A REVIEW OF EMPIRICAL STUDIES OF FIREBAND BEHAVIOUR

Part 1: A review of empirical studies of in-flight behaviour of firebrand samples

Part 2: A review of empirical studies of fuelbed ignition by firebrands

[Bushfire CRC Project: Fire behaviour under extreme fire weather conditions: Milestone 3.2.1a(ii)]

Peter F.M. Ellis

CSIRO Ecosystem Science and CSIRO Climate Adaptation Flagship

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PO Box 284, Canberra, ACT 2601, Australia
Corresponding author. Email: peter.ellis@csiro.au

Abstract

Ignition probability and early spotfire growth are critical to the impact of given levels of firebrand generation and transport. There is little information on fuelbed ignition probability and early spotfire growth for firebrand and fuelbed combinations relevant to Australia, especially for conditions of Very High to Extreme Fire Danger during which the hazard and potential losses caused by spotting are greatest. Hence, there is a need to further investigate these processes.

Introduction

The significance of ignition probability

The significance of firebrand transport and spotting in terms of direct and indirect costs and threat to human life has been frequently highlighted (McArthur 1969, Ellis 2000, Pagni 1993, McCarthy and Tolhurst (1998) Ellis and Sullivan 2003, Koo *et al.* 2010). The numbers of firebrands generated, their transport distances, the probability of the firebrands igniting the fuel and the rapidity of development of the subsequent spotfire, determine the nature, magnitude and effect of ‘ember attack’ and spotting. Spotting not only increases the demand on resources by starting new fires, but can increase the spread rate of the source fire (McArthur 1967, Tolhurst and MacAulay 2003 Porterie 2005). Entrapment of fire crews or civilians between developing spotfires and the source bushfire is potentially life threatening. Mass ignition is possibly the most dangerous situation, because very rapid coalescence of a dense distribution of spots over a relatively large area means that escape may be impossible. This phenomenon supposedly requires a certain density of spotfire ignitions (hence the importance of ignition probability), combined with conditions conducive to their rapid spread. McArthur supposed (1967) that concentrations of 100 ignition points per square mile (about 40 per square km) could produce fire storm (mass fire) effects, and McArthur (1969) described a ‘critical level of fuel dryness…where the spotting process reaches maximum efficiency’.

Ignition probability is influenced by weather, firebrand and fuelbed variables (Cheney and Bary 1969), although the processes are generally poorly understood and quantified. The following sub-sections summarise the process of ignition by point sources, critical variables influencing ignition probability, methodologies used to measure ignition probability and the results of experiments particularly relevant to spotfire ignition in Australia.

The process of ignition

Babrauskas (2003) summarises theories of heat transfer by small glowing and flaming particles to elements in a porous, organic fuelbed, and the results of laboratory and field ignition tests. Flaming ignition is defined as the exothermic combustion of gases obtained by (endothermic) pyrolysis of solid fuel, requiring adequate concentration and aeration as well as sufficient heat to ignite the gas mixture, or a pilot flame. Glowing combustion is the rapid oxidation of the surface of solid-phase char material.

Boonmee and Quintiere (2002) used a cone calorimeter to study flaming autoignition of wood, and described two processes. At high heat fluxes of between 40 and 70 kW m^{-2} flaming ignition occurred, with the initial flame appearing above the surface in the gas phase and then propagating to the surface. Ignition is the commencement of some form of combustion. Glowing combustion, which is rapid oxidation of fuel at the surface, could occur initially at heat fluxes less than 40 kW m^{-2}, and the transition to flaming combustion apparently required sufficient extra energy to ignite the gas phase. The process of transition of glowing combustion of fuelbed elements to flame in the absence of a pilot flame, as typically occurs with glowing sources, is apparently affected by firebrand dimensions and composition, wind velocity, and the moisture content, size and spatial arrangement and continuity of the fuelbed (Babrauskas 2003) and the competitive thermokinetics of cellulosic combustion (Sullivan 2007). Critical factors in ignition could be expected to include firebrand size, state, heat flux and remaining endurance after reaching the fuelbed, and the size, composition, including minerals, volatiles and moisture, and spatial arrangement of fuel elements, and wind.

Flaming firebrands generally have a significantly greater ignition probability than do glowing ones because they potentially generate greater heat flux and because of the presence of a flame provide small-scale turbulence for mixing and to ignite the products of pyrolysis. Ignition probabilities of fine fuels by flaming firebrands during days of Very High to Extreme Fire Danger may be 100%.

For ignition by glowing firebrands, heat conduction may be the dominant mode of heat transfer (Babrauskas 2003). Countryman (1983) identified two fuel effects in ignition, one being the probability of achieving a minimum contact area between firebrand and fuel elements, and the other, presence of a sufficient density of fuel elements such that initial ignition points propagate. Hence, firebrand size (surface area) and fuelbed packing ratio or bulk density are potentially significant determinants of ignition probability.

Ignition cannot occur until most moisture is driven off and it therefore could be expected that for firebrands, which have a limited heat content, ignition success will be decreased by increasing fuelbed moisture content, as demonstrated by Dimitrakopoulos and Papaionnou (2001).

Airflow will affect the heat flux produced by firebrands and ignited fuel elements as well as the amount and mixing of concentrations of fuel and oxidizer in the gas stream, and depending on velocity and other conditions, could either aid or inhibit ignition. Airflow may be induced by wind, convection above the flaming or glowing firebrand, and by solar heating of the fuelbed (Butler 2006).

Firebrand moisture content can be expected to reduce its heat flux. However, in the case of a relatively small, glowing firebrand with low initial moisture content it is likely that all remaining moisture would have been driven off during its ignition and initial flaming combustion.

Critical firebrand characteristics

The critical characteristics of temperature and radiant heat flux (RHF) are influenced by firebrand state (flaming or glowing), material and possibly mass. The characteristics of a firebrand which lands on a fuelbed are significantly affected by its airborne transport, during which it has been combusting in airflow approximately equal to its terminal velocity. In addition, combustion may be enhanced or retarded by the effect of natural gyration or movement on relative airflow.

Different firebrand materials combusting at their terminal velocity display different behaviour. Most timber firebrand samples have relatively high terminal velocities (Tarifa *et al*. 1967) and relatively short flameout times (Muraszew 1974, Muraszew *et al*. 1975, 1976). Ellis (2000) showed that samples of messmate stringybark (*E. obliqua* L'Her) had relatively low terminal velocities, had long flameout times and occasionally reflamed during their glowing combustion stage.

The colour temperature of glowing firebrands at 500-600 °C (dull red), 600-800 °C (dark red) and 800-1000 °C (bright red) correspond to theoretical ranges of RHF of 20 to 35, 35 to 75 and 75 to 150 kW m^{-2}. The number of fuel elements potentially contacted by a firebrand is affected by firebrand size. In cases of proximity rather than contact, the RHF incident on a given fuel element is the product of firebrand RHF flux and view factor. View factor is a function of size of the emitter (firebrand) and the proximity of the fuel element, and decreases quickly with distance. For example, for a fuel element at a point orthogonal to a square emitting surface ($a \times a$), the view factors at distances 0.35a and a are 0.71 and 0.24, respectively (Drysdale 1985). Hence, a fuel element at a distance of 5 mm from a firebrand with an emitting surface 5 mm × 5 mm would receive about a quarter of the theoretical values of radiant heat flux. Huang *et al*. (2007) measured values of radiant heat flux between 9 and 13 kW m^{-2} for combusting ‘plate’ shaped pieces of charcoal with areas ranging from less than 1 cm^2 up to about 10 cm^2, but did not explain their methodology.

The period during which a firebrand maintains its heat flux, its endurance, is also important, and is likely to be affected by firebrand material and mass.

Critical fuelbed characteristics

The size of the elements of their fuelled, their mineral and oil composition and their spatial arrangement, the last influencing aeration, are all potentially significant. Aeration is significant for the drying of the fuelbed as well its combustibility. In addition, fuel continuity and homogeneity may influence ignition probability on a broad scale. The moisture content of the profile of the surface fuel will influence rapidity of subsequent spotfire development and spread (McArthur 1967).

Critical weather characteristics

Conditions of Very High to Extreme Fire Danger (McArthur 1967) typically occur when the fuelbed and soil profiles are very dry, often due to drought, and ambient temperatures are high, humidity low and winds strong. Such conditions enhance firebrand generation and spotfire ignition, as well as subsequent spotfire growth. It is likely that the effect of solar radiation in heating surface fuel elements and affecting small-scale turbulence near the surface, are also significant (Butler 2006). Topography will influence many of the above variables. In Australia, the presence of very dry 'cells' of air at altitude have been associated with subsequent extreme fire behaviour events (Mills 2008) which occur when are entrained to the surface by large-scale eddy mixing. This mixing, which generally occurs as the surface heats due to solar radiation, also induces 'cascades' of turbulence to descend to the surface (Sullivan and Knight 2001), and consequently, is potentially significant to ignition probability and subsequent spotfire spread. In addition, adiabatic lapse rate of the boundary layer to thousands of metres altitude has been shown to influence fire development (Byram 1954). Keifer (2007) modelled the development of fire convection plumes under different conditions, and defined conditions during which intense plumes and firestorms could develop. It is not known what influence such atmospheric conditions have on early spotfire development.

Methodologies

Field investigations include those which test ignition using a standard 'firebrand' on a given fuel type (Blackmarr 1972), those which document spotfire occurrence from dedicated experimental fires (Gould *et al*. 2007), and those which collate spotfire occurrence during wildfires (SALTUS 2001). The data from Gould *et al*. (2007), quantifies firebrand density and the number of spotfires, and thus could be used to give an estimate of ignition probability. However, information concerning firebrand type and size is difficult to extract. The European study describes the combinations of fuel, fire behaviour and weather likely to cause spotting.

In order to investigate the influence of a limited number of specific, controlled variables, and to investigate the process in detail, most ignition probability studies are performed in the laboratory. Typically, in order to obtain repeatable results from tests which may be limited in number for practical reasons, homogenous fuelbeds of natural or artificial fuels are prepared and conditions such as moisture content and wind limited to a few values. In some investigations the ignition source is artificial and standardised, and in others it may be natural 'firebrand' material, of uniform size or in a range of sizes, and ignited to a consistent standard prior to placement on the fuel bed. Such tests can be used to obtain threshold ignition criteria, such as the minimum temperature and radiant heat flux of the ignition source, or to investigate the effects of fuelbed moisture content or wind velocity, say, on ignition probability. The process of ignition relevant to most ignition probability studies is the relatively rapid attainment of flaming ignition, with or without an antecedent glowing stage. Time to (flaming) ignition is another variable which will potentially influence the effect of firebrand transport, particularly at short distances. For example, a firebrand generated from a fire moving at 2 km hr^{-1} and landing 55 m ahead will be over-run before igniting a spotfire if its ignition time exceeds 100 s.

The definition of (success) flaming ignition is important and may differ between researchers. For example, **Ellis** (2000) used small (50 mm × 50 mm) ignition sites in which firebrand samples were deposited, and defined ignition as the merely occurrence flaming of fuel elements. **Plucinski and Anderson** (2008) defined an 'ignition threshold' as sustained combustion resulting in fire spread from the central test site to the edge of the fuel tray, a distance of 125 mm.

Problems with laboratory experiments include the potential effects on fuelbed ignitibility induced by artificial conditioning (Matthews 2010), the fact that the combustion characteristics of the firebrand samples may not be equivalent to those resulting from aerial transport and that the turbulence of artificially produced airflow may have unknown differences to wind in a forest (say). Hence the results of laboratory tests may not reflect ignition probability in the field. In addition, it may be very difficult to compare the results of experiments which employed different techniques.

Experiments and Findings

A. *Ignition by flaming sources*

Blackmarr (1972) tabled the ignition probabilities of slash pine litter at moisture contents up to about 30%, by dropping single, flaming matches on to the fuel. He found ignition probabilities of 40% and 90% for moisture contents of 20% and 15%, respectively. However, the USDA National Fire-Danger Rating System (1974), which tables ignition probability applicable to all fine-fuel types for given ambient conditions, gives a maximum value of 5% ignition probability for a fuel moisture content of 20%. It is possible that this discrepancy is due to the difference in fuelbed uniformity between slash pine litter and that of other fuels.

Ellis (2000), Manzello *et al*. (2006, 2008), Plucinski and Anderson (2008) confirmed that the probability of ignition of fine fuels of less than about 10% moisture content, by flaming samples is about 100%. Ellis (2000) used single samples of the outer bark of *E. obliqua* of initial mass between 0.8 and 1.8 g, ignited until well flaming and placed on the fuelbed when they were reduced to 60% of their initial mass. He used fuelbeds of sections of *P. radiata* needles, excised from litterbed under a mature stand in order to have fine, homogeneous fuel, and no-wind conditions. Manzello *et al*. (2006) dropped single, machined disks of wood of *P. ponderosa*, 25 mm and 50 mm diameter, onto fuelbeds of shredded hardwood mulch, pine straw mulch and cut grass, which had been conditioned to 0% and 11% moisture content. They tested wind conditions of 0.5 and 1.0 m s^{-1}, and found that for 0% moisture content all fuelbeds ignited, whereas at 11% moisture content only pine straw had 100% ignition probability. Plucinski and Anderson (2008) tested the ignition probability of nine reconstructed shrubland litter types, conditioned to a range of moisture contents. They used methylated spirits applied to cotton balls or injected into the fuelbed, or aerial incendiaries as their standard ignition sources. Plucinski and Anderson (2008) found that the thickness of the surface fuel elements, their mineral and moisture content and state (live dead, curing), their spatial arrangement in terms of bulk density (mass per unit volume) and packing ratio (volume of fuel per volume of fuel bed) and surface area of fuel per volume of fuel bed were all significant. Broadly, they found that at all types ignited at moisture contents less than about 20%, except two types, which had densely-packed litters with bulk densities exceeding 115 kg m^{-3}. Plucinski and Anderson (2008) showed that the value for fuelbed moisture content at which 50% of tests resulted in ignition decreased from about 30% to 5% as bulk density increased from about 35 to 105 kg m^{-3}. They thus indirectly demonstrated that increasing bulk density between the values above effectively reduced ignition probability.

Ganteaume *et al*. (2009) tested flaming samples of twigs, barks, leaves, cones and cone scales commonly occurring in Europe, on fuelbeds of needles of *Pinus pinea*, P.

pinaster and *P. halepensis,* leaves of *E. globulus* as well as dried and cured grass with fuel moisture contents (FMC) between 3.3% and 11.3%, for ‘no-wind’ conditions. Firebrand initial moisture contents ranged between 4% and 5%. The ignition probabilities (PI) and ignition times (TI) of combinations of firebrand and fuelbed most relevant to Australia are given in Table 1.

Table 1. Ignition probabilities (PI) for combinations of flaming firebrand and fuelbed most relevant to Australia. Firebrand type and initial mass (m_0), Fuelbed type and oven-dry moisture content (MC%). Conditions are ‘no wind’. Experiments were performed by Ganteaume *et al*. (2009). The researchers did not measure time to ignition for the combinations tabled, but times for the other combinations tested ranged between 1 s and 64 s, with a mean of 10 s.

Firebrand	**m_0 (g)**	**Fuelbed**	**MC%**	**PI (%)**
P. radiata bark	1.3 – 8.3	*P. pinaster* needles	3.98	45
P. radiata bark	1.3 – 8.3	*E. globulus* leaves	3.3	20
E. globulus bark	0.2 – 2.0	*P. pinaster* needles	3.98	97.5
E. globulus bark	0.2 – 2.0	*E. globulus* leaves	3.3	100
E. globulus leaf	0.2 – 1.4	*P. pinaster* needles	3.98	97.5
E. globulus leaf	0.2 – 1.4	*E. globulus* leaves	3.3	90

Ganteaume *et al*. (2009) did not find firebrand moisture content as a significant variable, and modelled ignition probability for the fuelbeds as a function of firebrand type, fuelbed bulk density and fuelbed moisture content.

B. Thresholds conditions for glowing sources

Temperature and radiant heat flux

Wright (1932), using heated iron discs and Fairbanks and Bainer (1934), using simulated exhaust manifolds, found that surface temperatures of 725 and 760 °C, respectively, were required to ignite pine needles. Harrison (1970) tested ignition of dry pine needles using a rod-shaped electric heating element. He found that for ignition times of 100, 50, 25 and 10 s, surface temperatures required were 375, 410, 460 and 575C, respectively. Filippov (1974) found that pine needles from the forest floor autoignited in about 30 s when exposed to a radiant heat flux (RHF) of 45 kW m^{-2}. It is likely that, as for solid wood samples (Simms and Hird 1958), the flaming ignition of pine needles will occur for a continuum of combinations of RHF, exposure time and proximity of pilot flame.

Wind velocity

Harrison (1970) found a windspeed of 0.9 m/s wind optimum for the ignition of pine needles by a heating element. A wind velocity which produces the maximum heat flux from a firebrand could be expected to decrease its burnout time (endurance). Ellis (2000), Manzello *et al*. (2006) and Ganteaume (2009) found that glowing firebrand samples could not ignite dry fuelbeds in the absence of airflow (‘wind’). It is likely that a wind velocity of about 1 m s^{-1} optimises the compromise between enhanced radiant heat flux and dilution of combustible gases resulting from pyrolysis.

Fuel moisture content

McArthur (1969) described a ‘critical level of fuel dryness…where the spotting process reaches maximum efficiency’, but no studies to date have demonstrated such a phenomenon.

C. Ignition by glowing sources

Ellis (2000) tested stringybark (*E. obliqua*) firebrand samples of initial mass 0.8 to 1.8 g ignited by match and allowed to combust until they had reached 20% of initial mass.

The (glowing) samples were placed on excised sections of *Pinus radiata* litterbed exposed to a near-horizontal ‘wind’ produced by a domestic fan, of 1 m s^{-1}. He showed that ignition probability by single glowing firebrands of mass between about 0.1 and 0.4 g increased from about 10% to about 60% as fuel moisture content decreased from about 9% to about 3%. He found that glowing samples with a mass as small as 0.11 g could result in ignition.

Ganteaume *et al*. (2009) similarly tested the ignition probability by glowing samples, initially ignited using a small electric radiator and dropped on to fuelbeds. ‘Wind’ across the fuelbed was produced by a domestic fan, and varied in velocity between 0.8 m s^{-1} and 4.5 m s^{-1}. They also tested the effect of horizontal and oblique (45°) orientation of airflow to fuelbed. The ignition probabilities (PI) and ignition times (TI) of combinations of firebrand and fuelbed most relevant to Australia are given in Table 2.

Table 2. Ignition probabilities (PI) and time to ignition (TI, mean bold, and range in brackets) for combinations of glowing firebrand and fuelbed most relevant to Australia, by Ganteaume *et al*. (2009). Firebrand type and initial mass (m_0), Fuelbed type and oven-dry moisture content (MC%), orientation of 0.8 m s^{-1} airflow ('Wind') is oblique at 45° (O) or horizontal (H) to the fuelbed.

Firebrand	**m_0 (g)**	**Fuelbed**	**MC%**	**'Wind'**	**PI (%)**	**TI (s)**
P. radiata bark	1.3 – 8.3	*P. pinaster* needles	3.98	O	2.5	**70** (NA)
				H	17.5	**55** (7-120)
P. radiata bark	1.3 – 8.3	*E. globulus* leaves	3.3	O	0	NA
				H	7.5	**63** (27-117)
E. globulus bark	0.2 – 2.0	*P. pinaster* needles	3.98	O	82.5	**15** (5-55)
				H	55	**10** (3-27)
E. globulus bark	0.2 – 2.0	*E. globulus* leaves	3.3	O	20	**9** (3-25)
				H	22.5	**15** (12-21)
E. globulus leaf	0.2 – 1.4	*P. pinaster* needles	3.98	O	2.5	**14** (NA)
				H	0	NA
E. globulus leaf	0.2 – 1.4	*E. globulus* leaves	3.3	O	0	NA
				H	0	NA

For the former three combinations, Ganteaume *et al*. (2009) found that, in addition to 'wind' orientation and firebrand type, firebrand sample initial mass, surface area and moisture content were significant. For the latter three, they found that sample surface area was significant. The results show that 'wind' orientation can potentially affect ignition probability, and the authors did not explain it. It is likely that different orientation of airflow results in different patterns of turbulence at the surface of the fuelbed, thus influencing ignition.

D. Rate of initial spotfire growth

Ganteaume *et al*. (2009) also tested ignition frequency, the time to ignition, subsequent rate of spread, rate of fuel consumption, mean flame height and fuel consumption ratio, of fire within prepared trays (0.70 m square, or 0.70 m dia.) of five common European litter types. Their standard ‘firebrand’ was a 2 × 2 × 1 cm block of *Pinus sylvestris* wood ignited using an electric radiator (Standard NF P 92-509-1985), and tests were carried out in ‘no-wind’ conditions. They modelled the six parameters of ignition and growth as linear functions of fuel moisture content and fuelbed bulk density.

The pine needle fuelbeds of *P. halepensis* and *P. pinaster* in these experiments (Ganteaume *et al*. 2009) potentially have similarities with those of *P. radiata*, and hence data from those tests may be relevant to Australia, but this will require verification. The *E. globulus* litter fuelbeds had mean values for fuel load, moisture content and bulk density of 1.01 kg m^{-1}, 7.89% and 35.72 kg m^{-3}. The ignition probability and mean values for time to ignition and rate of spread for 64 tests of *E. globulus* litter were 94%, 9.1 s and 0.17 cm s^{-1}.

Butler (2006) investigated the effect of surface fuel heating by solar radiation by comparing the rate of combustion of 2.4 m long non-irradiated and halogen irradiated fuelbeds in a horizontal wind tunnel. He postulated that the faster rate of spread observed in fuels irradiated at between 0.8 and 1.0 kW m^{-2} could be attributed to increased turbulence at velocity scales less than 0.1 m s^{-1}, decreased fuel moisture and increased preheating of the fuel bed. He envisaged that the turbulence created by irradiation would act to increase the mixing of oxygen adjacent to the surface.

Summary and Recommendations

Ignition probability is a critical variable in determining the number of spotfires resulting from a given number of firebrands transported, and hence subsequent potential impact on firefighters and communities. In Australia, eucalypt barks are supposed to be the principal firebrand material (McArthur 1966, Cheney and Bary 1969). There have been few published studies of ignition of Australian litter types, and of ignition by eucalypt barks. Plucinski and Anderson (2008) compared the ignition probabilities by a standard flaming 'firebrand', of prepared trays of Australian shrubland litters and determined the significant fuelbed variables. These authors confirmed the influence of fuel moisture content and bulk density on ignition probability. Ellis (2000), Plucinski and Anderson (2008) and Ganteaume *et al*. (2009) confirmed that flaming sources typically had 100% ignition probability of fine fuels at low moisture contents. Ellis (2000) and Ganteaume *et al*. (2009) showed that glowing samples of eucalypt bark had high ignition probabilities of such fuels. The latter authors showed that 'wind' orientation to the fuelbed, fuelbed type and moisture content, firebrand sample state, and to some extent its size and mass, were all important. These authors also measured the initial spread rate following ignition trays of this litter type.

However, it is arguable that the firebrand samples used in both the studies did not reflect the condition of similar samples following airborne flight. In addition, because fuelbed ignition methodologies are not standardised, it is very difficult to make comparisons between studies. Thus, there is a need to validate and extend work ignition probability work by Ellis (2000) and Ganteaume *et al*. (2009) to other firebrand types and fuelbeds implicated in major spotting events. As well, there appears to be no information concerning the phase of early spotfire growth in ‘wind’ conditions, apart from unpublished data by McArthur on fire growth from point ignitions. Table 3 lists details of methodologies which should be considered before designing experiments to investigate ignition and early spotfire growth.

Table 3. Details of methodologies which should be considered in the design of experiments to investigate fuelbed ignition and initial spotfire growth.

Variable	**Consideration**	**Possible solution**
Natural wind over fuelbed surface in the field	How will laboratory ‘wind’ compare with natural wind?	Characterise surface wind in the open and under open forest
Laboratory ‘wind’	How to transfer of lab results to field and comparison of results between experiments?	Design an airflow system, then describe the resulting airflow across the fuelbed trays
Natural solar radiation, which is particularly relevant in open eucalypt forest	How will laboratory ‘solar radiation’ compare with natural radiation?	Set a laboratory standard of 1 kW m^{-2}, say, and measure its effect on fuel temperature and turbulence at the surface of the fuelbeds.
Variations in heat flux for samples of natural material	How to compare ignitibility of different fuelbeds?	For some tests use ‘standard’ firebrands to produce a consistent flaming or glowing ignition source.
Differences between the characteristics of a firebrand sample burning in the laboratory and one which has been transported by air in the field	How to relate ignition probability for a particular firebrand material measured in the laboratory, with that in the field?	Characterise the difference between laboratory sample and sample which has been burning at its terminal velocity.
Differences between the characteristics of a fuelbed which has been dried artificially in the laboratory and one which has dried naturally in the field	How to relate ignition probability for a particular fuelbed type measured in the laboratory, with that in the field?	Difficult.
Variation in ignitibility between different fuelbeds of given moisture content	How to compare ignition success by different firebrands?	For some tests use a ‘standard’ fuelbed to allow comparison.

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