NBSIR 83-2642

Fire Hazard Evaluation of Shipboard Hull Insulation and Documentation of A Quarter-Scale Room Fire Test Protocol

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
Washington, DC 20234

August 1983

Prepared for:
Ship Damage Prevention and Control
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362

NBSIR 83-2642

FIRE HAZARD EVALUATION OF SHIPBOARD HULL INSULATION AND DOCUMENTATION OF A QUARTER-SCALE ROOM FIRE TEST PROTOCOL

B. T. Lee

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
Washington, DC 20234

August 1983

Prepared for:
Ship Damage Prevention and Control
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, ***Secretary***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

TABLE OF CONTENTS

Page

LIST OF FIGURES iv

LIST OF TABLES v

ABSTRACT 1

1. INTRODUCTION 1

2. FACILITIES AND EXPERIMENTAL TESTS 2

2.1 Facilities and Instrumentation 2
2.2 Calibration of Exhaust Collector Hoods for Heat Release Rate Measurement 4
2.3 Test Materials 4
2.4 Experimental Tests 5
2.4.1 Room and Laboratory Fire Test Procedures 5
2.4.2 Room and Laboratory Fire Tests 5

3. RESULTS AND DISCUSSION 7

3.1 Fire Performance Evaluation of Materials 7
3.1.1 Quarter-Scale Room Fire Test 7
3.1.2 Laboratory Fire Tests 7
3.2 Full-Scale Tests and Comparisons with Quarter-Scale Tests 9
3.3 Effect of Paint on Fire Performance of Hull Insulation 11
3.4 Test Protocol for Quarter-Scale Test 12

4. CONCLUDING REMARKS 14

5. ACKNOWLEDGEMENTS 15

6. REFERENCES 15

APPENDIX A. Test Protocol on the Determination of the Flashover Potential of Shipboard Hull Insulation Using a Quarter-Scale Room Fire test 17

LIST OF FIGURES

		Page
Figure 1.	Layout and instrumentation for quarter-scale test	19
Figure 2.	Quarter-scale and full-scale room fire tests	20
Figure 3.	Layout and instrumentation for full-scale test	21
Figure 4.	Air temperatures near center of ceiling for full-scale test 2 and corresponding quarter-scale tests	22
Figure 5.	Air temperatures near center of ceiling for full-scale test 3 and corresponding quarter-scale tests	23
Figure 6.	Air temperatures near center of ceiling for full-scale test 4 and corresponding quarter-scale tests	24
Figure 7.	Air temperatures near top of doorway for full-scale test 2 and corresponding quarter-scale tests	25
Figure 8.	Air temperatures near top of doorway for full-scale test 3 and corresponding quarter-scale tests	26
Figure 9.	Air temperatures near top of doorway for full-scale test 4 and corresponding quarter-scale tests	27
Figure 10.	Heat flux on floor for full-scale test 2 and corresponding quarter-scale tests	28
Figure 11.	Heat flux on floor for full-scale test 3 and corresponding quarter-scale tests	29
Figure 12.	Heat flux on floor for full-scale test 4 and corresponding quarter-scale tests	30
Figure 13.	Mass flow rate of carbon monoxide for full-scale tests 2 and 3 and their corresponding quarter-scale tests	31
Figure 14.	Mass flow rate of carbon monoxide for full-scale test 4 and corresponding quarter-scale tests	32
Figure 15.	Rate of heat release from full-scale tests 2 and 3 and their corresponding quarter-scale tests	33
Figure 16.	Rate of heat release from full-scale test 4 and corresponding quarter-scale tests	34

LIST OF TABLES

		Page
Table 1.	Materials used in the room and laboratory fire tests	35, 36
Table 2.	Comparison of results from full-scale room fire tests and their counterpart quarter-scale tests	37
Table 3A.	Summary of quarter-scale test results	38
Table 3B.	Summary of quarter-scale test results	39
Table 4.	Ignitability, flame spread, and smoke characteristics of materials used in room fire tests	40
Table 5.	Heat release rate and potential heat of materials used in room fire tests	41
Table 6.	Comparison of peak air temperatures at several elevations near the ceiling and top of the doorway	42

FIRE HAZARD EVALUATION OF SHIPBOARD HULL INSULATION AND DOCUMENTATION OF A QUARTER-SCALE ROOM FIRE TEST PROTOCOL

B.T. Lee

Abstract

A variety of shipboard hull insulations including damping and acoustical materials, painted and unpainted, were evaluated for their flashover potential using a quarter-scale room fire test developed by the Center for Fire Research at the National Bureau of Standards. Three painted insulations were also evaluated in full-scale room fire tests. Comparison of full-scale and quarter-scale fire behavior again demonstrated that the quarter-scale test can predict full-scale room fire buildup. It was found that decorative paints, including the Navy's chlorinated alkyd formulation, could seriously compromise the fire safety of otherwise low fire risk insulations. A recommended test protocol was developed for determining the flashover potential of hull insulation using the quarter-scale room fire test.

Keywords: Flammability; flashover; heat release rate; insulation; interior finishes; paints; room fires; ships; small-scale fire tests.

1. INTRODUCTION

Recent research [1][1] has demonstrated that fire hazards associated with the use of certain synthetic foam materials, in the insulation of the interior of submarines, can be satisfactorily assessed only with room fire testing and not with small scale laboratory fire tests which are employed for measuring fire properties of materials. As part of the same study, a one-quarter size room fire test was developed for screening these kinds of materials with the same reliability as full-scale testing but much more economically. This quarter-scale test was a less severe fire test than its counterpart full-scale test, but did give the same order of rating, based on the degree of room fire buildup achieved, as the full-scale test for the foam materials evaluated. The quarter-scale test has also been successful in simulating full-scale room fire tests of some interior finish material not associated with shipboard use [2]. Nevertheless, there is a need to evaluate the quarter-scale room fire test with a wider range of materials intended for use on shipboard to assess its strengths and limitations. Additionally, a standardized

---

[1] Numbers in brackets refer to references at the end of this report.

quarter-scale test room and test procedure must be established such that the testing can be repeated and the capabilities of the test verified by others. Concurrent with these goals is the present need to use the test as a tool for screening shipboard finish materials. Thus, the present work has the following objectives:

1. to evaluate the potential fire hazards of shipboard hull insulations including damping and acoustical materials, painted and unpainted;

2. to further evaluate the effectiveness of the one-quarter size room test and the suitability of laboratory fire tests for assessing the fire performance of these materials; and

3. to document a test protocol such that the Navy and other test facilities may independently conduct fire test evaluations on such materials.

This report discusses the quarter-scale room fire tests of a variety of shipboard hull insulations and the degree of agreement achieved with full-scale room test results for three painted insulations. Also included in this report are laboratory fire test data obtained on these insulation materials using: an ease of ignition test [3], the ASTM E 162 [4] and E 84 [5] tests for measuring surface flammability, a rate of heat release calorimeter test [6], and the potential heat [7] and smoke generation [8] tests. These laboratory fire test results are compared with the performance of the materials as observed in the room fire tests.

In this study, the basic criterion adopted for limiting fire growth was that the painted and unpainted insulations, when subjected to a moderately large fire exposure, would not lead to flashover of the test room during an exposure period of 1800 s. Flashover is defined here as that condition where the thermal radiation level becomes high enough to spontaneously ignite light combustible materials (such as newspaper) located in the lower half of the room. Flashover is frequently preceded by flameover, a condition where flames emerge from the room across the top of the doorway.

2. FACILITIES AND EXPERIMENTAL TESTS

2.1 Facilities and Instrumentation

The quarter-scale room enclosure measured 0.76 m x 0.76 m x 0.61 m high and scaled a room measuring 3.05 m x 3.05 m x 2.44 m high. This enclosure consisted of a 6.4 mm thick aluminum alloy shell which was positioned over a 6.4 mm steel floor. The model enclosure had a doorway opening of 0.49 m x 0.43 m high based on scaling principles and empirical adjustments developed earlier [1].

A 0.61 m x 0.91 m hood having an exhaust capability of 0.18 m^3/s was located above the door opening of the quarter-scale enclosure to collect the exhaust from the fire. A 1.22 m long, 0.15 m diameter vertical stack having an inlet diameter of 83 mm was connected to the hood. The smaller diameter opening was used to increase turbulent mixing of the exhaust. Smoke attenuation of a light beam was measured at 0.55 m above the inlet. Temperature, air velocity, and oxygen, carbon dioxide, and carbon monoxide concentrations in the stack were measured at a position 1.0 m above the inlet, where the exhaust across a cross-section of the stack was found to be well mixed. From these measurements, the rate of heat release, the mass flow of carbon monoxide, and the optical density of smoke generated from the fire were determined.

Figure 1 indicates the type and location of instrumentation employed in the quarter-scale room fire tests. Figure 2 shows the test arrangement. The stack temperature was measured with a chromel-alumel thermocouple made from Brown and Sharpe 24 gauge (0.51 mm) diameter wire. Air velocity in the stack was monitored with a pitot tube. Oxygen concentration was sensed directly with a paramagnetic analyzer. Carbon monoxide and carbon dioxide were monitored with non-dispersive infrared analyzers. In addition, thermocouples fabricated from 0.05 mm chromel and alumel wires were located along the vertical centerline of the doorway opening at distances of 25, 51, 102, 203, 254 and 356 mm below the top of the doorway. Small junction thermocouples made from 0.05 mm wire were chosen to minimize thermal radiation errors in the measurement of air temperatures in the room fires [9]. Identical thermocouples were located at distances of 25, 51, 102, 203, 305, 457 and 610 mm below the center of the ceiling. These thermocouple trees were used to ascertain the most suitable heights in the doorway and inside the room for measuring the peak air temperatures. The thermal flux at the floor, measured with water-cooled, total heat flux gauges of the Gardon type, was also taken to characterize the room environment.

In previous work [1], a full-scale fire test room was assumed to measure 3.05 m x 3.05 m x 2.44 m high with a 762 mm x 2032 mm high opening at the middle of one wall. However, based on recent recommendations by the ASTM E 5 committee on fire standards, a standard full-scale fire test room shall have dimensions of 2.44 m x 3.66 m x 2.44 m high with the same size opening at the middle of the 2.44 m wide wall. It is expected that this change should have little effect on the fire development as the floor area is decreased by only 4 percent and the air flow into the room depends mainly on the doorway opening which remains unchanged. All four walls and the ceiling were fabricated from 6.4 mm thick aluminum alloy plate or sheet mounted over 51 x 102 mm steel spacer studs 0.41 m apart. The floor consisted of 3.2 mm thick aluminum sheets over a concrete slab. The room was constructed within a large building, so that the effects of temperature extremes and wind were eliminated. The test room was located adjacent to a large 3.66 m x 4.88 m exhaust collector hood having an exhaust capacity of about 3.0 m^3/s.

The stack to the hood and the room were instrumented similarly to that used with the quarter-scale test. The full-scale test arrangement and instrumentation layout are given in figures 2 and 3.

2.2 Calibration of Exhaust Collector Hoods for Heat Release Rate Measurements

The exhaust collection stack for the quarter-scale test was calibrated for measurement of heat release rate using the quarter-scale methane burner,described in section 2.4.1, positioned directly under the hood as well as inside the room. The same burner was also used as the ignition source for the room fire tests. The burner operated at a heat release rate of 16.5 kW based on a flow rate of 490 mℓ/s of methane to the burner. The rate of heat release from the burner can also be determined from the measurement of the volume flow rate and the oxygen depletion of the air passing through the stack [10]. The calculated value based on this latter technique was 17.1 kW, or 4 percent larger than the actual value based on the methane flow rate, for the burner located directly under the hood. When the burner having the same methane flow rate was positioned at the center of the floor, the calculated value was 15.8 kW, or 4 percent smaller than the actual rate. The ±4 percent accuracy is well within an estimated ±10 percent experimental uncertainty. Thus, the measurement of heat release rate with the hood system was found to be adequate, and no calibration factor was needed. For the full-scale exhaust system, the stack was calibrated in another study [9]. The study indicated that the flow in the full-scale stack was highly non-uniform and the heat release rate measurements had to be multiplied by 0.77 to give the actual values. That calibration was used for the calculations of heat release rate in this report.

2.3 Test Materials

The materials selected by the Navy and used in the room and laboratory fire tests are described in table 1. The acoustic materials conforming to specification MIL-I-22023 are general purpose insulations. Materials TS-GM and M-AL are currently in use, while the M, TS-MG, and TS-GMG are candidate materials. The W-1 and W-2 materials conform to MIL-A-23054 and are used primarily in the ventilation equipment spaces. Of the five insulations listed under the heading of hull insulation, material G is mainly for surface ship application. The B2II and cork are utilized on submarines. The hydrophilic polyurethane H and the silicone rubber SR are candidate materials. The six damping materials are used more on board submarines than on surface ships. The adhesives and coatings listed are presently used shipboard materials with the exception of the O-1001, which is a candidate coating. On board ship, glass cloth conforming to MIL-C-20079 is used to cover the joints between insulation sections for all of the acoustic materials and the hull insulation G. The other insulations and the damping materials do not have taped joints.

2.4 Experimental Tests

2.4.1 Room and Laboratory Fire Test Procedures

In both quarter-scale and full-scale room fire tests, the test material fully covered the walls and ceiling. As much as possible, the materials were mounted in the same manner as on board ship. For the quarter-scale room test, a 76 mm x 76 mm diffusion flame gas burner, with its horizontal surface located 76 mm off the floor, was positioned snugly against one back corner of the test room such that there was no air gap between the burner and the two walls. This burner served as the ignition source and was left on throughout the test period. A flow rate of 150 ml/s (0.32 CFM) of methane was metered to the burner to produce a constant heat input of 5.6 kW. This represented 1/16 of the rate for a full-scale room burner, based on previously developed scaling principles [1]. The test duration was chosen to be 1800 s except when flashover occurred earlier or when the fire environment posed a danger to the structural integrity of the quarter-scale test facility, at which time the test was terminated. The test was also stopped after 900 s for materials that did not appear to burn significantly by that time. In the full-scale room test, 2.4 ℓ/s (5.1 CFM) of methane corresponding to 90 kW was metered to a 305 mm x 305 mm x 305 mm high diffusion flame burner positioned snugly against a rear corner of the room. As in the quarter-scale test, the burner was left on over the duration of the test. The full-scale facility was intended to withstand severe fire exposures over a long period of time. Consequently, all full-scale tests were conducted over the 1800 s duration, regardless of the fire environment. Measurements in the full-scale and quarter-scale room tests, using the instrumentation described in section 2.1, were recorded continuously. In addition, four pieces of crumpled newspaper on the floor served as visual indicators of flashover.

Only currently used laboratory fire tests with published test procedures were used in this study. Consequently, these procedures were employed for the ease of ignition test, the ASTM E 162 and E 84 tests, the rate of heat release calorimeter, potential heat and smoke generation tests.

2.4.2 Room and Laboratory Fire Tests

Twenty-nine quarter-scale tests and three full-scale room fire tests were performed. Nine of the quarter-scale and all of the full-scale tests were on insulations with painted surfaces. Descriptions of the full-scale room tests and their counterpart quarter-scale tests are given in table 2. A listing of all of the tests with the quarter-scale enclosure is given in table 3. For the insulations used in full-scale tests FS-2 and FS-3 and quarter-scale tests 1 to 9, 13, 5R and 7R, the test material was impaled on 44.5 mm long, 2.4 mm diameter steel studs fastened to the aluminum enclosure at locations 76 mm away from the corners and edges and at 0.305 m maximum spacing between studs everywhere else. Where the spacing was greater than 0.305 m but less than 0.61 m, a stud was used midway. Steel clips were then used over the studs to keep the test material in place. All other materials were glued to the enclosure surface using the M-30 adhesive. Test 20 also had the material mechanically attached to the enclosure using screws to prevent separation during the fire exposure.

Data on heat release rate, smoke, and carbon monoxide could not be measured reliably in tests 1 though 10 due to flow measurement difficulties. Of these 10 tests, numbers 5 and 7 were particularly important as they were counterpart tests for two of the three full-scale tests. Consequently, tests 5R and 7R, the repeat runs of tests 5 and 7, were conducted to give data on heat release rate, smoke, and carbon monoxide production and to verify other data from tests 5 and 7. Tests 14R, 16R, 22R, and 27R were also repeat tests of runs 14, 16, 22 and 27 and were performed to verify near-flashover situations. Test 21R was run to verify the finding in test 21 that the B2II insulation did not lead to flashover.

Tests 7, 8, and 9 were stopped at 900 seconds when steady state conditions appeared to have been reached. In test 12, a section of the test foam insulation on the ceiling directly over the gas burner fell off exposing the aluminum substrate at 780 seconds. The test was terminated at 900 seconds to protect the test enclosure. Test 14 was stopped at 780 s, when flaking from the ceiling surface ignited the newspaper flashover indicators. In test 19, some of the material was hanging off the ceiling and small pieces were dropping off by 1140 seconds. By 1320 seconds, large pieces were falling and burning on the floor; at 1380 seconds, the test was terminated.

A summary of the tests with the ease of ignition apparatus, the ASTM E 162 radiant panel, the ASTM E 84 tunnel, the rate of heat release calorimeter, and the potential heat and smoke generation tests is given in tables 4 and 5. As surface flammability could be measured with either the E 162 or E 84 test, it was decided to conduct E.162 tests on all the test materials and E 84 tests only on selected acoustical insulations. The E 84 test evaluated materials in an overhead configuration which made it unsuitable for damping insulation, which is used only on vertical surfaces. In addition, the E 84 test required a relatively large quantity of material which made test evaluation costly for expensive materials like the damping insulations. As for hull insulations, similar insulations had been evaluated with both tests in an earlier study [1] with the finding that the E 84 test performed no better than the E 162 test in predicting full-scale room fire behavior. On the other hand, acoustical insulations have not been tested with both surface flammability tests. Consequently, the Navy requested that selected acoustical insulations be evaluated with both the E 162 and E 84 tests.

3. RESULTS AND DISCUSSION

3.1 Fire Performance Evaluation of Materials

3.1.1 Quarter-Scale Room Fire Test

Quarter-scale room test results are given in table 3. Test 5R with the painted TS-GM, test 10 with the cork, and tests 22, 27 and 27R with the painted B2II produced room flashovers in about 100 s or earlier. The remaining tests which reached flashover, i.e., test 11 with the SR, tests 16 and 16R with the BR2-1, and test 14R with the BR1-1 took over 500 s to reach flashover. Near flashover situations were achieved in test 5 with the painted TS-GM, test 14 with the BR1-1, and test 22R with the B2II having two coats of paint. Tests 5, 14, and 22R reached peak interior air temperatures of 770°C, 650°C, and 540°C, respectively, with none of the newspaper flashover indicators igniting in those three tests. Repeat runs of those room fires, tests 5R, 14R and 22 did experience flashover. Tests of two other materials resulted in a moderate rise in air temperature. Test 19 with the LK-1 had peak interior and doorway air temperatures of 500°C and 340°C, respectively. Test 21R with the B2II had maximum interior and doorway air temperatures of 440°C and 330°C, respectively. Evidence from previous studies [1,2] has shown that the quarter-scale test is less severe than its counterpart full-scale test. This is further substantiated by the data given in section 3.2, showing that full-scale tests required less time to reach flashover than their corresponding quarter-scale tests. Consequently, there is the possibility that the LK-1 and B2II materials could become borderline fire hazard materials when evaluated with full-scale room fire tests.

Material thickness could have a significant effect on the room fire development. Tests 14, 14R, 16, and 16R with the 9.5 mm BR1-1 and the 8.0 mm BR2-1 damping materials experienced flashover or near flashover. The 15.9 mm BR1-2 and 12.7 mm BR2-2 were similar to the BR1-1 and BR2-1, respectively, except the former two materials were thicker. Fire tests of rooms lined with the BR1-2 and BR2-2 did not approach flashover conditions. All four materials have a high thermal conductivity as heat was readily transferred to the test enclosure when these materials were used. Consequently, the thick materials would reach lower temperatures, because of their greater mass, than the thinner materials for the same quantity of heat absorbed.

3.1.2 Laboratory Fire Tests

Data from the ease of ignition test, the ASTM E 162 and ASTM E 84 flame spread tests, and the ASTM E 662 smoke density chamber test are given in table 4. The heat release rates and potential heats for the materials used in the room fire tests are presented in table 5. Results of the ease of ignition tests in table 4 showed that only the painted TS-GM, the B2II with three coats of paint, CK, SR, and one of three specimens of the BR2-1 produced measurable fuel contribution. The quarter-scale room fire tests of these five materials, i.e., tests 5R, 27 and 27R, 10, 11, and 16 and 16R, resulted in room flashover. One of the two quarter-scale tests of the B2II having two coats of paint also resulted in room flashover even though the ease of ignition test showed no fuel contribution from the painted material. The same situation occurred with the BR1-1 material. An earlier study [1] demonstrated that the ease of ignition test could sometimes show fuel contribution for materials which would not flashover in the quarter-scale and full-scale room fire tests.

The correlation between flame spread tests and quarter-scale room fire tests is poor. Materials listed in table 4 which flashed over in the quarter-scale room fire tests had E 162 flame spread indices (I_s) ranging from values as low as five for the B2II having three coats of paint and 21 for the SR to values as high as 97 for the painted TS-GM and 347 for the CK material. Materials which did not lead to room flashover had E 162 indices ranging from one for TS-GM, W-2, and the G insulation coated with 0-1001 to values of 60 for the BR1-2 and 103 for the M acoustical material. Limited data were obtained with the ASTM E 84 test. Of the five insulations evaluated with this test, only the painted TS-GM had a flame spread classification (FSC) which exceeded the "fire-safe" FSC rating of 25. This painted insulation had a FSC of 35 and did flash over in the room fire test. However, another study [1] demonstrated that room flashover could occur with a material having a "fire-safe" FSC rating of 25.

There is also no direct relation between the data from the rate of heat release calorimeter and room fire development. For materials in table 5, which flashed over in the quarter-scale room fire tests, the peak rate of heat release varied from 159 to 353 kW/m^2, the maximum 60 s average rate ranged from 52 to 250 kW/m^2, and the peak 180 s average rate varied from 20 to 235 kW/m^2. However, for materials which did not exhibit flashover, the peak rates varied from 40 to 267 kW/m^2, the 60 s rate ranged from 14 to 248 kW/m^2, and the 180 s rate varied from 9 to 240 kW/m^2. Similarly, there is no direct relation between potential heat of a material and the contribution of the material to room fire growth. For materials which flash over in the room fire test, the potential heat values varied from 7040 to 27000 kJ/kg. The potential heat for the rest of the materials in table 5 ranged from about 2000 to 14130 kJ/kg. Potential heat values are accurate to within $\pm$ 200 kJ/kg. Thus, e.g., any real difference in the values existing between the two G insulations having the two and three coats of paint would be obscured by the experimental variation inherent in the measurement.

The rate of smoke production in the quarter-scale room fire tests depends to a great extent on whether flashover occurred. In every case in this study where room flashover occurred, the peak smoke generation equalled or exceeded an optical density per meter, O.D./m, value of 13.8 over a path length of 0.15 m. All the material which resulted in room flashover, with the exception of the painted TS-GM, had peak specific optical density, D_m, values ranging from 220 to 570 for the flaming exposure and 152 to 538 for the smoldering exposure with the E 662 smoke density chamber test. The painted TS-GM had D_m values of 43 and 66 for the flaming and smoldering exposures, respectively. On the other hand, materials which did not lead to flashover had O.D./m values of 4.4 or less in the room tests, but had D_m values as high as 572 and 582 for the flaming and smoldering modes with the E 662 test. These findings clearly show the difficulty in correlating smoke data from a laboratory test like the E 662 test with smoke production from the quarter-scale room fires.

3.2 Full-Scale Tests and Comparisons with Quarter-Scale Tests

The three painted hull insulations shown in table 2 were fire-tested in the full-size room to evaluate the room fire environment and generation of heat, smoke, and carbon monoxide for these insulations. Counterpart quarter-scale tests were conducted and comparisons were made with the full-scale tests to further demonstrate their ability to simulate full-size fires. Table 2 and figures 4 to 16 summarize the full-scale results and compare them with the results from their corresponding quarter-scale tests. In table 2 and in the following discussion, peak or maximum values refer only to those maximum values occurring at times up to and including the time of flashover, unless stated otherwise. The principal interest was in the peak level of fire buildup achievable up to and including room flashover. However, the fire development over the entire test duration of 1800 s for each of these tests was also of interest to the Navy and was included in figures 4 to 16.

Full-scale tests FS-2 and FS-4 reached flashover conditions in 58 and 51 s, respectively. Their corresponding quarter-scale counterpart tests 5R, 27, and 27R took between 79 and 94 s to reach flashover. The quarter-scale test 5, which also scaled the full-size test FS-2, did not have sufficient fuel from the paint to maintain the fire long enough to ignite the newspaper flashover indicators. Each coat of paint used in test 5 was only about 0.08 mm in thickness versus the 0.10 to 0.13 mm thickness used in tests 5R and FS-2. However, test 5 did experience a peak interior air temperature of well over 600°C, a condition which is frequently indicative of flashover. The doorway air temperature for test 5 was unavailable due to a malfunction of the thermocouple. Table 2 showed that full-scale test FS-3 experienced a maximum interior air temperature of only 310°C. Interior air temperatures in the counterpart quarter-scale tests 7 and 7R reached peak values of 380 and 400°C, respectively. A peak doorway air temperature of 260°C was attained in FS-3. This compared with maximum doorway air temperatures of 260 and 290°C in tests 7 and 7R, respectively. The aforementioned results reinforced the conclusion from another study [2] that materials which resulted in rapid flashover in the full-scale tests also did so in the quarter-scale room fire tests, while those materials which did not contribute significantly to the full-scale room fire development also did not contribute much to the model room fire growth. The same study concluded that time to reach flashover took longer in the quarter-scale test, which was also the case here.

Heat release rates as high as 2570 kW and 3450 kW occurred in full-scale tests FS-2 and FS-4, respectively, by the time of flashover. Quarter-scale tests 5R and 27, corresponding to FS-2 and FS-4, respectively, had peak full-scale equivalent heat release rates of 1220 and 2100 kW, respectively. The repeat run, 27R, of test 27 gave a peak full-scale equivalent of 4430 kW. The total heat production or time integrated heat release, however, was about the same for tests 27 and 27R. All of these rates were well above steady state rates needed for flashover. Room fires with just gas burners as the fire source have shown that when steady state rates of heat release were employed, a rate as low as 340 kW maintained for about 300 s or, in the case of a rapid fire buildup, a rate of about 650 kW maintained for 45 s could cause flashover in this size room [2]. For test FS-3, the peak rate of heat production was 160 kW including the 90 kW from the ignition burner. Its corresponding quarter-scale test 7R had a maximum full-scale equivalent heat release rate of 110 kW.

Thermal radiation levels at the floor in test FS-2 reached 38 kW/m^2 at the time of flashover compared with a level of 34 kW/m^2 in its corresponding quarter-scale test 5R. The floor radiation reached 31 kW/m^2 at the time of flashover in test FS-4, but the counterpart quarter-scale tests 27 and 27R achieved radiation levels of only 18 and 14 kW/m^2, respectively, at the onset of flashover. However, the radiation flux at the floor for tests 27 and 27R was increasing rapidly at flashover, and the observed times for flashover were accurate only to within one or two seconds. Thus, the radiation levels for tests 27 and 27R could have been higher than 20 kW/m^2 when the newspaper flashover indicators ignited. This would then be consistent with the fact that newspaper ignites over a range of fluxes between 17 and 25 kW/m^2 [11]. For test FS-3, the radiation level at the floor peaked at 2.1 kW/m^2. Floor flux levels in its counterpart quarter-scale tests 7 and 7R reached maximum levels of 2.3 and 2.2 kW/m^2, respectively.

Peak carbon monoxide production at times up to and including flashover is shown in table 2 and was about 27 g/s for both FS-2 and FS-4. This compared with the peak full-scale equivalent values of 40, 24, and 42 g/s in the quarter-scale tests 5R, 27, and 27R, respectively. However, little carbon monoxide was produced in test FS-3 and in its corresponding quarter-scale test 7R. Smoke data were not available for the full-scale tests due to a malfunction of the smoke measurement system. Peak smoke concentrations were available for the quarter-scale tests 5R, 7R, 27 and 27R and are shown in table 2. The smoke levels in tests 5R, 27, and 27R exceeded the limit of 16.4 OD/m for the measurement system. Only test 7R produced little smoke. The data on smoke, heat release, and generation of carbon monoxide from the quarter-scale fire tests 5 and 7 were not available, as reliable means for measuring these quantities were not ready until after tests 1 through 10 were completed.

3.3 Effect of Paint on Fire Performance of Hull Insulation

An earlier study, involving quarter-scale room fire tests of insulations [1], indicated that decorative paints over two types of nitrile foams increased the surface flaming to the extent where flashover was imminent or had occurred in six of the seven cases (tests 6 to 9 and 11 to 13) where these foams were painted. The room fire tests of the unpainted nitrile foams (tests 4, 5, and 10) in that study resulted in interior and doorway air temperatures of less than 300°C. A 3.9 kW ignition source was used for those tests. In the current work, a 5.6 kW ignition source was used for the tests shown in table 3. Comparisons of test 5R with test 2 and tests 27 and 27R with tests 21 and 21R in table 3 support the findings from the earlier study that decorative paints could often cause insulations to fail the criterion of no flashover over an 1800 s exposure to a moderately large fire.

The effect of paint on the fire development could have little effect on the room fire, as in test FS-3, or it could result in rapid transitory fire buildup to flashover with temperatures and thermal flux levels receding rapidly when the paint is consumed, as in test FS-2. Coatings of paint could also result in the fire involvement of the insulation such that a much more serious shipboard fire threat occurs, as in test FS-4. Figure 10 shows that in full-scale test FS-2, with the TS-GM insulation and coatings of 0-634 and chlorinated alkyd 124 paints, the coatings enhanced the fire such that the radiant flux to the floor exceeded 20 kW/m^2, the threshold value for flashover, for a post-flashover duration of 50 s. For full-scale test FS-4 with the B2II insulation and 0-634 coating, the fire reached flashover in 51 s. After the paint was consumed, the interior and doorway air temperatures receded until about 135 s at which time fire involvement of the B2II insulation began to increase dramatically due to the intense thermal environment in the room. Figure 12 shows that the flux to the floor in test FS-4 gradually increased to above the threshold value of 20 kW/m^2 after reaching a low of about 11 kW/m^2 at 165 s. It was 420 s into the test before the flux level at the floor receded below 20 kW/m^2 again.

The quarter-scale counterparts of FS-2 and FS-4, i.e., tests 5R, 27, and 27R, also experienced flashover. For tests 7 and 7R, the room was lined with fibrous glass hull insulation G and covered by two coats of the vapor barrier 0-1001. These tests, like their corresponding full-scale test FS-3, did not exhibit flashover. Test 8 was similar to tests 7 and 7R, except that its surface had an additional topcoat of chlorinated alkyd 124 paint over the 0-1001. The chlorinated alkyd paint did not increase the fire risk of the insulation G. Test 6, with the TS-GMG material painted with 2 coats of 0-9788, also did not approach flashover conditions. Tests 22, 22R, 27, and 27R, with the painted B2II insulations, demonstrated the importance of paint thickness to room fire growth. Tests 22 and 22R had 2 coats of the 0-634, but only test 22 achieved room flashover. Tests 27 and 27R, with 3 coats of 0-634, reached flashover in 91 s and 79 s, respectively, compared with a time of 101 s for test 22.

3.4 Test Protocol for Quarter-Scale Test

A recommended test protocol on the determination of the flashover potential of hull insulation using the quarter-scale room fire test is given in the appendix. The following discussion gives some of the rationale for the protocol development. In the construction of the room, there is a need to simulate the actual construction as much as is possible. Shipboard hull insulation is generally attached to metal bulkheads with adhesive or impaled on metal studs on the bulkhead. Thus, the quarter-scale room should be constructed from either aluminum or steel sheet or plate to assure proper adhesion between the insulation and the metal substrate when adhesives are used and to provide a similar substrate which has a high thermal sink. Aluminum construction is recommended for its lower weight for the same wall thickness, making refitting operations easier. As for burner location the center of the floor is not suitable as the flames from any reasonably sized fire cannot directly contact the wall material. Placement of the ignition source against the back wall or in a rear corner are two practical alternatives. Corner placement appears to be more desirable as the wall insulation would be evaluated under the more demanding fire exposure for any given rate of heat release for the burner. The severity of the ignition source should be large enough to adequately assess the fire hazard potential of materials, but should not be so large as to overwhelm the material being evaluated. The 5.6 kW source recommended in the protocol represents approximately the quarter-scale version of a small upholstered chair burning in a room. A 5.6 kW burner rate in the corner of the room, maintained for 300 s, represents about one-fourth of the rate needed for flashover of a quarter-scale room lined with fire-exposed fibrous glass hull board [2]. The test insulation itself must then contribute three times the burner rate of heat release in order to achieve flashover of the room. (Fire-exposed hull board is fibrous glass insulation which has had much of the organic binder burned off, leaving a relatively inert material. This was accomplished by subjecting the room lined with the insulation to a 11.3 kW burner exposure for 900 s several hours before actual testing began.)

Measurement of the degree of fire buildup up to and including the time of flashover, if it should occur, can be obtained by monitoring the rise in air temperature at the doorway and near the center of the ceiling. Although 0.05 mm wire thermocouples were used in this study for precision measurement of air temperatures, they are difficult to prepare and are vulnerable to breakage. It is suggested that thermocouples fabricated from 0.25 mm diameter chromel and alumel wires be used for durability. For the room test lined with the fire-exposed fibrous glass and a burner rate of 5.6 kW, steady temperature conditions are reached by 1200 s. In order to get an indication of the variability of air temperatures expected under such steady conditions for facilities following the recommended test protocol as given in the appendix, the above test with the fire-exposed insulation was run at three facilities. These facilities were the National Bureau of Standards, the David Taylor Naval Ship Research and Development Center in Annapolis, Maryland, and the Bath Iron Works in Maine. At 1200 s into the test, the air temperatures, as measured with 0.25 mm wire thermocouples at these three facilities, were all within ± 10°C of 240°C at 25 mm below the doorway and within ± 10°C of 355°C at 25 mm below the center of the ceiling.

The basic criterion for limiting the fire growth potential of shipboard interior finish materials requires that the insulation or combination of insulation and coating materials must not lead to flashover of the room over the exposure period of 1800 s using the prescribed burner rate of heat release of 5.6 kW. However, the degree of fire buildup that is achievable, short of flashover, is also important in determining the fire hazard of materials. It has been demonstrated that the air temperatures inside the room and in the doorway provide reliable indications of the degree of fire buildup [1,2]. Table 3 gives a comparison of peak air temperatures near the ceiling and near the top of the doorway for all of the quarter-scale room fire tests. Earlier work [1] suggested that flashover conditions could be expressed in terms of the temperature levels for the hot air at the doorway and inside the room. In that work, the data showed that even interior air temperatures of about 600°C could result in the ignition of the flashover indicators in the room. For example, tests 45, 33, and 30 in that study had peak interior air temperatures of 587, 604, and 616°C, respectively, at times up to and including the time of flashover. The same study showed that peak doorway air temperatures could be as low as 427 to 451°C at times up to and including the time when flashover occurred. For instance, tests 20 and 36 in that test series exhibited peak doorway air temperatures of 427°C while test 33 had a maximum doorway air temperature of 451°C. All three tests experienced flashover and had interior air temperatures of over 600°C.

An examination of the data in table 6 further substantiated such a correlation between room interior air and doorway air temperatures and flashover conditions. Tests 5R, 10, 11, 14R, 16, 16R, 22, 27, and 27R in table 6 experienced flashover. Of these tests, all experienced interior and doorway air temperatures of at least 650°C and 430°C, respectively, except for test 16. Test 16 reached flashover at 550 s and had peak interior and doorway air temperatures of 590 and 410°C, respectively. A repeat test, 16R, of test 16 experienced flashover at 1485 s and peak air temperatures of 790 and 480°C at the interior and doorway, respectively. There was a chance that burning material in the form of surface flaking may have ignited the newspaper flashover indicators in test 16, as pieces of material began falling from the ceiling as early as 390 s into the test. It is also possible to have interior temperatures much higher than 600°C and with no ignition of the flashover indicators, as in test 5. Test observations indicated that flames in that test were localized and spread only near the interior thermocouple before receding. Unfortunately, the doorway air temperatures were unavailable at the 25 mm and 51 mm locations below the doorway to help in understanding the fire development. The thermocouples at these locations malfunctioned. However, the doorway thermocouple at the 104 mm location gave a reading of only 60°C versus the lowest recorded value of 340°C (test 14) at that location for those tests where flashover occurred. Thus, flashover in the quarter-scale test could be defined as the room condition where the peak interior air temperature is at least 600°C and the maximum doorway air temperature is also at least 400°C. The latter requirement is used to help avoid giving a flashover classification to the room fire condition where localized fire involvement along the ceiling resulted in interior air temperatures exceeding the "flash-over threshold" of 600°C without an accompanying flashover. From the aforementioned discussion, it appears then that the fire risk potential of hull insulations and coatings can be assessed solely by the peak air temperatures achievable in the quarter-scale test.

Measurement of the peak air temperatures in the quarter-scale test, however, is complicated by the stratification of air temperatures inside the room and at the doorway. Boundary layer effects, thermal losses to the surface, and out-gassing or fuel generation at the surface also affect the temperature gradient near the ceiling. Constriction of the flow through the doorway and stratification of the hot air affect the temperature gradient at the doorway. Consequently, the room fire test data were analyzed to find the most suitable heights at the doorway and below the ceiling in the room for measuring peak air temperatures with a minimum number of thermocouples. The data in table 6 showed that peak doorway air temperatures usually occurred at 25 mm below the doorway lintel. However, in tests 5R, 10, and 14R, the peak value occurred at the 51-mm location. Maximum interior temperatures usually occurred at the 25-mm location below the ceiling, but in many cases, the peak values were measured at greater distances away from the ceiling. Sometimes this may be a consequence of the material separating from the ceiling and then possibly burning in the vicinity of the lower thermocouples, e.g., in test 19. More often, it may be the result of an inverted thermal stratification arising from the burning behavior of the material. At any rate, the quarter-scale test should have the capability of detecting these peak temperatures which affect the radiation flux to the lower part of the room which in turn determines the degree of fire buildup. The data in table 6 show that the maximum air temperatures could occur at an elevation as low as 51 mm below the doorway lintel and at 51 to 102 mm below the ceiling. Based on these data, as well as on past observations of quarter-scale fire tests, it is recommended that, in the test protocol developed for the quarter-scale test, thermocouples be used at the 25 and 51 mm locations below the top of the doorway and at 25 mm and 76 mm below the ceiling.

4. CONCLUDING REMARKS

1. No reliable correlations exist between the laboratory materials fire property test performance and full-scale or quarter-scale room fire test behavior of the shipboard insulations evaluated. This is in accord with earlier findings involving hull insulation [1].

2. Quarter-scale room fire testing demonstrated that it is a reliable indicator of full-scale room fire behavior for the three cases discussed in this report where there was flashover in two tests

and only a low level fire buildup in the third test. This was consistent with prior studies involving a variety of materials [1,2].

3. Cork, silicone rubber SR, and the polyvinyl chloride-polyvinyl acetate BR1-1 and BR2-1 tiles failed the requirement of no flash-over in the quarter-scale room fire test over a 1800 s test period.

4. Vapor barrier 0-1001 did not significantly affect the fire performance of fibrous glass hull board.

5. Decorative paints such as 0-634 and the Navy's chlorinated alkyd formula 124 could transform an otherwise fire-safe insulation into a fire-risk material.

6. A test protocol has been developed for the quarter-scale room fire test and is included in the appendix.

7. Round robin evaluation of the quarter-scale room fire test among at least three participating laboratories is recommended as a logical follow-up to this work. The study should involve a variety of materials having a wide range of fire properties with at least three tests of each material. The results from all three laboratories should be analyzed to demonstrate the repeatability of results within each laboratory and the reproducibility among laboratories before this protocol is adopted for general use in material specifications. The acceptable level of reproducibility should be determined from the fire situations being replicated.

5. ACKNOWLEDGEMENTS

Appreciation is expressed to Mr. Charles Veirtz, who performed the quarter-scale tests; to Messrs. Charles Veirtz and Oscar Owens for conducting the full-scale tests, and to Mr. J. N. Breese for the data reduction and preparation of most of the figures in the report.

This study was supported by the Naval Sea Systems Command, Department of the Navy, under the direction of Messrs. William Dunham and John Pinto.

6. REFERENCES

1. Lee, B.T.; Breese, J.N.; Submarine Compartment Fire Study - Fire Performance Evaluation of Hull Insulation. Nat. Bur. Stand. (U.S.) NBSIR 78-1584; 1979 May.

2. Lee, B.T. Quarter-Scale Modeling of Room Fire Tests of Interior Finish. Nat. Bur. Stand. (U.S.) NBSIR 81-2453; 1982 March.

3. Lawson, J.R.; Parker, W.J.; Development of an Ease of Ignition Test Using a Flame Exposure. Nat. Bur. Stand. (U.S.) NBSIR 82-2503; 1982 June.

4. Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source. ASTM E 162. Philadelphia, PA: American Society for Testing and Materials; 1981.

5. Standard Test Method for Surface Burning Characteristics of Building Materials. ASTM E 84. Philadelphia, PA: American Society for Testing and Materials; 1981.

6. Tordella, J.; Twilley, W.; Development of a Calorimeter for Simultaneously Measuring Heat and Mass Loss. Nat. Bur. Stand. (U.S.) NBSIR in preparation.

7. Standard Test Method for Potential Heat of Building Materials. NFPA 259-1976. Boston, MA: National Fire Protection Association; 1976.

8. Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials. ASTM E 662. Philadelphia, PA: American Society for Testing and Materials; 1979.

9. Lee, B.T. Effect of Ventilation of the Rates of Heat, Smoke, and Carbon Monoxide Production in a Typical Jail Cell Fire. Nat. Bur. Stand. (U.S.) NBSIR 82-2469; 1982 March.

10. Parker, W.J. Calculations of the Heat Release Rate by Oxygen Consumption for Various Applications. Nat. Bur. Stand. (U.S.) NBSIR 81-2427-1; 1982 March.

11. Fang, J.B. Fire Buildup in a Room and the Role of Interior Finish Materials. Nat. Bur. Stand. (U.S.) Tech. Note 879; 1975 June.

APPENDIX A

Test Protocol on the Determination of the Flashover Potential of Shipboard Hull Insulation Using a Quarter-Scale Room Fire Test

A1. SCOPE

A1.1 Scope. This method describes a procedure to determine the flashover potential of shipboard hull lining materials subjected to a fire exposure in a mock-up room.

A1.2 The method gives an indication of the potential room fire buildup up to and including room flashover. It yields a time from the introduction of the fire exposure until the moment of flashover, or until the peak room air temperature is reached, if flashover does not occur.

A2. JUSTIFICATION

A2.1 In the interest of reducing both the set-up time and cost associated with fire testing in a full-size room, herein defined as a 3.0 x 3.0 x 2.4 m high enclosure having a 0.76 x 2.03 m high doorway, a one-quarter scale room fire test was devised for determining the flashover potential of lining materials exposed to fire.

A3. EQUIPMENT

A3.1 The quarter-scale room shall be constructed from 6.4 mm aluminum or steel sheet and shall form a box having a ceiling and four sides with air tight joints. The box shall sit on a floor fabricated with the same material. The interior dimensions of the fully lined quarter-scale room are 0.76 x 0.76 x 0.61 m high. A doorway is located at the center of one wall and must be 0.50 m wide and 0.43 m high to secure the proper ventilation and fire development. The distance between the finished ceiling and the top of the doorway must be 178 mm. The floor of the model room must extend at least 0.30 m outside of the doorway. The box is removable to allow for application of paint and/or ceiling and wall covering. The entire base of the box in contact with the floor shall be made air tight.

A3.2 A porous ceramic plate diffusion flame burner shall be used as the fire source. The burner shall be 89 x 89 x 76 mm high consisting of a horizontal porous plate area of 76 x 76 mm with a 6.4 mm wide steel plate perimeter and steel plate sides and bottom.

A3.3 Four chromel-alumel thermocouples, fabricated from 0.25 mm diameter (Brown and Sharpe 30 gage) wire, shall be used -- 25 and 76 mm below the center of the overhead and 25 and 51 mm below the top of the doorway.

A4. PROCEDURE

A4.1 The test material shall fully line the walls and ceiling. As much as possible, the material shall be mounted in the same manner as is used on board ship.

A4.2 Prior to testing, the fully lined test room shall be conditioned for at least 24 hours at a relative humidity between 50 $\pm$ 10 percent and a temperature of 23 $\pm$ 5°C.

A4.3 The diffusion burner shall be positioned on the floor snugly against one rear corner of the test room such that there is no air gap between the burner and the two walls. A flow rate of 150 ml/s (0.32 CFM) of methane shall be used to produce a constant heat input of 5.6 kW (320 Btu/min) for the duration of the test.

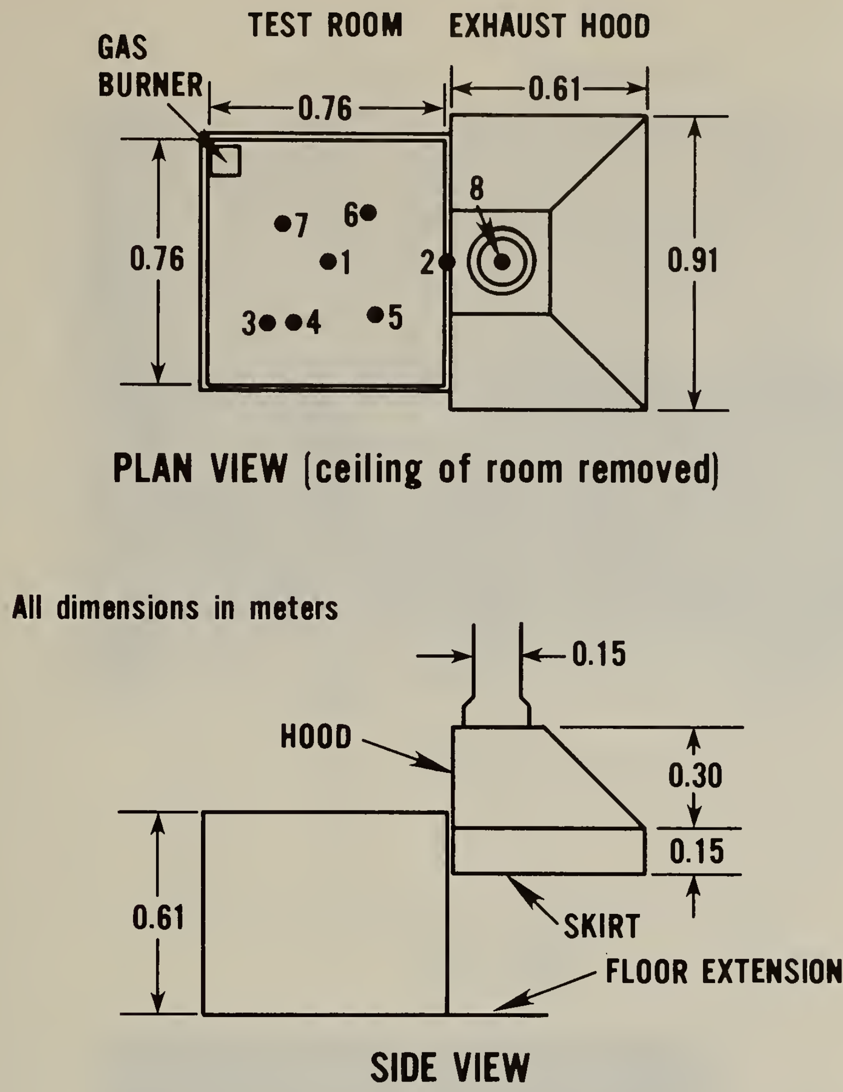
A4.4 The test data from the four thermocouples shall be recorded continuously during the test.

A4.5 The primary data generated by this test will be the time to room flashover, if it occurs, and the maximum temperature if flashover is not reached. Flashover is characterized by thermal flux levels equal to or greater than 20 kW/m^2 at the floor level. This corresponds to interior temperatures of 600°C and higher and doorway temperatures of 400°C and higher. For the purpose of qualification/acceptance, flashover is defined here as that fire condition where one of the interior thermocouple measurements reaches 600°C and one of the doorway measurements reaches at least 400°C. For qualification/acceptance of a material, room flashover shall not occur within 1800 s.

A4.6 Color 35 mm slides be taken at 15 s intervals during the first 180 s and at 30 s intervals thereafter to document the growth of the fire.

A5. SUMMARY

The quarter-scale room test procedure described here provides a relatively low cost, and generally reproducible, method for determining the flashover potential of materials used to line the interior surfaces of shipboard compartments. The lining materials may be insulation, paint (used over lining materials), sheathing, acoustic panels, or the like.



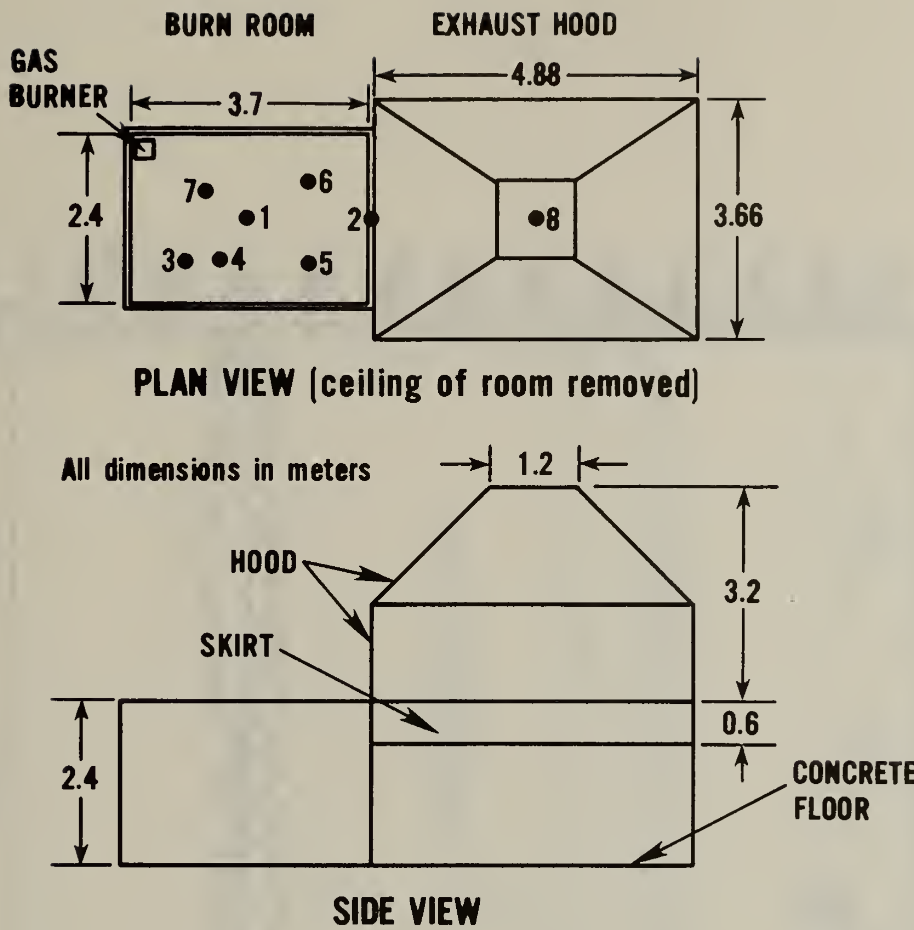
Station	Instrument
1	- Vertical strand of seven 0.05 mm thermocouples at 25, 51, 102, 203, 305, 457 and 610 mm down from center of ceiling.
2	- Vertical strand of six 0.05 mm thermocouples located along the centerline of the doorway at distances of 25, 51, 102, 203, 254, and 356 mm below the top of the doorway.
3	- Thermal flux gauge on floor.
4 to 7	- General vicinity for newspaper flashover indicators on floor.
8	- Thermocouple, pitot tube, gas sample port (O_2, CO, CO_2), and smoke meter in stack.

Figure 1. Layout and Instrumentation for Quarter-Scale Test

Quarter-Scale Test

Full-Scale Test

Fig. 2 Quarter-Scale and Full-Scale Room Fire Tests



Station	Instrument
1	- 0.51 mm (24 gauge) thermocouples at 0, 0.03, 0.10, 0.60, 0.90, 1.20, 1.50, 1.80, 2.10, 2.34, and 2.44 m below center of ceiling. 0.05 mm thermocouples at 0.10, 0.60, 1.20, 1.80 and 2.34 m below center of ceiling.
2	- 0.51 mm (24 gauge) thermocouples at 0.03, 0.10, 0.30, 0.50, 0.70, 0.90, 1.10, 1.30, 1.50, 1.78, and 1.90 m from top of doorway. 0.05 mm thermocouples at 0.10, 0.50, 0.90, 1.30 and 1.78 m from top of doorway.
3	- Thermal flux gauge on floor.
4 to 7	- General vicinity for newspaper flashover indicators on floor.
8	- Thermocouple, pitot tube, gas sample port (O_2, CO, CO_2), and smoke meter in stack.

Figure 3. Layout and Instrumentation for Full-Scale Test

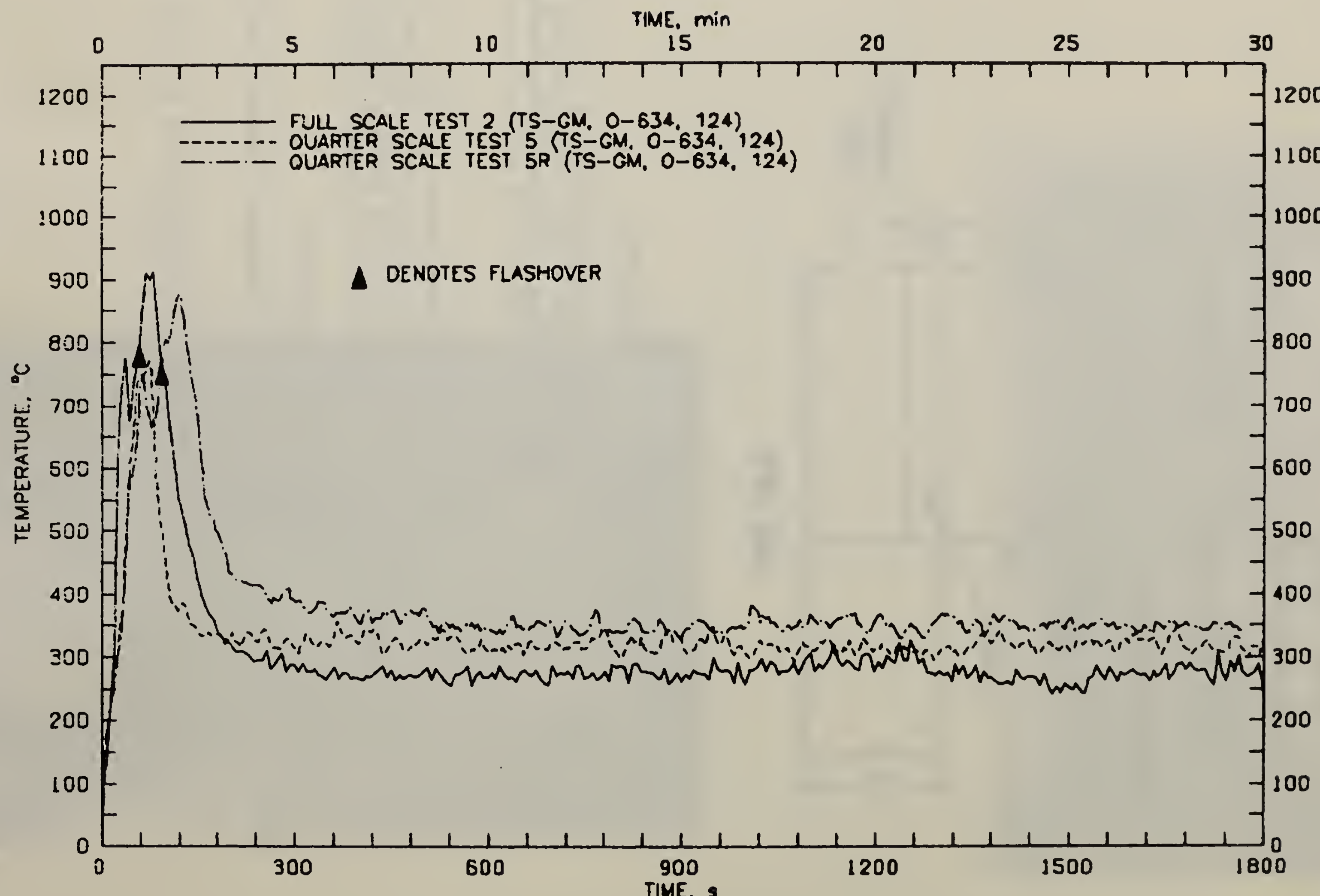


Figure 4. Air temperatures near center of ceiling for full-scale test 2 and corresponding quarter-scale tests

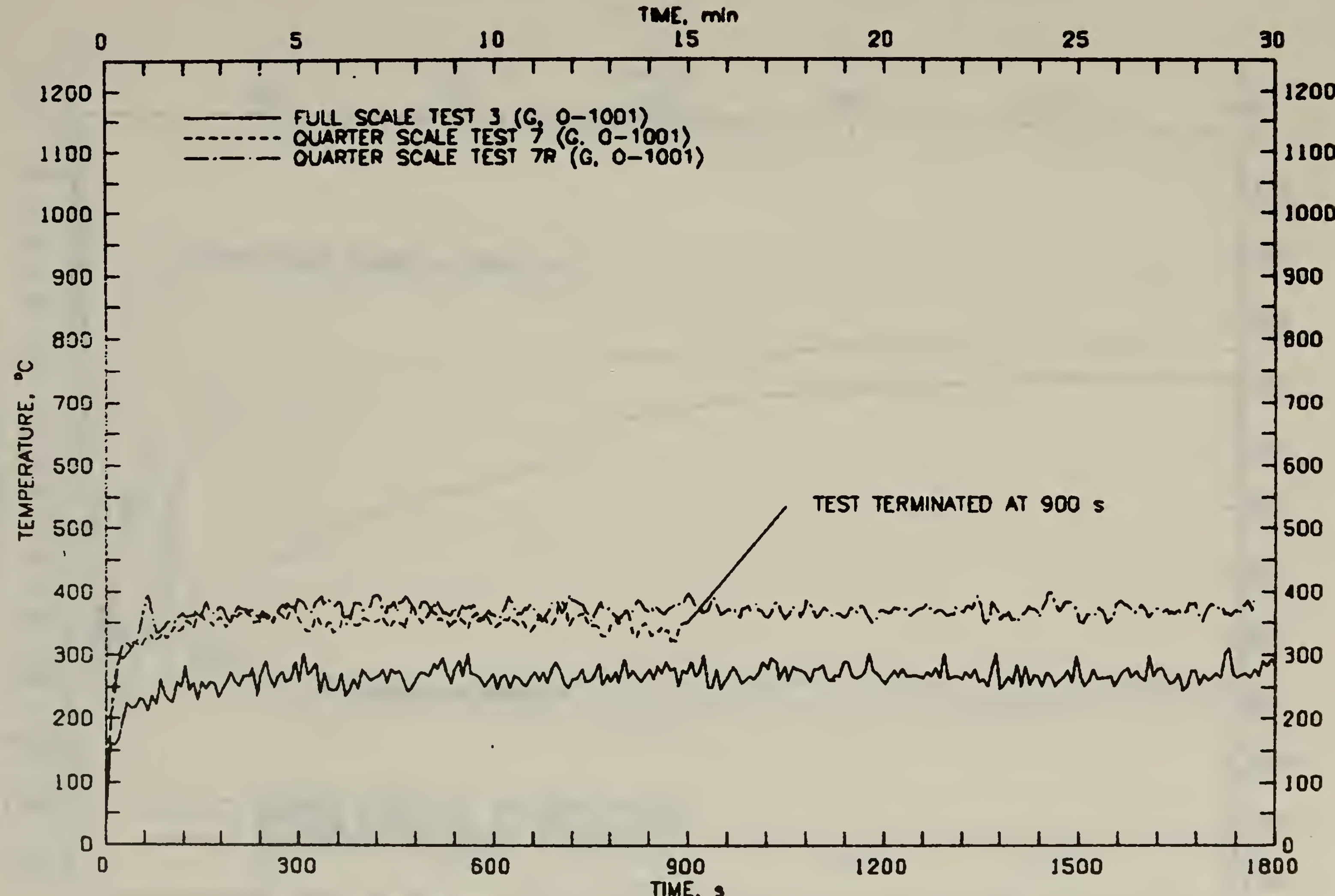


Figure 5. Air temperatures near center of ceiling for full-scale test 3 and corresponding quarter-scale tests

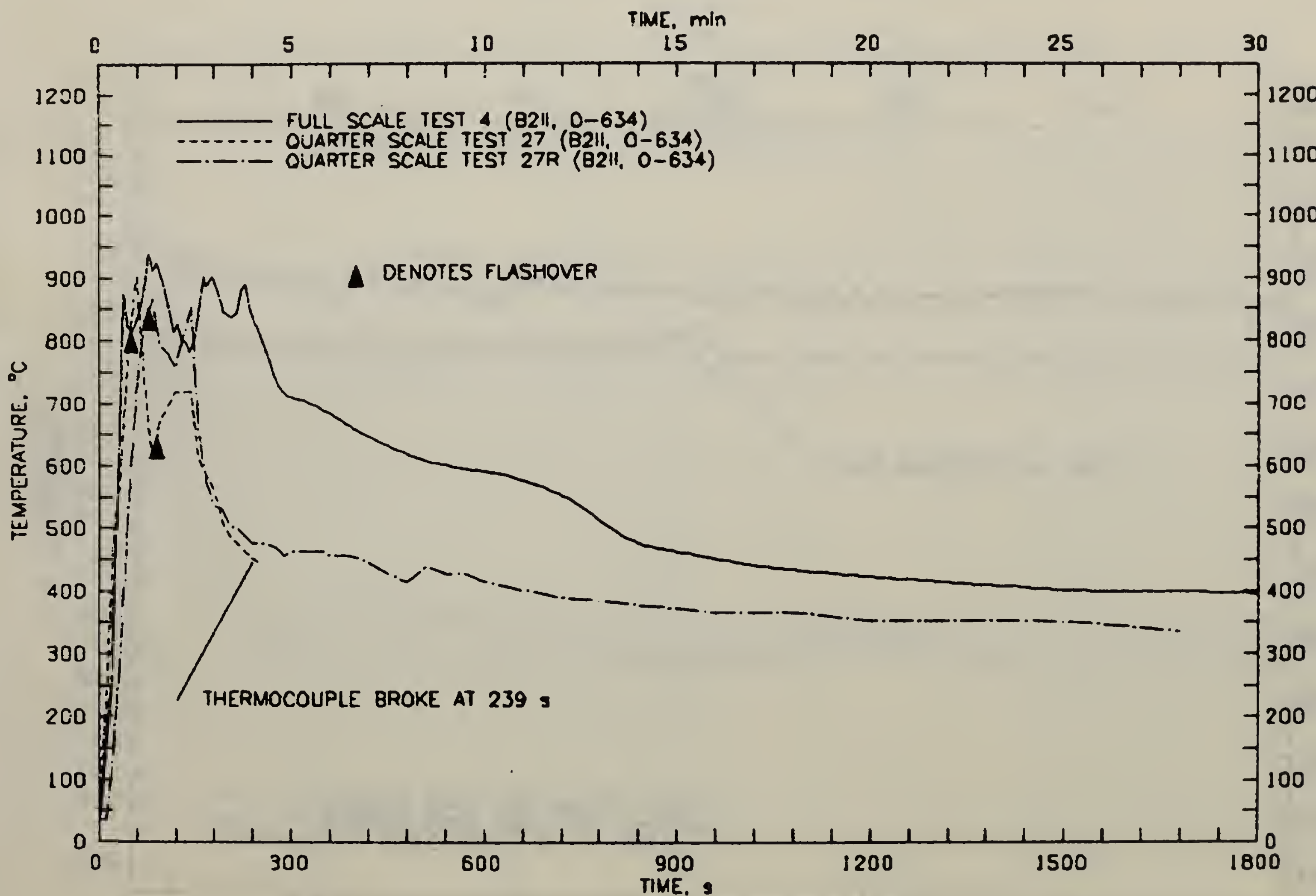


Figure 6. Air temperatures near center of ceiling for full-scale test 4 and corresponding quarter-scale tests

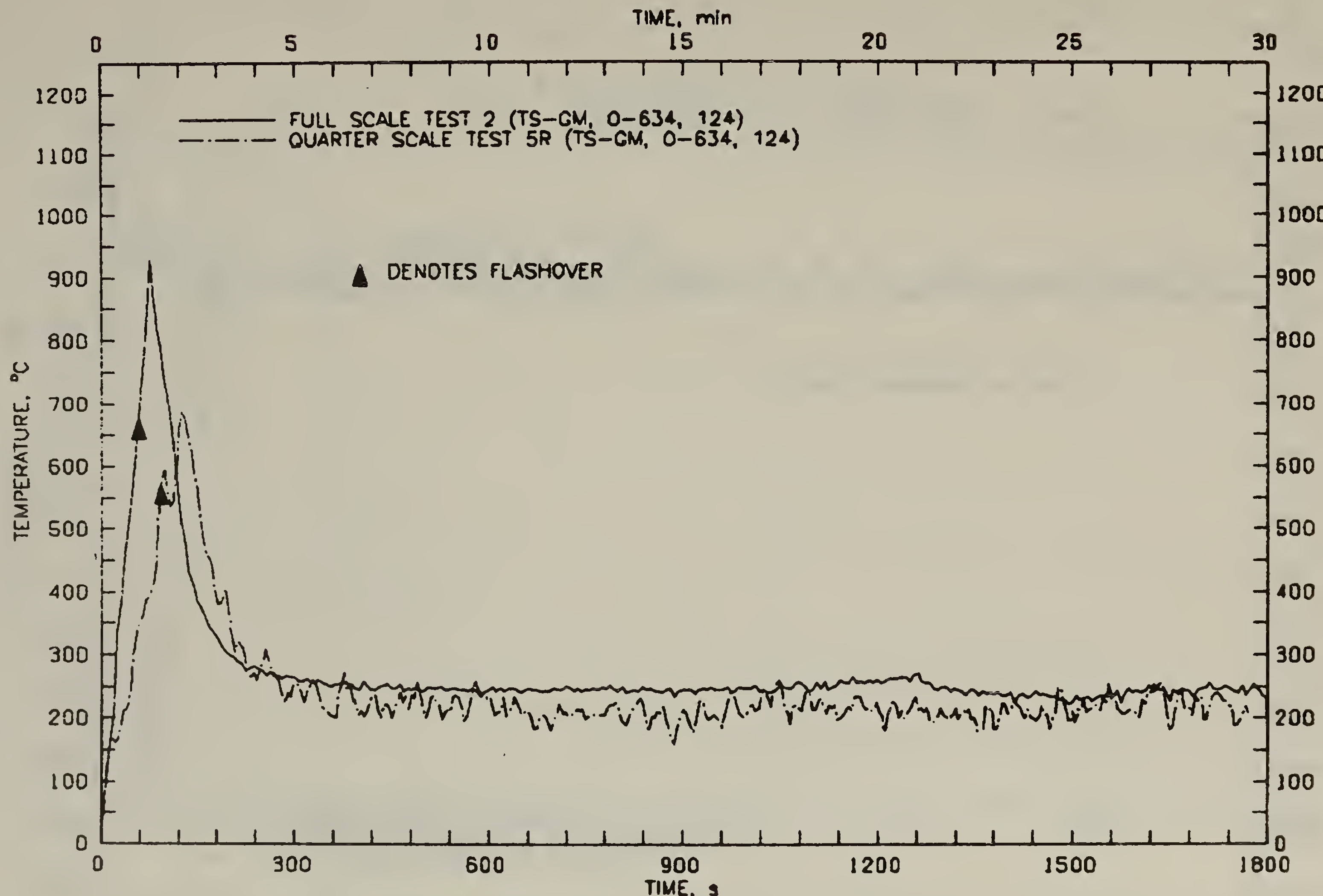


Figure 7. Air temperatures near top of doorway for full-scale test 2 and corresponding quarter-scale tests

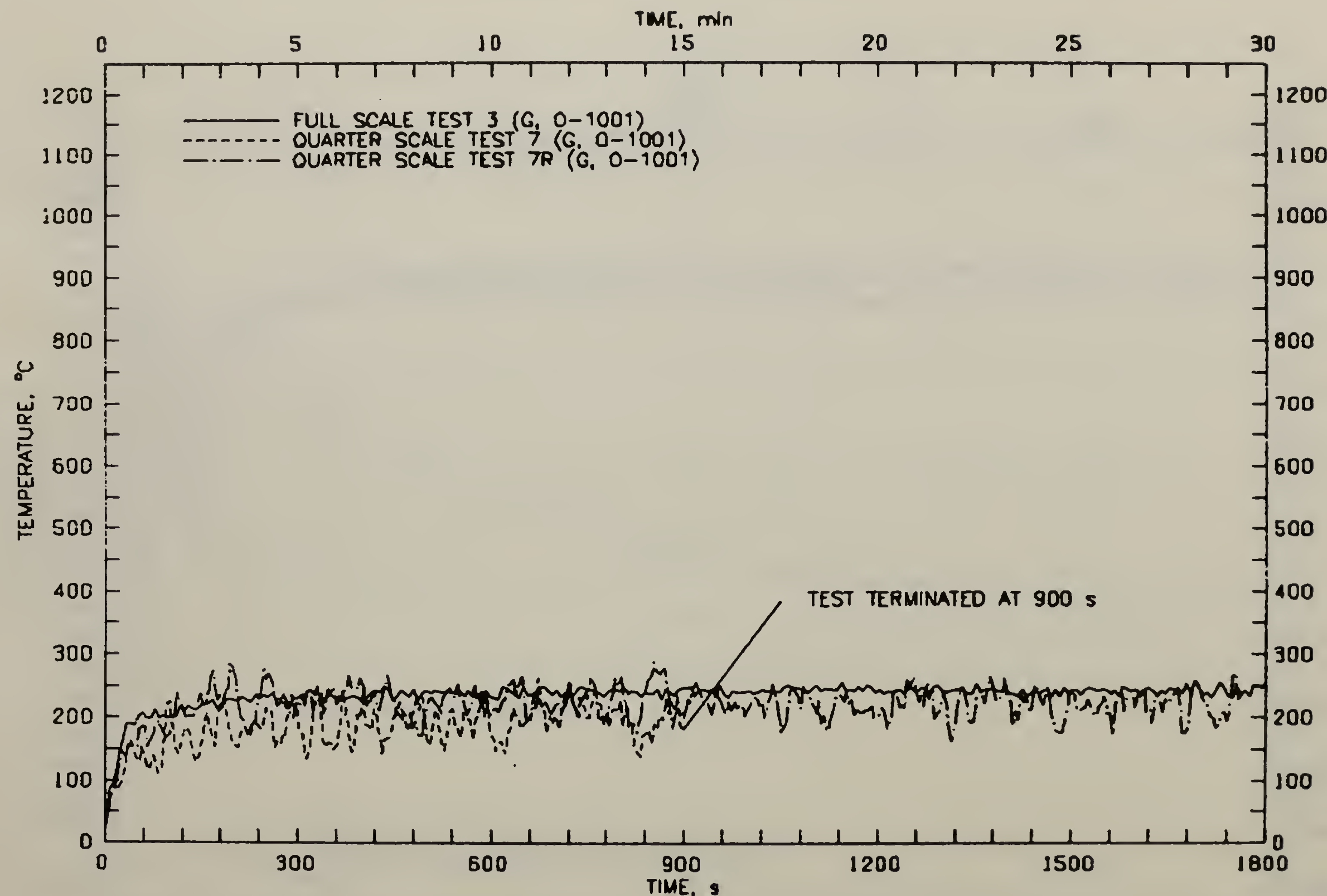


Figure 8. Air temperatures near top of doorway for full-scale test 3 and corresponding quarter-scale tests

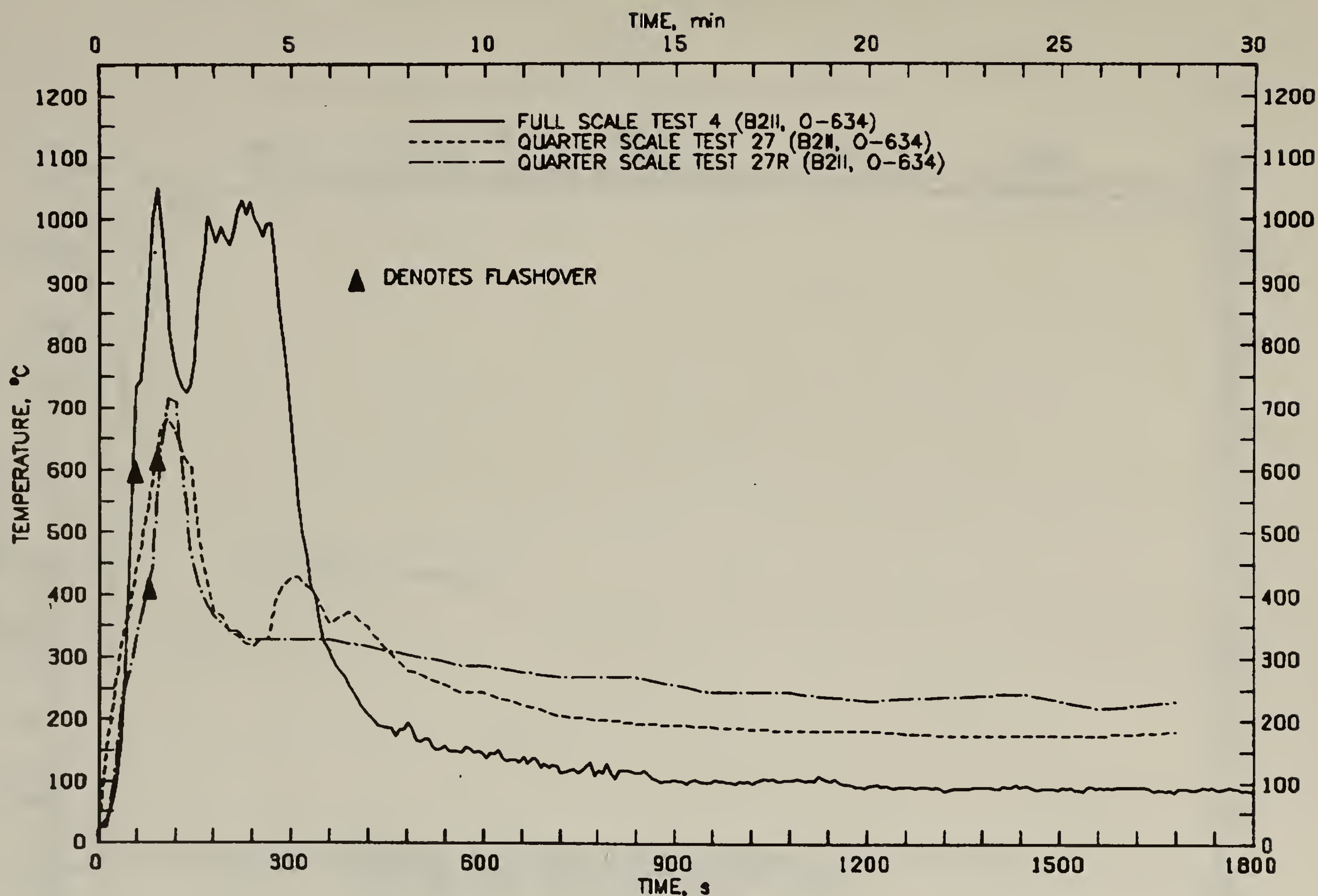


Figure 9. Air temperatures near top of doorway for full-scale test 4 and corresponding quarter-scale tests

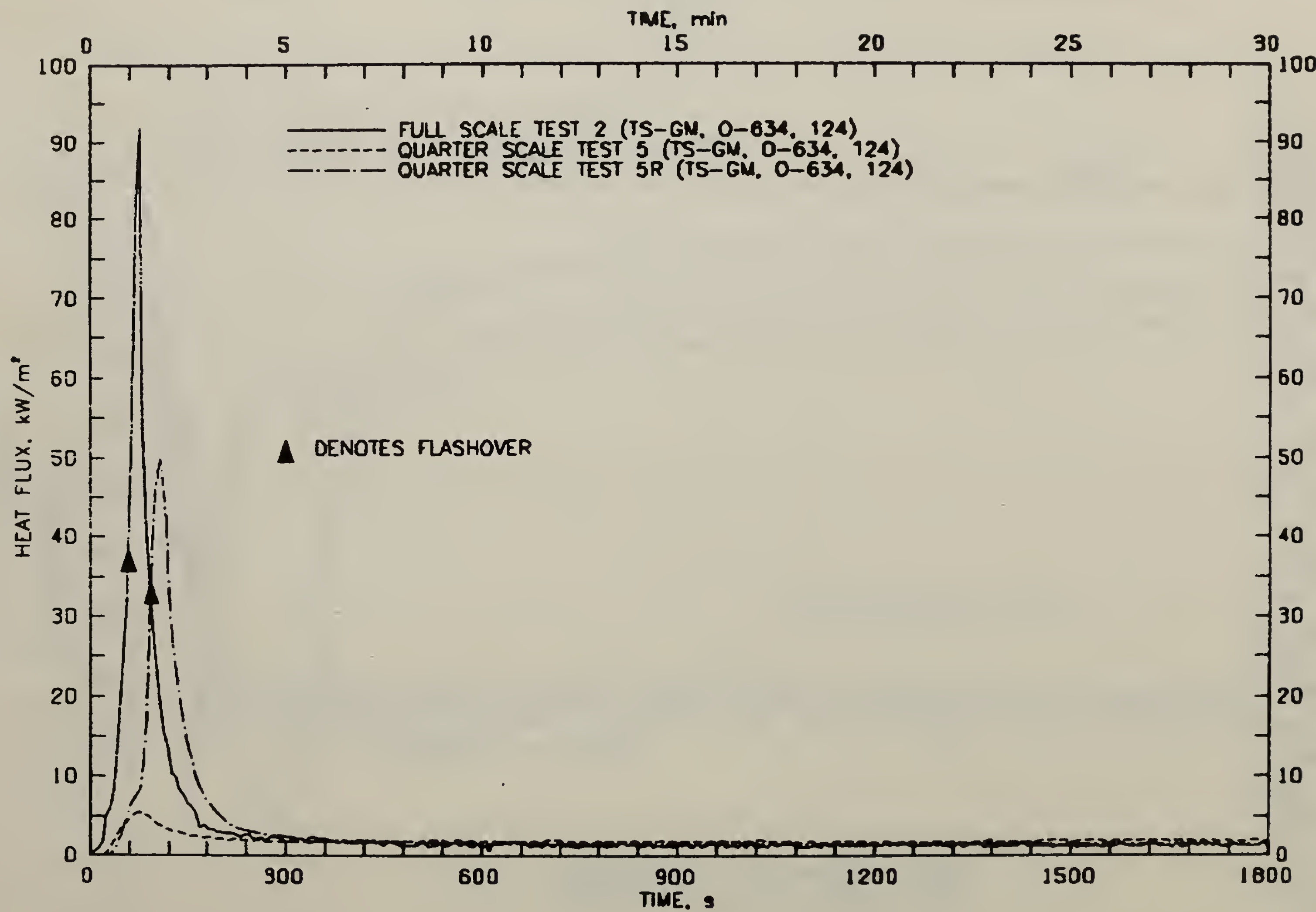


Figure 10. Heat flux on floor for full-scale test 2 and corresponding quarter-scale tests . . . . .

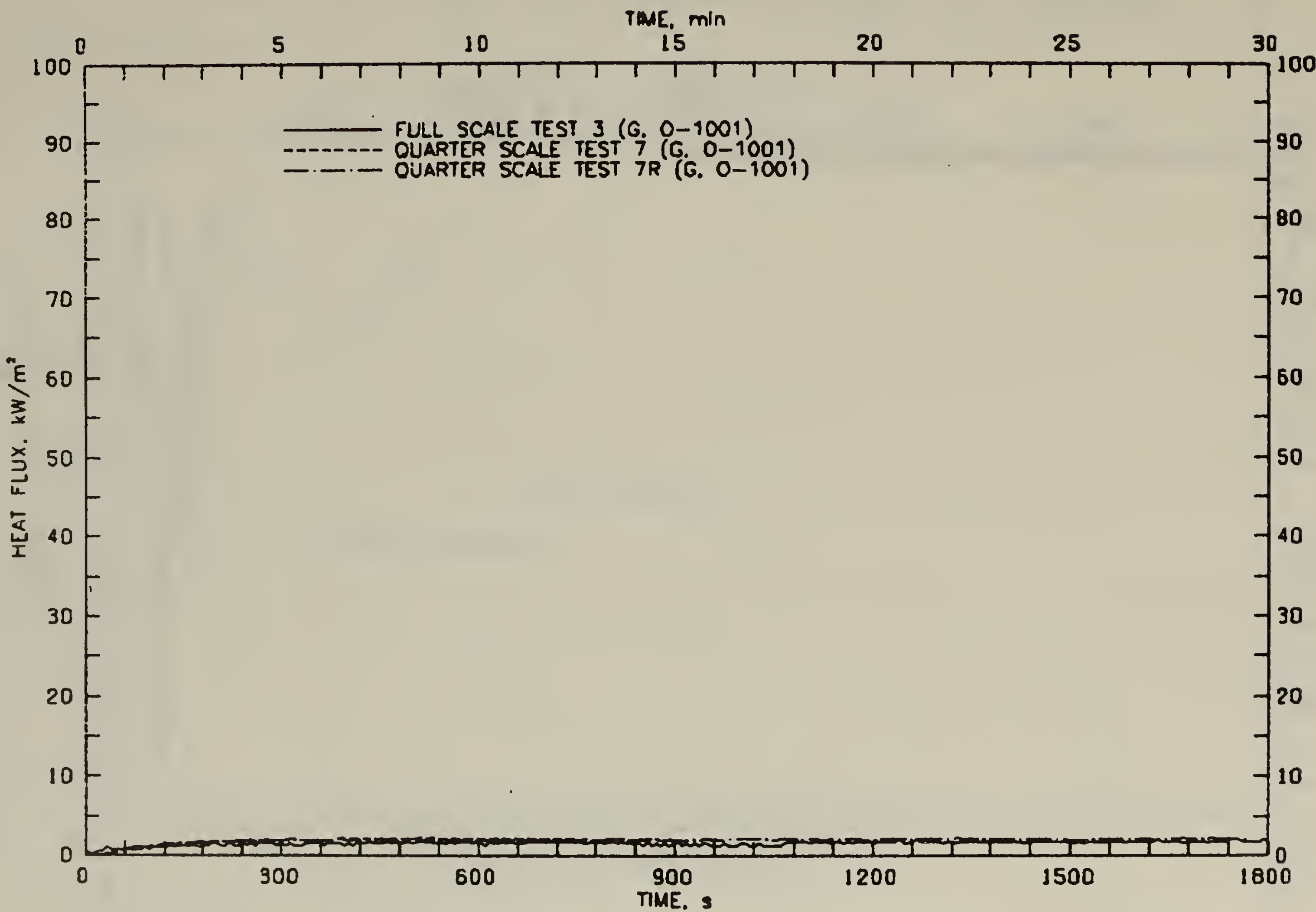


Figure 11. Heat flux on floor for full-scale test 3 and corresponding quarter-scale tests . . . . .

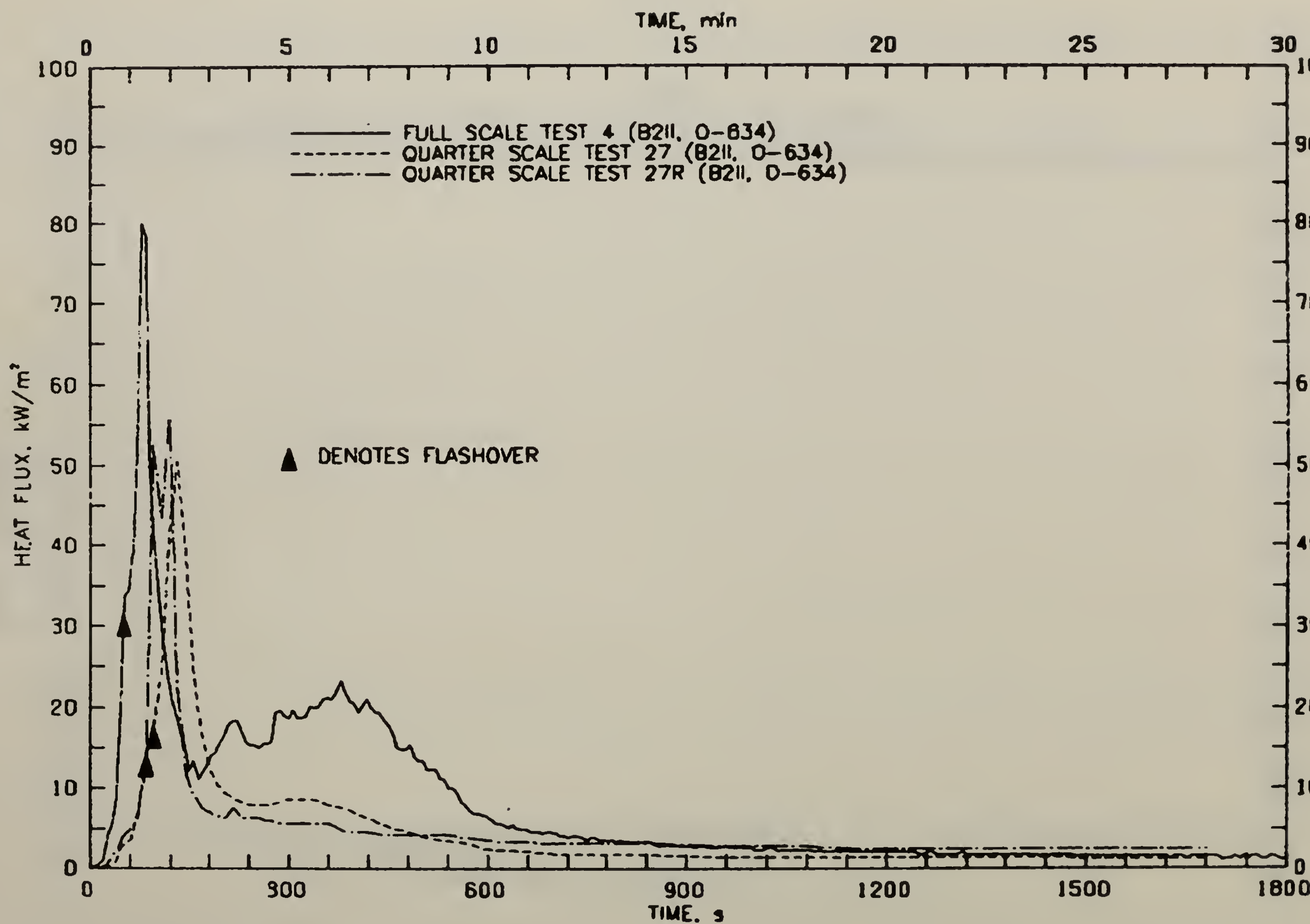


Figure 12. Heat flux on floor for full-scale test 4 and corresponding quarter-scale test . . . . .

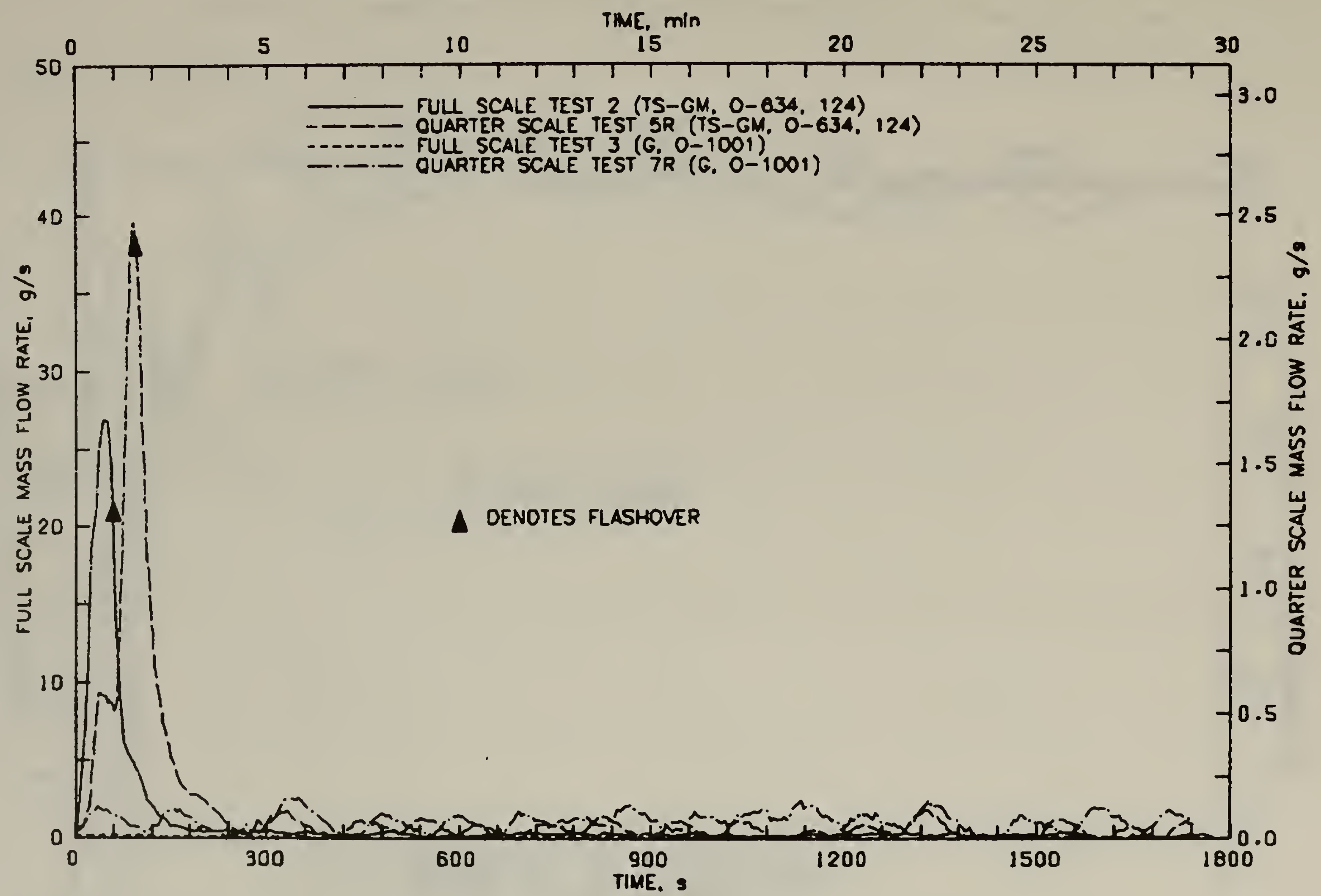


Figure 13. Mass flow rate of carbon monoxide for full-scale tests 2 and 3 and their corresponding quarter-scale tests . . . . .

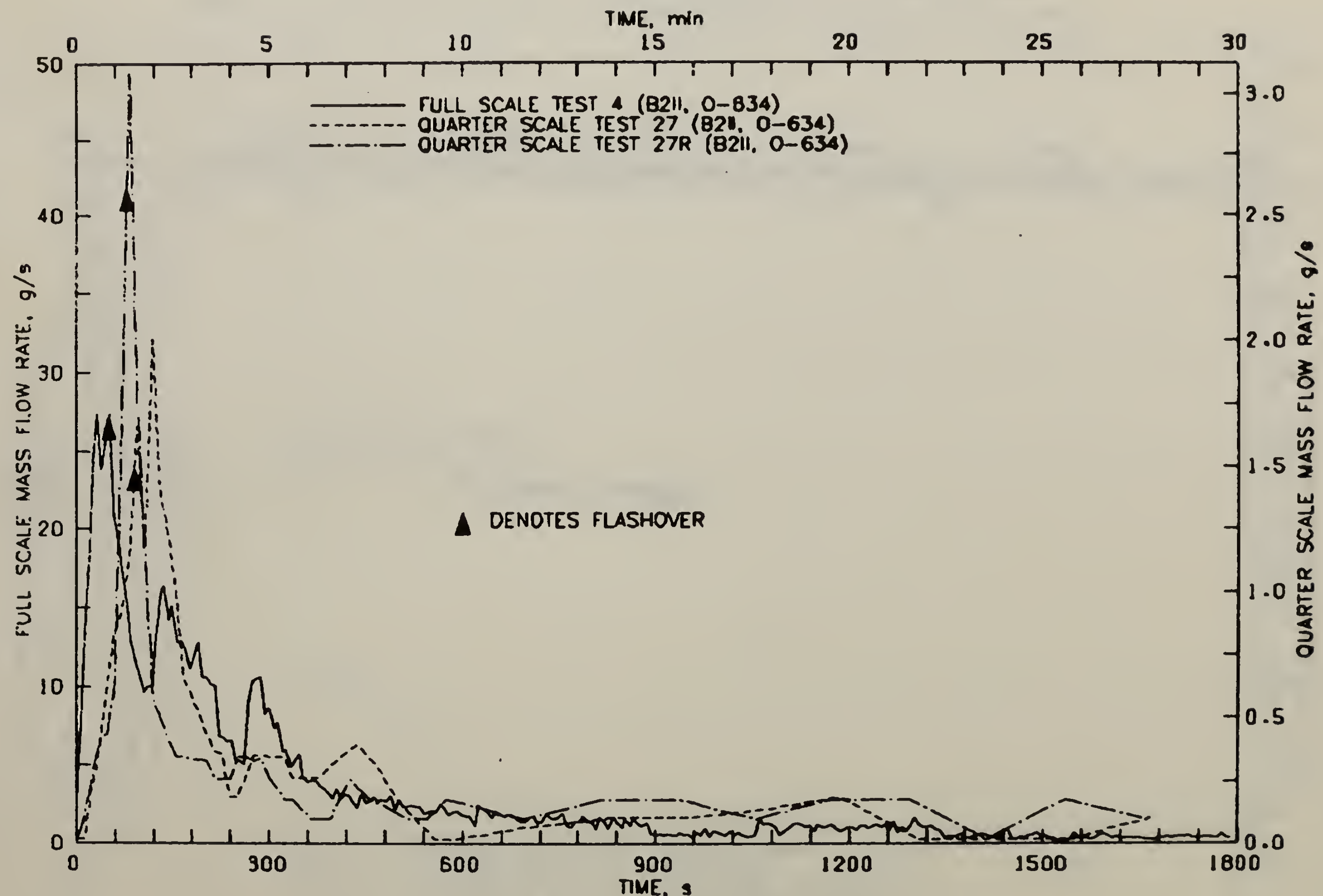


Figure 14. Mass flow rate of carbon monoxide for full-scale test 4 and corresponding quarter-scale tests . . . . .

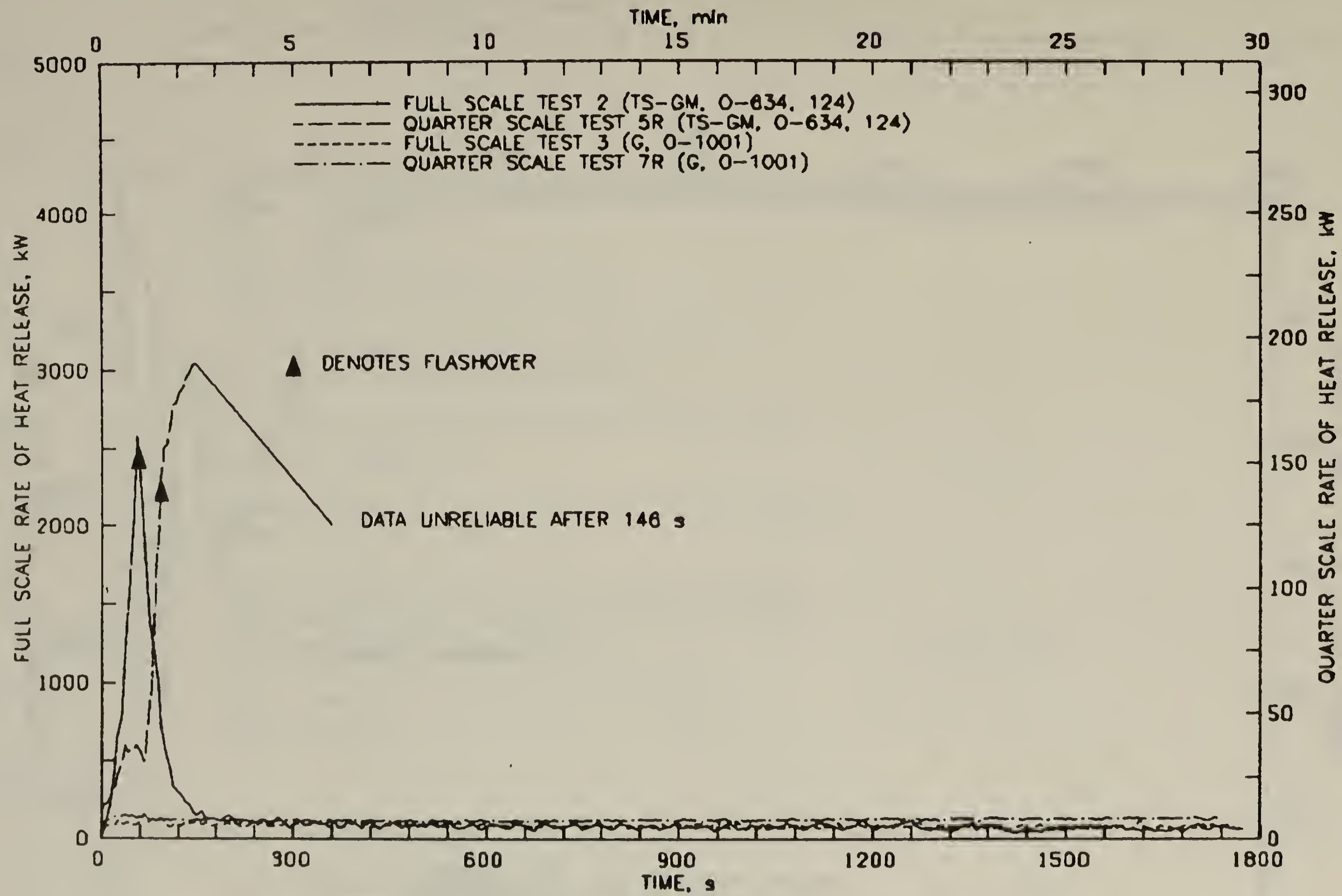


Figure 15. Rate of heat release from full-scale tests 2 and 3 and their corresponding quarter-scale tests . . . . .

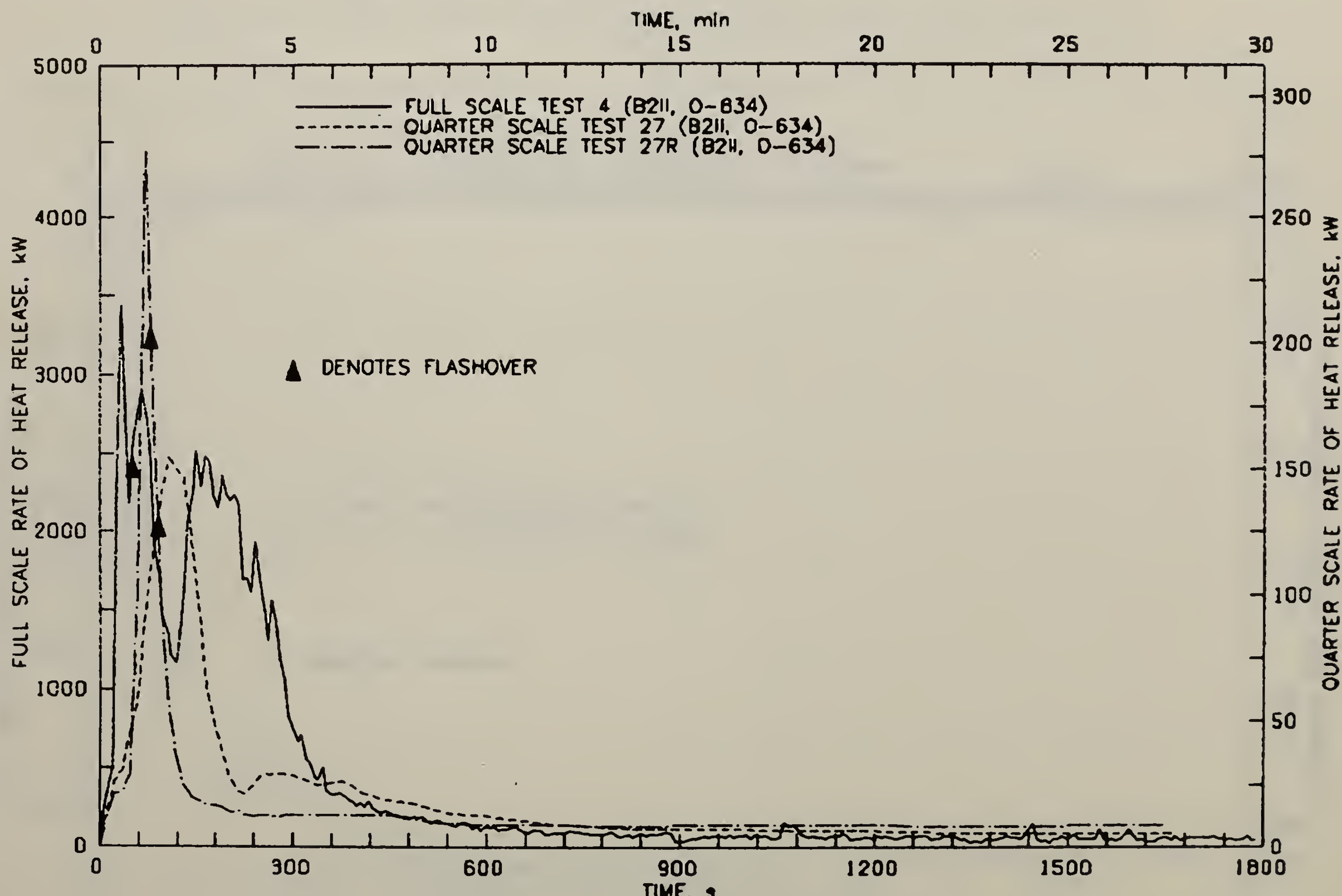


Figure 16. Rate of heat release from full-scale test 4 and corresponding quarter-scale tests . . . . .

Table 1. Materials Used in the Room and Laboratory Fire Tests

Material Composite	Description	Specification	Thickness+ (cm)	Density (g/cm^3)
Acoustic				
M	Lightweight glass batting, faced with 0.050 mm ET*	MIL-I-22023	2.5	0.015
TS-GM	Glass batting, faced with 0.38 mm thick glass cloth with 0.013 mm ET lining	"	2.2	0.050
TS-MG	Glass batting, faced with 0.013 mm ET with 0.38 mm thick glass cloth lining	"	2.2	0.050
M-AL	Perforated 1.12 mm thick aluminum sheet over material composite M	"	2.5	0.015**
TS-GMG	Glass batting, 0.76 mm thick sandwich facing of glass cloth, ET, glass cloth	"	4.1	0.082
W-1	Glass batting, intermediate layer of 6.4 mm thick fibrous glass honeycomb waffle, 0.38 mm perforated glass cloth facing	MIL-A-23054	2.5	0.082
W-2	Same as W-1 with extra 2.5 cm thickness of glass batting	"	5.1	0.066
Hull Insulation				
G	Glass batting, glass cloth facing	MIL-I-742D	2.8	0.062
B2II	PVC nitrile foam rubber***	MIL-P-15280	2.5	0.080
Ck	Cork	HH-I-525	2.5	0.110
H	Hydrophilic polyurethane	N/A	2.5	0.136
SR	Silicone rubber	N/A	1.3	0.527

Table 1 (continued)

Material Composite	Description	Specification	Thickness+ (cm)	Density (g/cm^3)
Damping				
BR1-1	Polyvinyl chloride, polyvinyl acetate, graphite inpregnated class 1 title	MIL-P-23653	0.95	1.37
BR1-2	Same as BR1-1 except for thickness	"	1.59	1.37
BR2-1	Class 2 tile, otherwise same as BR1-1	"	0.80	1.71
BR2-2	Class 2 tile, otherwise same as BR1-2	"	1.27	1.71
LK-1	Acrylic++ class 3 tile	"	0.95	1.49
LK-2	Same as LK-1 except for thickness	"	1.43	1.49
Adhesives				
M-30	Latex base	MIL-A-24179-1	--	--
F 3036	Latex base	MIL-A-3316B	--	--
Coatings				
124	Chlorinated alkyd	MIL-E-17970	0.010-0.015	--
0-634	Latex base decorative paint	N/A	0.010-0.015	--
0-1001	Non-intumescent vapor barrier	N/A	0.013	--
0-9788	Solvent base intumescent paint	N/A	0.025	--
Other				
Tape	Glass cloth 5.1 cm wide	MIL-C-20079	--	--

*ET - poly(ethylene terephthalate)

**Excluding aluminum sheet

***Polyvinyl chloride acrylonitrile butadiene, closed-cell, foam

+Thickness for coatings refers to two coating layers when dry

++Poly(methyl methacrylate)poly(ethyl ethacrylate) with filler materials

Table 2. Comparison of Results from Full-Scale Room Fire Tests and their Counterpart Quarter-Scale Tests+

Test	Scale	Material Composite	Coating	Ignition Time for Flashover Indicator (s)	Max.+ Upper Air Temp., T_1 (°C)	Time to T_1 (s)	Max.+ Doorway Air Temp., T_2 (°C)	Time to T_2 (s)	Time to Flameover (s)	Test Duration (s)	Ambient Room Condition Temp. (°C)	Relative Humidity (%)
FS-2	F.S.	TS-GM	1 coat 0-634, 2 coats 124	58	800	58	680	58	58	1800	28	65
5	Q.S.	TS-GM	" "	None	770	73	--	--	None	1800	25	65
5R	Q.S.	TS-GM	" "	94	770	94	570	94	89	1800	24	41
FS-3	F.S.	G	2 coats 0-1001	None	310	1730	260	1691	None	1800	27	60
7	Q.S.	G	"	None	380	704	260	673	None	900	27	58
7R	Q.S.	G	"	None	400	419	290	853	None	1800	22	52
FS-4	F.S.	B2II	3 coats 0-634	51	880	39	610	51	43	1800	24	28
27	Q.S.	B2II	"	91	900	60	630	91	73	1800	24	32
27R	Q.S.	B2II	"	79	850	79	430	79	74	1800	23	25

Test	Scale	Material Composite	Coating	Stack Peak Heat++ Release Rate Q_s (kW)	Time to Q* (s)	Peak CO in Stack (g/s)	Time to Stack CO* (s)	Peak Smoke in Stack*** Conc. O.D./m	Peak Smoke in Stack*** Time (s)
FS-2	F.S.	TS-GM	1 coat 0-634, 2 coats 124	2570	57	27	44	--	--
5	Q.S.	TS-GM	" "	--	--	--	--	--	--
5R	Q.S.	TS-GM	" "	76(1216)**	94	2.5(40)**	94	>16.4	65
FS-3	F.S.	G	2 coats 0-1001	160	68	<1.0	347	--	--
7	Q.S.	G	"	--	--	--	--	--	--
7R	Q.S.	G	"	7 (112)	40	<0.2(<3)	349	0.7	199
FS-4	F.S.	B2II	3 coats 0-634	3450	33	27	33	--	--
27	Q.S.	B2II	"	131(2096)	91	1.5(24)	91	>16.4	51
27R	Q.S.	B2II	"	277(4432)	79	2.6(42)	79	>16.4	36

+Peak values of T_1, T_2, Q_s, CO, and O.D./m measured at times prior to or at ignition of newspaper flashover indicator. T_1 measured at 25 mm below ceiling, and T_2 measured at 25 mm below doorway for quarter-scale tests. T_1 and T_2 measured at 102 mm for full-scale tests.

++Includes ignition gas burner rate of heat release of 90 kW in full-scale test and 5.6 kW in quarter-scale test.

*Times to peak rate of heat release (based on oxygen consumption) and peak CO production have been adjusted for the transit times of these gases in the sampling lines.

**Values in parenthesis represent full-scale equivalent values which are 16 times greater than the quarter-scale values.

***Smoke attenuation over path length of 152 mm.

Table 3A. Summary of Quarter-Scale Test Results

Test	Material Composite	Coating	Max.+ Upper Air Temp. T_1 (°C)	Time to T_1 (s)	Max.+ Doorway Air Temp. T_2 (°C)	Time to T_2 (s)	Time to Flashover (s)	Ignition Time for Flashover Indicator (s)	Test Duration (s)
1	M		370	35	90	1775	None	None	1800
2	TS-GM		370	35	160	603	"	"	1800
3	TS-MG		360	250	170	1603	"	"	1800
4	M-AL		340	356	160	638	"	"	1800
5	TS-GM	1 coat 0-634, 2 coats 124	770	73	---	---	"	"	1800
5R(26)*	TS-GM	1 coat 0-634, 2 coats 124	770	94	570	94	89	94	1800
6	TS-GMG		410	810	120	1206	None	None	1800
7	G	2 coats 0-1001	380	704	260	673	"	"	900
7R(25)*	G	2 coats 0-1001	400	419	290	853	"	"	1800
8	G	2 coats 0-1001, 1 coat 124	330	548	120	868	"	"	900
9	W-1		370	115	220	265	"	"	900
10	Ck		860	39	720	65	58	66	66
11	SR		680	743	550	743	730	745	745
12	H		370	473	260	134	None	None	900
13	W-2		400	93	310	530	"	"	1800
14	BR1-1		510	677	530	780	780	"	780
14R(18)*	BR1-1		750	1140	580	1144	None	1161	1161
15	BR1-2		400	489	230	485	"	None	1800
16	BR2-1		570	520	410	549	"	549	555
16R(28)*	BR2-1		530	1485	480	1481	1413	1485	1510
17	BR2-2		380	493	240	554	None	None	1800
19	LK-1		450	1117	340	1260	"	"	1380
20	LK-2		260	1376	190	1177	"	"	1800
21	B2II		400	243	310	563	"	"	1800
21R(23)*	B2II		440	225	330	476	"	"	1800
22	B2II	2 coats 0-634	880	48	710	101	73	101	101
22R(24)*	B2II	2 coats 0-634	540	47	320	215	None	None	1800
27	B2II	3 coats 0-634	900	60	630	91	73	91	1800
27R(29)*	B2II	3 coats 0-634	850	79	430	79	74	79	1800

*Tests in parenthesis are repeat runs; e.g., test 18 is a repeat of test 14 and is denoted by 14R.

+Peak values measured at times up to and including ignition of newspaper flashover indicator. T_1 measured at 25 mm below ceiling, and T_2 measured at 25 mm below doorway.

Table 3B. Summary of Quarter-Scale Test Results

Test	Material Composite	Coating	Stack Peak Heat Release Rate $\dot{Q}_s$ (kW)	Time to $\dot{Q}_s$** (s)	Peak CO in Stack Mass Flow (g/s)	Peak CO in Stack Time** (s)	Peak Smoke in Stack Conc. (O.D./m)	Peak Smoke in Stack Time (s)	Ambient Room Condition Temp. (°C)	Ambient Room Condition Relative Humidity (%)
1	M		--	--	--	--	--	--	24	47
2	TS-GM		--	--	--	--	--	--	24	54
3	TS-MG		--	--	--	--	--	--	24	52
4	M-AL		--	--	--	--	--	--	25	60
5	TS-GM	1 coat 0-634, 2 coats 124	--	--	--	--	--	--	25	65
5R(26)*	TS-GM	1 coat 0-634, 2 coats 124	60	94	2.48	94	>16.4	65	24	41
6	TS-GMG		--	--	--	--	--	--	27	66
7	G	2 coats 0-1001	--	--	--	--	--	--	27	58
7R(25)*	G	2 coats 0-1001	7	40	0.16	358	0.7	199	22	52
8	G	2 coats 0-1001, 1 coat 124	--	--	--	--	--	--	24	48
9	W-1		--	--	--	--	--	--	23	26
10	Ck		291***	57	2.50***	57	--	--	23	28
11	SR		76	722	0.30	722	13.8	738	24	35
12	H		7	212	0.18	131	0.5	86	20	22
13	W-2		--	--	--	--	--	--	22	24
14	BR1-1		41	708	0.92	687	>16.4	772	24	28
14R(18)*	BR1-1		44***	1088	1.43***	1088	>16.4	1123	25	27
15	BR1-2		16	461	0.17	435	3.3	463	26	31
16	BR2-1		24***	472	0.46	433	>16.4	535	24	20
16R(28)*	BR2-1		174	1485	3.66	1485	>16.4	1258	24	40
17	BR2-2		16	480	0.29	467	3.0	502	27	27
19	Lk-1		28	1238	0.38	1169	2.5	1541	27	56
20	Lk-2		6	69	0.13	1710	--	--	27	60
21	B2II		8	44	0.21	126	1.1	83	26	65
21R(23)*	B2II		9	65	0.20	1134	1.4	165	27	55
22	B2II	2 coats 0-634	70	101	1.02	101	>16.4	≥44	26	52
22R(24)*	B2II	2 coats 0-634	14	38	0.29	38	4.4	64	22	61
27	B2II	3 coats 0-634	120	91	1.24	91	>16.4	51	24	32
27R(29)*	B2II	3 coats 0-634	248	79	1.46	79	>16.4	36	23	25

*Tests in parenthesis are repeat runs; e.g., test 18 is a repeat of test 14 and is denoted by 14R.
**Time has been adjusted for the transit time for the exhaust to reach the gas analyzers.
***Rate of heat release and/or mass flow rate of CO still rising by this time (when the data acquisition was terminated) due to the transit delay time.

Table 4. Ignitability, Flame Spread, and Smoke Characteristics of Materials Used in Room Fire Tests

	Corresponding Room Tests	Material Composite	Coating	Ease of Ignition Time for Fuel Contribution (s)	ASTM E 162 Flame Spread Index I_s			ASTM E 662 Peak Smoke Specific Optical Density D_m*		ASTM E 84 Flame Spread FSC		
					min.	max.	avg.			min.	max.	avg.
ACCOUSTICAL	1	M		N+	31	202	103	30 F	17 NF	12	14	13
	2	TS-GM		N	1	2	1	24 F	20 NF	—	—	—
	5, 5R	TS-GM	1 coat 0-634, 2 coats 124	19.8	62	131	97	43 F	66 NF	35	35	35
	3	TS-MG		N	0	18	6	31 F	22 NF	16	16	16
	6	TS-GMG		N	5	7	6	112 F	368 NF	—	—	—
	9	W-1		N	3	5	4	103 F	96 NF	17	24	21
	13	W-2		N	0	2	1	103 F	96 NF	17	20	19
HULL INSULATION	7, 7R	G	2 coats 0-1001	N	0	2	1	24 F	10 NF			
	8	G	2 coats 0-1001, 1 coat 124	N	21	105	58	37 F	35 NF			
	21, 21R	B2II		N	3	6	4	206 F	172 NF			
	22, 22R	B2II	2 coats 0-634	N	3	59***	22	220 F	188 NF			
	27, 27R	B2II	3 coats 0-634	40.7	4	6	5	220 F	152 NF			
	10	Ck		17.6	287	401	347	233 F	327 NF			
	12	H		N	5	5	5	250 F	230 NF			
	11	SR		125.0	19	21	21	278 F	353 NF			
DAMPING	14, 14R	BR1-1		N	23	64	40	570 F	527 NF			
	15	BR1-2		N	51	65	60	568 F	582 NF			
	16, 16R	BR2-1		110.0**	40	56	48	550 F	538 NF			
	17	BR2-2		N	45	64	54	572 F	537 NF			
	19	Lk-1		N	32	42	39	373 F	333 NF			
	20	Lk-2		N	20	25	23	334 F	336 NF			

+ N=No fuel contribution
* F=flaming exposure, NF = nonflaming exposure

** Only one of three tests had fuel contribution.
*** Two specimens did not exhibit any flame spread, but one specimen had flashing to a distance of 305 mm along the specimen surface.

Table 5. Heat Release Rate and Potential Heat of Materials Used in Room Fire Tests

	Corresponding Room Tests	Material Composite	Coating	Rate of Heat Release* Peak kW/m^2	Max. 60 s Avg. kW/m^2	Max. 180 s Avg. kW/m^2	Potential Heat kJ/kg
ACCOUSTICAL	1	M		163	54	21	10200
	2	TS-GM		123	26	11	5200
	5, 5R	TS-GM	1 coat 0-634, 2 coats 124	256	52	20	7000
	3	TS-MG		119	23	9	5200
	6	TS-GMG		80	39	32	8000
	9	W-1		48	25	18	3100
	13	W-2		40	24	21	3100
HULL INSULATION	7, 7R	G	2 coats 0-1001	64	14	11	2400
	8	G	2 coats 0-1001, 1 coat 124	211	53	25	1900
	21, 21R	B2II		198	70	56	14100
	22, 22R	B2II	2 coats 0-634	210	98	82	14500
	27, 27R	B2II	3 coats 0-634	353	127	88	14500
	10	Ck		216	106	73	27000**
	12	H		251	98	56	9500
	11	SR		159	141	121	19100
DAMPING	14, 14R	BR1-1		301	250	235	***
	15	BR1-2		267	248	240	***
	16, 16R	BR2-1		198	163	155	***
	17	BR2-2		223	196	188	***
	19	Lk-1		149	130	126	***
	20	Lk-2		221	213	202	***

*Under exposure of 40 kW/m^2.

**Value from reference [1].

***Cannot be evaluated as specimen splatters in test apparatus.

Table 6. Comparison of Peak Air Temperatures at Several Elevations Near the Ceiling and Top of the Doorway

Test	Material Composite	Coating	Distance Below Doorway Lintel* 25 mm Temp. °C	Time s	51 mm Temp. °C	Time s	102 mm Temp. °C	Time s	Distance from Ceiling* 25 mm Temp. °C	Time s	51 mm Temp. °C	Time s	102 mm Temp. °C	Time s
1	M		90	1775	70	1775	50	1792	370	35	360	35	310	31
2	TS-GM		160	603	70	1387	50	1783	370	35	350	216	320	568
3	TS-MG		170	1603	60	1414	50	1190	360	250	360	110	320	949
4	M-AL		160	638	60	1321	50	1188	340	356	330	352	300	444
5	TS-GM	1 coat 0-634, 2 coats 124	—	—	—	—	60	81	770	73	730	61	530	69
5R(26)**	TS-GM	1 coat 0-634, 2 coats 124	570	94	730	94	640	94	770	94	800	94	770	94
6	TS-GMG		120	1206	80	1558	60	1475	410	810	380	713	300	1792
7	G	2 coats 0-1001	260	673	90	880	60	770	380	704	370	673	320	519
7R(25)**	G	2 coats 0-1001	290	853	140	591	60	1539	400	419	380	1431	360	1668
8	G	2 coats 0-1001, 1 coat 124	120	868	80	565	60	723	330	548	380	465	320	451
9	W-1		220	265	80	788	50	460	370	115	360	314	290	327
10	Ck		720	65	820	65	450	66	860	39	910	52	850	65
11	SR		550	743	540	745	400	745	680	743	700	743	720	743
12	H		260	134	110	340	60	821	370	473	350	331	290	318
13	W-2		400	93	—	—	—	—	310	530	—	—	—	—
14	BR1-1		530	780	520	780	340	780	510	677	650	776	440	737
14R(18)**	BR1-1		580	1144	600	1144	430	1144	750	1140	780	1144	720	1161
15	BR1-2		230	485	130	476	50	1775	400	489	340	485	270	511
16	BR2-1		410	549	400	549	360	549	570	520	590	524	500	549
16R(28)**	BR2-1		480	1481	460	1481	410	1485	530	1485	700	1481	790	1481
17	BR2-2		240	554	160	575	50	1675	380	493	350	493	270	493
19	Lk-1		340	1260	220	1251	110	1247	450	1117	400	1312	500	1294
20	Lk-2		190	1177	110	614	40	1571	260	1376	250	1052	200	1446
21	B2II		310	563	150	221	70	1134	400	243	380	247	330	269
21R(23)**	B2II		330	476	130	1552	80	1559	440	225	410	264	340	243
22	B2II	2 coats 0-634	710	101	700	101	640	101	880	48	820	63	760	101
22R(24)**	B2II	2 coats 0-634	320	215	190	189	80	1021	540	47	440	47	340	741
27	B2II	3 coats 0-634	630	91	—	—	—	—	900	60	—	—	—	—
27R(29)**	B2II	3 coats 0-634	430	79	—	—	—	—	850	80	—	—	—	—

*Underlined temperatures are the highest values over the three elevations.
**Tests in parenthesis are repeat runs; e.g., test 18 is a repeat of test 14 and is denoted by 14R.

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 83-2642	2. Performing Organ. Report No.	3. Publication Date August 1983

4. TITLE AND SUBTITLE

Fire Hazard Evaluation of Shipboard Hull Insulation and Documentation of a Quarter-Scale Room Fire Test Protocol

5. AUTHOR(S)

B. T. Lee

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

Ship Damage Prevention and Control
Naval Sea Systems Command
Department of the Navy
Washington, D.C. 20362

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

A variety of shipboard hull insulations including damping and acoustical materials, painted and unpainted, were evaluated for their flashover potential using a quarter-scale room fire test developed by the Center for Fire Research at the National Bureau of Standards. Three painted insulations were also evaluated in full-scale room fire tests. Comparison of full-scale and quarter-scale fire behavior again demonstrated that the quarter-scale test can predict full-scale room fire buildup. It was found that decorative paints, including the Navy's chlorinated alkyd formulation, could seriously compromise the fire safety of otherwise low fire risk insulations. A recommended test protocol was developed for determining the flashover potential of hull insulation using the quarter-scale room fire test.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

flammability; flashover; heat release rate; insulation; interior finishes; paints; room fires; ships; small-scale fire tests

13. AVAILABILITY

- [XX] Unlimited
- [ ] For Official Distribution. Do Not Release to NTIS
- [ ] Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
- [XX] Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

47

15. Price

$8.50