FLASHOVER MODELING FOR DIRECT COURSE

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ABSTRACT

The current fire defense doctrine for nuclear attack preparedness is possibly erroneous. The guidance to local planners has been strongly influenced by the concept that fires started by the thermal pulse of the nuclear fireball are initially feeble and quite susceptible to airblast extinction. This concept ignores a potentially crucial observation made during the days of atmospheric nuclear testing, that has since been termed an anomaly. Nevertheless, this observation may provide the explanation for some of the puzzles--the contradictions of experimental tests vis-a-vis historical fact--that have for years persisted about the incendiary consequences of nuclear explosions in or near urban complexes.

Operation DIRECT COURSE offers an opportunity to resolve a part of the quandary. The question to be answered is whether fires of the rapid fire-growth-to-flashover type, as associated with nuclear thermal-pulse scenarios, are as susceptible to extinction as the current doctrine supposes. This paper describes an experiment designed to gain an answer to that question.

INTRODUCTION

The currently accepted models of the incendiary effects of nuclear explosions in urban areas focus on fire starts in rooms, the underlying assumption being that fires in rooms will dominate the outcome. Unquestionably, fires in rooms constitute a category of special interest in fire growth dynamics. The enclosure not only serves to limit air supply to the fire, but it conserves a portion of the heat released by the fire to intensify it, often leading to a relatively abrupt involvement of the entire room and its contents in an event called "flashover." Viewed operationally, as well as in straight forward damage assessment terms, flashover is a critical endpoint to the development of the incipient fire. The nuclear-effects predictive models customarily treat the incipient fire, prior to flashover, as a feeble--and therefore blast-sensitive--stage in the growth of the fire. Full-scale tests of incipient room fires that were conducted in the Ft. Cronkhite blast tunnel in 1970 (1) consistently resulted in blowout thresholds only slightly higher than 2 psi. Even under airblast conditions failing to extinguish it, the conventionally modeled fire is perceived to be still quite easily extinguished by prompt action of the first-aid firefighting sort, up to the onset of flashover (2). There is good reason to believe, however, the conventional wisdom may be wrong.

During the ENCORE event (3) of Operation UPSHOT/KNOTHOLE in 1953, a furnished room, its window facing the fireball, flashed over in less than a minute after exposure to a thermal fluence of about 25 cal/cm^2. The building was rapidly destroyed by a fire that did not blow out despite an incident air blast of about 6 psi or higher peak overpressure. A conclusion that the ENCORE response, rather than being an anomaly, is the more realistic situation to expect--as opposed to the slow buildup of fire from a feeble and airblast-vulnerable start--could go a long way toward providing the explanation for some of the puzzling inconsistencies between experimental results and the historical experiences. Should such a conclusion be substantiated by further research, it could significantly impact current perceptions of the dynamics and threat potential of fire caused by nuclear explosions. In turn, it might lead to modification of civil defense planning, calling for reexamination of such operational concepts as crisis relocation, the choice and design of risk-area shelters, and the efficacy of preattack fire-defense preparations and both trans-attack and post-attack firefighting strategies.

THE EXPERIMENT

OBJECTIVES

The objective of the room-fire experiments at DIRECT COURSE is to determine the susceptibility to blowout of fires that are dynamically comparable to the ENCORE response. The tests are to be conducted to reveal effects of fire intensity, representing differences in time intervals between fire initiation and blast wave arrival.

SCOPE

This experiment comprises the test of four separate blockhouses (of non-responding design), furnished as a representative urban occupancy, with fire initiated by propane gas supply. Two distinct variations are planned: (1) a room fully flashed over prior to shock arrival; (2) a room experiencing rapid heat buildup at the time of shock arrival, but not yet flashed over. Two blockhouses, one of each of the two fire-state variations, will be located together in the DIRECT COURSE test bed at a distance expected to experience a peak overpressure of 7 psi. An additional variation (1) blockhouse will be located to experience a 9 psi overpressure, and an additional variation (2) blockhouse, to receive 3 psi.

Details of the experiment are given in a companion paper to be presented at this conference. This paper focuses on the requirement for reliably achieving the prescribed fire state at the instant of blast wave arrival and on the theoretical/empirical basis for selecting the experimental conditions to ensure that this requirement is met.

EXPERIMENTAL RATIONAL

DESIGN CONSTRAINTS

Dynamic similarity to the ENCORE event requires rates of rise in temperatures that are not ordinarily encountered in growing fires. To properly simulate exposures to the high thermal radiation fluxes from a nuclear fireball, large rates of heat release within the room must be provided in some alternative manner, and the duration of heat supply must be short. By comparison, the development of quasi-steady flow of air into, and combustion products out of, the room is a much slower process. Accordingly, even after flashover occurs, conditions in the room that influence its fire behavior continue to change with time. Therefore, the elapsed time between flashover and shock arrival must be controlled by experimental design. In the room fires that have not yet reached the flashover stage by the time the blast wave impacts them, predictable conditions can be achieved only by close control of the rate of fire growth and the elapsed time from fire initiation to shock arrival.

BACKGROUND CONSIDERATIONS

In designing the room fire experiments for DIRECT COURSE, the following factors have been considered:

- It is desirable to relate these experiments to the blockhouse tests at ENCORE (a 27-KT yield airburst, at a height of 2425 ft) that were fielded by the U.S.F.S. Forest Products Laboratory.
- It is also desirable to relate these experiments to the reduced-scale model experiments conducted at SRI in 1978 for the Products Research Committee (PRC, see Ref. 4), because of the potential this offers for predicting flashover conditions and unsteady characteristics of compartment-fire growth. This would require designing the DIRECT COURSE experiments to retain geometric similarity and to preserve the magnitude of several non-dimensional parameters pertaining to fuel supply and convective flow.
- Several other experiments are expected to have a bearing on the design of the DIRECT COURSE room fire experiments. (See, as examples, Refs. 5 through 10).

Further elaboration is given below.

Details of the ENCORE Blockhouses

The ENCORE Blockhouses had approximate inside dimensions of 9½ ft width, 13 ft depth, and 8 ft ceiling height. The single opening, a window, was 6 ft wide and 4 ft high, centered in the front wall, its soffit about 2 ft below the ceiling. Accordingly, each FPL blockhouse had a plan area of about 123 ft^2 (11.5 m^2) and a volume of about 988 ft^3 (27.9 m^3). The volume of room air above the window soffit was about 246 ft^3 (7 m^3), and the (Kawagoe) ventilation factor of the window was 2.46 (mks units)*. It is estimated that during the (2 second) thermal pulse prior to shock arrival, the window transmitted 5×10^5 calories to the room interior (about 2 megajoules), and that flashover occurred in about 30 seconds.

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*The significance of this is that, once steady flow through the room is established, ventilation sets a limit on the rate of heat release in the room to a value in the range 2×10^5 to 7.3×10^5 cal sec^{-1} (roughly 1 to 3 megawatts).

The PRC Model

The PRC model was roughly a third-scale counterpart of the ENCORE blockhouses. Among the PRC experiments, the configuration that best simulated ENCORE was the one used in the 14 tests numbered 40 through 57, in which a window of 18-inch width and 17-inch height was used, having a 9-inch ceiling-to-soffit drop.

The PRC enclosures were lined with insulating wallboards (Kaowool M-board and Marinite XL) and heated with a propane-fueled diffusion flame burner. The propane supply rate ($\dot{m}_v$) was held constant in each test; but, from test to test, varied over the range from 0.3 to 2.0 SCFM (about 0.28 to 1.84 g/sec). The shortest estimated times to flashover conditions were 40 to 45 seconds, achieved only when Kaowool M-board insulated the walls and ceiling. Test No. 51 was judged to have arrived at flashover conditions in 52 seconds. In this test, the propane supply rate was 1.38 g/sec ($\sim$ 15.2 kcal/sec rate of heat release, $\phi \equiv \dot{m}_v/1.6W_oH_o^{3/2} = 6.6 \times 10^{-3}$)*, with the burner positioned in the middle of the floor. Extrapolation to 30 seconds (the approximate time to flashover in ENCORE blockhouse No. 1) would require 2.2 g/sec propane flow ($\sim$20 kcal/sec heat release rate, $\phi = 10.6 \times 10^{-3}$).

Over long periods of heating, the heat released in the PRC enclosures was divided roughly equally between convected enthalpy flow out of the window and heat stored in the upper region of the room (hot gases and flames trapped under the ceiling, above the soffit, and heated ceiling and upper wall boards). At early times in such situations, however, a disproportionate share goes into heating the upper portion of the room, and the heat losses are relatively independent of window size, being more dependent on an area of the ceiling (specifically on the scale-factor squared and either the interface heat-transfer coefficient, h, or the thermal inertial, $k\rho c$, of the wallboard) than on volume of the room (i.e., scale-factor cubed and heat capacity of the air). For cases like ENCORE, we may be justified in disregarding h also.

DESIGN FACTORS

The enclosure design is a full-scale approximation to the FPL blockhouse that was exposed to the ENCORE nuclear airburst, retaining as much as possible of the geometry, thermal, and flow properties of the PRC model. Because of the remaining uncertainties about the role of the thermal properties of wall and ceiling insulation, we plan to use Kaowool M-board for this purpose. Most of the PRC experiments were conducted with this material. It is quite serviceable, and due to its low thermal inertia, it offers the prospect of rapid flashover with relatively low expenditure in fuel supply. For the DIRECT COURSE blockhouses, a window identical in size and geometry to the ENCORE case has been selected, and it is planned that they be furnished following the description published in the WT-Report (Ref. 3). The following material is provided in justification of the selected design.

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*The constant 1.6 is in mks units.

Blast Filling

To minimize the effects of the particular details of the pressure-time history that acts on the experimental enclosures at DIRECT COURSE, and, by so doing, making as generally applicable as possible the results, e.g., independent of explosion yield, the room filling time should be kept short in comparison to the duration of the airblast overpressure. Rempel (11) notes that most room filling situations lie in the regime that cannot be simplified as approximate to either the case in which the opening is such a large part of the wall that the blast wave passes into the room with only slight perturbation or the case in which the opening is so small that filling is not a shock process at all. With the admonition that any simplified method of calculation requires independent checking, Rempel (11) offers the following as an approximate estimate of the time of room filling (in ms): V/2A, where V is the room volume in cubic feet and A is the area of the window in square feet. He notes that this is an empirical relationship in which the dimensions cannot be changed willy-nilly. This predicts for the FPL blockhouses at ENCORE a filling time of about 20 ms. Even if we scale the volume up (with a scale factor of 3) from the PRC model to 1296 ft^3, the filling time increases to only 27 ms. Within this time period, we can expect the free-field overpressure at DIRECT COURSE to decay to no less than 80% of the peak value, reasonably approximating a time-invariant external pressure. At the same time, since the window opening is ¼ of the area of the shock-incident wall, substantial effects of the transmitted shock can be expected within the room.

Fuel Supply

To achieve flashover in a period of roughly 30 sec, the fuel supply rate needs only be scaled from the PRC tests in accordance with the change of enclosure dimensions. Flashover in 30 sec was extrapolated for the conditions of the PRC tests (with Kaowool M-board) to a fuel supply rate of 2.2 g/sec (propane). Further scaling to a 12 ft x 12 ft plan area, increases the supply rate by a factor of nine (x9) to about 20 g/sec, or a gaseous propane supply rate of about 21 SCFM.

Although the convective flow providing the continued oxygen supply to maintain a well ventilated fire develops slowly in relation to the growth of the fire, sufficient air is contained in the room volume to ensure the required release of heat within the enclosure itself.

EXPECTED RESULTS

From the results of the Ft. Cronkhite experiments, we might reasonably expect all of the blockhouse fires at DIRECT COURSE to be extinguished, since the expected overpressures will exceed 2 psi. However, differences between the two experiments in states of fire development are graphic; it is unlikely that the flames will be extinguished in all cases. Possibly none will be, but we expect that at least one, hopefully two or more, will be extinguished, if not permanently, at least for an observable time. Often when flames are extinguished, a smoldering fire persists to rekindle a flaming fire. Depending on a variety of factors, including wind currents, this can happen quickly, be delayed for an hour or more, or fail altogether. Whether rekindle occurs, and if so, how long it takes, can influence the formulation of civil defense doctrine in the future; its determination by post-shot observation is, therefore, an important technical objective of this experiment.

Finally, as a bonus, these room fire tests, even without blast effects, will extend the range of fire dynamics experience to help confirm the general validity of room fire scaling rules.

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