Risk of ignition of forest fires from black powder or muzzle-loading firearms

A Study Prepared for the U.S. Forest Service, San Dimas T&D Center

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Introduction

As stated by the US Forest Service, the objectives are:
To establish evidence and data to determine:

1) if and which type of black powder firearm might ignite forest and field vegetation and,
2) under what conditions this ignition might occur and likely will occur.

Scope of work for Phase I

Phase I work will be preliminary to scope the problem, determine the already-available data that can be used, and to provide an initial experimental plan for obtaining needed data that are not currently available.

Ignition of forest fires from black-powder firearms can occur directly or indirectly. "Directly" means the ignition of vegetation from a discharge of the firearm. "Indirectly" means due to the expected presence and activities of individuals using black powder firearms. The activities that can indirectly lead to ignition include use of motor vehicles, accidental disposal of focusing-power articles (e.g., lens-like or mirror-like substances), and carelessness in camping, cooking, or smoking.

The first part of the Phase I work will be to review existing data on the ignition of vegetation to identify data that can already be used to establish conditions under which direct or indirect ignition of vegetation can occur due to individuals using black powder firearms. The deliverable will comprise a summary of this identified data.

The second part of the Phase I work will be to provide a preliminary experimental plan for obtaining needed data where a review of the literature indicates that suitable data are not available. Details of this will be developed once it is identified which areas are lacking in needed ignition data. The deliverable will be the initial experimental plan for obtaining the required data.

Part 1 – Review of the literature

The potential for ignition of forests under the jurisdiction of the U.S. Forest Service by users of black powder or muzzle-loading firearms has to be considered in the full context of the activities—there is the use, firing, and cleaning of the firearms themselves. In addition, however, firearms usage necessarily entails human activity, that is, hunters with such firearms need to transport themselves to the site where they will be using their firearms and possibly there may be camping and cooking as part of their activities. In addition, while smoking will invariably be prohibited during periods of high fire hazard, the risk of disobedience of such regulations must be considered. In the same manner, if open-fires associated with camping, or camping itself, are prohibited, the risk also has to be considered that these regulations may be disobeyed.

Since there are no statistics on the modes by which hunters using black powder firearms can cause forest fires, it is necessary to consider ignition modes from basic physics principles, i.e., what activities or operations have the potential to introduce ignition sources into the vicinity of combustibles. The following is a first-cut list. Direct activities associated with using or discharging of black-powder or muzzle loading firearms:

(1) A pan flash or burning grains of the priming charge ejected from a flintlock firearm and landing onto vegetation, an open can of black powder, or other combustibles.
(2) The ejection of flaming wadding, residual powder, or a lingering spark from the barrel after firing.
(3) Improper use of a firearm very close to ignitable substances, with the consequence that the touch hole blast ignites adjacent material.
(4) An improperly seated or manufactured cap in a percussion firearm, from which pieces are ejected during firing.
(5) A bullet (or ball) igniting vegetation due to sparking or frictional heating, upon contacting a rock or other hard object.
(6) A burst barrel or other catastrophic failure of the firearm.
(7) Improper use of the firearm, e.g., blowing down the barrel after a shot, which may cause a flash of unburned powder and ignition of nearby combustibles.
(8) Use of exploding targets.

Other activities associated with human presence in Forest Service lands:

(9) Motor vehicles as an ignition source.
(10) Smoking.
(11) Camping fires or cooking activities.
(12) Disposal of materials leading to solar-energy ignition.

The pertinent literature to each of these ignition modes will now be considered in turn.

(1) A pan flash or burning grains of the priming charge ejected from a flintlock firearm and landing onto vegetation, an open can of black powder, or other combustibles.
Here, the mechanism of ignition corresponds to a small flame or a firebrand. The literature on the ignition of vegetation from these sources is extensive.

For ignition from small flames, moisture content must be 20 – 25% or lower, for fine forest or grassland fuels to be ignitable[1]. However, this refers to the MC of the specific plant to be ignited. Drying is non-uniform and, as the average MC of a field starts dropping below about 170%, an increasing fraction will contain individual plants (and patches of them) which are dry and which can be match-ignited and then serve to ignite the rest of the field. Parrott and Donald[2] tested four species of annual grasses for match-flame ignition and found that ignition was possible, at the 50% probability level, when the overall field's MC was 70 – 120%. At the 5% probability level, this rose to 120 – 250%. This can be expressed in a different way: a field becomes ignitable, at the 50% probability level, when the fraction of dry plants within it reaches about 40 – 80%. For a given MC level, the instantaneous atmospheric temperature and RH values were found not to be a significant effect on the probability of ignitability.

Sale[3] conducted experiments on the ignition of dried grass by matches. The moisture content of the grass was ca. 5%. When matches were dropped from a distance of 0.9 m, 80% of matches caused ignitions, but at a distance of 3 m the probability went down to 25%. An old US Forest Service report[4] which has been widely cited advised that dropped matches will not ignite forest fires at wind speeds above 1.8 m/s (4 mph), but the author provided no experimental data and the conclusion is questionable.

The effect of moisture on the ignitability of forest-floor pine-needle litter was studied by Blackmarr[5]. He used three different wood match igniters: (1) a miniature match; (2) kitchen match; and (3) three kitchen matches tied together. The results focused on the role of moisture content for needles of *Pinus elliottii* (slash pine), and it was found that there is a relatively narrow range of moisture contents over which the probability of ignition goes from near-zero to near-100%. For the miniature match, the 50% probability of ignition corresponded to 19.3% moisture content.

Concerning ignition by firebrands, the experience of the U.S. Forest Service is that a glowing brand only tens of milligrams in mass can start a smoldering fire in a highly susceptible target fuel[6]. This is consistent with the laboratory results[7] which showed that burning coal particles of only 5 mg (about 2 mm diameter) inevitably cause ignition when dropped onto cotton wool. This is relevant, since fine, dry vegetation material is roughly of similar ease of ignition as cotton wool. A number of other studies using large (inches, rather than millimeters) size have been published and reviewed[8], but these results are not directly applicable.

The exhaust from the engines of automobiles, trucks, locomotives, farm equipment, etc. can discharge burning carbonaceous particles. These have been known to cause ignitions of vegetation and other combustibles. Fairbank and Bainer[9] designed a transportable furnace to expel hot particles onto test vegetation. Particles even below 0.6 mm diameter were able to ignite vegetation, although the probability was low for the smallest sizes. Maxwell et al.[10,11] examined exhaust particles from diesel engines and found that 1.5 – 2.0 mm particles were readily able to ignite cheat grass (*Bromus tectorum*).

(2) The ejection of flaming wadding, residual powder, or a lingering spark from the barrel after firing.

This cause is specifically listed by Libershal[12] as a known cause of forest fires, however, he provided no data or specific details. Technically, the problem is a similar situation to burning grains being discharged from a pan. The available literature consists of the studies cited in #1 above, pertinent to firebrand ignition.

(3) Improper use of a firearm very close to ignitable substances, with the consequence that the touch hole blast ignites adjacent material.

This is a similar situation to flames from a pan flash. The available literature consists of the studies cited in #1 above, pertinent to small-flame ignition.

(4) An improperly seated or manufactured cap in a percussion firearm, from which pieces are ejected during firing.

This is a similar situation to burning grains being discharged from a pan. The available literature consists of the studies cited in #1 above, pertinent to firebrand ignition.

(5) A bullet (or ball) igniting vegetation due to sparking or frictional heating, upon contacting a rock or other hard object.

Libershal[12] published a short paper where point out the special hazard of tracer, incendiary, and armor-piercing ammunition. This type of ammunition is normally not used by black-powder shooters, nor is it appropriate for game hunting, however, the possibility of users of black-powder firearms bring such ammunition into a forest must be considered. Libershal also noted that, at one time, the Angeles National Forest had a fire problem due to use of a particular type of Chinese bullets that have a steel 'penetrator core.' Sparking potential of lead against rock is minimal, but it is high for steel, and Libershal pointed out that shooters were often not aware that these bullets had a steel core. No studies have been found pertinent to the fire-setting potential of more conventional ammunition, nor to ammunition specifically likely to be used in black-powder firearms.

(6) A burst barrel or other catastrophic failure of the firearm.
No known studies exist on this topic, nor it is feasible to generalize from studies conducted for other purposes.

(7) Improper use of the firearm, e.g., blowing down the barrel after a shot, which may cause a flash of unburned powder and ignition of nearby combustibles.
The mechanism is similar to that discussed for #1, however no specific studies are known to exist on this topic.

(8) Use of exploding targets.
Libershal[12] mentions that forest fires have been set by individuals using exploding targets ("Bullz-I" or similar). No specific data was provided, however.

(9) Motor vehicles as an ignition source.
This ignition mechanism has been extensively studied. There is a very wide range of causes for motor vehicle fires, and any one of them can suffice to start a forest fire, if the vehicle is near vegetation and the moisture content of the vegetation is low. There exist, however, at least two causes which do not require an overt fire to be present at the motor vehicle, yet may lead to the ignition of a forest fire: (1) discharge of hot exhaust particles; and (2) hot exhaust system surfaces coming into contact with vegetation. Studies on the ignition potential of hot exhaust particles were discussed in connection with #1, above. Harrison[13] studied the hot-exhaust-system problem and found that 350ºC was needed to ignite dry pine needles and 400ºC to ignite dry grass during a 4 min exposure. Under certain vehicle conditions and driving situation, temperatures can be found on exterior surfaces of exhaust system components of some vehicles which are significantly higher than these ignition temperatures. Studies on this topic were published by the California Air Resources Board[14], Harrison[15], and Knight[16].

(10) Smoking.
Smoking accounts for a significant fraction of U.S. forest fires[17], and presumably the bulk of these losses have occurred at times and places where smoking was banned. Thus, ignitions due to smoking have to be considered.

Hoffheins et al.[18,19] conducted experiments on the ignition of grass and forest duff and litter by cigarettes and found that ignition probability depends strongly on the wind speed. Probabilities approaching 100% were found for a variety of target materials under wind speeds of around 3 m/s. Countryman[20,21] found that grass is unlikely to ignite if a cigarette falls on stalks of grass that support the cigarette above the actual litter layer. He then determined that ignition probability depends greatly on whether the fuel was coarse or fine. For fine fuel, ignition readily occurred for moisture contents up to 13%, with marginal ignitions up to about 14 – 15% and none beyond. Coarse fuel was not possible to ignite even for the lowest moisture tested, 1.9%. Ford[22] reported that, under some circumstances, vegetation with moisture contents of 18 – 22% is ignitable by cigarettes, but provided no details on vegetation type nor on wind conditions. He also concluded that the cigarette must contact fine vegetation for at least 1/3 of its perimeter for ignition to be possible. Markalas[23] studied the potential of cigarettes to ignite foliage of various types. For materials dried to 4.5 – 6.5% MC, he found that: (a) no ignition could be achieved without wind; (b) with wind, ignition probability depended greatly on the species; (c) filter cigarettes were slightly less likely to cause ignition; and (d) thicker layers of vegetation were more readily ignited than thinner ones.

(11) Camping fires or cooking activities.
Forest fires due to camping activities are an even greater factor than are those due to smoking[17]. Thus, these ignitions must also be considered. Experimental studies have not been made concerning camping fires since they can entail large, sustained flames. Such flames can ignite any reasonably dry target fuels.

(12) Disposal of materials leading to solar-energy ignition.
Any lens-like or mirror-like object that can focus solar radiation sufficiently can act as an ignition to vegetation. These objects may be bottles, jugs, containers or other objects having a primary purpose other than for focusing solar radiation. Statistics are not available for this mechanism, but the problem is sufficiently important that Fuquay[24] did specific laboratory studies on the topic.

In all of the above, it should be noted that no factors were identified that would limit the problem to a particular *type* of black-powder firearm. In other words, if the hazard potential exists, indications are that it exists irrespective of the exact nature of the black-powder firearm being used. This conclusion does not extend to type of ammunition, however, since it was identified clearly that steel-containing ammunition carries a significantly higher risk for ignition.

Part 2 – Experimental work needed

The review of the literature in Part 1 indicates that there is more than one mechanism for which research is not available. In addition, because fire loss statistics are not available to the necessary level of detail, there is not a basis for prioritizing the experimental work according to the loss potential of each particular ignition mechanism. Thus, the mechanisms established above are now considered in turn, with the objective of determining for which ones further research is recommended and, for those, what the research should consist of.

For mechanisms (1), (2), (3), (4), (7), (9), (10), and (12) the scientific literature does contain studies that have a direct bearing, so new experimental studies is not the highest priority.

Mechanism (5) has never been studied experimentally. Conceptually, the problem can be subdivided into steel-containing and pure-lead bullets (or balls). If steel-containing bullets have to be considered as potentially being used by some black-powder shooters, then the most likely bullet types should be identified and tests should be run by firing into rock surfaces, adjacent to which is fine-fuel vegetation of controlled moisture and temperature. If use of steel-containing bullets is excluded as being of very low probability, then there still remains the need to study ignition potential due to frictional heating, as opposed to sparking. Probably the best type of target here would be punky wood, where the task would be to determine the possibility of a smoldering ignition of the material due to heating by a penetrating bullet.

Mechanism (6) has never been studied experimentally. This is a low-probability event, but with serious consequences if it occurs. A specialized facility would have to be found or constructed that allows barrel bursting to be done safely, while recording the events with video. An appropriate nearby target would be fine, dry fuels of controlled moisture content and temperature.

Mechanism (8) has never been studied experimentally. It would first have to be established whether the U.S. Forest Service considers this to have a high enough probability of being employed in connection with black powder shooting activities. If it is concluded that there is a sufficiently high probability, then experiments can be arranged without great difficulty. Commercially available exploding targets should be procured and fine, dry vegetation of controlled moisture content and temperature should be placed in direct contact with the target.

Mechanism (11) has not been studied experimentally, but this is largely because ignition is almost certainly assured, if a large, sustained flame is applied to dry vegetation. The risk of these activities must be carefully assessed, but it does not appear that experimental studies are necessary on this point.

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