Full Scale Simulation of a Fatal Fire and Comparison of Results with Two Multiroom Models

ROBERT S. LEVINE AND HAROLD E. NELSON
Center for Fire Research
National Institute of Standards and Technology
Gaithersburg, MD 20899, USA

ABSTRACT

A fire in a kitchen in Sharon, Pennsylvania killed three persons in upstairs bedrooms, one with a blood carboxyhemoglobin content of 91%. Considerable physical evidence remained.

The fire was successfully simulated at full scale in a fully instrumented seven room test called Sharon 2. The data are used to evaluate the precision of two multiroom fire codes; FAST 18 and HARVARD 6.3.

During the simulation, a coherent ceiling layer flow was observed that quickly carried high CO concentrations to remote compartments. Such flow is not directly accounted for in either fire code. However, both codes well predict the CO buildup. Prediction of temperatures was less successful. Hypotheses are presented as to the reasons for the differences. At least some are believed due to phenomena not in the codes.

INTRODUCTION

About 2:00 a.m., on Saturday, September 26, 1987, a kitchen fire in a three-bedroom duplex house resulted in the deaths of three young women living in the house in Sharon, Pennsylvania. Figure 1 is a floor plan of the facility. For the most part, the fire itself was confined to the first floor kitchen. All three of the victims were on the second floor. All had apparently been awakened, presumably by one of the two smoke detectors in the house. Two died during the fire of carbon monoxide poisoning; one was rescued but badly burned. She died later that day. Since the kitchen had wood paneled walls and a combustible ceiling, the total burning surface in that room was very large and the fire generated much more fuel than that which could be burned by the air in the building plus that drawn in through the kitchen windows which broke during the fire.

Prior analysis by NIST (Nelson [1]), has indicated a potentially lethal condition when:

a. The fire has a large readily available fuel supply (in this case, the combustible walls and ceiling in the kitchen).

b. There is enough air to sustain a serious fire (in this case, the air drawn through the broken kitchen window is consumed by the fire).

c. The fuel source (burning walls and ceiling) continues to supply more fuel to the fire than can be burned by the available air within the building.

d. There is an opening from the burning room (kitchen in this case) to the rest of the building and the potential victims are in that portion of the structure.

When this combination of conditions occurs, it is believed that the fire abstracts the oxygen from the air in the building and replaces it with harmful products of combustion, the main lethal products being carbon monoxide and carbon dioxide. In addition, the amount of available oxygen can be reduced below that necessary to sustain life. As has been demonstrated by Zukowski [2], Beyler [3], and others, the CO/CO_2 ratio rises sharply as the fuel to oxygen ratio rises beyond the stoichiometric ratio for the particular fuel.

The fire site was investigated by the authors. The on-site evaluation indicated that the conditions described above may well have occurred in this fire. The damage to the building (confined mostly to the kitchen) as well as the apparent causes of death of the victims supported this thesis. To better investigate this potential, a fully instrumented, full-scale test, involving arrangements and conditions approximating those in the actual fire were conducted in the NIST test facilities at Gaithersburg on September 28, 1988. This test has been identified as Sharon 2.

The two-story "townhouse" test arrangement was used. The townhouse was configured as shown in Figure 2. Nine thermocouple trees, each with eleven or more thermocouples and five sets of gas composition ($CO/CO_2/O_2$) instruments were installed. Three additional oxygen meters were used. The fuel load consisted of wood cribs and sheets of plywood. This load was weighed continuously during the fire by a load cell arrangement.

The breaking of the kitchen window during the Sharon, Pennsylvania fire was simulated by an aperture with a value of $A\sqrt{H}$ related to the kitchen windows broken in the actual accidental fire. Calculations made to plan the test indicated that twelve wood cribs would be sufficient to drive the simulated kitchen to flashover. Eighteen were actually used, along with sheets of 0.014m (1/2 inch) thick plywood. The total weight of the fuel was in excess of 200 kg. The total surface area was enough to insure that the fire would maintain itself in a flashed-over condition through a significant portion of the test. Ignition was made using heptane in trays to assure rapid involvement. There was no attempt to simulate the ignition conditions that occurred in the actual Sharon fire.

Video records were taken. Both an internal view through a window and external views were recorded. The internal view provided data until such time as smoke conditions obscured any further information.

Results

Flashover conditions occurred about 125 seconds after ignition. The "window" aperture was opened at 134 seconds. The fuel weight loss curve is shown in Figure 3.

Figure 4 shows several oxygen concentration-time curves. It should be noted that the oxygen concentration of gas coming out of the burn room and that at the head of the stairs are nearly identical. This is interpreted as an indication that the ceiling layer jet from the burn room traversed two

downstairs rooms, made a 180° turn, and flowed up the sloped ceiling of the stairs without gaining oxygen or hence, losing CO concentration. This may provide an explanation for the very high COHB concentration in one of the victims. It is possible that briefly after flashover, she was inundated with a ceiling wave with a sudden massive increase in carbon monoxide concentration. As shown in Figure 5, the CO/CO_2 ratio reached nearly 0.5 early in the fire and remained there for 25 seconds.

The video recordings through the kitchen aperture (window) commenced when the window was opened. Flashover was developed by that time. These videos show intense mixing in the burn room and intense smoke. This is interpreted to mean that wood not near the opening is burning in an extremely oxygen deficient gas while pyrolyzing rapidly due to the high radiant flux from the regions near the opening that were accessible to the fresh air. It is believed that the fire in the burn room was heterogeneous and not a simple well mixed reactor. This may well account for the high CO output early in the fire.

The measured ceiling layer temperature in the upstairs bedrooms reached 220°C. This value was in the range corresponding to the fire damage and harm that occurred on the second floor in the actual Sharon fire.

Comparison of Mathematical Models with Data

FAST 18 [4] and HARVARD 6 [5] are multiroom models. FAST 18 is the basis for the current version of the HAZARD I evaluation system [6]. The extensive data recorded in this test provided an opportunity to evaluate these models. In such multiroom models, any erroneous results in calculating parameters for intervening rooms will not be compensated for in subsequent rooms. This instrumented test of a seven room facility provided an excellent opportunity to severely test these two models.

Figure 6 shows the CO-time curve for the ceiling layer in the sixth bedroom and compares it with the calculation of both models. This parameter has the best correlation of data and calculation of any of the variables tracked by the test and calculated by the models. The calculations diverge from the data only after the CO concentration exceeds 4%. There would be no human survival at this concentration.

Figure 7 shows upper level temperatures versus time measured in the test. Figure 8 shows calculated values from FAST 18 and Figure 9 shows calculations with HARVARD 6. Both programs calculated lower temperatures in the second room than that which was achieved in the test. This under-prediction cascaded in subsequent rooms. Therefore, all of the rooms beyond the fire room were under-predicted in terms of temperature. It is hypothesized that the hot gases in the real fire were shielded by a dense layer of soot and did not lose as much heat as calculated by the radiation routines in both of the models. The HARVARD 6 calculation indicates that such a radiation shield could have reduced the radiant losses by a factor of 4 to 5.

Further test runs were made with FAST 18, varying the value of Limiting Oxygen Index. In FAST 18, this is the value, in percent, below which the model assumes no burning in the oxygen depleted layer. The initial run (the solid lines in Figure 8) used an index of 6% and the under-prediction described

above occurred. Additional runs were made with indices of 2% and 0%. The 0% results are shown as dashed lines in Figure 8. As the index is lowered, the temperatures calculated by FAST 18 for the Sharon simulation increased. This impact is present after flashover. The actual fire at this time was highly turbulent. It is possible that the plume entrainment assumptions used in FAST 18 are not valid under this condition.

One of the upstairs bedrooms (as shown in Figure 2) was vented to the outside by a small window. The other bedroom was not. HARVARD 6 calculates large differences in the flow through the doorways but as shown in Figure 10 (CO vs time), substantially the same flow entered each room.

This would indicate that some phenomenon is augmenting the flow through the doorway of the dead-ended room. It is possible that the warm gases in the room lose heat the walls, and the cooled gases losing buoyancy, flow out through the lower portion of the doorway. This sets up a circulation that encourages the flow of hot gas into the top part of the room.

This particular calculation was conducted only on HARVARD 6 because the version of FAST 18 used has a maximum of six rooms.

Modelers frequently look at the changing height of the interface between the ceiling layer and the floor layer as an indication of satisfactory operation of the model. In this case, only the burn room data shows a sharp interface. In all the other rooms, the thermocouple trees show a continuous gradation of temperature from floor to ceiling. If it is assumed that the "layer height" is the level of which temperature increase is 15% of the final temperature increase (a frequently used criterion), FAST 18 best matches the results for the first 200 seconds. If we assume the "layer height" is where half the temperature increase occurs, approximating the enthalpy definition of layer height, HARVARD 6 does best.

Several of the following items raise research issues.

1. The CFR simulation test results agreed with the physical evidence and the field hypotheses made during the on-site investigation.

2. Ceiling jet flows can occur without dilution by other gases and can carry toxic gases quickly from the fire room to remote locations (in this case, on a different floor).

3. Gas concentrations in a flashed over room with distributed fuel packages can quickly reach CO/CO_2 ratios as high as 0.5.

4. Both FAST 18 and HARVARD 6 reasonably calculate the onset of toxic hazards in a multiroom flow. An exception to this conclusion is the additional ceiling jet flow observed in the CFR test and suspected in the Sharon fire.

5. Radiant heat losses from very hot gas appear to be over-predicted in both models. This may be due to shielding by soot surrounding the hot gas flow.

6. There may be a mechanism increasing the doorway flow and the transfer of hot gases into dead-ended rooms beyond that calculated by FAST 18 and HARVARD 6.

7. Combustion in the flashed over burn room may not properly be simulated by current plume entrainment assumptions.

8. The ceiling layer height is a questionable parameter on which to judge the success of a model, particularly in rooms remote from the fire.

9. The test data produced are available for comparing other model predictions.

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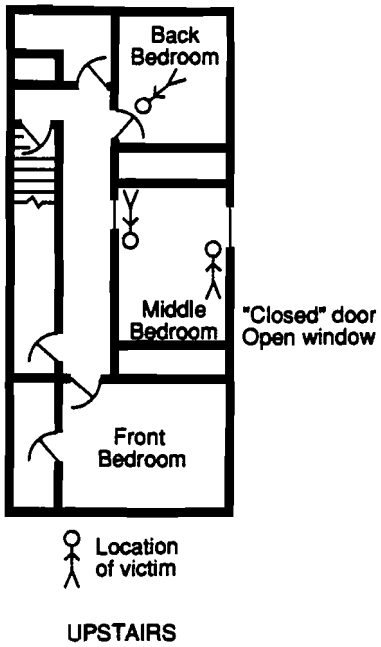
2. Zukowski, E.E., Personal Communications.

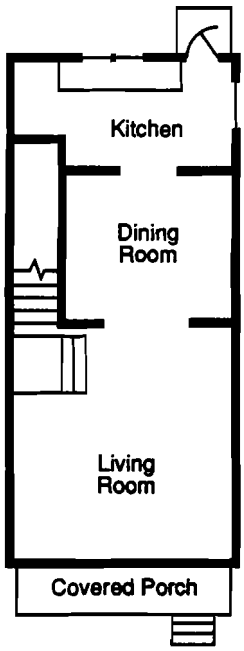
3. Beyler, C.L., Major Species Production by Solid Fuels in a Two-Layer Compartment Fire Environment, Fire Safety Science - Proceedings of the First International Symposium, International Association for Fire Safety Science, Hemisphere Publishing Corp., New York, NY, (1986).

4. Jones, W.W. and Peacock, R.D., Technical Reference Guide for FAST Version 18, NIST Tech. Note 1262, National Institute of Standards and Technology, Gaithersburg, MD, (1989).

5. Rockett, J.A. and Morita, M., The NBS/Harvard VI Multi-Room Fire Simulation, Fire Science and Technology 5, no. 2, p.159, (1985).

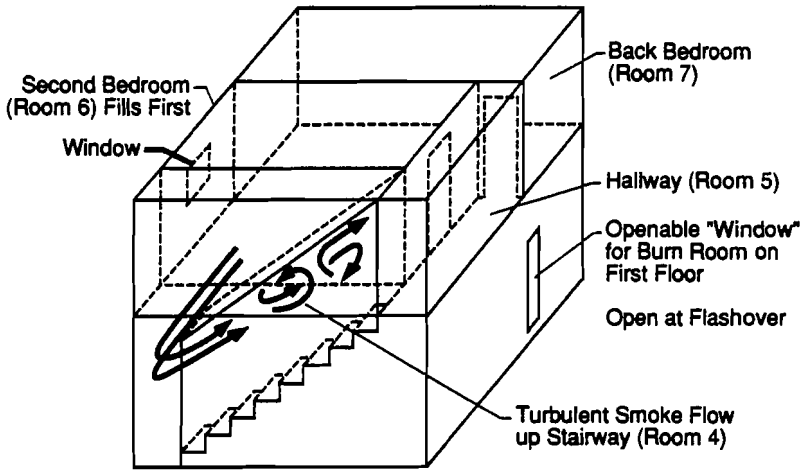


UPSTAIRS

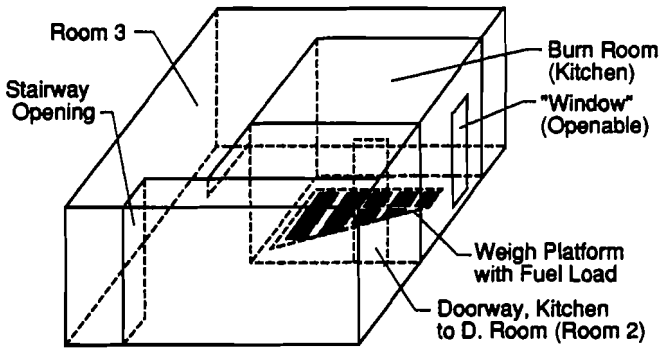


GROUND LEVEL

Figure 1. Floor plan of Sharon, Pa. fire



"TOWNHOUSE" UPPER FLOOR AND ENCLOSED STAIRWAY



"TOWNHOUSE" LOWER LEVEL

Figure 2. Floor plan of Sharon 2 test

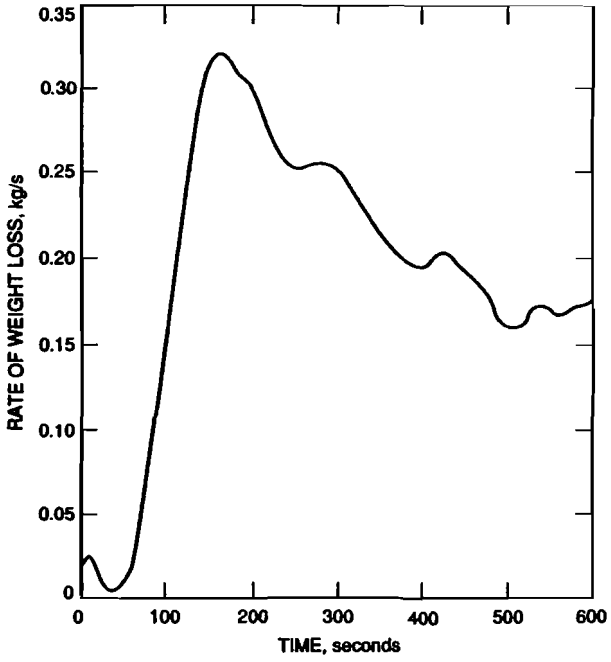


FIGURE 3. Rate of fuel weight loss
Sharon 2 Fire Simulation

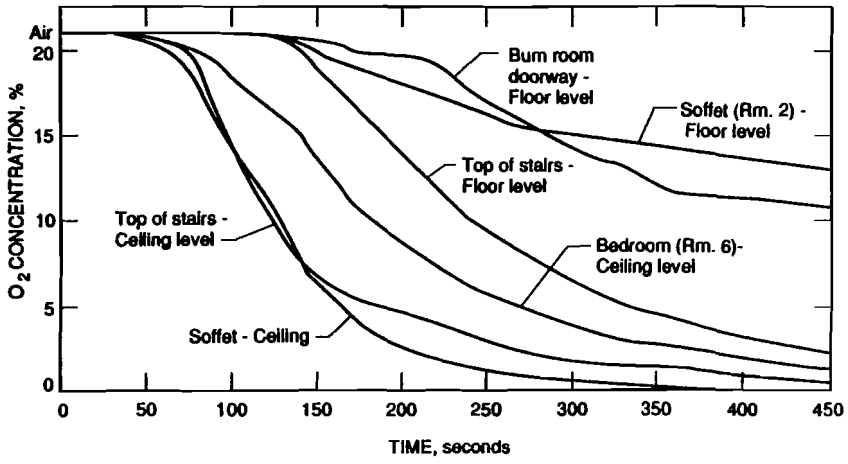


Figure 4. Sharon 2 data - O_2 content at various sampling sites

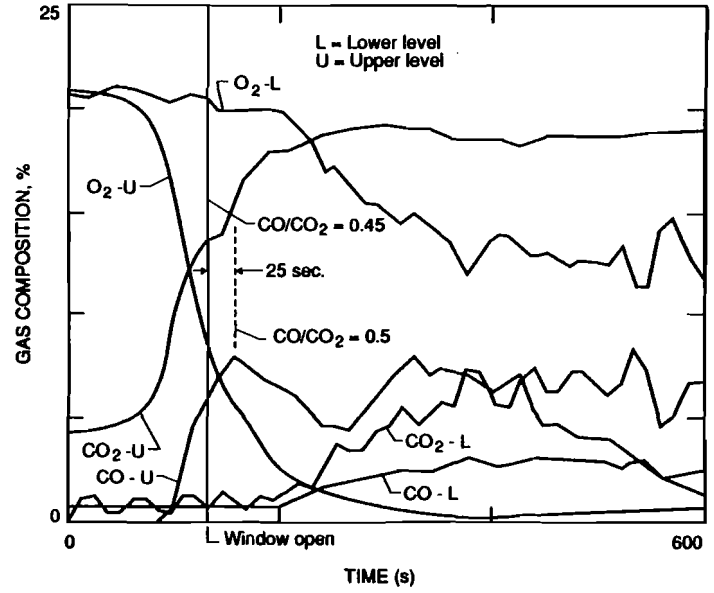


Figure 5. Gas composition of layer flows near burn room doorway
Sharon 2 fire simulation

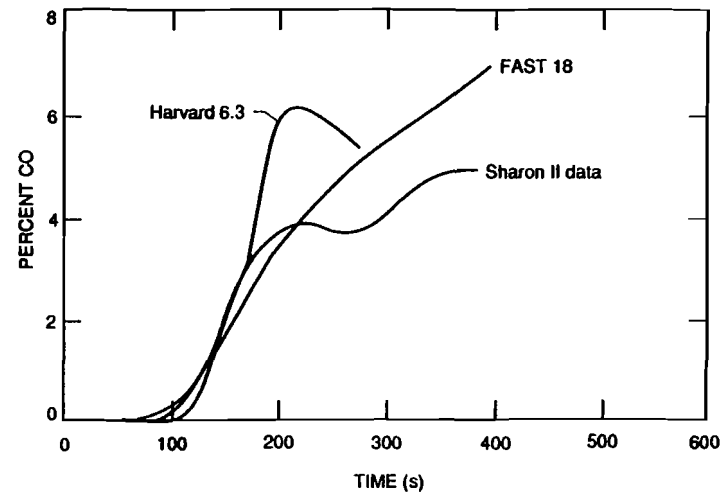


Figure 6. Comparison of Sharon II data and predictions of two multiroom models for the 6th room.

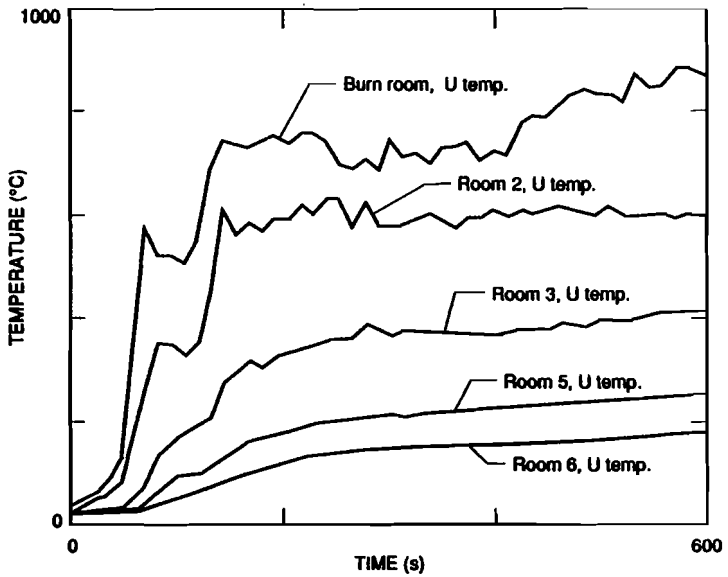


Figure 7. Average ceiling layer temperature for several rooms Sharon 2 Simulation data

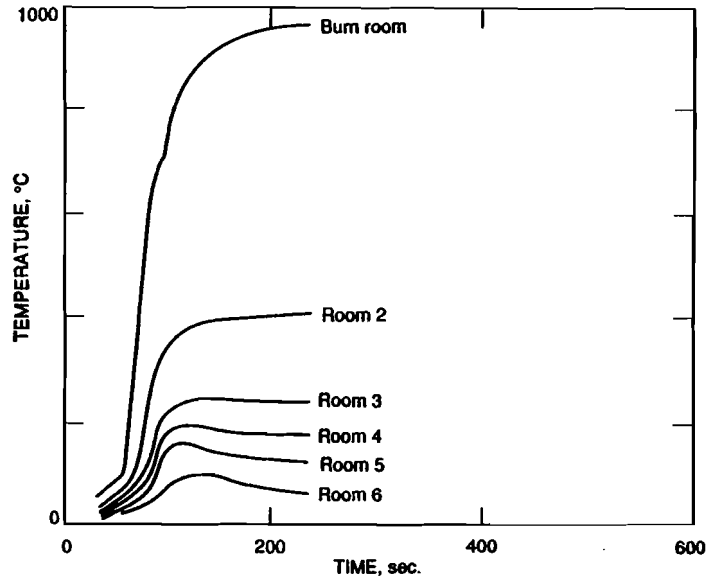


Figure 9. Average ceiling layer temperatures calculated using Harvard 6.3 model of Sharon 2 test

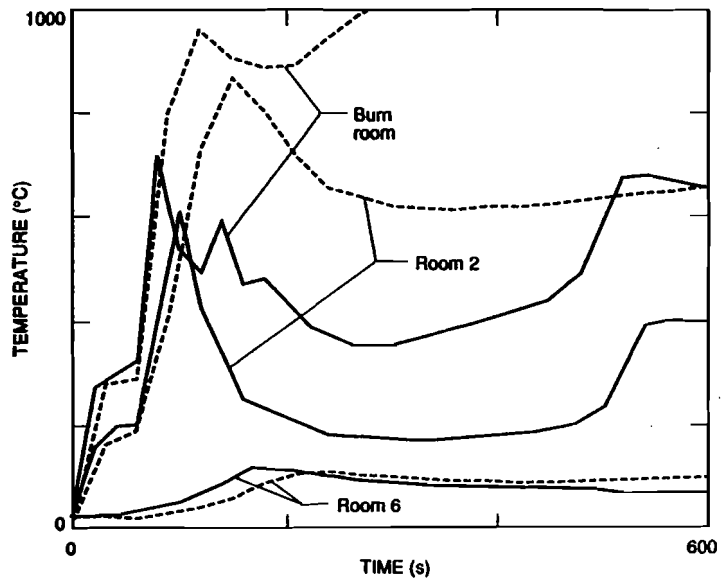


Figure 8. Average ceiling layer temperaures calculated using FAST 18 model of Sharon 2 test

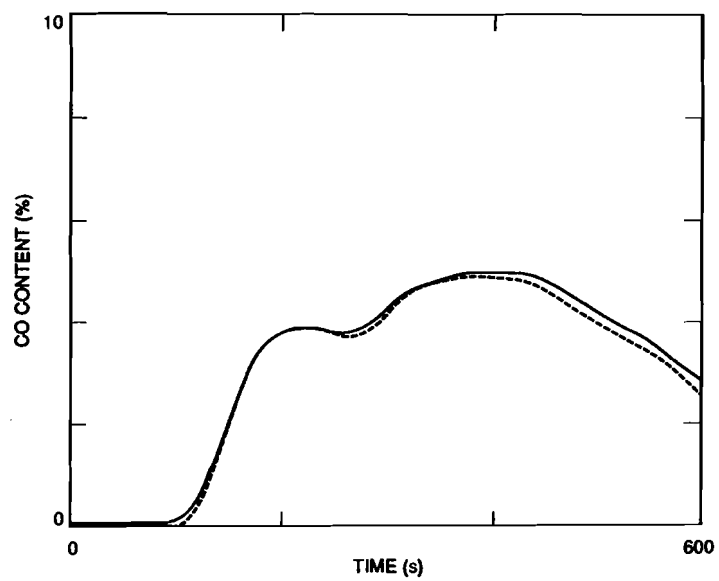


Figure 10. Comparison of CO concentration in ceiling layers of rooms 6 & 7. Measured data from Sharon 2 test