Thermal Hazards from the Accidental Ignition of Pyrotechnic Compositions

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ABSTRACT

In this paper we have analysed further some of our previously published data relating to thermal effects produced on the ignition of a range of pyrotechnic compositions, and have evaluated the hazards posed to those handling and working with such materials by reference to the distances for different degrees of burn injury.

Keywords: thermal hazard, radiation, burn injury, pyrotechnics

Introduction

The thermal characteristics of fireballs from a number of fuel sources other than pyrotechnics have been reported in the literature, including liquid propellants,[1] motor fuels[2] and propane.[3] Fireball effects can be described in terms of the maximum diameter D (m), the duration of the thermal effect t (s) and the heat flux radiated from the fireball surface q (kW m^{-2}). In many cases both D and t are related to the fuel mass M (kg) by a power law relationship of the approximate form $M^{1/3}$.

To investigate the applicability of this generalised equation to pyrotechnics, a series of experiments was recently done[4] with a range of compositions in which D, t and q were quantified at various values of M, up to 25 kg. The results from these trials indicated that relationships of the form $D = aM^x$ and $t = bM^x$ applied. However, the values of x varied from 1/3, sometimes significantly, in both equations, and different compositions gave different values for the constants a and b (within the range 0.53–26.0).

The predictive equations obtained from the study were used in a subsequent paper to examine both the fire and explosion hazards of the pyrotechnics that had been tested.[5] Explosion hazards were evaluated since some of the compositions exploded under conditions of self confinement. The Eisenberg thermal radiation dose criterion[6] was used to evaluate potential levels of harm (blister thresholds and degrees of burn) at different distances.

In this short paper, some of the implications of these results are examined with respect to those in the pyrotechnics industry working with relatively small quantities of loose (self confined) composition.

Discussion

Table 1 lists the compositions of the pyrotechnics examined. The potential hazards of pyrotechnic fireballs can be defined in terms of heat flux, time of exposure (or burning time, if less) and distance from the fireball surface since distance determines thermal exposure and duration influences the dose received.

The various design requirements of pyrotechnic mixes are reflected partly in their burn times and these show a significant range in duration from $t < 1$ s to >50 s for 1–25 kg quantities of different materials.[4]

It has been reported in the literature[7] that it takes approximately 5 s to sense high levels of thermal radiation and start to make an escape, and it is also known that a proportion of the

Table 1. List of Pyrotechnic Compositions and Their Ingredients.

Pyrotechnic Substance	Ingredient	% by Mass
Gunpowder 3/7 Grist	Potassium nitrate	75.0
	Carbon	15.0
	Sulfur	10.0
Flare Composition 1	Magnesium	26.0
	Lithographic varnish	4.0
	Sodium nitrate	42.0
	Calcium oxalate	16.0
	PVC powder	12.0
Flare Composition 2	Magnesium	49.0
	Lithographic varnish	4.5
	Sodium nitrate	39.5
	Calcium oxalate	7.0
Star Composition 1	Magnesium	42.0
	Boiled linseed oil	6.0
	Barium nitrate	17.0
	Potassium perchlorate	27.0
	PVC powder	8.0
Star Composition 2	Gunpowder	55.6
	Potassium nitrate	18.5
	Dextrin binder	7.4
	Aluminium	18.5
Priming Composition 1	Potassium nitrate	40.0
	Silicon powder	40.0
	Gunpowder sulfurless mealed	20.0
Priming Composition 2	Gunpowder	68.0
	Potassium nitrate	14.6
	Silicon	14.6
	Dextrin binder	2.8
Flash Composition 1	Magnesium	57.0
	Potassium perchlorate	37.0
	Graphite	6.0

final burn injury can occur during the phase when the skin is cooling.[7]

It may be possible for workers exposed to the thermal radiation from fireballs with $t > 5$ s to limit their potential thermal dose by making a rapid escape. On the other hand, certain pyrotechnic materials burn for less than 5 s and for such events an eventual escape would not be likely to limit the received thermal radiation dose.

To compare the potential of different pyrotechnics to cause burn injuries, with fireballs burning for greater than 5 s we have still used the 5 s reaction time[7] in our calculations since, although a process operator seated directly in front of an igniting pyrotechnic material is likely to respond in less than 5 s, the overall duration of exposure can be assumed to be approximately 5 s. The extreme conditions arising from engulfment within the fireball have been assumed to be fatal.

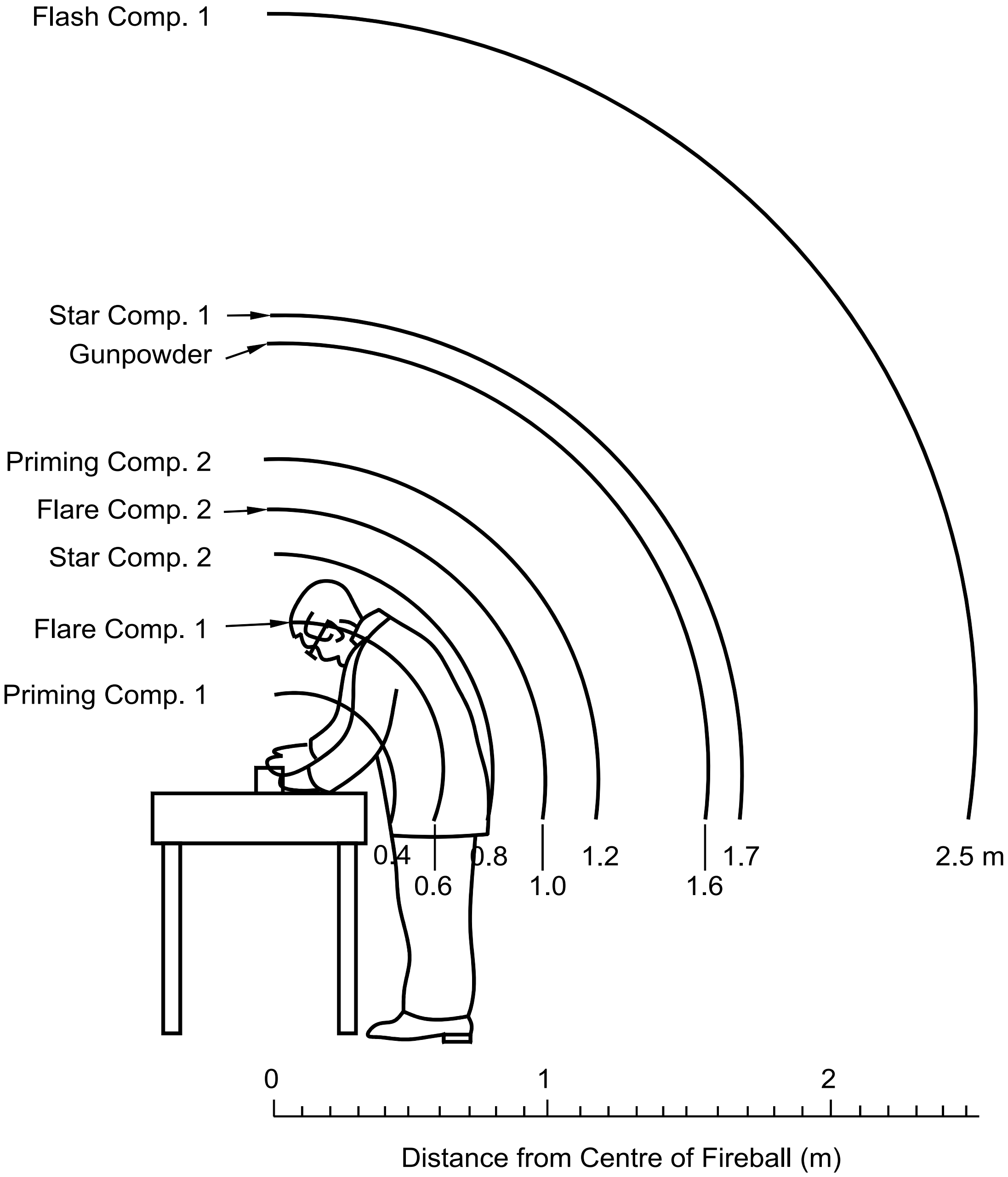

Figure 1. Flare / fire / fireball dimensions (m) for 1 kg quantities of loose pyrotechnic compositions.

From our previously published results,[4] it is possible to compare the sizes of actual and pseudo fireballs produced by the ignition of different compositions with M = 1 kg, Figure 1. This diagram indicates that most of the materials examined produce fireballs that would engulf a process worker positioned at arms length from the point of initiation. Dose levels and corresponding burns injuries for process workers positioned beyond the fireball radius can be calculated using a maximum exposure time of 5 s. A dosage of 1200 $(\text{kW m}^{-2})^{4/3}\text{s}$ has been used in the literature[7] as the mean value to produce second degree burns with depths >0.1 mm on unprotected skin and this value was employed in our work. Clearly, appropriate fire protective clothing can offer some mitigation, but nevertheless, this dose has been reported to result in 1% lethality to averagely dressed exposees.[7] The distances to second degree burns for every composition with M = 1 kg, Figure 2, show that other process workers in the same room could

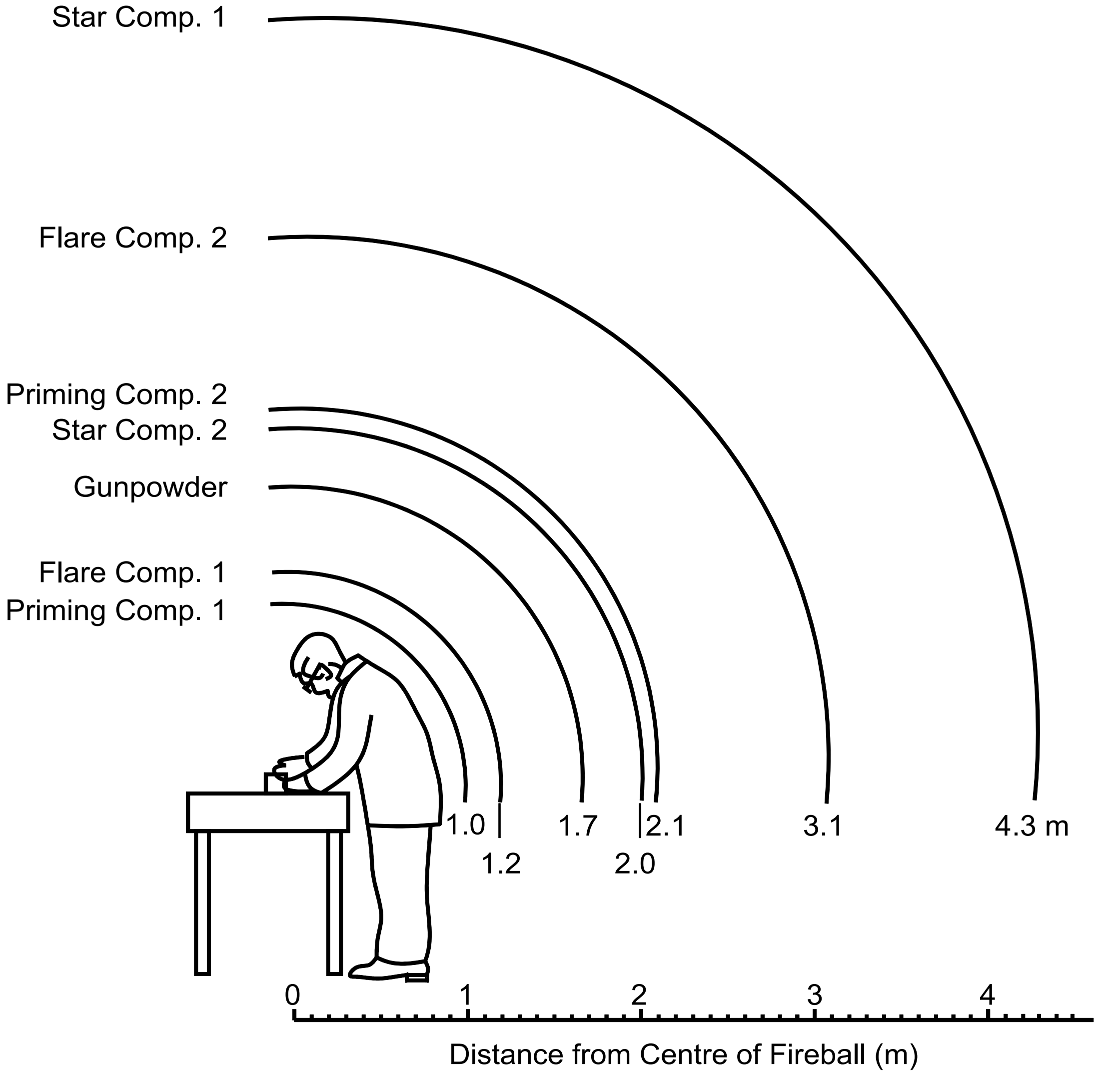

Figure 2. Distances (m) to second degree burns from 1 kg quantities of loose pyrotechnic compositions.

well be within the minimum distances to be affected. The information summarised in Figure 2 should, however, be taken as a first approximation since the hazards posed by the slowest burning materials may be overestimated because the flames can take time to build up to peak irradiance (i.e., the calculations assume 5 s of exposure to the peak surface emissive power from fireballs).

Since the blister threshold dosage[7] is only 210 (kW $m^{-2})^{4/3}$s, such injuries can be sustained at greater distances from the point of initiation of a range of substances with $M = 1$ kg, Figure 3. Again, other workers in the same process room and at considerable distances from the source could receive blister injuries.

The importance of taking account of exposure time in determining dosage is illustrated by the different rankings obtained for the potential hazards posed by the fireballs from 1 kg quantities of materials when using either distance to second degree burns (dosage) or fireball dimensions as the ranking criterion, Table 2. This Table shows that a simplistic ranking based on fireball dimensions alone may not accurately represent the hazard posed to workers outside the fireball diameter by the ignition of certain

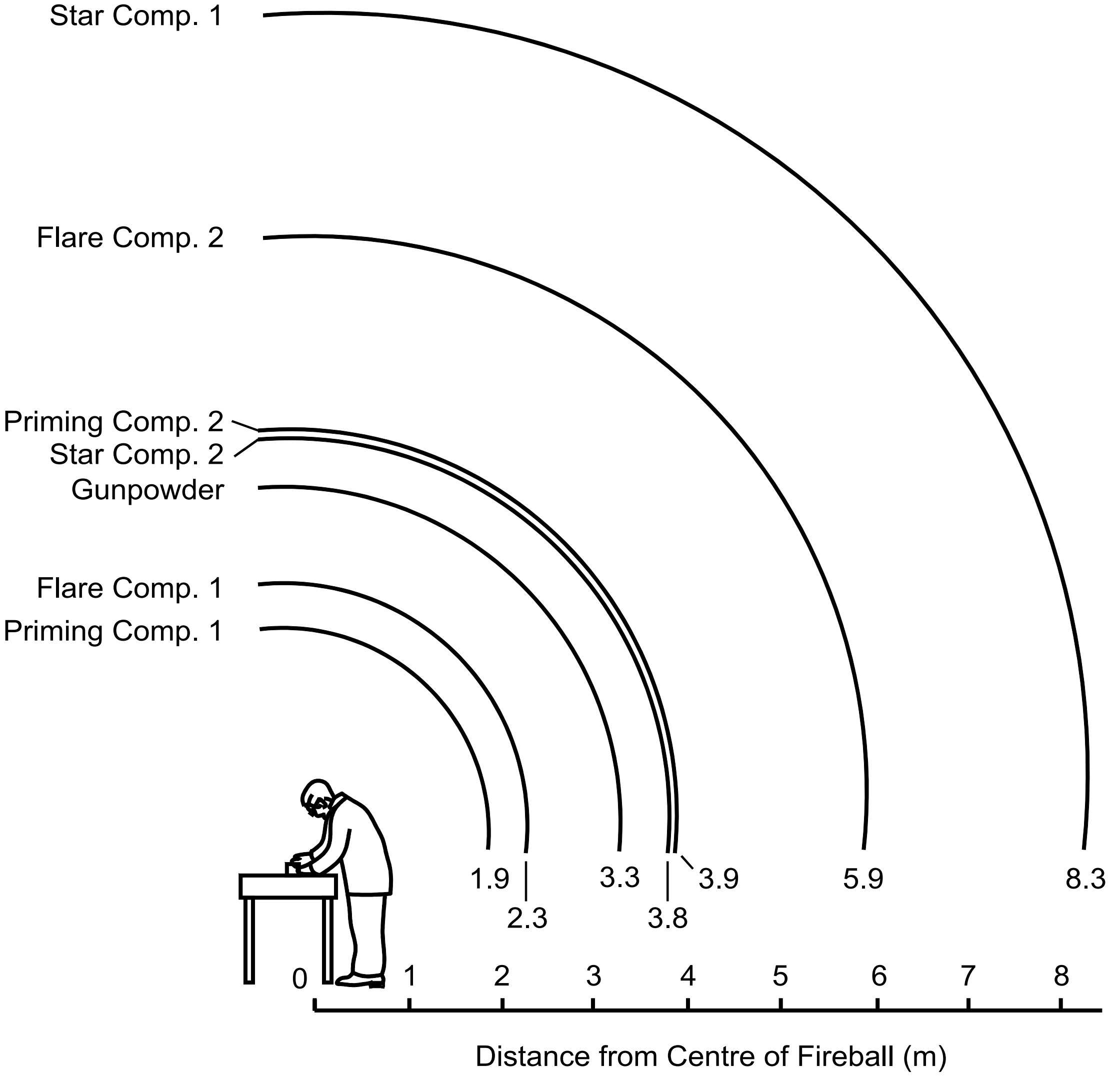

Figure 3. Distances (m) to blister threshold for 1 kg quantities of loose pyrotechnic compositions.

pyrotechnic compositions (e.g., gunpowder and flare composition 2).

By assuming that our fireball data for gunpowder with $M = 1$ to 25 kg can be extrapolated to lower values of M, it is possible to use the relationship[4] $D = 3.1\ M^{0.279}$ to estimate fireball sizes and hence the hazards posed by the ignition of small quantities of gunpowder, as indicated in Figure 4. This diagram shows that a fireball produced by burning quantities as low as 100 g can engulf a process worker.

In terms of reducing potential hazards in the working environment posed by the accidental ignition of pyrotechnics, the first step is to minimise the quantities being handled. This is often supplemented by the introduction of engineering controls to ensure that a suitable physical separation exists between the worker and the potential heat source. Techniques employed include remote handling, the use of robotics, and the use of protective screens. Some fire protection can also be gained by using quenching systems.[8,9,10]

As a last resort, personal protective equipment can be employed and a recently published guide gives an indication of the current position with regard to the selection and use of fire protective clothing for explosives workers in the UK.[11] The ICARUS code[12] is also able to

Table 2. Relative Rankings of the Hazards Posed by Fireballs from 1 kg Quantities of Pyrotechnic Compositions.

Pyrotechnic	Fireball Radius (m)	Ranking Based on Fireball Dimensions	Distance to Second Degree Burns (m)	Ranking Based on Level of Harm (Second Degree Burns)
Star comp. 1	1.7	1	4.3	1
Gunpowder	1.6	2	1.7	5
Priming comp. 2	1.2	3	2.1	3
Flare comp. 2	1.0	4	3.1	2
Star comp. 2	0.8	5	2.0	4
Flare comp. 1	0.6	6	1.2	6
Priming comp. 1	0.4	7	1.0	7

predict burn injuries for workers exposed to thermal radiation when wearing appropriate protective clothing.

Research sponsored by the Health and Safety Executive is currently underway to develop a full torso portable manikin to enable the evaluation of complete garments against the thermal threat posed by burning pyrotechnics and propellants, and this may provide a useful means of ranking the performance of protective clothing, thus aiding selection.

Conclusions

In this paper the potential thermal hazards posed to workers in the pyrotechnics industry by the ignition of different types of compositions have been examined. Relatively small quantities of material can produce a significant fireball and, because thermal emissive powers are relatively large, even short duration exposure can result in burn injuries at considerable distances from the source.

The main factors affecting hazard are the close proximity of the pyrotechnic worker to the composition and the quantity present in the process room. Means of minimising the role of these factors (i.e., reducing quantity, increasing distance) are desirable in terms of improving safety in the workplace.

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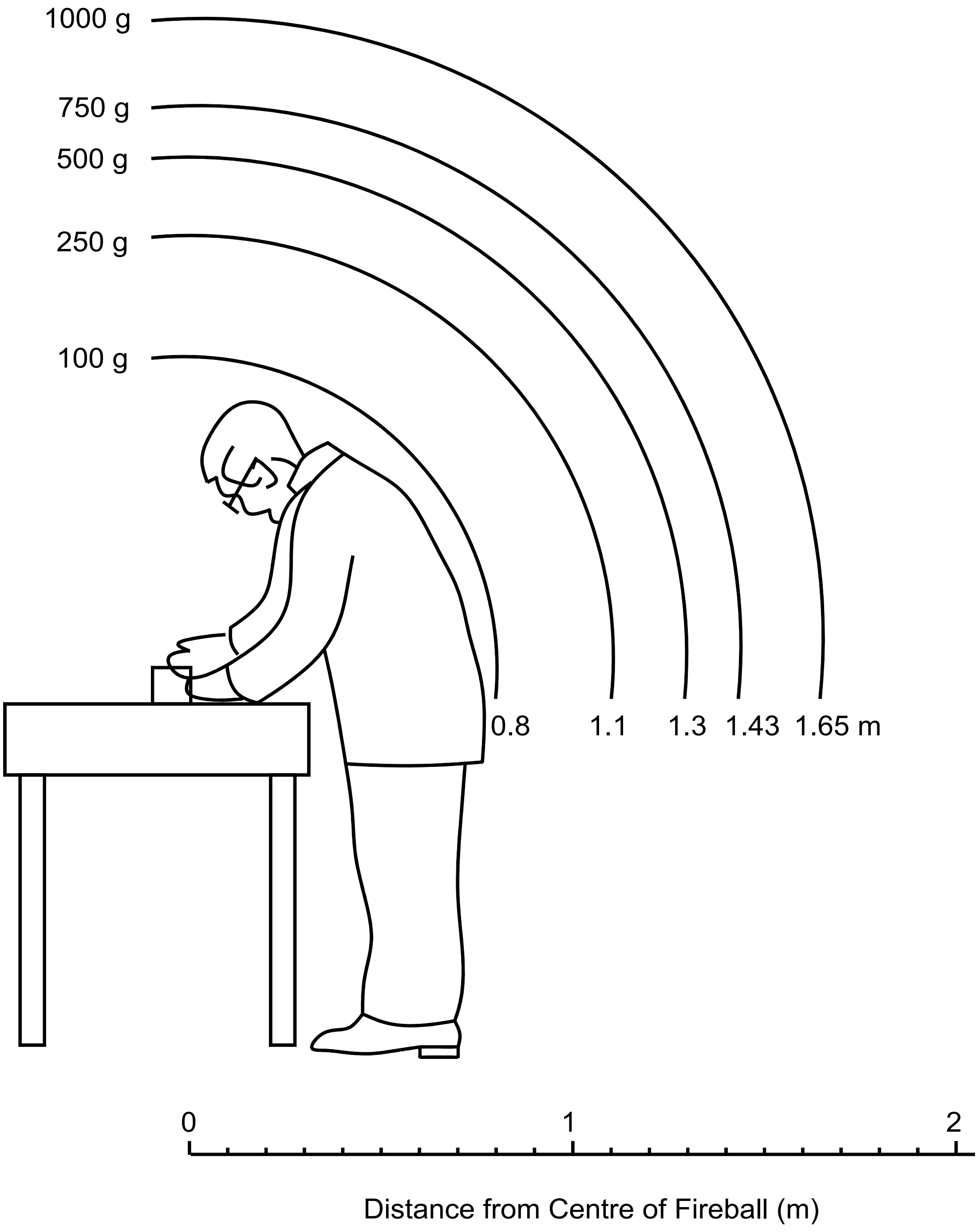

Figure 4. Fireball dimensions for small quantities of loose gunpowder.

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