NATIONAL BUREAU OF STANDARDS REPORT

10 462

DEVELOPMENT OF A HEAT RELEASE RATE CALORIMETER AT NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards[1] was established by an act of Congress March 3, 1901. The Bureau's overall goal is to strengthen and advance the Nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the Nation's physical measurement system, (2) scientific and technological services for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau consists of the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Center for Computer Sciences and Technology, and the Office for Information Programs.

THE INSTITUTE FOR BASIC STANDARDS provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of a Center for Radiation Research, an Office of Measurement Services and the following divisions:

Applied Mathematics—Electricity—Heat—Mechanics—Optical Physics—Linac Radiation[2]—Nuclear Radiation[2]—Applied Radiation[2]—Quantum Electronics[3]—Electromagnetics[3]—Time and Frequency[3]—Laboratory Astrophysics[3]—Cryogenics[3].

THE INSTITUTE FOR MATERIALS RESEARCH conducts materials research leading to improved methods of measurement, standards, and data on the properties of well-characterized materials needed by industry, commerce, educational institutions, and Government; provides advisory and research services to other Government agencies; and develops, produces, and distributes standard reference materials. The Institute consists of the Office of Standard Reference Materials and the following divisions:

Analytical Chemistry—Polymers—Metallurgy—Inorganic Materials—Reactor Radiation—Physical Chemistry.

THE INSTITUTE FOR APPLIED TECHNOLOGY provides technical services to promote the use of available technology and to facilitate technological innovation in industry and Government; cooperates with public and private organizations leading to the development of technological standards (including mandatory safety standards), codes and methods of test; and provides technical advice and services to Government agencies upon request. The Institute also monitors NBS engineering standards activities and provides liaison between NBS and national and international engineering standards bodies. The Institute consists of the following technical divisions and offices:

Engineering Standards Services—Weights and Measures—Flammable Fabrics—Invention and Innovation—Vehicle Systems Research—Product Evaluation Technology—Building Research—Electronic Technology—Technical Analysis—Measurement Engineering.

THE CENTER FOR COMPUTER SCIENCES AND TECHNOLOGY conducts research and provides technical services designed to aid Government agencies in improving cost effectiveness in the conduct of their programs through the selection, acquisition, and effective utilization of automatic data processing equipment; and serves as the principal focus within the executive branch for the development of Federal standards for automatic data processing equipment, techniques, and computer languages. The Center consists of the following offices and divisions:

Information Processing Standards—Computer Information—Computer Services—Systems Development—Information Processing Technology.

THE OFFICE FOR INFORMATION PROGRAMS promotes optimum dissemination and accessibility of scientific information generated within NBS and other agencies of the Federal Government; promotes the development of the National Standard Reference Data System and a system of information analysis centers dealing with the broader aspects of the National Measurement System; provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world, and directs the public information activities of the Bureau. The Office consists of the following organizational units:

Office of Standard Reference Data—Office of Technical Information and Publications—Library—Office of Public Information—Office of International Relations.

---

[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Part of the Center for Radiation Research.
[3] Located at Boulder, Colorado 80302.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
4219420	March 14, 1972	10 462

DEVELOPMENT OF A HEAT RELEASE RATE CALORIMETER AT NBS

by
W. J. Parker
and
M. E. Long
Fire Research Section
Building Research Division
National Bureau of Standards
Washington, D. C. 20234

Prepared for:
Naval Ship Systems Command
Department of the Navy
Order No. N00024-69-F-5177:Contract 6101C-NN531

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

DEVELOPMENT OF A HEAT RELEASE RATE CALORIMETER AT NBS*

by

W. J. Parker

and

M. E. Long

Fire Research Section

National Bureau of Standards

ABSTRACT

The heat release rate calorimeter being developed at the National Bureau of Standards measures the rate of heat release for building materials exposed to radiant fluxes up to 10 W/cm^2 with a response time of a few seconds. The calorimeter and its operation are described and preliminary results are presented on the maximum one minute average heat release rates for a variety of building materials. Also given is the effect of irradiance on the maximum one minute average heat release rate of a wood fiber insulating board. The total heat generated by a pine specimen is compared with the heat of combustion measured with an oxygen bomb calorimeter. This heat release rate calorimeter has adequate sensitivity, accuracy, and time response to provide useful

---

*Sponsored by the U. S. Navy

information on the heat release characteristics of building materials in a fire environment.

Key Words: heat release rate, calorimeter, thermal radiation, radiant panels, fire, tests, building materials, burningg.

INTRODUCTION

The rate at which a burning material releases heat in a fire environment is an important characteristic of that material and should be considered when specifying its use in a particular construction. In a room fire a large portion of the heat released is absorbed in the walls and ceiling. The attendant rise in temperature creates radiation levels which serve to increase flame spread rates, produce new ignitions, and further increase the rate of heat release of the burning materials. So, the rate of fire buildup depends on the rate of heat release of the materials used in the interior construction and in the furnishings.

The rate of heat release under constant exposure conditions tends to fall off with time as the pyrolysis products originate at greater distances from the surface. In order to properly evaluate the potential performance of a combustible material in a fire environment, the rate of heat release as a function of both the time and the controlling factors of the environment must be known. These environmental conditions include the irradiance level, the air velocity past the surface, the air temperature, and the chemical composition of the air.

An adequate mathematical model of fire buildup in a room

does not exist so that at the present time a comparison of the rates of heat release of different materials used in building construction and furnishings must serve as a practical guide in specifying materials for fire safety. It is desirable to develop a test apparatus which would be capable of providing the detailed information needed when an adequate model becomes available. An instrument capable of gathering such information may prove useful in the development of a workable model and at the same time contribute to an understanding of the burning processes.

The heat release rate can be measured by exposing a specimen to a simulated fire environment inside a closed furnace, either gas fired or electrically heated, with a constant flow of air through it. The heat release rate can be determined from the increase in temperature of the exhaust gases or from the required rate of flow of a comparison fuel burned to produce the same temperature rise. However, the thermal inertia of the furnace prevents the gas temperature from following rapid changes in the heat release rate so the time constant is usually of the order of several minutes with this method. Because the time required for ignition by flame contact is of the order of a minute or less, an analysis of fire buildup in a room requires a knowledge of heat release rates with higher time resolution. If the heat release rate is calculated directly

from the temperature rise of the flue gases, heat losses through the walls are crucial to the accuracy of the test. If the comparison method is used, as it is in some existing calorimeters, heat losses cancel out, but two complete runs, one with the comparison fuel, must be made for each test.

This paper describes the heat release rate calorimeter under development at NBS. This apparatus has a response time of a few seconds, is relatively insensitive to heat losses, and produces a recorded output of the heat release rate in a single run. Furthermore, it is well suited to studying the effect of irradiance and other environmental parameters on the heat release rate.

The fast time response is achieved by maintaining the calorimeter at a constant temperature so that there is little change in the rate of heat losses between the furnace gases and the parts of the instrument. The constant temperature operation is accomplished with an auxiliary burner whose fuel supply is regulated by an automatic temperature controller so that the increase in heat due to the burning of the specimen is compensated by a decrease in the fuel flow rate. The decrease in the rate of flow of the fuel, which is proportional to the rate of heat release of the specimen, is recorded.

The total heat released in a fire environment is another important characteristic of a combustible building material which can be determined by integrating the heat release rate over the burning period.

2.0 DESCRIPTION OF THE INSTRUMENT

A drawing of the NBS heat release rate calorimeter appears in figure 1 and photographic views are shown in figures 2 and 3. The calorimeter consists of a combustion chamber, a control chamber, and a mixing chamber.

2.1 Combustion Chamber

The combustion chamber whose inside dimensions are 33 by 33 by 36 cm (13 by 13 by 14 in.) is lined on three sides with gas fired radiant panels. Each panel is a porous ceramic plate which is heated by the flame from the variable gas air mixture which flows through it. Most of the radiation comes from the surface of the panel whose temperature is varied between 900 K and 1300 K (627°C and 1027°C, 1160°F and 1880°F) to produce the desired irradiance of the specimen. The fourth side of the combustion chamber contains the door through which the specimen is admitted. A 16.5 cm (6.5 in.) diameter mica window restrained by a wire screen is located in the door so that the flames

extending above the top of the specimen can be seen.

The fuel for the radiant panels is drawn in through an aspirator which provides an adjustable mixture of air and city gas which is principally methane. Variation of the fuel air ratio provides the range of specimen irradiances required for the measurements. The air flow rates for the radiant panel, for combustion of the specimen, and for dilution of the combustion gas are each monitored separately by means of a water manometer which measures the differential pressure produced across an orifice plate in each individual air supply line. These flow rates are held constant during the measurement period.

The 11.4 by 15 cm (4 1/2 by 6 in.) specimen, up to 2.5 cm (1 in.) in thickness, is oriented vertically at the center of the combustion chamber. Only its front surface is exposed to the radiant panels. Its edges are shielded by the insulated box which serves as a holder. The holder is shown in figure 4. The rear surface of the specimen is exposed to a 2.5 cm (1 in.) thick water cooled brass block located inside the insulated box. Four adjustable standoff screws prevent the specimen from contacting the water cooled block and locate the front surface of specimen flush with the front of the specimen holder for specimen thicknesses up to 2.5 cm (1 in.). This configuration represents a

section of a burning wall where the back surface of the wall is exposed to a relatively cool surface. The heat carried away by the water is calculated from its flow rate and temperature rise. Air for combustion of the sample passes up through the floor of the combustion chamber by way of a porous plate of the same type as the radiant panels. The regulation of the flow through this plate controls the mass flow rate of air past the surface of the specimen.

The sample holder is secured to the door by means of the water cooling inlet and outlet tubes as seen in figure 1. The door is moved outward from the calorimeter on rollers confined by tracks. The specimen is quickly inserted and the door is closed by locking it securely against an asbestos gasket. During the time the door is open there is an appreciable heat loss which is partially compensated when the temperature controller calls for a large increase in the gas flow rate to the auxiliary burner. The system recovers within a few seconds after the door is closed so that very little information is lost.

2.2 Control Chamber

The combustion chamber is open at the top allowing the hot combustion gases to pass freely into the control chamber. The control chamber which is 45 cm (18 in.) high and 33 by

33 cm (13 by 13 in.) in cross section, is open at both the bottom and the top. The side walls consist of porous panels of the same type used for the radiant panels in the combustion chamber. Excess air, from the laboratory air supply, flowing at about 5.7m^3/min (200 ft^3/min) referred to standard conditions of temperature and pressure (273K, OC, 32F and 101 kN/m^2, 1 atmosphere) (STP) is admitted through the walls to mix with the hot combustion products. This dilution serves to reduce the temperature of the stack gases to a manageable level and to minimize the error associated with combustion products of various enthalpies. This error is discussed in the section on accuracy. The high velocity air passing into the chamber through the porous plates effectively blocks the heat transfer out through the side walls.

The gas flow to an auxiliary burner located near the center of the control chamber is automatically controlled so that the average temperature of the gases passing up into the mixing chamber remains constant. Propane is used for the fuel rather than city gas because higher pressures are required to produce the necessary flow through the control valve to the burner. The heat produced by the burning specimen is exactly compensated by a reduction in the heat produced by the burner. The rate of heat release of the specimen is measured by recording the reduction in gas flow

to this burner. The constant temperature of the system eliminates the effect of thermal inertia and thus permits a rapid response to changes in the heat release rate. The steady state gas flow rate to the auxiliary burner is set high enough to prevent the flame from going out during the anticipated peak heat release rates. A steady pilot flame is located in the proximity of the auxiliary burner to relight it in case it should be extinquished by a high surge in the heat release rate of the specimen.

The thermostatic control is achieved by varying the gas flow to the auxiliary burner by means of the pneumatic control valve which is operated by the valve positioner on command from the proportional temperature controller which has an automatic reset.

The gas flow rate is recorded by a system consisting of an orifice plate, which creates a differential pressure proportional to the square of the flow rate, a differential pressure transmitter which produces a current proportional to the differential pressure, a square root extractor which produces an output voltage proportional to the square root of the input current and finally a strip chart recorder which records the extractor output voltage which is directly proportional to the gas flow rate.

The recorder was calibrated by burning high purity methane, at a series of known flow rates, in the small calibration burner tube just under the specimen holder. The calibration is in terms of heat released per unit area of the specimen per volt deflection. An asbestos cement board reference blank was in place during this operation. The resulting calibration factor, 132 $W/(cm^2.v)$, represents the calibration data over the heat release rate range from 0 to 25 W/cm^2 within ± 5 percent.

2.3 Mixing Chamber

The mixing chamber, which is 45 cm (18 in.) high and 33 by 33 cm (13 by 13 in.) in cross section, is above the auxiliary burner and contains a system of sheet metal baffles which extend the path length of the gases by a factor greater than 3, and includes two reversals of direction. The outside wall of this chamber consists of two layers of 1.9 cm (0.75 in.) thick asbestos cement board. Four thermocouples, one located at each side of the chamber just past the second direction reversal of the hot gases, are averaged and connected to the electronic temperature controller in order to maintain the temperature of the system constant. From the mixing chamber the gases pass up the flue and exit to the atmosphere. There is a sampling tube connected to the flue to

analyze the combustion gases for oxygen, carbon dioxide and carbon monoxide content.

3.0 OPERATION

The reference blank is inserted in the specimen holder during the warmup period, which is about two hours. The setting on the temperature controller determines the gas flow to the auxiliary burner when stable operating conditions have been reached. This flow should produce a positive deflection at least twice the negative deflection expected at the peak of the specimen burning period. The control temperature will normally run between 650 K to 750 K (370°C to 470°C, 670°F to 850°F). While the reference blank is in place, the pressure at the regulator valve on the propane tank is adjusted so that the control valve is about half open. This keeps the valve from closing down completely during the run and allows the flow to become much larger during the period that the door is open, to compensate for the large heat losses at that time.

After every change in operating conditions the irradiance at the specimen holder should be determined. This is done with a calorimeter consisting of a 3.2mm (0.125 in.) thick copper disk, 1.9 cm (0.75 in.) in diameter, located by 3 pins in

an oversize hole at the center of an 11.4 by 15 cm (4.5 by 6 in.) asbestos cement board blank which replaces the specimen in the holder. The front surface of the disk is located in the plane of the front surface of the blank and is covered with a black velvet paint which has an absorbance of 0.95. The total heat flux is determined from the rate of temperature rise of the copper disk. The contribution of the hot air heating is only about 5 percent of the total at low irradiances as verified by the measurements reported in the accuracy section. It can therefore be assumed within the accuracy of the calorimeter that the irradiance is equal to the total heat flux.

The reference blank is reinserted in the specimen holder for a long enough time to obtain a stable base line on the recorder. Then the door is opened for as brief a time as possible while the blank is replaced by the specimen. At the end of the burning period when the position of the recorder trace becomes constant again, the blank is reinserted into the holder and the trace should return to its original level prior to the exposure of the specimen. Otherwise a correction for drift is indicated.

The difference between the steady recorder levels at the end of the burning period and the running of the blank is due to different heat fluxes transmitted through the burned

out specimen and through the blank. This difference should be equal to the difference in the heat carried away by the water. The heat carried away by the water during the test is important in determining the total rate of heat release of the specimen. The heat release rate indicated by the recorder trace is a measure of that which would be released into the burning room.

The complete information from the measurement is contained in the graph of heat release rate as a function of time throughout the burning period. However, it is desirable to derive numbers from the measurement which can be conveniently compared with those of other materials. The peak burning rate may be of such a short duration that it presents little hazard and can also occur so early in the exposure that the highest part is lost in the few seconds involved in door closure. The best procedure then may be to quote the highest average heat release rate for some particular time interval. The choice of interval might depend on a particular application. The numbers for maximum heat release rate quoted in this paper are based on an interval of one minute. This is of the order of the time required to ignite a building material by flame contact. Thus it could be a reasonable choice for the consideration of fire buildup in a room. A second useful number to be obtained from the measurement would be the "effective heat" which would be equal to the integral under

the heat release rate curve. "Effective heat" refers to the total heat that would be released into the burning room. It differs from the total heat released, by the amount transferred from the back surface of the specimen.

4.0 MEASUREMENTS

4.1 Heat Release Rates

Because of their preliminary nature, the results presented in this section are intended to illustrate the capability of the instrument in its present state of development rather than to serve as a source of data. Figure 5 shows a tracing of the data curve for a dried specimen of pine exposed at $6 W/cm^2$. The drop at the beginning of the trace is due to the heat loss during the door opening. The deflection recovers rapidly as soon as the door is closed. Ignition of the specimen occurred as the door was being closed. The peak heat release rate was achieved almost immediately along with maximum flaming as seen through the window. Flames could be observed above the specimen holder for the first 18 minutes as indicated on the curve. When the burning of the specimen was complete (50 minutes), the trace crossed below the base line since the water cooled block was receiving heat directly from the radiant panels. The small drop near the end of the trace was due to opening the door to reinsert the reference blank.

The peak heat release rate was 22W/cm^2. The maximum one minute average was 19W/cm^2. The integrated heat release was 14.9kJ/cm^2. Taking the density and thickness of the specimen into account the total heat release into the room can be expressed as 18.8kJ/g. The heat of combustion of a similar sample as determined by the oxygen bomb calorimeter was 20.8kJ/g. This would be reduced to 19.4kJ/g if the water produced were in the gaseous state as it would be in the calorimeter. Both numbers are based on the dry weight of the specimens. Although the heat carried away by the water was not measured for the specimen in figure 5, it was determined to be 1.9kJ/g for another pine specimen from a different lot under different exposure conditions.

One of the requirements of this apparatus is to be able to measure the heat release rates for materials which burn for very short periods of time like the paper surface on gypsum board. Figure 6 shows a tracing of a data curve for gypsum board exposed at 6W/cm^2. The deflection was negative while heat was being lost out the door. Ignition occurred about 20 seconds after the door was closed. Flaming lasted 28 seconds and was followed by a glowing phase of another 53 seconds. The maximum heat release rate was 6W/cm^2 and the total heat released from the front surface during the active burning period was 376J/cm^2. The latter figure does not include the heat conducted into the gypsum board or the

slow absorption of heat due to endothermic reactions of the gypsum which occurred over a much longer time interval.

A comparison of the maximum one minute averages for the heat release rates of various building materials is presented in figure 7. The wood specimens had moisture contents of about 8 percent which account for the lower heat release rate of pine than that shown for the dried specimen in figure 5. The low value for gypsum board reflects the fact that the flaming phase persisted less than 30 sec.

4.2 Effect of Irradiance

Another feature of the calorimeter is the ability to find how the heat release rate varies with the irradiance. The preliminary investigation was done on a wood fiber insulating board and the results are presented in figure 8.

A least squares fit through the data establishes a relationship between the heat release rate and the irradiance which can be expressed as

$$H = 4.8 + 7.4I$$

where H is the heat release rate in W/cm^2, and I is the irradiance in the same unit.

5.0 CALORIMETER PROPERTIES

5.1 Time Response

The time response of the system can be determined from figure 9. The calorimeter was equilibrated with the reference blank in place. The methane flow to the calibration burner was suddenly turned on, held constant for 20 seconds, and was then turned off. The response time for this particular run was 3.7 seconds.

5.2 Accuracy

Heat Content of the Flue Gases

One of the assumptions implicit in the description of the operation of the calorimeter was that the total heat content of the flue gases remains constant as well as the flue gas temperature. The difference in this heat content for the burning of the calibration gas and for the burning of the specimen with the same reduction in propane flow, as noted on the recorder chart, represented an error in the measurement. This difference, if known, should be added to the product of the flow rate of the calibration gas and its heat of combustion when calibrating the calorimeter for a particular type of specimen. A general expression was developed in the appendix to calculate this difference when chemical reactions are

known. A correction of 1.5 percent to the calculated heat release rate was found for cellulosic specimens and methane calibration gas. For cellulose this difference is small enough to be neglected. If the chemical composition of the specimen is known or if the combustion products are analysed, a correction could be made for this effect in those cases where it is necessary.

Heat Losses

During a typical run heat flux meters were attached at various places on the external surface of the calorimeter and a radiometer was positioned to measure the heat escaping through the viewing window in the door. The estimated total heat loss was about 3 percent of the heat produced by combustion. Heat losses have no effect on the accuracy of the measurement if they remain constant with the specimen in place. However, there is likely to be a small difference due to a slight redistribution of temperature if part of the heat is released at the specimen holder rather than at the auxiliary burner. In order to examine this difference, methane was introduced in the calibration burner just below the specimen holder. The flow was adjusted to produce a high heat release rate equivalent to $21 W/cm^2$ over the surface of the reference blank. Except for the window in the door the increase in the heat losses through the exterior surface of the combustion chamber was almost exactly compensated by a

decrease in the heat losses through the walls of the control chamber. There was a 17 percent increase in the radiation through the window. The net change in heat loss was equal to 1 percent of the heat contributed by the burning of the methane in the calibration burner. Because of the proximity of the specimen and the calibration burner, the effect of changes in heat losses due to the difference in location of the specimen and the auxiliary burner was virtually eliminated in the calibration process, except for differences in the flame radiation through the window. It may be necessary to cover the window or reduce its effective opening in order to provide for specimens which have highly luminous flames.

Hot Air Heating

The copper disk calorimeter measures the total heat flux received by the specimen without distinguishing between radiation and hot air heating. However, the amount of hot air heating is so low that the total heat flux can be considered to be radiation alone within the accuracy of the heat release rate calorimeter. The region of flame heated air is limited to less than 11 cm (4.5 inches) from the radiant panel surfaces as evidenced by thermocouple measurements and visual observation on a radiant panel burning in the open under similar operating conditions. The specimen is located 6 inches away from the surface of the radiant panel in the calorimeter.

Estimation of the heating by the hot air passing up from the irradiated panel on the floor of the combustion chamber indicates a transfer rate well under 0.1 W/cm^2 on the specimen surface.

In order to distinguish more directly between hot air and radiant heating, heat flux measurements were made with both clean and blackened surfaces on the copper disk. The clean surface was prepared by sanding. One set of measurements was made with the copper disk calorimeter in the specimen holder, and a second set was made through the open door of the calorimeter in the complete absence of hot air heating to get the absorptivity of the clean copper surface. From these measurements the hot air heating was deduced to be about 5 percent of the total for an irradiance of 2 W/cm^2. In this calculation it was assumed that the hot air heating was the same for the black and the clean surfaces.

Irradiance Distribution

The irradiance distribution across the specimen was calculated using radiation exchange factors, assuming that the radiation is uniform across the surfaces of the radiant panels and that the radiation intensity is proportional to the cosine of the angle of emergence. With these assumptions the irradiance everywhere on the specimen is within 10 percent of the value at the center.

5.3 Heat Balance

A heat balance determination was carried out with the auxiliary burner and upper pilot off. The fuel gas flow rate to the radiant panels was .059 m^3/min. (2.1 ft^3/min) STP and the total heat release rate was 2260 kJ/min (2140 BTU/MIN) and this was distributed among 5.5m^3/min (195 ft^3/min) STP of flue gases. This yields an average enthalpy of 8.66 kJ/mol. This corresponds to a temperature of 590 K taking the change in enthalpy with the species of the gas into account. Taking the heat losses to be 3 percent of the total heat produced, this temperature should be reduced to 572 K. The measured temperature of the flue gases was 569 K.

6.0 CONCLUSIONS

The principles upon which the heat release rate calorimeter being developed at NBS are based have proven to be sound. The prototype instrument appears to have adequate sensitivity, accuracy, and response time to provide a useful tool for measuring the rate of heat release of building materials in a fire environment. It can determine the total flow of heat through the exposed and unexposed surfaces individually. Furthermore it has the capability of examining the effect of environmental conditions on the total heat release and its rate.

Some additional modifications of the instrumentation and the operational procedures may be indicated after a more thorough study of the heat release rates on a wide variety of materials.

REFERENCES

1. "JANAF THERMOCHEMICAL DATA", Dow Chemical Company, Thermal Research Laboratory, Midland, Michigan, 1965.

2. TANG, W. K. AND NEILL, W. K., J Polymer Sci: Part C No. 6 pp 65-88 (1964)

3. "SELECTED VALUES OF PROPERTIES OF HYDROCARBONS", Circular of the National Bureau of Standards C 461 (1947), U. S. Government Printing Office, Washington, D. C.

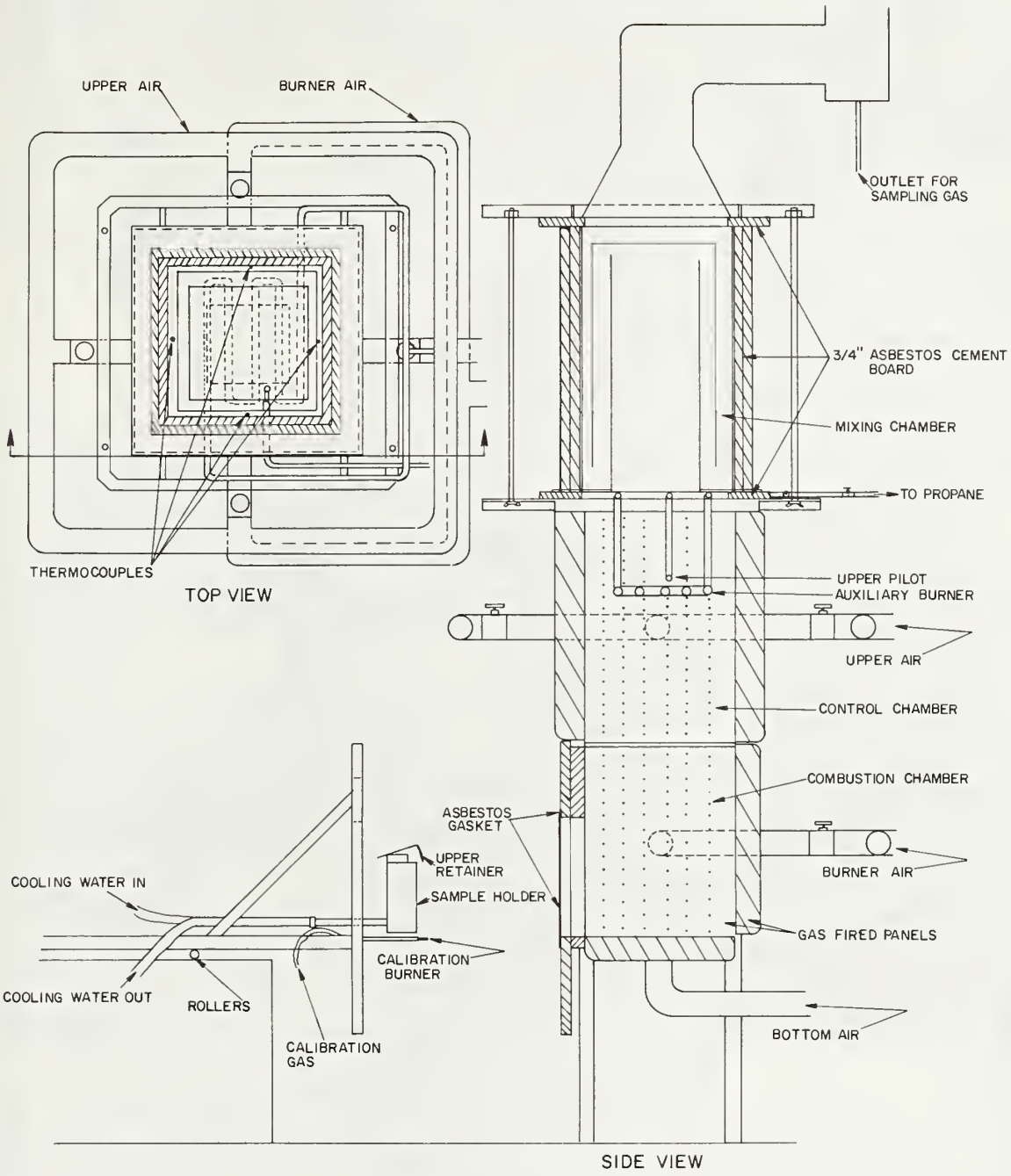
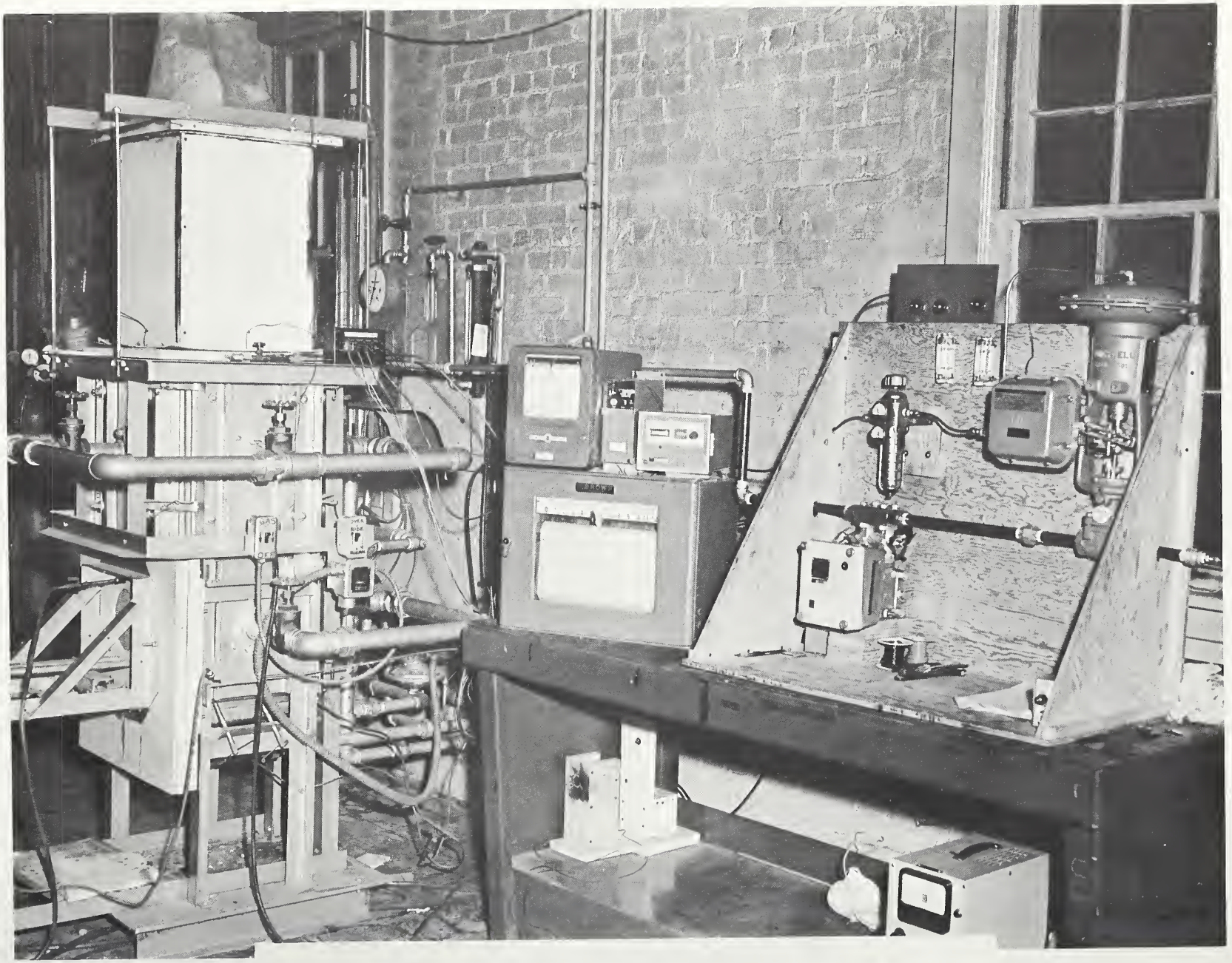
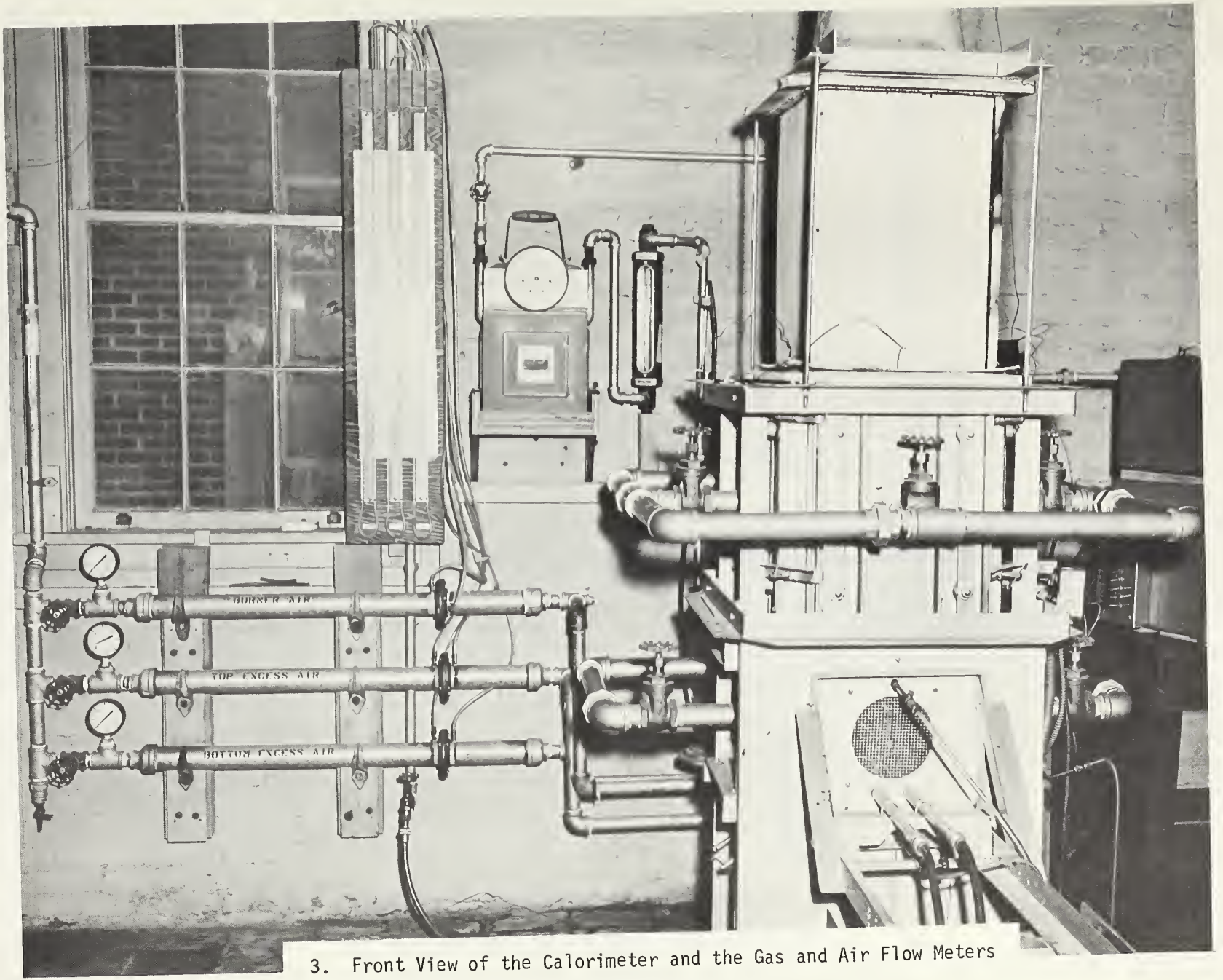


Figure 1. Heat Release Rate Calorimeter



2. Side View of the Calorimeter and Associated Instrumentation



3. Front View of the Calorimeter and the Gas and Air Flow Meters

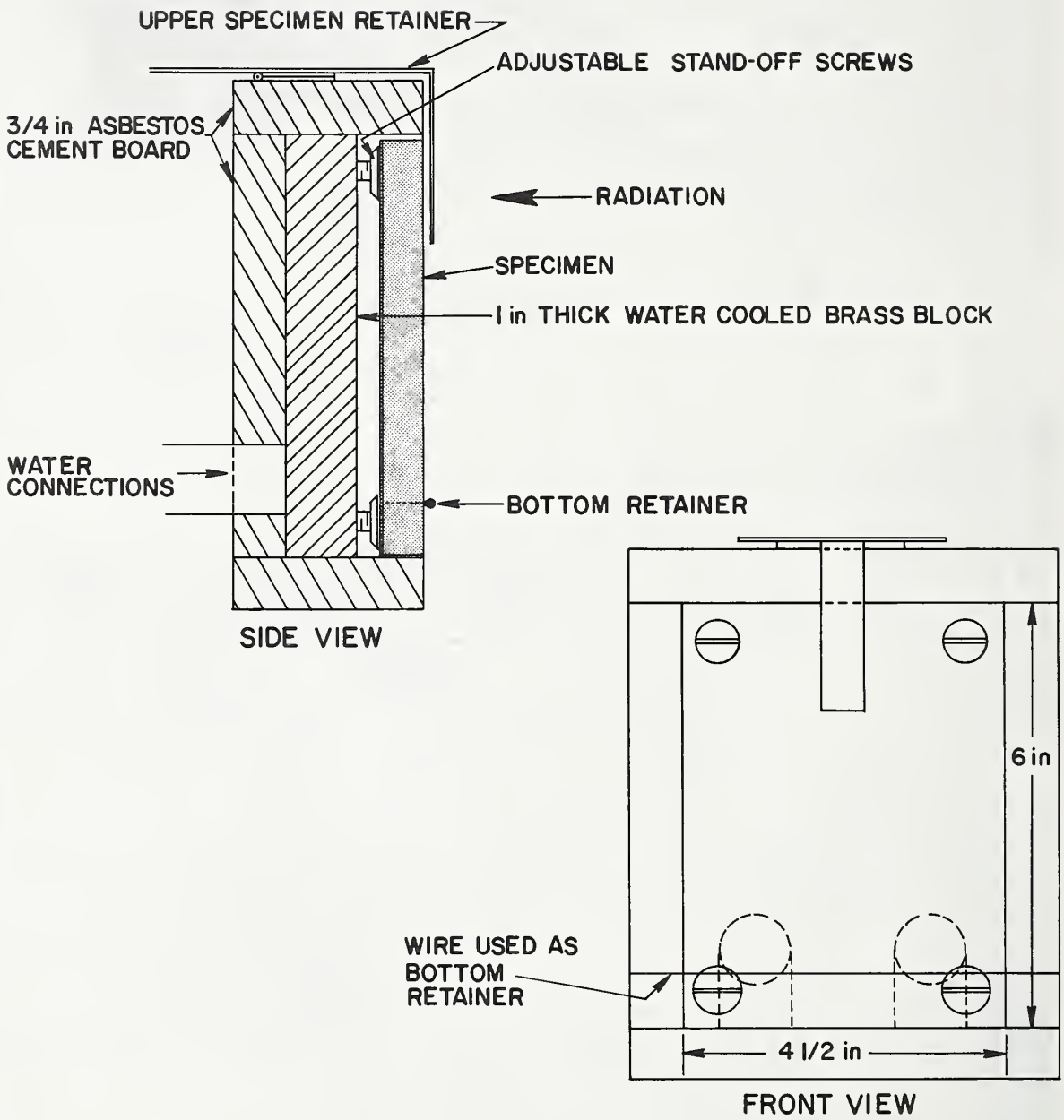


Figure 4. Specimen Holder

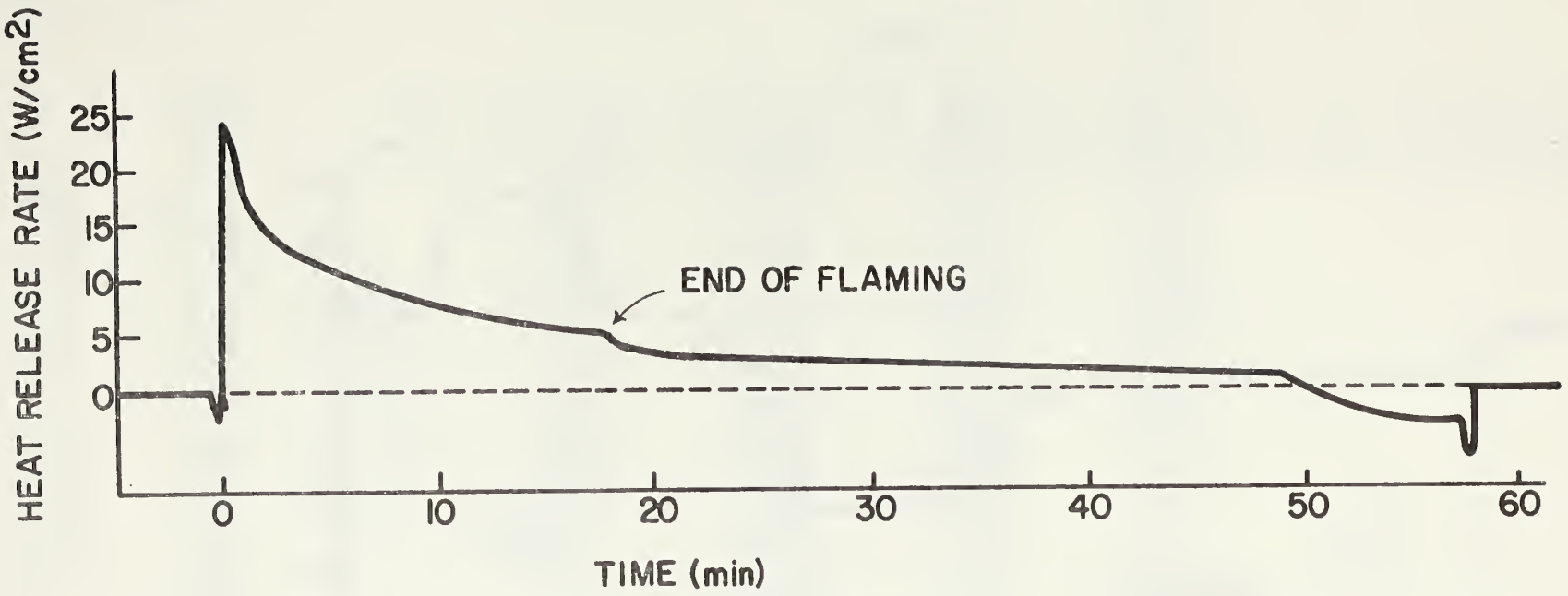


Figure 5. Heat Release Rate Curve
for Pine Specimen

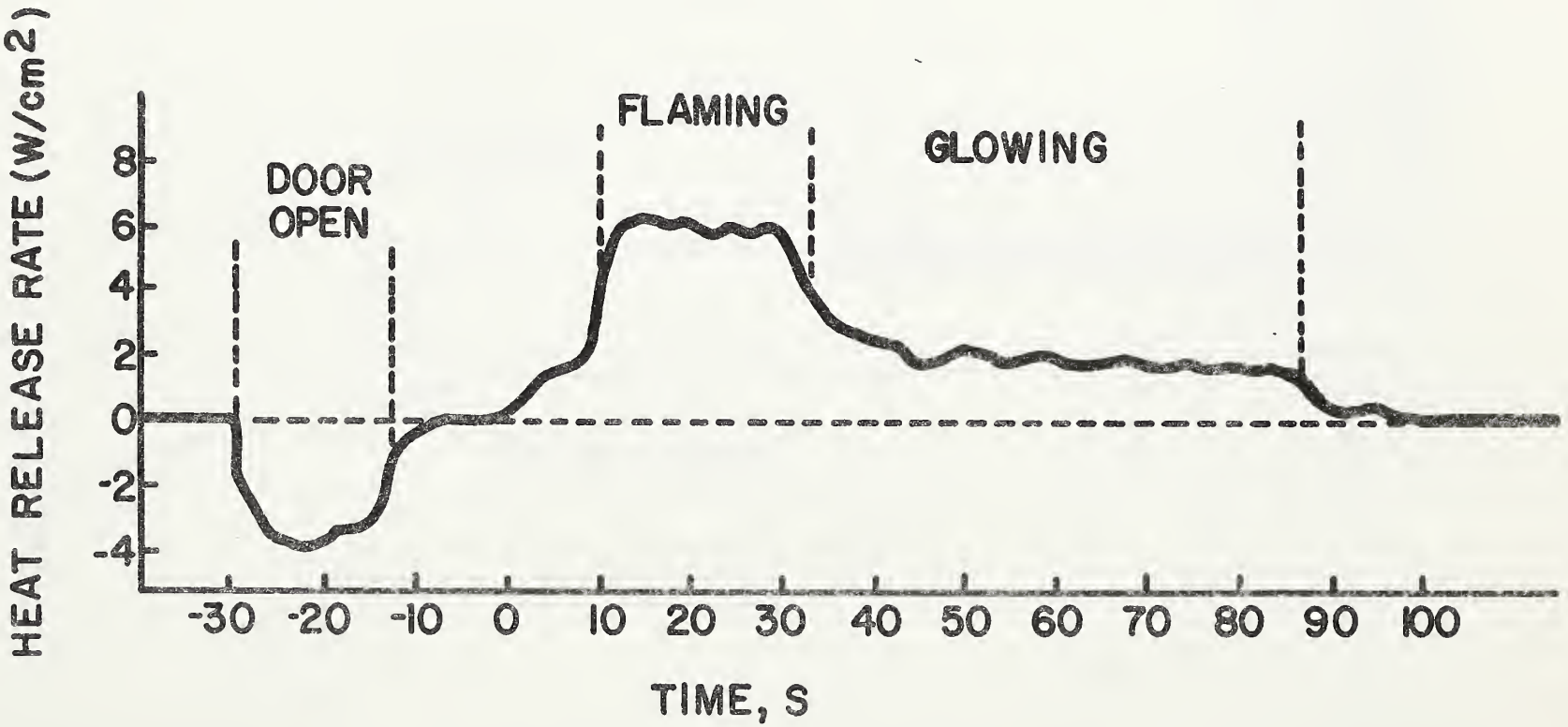


Figure 6. Heat Release Rate Curve
for Gypsum Board

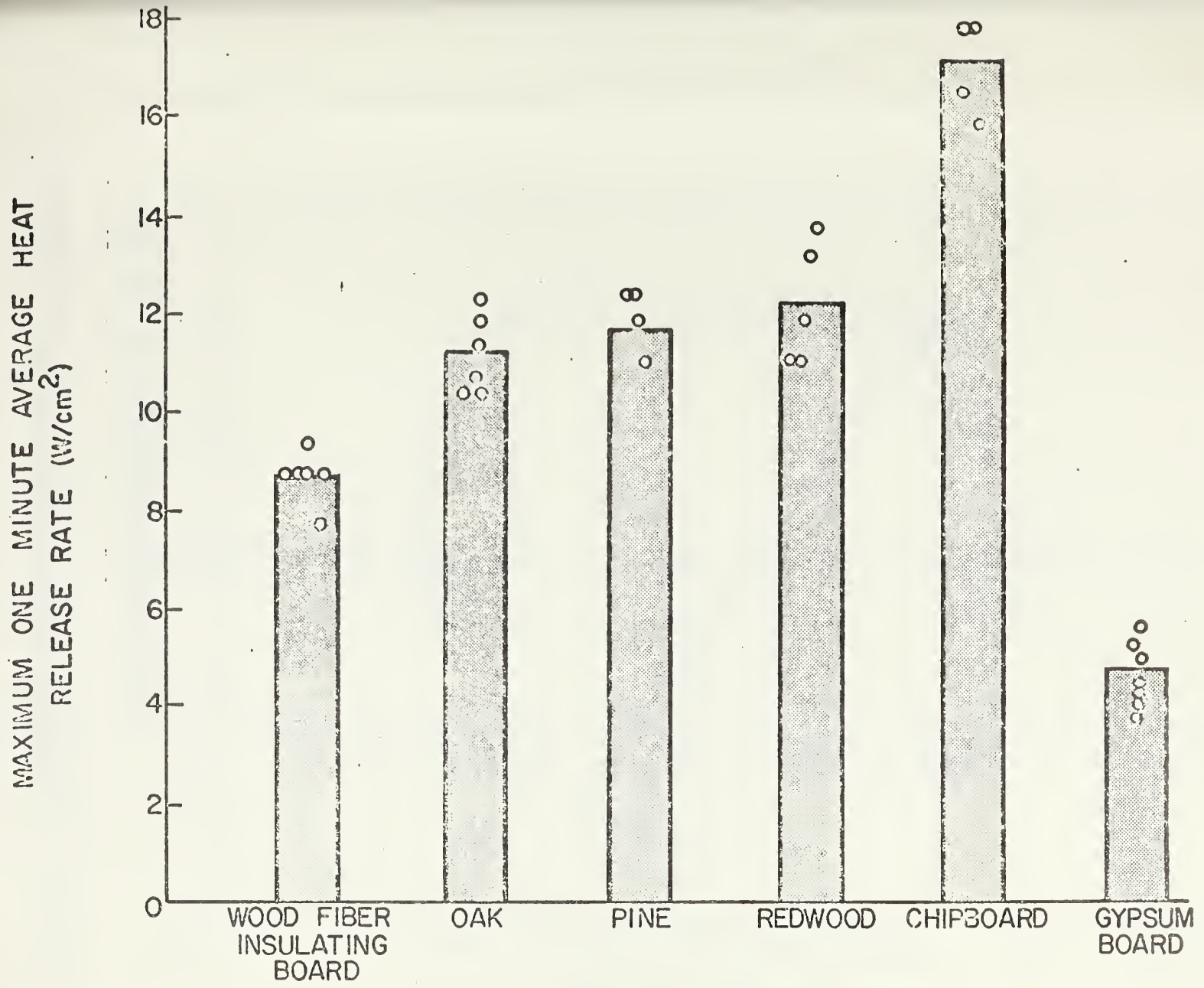
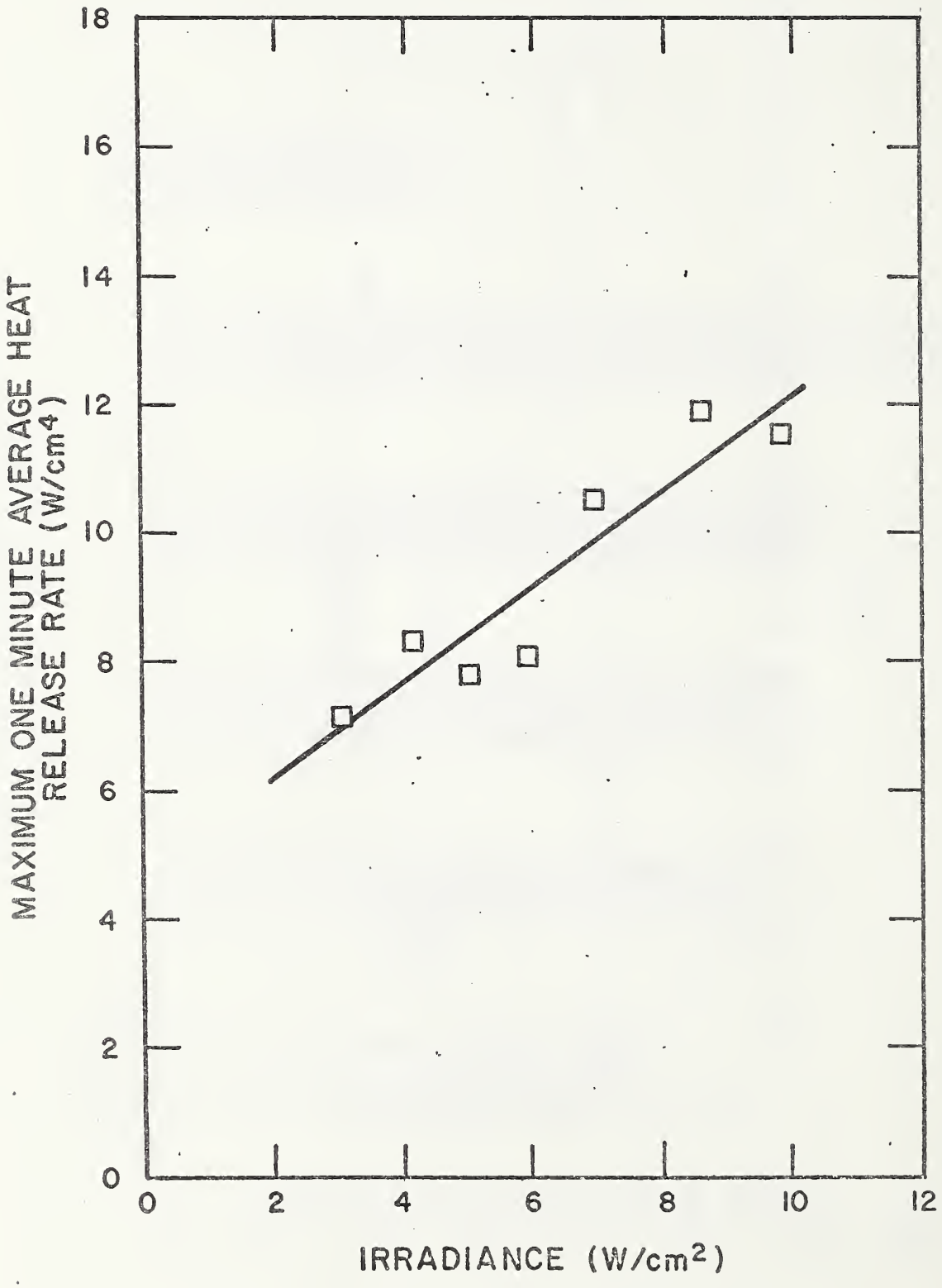


Fig. 7. Maximum One Minute Average Heat Release Rate for Some Building Materials at an Irradiance of 6.0 Watts/cm^2



8. Heat Release Rate Versus Irradiance for Wood Fiber Insulating Board

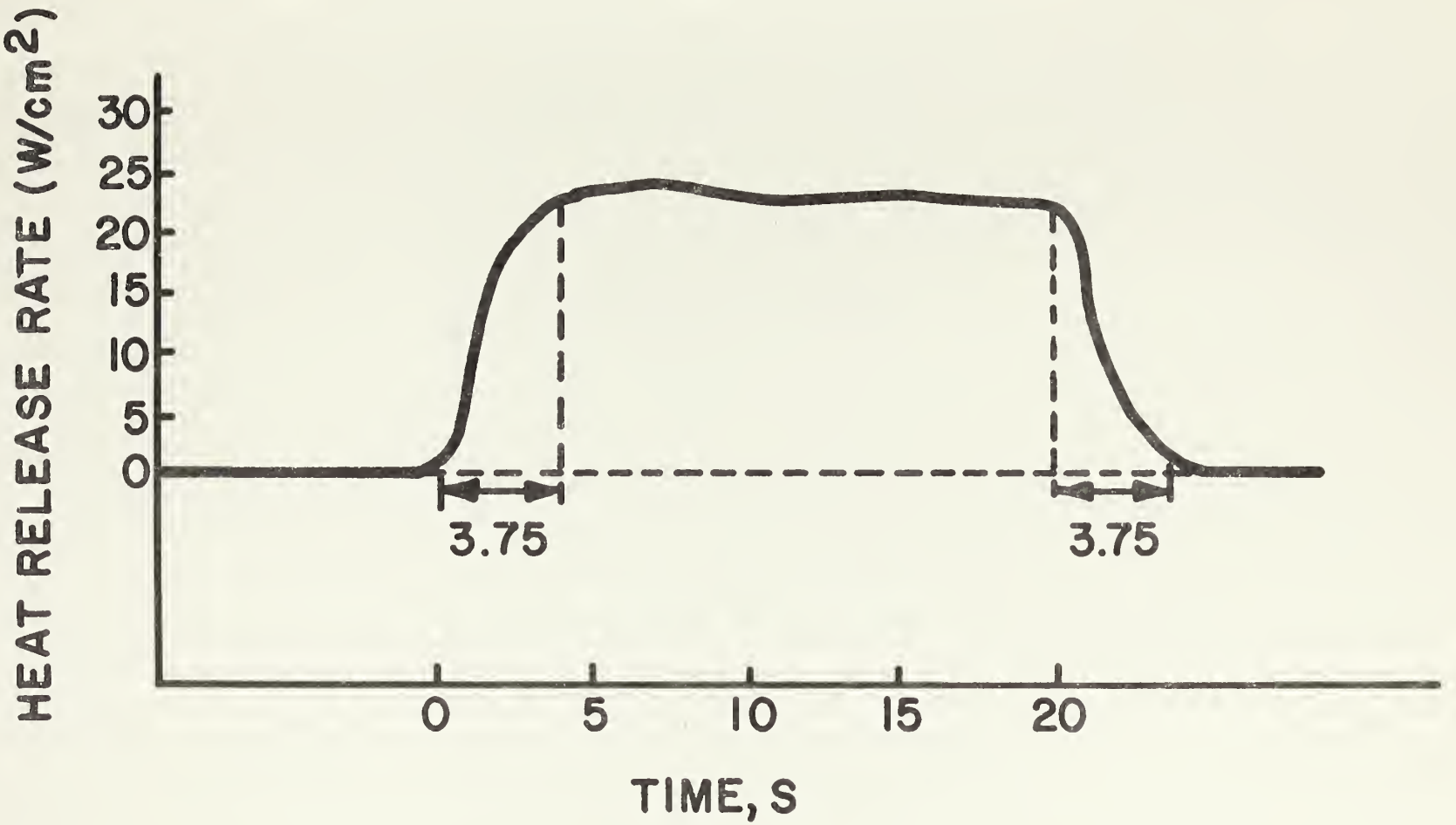


Figure 9. Time Response to a Step Change in the Heat Release Rate