NISTIR 4961

Comparison of Full Scale Fire Tests and a Computer Fire Model of Several Smoke Ejection Experiments

Emil Braun, Darren L. Lowe, Walter W. Jones, Patricia Tatem, Jean Bailey, Richard Carey

United States Department of Commerce
Technology Administration
ıational Institute of Standards and Technology

NISTIR 4961

Comparison of Full Scale Fire Tests and a Computer Fire Model of Several Smoke Ejection Experiments

Emil Braun
Darren L. Lowe
Walter W. Jones

Patricia Tatem
Jean Bailey

Naval Research Laboratory, Washington, DC 20375

Richard Carey

David Taylor Naval Ship Research and Development Center, Annapolis Division

Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899

Issued November, 1992

U.S. Department of Commerce
Barbara H. Franklin, *Secretary*
Technology Administration
Robert M. White, *Under Secretary for Technology*
National Institute of Standards and Technology
John W. Lyons, *Director*

Prepared for:
Naval Research Laboratory
Washington, DC 20375

Contents

	Page
Abstract	1
Introduction	1
Full-Scale Fire Tests	2
Instrumentation	2
Closed Doors and Vents	3
Diesel and Polyethylene Fueled Fires at a nominal fire size of 0.5 MW	3
(Initially) Open Doors and Vents	4
Diesel Fuel Fire at a nominal fire load of 1 MW	4
Polyethylene Fuel Fire at a nominal fire load of 1 MW	5
Numerical Simulations	7
. . . .	9
Conclusions	9
References	9
Acknowledgments	9

Comparison of Full Scale Fire Tests and a Computer Fire Model of Several Smoke Ejection Experiments

by

Emil Braun, Darren L. Lowe, Walter W. Jones, Patricia Tatem[1]
Richard Carey[2], and Jean Bailey[1]

Abstract

Data were obtained from four large scale shipboard fire tests. The test series was designed to evaluate the efficacy of a smoke ejection system for the removal of smoke and heat from compartments around the compartment of fire origin. Using diesel oil and polyethylene beads as fuel, tests were conducted at 0.5 MW and 1.0 MW. The data obtained from these tests were evaluated in terms of the reduction of heat and smoke in adjacent passageways. These results were compared to numerical simulations of the shipboard environment. The test results showed that the atmospheric conditions in compartments/passageways adjacent to the compartment of fire origin could be made survivable by isolating the fire compartment and ventilating adjacent spaces. It was found that, under the ventilation conditions of these tests, effective reduction in smoke and heat from peak values to ambient values took 350 to 400 s, depending on the compartment's proximity to the door of the compartment of fire origin. Comparisons with the numerical simulation showed that we can predict the environment which develops with reasonable confidence.

Key words: computer simulation;diesel;fire tests;numerical simulation;polyethylene;ships;ventilation

Introduction

Successful damage control on surface ships reduces the time necessary for a combat ship to make itself fit for its primary mission of engaging the enemy. It can also improve the chances of a severely damaged ship to return safely to port. Damage control relies on correctly assessing the location, spread, and size of a fire. This information is used to marshal limited fire fighting resources in such a way as to have a major impact on controlling fire growth and minimizing the thermal threat to fire fighting personnel.

The primary purpose of this work is to validate a numerical model of fire growth and smoke transport. Traditionally, full scale or real scale experiments have been used to test concepts which might be applicable to intervention strategies in combat situations onboard warships. Models of fire and attendant understanding of such systems hold the promise of a substantial reduction in cost and of providing a much wider range of analysis. It is often the case that the most probable failure is not the same as the maximum damage scenario. Covering both allows one to assess what level of intervention might be necessary to achieve a specified level of reliability and operational capability.

This report details an analysis of the comparison of full-scale fire tests conducted on the ex-USS SHADWELL and computer calculations on geometrically similar enclosures with fire sources of equal strength. Experimental data from the Smoke Ejection System (SES) experiments

---

[1] Naval Research Laboratory, Washington, DC 20375

[2] David Taylor Naval Ship Research and Development Center, Annapolis Division.

were obtained for two fuels and two ventilation conditions. These results were analyzed to 1) determine the mass loss characteristics of the fuel source; 2) consider the development of fire conditions in the compartment of fire origin; and 3) analyze the development of fire conditions in compartments removed from the fire source. The mass loss data were used as input data along with compartment configuration and orientation for a computer model simulation of smoke spread. Comparisons were done with the compartment of fire origin either nominally sealed or opened to the rest of the ship and with and without an operating ventilation system. The numerical model was then used to quantify ventilation effects over a range of fan sizes not previously tested.

Full-Scale Fire Tests

In the first quarter of 1989, a series of full-scale fire tests were conducted on the ex-USS SHADWELL. These tests were designed to test the feasibility of preventing a ship from being engulfed by smoke by containing the fire in a closed compartment and properly controlling the ventilation system. Specific parameters determined were: the mass loss of the fuel; the gaseous concentrations of O_2, CO, and CO_2; and the density of smoke and the temperature profiles in the fire compartment. Figure 1 shows the floor plan for the second deck fire test compartments. This deck was connected to the main deck by way of ladders in the port and starboard passageways. The bow passageway provided a connection between the port and starboard passageways. The door on the port passageway was used to control the flow of smoke into the other passageways.

Data from four tests were analyzed. Two tests used diesel fuel pan fires of nominally 0.5 MW and 1 MW; the other two tests were polyethylene fueled pan fires also of 0.5 MW and 1 MW. The 0.5 MW fires were conducted with the doors and vents into the fire compartment closed. The 1 MW fires were conducted with the doors and vents into the fire compartment initially open. During the 1 MW fire tests the openings to the fire compartment were closed and the characteristics of the SES could be measured. Specific details regarding optimum ventilation efficiency will not be discussed because of the lack of understanding of the total ventilation system used aboard the fire test ship. However, qualitative data showing the performance of SES are presented.

Instrumentation

Figure 1 shows the location of instruments used in this analysis, except for the main deck O_2, CO, and CO_2 analyzers. Conditions in the fire compartment were determined from the measurements of:

- a load platform to characterize mass (fuel) consumption;
- 4 thermocouple trees distributed around the fuel source; and
- a set of O_2, CO, and CO_2 gas analyzers at 0.5 and 1.5 meters.

The atmosphere in adjacent spaces was characterized by monitoring the gas concentration at three locations: the port and starboard passageways and the main deck, and smoke density at five locations in the port, starboard, and bow passageways.

Closed Doors and Vents

Diesel and Polyethylene Fueled Fires at a nominal fire size of 0.5 MW

Figures 2 and 3 show the mass loss and oxygen data for the 0.5 MW diesel fuel and 0.5 MW polyethylene fire tests, respectively. Qualitatively, these tests were identical. As fuel was consumed, the data show that the oxygen concentration decreased. Oxygen concentrations in other areas of the ship were unaffected by the fire in the fire compartment. Both tests demonstrated that, for moderate size fires, the fire compartment could effectively be sealed from other sections of the ship. All the figures which are labeled mass loss are readings of the load cell and show the negative of the mass of the fuel weight, starting from an initial value of zero. The pyrolysis rate is the derivative of this value and will be (nominally) positive definite. In many cases there is a transient on the load cell when the fuel is ignited, depending on the care with which it was done. This is an artifact, and not part of the experiment.

For the diesel fuel test approximately 20 kg of fuel was consumed. The mass of the fuel package and the oxygen concentration are shown in Figure 2. The oxygen concentration dropped to 13% about 2700 s after the start of the test. It is possible that with such a low oxygen concentration the fire self-extinguished. Alternatively, the entire fuel load may have been consumed by this time. In either event, with the end of combustion, the oxygen concentration returned to a pre-test level of 21% within 3300 s.As shown, the mass loss rate was approximately constant from ignition to 3000 s, after which the fuel stopped burning. After 2500 seconds, we did not use the mass load data to calculate the mass loss rate, but rather assumed it (the rate) went asymptotically to zero, as with the other experiments. At some point between 2500 and 3000 seconds, the load cell suffered physical damage and was no longer reliable.

Figure 3 shows that for the polyethylene fueled fire the oxygen concentration dropped to 15%. Normally, this level of oxygen would be expected to support continued combustion, however, failure in the load platform instrumentation makes it impossible to determine if the fire self-extinguished or consumed all available material. It is estimated that about 17 kg of material was consumed during the first 1600 s of the test. Some form of combustion may have continued after this time because the oxygen concentration for this test took approximately 4000 s to return to pre-test level. This is about 25% longer than the diesel fuel test under presumably identical ventilation conditions.

Figures 4 and 5 show the calculated location of the interface plane between the hot and cold gases in the fire compartment and the gas temperatures in each layer. These were based on the data collected from the four thermocouple trees surrounding the fire source. The interface plane reached a minimum of 0.88 m and 0.69 m for the diesel and polyethylene fires, respectively. The maximum upper and lower gas temperatures were about the same for both tests (135°C and 132°C for the upper layers and 75°C and 73°C for the lower layers). It can be seen from these figures that the maximum upper and lower layer gas temperatures occurred at about the same time. Comparing Figures 2 and 3 with Figures 4 and 5 shows that the decrease in upper layer temperature followed the return to pre-test oxygen levels. The erratic behavior exhibited by these data in Figure 5 late in the polyethylene test (beyond 5000 s) is indicative of thermocouple failure.

Figures 6 and 7 show the CO_2 and CO data for the 0.5 MW diesel fuel fire test for the burn room and the port passageway. For comparative purposes the O_2 data are also shown for the same probe locations. A peak CO_2 value of 5% coincided with the minimum O_2

concentration. The peak CO concentration of 0.13% occurred approximately 580 s before the minimum O_2. An interesting feature of these data is the appearance of some CO and CO_2 at the sensor probe located at the port passageway. This is mirrored by a fluctuation in the O_2 data. If this data represents a real event then two possible explanations exist: the port side door was opened momentarily or there was some leakage through the door or closed vents in the compartment after the fire size had peaked.

This experiment produced a very large amount of soot. There were no soot or unburned hydrocarbon analyzers in the burn room, but visual observation indicated large quantities of soot both during and after the burning phase, and the mass balance of the species indicate that as much as two percent of the mass was in unburned carbon.

Figures 8 and 9 show the same type of data (CO_2 and CO, respectively) for the 0.5 MW polyethylene fueled fire. The CO_2 data show that an instrument malfunction occurred not long after the start of the test. Since the full-scale reading of this analyzer was supposed to be 10% the flat line at 1% represents an instrument scaling problem or some other instrument fault. The CO data appears to be more realistic. It showed a peak concentration of 0.03% during the period of minimum oxygen concentration. The port passageway gas analyzers showed anomalous readings similar to the data from the 0.5 MW diesel fuel test, while the starboard passageway and main deck analyzers showed no significant deviations from background.

(Initially) Open Doors and Vents

Diesel Fuel Fire at a nominal fire load of 1 MW.

Figure 10 shows the mass loss and oxygen data for the 1 MW diesel fuel fire with the doors and vents initially opened. At approximately 3700 s the doors and vents were closed. These tests were designed to measure the recovery time (time to return to ambient) of the passageways following the isolation of the burn room from the rest of the ship. With the doors and vents open, the data show that a steady mass burning rate was achieved of about 15.3 g/s. At the time the burn room door was closed, the oxygen concentration in the burn room and the port and starboard passageways dropped to 16%, while the oxygen concentration on the main deck appeared to be maintained at ambient conditions throughout the test. The oxygen concentration in the burn room and passageways would be expected to be sufficient to support continued combustion in the burn room, if the fuel supply was maintained. When the burn room door was closed the oxygen concentration in the burn room continued to decrease to about 12%. The oxygen concentration in the passageways began to recover. It took approximately 600 s for the passageway atmosphere to return to pre-test conditions. The port side passageway began to recover about 230 s before the starboard side passageway. After the minimum O_2 level of 12% was reached, the burn room took about 2700 s to return to pre-test conditions.

Figure 11 shows the location of the interface plane as it is derived from the experimental data and the average temperature above and below this plane. Except for the early part of the test, the neutral plane was located approximately 0.8 m from the floor. The peak temperature above the interface was 195 °C and below the interface it was 110 °C. This temperature coincides with the minimum oxygen concentration in the burn room. As can be seen from Figure 11, no steady state temperature was achieved. As the oxygen concentration began to return to its pre-test condition, the temperature in the compartment decreased.

Figures 12 and 13 show that the CO_2 and CO data mirrored the O_2 data. At the time the compartment door was closed, the CO_2 concentration in the three areas was between 3.9 % and 4.2% and the CO concentration was about 0.12%. While the burn room gas concentrations continued to increase to 6.8% for CO_2 and 0.16% for CO, the passageway gas concentrations decreased. It is assumed that the rapid decrease in the passageway gas concentrations were due to the use of the shipboard ventilation system. While some understanding of the ventilation system is necessary to explain the data, it should be noted that the port passageway responded to the door closing and ventilation system approximately 350 s before the starboard passageway. It took about 400 s from its peak value for the port passageway to return to near ambient conditions. The starboard passageway returned to near ambient conditions about 300 s after its peak value.

As noted above, five smoke meters were located in the passageways surrounding the burn room. These smoke meters were placed 1.5 m from the floor. Figure 14 compares the results of these smoke meters. The smoke filling pattern for the second deck shows that the rate of filling was about the same for all smoke meters except for the aft smoke meter on the starboard side. The peak optical density varied with distance from the port side compartment door. The slow rate of filling in the vicinity of the starboard side aft smoke meter is suggestive of the existence of a partial block in the passageway leading to this smoke meter. Figure 15 shows the relationship between height from the floor and the concentration of smoke. Shown are the optical density at 0.5 m and 1.5 m. The optical density of the smoke is greater at 1.5 m from the floor than at 0.5 m from the floor. It should be noted that, while the rate of rise in smoke density is about the same, the lower smoke meter responded sooner to the development of smoke than the upper smoke meter. No obvious explanation can be found for the phenomenon. The smoke data, however, are consistent with the other data previously presented. The data make clear the effect of isolating the fire compartment and of ventilating the adjoining passageways. Because of smoke deposition on the smoke meter lenses, the smoke meters do not necessarily return to the initial value. This drift in baseline tends to mask the true effect of isolation and ventilation.

Polyethylene Fuel Fire at a nominal fire load of 1 MW.

Figure 16 show the mass loss and oxygen data for the 1 MW polyethylene fuel fire with the doors and vents initially opened. At approximately 2500 s the doors and vents were closed. These tests were also designed to measure the recovery time of the passageways following the isolation of the burn room from the rest of the ship. With the doors and vents open, the data shows that a steady mass burning rate of 24.0 g/s was achieved. At the time the burn room door was closed, the oxygen concentration in the burn room and the port passageway had dropped to about 13%, while the oxygen concentration on the starboard passageway was 15% and the main deck appeared to be at 18%. While ambient conditions on the main deck were maintained throughout the 1 MW diesel fuel test, the drop in the main deck oxygen analyzer seems to indicate that test configurations were not the same for both 1 MW tests. Alternatively, instrument failures could be used to account for the observed differences. The oxygen concentration in the burn room and port passageway were barely sufficient to support continued combustion in the burn room. When the burn room door was closed the oxygen concentration in the burn room began to gradually increase as compared to the sharp increase in the oxygen concentration in the passageways. If the burn room were really sealed, the oxygen concentration would have been expected to remain relatively constant. This also suggests the presence of unreported leakage paths into and out of the burn room. The oxygen concentration in the passageways began to recover. It took approximately 290 s for the starboard passageway and main deck atmospheres to return to pre-test conditions. The port side passageway required nearly

1600 s to recover. After a minimum O_2 level of 13%, the burn room took about 2600 s to return to about 15%. At this time a sharp increase in oxygen concentration was noted indicating that something was altered in the test protocol. The burn room returned to ambient conditions about 3900 s after the burn room door was closed.

Figure 17 shows the location of the interface height and the average temperature above and below this plane. Except for the early part of the test, the neutral plane was located approximately 1.1 m from the floor. The peak temperature above the neutral plane was 265°C and below the neutral plane it was 110 °C. Unlike the 1 MW diesel fuel fire (Figure 11), a steady state temperature was quickly achieved. As the oxygen concentration began to return to its pre-test condition, the temperature in the compartment decreased. The neutral plane height remained relatively constant throughout the test.

As before, the CO_2 and CO data, shown in Figures 18 and 19, mirror the O_2 data, shown in Figure 16, in the respective areas of the ship. At the time the compartment door was closed, the CO_2 concentration in the burn room and port passageway was about 5.0% and the CO concentration was nearly 0.07% in the burn room. (The CO analyzers in the port passageway and on the main deck malfunctioned.) The starboard passageway contained about 2.0% CO_2 and about 0.06% CO. The gas concentrations in all of the monitored areas appeared to decrease once the burn room door was closed. It is assumed that the rapid decrease in the gas concentration in the passageway was due the use of the shipboard ventilation system. While some understanding of the ventilation system is necessary to explain the data, it should be noted that the port and starboard passageways appeared to respond almost simultaneously to the closure of the burn room door and initiation of the passageway ventilation system. The second deck passageways returned to near ambient conditions within 200 s. The main deck took about 1000 s to return to ambient conditions. The CO and CO_2 data in the burn room show the same anomalous behavior previously noted in the O_2 data.

Figure 20 compares the results of the smoke meters located 1.5 m from the floor of the passageways on the second deck. The smoke filling pattern for the second deck can be seen to indicate that the peak optical density varied with distance from the port side compartment door as well as the rate of reaching a specific peak optical density. In comparison to the 1 MW diesel fuel fire test, this suggests that the starboard side smoke meters may have been located in a partially blocked passageway. The peak optical density at a specific location was lower for these tests than for the 1 MW diesel fuel fire test. Figure 21 shows the relationship between height from the floor and the concentration of smoke in the vicinity of the port door. The optical density of the smoke is greater at 1.5 m from the floor as compared to 0.5 m from the floor. As previously noted with the 1 MW diesel fuel fire test the rate of rise in smoke density is about the same for both smoke meters. However, the lower smoke meter responded sooner to the development of smoke than the upper smoke meter. No obvious explanation can be found for the phenomenon. The smoke data, however, are consistent with the other data previously presented. The data make clear the effect of isolating the fire compartment and of ventilating the adjoining passageways. Because of smoke deposition on the smoke meter lenses, the smoke meters do not necessarily return to their initial value. This drift in baseline tends to mask the true effect of isolation and ventilation. Nevertheless, a significant decrease was noted in the optical density of all smoke meters following the closing of the port door.

Numerical Simulations

In this section we consider four aspects of the modeling problem. The first is a comparison of the model with the experiments as performed. In this case we can compare temperatures and layer height in the burn room, and carbon dioxide concentration in the port passageway. In the next section we demonstrate the effect which the fans used in the experiment had on the temperatures in the burn room, and what effect the various possible ventilation conditions had on layer temperatures remote from the fire. The third calculation demonstrates the various algorithms (ventilation parameters) which have been developed under this project, in order to model these particular experiments. Finally, as a demonstration of these algorithms, we show the effect which fans can have on the smoke concentration in the various compartments. The model we have used is CFAST[1],[2],[3].

Experimental versus Predicted Temperatures in the Burn Room

Figure 22 shows a comparison of the temperatures in the burn room for the 1 MW diesel fuel case. Both the upper and lower layers are shown. The solid lines are experimental values, and the points are predicted values for the respective layers. Similarly, Figure 23 shows the carbon dioxide concentration in the port passageway. As can be seen, in both cases the agreement is quite good. This comparison does not depend heavily on the ventilation conditions, so the effect of the fans is not important. That effect will be discussed next.

Effect of Configuration and Fans on Temperature in Distant Compartments

Figure 24 shows the effect that the fans used in this experiment had on the ventilation and thus the temperature and species density. The prediction is for the upper layer temperature on the main deck. The two sets of curves (four curves) show the effect of modeling the passageway as a single compartment, two decks in height (these are the hotter of the two pairs), or with the deck between and a hatch connecting them. The difference within each set of curves shows the effect of no fans (upper curve of each figure), and the fan as specified in the experiment. The fans ran at 0.143 m^3/s (230 cubic feet per minute). In this particular case, the effect of the fans is small, simply because the flow from the fans is small compared to the rate of entrainment in the fire plume. However, the effect of the correct geometric specification (having the deck between them and including the vertical flow component) is very important. The solid curve is the calculated temperature with no deck and no fans. The dashed curve has the fan turned on. The curve with the long dashes includes the deck between the 2nd deck and the main deck in the passageway, and similarly, the dot-dash curve is that configuration with the fans turned on.

The Effect of Ventilation Parameters on Smoke Dispersal

Ventilation is influenced by the relative force driving flow, and resistance to the flow caused by doors, hatches and scuddles. The driving forces are buoyancy and forced flow. Buoyancy comes from pressure differences caused by heating and vertical separation of compartments. Forced flow arises from fans. Resistance is determined by the type of openings, such as doors, hatches and scuddles, and their orientation, whether vertical or horizontal. An appreciation of the relative effect of each of these mechanisms to influence the flow and the resulting environment is important to simulating fires in actual circumstances. The comparison discussed in this section is of the various types of flow which can occur in a ship. The starting point is the relative size of each of these types of flow. The physical situation is chosen to demonstrate the importance of each phenomenon, and is based on physical situations that actually arise.

The calculations which follow are based on the two compartments shown in Figure 25. There are two compartments, one on top of the other. Both are 4.0x4.0x2.3 m. This is analogous to the configuration used, namely the fire on the second deck, connected to the main deck through a hatch in the port passageway and also a fan and duct system. The equivalent ship schematic is shown in Figure 26.

The comparison is of the vent flow, so the physical parameters were chosen to yield flows of approximately equal magnitude for each phenomenon. The fire used was a constant 25kW. The absolute height of the floor of the second compartment is 2.3 meters, so it coincides with the ceiling of the first compartment. There is a door from the first compartment (1.07x1 m^2) to the outside, and a window (1.07x1.0 m^2) from the second compartment to the outside. The comparison is for flow through normal vents, through a vertical vent (0.34 m diameter), a duct (0.1 m diameter) with no fan and finally a fan system (fan flow is 0.143 m^3/s). The cases are

1) door only from compartment 1 to the outside
2) no door, a hole in the ceiling/floor between 1 and 2, window from 2 to the outside
3) door from 1 to the outside, duct work from 1 to 2, window from 2 to the outside
4) door from 1 to the outside, duct system with a fan from 1 to 2, window from 2 to the outside.

The results are shown in Figure 27a,b,c. The numbers shown on the curves refer to the case numbers discussed above.

As might be expected, for case 1, there is no flow to or out of compartment 2. In case 2, there will be no flow between compartment 1 and the outside since the door is closed. Figure 27a shows the effect of providing alternate routes for hot gas to leave a space, namely there will be less flow in a given direction as the alternate routes are opened up. The complement to this observation is shown in Figure 27b, namely as flow out of compartment 1 to the outside decreases, and the total flow increases, makeup mass comes from the outside.

The most important and dramatic effect is shown in Figure 27c, which compares the flow out of the upper compartment (2) to the outside. The flow shown here is from the *lower layer* of the upper compartment to the outside through the window. The lower layer was chosen to show the dramatic and unintuitive flow which results in these four cases. Although gases can escape through ducts, adding a fan to such a configuration has a noticeable effect on the flow and thus could be important in making decisions on whether to use mechanical ventilation to exhaust smoke to aid intervention strategies.

Effectiveness of Fans in Reducing Smoke Concentration

Finally, we can ascertain the importance of fans on reducing the effect of smoke concentration in compartments adjacent to those which contain fires. Figure 28 shows temperature that would be measured in the compartment of fire origin (labeled "CIC") and the port passageway (labeled "Passage"). The two curves are the original fan (w), discussed above, and one ten times larger (wo). The effect can be quite dramatic for the adjacent compartments. The temperature is not changed very much in the fire room simply because the fire is in that compartment. There is, though, a time dependent effect on the modified flow, and the ensuing change in the type of entrainment. Similarly, the layer height is changed slightly, simply because more air is available. With the larger fan, the flow is reversed. That is, rather than flow from the fire room to the passageway, the fan overpowers the fire, and removes the hot gases sufficiently fast that smoke does not migrate. It is important to remember that this is specific to the particular fire and ventilation system. In order to ascertain trends and provide guidance in fire fighting, a much wider range of parameters must be studied.

Conclusions

For moderate size fires (0.5 to 1.0 MW), the experimental results seem to indicate that sealing the compartment of fire origin from the rest of the ship and ventilating the adjoining compartments and passageways does provide a habitable environment for fire fighting accessibility to the fire. Under the ventilation conditions used in these experiments, 350 to 400 s was needed to return the spaces adjoining the compartment of origin to ambient conditions. Further, the model CFAST is capable of predicting the environment in such a ship configuration and with the range of fires used. This indicates that such a model could be used for a parametric study of the environment caused by a fire. These types of studies would be useful in ascertaining the most effective fire fighting doctrine for various ships without actual full scale experiments.

References

1. Jones, W. W., A Multicompartment Model for the Spread of Fire, Smoke and Toxic Gases, Fire Safety Journal. 9, 55 (1985).

2. Jones, W. W. and Peacock, R. D., Refinement and Experimental Verification of a Model for Fire Growth and Smoke Transport, Proceedings of the Second International Symposium on Fire Safety Science, Tokyo (1988).

3. Jones, W. W. and Forney, G. P., A Programmer's Reference Manual for CFAST, the Unified Model of Fire Growth and Smoke Transport, National Institute of Standards and Technology Technical Note 1283 (1990).

Acknowledgments

This work was sponsored in part by the Office of Naval Technology (ONT-211) as part of the damage control project (RH21S22) of the surface ship technology program (NDIA-PE62121N), task 2 - improved analytical predictive techniques, milestone 3 (Report). The experimental tests were performed by Hughes Associates, the Naval Surface Weapons Center (Carderock Division, Annapolis Detachment) and the Naval Research Laboratory. The experiments were conducted at the Mobile, Alabama fire test facility (ex USS SHADWELL).

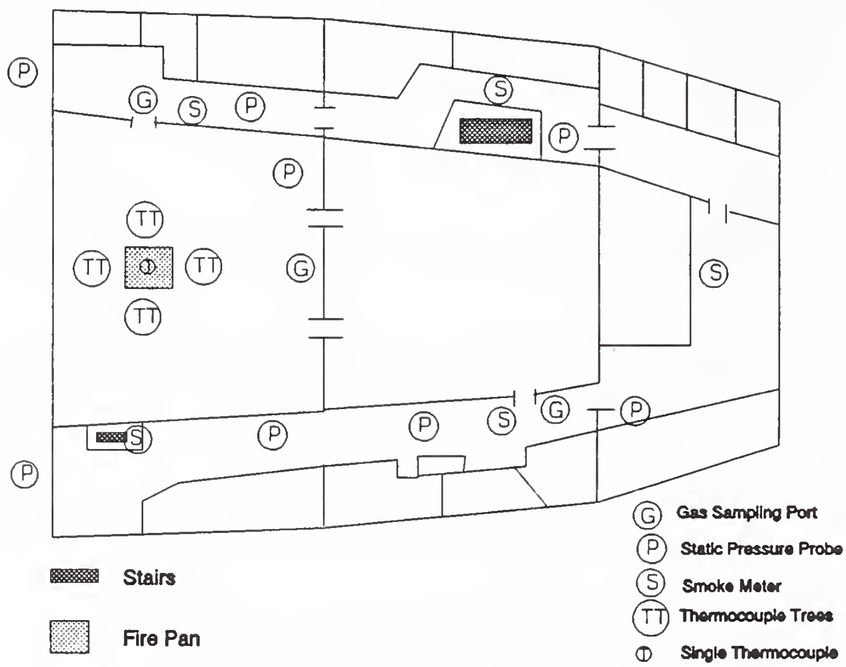

Figure 1. Schematic description of fire test area and location of instruments used in the evaluation program.

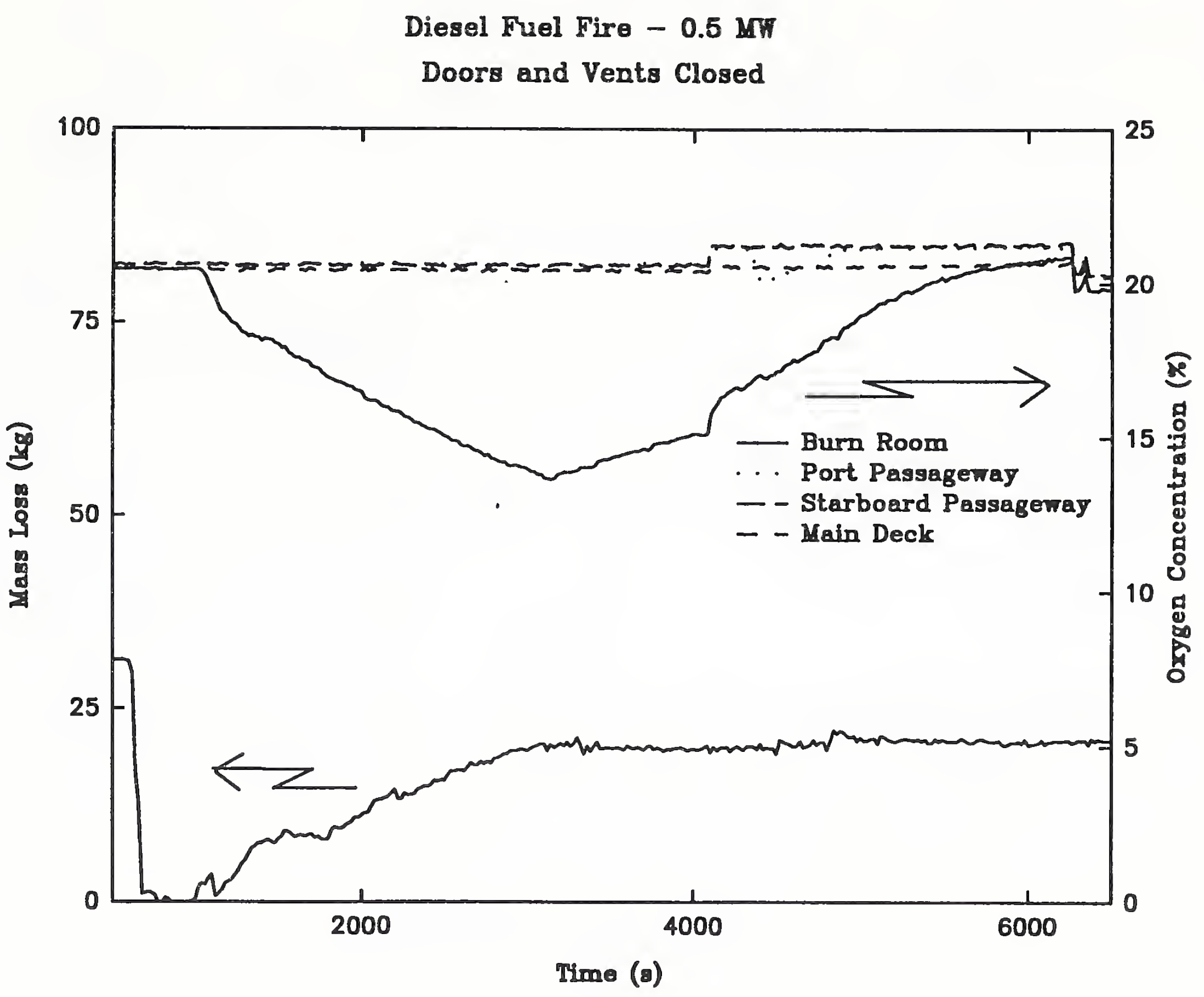

Figure 2: Mass loss and oxygen concentration in the burn room for the 0.5 MW diesel fuel fire with doors and vents closed.

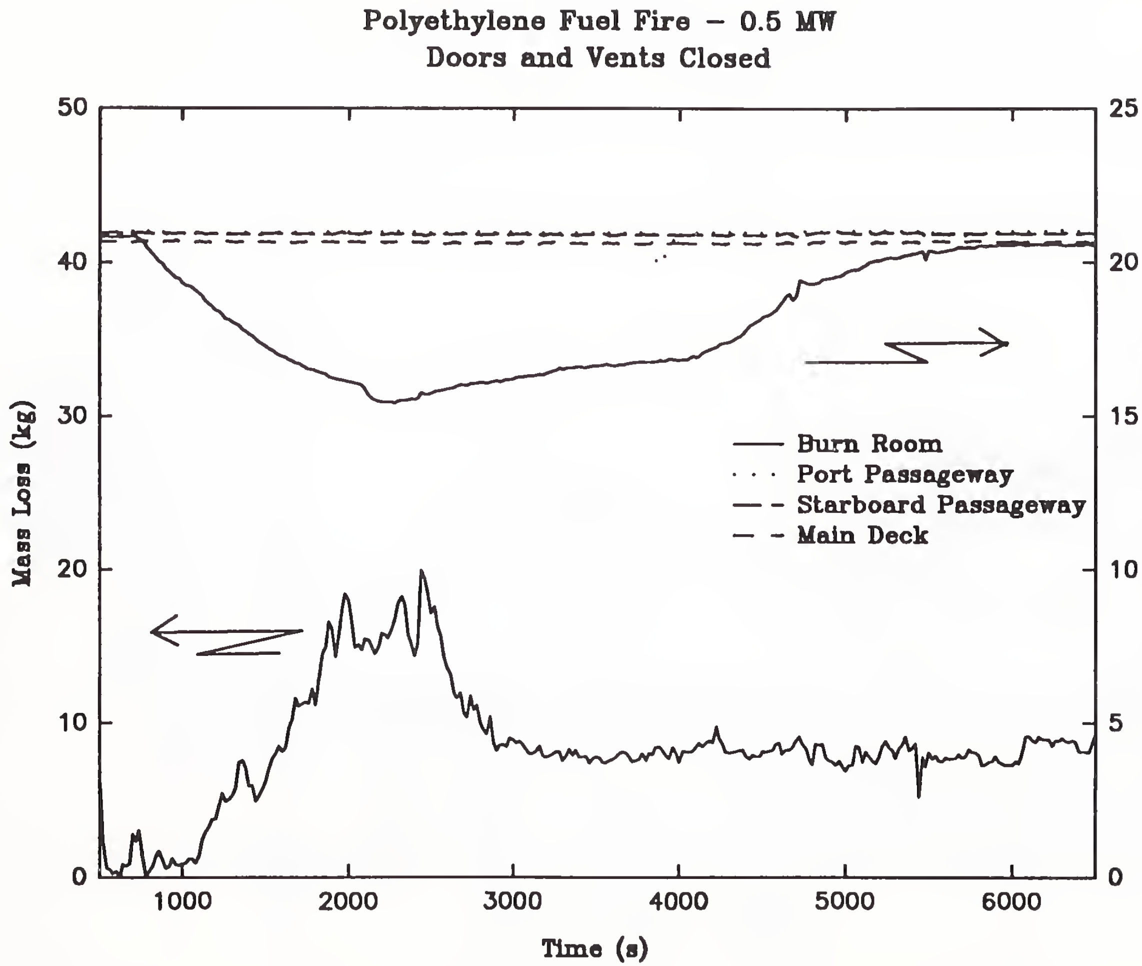

Figure 3: Mass loss and oxygen concentration in the burn room for the 0.5 MW polyethylene fuel fire.

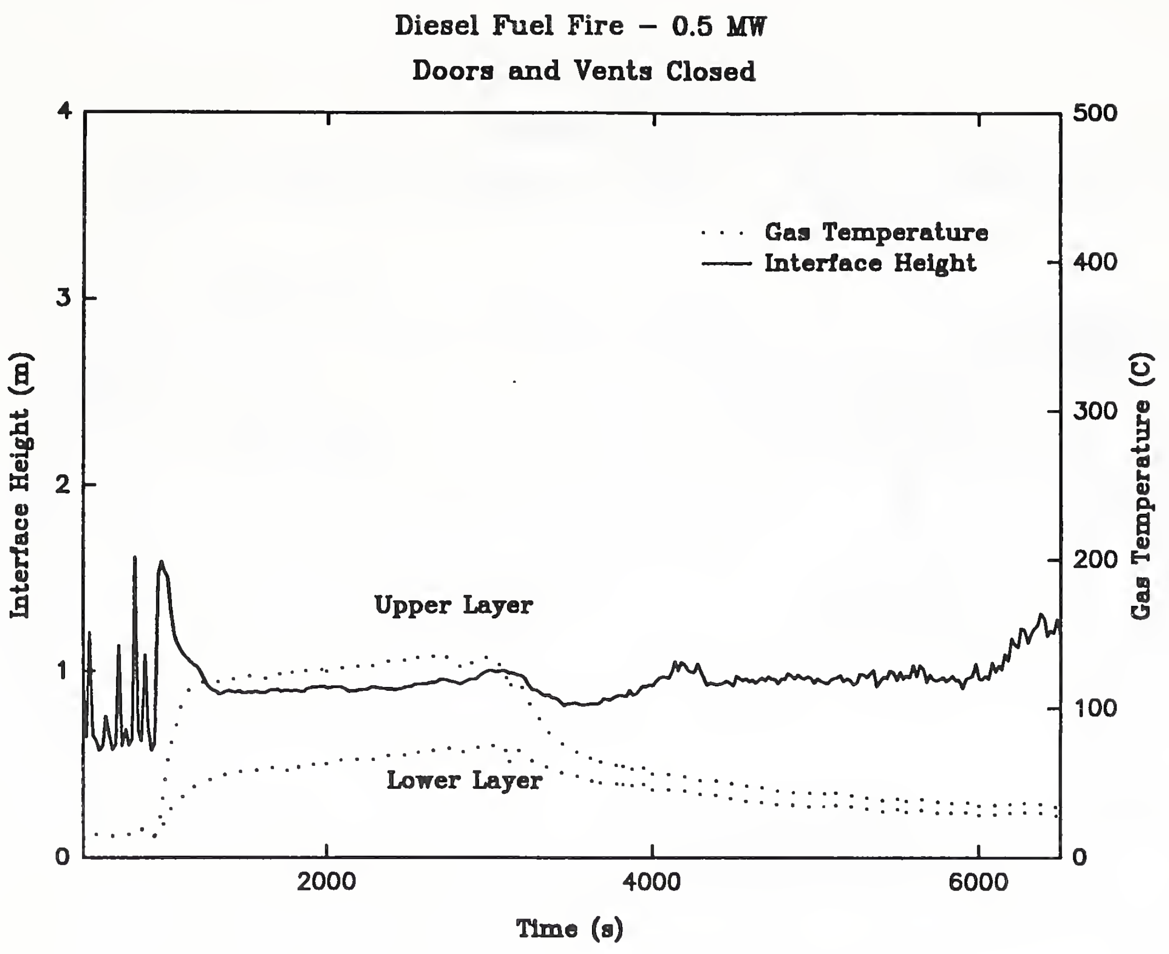

Figure 4: Location of the interface and the average layer temperatures in the burn room for the 0.5 MW diesel fuel fire.

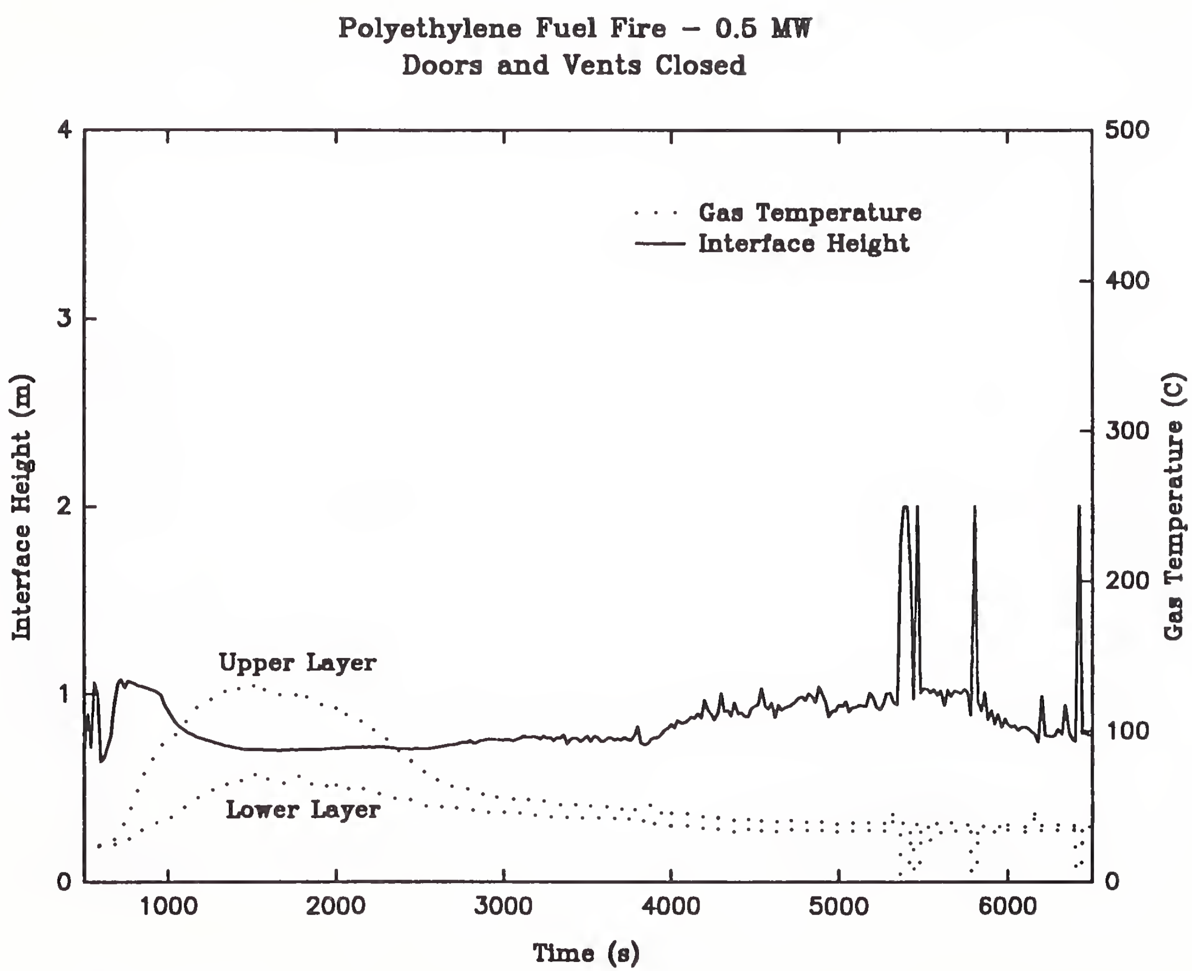

Figure 5: Location of the interface and the average layer temperatures in the burn room for the 0.5 MW polyethylene fuel fire.

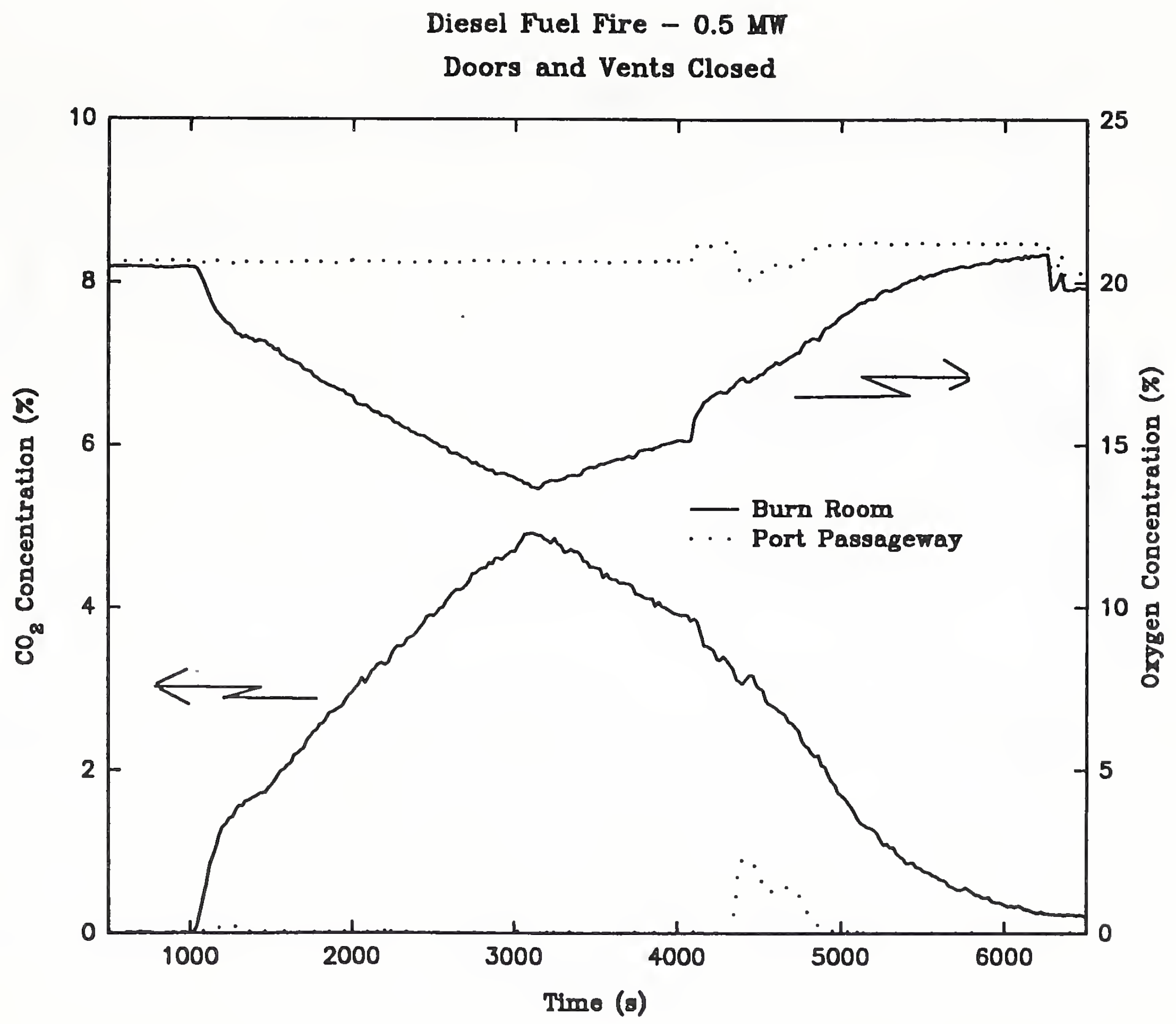

Figure 6: CO_2 concentration for the 0.5 MW diesel fuel fire.

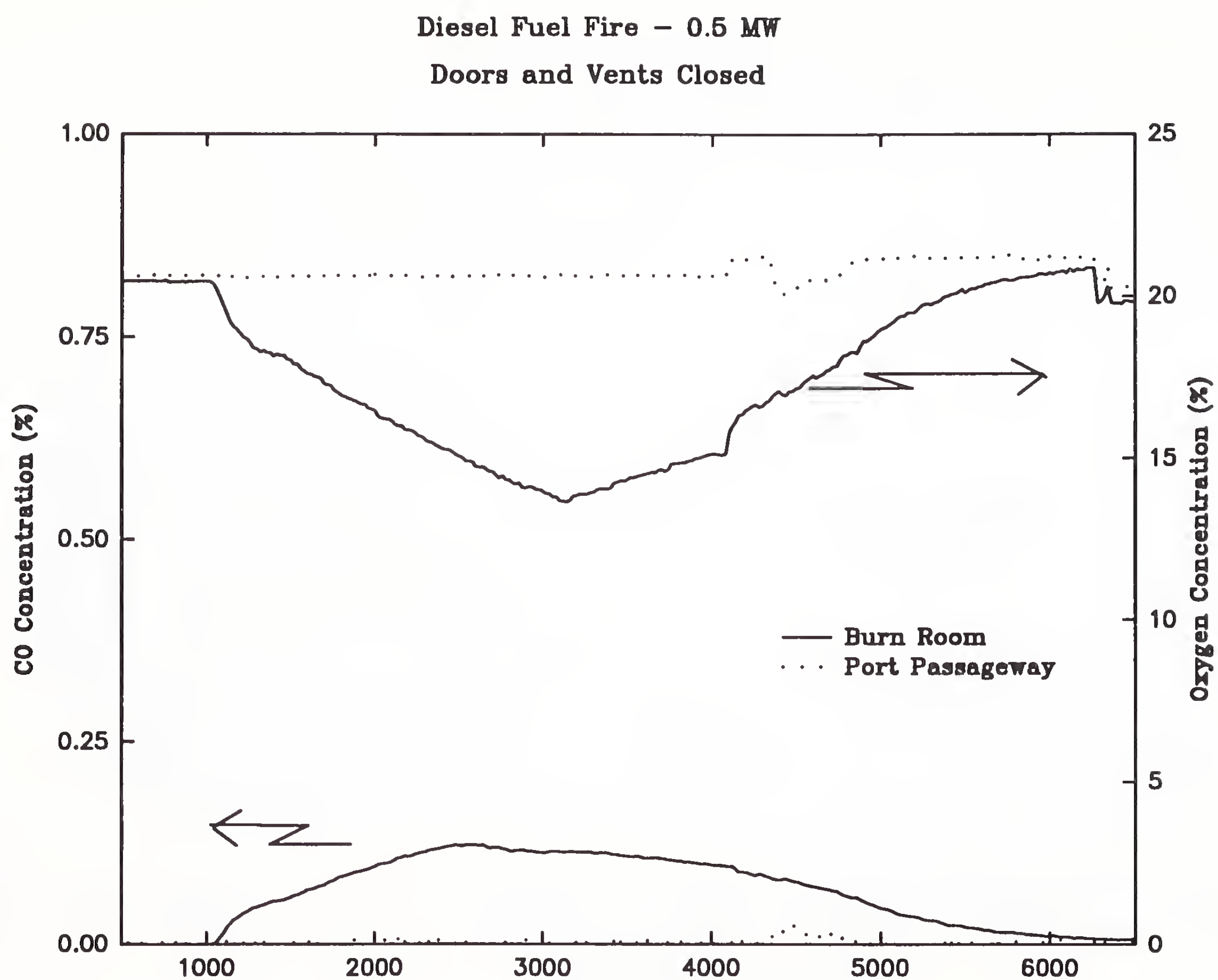

Figure 7: CO concentration for the 0.5 MW diesel fuel fire.

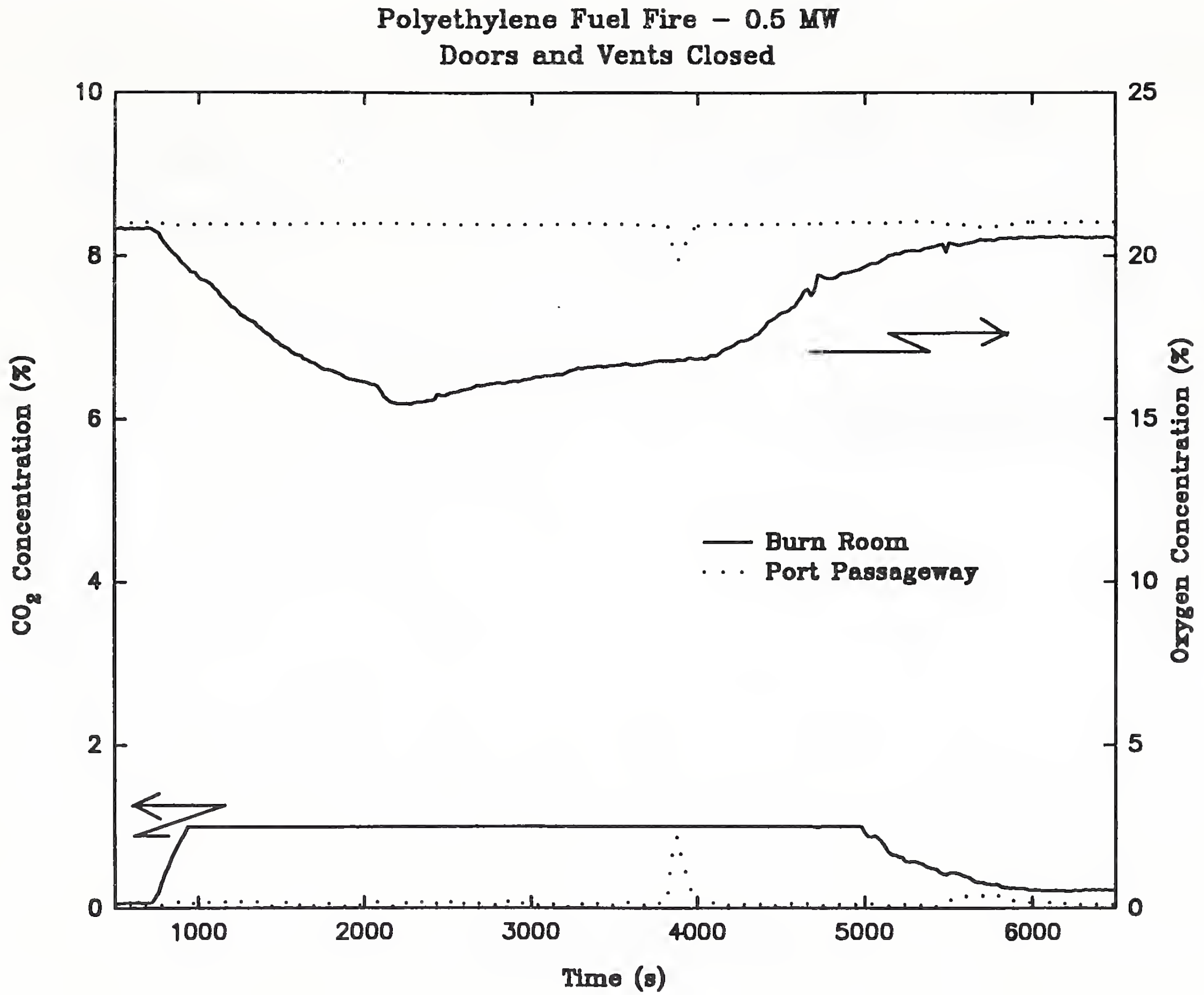

Figure 8: CO_2 concentration for the 0.5 MW polyethylene fuel fire.

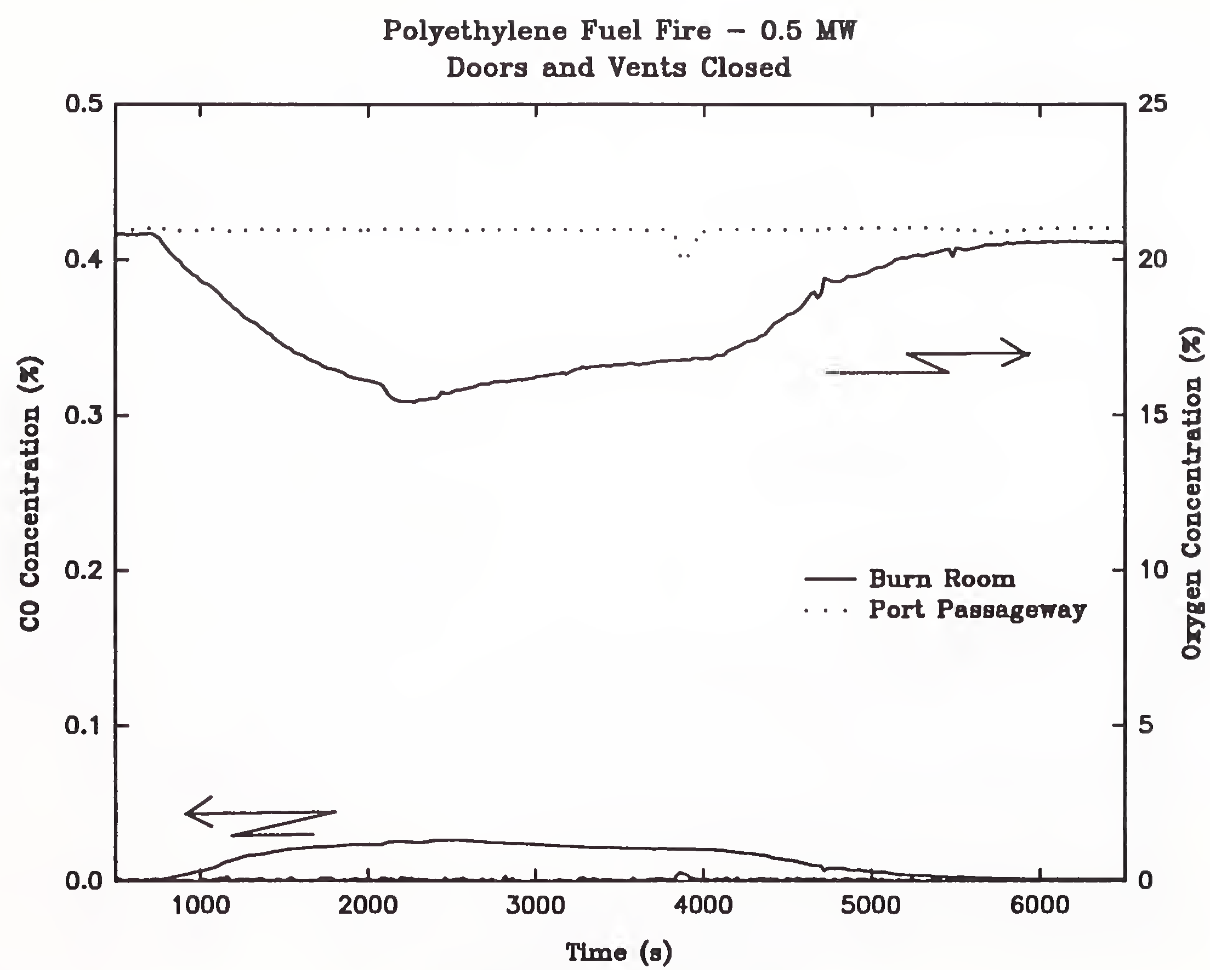

Figure 9: CO concentration for the 0.5 MW polyethylene fuel fire.

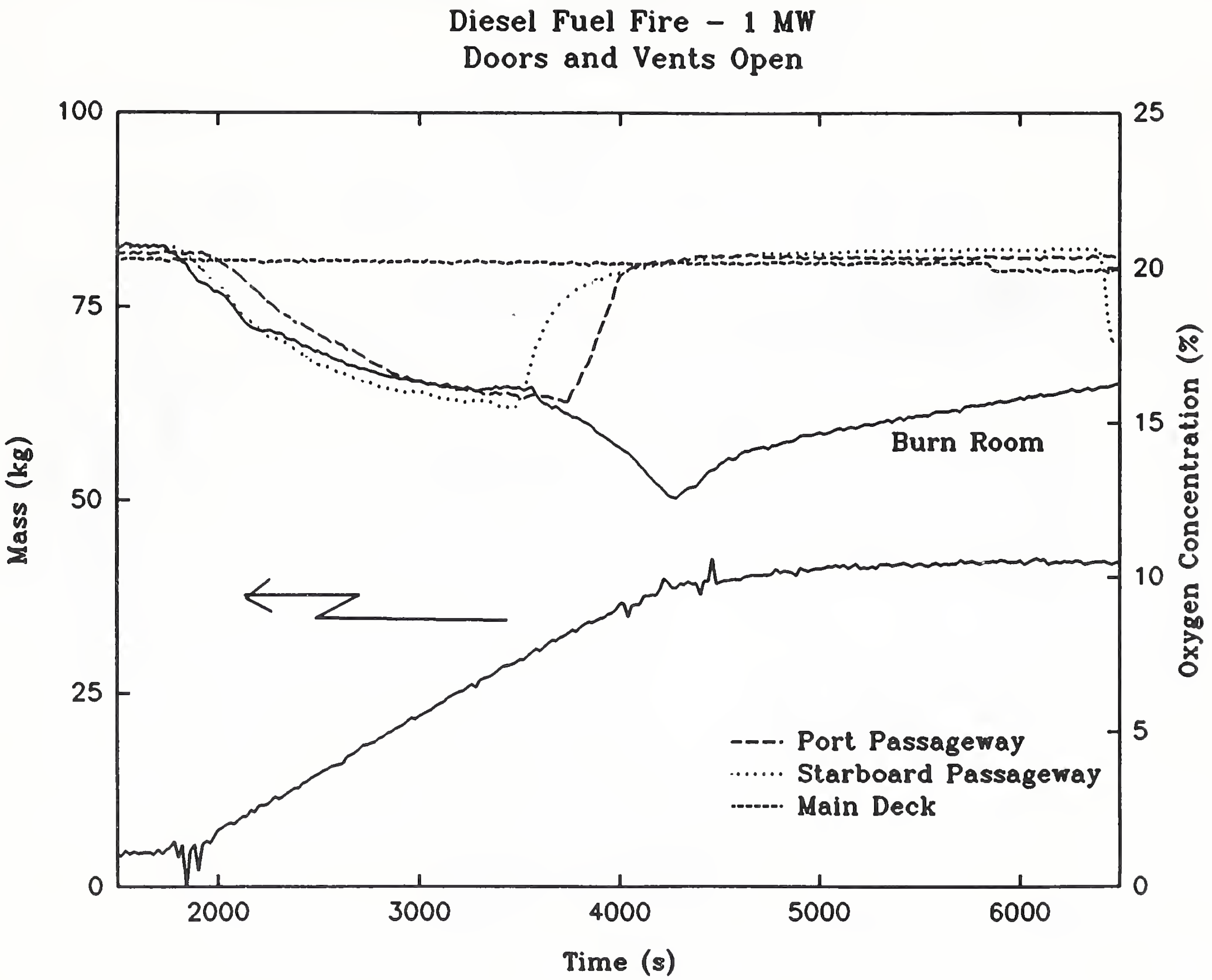

Figure 10: Total fuel mass (showing mass loss rate) and oxygen concentration for the 1 MW diesel fuel fire with doors and vent initially open.

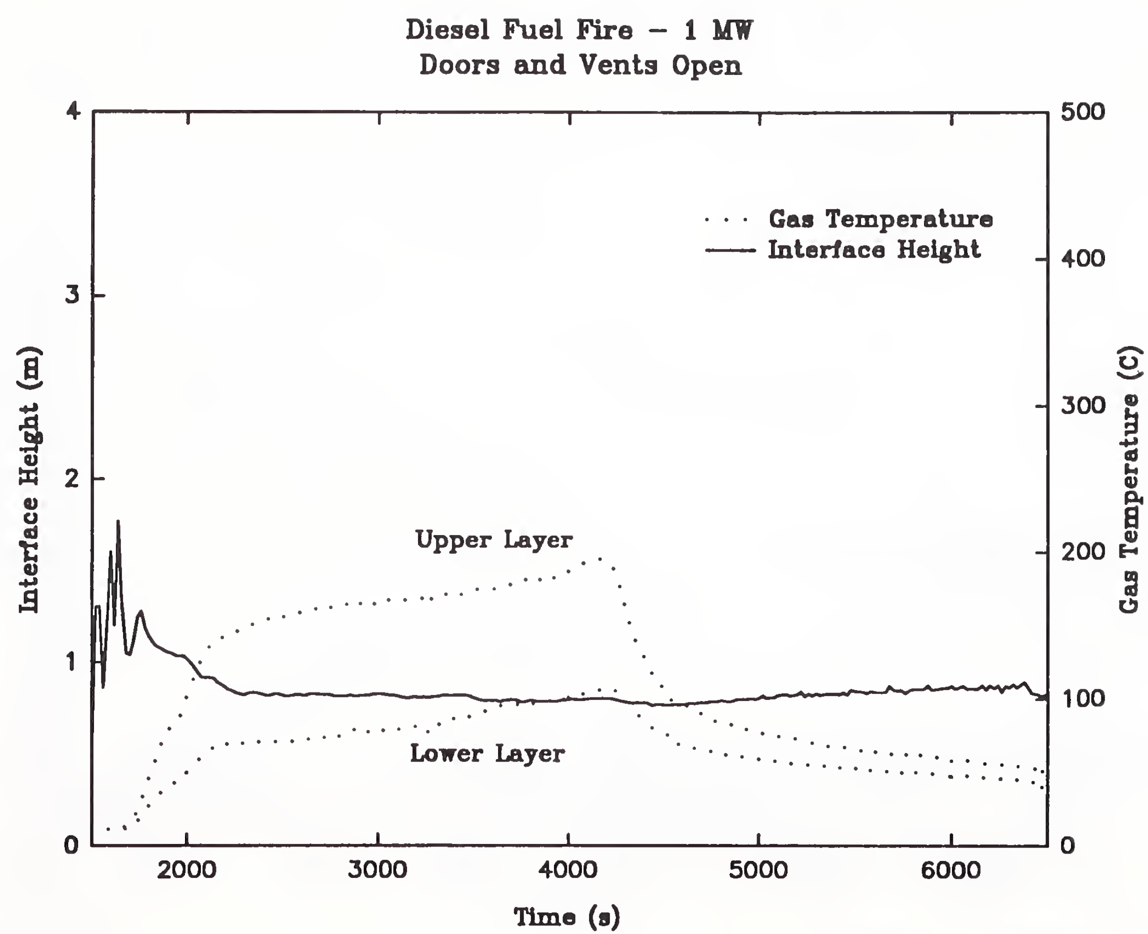

Figure 11: Interface height and upper and lower layer temperatures in the burn room for the 1 MW diesel fuel fire.

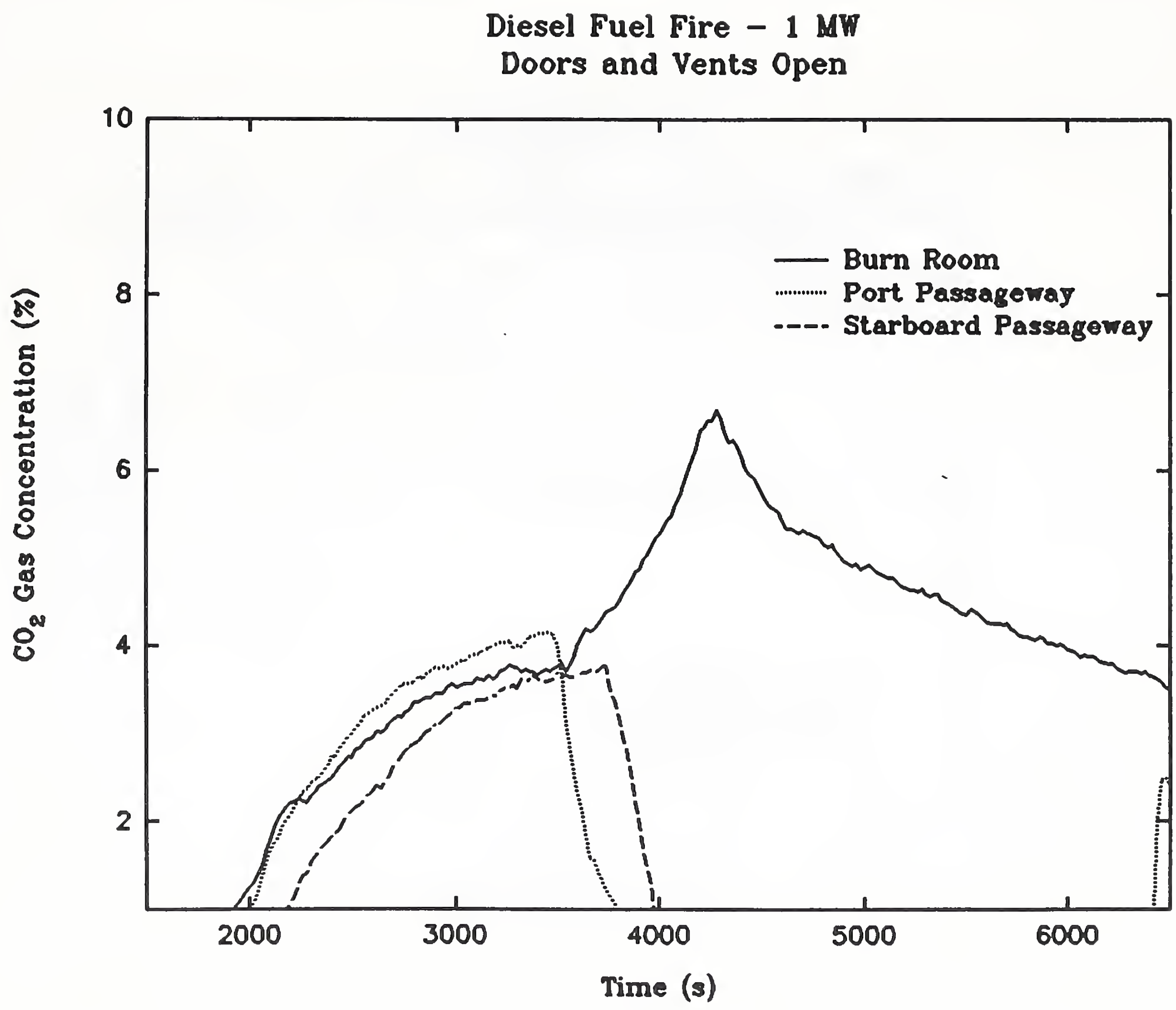

Figure 12: CO_2 concentration in all compartments for the 1 MW diesel fuel fire.

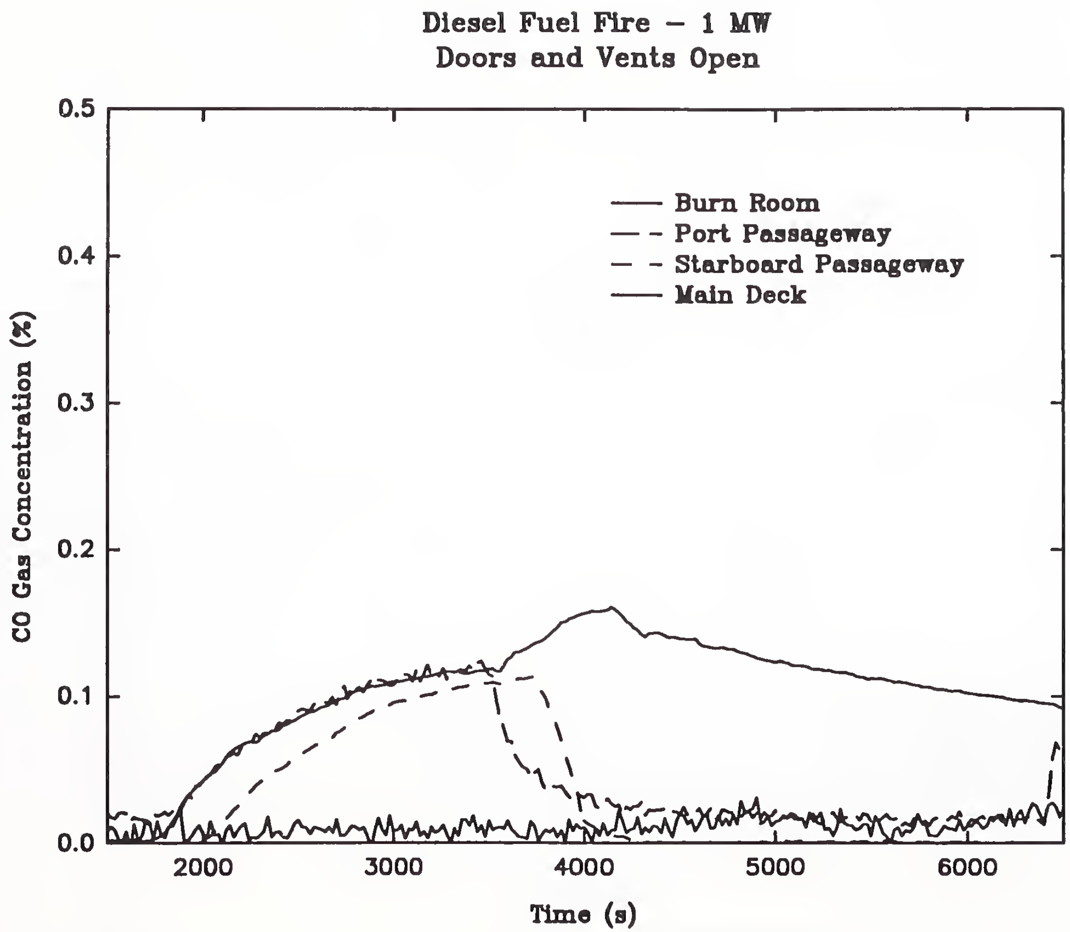

Figure 13: CO concentration in all compartments for the 1 MW diesel fuel fire.

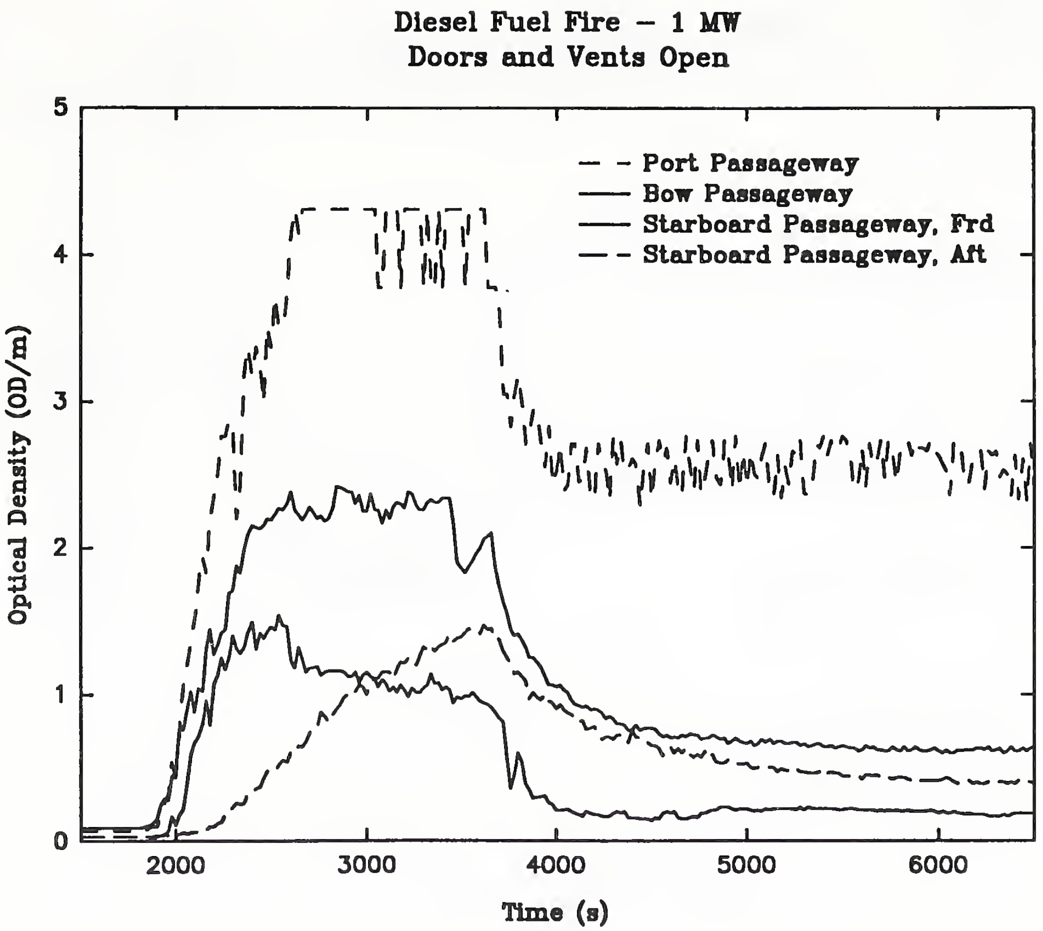

Figure 14: Optical density at 1.5 meters above the deck for all compartments for the 1 MW diesel fuel fire.

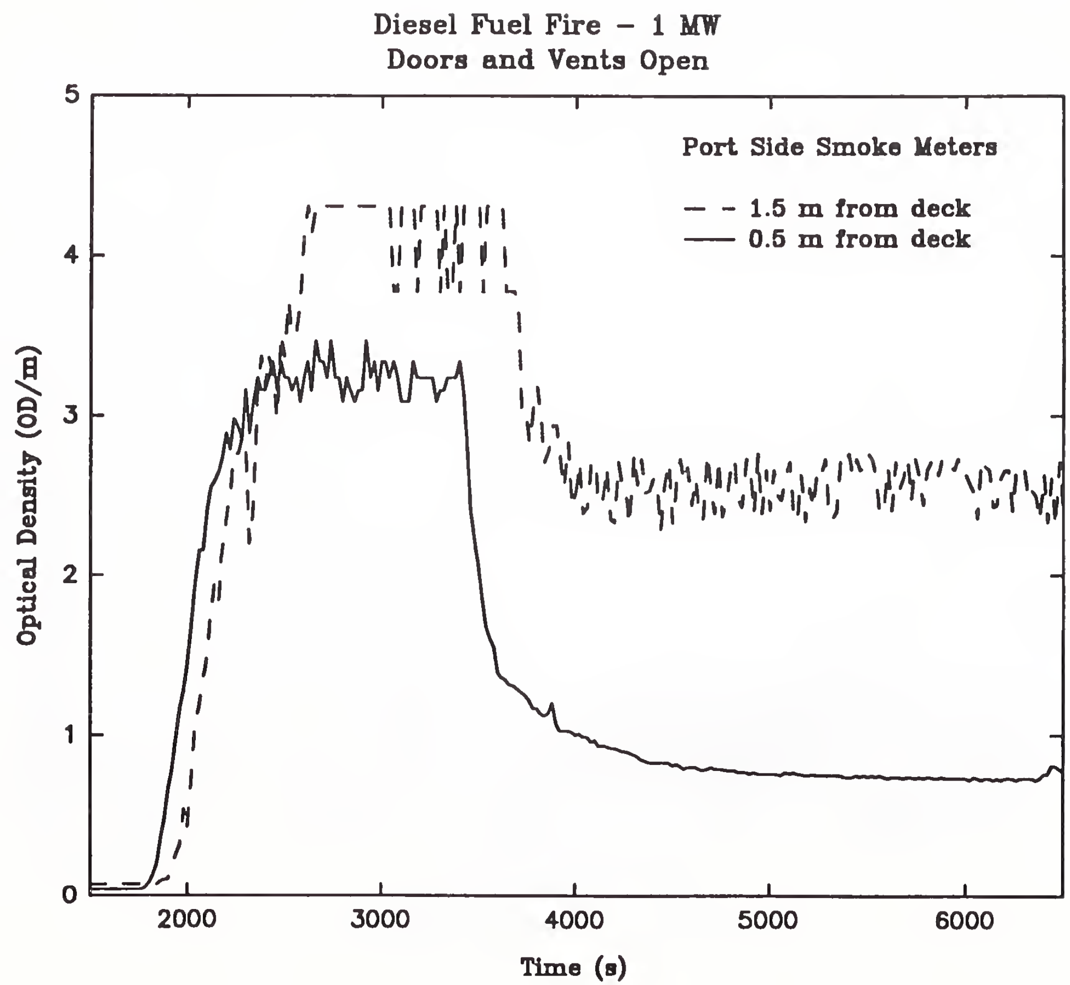

Figure 15: Optical density at 0.5 and 1.5 meters above the deck in the port passageway for the 1 MW diesel fuel fire.

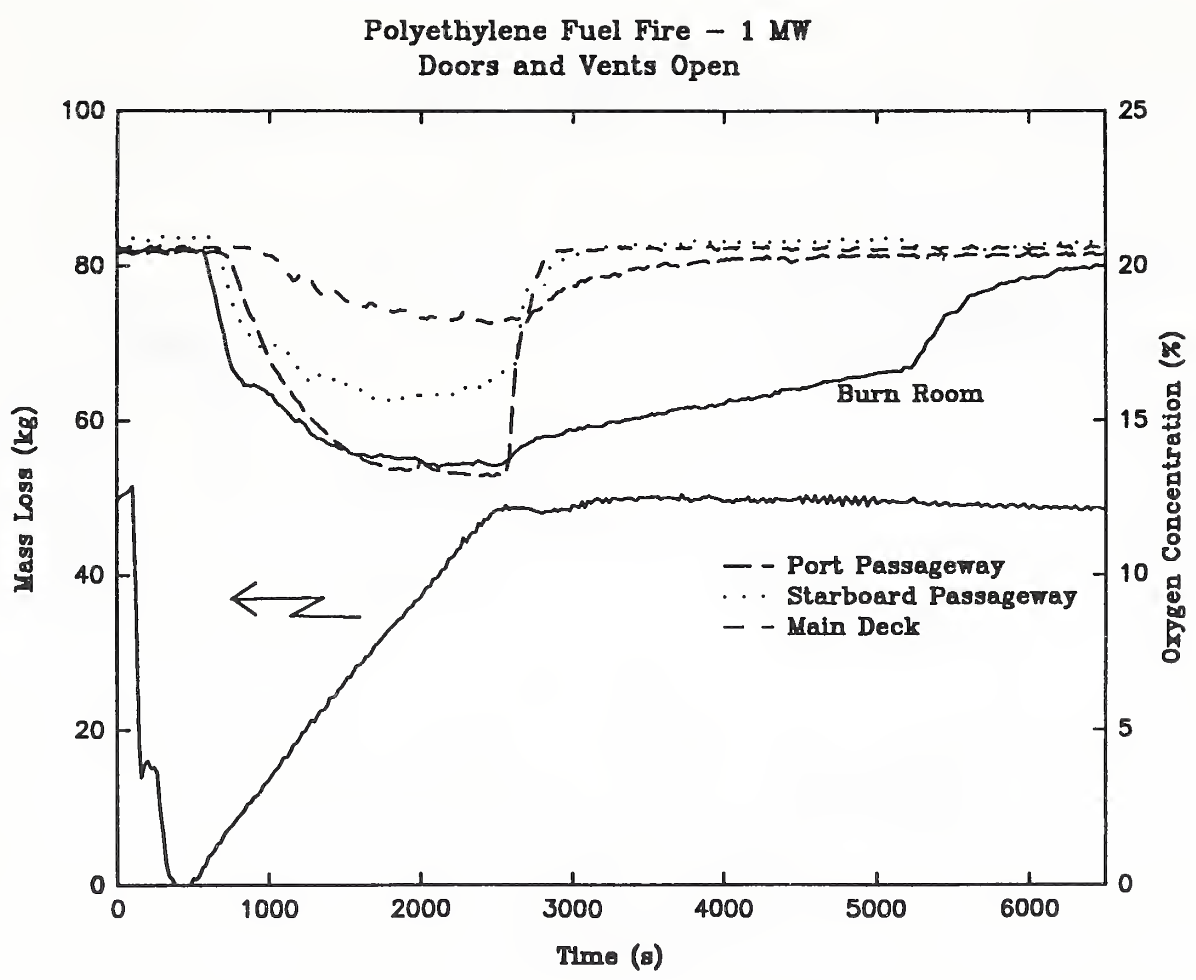

Figure 16: Total fuel mass (showing mass loss rate) and oxygen concentration for the 1 MW polyethylene fuel fire with doors and vent initially open.

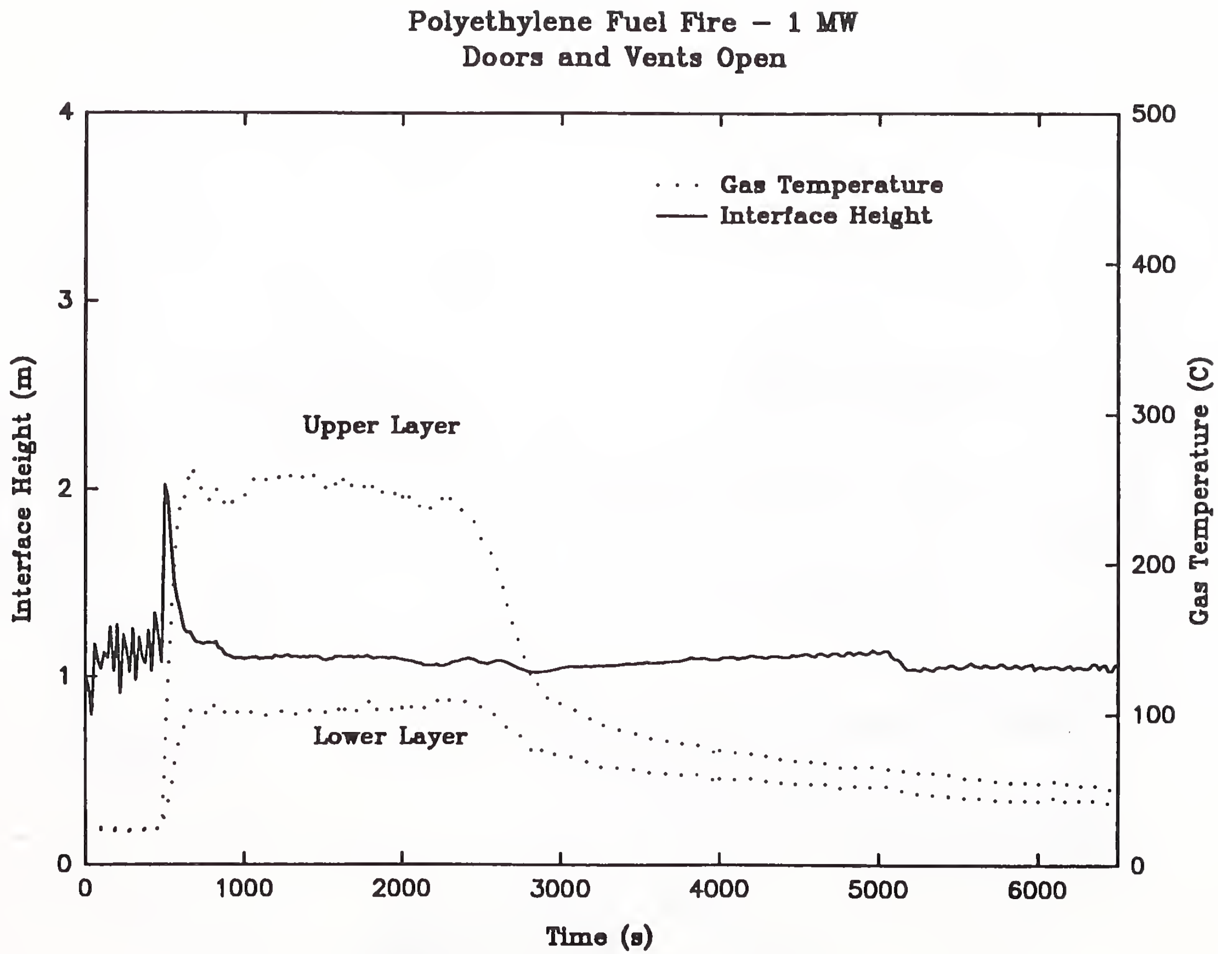

Figure 17: Interface height and upper and lower layer temperatures in the burn room for the 1 MW polyethylene fuel fire.

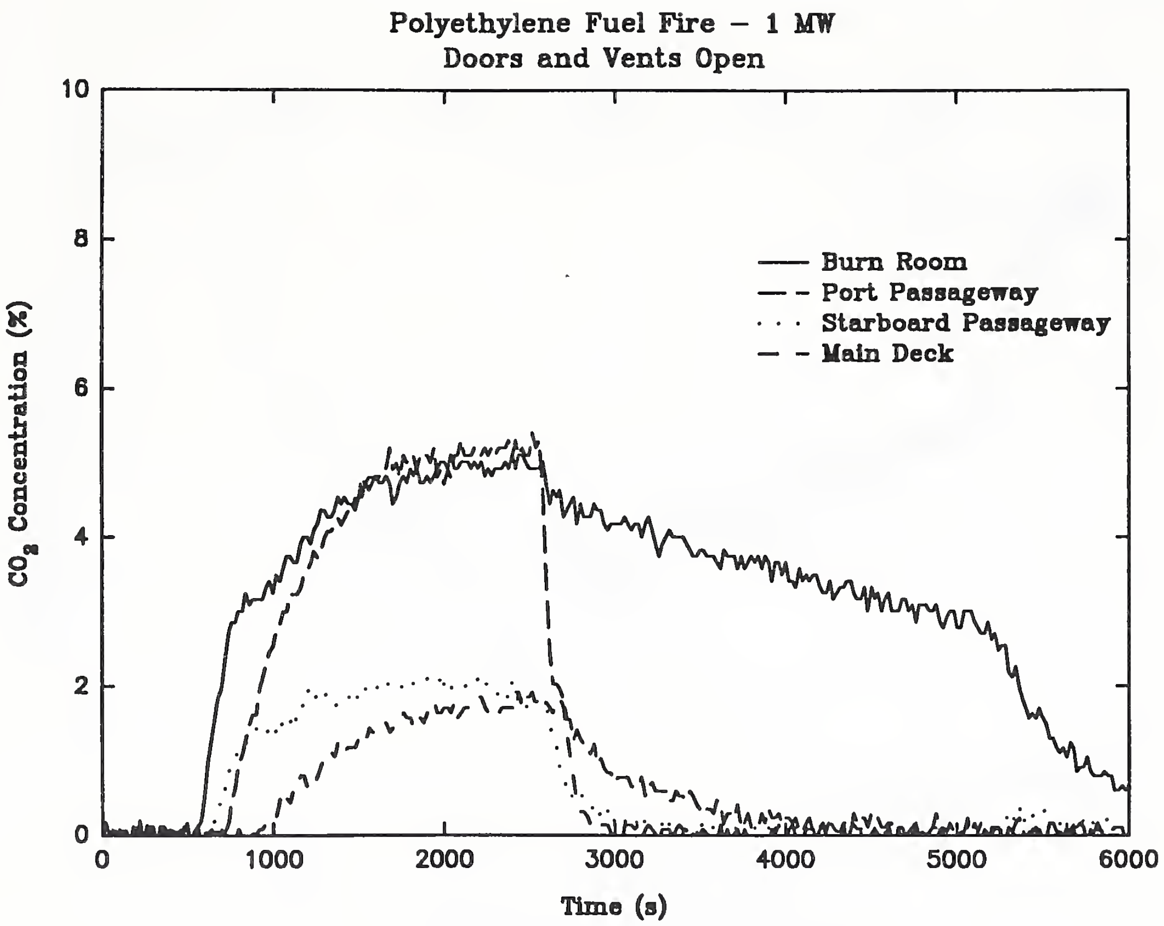

Figure 18: CO_2 concentration in all compartments for the 1 MW polyethylene fuel fire.

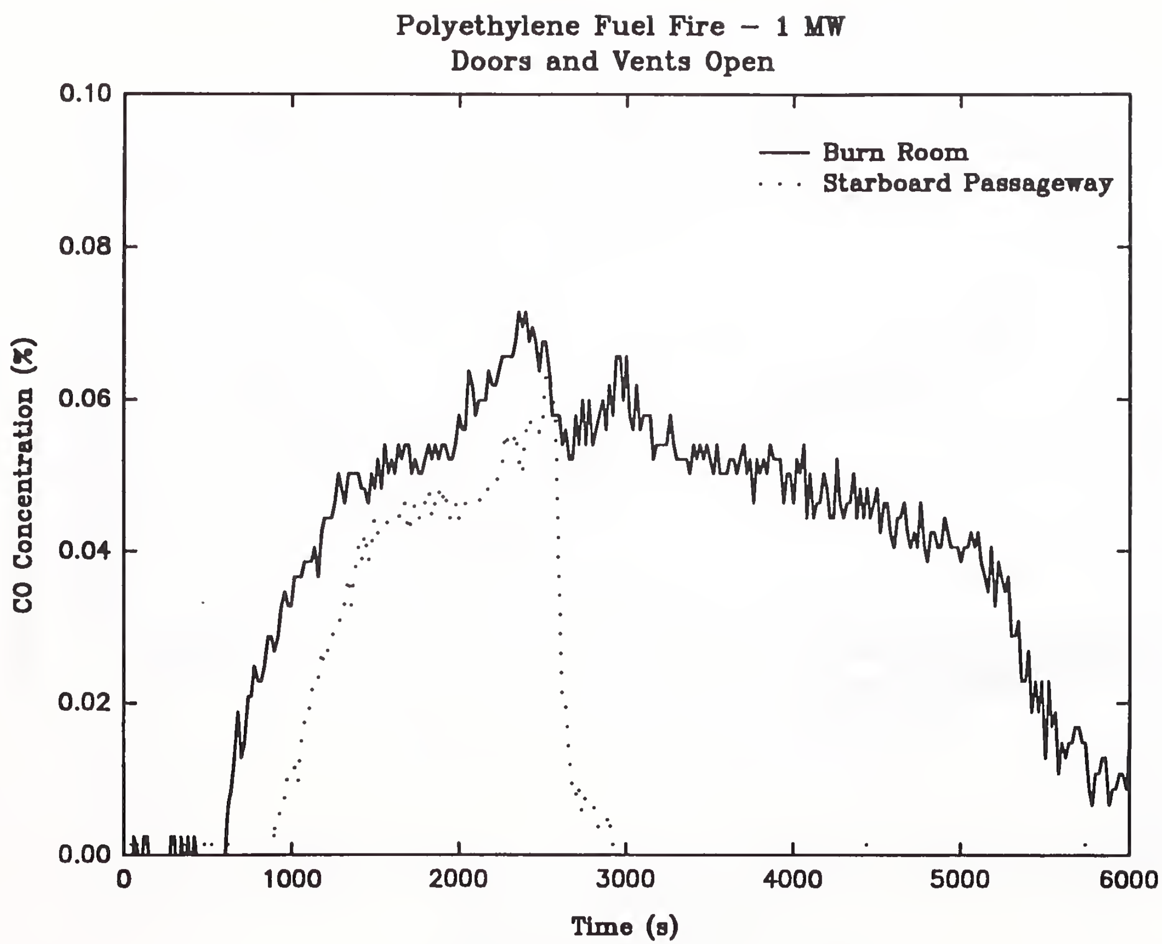

Figure 19: CO concentration for the 1 MW polyethylene fuel fire.

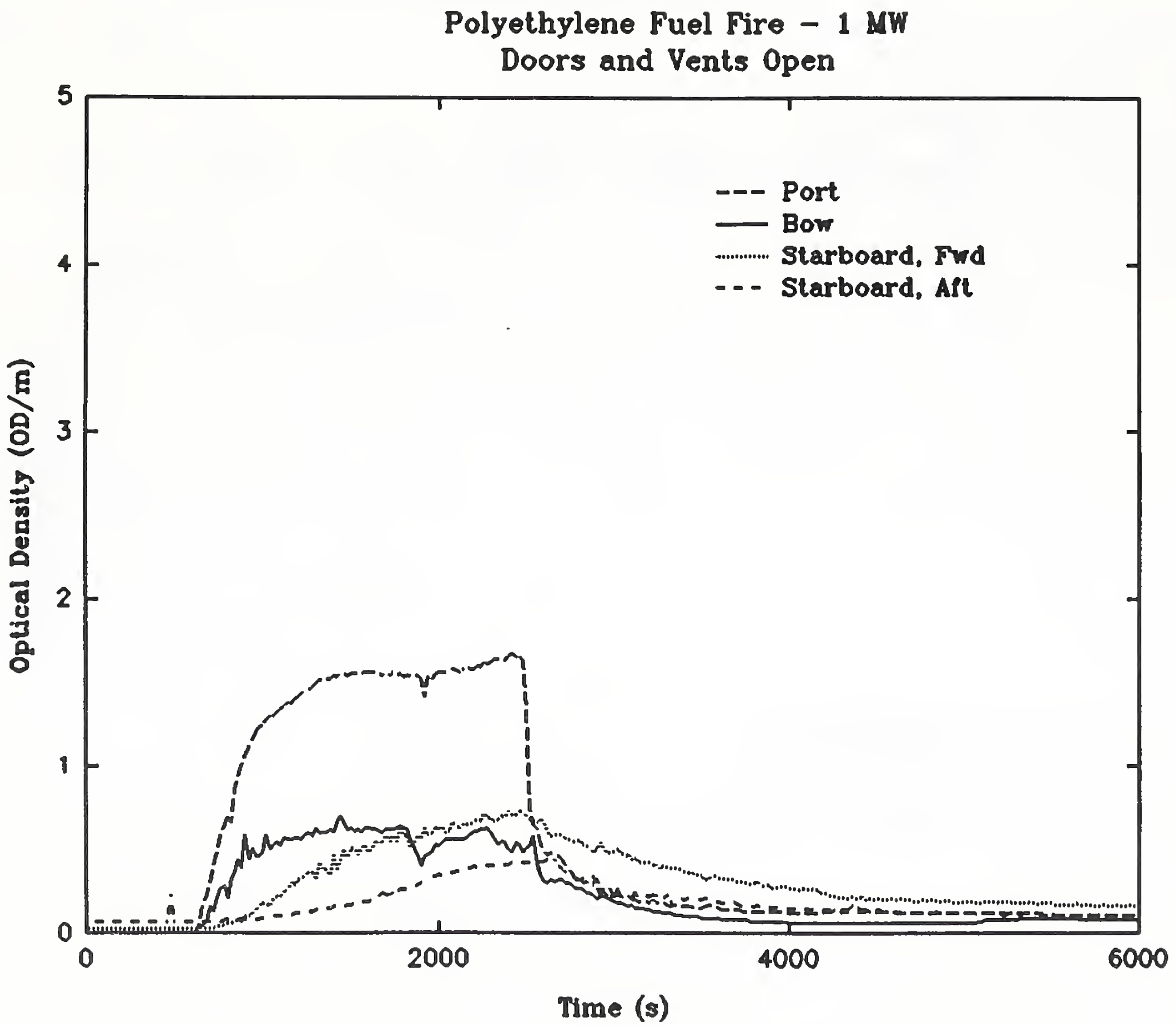

Figure 20: Optical density at 1.5 meters above the deck for all compartments for the 1 MW polyethylene fuel fire.

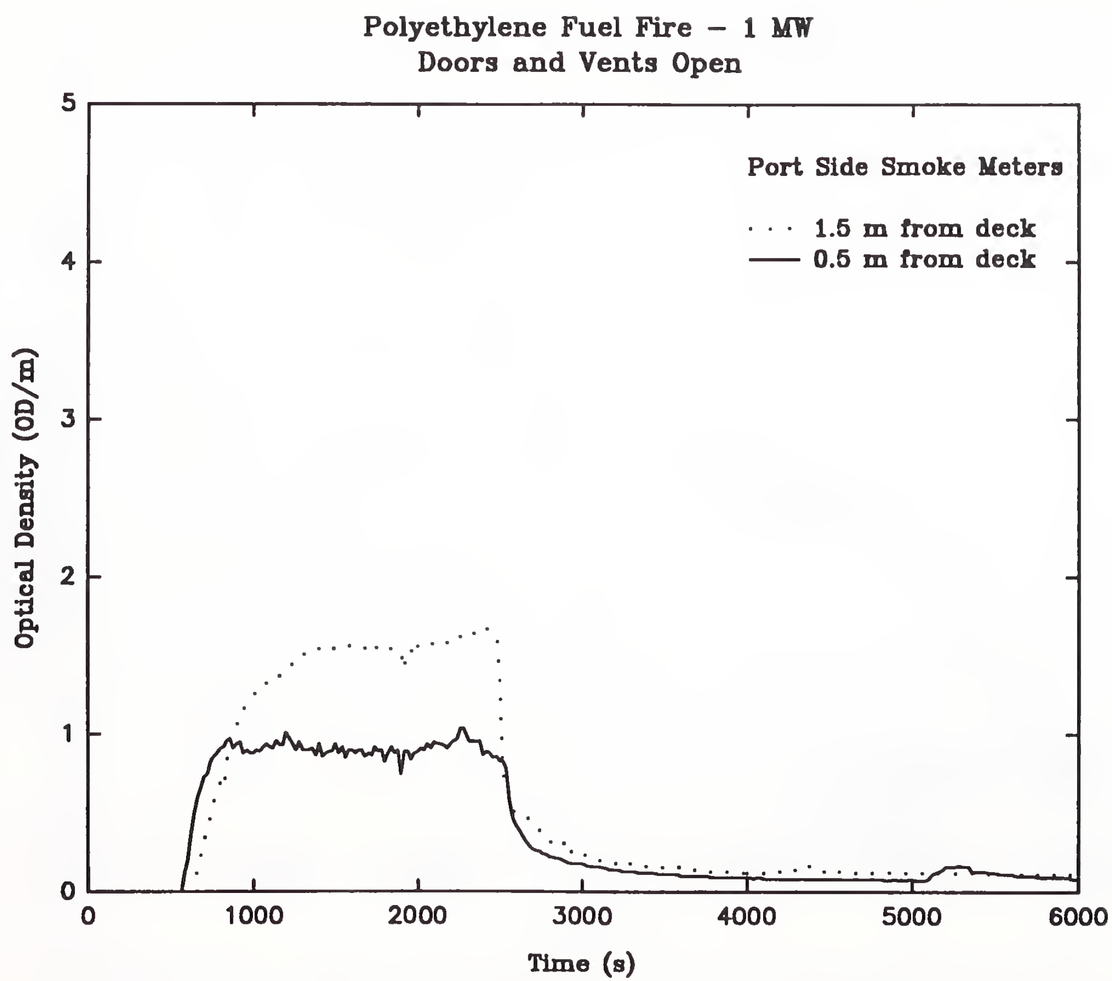

Figure 21: Optical density at 0.5 and 1.5 meters above the deck in the port passageway for the 1 MW polyethylene fuel fire.

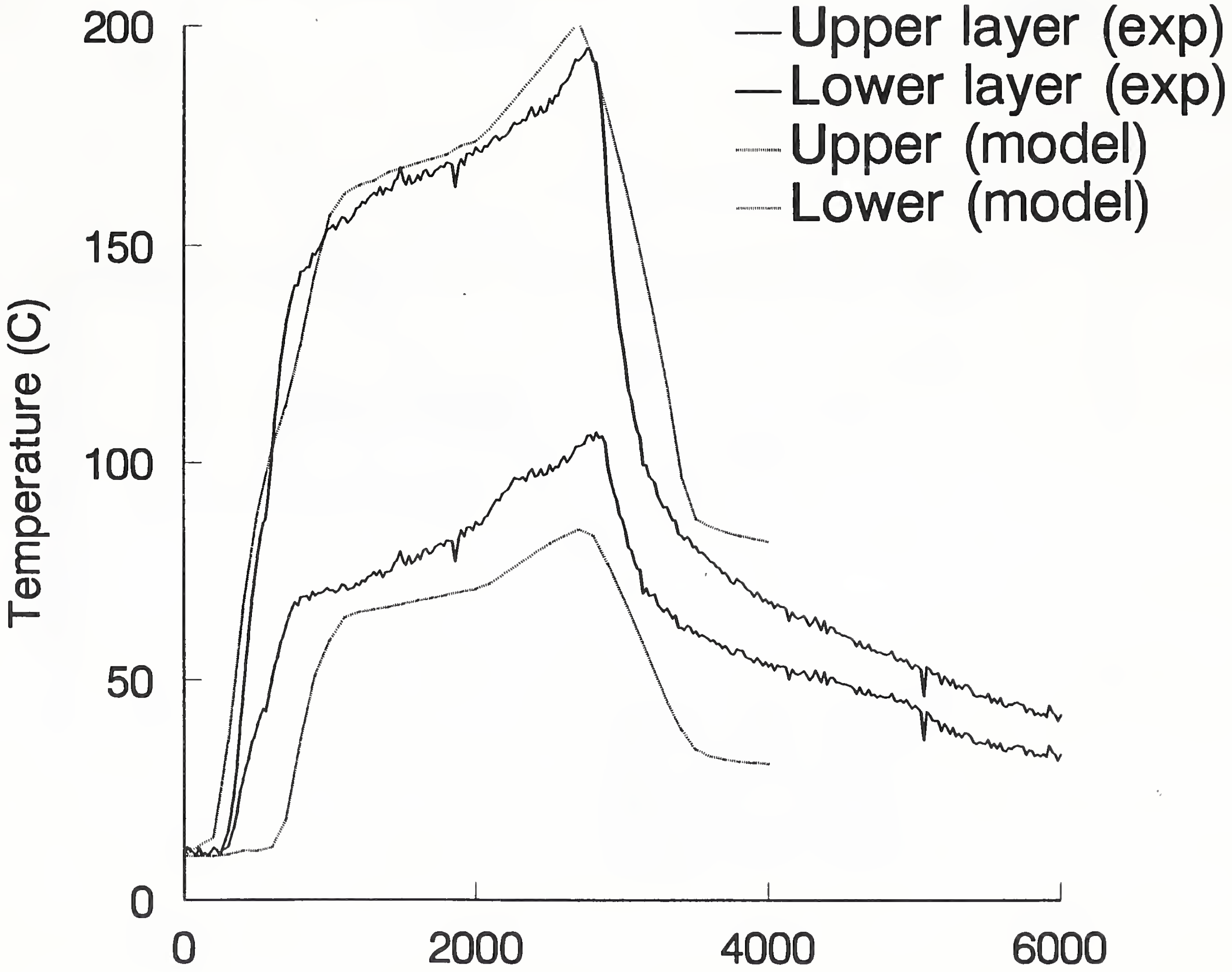

Figure 22: Comparison of measured and predicted temperatures in the upper and lower layers.

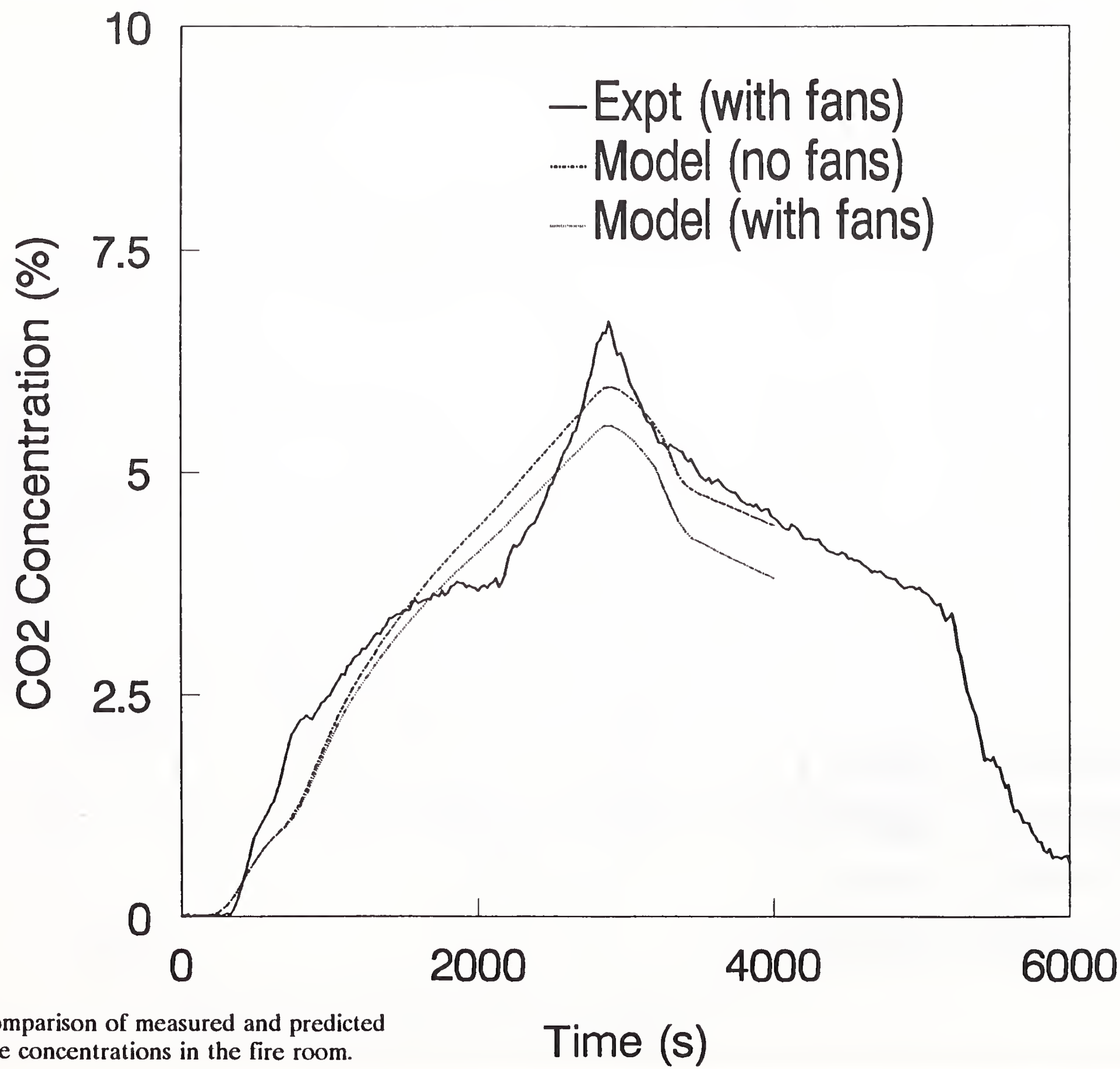

Figure 23: Comparison of measured and predicted carbon dioxide concentrations in the fire room.

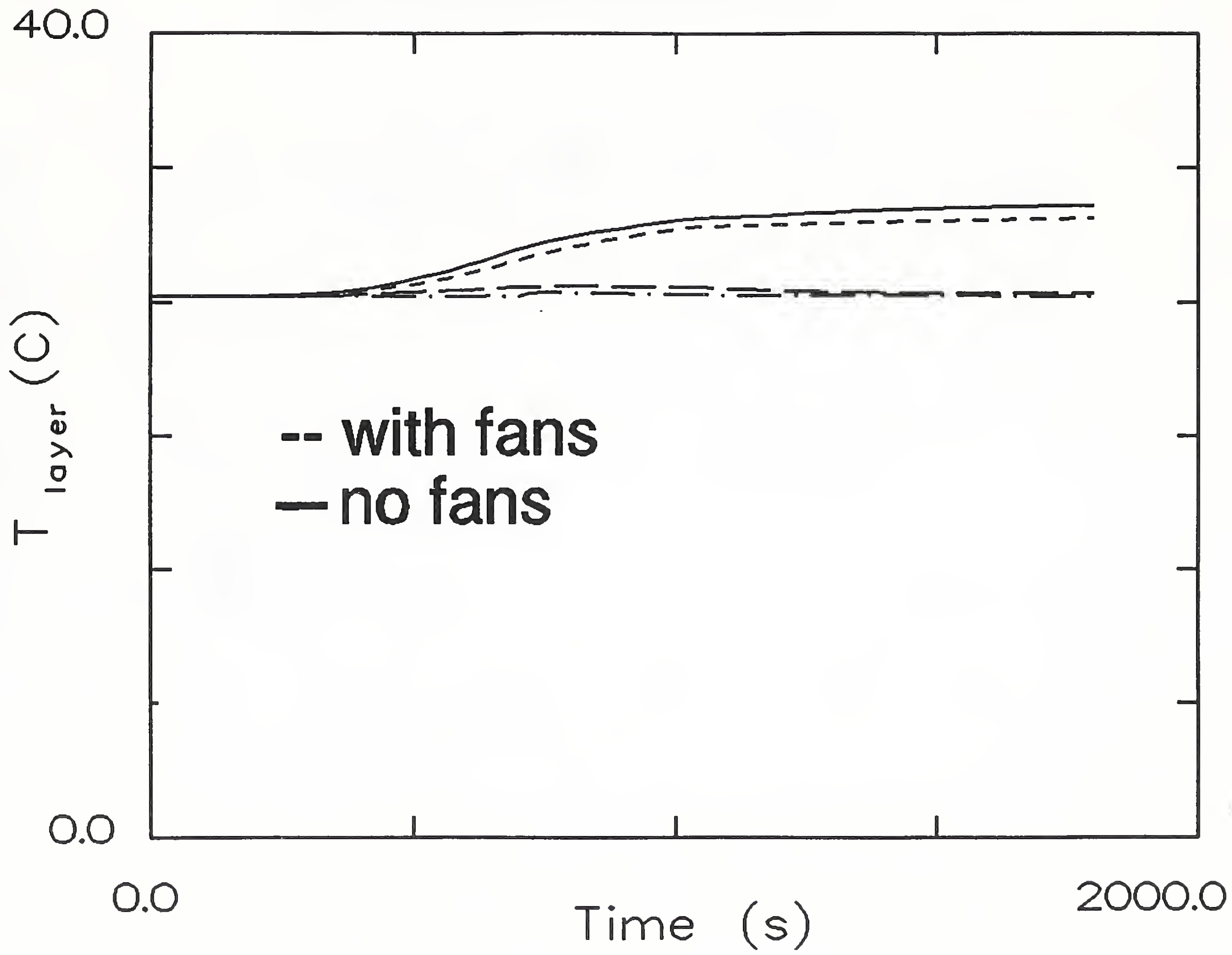

Figure 24: Upper layer temperature in the compartment on the main deck above the fire compartment.

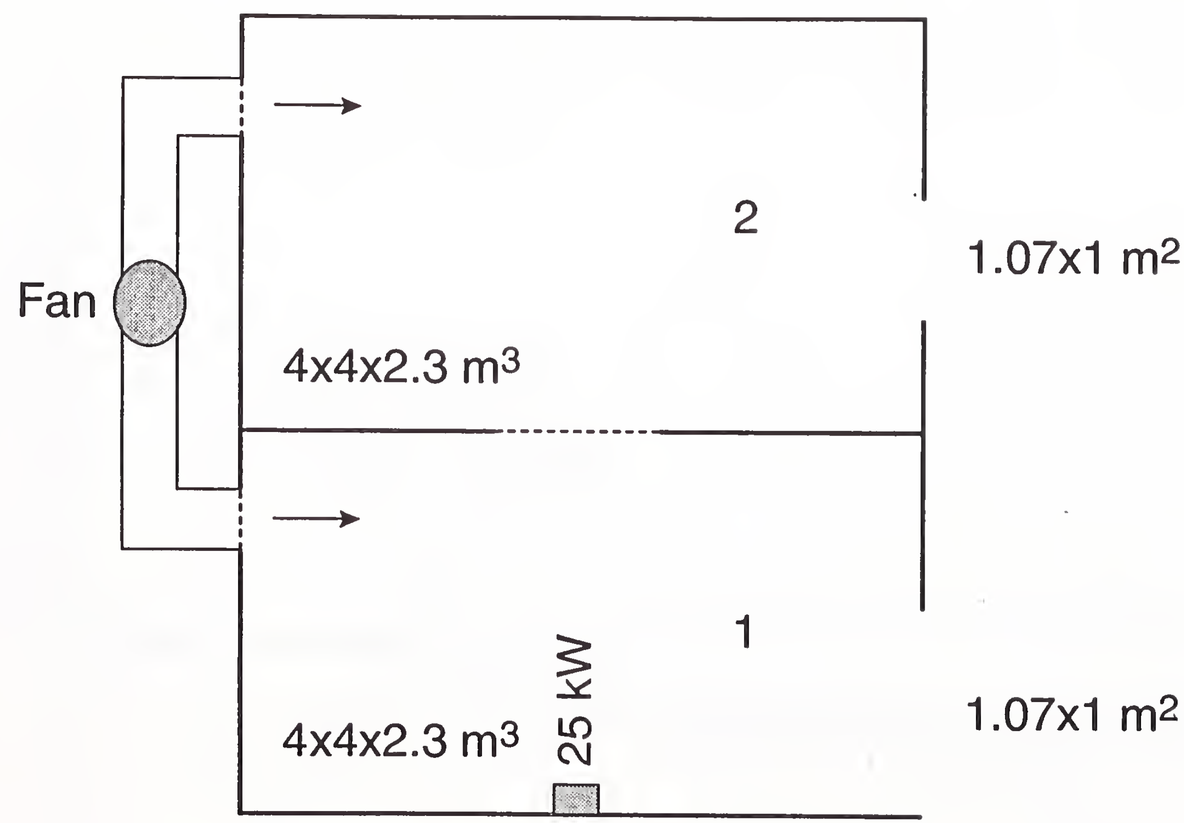

Figure 25: Simplified layout of the ventilation diagram used in the "2nd deck/main deck" SES experiments.

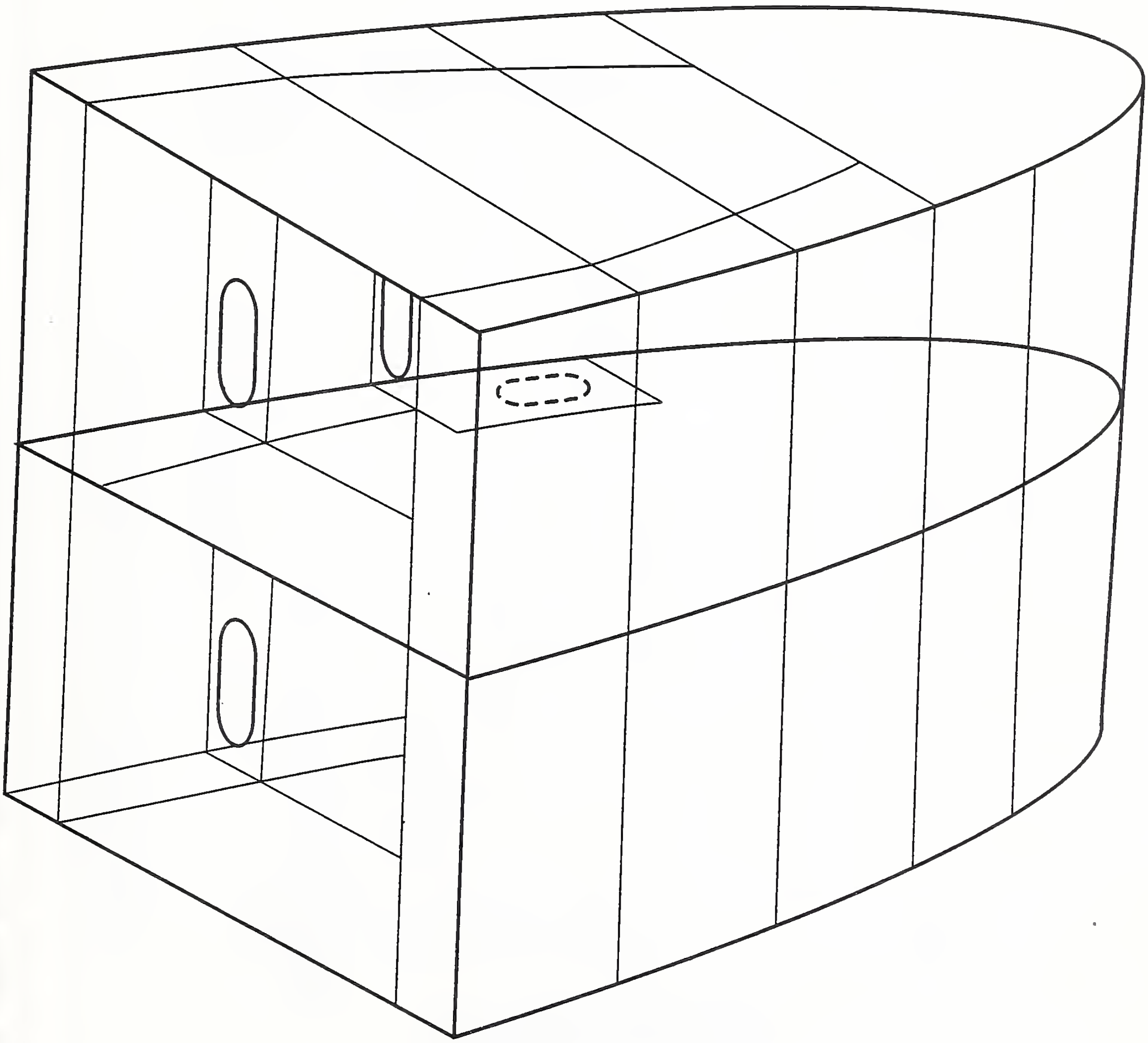

Figure 26: Equivalent ship diagram for the prediction of fire growth and smoke movement through the two decks in the ex USS SHADWELL.

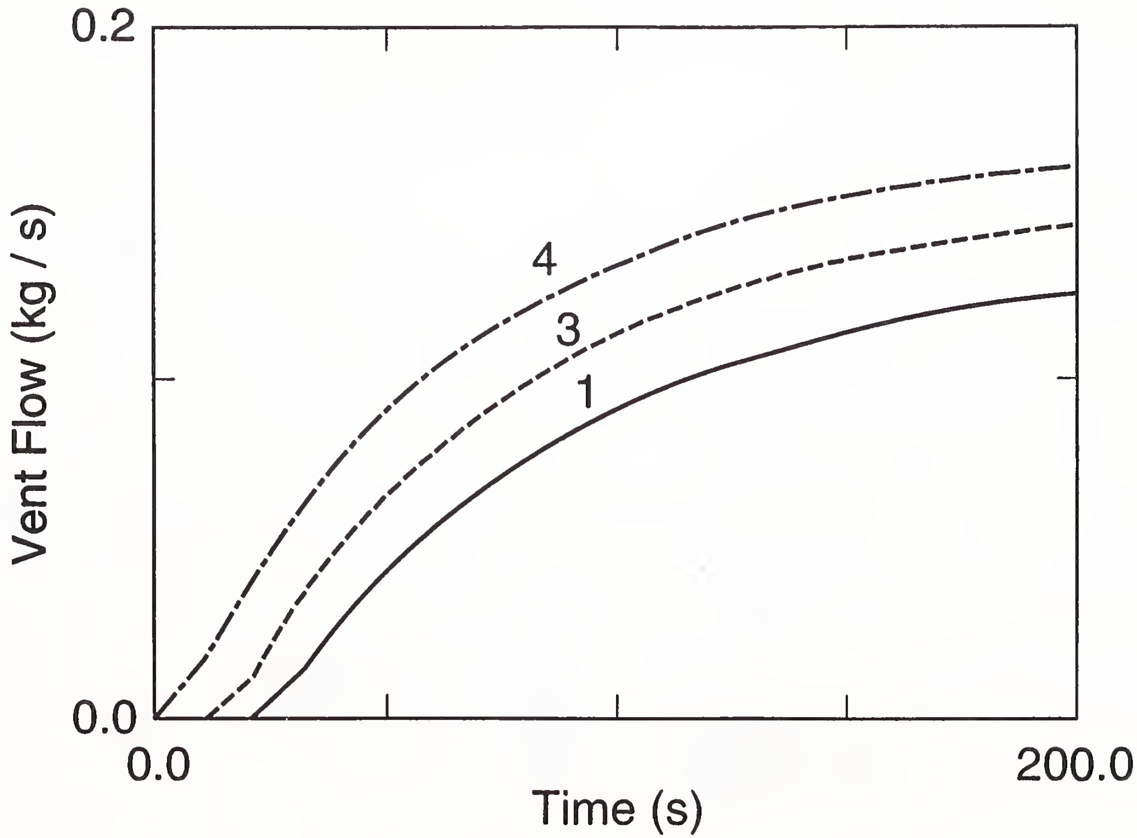

Figure 27a: Flow out of the upper layer of the lower compartment (#1).

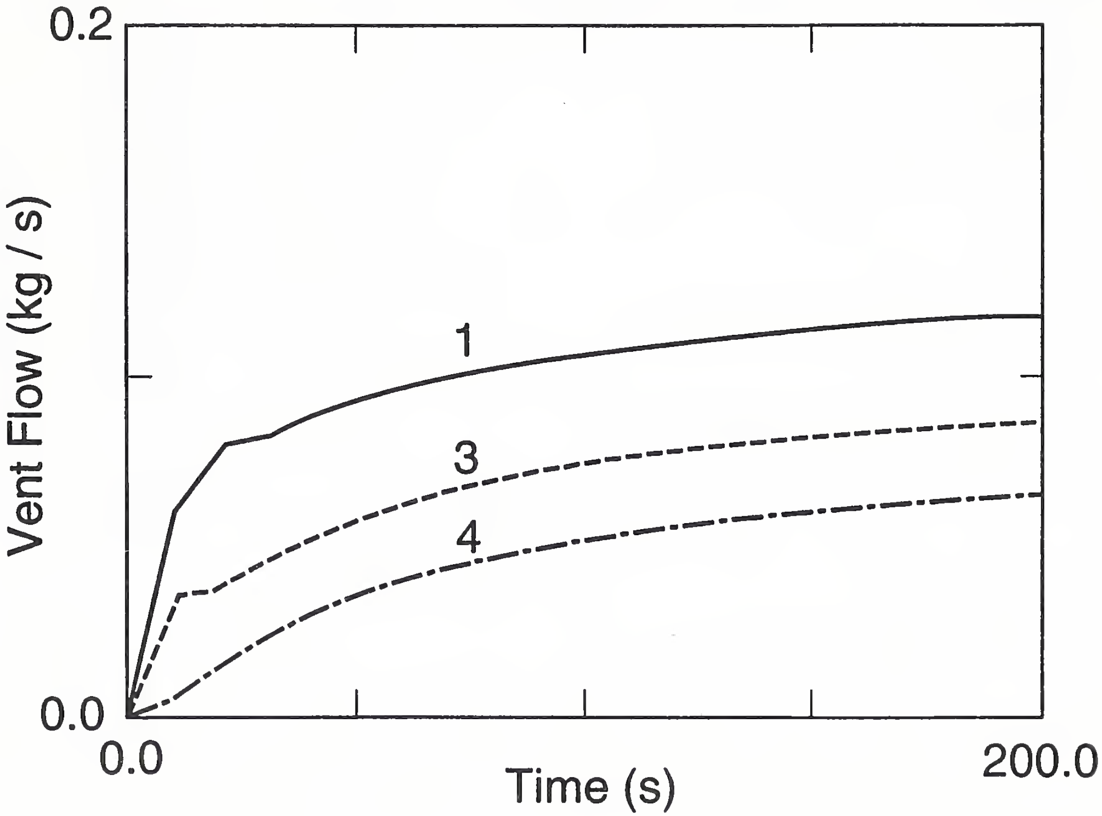

Figure 27b: Flow into the lower layer of the lower compartment (#2).

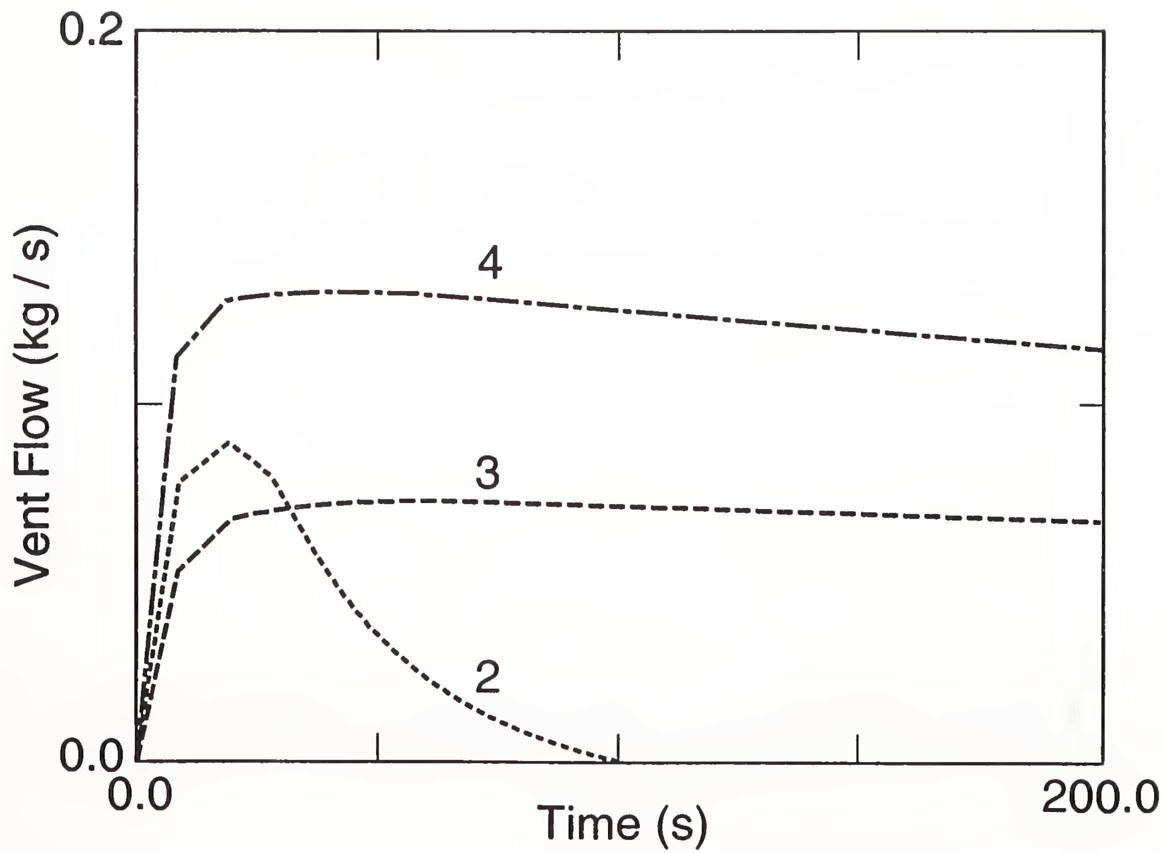

Figure 27c: Flow out of the LOWER layer of the upper compartment (#2).

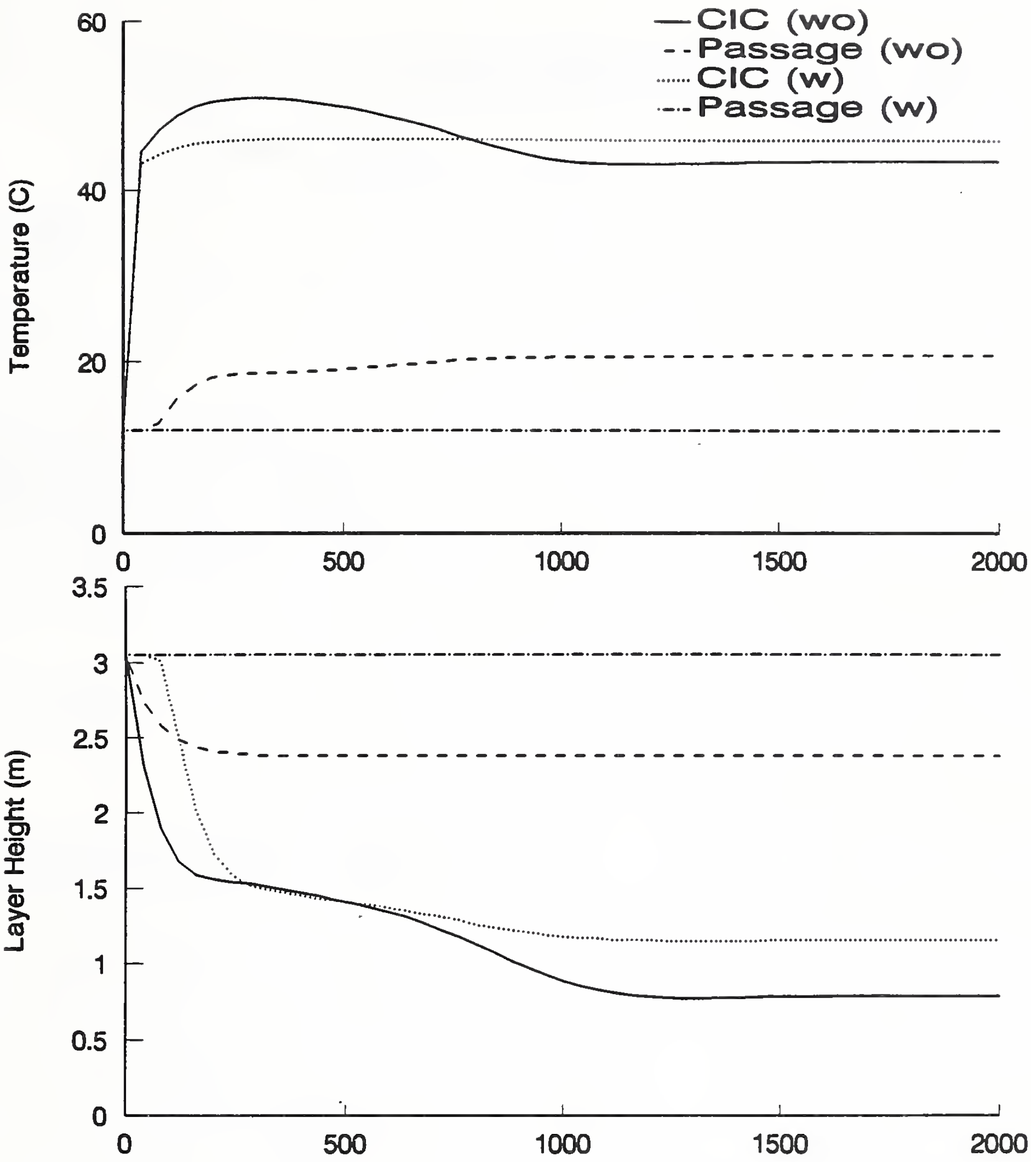

Figure 28: Predicted temperature of the upper layer and height of the smoke layer interface with the nominal fan (0.143 m^3/s) and a fan ten times larger.

NIST-114A (REV. 3-90)	U.S. DEPARTMENT OF COMMERCE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY	1. PUBLICATION OR REPORT NUMBER NISTIR 4961
	BIBLIOGRAPHIC DATA SHEET	2. PERFORMING ORGANIZATION REPORT NUMBER
		3. PUBLICATION DATE November 1992

4. TITLE AND SUBTITLE

Comparison of Full Scale Fire Tests and a Computer Fire Model of Several Smoke Ejection Experiments

5. AUTHOR(S)

Emil Braun, Darren L. Lowe, Walter W. Jones, Patricia Tatem, Richard Carey, Jean Bailey

6. PERFORMING ORGANIZATION (IF JOINT OR OTHER THAN NIST, SEE INSTRUCTIONS)	7. CONTRACT/GRANT NUMBER
U.S. DEPARTMENT OF COMMERCE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY GAITHERSBURG, MD 20899	Internal Report
	8. TYPE OF REPORT AND PERIOD COVERED

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (STREET, CITY, STATE, ZIP)

Naval Research Laboratory
Washington, D.C. 20375

10. SUPPLEMENTARY NOTES

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.)

Data were obtained from four large scale shipboard fire tests. The test series was designed to evaluate the efficacy of a smoke ejection system for the removal of smoke and heat from compartments around the compartment of fire origin. Using diesel oil and polyethylene beads as fuel, tests were conducted at 0.5 MW and 1.0 MW. The data obtained from these tests were evaluated in terms of the reduction of heat and smoke in adjacent passageways. These results were compared to numerical simulations of the shipboard environment. The test results showed that the atmospheric conditions in compartments/passageways adjacent to the compartment of fire origin could be made survivable by isolating the fire compartment and ventilating adjacent spaces. It was found that, under the ventilation conditions of these tests, effective reduction in smoke and heat from peak values to ambient values took 350 to 400 s, depending on the compartment's proximity to the door of the compartment of fire origin. Comparisons with the numerical simulation showed that we can predict the environment which develops with reasonable confidence.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

compartment fires; fire growth; mathematical models; numerical models; room fires; smoke; toxicity

13. AVAILABILITY		14. NUMBER OF PRINTED PAGES
X	UNLIMITED	43
	FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NATIONAL TECHNICAL INFORMATION SERVICE (NTIS).	
	ORDER FROM SUPERINTENDENT OF DOCUMENTS, U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, DC 20402.	15. PRICE A03
X	ORDER FROM NATIONAL TECHNICAL INFORMATION SERVICE (NTIS), SPRINGFIELD, VA 22161.	

ELECTRONIC FORM