	1525 a	1530 a	6	-
2	1365	990 bX	1705 a	1260 a	1260 bX	1085 bX	1445 a	1300 a	1460	1520 a	5	3
3	1435 aX	970 b	1475	1100	1385 aX	1165	1290 b	1110 b	1450	1480 aX	3	3
4	1380	1075	1385 b	1095	1385 aX	1365 aX	1380	1150 b	1405	1410	2	2
5	1485 aX	1220 aX	1450	1150	1485 aX	1250 aX	1430 aX	1375 aX	1530 aX	1585 aX	8	-
6	1400	1065	1510	1110	1300	1125	1405	1100 bX	1625 a	1570 a	2	1
7	1060 b	965 b	1240 b	770 b	1130 b	975 b	1180 b	985 b	1150 b	690 b	-	10
TOTAL	9650	7330	10240	7785	9235	8130	9550	8470	10145	9785		
MEAN	1379	1047	1463	1112	1319	1161	1364	1210	1449	1398		
X's	2	2	0	0	4	3	1	2	1	2		

TABLE B-6

AVERAGE TEMPERATURES (°F) OF REPEAT TESTS FOR TIME THREE MINUTES

MATERIAL No.	I		II		III		IV		V	VI	a's	b's
	T_2	T_3	T_2	T_3	T_2	T_3	T_2	T_3	T	T		
1	1630 a	1455 a	1575 a	1735 a	1435 a	1445 a	1605 a	1790 a	1650 a	1605 a	10	-
2	1505 a	1400	1780 a	1675 a	1430	1345	1615 a	1700 a	1535 a	1565 a	7	-
3	1445	1345	1455	1445	1415	1330	1380 b	1360 b	1465	1440	-	2
4	1380 b	1355	1390 b	1395 b	1390	1390	1385 b	1405 b	1400 b	1395 b	-	7
5	1430	1550 aX	1400 b	1470	1425	1530 aX	1395	1485	1435	1455	2	1
6	1495 a	1330 bX	1540 a	1540 a	1425	1335	1490	1520	1615 a	1560 a	5	1
7	1160 b	1240 b	1290 b	1130 b	1170 b	1235 b	1220 b	1220 b	1255 b	1250 b	-	10
TOTAL	10045	9675	10430	10390	9690	9610	10090	10480	10355	10270		
MEAN	1435	1382	1490	1484	1384	1373	1441	1497	1479	1467		
X's	0	2	0	0	0	1	0	0	0	0		

TABLE B-7

AVERAGE TEMPERATURES (°F) OF REPEAT TESTS
FOR TIME FIVE MINUTES

MATERIAL No.	I		II		III		IV		V	VI	a's	b's
	T_2	T_3	T_2	T_3	T_2	T_3	T_2	T_3	T	T		
1	1665 a	1535 a	1565 a	1765 a	1550 a	1495 a	1670 a	1680 a	1570 a	1610 a	10	-
2	1605 a	1460	1840 a	1860 a	1495 a	1415	1705 a	1840 a	1585 a	1620 a	8	-
3	1460	1410	1440 b	1445 b	1430	1395	1390 b	1375 b	1465	1445	-	4
4	1385 b	1375	1395 b	1420 b	1395	1405	1395 b	1415 b	1395 b	1395 b	-	7
5	1395 b	1460	1390 b	1420 b	1410	1455	1390 b	1450 b	1425 b	1435 b	-	7
6	1515	1360 bX	1530	1615 a	1475	1370	1505	1565	1595 a	1555 a	3	1
7	1265 b	1345 b	1340 b	1300 b	1295 b	1320 b	1270 b	1340 b	1375 b	1345 b	-	10
TOTAL	10290	9945	10500	10825	10050	9855	10325	10665	10410	10405		
MEAN	1470	1421	1500	1546	1436	1408	1475	1524	1487	1486		
X's	0	1	0	0	0	0	0	0	0	0		

TABLE B-8

AVERAGE TEMPERATURES (°F) OF REPEAT TESTS
FOR TIME SEVEN MINUTES

MATERIAL No.	I		II		III		IV		V	VI	a's	b's
	T_2	T_3	T_2	T_3	T_2	T_3	T_2	T_3	T	T		
1	1540 a	1570 a	1545 a	1720 a	1515 a	1520 a	1645 a	1635 a	1565 a	1575 a	10	-
2	1605 a	1495 a	1655 a	1795 a	1550 a	1455	1750 a	1865 a	1665 a	1785 a	9	-
3	1445	1430	1425	1430 b	1435	1410	1405 b	1410 b	1455.	1455 b	-	4
4	1385 b	1380 b	1395 b	1415 b	1390 b	1405	1395 b	1420 b	1395 b	1395 b	-	9
5	1450	1435	1385 b	1415 b	1405	1450	1390 b	1450 b	1420 b	1435 b	-	6
6	1540 a	1395	1515	1610 a	1490	1405	1500	1560	1565 a	1540	3	-
7	1335 b	1380 b	1395 b	1380 b	1355 b	1375 b	1330 b	1390 b	1430 b	1405 b	-	10
TOTAL	10300	10085	10315	10765	10140	10020	10415	10730	10495	10590		
MEAN	1471	1441	1474	1538	1449	1431	1488	1533	1499	1513		
X's	0	0	0	0	0	0	0	0	0	0		

TABLE B-9

AVERAGE TEMPERATURES (°F) OF REPEAT TESTS
FOR TIME NINE MINUTES

MATERIAL No.	I		II		III		IV		V	VI	a's	b's
	T_2	T_3	T_2	T_3	T_2	T_3	T_2	T_3	T	T		
1	1540 a	1570 a	1525 a	1655 a	1505	1510 a	1605 a	1580 a	1555 a	1565 a	9	-
2	1640 a	1530 a	1610 a	1710 a	1615 a	1485	1710 a	1785 a	1590 a	1585 a	9	-
3	1440	1435	1415 b	1425 b	1440	1425	1405 b	1415 b	1455	1455	-	4
4	1390 b	1380 b	1395 b	1415 b	1390 b	1405	1400 b	1425 b	1395 b	1395 b	-	9
5	1395 b	1450	1385 b	1415 b	1405 b	1445	1390 b	1450 b	1415 b	1435	-	7
6	1535 a	1425	1500	1595 a	1500	1435	1490	1540	1555 a	1525	3	-
7	1375 b	1405 b	1435	1445 b	1380 b	1410	1370 b	1430 b	1445	1425 b	-	7
TOTAL	10315	10195	10265	10660	10235	10115	10370	10625	10410	10385		
MEAN	1474	1456	1466	1523	1462	1445	1481	1518	1487	1484		
X's	0	0	0	0	0	0	0	0	0	0		

TABLE B-10

AVERAGE TEMPERATURES (°F) OF REPEAT TESTS
FOR TIME ELEVEN MINUTES

MATERIAL No.	I		II		III		IV		V	VI	a's	b's
	T_2	T_3	T_2	T_3	T_2	T_3	T_2	T_3	T	T		
1	1535 a	1575 a	1510	1575 a	1495	1490	1555 a	1545	1550 a	1560 a	6	-
2	1590 a	1540 a	1580 a	1675 a	1575 a	1495	1655 a	1715 a	1570 a	1565 a	9	-
3	1440	1430	1415	1425 b	1440	1430	1410 b	1425 b	1450	1450	-	3
4	1390 b	1380 b	1395 b	1415 b	1390 b	1405	1400 b	1425 b	1395 b	1395 b	-	9
5	1390 b	1450	1385 b	1410 b	1405 b	1445	1390 b	1450 b	1415 b	1430 b	-	8
6	1525 a	1445	1490	1575 a	1510	1470	147[illegible]	1520	1540 a	1520	3	-
7	1405 b	1425	1460	1490	1410 b	1435	1410 b	1460	1470	1445	-	3
TOTAL	10275	10245	10235	10565	10225	10170	10290	10540	10390	10365		
MEAN	1468	1464	1462	1509	1461	1453	1470	1506	1484	1481		
X's	0	0	0	0	0	0	0	0	0	0		

TABLE B-11

AVERAGE TEMPERATURES (°F) OF REPEAT TESTS
FOR TIME ELEVEN MINUTES

MATERIAL No.	I		II		III		IV		V	VI	a's	b's
	T_2	T_3	T_2	T_3	T_2	T_3	T_2	T_3	T	T		
1	1535 a	1570 a	1480	1545	1495	1490	1515 a	1510	1535 a	1530 a	5	-
2	1580 a	1540 a	1555 a	1645 a	1570 a	1495	1615 a	1665 a	1560 a	1560 a	9	-
3	1440	1425	1415	1425 b	1440	1430	1410 b	1420 b	1450	1450	-	3
4	1395 b	1385 b	1395 b	1415 b	1390 b	1405 b	1400 b	1425 b	1395 b	1395 b	-	10
5	1390 b	1445	1385 b	1410 b	1405 b	1445	1390 b	1450	1415 b	1435	-	6
6	1510	1460	1485	1550	1510	1485	1465	1505	1535 a	1515	1	-
7	1430	1445	1470	1515	1435	1455	1440	1495	1490	1465	-	-
TOTAL	10280	10270	10185	10505	10245	10205	10235	10470	10380	10350		
MEAN	1469	1467	1455	1501	1464	1458	1462	1496	1483	1479		
X's	0	0	0	0	0	0	0	0	0	0		

TABLE B-12

AVERAGE TEMPERATURES (°F) OF REPEAT TESTS FOR TIME FIFTEEN MINUTES

MATERIAL No.	I		II		III		IV		V	VI	a's	b's
	T_2	T_3	T_2	T_3	T_2	T_3	T_2	T_3	T	T		
1	1525 a	1570 a	1450	1505	1495	1495	1465	1485	1530	1520	2	-
2	1560 a	1540 a	1545 a	1615 a	1565 a	1495	1575 a	1625 a	1555 a	1555 a	9	-
3	1440	1425	1415	1430 b	1440	1435	1410	1420 b	1450	1450	-	2
4	1395 b	1385 b	1395 b	1415 b	1395 b	1405 b	1400 b	1425 b	1395 b	1395 b	-	10
5	1390 b	1445	1380 b	1410 b	1405 b	1445	1390 b	1450	1415 b	1430	-	6
6	1505	1470	1480	1545 a	1510	1495	1460	1495	1525	1510	1	-
7	1455	1465	1485	1535	1455	1475	1460	1515	1505	1485	-	-
TOTAL	10270	10300	10150	10455	10265	10245	10160	10415	10375	10345		
MEAN	1467	1471	1450	1494	1466	1464	1451	1488	1482	1478		
X's	0	0	0	0	0	0	0	0	0	0		

TABLE B-13

TOTAL NUMBER OF X's IN TABLES B-5 TO B-12

TIME IN MINUTES	I		II		III		IV		V	VI
	T_2	T_3	T_2	T_3	T_2	T_3	T_2	T_3	T	T
1	2	2	0	0	4	3	1	2	1	2
3	0	2	0	0	0	1	0	0	0	0
5	0	1	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
X's	2	5	0	0	4	4	1	2	1	2

TABLE B-14

TOTAL a's LESS TOTAL b's OVER TABLES B-5 TO B-12

MATERIAL No.	I		II		III		IV		V	VI	
	T_2	T_3	T_2	T_3	T_2	T_3	T_2	T_3	T	T	MEAN
1	8	7	4	6	3	4	7	5	7	7	5.8
2	7	4	8	8	5	-1	8	8	7	8	6.2
3	1	-1	-2	-6	1	-	-7	-8	-	0	-2.2
4	-7	-5	-8	-7	-4	-1	-7	-8	-7	-7	-6.1
5	-4	2	-7	-6	-3	2	-5	-3	-5	-2	-3.1
6	4	-2	1	6	-	-	-	-1	7	3	1.8
7	-6	-5	-4	-5	-6	-4	-6	-5	-4	-5	-5.0
Consistency Index	0.97	0.83	0.95	0.94	0.91	0.49	0.96	0.93	0.94	0.99	