J. of Fire Prot. Engr., 5 (2), 1993, pp 67–78

CANADIAN MASS FIRE EXPERIMENT, 1989

by

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SUMMARY

Working with Forestry Canada and the Ontario Ministry of Natural Resources, the Defense Nuclear agency carried out an extensively instrumented experiment of a prescribed burn in forest debris to simulate conditions of a mass fire. In addition to the Canadian team, a multi-institutional US team made both ground and airborne measurements of the fire and smoke conditions. The fire reported on was in Hill Township, Ontario and covered nearly 480 ha in its overall burning area. Both flaming and smoldering modes contributed to the energy and combustion products of this fire. Significant quantities measured and determined included estimations of energy release rate, emission factors for smoke particulates and species, ground level wind and temperatures, and aspects of cloud dynamics and cloud particles. The fire caused a capping cloud to form and reach a level of 6.5 km. Rain, snow, hail and lightning were reported along with ground level fire whirls and water spouts on the adjoining lakes. Fire spread rates reached 1 m/s and fire induced winds reached 12 m/s.

INTRODUCTION

Need for Mass Fire Research

Over the ages, large destructive fires have occurred which have involved many acres of continuous burning regions. Most notable among city fires have been London in 1666, Chicago in 1871, San Francisco in 1906, and Tokyo in 1923.[1,2] The first two originated by relatively small accidental fires and were promoted to spread by high winds. When the winds died, the fire was brought under control. The last two city fires were initiated due to earthquakes. In the Tokyo fire, a large fire whirl (combusting tornado structure) was reported to have killed nearly 38,000 people who were seeking refuge in a large open field away from the main fire.[3]

In recent times, forest fires, such as the Yellowstone fires of 1988, have been prominent in the news and demonstrate the impact of fire at the urban-wildland interface. In general, large expanses of forests can burn over very large regions for days and even weeks. Indeed, the great forest fire in China in 1987, which destroyed forest and towns over an area the size of New England, was driven by winds of 50 mph and burned for several weeks.[4] In past times, on the same day as the Chicago fire, the town of Peshtigo, Wisconsin, was devastating by a surrounding forest fire killing 800 people.[5]

During World War II, conventional weapon and nuclear air attacks on cities induced large fires, some of which have been additionally labeled as "firestorms". These firestorms were the result of very large area fires, and most likely some favorable environmental wind conditions that led to fire induced surface winds of storm-like strength. Either due to the merging of many individual fires under unstable atmospheric conditions, or ambient vorticity which caused rotation of the fire convective column, ground level induced winds of up to 100 mph were reported for the wartime fire bombing of Hamburg. The Hamburg fire covered a region of 4–5 miles.[6] In addition, it has become evident that in many of these wartime cases, the collateral fire damage was significant when compared to the direct effects of the weapons.[2]

These examples of catastrophic fires all have involved burning regions of a large area with numerous or continuous fuel sources. They are generally classed as "mass" fires. There is no precise definition of a mass fire, but most might accept it as a flaming region of roughly 100 m in diameter. In terms of fluid mechanics, a fire that has mass fire properties might be described in which the turbulent flame height was small compared to the diameter of the fire. Mass fires can induce high storm-like winds and can possess a rotating column—this has been termed a firestorm. Mass fires can be driven by high winds, spawning localized fire whirls—this has been termed a "conflagration" by Countrymen.[2] All of this terminology is subjective and is the jargon of this subject area for large fires.

While some attempts have been made to study large mass fires, little systematic effort has been conducted nor sustained, and their behavior can not be predicted with certainty.[2] During the 1960's the Office of Civil Defense, along with the Forest Service, conducted the Flambeau project which was the most significant U. S. study of mass fires. The potential to predict the consequences of fire due to earthquake or war is empirical in the least, and accuracy is not easily assessable. Although models have been developed, they all differ in aspects of fire growth mechanisms so that without clear experimental support, it is impossible to judge their validity.

In recent years, the prospect of "nuclear winter" (a reduction in the global temperature due to the resultant smoke cloud produced by a large scale nuclear war) has prompted more research on mass fires. In addition, the realization that wartime bombing damage was accompanied by significant collateral fire damage has motivated the Defense Nuclear Agency (DNA) to initiate research on mass fires with the overall objective of predicting their development and fire products, especially smoke and its deposition in the atmosphere.

It is in this context that this mass research effort was initiated. As with other fields involving the need to study large scale phenomena, a strategy of study must evolve that encompasses many physical scales. It is nearly impossible to conduct fully controlled experiments of realistic urban mass fires, and the cost in time and effort of analysis would be enormous if the results are to be productive. On the other hand, it is impossible to proceed with alternative strategies without making careful observations of appropriate full scale phenomena. Only then can the phenomena be dissected into tractable theoretical and laboratory studies to more intensely and completely derive the information to accurately predict the whole. In this sense, this large scale experimental effort should not be looked upon as an end in itself, but as a means to an end. It should serve as the basis for more systematic research needed to establish the principles of mass fire behavior and their prediction.

This report summarizes a large mass fire experiment that culminated from experiences gained in similar mass fires studies in recent years. Those previous studies were motivated by the need to understand the production of smoke particulates relative to the Nuclear Winter Scenario, and more generally to address issues of environmental global pollution. The current experimental study has been an attempt to develop a more complete characterization of a large urban-like mass fire.

Motivation Of 1989 Experiments

Early in the Spring of 1989, a group of Canadian and U. S. researchers were invited by the Ontario Ministry of Natural Resources (OMNR) to participate in a large prescribed burn of forest harvestation debris involving an area of approximately 480 hectares (1 ha =10,000 m^2). The ignition of this region would be done rapidly to enable the resulting fire to have a mass fire character.

Participants Of Experimental Team

The participants of the DNA project consisted of several teams from government laboratories, universities, and private industry research institutions. The team organizations are:

- Defense Nuclear Agency (DNA)
- Forestry Canada (FC)
- USDA Forest Service (USFS)
- Pacific - Sierra Research Corp. (PSRC)
- University of Iowa (UI)
- University of Washington (UW)
- National Institute of Standards and Technology (NIST)

OBJECTIVES OF THE EXPERIMENT

The Canadian prescribed burn and mass fire experiment had several general objectives. The Canadians were interested in understanding how to perform prescribed burns for more effective reforestation, and to develop more insight into the dynamics of large forest fires. The DNA objectives were to measure and elucidate the characteristics of mass fires in terms of the ground level fire dynamics and in terms of the smoke emitted. The first DNA objective relates to the need to predict the damage due to fire growth, and the second objective relates to the need to improve the ability to estimate the atmospheric smoke obscuration at high altitudes. In particular, the prospect of obtaining high altitude cloud and fire plume interactive effects on the smoke accumulations was in the offering for this large area prescribed burn.

DESCRIPTION OF THE EXPERIMENT

Mass Fire Site

Location

The location of the prescribed burn was approximately 20 km northwest of Chapleau in Ontario, Canada. The site is in the Hill Township, and the experiments will subsequently be referred to as the Hill or Hill Township mass fire experiments of 1989. The prescribed burn site consisted of approximately 480 hectares (ha) and was divided into four blocks of nominally 80 to 140 ha each for successive burns. The general location of Hill Township and the demography of the blocks, labeled A, A1, B, and C, are shown in Figure 1 (USFS).

Forest Type And Fuel Nature (FC)

The forest fuels consisted of balsam fir, spruce, trembling aspen and white birch with shrubs of mostly mountain maple and hazel. The area had been harvested and tramped several years ago to prepare it for a prescribed burn and eventually reforestation. The tramping process levels the dead trees and in this case the bulldozing led to windrows of forest materials (slash). The moisture content of the slash ranged from 16 to 38 percent and increased with depth in the duff from 44 to 86 percent (based on percent of the oven dry weight).

Geography (FC)

The topography of the area consisted of rolling terrain. In particular for Block A where nearly all of the instrumentation was located for the ground fire measurements, transit data over the area suggest elevation changes of up to 35 m with relative flat regions throughout.

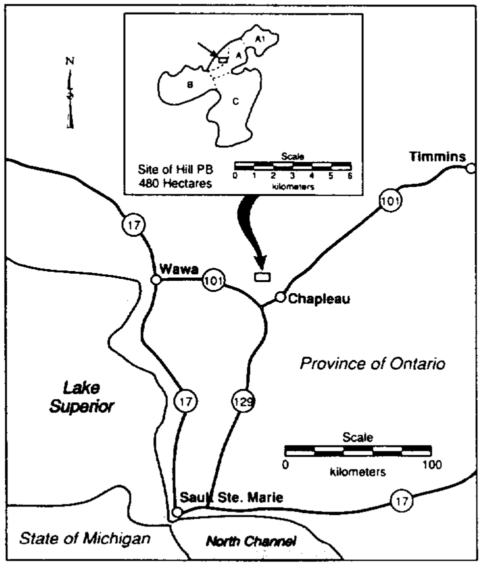

Figure1. Location of the Hill Township prescribed burn relative to Chapleau and Sault Ste. Marie, Ontario, Canada (FC).

Experimental Design and Implementation

Ground Measurements

Figure 2 (PRSC) shows an overview of the measurement sites in Block A, the instrumented Block of the prescribed burn region. The triangles indicate the locations at which the fuel mass samplings were taken along with temperature data in order to determine the fuel consumption rates (FC). The perimeter (FC) and interior (UI) towers principally recorded horizontal wind velocities at nominally 10 m above the ground. The PSRC fire dynamic array measured velocities and temperatures. The USFS fire chemistry pentagon tower array contained temperature, velocity, and gas measurement instrumentation. Real time measurements were made O_2, CO_2 and CO. Particulates of less than 5 um were collected on filters, and time interval gas samples were collected for more complete subsequent analytical analysis. Several of the towers in the USFS array contained video cameras to record the local flame characteristics as they advanced through the tower monitoring stations.

The USFS team set up two additional measurement objectives. Stereophotography was employed from a distance of approximately 7.5 km from the burn site. The other measurement objective was to determine the electrical charge characteristics of the fire generated smoke plume.

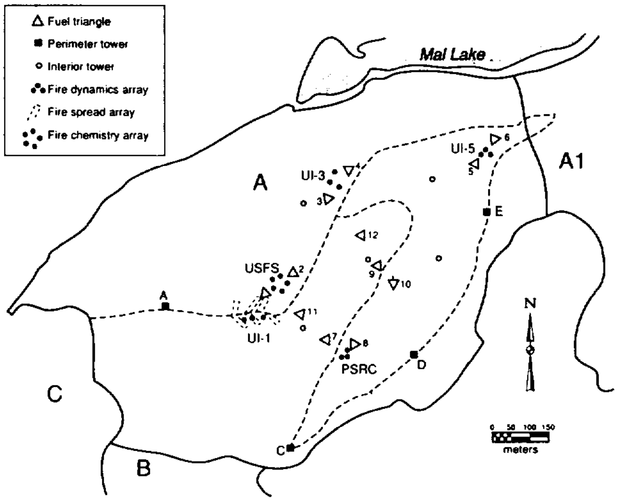

Figure 2. Ground instrumentation locations in Block A (PSRC).

Airborne Measurements

The primary airborne measurements were taken from the University of Washington's Convair C-131A. This aircraft has been designed with a sophisticated array of specialized instruments to measure the gas species and particulate properties in the smoke column at altitudes up to the top of the fire plume and resulting cloud formation. The full array of instruments are too numerous to describe here, but more information can be obtained from the UW source report on this study. Principal measurements included particle size (0.005 to 45 um) and particulate concentrations, particulate scattering and extinction coefficients, particulate morphology and chemistry, and trace species analysis of time integrated samples. The aircraft also contained two instruments that only have been used in an exploratory and a qualitative manner. These consisted of a LIDAR imaging device employed to measure the backscattering of soot particulates in a vertical crossection along the windblown plume axis downstream of the capping cloud. The other instrument was a "forward looking infrared" (FLIR) video camera to assess the ability to see the fire through the smoke column from high altitudes.

Seven atmospheric soundings (rawinsondes) were launched during the Hill burn on August 10, 1989.

Ambient And Initial Conditions

The experiment was begun on August 10, 1989 at approximately 13:55 Eastern Daylight Time (EDT). All time clocks on automated instruments and those for general field use were synchronized to EDT, and all data presentations and analyses are reported in this time base. At the time of the test the ambient temperature was nominally 26 C with winds of approximately 3 m/s out of the west. The sky was clear with a few widely scattered cumulonimbus capillatus clouds. The rawinsonde data initiated at 14:23 EDT is most applicable to the initial period of the fire and the instrumented fire growth period. Its data indicated that the atmosphere was superadiabatic through 900 mb or over the first 300 m (an elevation above sea level from 457 to 757 m), neutrally stable up to 2.5 km above sea level, and unstable above that level. An excerpt of some of the atmospheric sounding data are listed in Table 1.

Table 1
Excerpts of Rawinsonde Data No 3.
Como Lake, Hill Township, 14:23 EDT

Elevation Above Sea Level	Air Pressure	Temp.	Relative Humidity
m	mb	C	%
457	966	26.0	49
1190	887	14.4	62
2040	801	8.0	94
3020	711	0.9	78
4150	617	-6.0	55
6320	464	-18.3	34
7330	405	-26.0	15
9430	300	-43.3	43

Burn Scenario

The OMNR ignition technique is to drop flaming jelled gasoline from a helicopter in a radially outward spiral pattern, e.g. See Figure 3. This technique leads to converging fire rings, and the radial induced fire winds tend to counteract any ambient wind that could potentially drive the prescribed fire in an undesired direction. Also this technique tends to encourage a large area fire, or simulated mass fire condition, due to the rapid ground fuel ignition and spread behavior despite the relatively short flaming time of the forest debris fuel.

Because of the prevailing westerly winds and the desire to initiate a large mass fire before the instrumented Block A was affected by flames, the east region, Block Al was ignited first at 13:50 EDT. In approximately 40 minutes Block Al was completely involved, and the helicopter ignition activity ceased there by 14:18 at which time the ignition process was begun in Block A. The plan for initiating the fire in Block A was to centrally begin the fire in the vicinity of triangle 10 as illustrated in Figure 3. This initial fire was developed over a several 100–200 m diameter circular region, then an outer ring was initiated to the north and west of the USFS and PSRC fire tower arrays. This fire arrangement together with the prevailing westerly winds would cause the outer ring fire region to spread over the tower arrays towards the centrally ignited area.

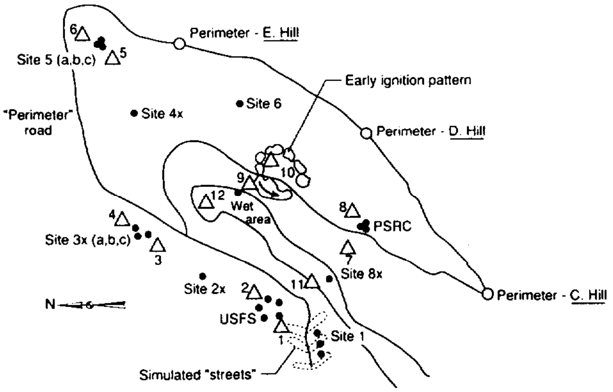

Figure 3. Layout of instrumentation in Block A relative to roads on site. Darkened, irregular circle indicates first area ignited by helitorch (NIST).

This insured the desired conditions for assessing the character of the fire dynamics consistent with the ground monitoring objectives. As anticipated the fire spread from the outer ring, generally west to east, through the tower arrays and across the simulated street spaces. The flames reached the fire spread array (Figures 2 and 3) at 14:33, and that region was fully involved in flames by 14:35. Subsequently, Blocks B and C were burned, but little relevant data were taken with respect to the period of those fires. Most monitoring stations recorded data until about 18:00, at which time the instrumented sites were examined in Block A and the data loggers and instruments were retrieved.

EXPERIMENTAL RESULTS AND ANALYSIS

The major results of the mass fire experiment will be reported as described by the team reports listed in the References. Comparison of results by different sources will be presented, but no critical evaluation of their analyses or measurement techniques will be developed. We shall describe the experimental results in terms of the significant aspects of the Hill Township mass fire experiment. These features will include the dynamics of the fire plume, the determination of the fuel consumption rate and the corresponding induction of the ground winds, the characteristics of the fire spread, and the emission of gas species and particulates with the associated dynamics of the cloud processes.

Plume Dynamics

The dynamics of a plume from a large mass fire can not be separated from atmospheric effects. The two are interdependent to some extent on a local level. The plume behavior will depend on the vertical distribution of temperature, humidity, and wind velocity. The fire behavior will depend on the local ground level winds and fuel characteristics. The plume buoyancy and composition will depend on the size of the fire and its rate of burning.

The effects of wind on the trajectory of the fire plume will cause the plume to bend and its horizontal cross section to change from circular to a horseshoe shape. Generally a plume will rise in a stratified atmosphere until it reaches a height of neutral buoyancy at which it will flatten out and disperse in the ambient wind. Due to atmospheric moisture entrained into a plume of a large (mass) fire, a capping cloud can form at a high altitude once the plume temperature achieves the saturation point. In addition, as saturation is achieved in the plume, the subsequent condensation process actually gives additional buoyancy to the plume since the thermodynamic energy of condensation is transferred to the plume gases. This condensation process led to the production of a cumulus cloud for the Hill Township fire which soared to 7 km.

Figure 4 shows the early development of the plume associated with the fire initiation in Block Al. This photograph was taken at approximately 14:10. It clearly shows the large eddy structure of the plume which is comparable in scale to its diameter. The formation of capping cloud can also be discerned in the picture. The large perimeter eddies of the plume rolled up and shed periodically. Small scale laboratory correlations, for pool fires up to 50 m in diameter, suggest that the eddy shedding frequency is inversely proportional to the square root of the diameter[8]. For a fire of 1000 m in diameter, the period of eddy shedding is 21 s from such a correlation, and this is consistent with observations of the Hill fire and plume conditions at this time.

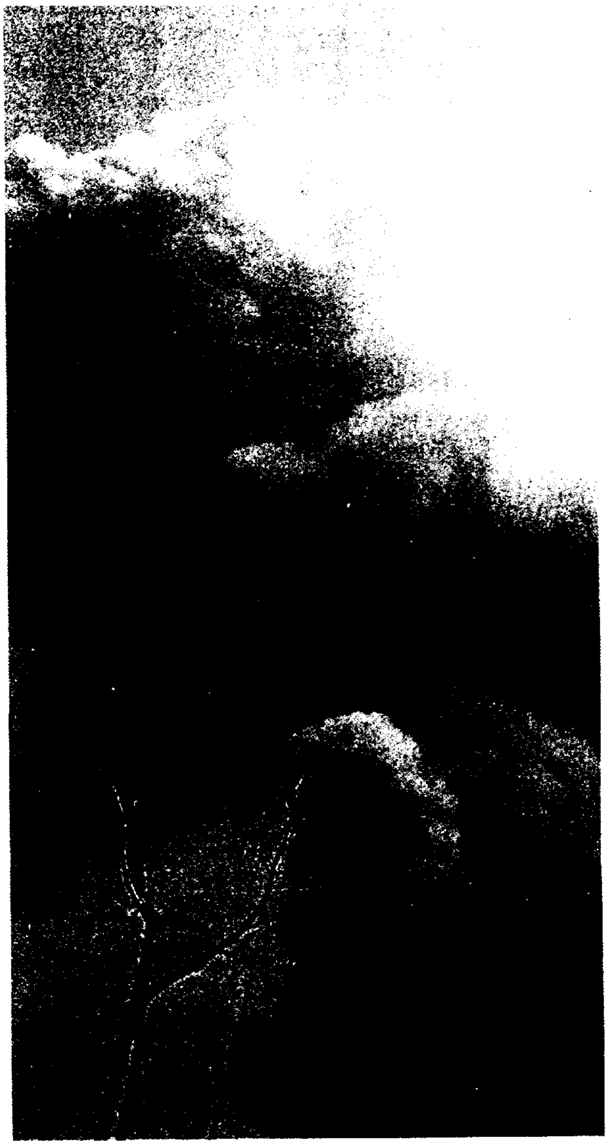

Figure 4. Photograph of the capping cloud formed after igniting Block Al at approx. 15 minutes after ignition (NIST).

A very dramatic aspect of the fire initiation was the nature and rate of the plume ascent in the atmosphere. Two measurement sources (FC and USFS) provided data on the plume elevation as a function of height with respect to sea level. These are shown in Figure 5 where the initial climb data are in close agreement, but the equilibrium position of the cloud top varies between 6 and 7 km.

The Hill fire was of sufficient intensity to produce a mature thunderstorm. Precipitation was evident in the capping cloud very early, and light showers reported downwind of the capping cloud. By 14:54 hail of several mm in diameter was recorded and shortly later, snow flakes were also observed.

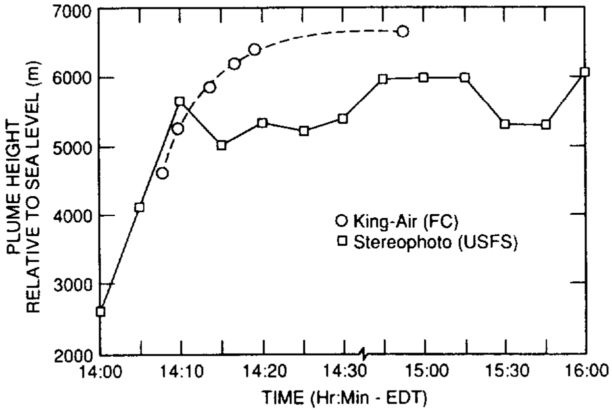

Figure 5. Plume rise as a function of time.

At this same period, lightning discharges began to be recorded by the electric field mill monitoring station 1 km from the fire and by the Ontario Province lightning network and continued through until approximately 16:30 (USFS). Sixteen cloud to ground discharges were noted downstream of the fire plume and capping cloud.

At 14:20 the fire had been underway for 30 minutes in Block Al, and the fire was ignited and began to spread in Block A. Even before this time, fire whirls and water spouts on the small lakes adjoining the fire blocks were noted by ground observers. The water sprays of these spouts were estimated to reach at least 10 m in the air.

Fuel Consumption Rate

The fuel consumption rate or energy release rate was viewed as one of the most important parameters of the experiment. The nature and magnitude of this energy release is the driving force of the mass fire. It is a necessary data parameter in order to characterize this fire and would be required input data for any predictive modeling of the plume. Its magnitude would allow future investigators to classify this fire in terms of its relationship to urban mass fires. The induced winds and the dynamics of the plume behavior in the atmosphere are all direct consequences of the rate and distribution of energy release.

Since the fire energy release rate is so important, and since it is impossible to make any direct measure of this dynamic parameter, it was not deemed redundant to have several of the teams pursue this estimate.

Model Variations.

The FC and NIST teams both used the mass loss data from the triangle regions (Figure 3) supplemented by thermocouple measurements, and the IR images of the FC helicopter. The USFS team based their estimation on local near ground measurements of the production of carbon combustion products as measured by their gas and particulate monitors. This also required the use of their vertical velocity data, and the assumption of only a vertical carbon mass flow rate.

Results for Block A.

A composite of the energy estimates are shown in Figure 6 in which three NIST models, varying in complexity and assumptions are presented, as well as the FC and USFS models. Although the accuracy of each are not assessable, their agreement with each other to within 50 percent suggests that these results may be reasonably valid. Therefore, a mean curve has been drawn through the data to orient the reader and to suggest a representative energy output based on these approximate, but independent methods. In applying the USFS results, a starting time of 14:19 for the fire in Block A was imposed on the USFS calculations since their report started the curve at a relative time of zero. Since it would be impossible to obtain any direct measurement of this important parameter, energy release rate, these multiple calculations represent a credible base for future modeling and analysis of this mass fire experiment.

Ground Winds

The ground level winds were measured in many places within and around Block A. A typical trace, taken from the UI tower at Site 1 (UI-1) as shown in Figure 2 is displayed in Figure 7. The results show the velocity is out of the west and increases from nominally 5 m/s to 12 m/s after the flames reach the tower at approximately 14:40. This is the pattern of much of the horizontal wind data.

An attempt to compute the ground wind field was made by the NIST team using a model previously developed by Baum and McCaffrey[9]. This model uses a reliable correlation for the velocity distribution of a fires plume developed from extensive comparisons with experimental data for pool fires of up to 30 m in diameter.

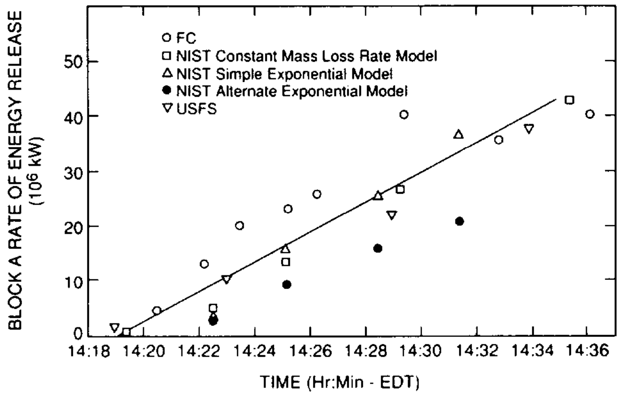

Figure 6. Estimated energy release rates of Block A.

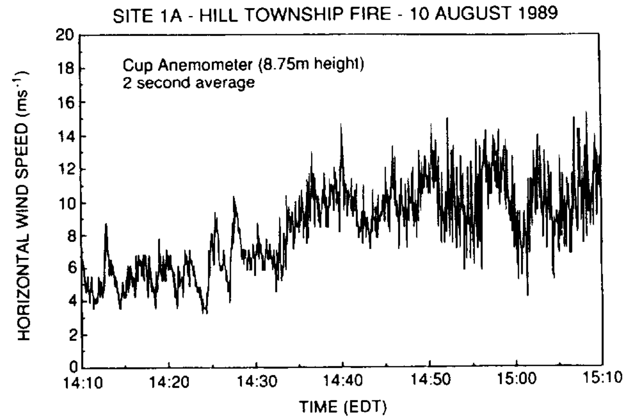

Figure 7. Example of wind speed at the UI-I site (UI).

Using this correlation to represent the energy release rate and vorticity of a series of fire plumes to simulate the distribution of this mass fire at an instant of time, it computes the velocity field in the ambient field surrounding each of the plumes near ground level. The model does not include any consideration of high altitude atmospheric effects. By superposition of this computed velocity field with the ambient initial wind, it has computed the velocity at several perimeter measurement stations of the Hill fire. Some of these FC perimeter stations, C, D and E, are shown in Figure 3. The computations have been done for three times as shown in Figure 8.

Ground Fire Dynamics

The sparseness of the ground level measurements relative to the area of fire involvement and the nearly random distribution of fuel and the flame pattern make it difficult to generalize from the tower measuring stations. But some limited results to illuminate the internal ground level fire conditions will be reported, and more details are available in the team reports.

Flame Velocities.

The FC team report, from the IR image analysis, that the flame front velocities ranged from 0.1 to 1 m/s, and this is consistent with the USFS analysis by local tower video records.

Flame Heights

The flame heights are reported to have ranged from 8 to 12 m as the fire swept through the tower arrays. Thus, in many instances the highest measuring station on the towers were above or just in the tip of the flame.

Oxygen Levels

For turbulent fire plumes in still air the ratio of excess stoichiometric air relative to fuel at the flame tip is roughly 10. With increased mixing for wind blown fires, we would expect even more excess air at the flame tip. This is supported by the USFS measurements of oxygen at 8 m above the ground which showed that the oxygen concentration only dropped by 2 percent at most.

A more important consideration on the oxygen is its availability in the local atmosphere surrounding the packets of burning fuel within the core of the fire. Figure 9 clearly shows that the oxygen sensors at 0.5 and 1.5 m above the ground are within the combusting region of the flame during the period when the temperatures are at least 500 C. The oxygen levels over that time period fall to as low as 40 percent of that of air, or to a low of 8 percent concentration. Again this concentration is indicative of high excess stoichiometric oxygen even at this low height in the flame. This figure also indicates that the flaming period is approximately 2 minutes. Following this period, the ground level temperatures are indicative of the wind blown combustion product gases and the effects of both upwind flaming and smoldering conditions. The corresponding oxygen concentrations are above 19 percent and may be nearly at air level values since electronic zero drift effects were present with these sensors. Hence these results suggest that for this fire, the atmosphere within the core of this mass fire from which available oxygen could be obtained was only slightly below normal air level concentrations.

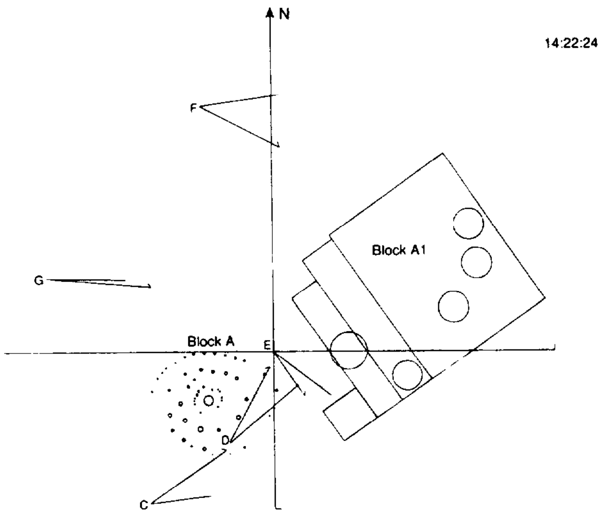

Figure 8. Velocities and fire at 14:22:24 (NIST).

Smoke Emissions and Cloud Effects

Carbon Smoke Yields

The carbon bearing particulate matter was measured both at the ground level[10,11] and in the plume-cloud system[12]. These were both done by collection of the particles on filters, and by a carbon mass balance method based on a 0.5 carbon fraction in the woody fuel. The ground level USFS measurements for particles less than 5 um ranged from 7 to 14 to 25 g/kg of fuel mass loss corresponding to their specified periods of flaming, intermediate and smoldering. These periods did not necessarily correspond to the actual times of these burning modes, but the results can be interpreted to represent the limits of smoke particulates emitted for the early flaming period and the later smoldering dominated period. No such distinction for the burning modes could be made for the cloud airborne data. These UW results for particles less than 3.5 um averaged 10 g/kg with a standard deviation of 6 g/kg. It would appear that the ground and airborne data are very consistent.

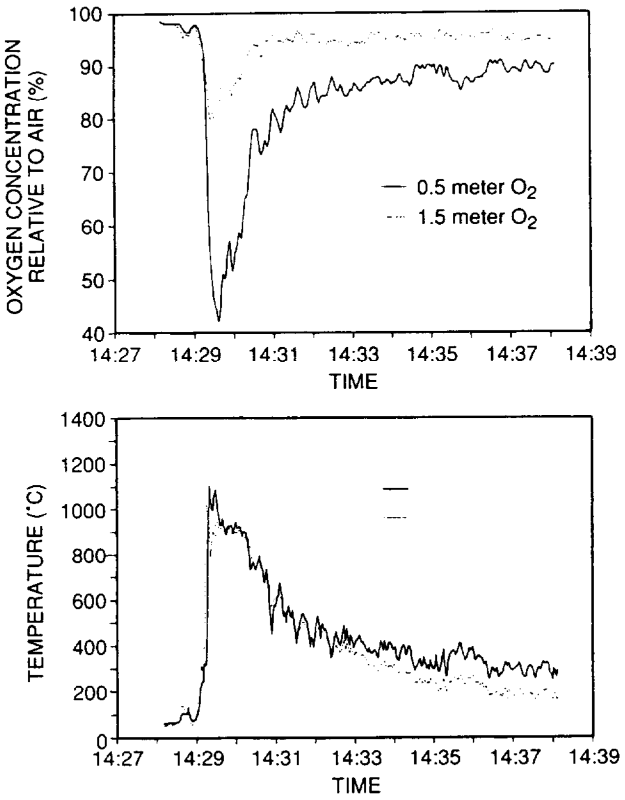

Figure 9. Real time measurements for ground level oxygen depletion relative to ambient air and air temperature (USFS).

Chemical Nature of Smoke

Chemical analysis of the particulates by USFS showed that the carbon is mostly in "organic" form rather than "graphitic" which implies that the particles are likely to be liquid tars rather than soot. This particulate composition is indicative of smoke generated under smoldering or pyrolytic, nonflaming conditions. For the Hill fire conditions, we already know that smoldering dominated the fuel consumption process so the smoke composition is consistent with those burning conditions.

Smoke Optical Properties

The UW team also report results for the optical properties of the particulates. They determined an average scattering albedo (ratio of the scattering to extinction coefficient) of 0.84, and a value for specific absorption coefficient (or area) of 0.59 ± 0.22 m^2/g. These results correspond to a value of specific extinction area equal to 3.7 m^2/g which corresponds to "white" smokes or smoke from smoldering conditions. This value compares to a generic literature value of 4.4 which is often cited as representative of nonflaming smoke[13]. In considering the above results, it was presumed that the UW measurements for these particulates are below the cloud level or that the condensed water droplets have been filtered from these smoke samples.

Cloud Scavenging of Smoke

Some preliminary analysis of the data for the Hill fire show an overall efficiency in removing carbon based particulates below 1 um at nominally 40 percent. This scavenging efficiency due to cloud processing and precipitation is generally a function of particle size. The UW team draw the general conclusions that supermicron smoke particles are removed in a capping cloud with high efficiency, and submicron particles are scavenged with an efficiency of 30 to 90 percent in precipitating cumulus clouds. Since capping clouds are a consequence of all large fires, these results suggest that a significant amount of the smoke particles would be scavenged by the cloud. These results are important to the Nuclear Winter modeling effort and to making accurate predictions for these cloud-particle inter-actions.

Smoke Deposition in the Atmosphere

Although results of the LIDAR are preliminary and still being analyzed, the data of the UW team show that the smoke particles in the Hill fire detrain, or leave the capping cloud, at an altitude of approximately 4 km. This is in contrast to the height of the capping cloud reaching 6 to 7 km which clearly shows that the smoke and the cloud boundaries do not coincide. The UW team concludes from this that if the fire capping cloud does not reach the stratosphere with its high velocity winds, then the smoke will be deposited at a much lower altitude than the top of the capping cloud.

Trace Specie

Trace gas and element emission factors were estimated by both the UW and USFS teams based on chemical analyses of their colbased on chemical analyses of their collected samples. These include a wide range of species and elements including most notably O3, NH_3, CH_4, NO_x, K and Ca. More details and the implications of these airborne substances can be found in the UW and USFS team reports.

CONCLUSIONS

The results of this fire provide a fairly complete description of the fire and its surroundings which should provide the basis for generalizing the characteristics of mass fires and for assessing predictive models in the future. Significant large scale phenomena have been identified that could not necessarily been identified by models or with laboratory studies alone. The quality of the data is good, and forms a fairly complete database for a simulated mass fire. The overall results appear to be reasonably consistent, especially where comparable results were obtained by different methods.

In general, a complete study of mass fires must go beyond the scope of this experiment. Such experiments are not sufficient in themselves to shed needed information for constructing sound and complete predictive models. Aspects of this mass fire experiment and its results must be dissected and studied in the laboratory and analyzed through focused mathematical models. Scaling studies can be fruitful for some features of the phenomena. Before significant new large scale experiments are considered, it would be desirable to review the quality of the instrumentation currently available, explore new concepts in instrumentation, and consider the best configuration and scale to match the urban fuel environment. There is no doubt that the Hill Township fire was a successful enterprise and the results contained in the team reports should be studied further and critically reviewed in planning new experiments or projecting new analyses.

ACKNOWLEDGEMENTS

The author gratefully wishes to acknowledge the funding support from the Defense Nuclear Agency and Maj. Richard Hartley, USAF, who led the DNA program. I also want to especially thank those participants who contributed comments and suggestions to this manuscript; namely, Darold Ward, Doug McRae, Ken Heikes, Larry Radke, and Tom Ohlemiller. This report is a compilation of the work of the U. S. and Canadian teams, and is derived from their individual reports. Contributing organizations include the Ontario Ministry of Natural Resources, Forestry Canada, USDA Forest Service, Pacific-Sierra Research Corp., University of Iowa, University of Washington, and the National Institute of Standard and Technology.

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