SPRINKLERS, VENT, AND DRAFT CURTAIN INTERACTION - MODELING AND EXPERIMENT

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Abstract

The second and most recent application of the NIST Industrial Fire Simulation (IFS) System is to predict the performance of sprinklers, draft curtains and roof vents in storage facilities and retail spaces. The IFS System is a series of computational fluid dynamics (CFD) fire models based on large eddy simulation (LES) techniques combined with means to exchange data and results. The model requires as input information about the activation properties of sprinklers and roof vents, the spray distribution of the sprinklers, and the burning and extinguishment properties of the commodity under consideration. These are obtained from bench scale and large scale experiments. The IFS2 model was developed and evaluated using a series of heptane spray fires and high rack storage fires of cartoned polystyrene cups.

INTRODUCTION

The IFS System is a major undertaking by the National Institute of Standards and Technology to help industry understand large fire events and intervention strategies with a minimum of testing, especially at large scale. The numerical methodology used in the system is based on the Large Eddy Simulation (LES) Fire Model [1, 2, 3], a computational fluid dynamics (CFD) code that solves the differential equations that govern the transport of smoke and hot gases from a fire. Other important features of the fire simulation, such as fuel properties and thermo-mechanical characteristics of suppression systems, must be obtained from measurements — in most cases at bench scale. The model combines fundamental phenomena of fluid dynamics with laboratory measurements of fire-specific phenomena to focus on those aspects of the problem for which experimentation is too expensive, difficult, or simply impossible to perform.

The first application of the IFS System was to the problem of smoke dispersion from large wind-blown fires. A combination of numerical modeling, laboratory measurements and large scale experimentation yielded a tremendous amount of information about the structure, trajectory and composition of smoke plumes from large crude oil fires. The resulting IFS System product, referred to as ALOFT (A Large Outdoor Fire plume Trajectory), contains a numerical model based on the fundamental conservation equations that govern the introduction of hot gases and particulate matter from a large fire into the atmosphere [4, 5] and data pertinent to oil fires and atmospheric conditions needed to produce results.

The second application of the IFS System, and the subject of this paper, has been to examine the interaction of roof vents, draft curtains and sprinklers in large industrial settings. There has been a long-standing debate in the fire protection community about the effect of roof vents and draft

curtains (curtain boards) on the performance of a sprinkler system. There have been numerous studies over the past few decades to reach a consensus, yet many questions remain. In order to answer these questions, a group of industrial sponsors was organized by the National Fire Protection Research Foundation (NFPRF) to oversee a series of large scale experiments involving both heptane spray burner and standard plastic commodity fires. In all, 39 tests were conducted in a space that was designed to simulate typical storage arrangements found in warehouses, warehouse retail stores, and manufacturing facilities. The experiments were divided into three series: an initial set of 22 heptane spray burner tests, 5 plastic commodity tests, and 12 additional heptane spray burner tests. Because of the relatively small number of commodity tests that could be afforded, a large effort was made to develop the basis for an IFS2 System that could be used to interpret and potentially supplement the physical experiments. In order to do this, technical progress was needed in the areas of burning rate prediction, with and without water sprays, and the prediction of multiple sprinkler response times in industrial building geometries.

GROUP A PLASTIC COMMODITY FIRE SIMULATIONS

Experimental burns of the Factory Mutual Research Corporation (FMRC) Standard Plastic test commodity[1] were performed at Underwriters Laboratories. Two, three and four tier configurations were tested. Figure 1 shows the convective[2] heat release rates for the same experiments compared with those computed in the numerical model. Figure 2 shows what one of these calculations looks like. For the period of time before water application, the agreement of the simulation and experiment is good, but it is unclear how well the agreement would be for longer times. The reason why this might be so is that the heat release rate per unit surface area used in the simulation is based on cone calorimeter burns of a 10 by 10 by 10 cm sample of cardboard surrounding a single plastic cup. The results of the cone burns are most appropriate for the first few minutes of full-scale burning when only the first layer of cups is involved. Beyond that, it is difficult to determine the best basis for burning rate prediction. For the purposes of the present study, a few minutes worth of prediction is sufficient because the sprinklers are expected to activate within about a minute of ignition.

A very useful application of the IFS2 model has been to simulate the five standard plastic commodity tests included in the NFPRF Sprinkler, Vent and Draft Curtain Project in order to verify the conclusions drawn from the experiments. The benefit of the numerical model in this application is that it provides a consistent means of varying test parameters and adds insight into physical phenomena that is not always easily seen or measured in large scale tests.

The commodity burn that caused the most damage was Test 3. In this test, the ignition point was placed close to the intersection of two draft curtains (see Fig. 3). An estimated 184 boxes were consumed during Test 3, compared to 103 in Test 4, a similar test where the only difference was that the ignition point was far from the draft curtains (see Fig. 4). In Test 3, 19 sprinklers activated; in Test 4, 5 sprinklers activated. It appears that the position of the draft curtains with respect to the racks accounted for the difference in results, but it is not immediately clear exactly why. A

[1]The FMRC Standard Plastic test commodity consists of rigid crystalline polystyrene cups packaged in compartmented, single-wall cardboard boxes [6].

[2]Based on measurement of the heat flux of the exhaust gases through the hood.

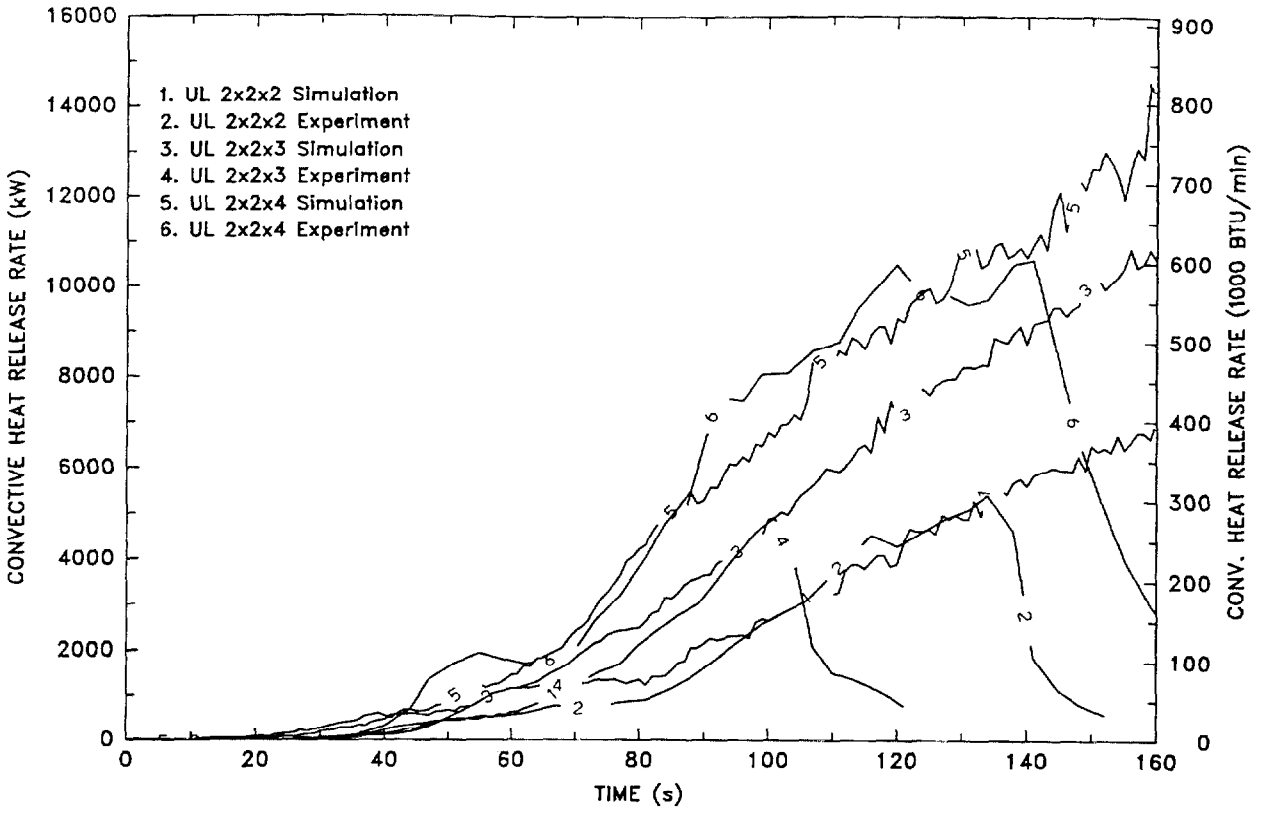

Figure 1: Comparison of experimental and simulated convective heat release rates for the two, three and four tier calorimetry burns of the plastic commodity.

replicate test could not be done given the constraints of the project budget. The measurements performed in the tests were limited to thermocouples arrays near the ceiling. There were no direct measurements with which to infer how the sprinkler spray interaction with the hot ceiling layer was affected by the draft curtains.

To gain insight into the problem, numerical simulations of both tests were performed. The calculations were performed with a spatial resolution of 0.2 m, covering a volume of dimension 20 m by 20 m by 9 m. Each palletload of commodity was discretized into a 5 by 5 by 6 array of cells. The heat release rate per unit surface area was prescribed as a function of time based on cone calorimeter measurements. Other empirical inputs included the thermal properties of the sprinklers obtained from plunge tunnel tests, and the thermal properties of the cardboard including its ignition temperature, absorption capacity and a simple model of extinguishment. The calculations required about 24 hours on either an IBM RISC/6000 or an SGI R10000 workstation. The calculation of thermal radiation from the fire to the sides of the boxes accounted for about 20% of the CPU time.

Figures 5 and 6 present the results of the simulations of Tests 3 and 4. Sprinkler activation times from the experiments (E) and simulations (S) are indicated. The vent nearest the ignition point in Test 3 opened at 4:11, and no vents opened in Test 4, thus venting did not have any impact on the

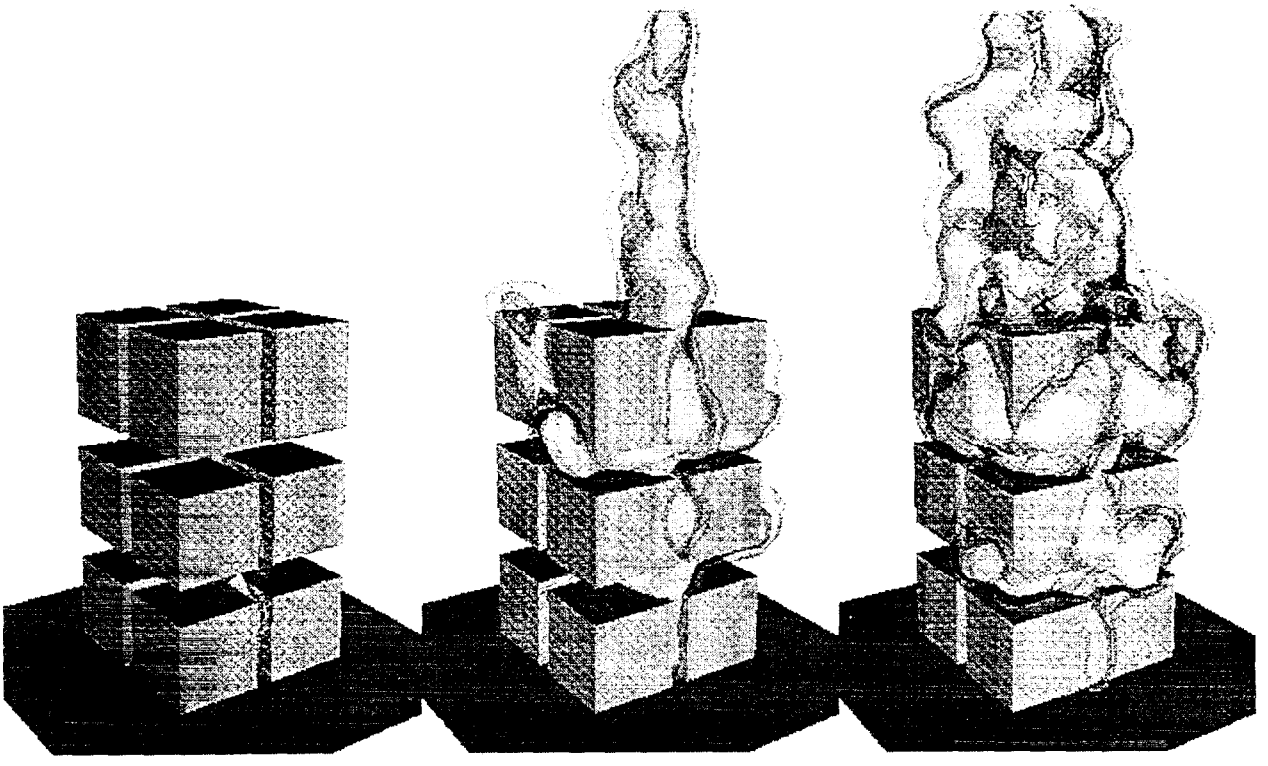

Figure 2: Simulation of three tier calorimetry burn at 30, 60 and 90 s following ignition.

results in either case, at least for the first 4 min. Clearly, the draft curtains had an effect on the performance of the sprinkler system. The draft curtains delayed the opening of the two sprinklers directly north of the first two sprinklers to activate. Less obvious, the draft curtains changed the near-ceiling flow pattern of both the sprinkler spray and the fire plume. Regardless of the sub-model used to simulate the burning of the standard plastic commodity, the calculation showed that less water reached the north side of the central array when the draft curtains were installed. Figure 8 shows a snapshot of the two simulations after 5 min. In Test 3, the fire has spread to the north face of the array, whereas in Test 4 the sprinklers in the north aisle prevent the spread to the north face.

The snapshots shown in Figs. 5 and 6 show that the simulation was able to provide correct predictions of the potential for trouble when a fire originates near draft curtains. In Test 3, the model predicted the activation of 21 sprinklers. The actual test showed 19. Both of these are far greater than the number of sprinklers activated (5) and predicted (4) in Test 4 where the ignition point and fuel array was away from the intersection of the draft curtains. Although the position of sprinklers predicted and actually operated did not always agree, the good prediction of the total number is a secondary indication that the model for the burning rate of the fuel (see Fig. 7) after sprinkler response, when measurements are not available, is capturing the important trends.

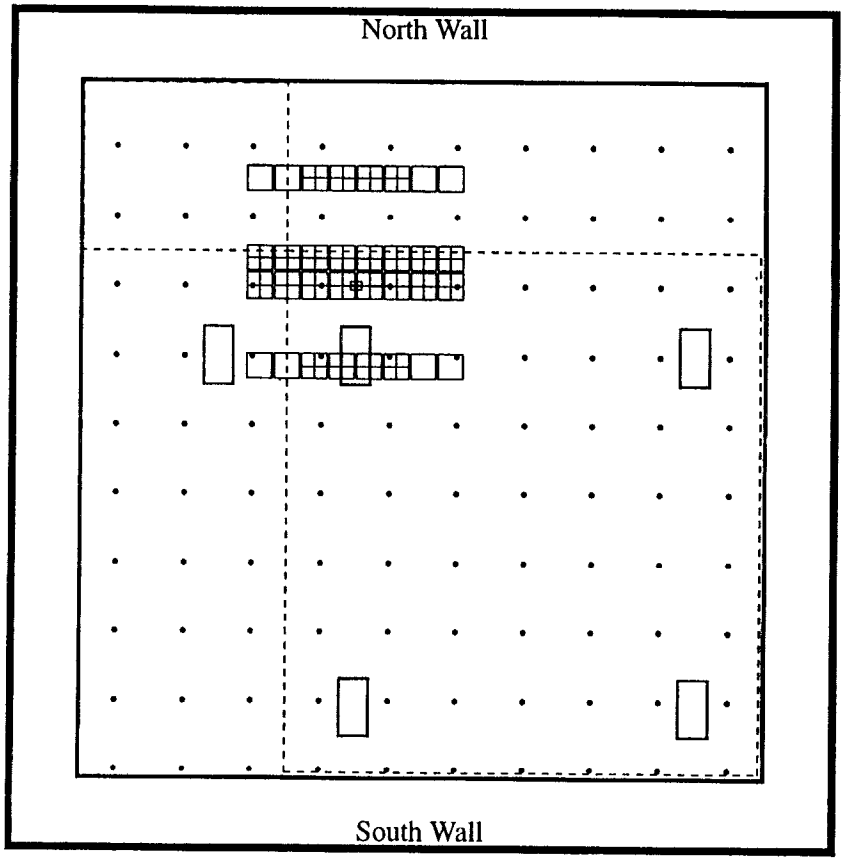

Figure 3: Plan view of the UL Large Fire Test Facility with the set-up for Test 3. The dimensions of the facility are 36.5 m by 36.5 m (120 ft by 120 ft). The adjustable height ceiling (inner square) is 30 m by 30 m (100 ft by 100 ft), and it was raised 8.2 m (27 ft) above the floor for this test. The sprinklers (dots) were spaced 3 m (10 ft) apart. The vents (rectangles) were 1.2 m by 2.4 m (4 ft by 8 ft). The ignition point is indicated by four small squares near the center of the fuel array. The 1.8 m (6 ft) deep draft curtains are indicated by the dashed lines.

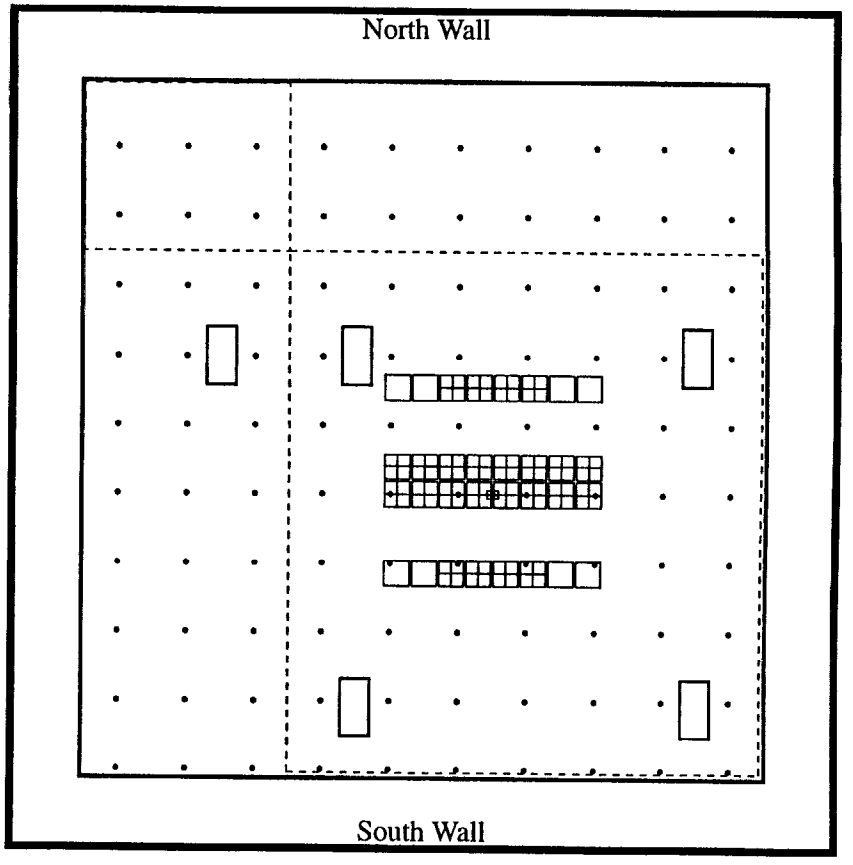

Figure 4: Plan view of the UL Large Fire Test Facility with the set-up for Test 4. The dimensions of the facility are 36.5 m by 36.5 m (120 ft by 120 ft). The adjustable height ceiling (inner square) is 30 m by 30 m (100 ft by 100 ft), and it was raised 8.2 m (27 ft) above the floor for this test. The sprinklers (dots) were spaced 3 m (10 ft) apart. The vents (rectangles) were 1.2 m by 2.4 m (4 ft by 8 ft). The ignition point is indicated by four small squares near the center of the fuel array. The 1.8 m (6 ft) deep draft curtains are indicated by the dashed lines.

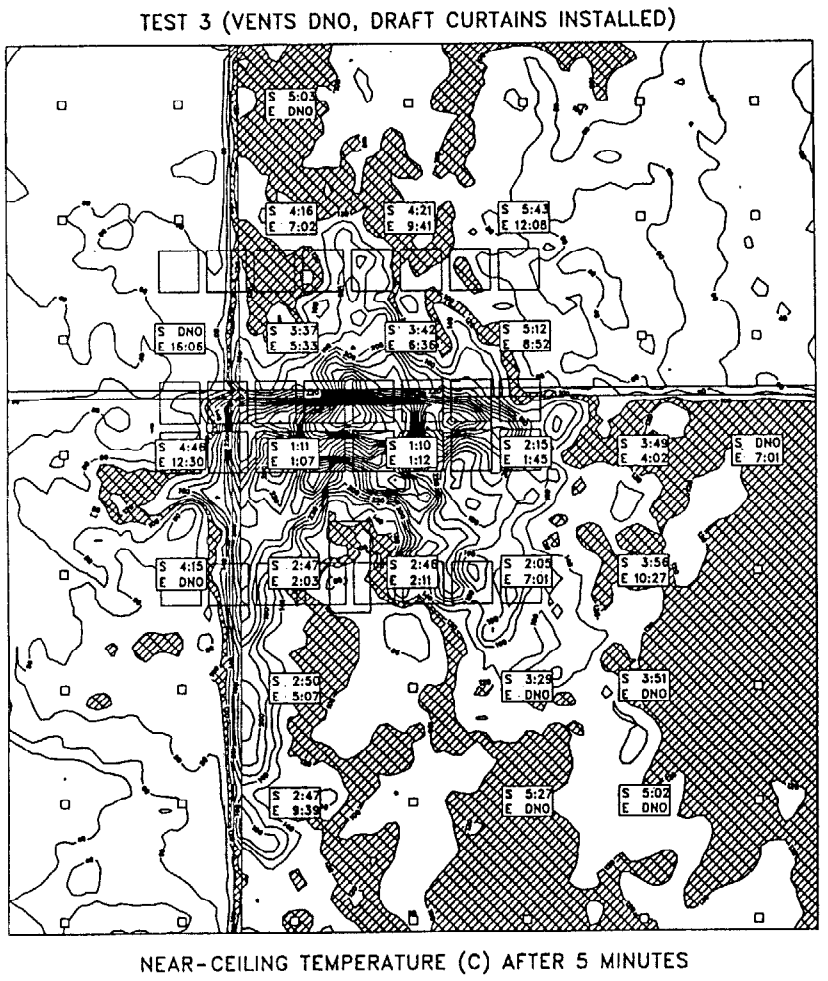

Figure 5: Results of the Test 3 simulation. "S" denotes simulation sprinkler activation time, "E" experiment. The cross-hatched area indicates temperatures between 100 and 120°C.

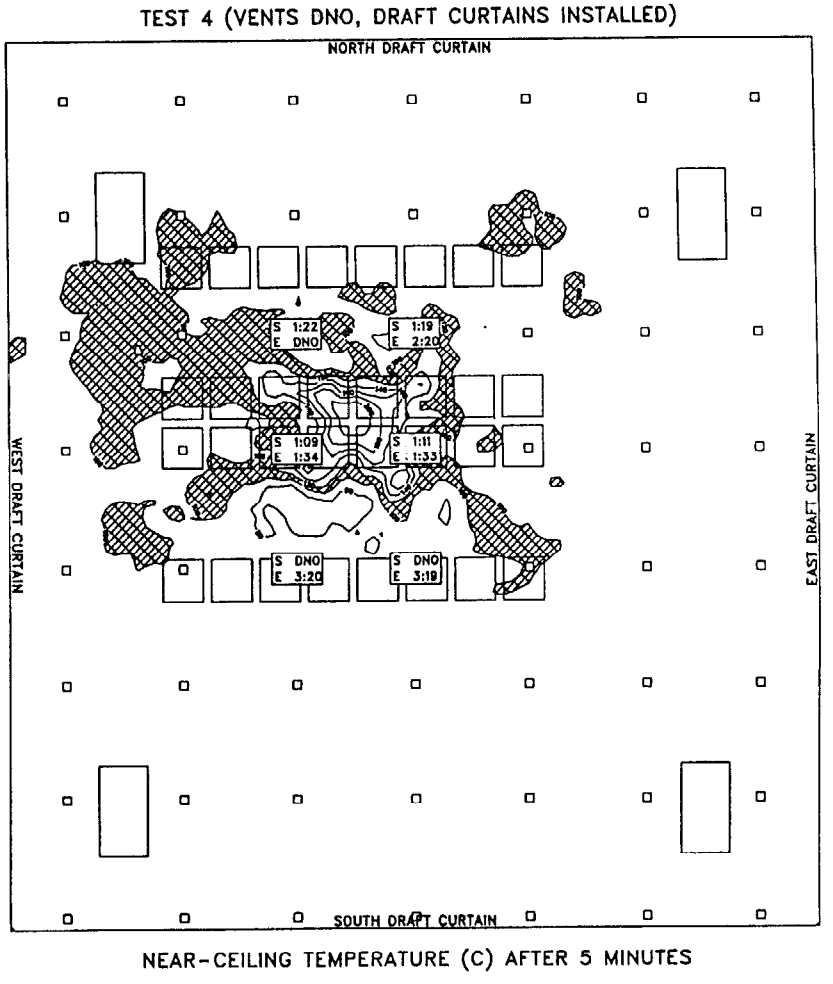

Figure 6: Results of Test 4 simulation. "S" denotes simulation sprinkler activation time, "E" experiment. The cross-hatched area indicates temperatures between 100 and 120°C.

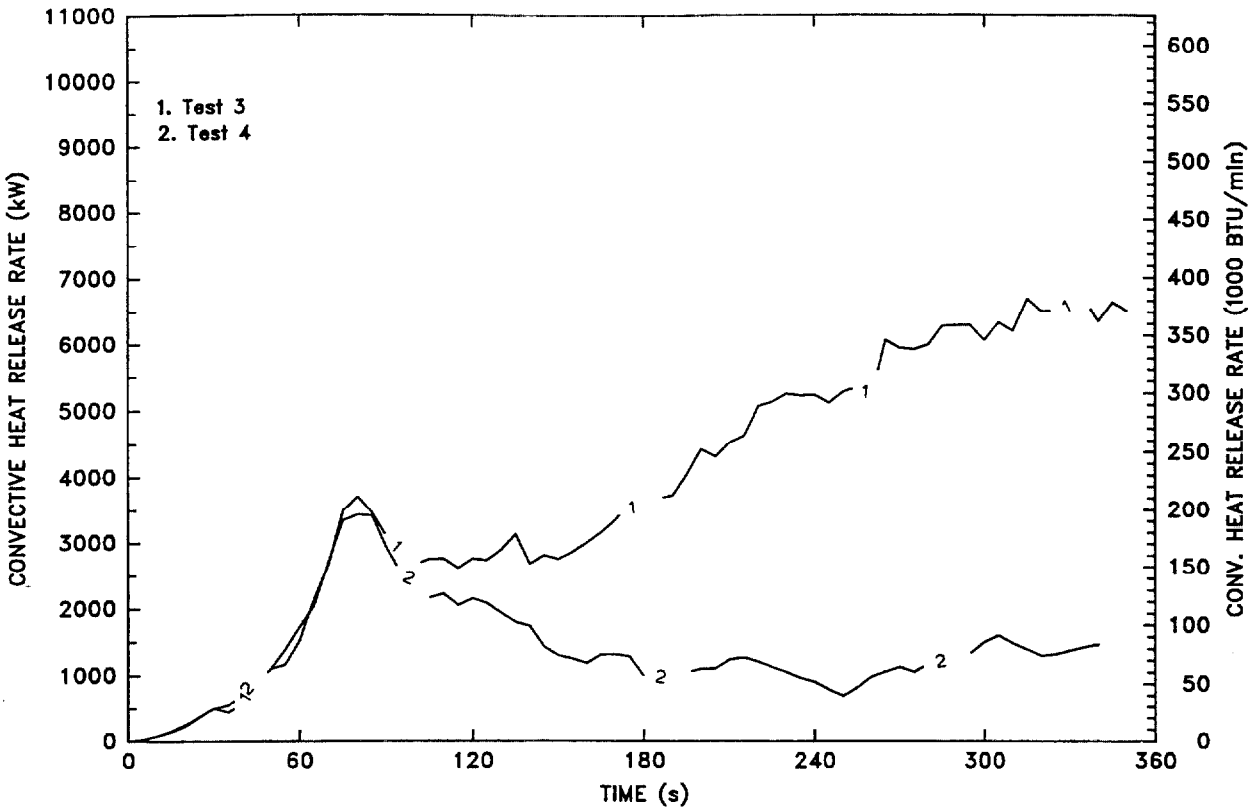

Figure 7: Heat release rates from the numerical simulations of Tests 3 and 4 of the Group A Plastic series.

CONCLUSIONS

The Industrial Fire Simulator 2 (IFS2) predicted the initial growth of standard plastic commodity fires with an accuracy of about 20%, consistent with the accuracy of the bench-scale measurements used to provide the necessary input parameters for the model. The accuracy of the burning rate model could not be assessed directly after the sprinklers activated, but the sprinkler activation pattern served as a substitute. The model was able to distinguish the differences between the commodity tests. The model is sufficient to gain insight into the first few minutes of a commodity test, but cannot be relied upon yet to simulate a full 30 minute test. Additional improvements are needed in the sprinkler response and spray sub-models, burning and extinguishment sub-models, prediction of the geometry of collapsed partially burned fuel, wind effects, and smoke obscuration.

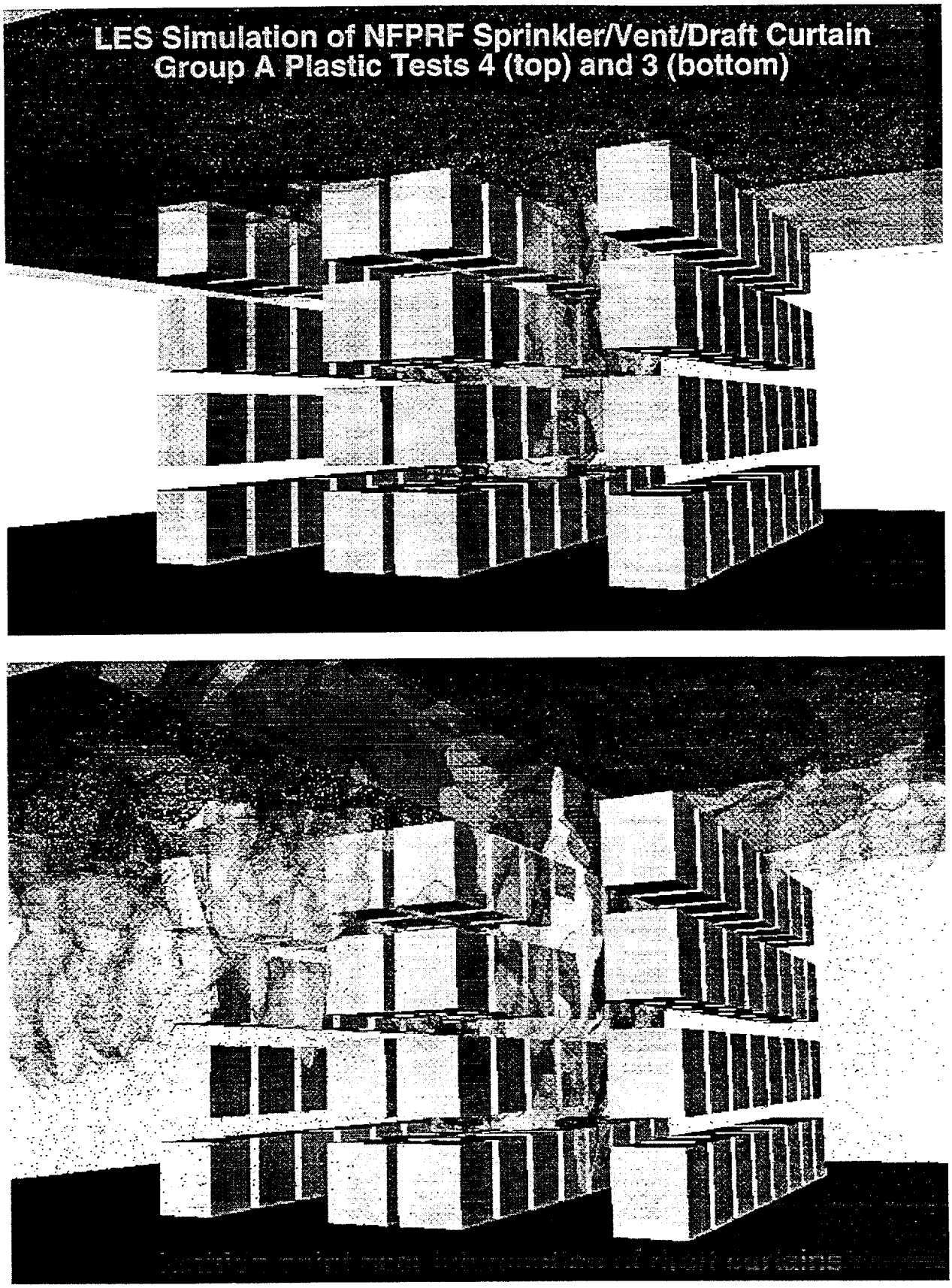

Figure 8: Snapshots of the simulations of Tests 3 and 4 after 5 min.

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