Evaluation of the Hazards Posed by High Energy Bangers
Part 1. Noise, Overpressure and TNT Equivalence

R. K. Wharton, D. Chapman and A. E. Jeffcock
Health and Safety Laboratory, Harpur Hill, Buxton, Derbyshire, SK17 9JN, United Kingdom

ABSTRACT

The work reported in this paper was undertaken to determine the hazards posed by certain types of European bangers (firecrackers) that use flash composition. Experiments were done to evaluate the overpressures and noise levels close to such fireworks when they function.

The results indicate that powerful flashbangers could cause hearing damage to those in their immediate vicinity.

The TNT equivalences derived from overpressure for the barium nitrate and potassium perchlorate flashbangers tested were found to be 25 and 57%, respectively.

Keywords: noise, overpressure, TNT equivalence, flash composition, bangers, firecrackers

Introduction

The 1988 British Standard BS7114[1] defined the types of fireworks that could be sold to the general public in the United Kingdom (UK). Category 2 bangers could contain up to 1.6 g of gunpowder (blackpowder) as the explosive charge and should not cause injury to a person 5 m away, while Category 3 bangers could contain up to 10 g of an unspecified explosive composition and should not cause injury to a person at a distance of 25 m from the firework.

The sale of bangers was banned in the UK in 1997 on safety grounds. Prior to this, flashbangers had been classed as Category 3 items.

Work is currently underway to produce a European (CEN)[2] Standard for Fireworks,[3] Table 1 gives details of the net explosive content of the proposed categories for flashbangers.

Additionally, the CEN standard sets maximum sound level requirements of 120 dB (AI_{max}) at 1, 8 and 15 m for Category 1, 2 and 3 bangers, respectively.

Typical flash compositions used in fireworks contain mixtures of either barium nitrate or potassium perchlorate with a metal powder.

The programme of work undertaken to quantify the hazards from energetic bangers was composed of two parts. The first study, which is reported in this paper, involved examination of the near field blast and medium range noise effects produced by the initiation of flashbangers containing the two types of composition under consideration by the CEN committee.

The second component of the study involved qualitative experiments to simulate and record the effects produced by different flashbangers when they function while being held. This work will be reported separately.[4]

Table 1. Net Explosive Content Proposed by CEN Committee CEN/TC212 for Flashbangers.

Banger Type	Net Explosive Content (g)		
	Category 1	Category 2	Category 3
Friction ignited flashbangers	—	1.0 nitrate based 0.5 perchlorate based	6.0 nitrate based 3.0 perchlorate based
Flashbangers	0.3 nitrate based 0.2 perchlorate based	1.0 nitrate based 0.5 perchlorate based	10.0 nitrate based 5.0 perchlorate based

Manufacture of Bangers

To simplify the experiments, the bangers for the tests were made with an electrical ignition system, rather than a manually lit fuse, and no work was undertaken with friction ignited flash-bangers. The bangers were specially manufactured by Standard Fireworks (now Black Cat Fireworks) of Huddersfield, UK.

The pyrotechnic materials chosen for the test programme were:

1) barium nitrate / aluminium powder

2) potassium perchlorate / aluminium powder

Since various types of cardboard tube can be employed in making bangers, it was decided that each firework would be produced in three tube types (i.e., weak, medium and strong). Also, since closures can be made of either paper or clay, each type was produced with two types of end plug. Different strengths of tubing were achieved by using rolled cardstock with different degrees of perforations. This is a common industry practice for banger construction as it introduces points of preferential weakness.

End plugs were either a standard clay type or a paper end-disc glued in place and then sealed with a layer of hot glue melt. Ignition in all instances was achieved by initiating an electrical fusehead (electric match) that had been incorporated beneath a tapered plug at the top of the firework.

Table 2. Type of Composition and Net Explosive Content Used in the Bangers.

Pyrotechnic Composition	Net Explosive Content (g)		
	Cat. 2	Cat. 3	
Potassium perchlorate / aluminium powder	0.5	3*	5
Barium nitrate / aluminium powder	1	6*	10

* These values would apply to friction ignited flashbangers.

Details of the net explosive content of the manufactured bangers are given in Table 2.

Physical measurements were made on randomly selected fireworks to check compliance with these requirements and the results are summarised in Tables 3 and 4.

All the bangers showed some variation in the amount of composition they contained, but this was typical of similar manufactured goods.

The oxidiser metal ion was measured by flame emission atomic spectroscopy: the barium nitrate bangers had a mean barium nitrate content of 64.6% compared with a specified level of 68%. Similarly, the potassium perchlorate bangers had a mean potassium perchlorate content of 68.8%, compared with the specified 71%. These minor deviations in chemical composi-

Table 3. Measurement of Barium Nitrate / Aluminium Bangers.

Type	Length (mm)	Tube Outside Diameter (mm)	Wall Thickness (mm)	Type of closure / tube	Mass of composition (g)
Small tube	69.60–70.20	10.90–11.10	2.10–2.30	clay / medium	1.01–1.25
Medium tube	107.70–107.85	23.30–23.50	5.45–5.55	cardboard / strong	5.84–6.71
Large tube	139.65–140.05	23.10–23.50	5.20–5.50	clay / strong	9.69–10.99

Table 4. Measurement of Potassium Perchlorate / Aluminium Bangers.

Type	Length (mm)	Tube Outside Diameter (mm)	Wall Thickness (mm)	Closure / Tube Type	Mass of Composition (g)
Small tube	69.90–70.50	10.80–10.90	2.40–2.45	clay / medium	0.53–0.61
Medium tube	107.20–107.60	17.85–17.95	2.60–2.65	clay / medium	2.37–2.91
Medium tube	107.75–107.95	17.70–17.85	2.45–2.50	cardboard / weak	4.63–5.22

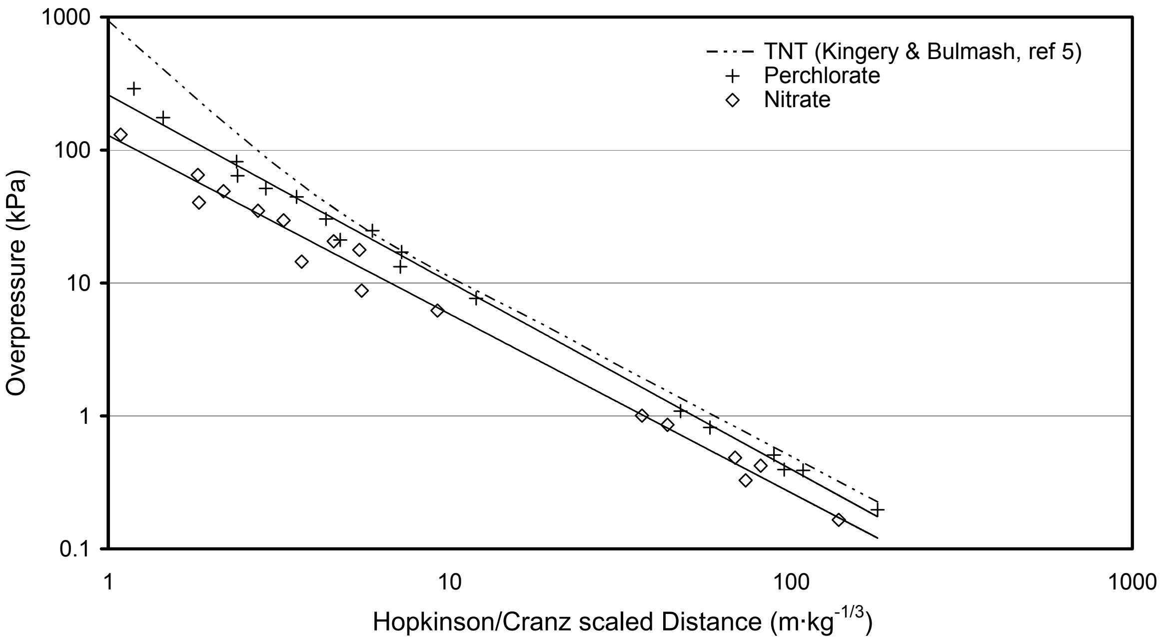

Figure 1. Measured overpressures from bangers containing barium nitrate and potassium perchlorate flash compositions.

tion were expected to have little effect on the overall performance of the bangers when compared with the effect of altering the masses of the compositions.

Experimental Programme

An experimental programme was undertaken to gain information on the blast and sound pressure levels generated by energetic bangers. Key elements of the programme were:

- All experiments (noise and blast measurements) were done outdoors.
- For each experiment, a record was taken of ambient temperature, ambient pressure, wind speed, and wind direction as well as the primary blast and noise data. Relative humidity was also recorded for each block of tests.
- Noise levels for each firework were measured at the proposed CEN Standard 'testing' distances of

Category 2	8 m
Category 3	15 m

- Pressures were monitored using four spear gauges (PCB type 137A23) mounted in a plane 1.5 m above ground and at distances of 0.2, 0.4, 0.6 and 1.0 m from the firework.
- Sound pressure levels (*SPL*) were measured using six calibrated recording instruments (CEL-414/3C) situated at distances of 1, 8 and 15 m from the functioning point and in two planes at right-angles to each other.
- Tests were undertaken with fireworks selected in a random order.
- Each firework type (i.e., net explosive content / tube / closure) was tested 5 times.

Blast Overpressures

The use of Hopkinson/Cranz scaling for distance permits experimental overpressure data to be used for estimating the overpressure of any mass / distance combination. Figure 1 illustrates the results from the tests with flashbangers and incorporates overpressures measured using the spear blast gauges and those derived from noise

Table 5. Constant Terms in the Relationship Linking the Decay of Mean Overpressure with Scaled Distance.

Pyrotechnic Composition	Constants		Correlation Coefficient (R^2)
	a	b	
Barium nitrate / aluminium	–1.344	2.110	0.991
Potassium perchlorate / aluminium	–1.408	2.415	0.996

measurements (converted to pressures from decibels). Mean values for a particular composition are shown, irrespective of tube type and closure since these parameters were found to exert little influence. In evaluating the results, the experimentally determined mean mass of composition was used to calculate the scaled distances.

The combined pressure and noise data were used to determine the dependence of the decay of overpressure with scaled distance (z) for each composition. The relationships are of the form

$$\text{Overpressure (mean)} = 10^{(a \log(z) + b)}$$

where z is the Hopkinson/Cranz scaled distance ($\text{m·kg}^{-1/3}$) and the constant terms are defined in Table 5.

The primary variables that affect the results are the net explosive content and the type of pyrotechnic composition used. As reported above, the effects of tube type and tube closure, though statistically measurable, were small compared to the effect of the pyrotechnic composition used. The effect of relative humidity was not statistically determinable for all banger types as it was subsumed within the random variability in the pressure and noise readings. A slight, statistically relevant, effect of wind speed on the noise measurements from potassium perchlorate / aluminium bangers was noticed, but the effect was so small that it can be ignored in any calculations to determine the pressure / distance relationship.

TNT Equivalence

It is common for the blast effects from explosions to be presented using a TNT-equivalence (TNT_e),[6] and compositions containing mixtures of aluminium and potassium perchlorate (such as are used for producing light and sound effects) are known[7] to generate blast waves similar to TNT when they explode. In general, lower energy pyrotechnics that deflagrate react much more slowly than conventional high explosives. As a result, the corresponding pressure wave is usually of much lower amplitude initially and of much longer duration. Even though information on the blast parameters from pyrotechnic compositions is somewhat limited, and the ability of pyrotechnics to cause blast damage is different to TNT-type explosions, it is still usual and convenient to equate them all to TNT.

There is a considerable amount of published work relating to the estimation of blast effects (blast scaling), although the majority of the studies have little application to relatively small distances from the explosion source. However, Yallop[8] has given the pressure at 1 m from 100 g of TNT derived from Cook's equation,[9] and De Yong and Campanella[10] have published data for the blast wave characteristics from 200 to 1000 mg quantities of pyrotechnics measured at 1 m.

The difficulty with theoretical estimation of blast damage from bangers is that the effect of the confinement of the tube on the blast characteristics (i.e., on TNT_e) is not known. However, De Yong and Campanella[10] have performed experiments with confined pyrotechnic powders that suggest that the TNT_e of MRL(X)210 (potassium perchlorate / aluminium / acroid resin in 59:40:1 proportions) is 60%.

A recent paper by Merrifield and coworkers[11] reported TNT_e values in the range of 40 to 130% for flash composition (30% aluminium / 70% potassium perchlorate) with the lower figure applicable to confinement in a firework. This lower value is broadly in keeping with the TNT_e values of 20 to 60% quoted by Contestabile and Augsten[12] for firework report shells.

Table 6. Values for the Constants A and B in the Equation $SPL = A\,D + B$ Used To Define the Dependence, at $D > 10$ m, of the Peak Sound Pressure Level (SPL) on Distance (D).

Firework	*A*	*B*	Correlation Coefficient (R^2)
Barium nitrate / aluminium banger (1g)	–0.59	147.5	0.978
Barium nitrate / aluminium banger (6g)	–0.77	156.2	0.951
Barium nitrate / aluminium banger (10g)	–0.63	157.4	0.975
Potassium perchlorate / aluminium banger (0.5g)	–0.63	149.3	0.978
Potassium perchlorate / aluminium banger (3g)	–0.65	155.5	0.978
Potassium perchlorate / aluminium banger (5g)	–0.67	157.0	0.978

Table 7. Values for the Constants A and B in the Equation $SPL = A\ln(D) + B$ Used To Define the Dependence of Peak Sound Pressure Level (SPL, dB(C)) on Distance (D, m).

Firework	*A*	*B*	Correlation Coefficient (R^2)
Barium nitrate / aluminium banger (1g)	–11.05	170.0	0.997
Barium nitrate / aluminium banger (6g)	–11.64	177.6	0.998
Barium nitrate / aluminium banger (10g)	–11.82	179.3	0.999
Potassium perchlorate / aluminium banger (0.5g)	–11.62	170.8	0.978
Potassium perchlorate / aluminium banger (3g)	–12.17	178.1	0.978
Potassium perchlorate / aluminium banger (5g)	–12.44	180.1	0.978

Using published methods[13] and the data presented in Figure 1, it is possible to calculate TNT_e values of 57.3 and 24.9% for potassium perchlorate/aluminium and barium nitrate / aluminium compositions, respectively. The results are in keeping with relative magnitudes of the peak overpressure data for perchlorate and nitrate flash salutes reported by Kosanke and Kosanke[14] and with the literature values for the TNT_e of pyrotechnics given above.

Noise

From the sound pressure level (*SPL)* results it is possible to evaluate equations for the relationships between *SPL* and linear distance (*D*, in metres).

Earlier studies[15,16] have reported that a simple linear relationship of the form

$$SPL = A\,D + B$$

where A and B are constants, adequately represents the dependence. For values of $D > 10$ m and with *SPL* measured in units of dB(C),* this was again found to be the case. To enable comparison with previous work, Table 6 gives the values of the constant terms.

However, it was found that inclusion of near field data at $D < 10$ m introduced some curvature, and in these instances the results were better represented by the logarithmic equation

$$SPL = A\ln(D) + B$$

The use of this equation produced a better overall fit to the total data, yielding improved correlation coefficients, Table 7.

The CEN fireworks committee has selected 120 dB (Al_{max}) as the noise level to be cited in

---

* There are a number of different measures of sound using dB scales. A-weighted (dB(A)) and C-weighted (dB(C)) are commonly used. They differ in the weighting given to different frequencies. The C-weighted scale approximates to a flat response while the A-weighting “corrects” the values at different frequencies to reflect the response of the ear. For further reading on sound measurement see:
A. Barber, *Handbook of Noise and Vibration Control,* Elsevier Science Publ. Ltd, Oxford (1992) pp 18–21.

D. A. Bies and C. H. Hanson, *Engineering Noise Control, Theory and Practice*, E & FN Spon, London (1988) pp 72–76

K. D. Kryter, *The Effects of Noise on Man,* Academic Press, Inc. Orlando (1989) pp 10–14.

Table 8. Distances for 140 dB(C) Derived from the Logarithmic Relationship and Mean Mass Data and also from the Overpressure / Scaled Distance Equation.

Composition	CEN Category	CEN Net Explosive Content (g)	Mean Mass of Composition in this Study (g)	CEN 'testing' Distance (m)	Distance for 140 dB(C) Evaluated from log Relationship (m)	Distance for 140 dB(C) Evaluated from Scaled Distance Equation (m)
Barium nitrate / aluminium	2	1	1.3	8	12.6	12.3
	3	6	6.2	8	25.4	23.4
	3	10	10.1	15	27.8	26.5
Potassium perchlorate / aluminium	2	0.5	0.6	8	14.2	12.9
	3	3	2.6	8	22.9	23.4
	3	5	4.8	15	25.0	27.8

the draft standards at various specified (testing) distances. From published work[16] this equates to approximately 140 dB(C), and this value can be substituted into the above equation to yield values of D using the constant terms derived for the various fireworks.

Table 8 summarises the results and indicates that, at the proposed CEN 'testing' distances of 1, 8 and 15 m, the sound levels for the flash compositions examined in this study will exceed 120 dB(Al_{max}) in all cases.

However, since the mean mass of composition contained in the various fireworks varied from the CEN notional masses, a more accurate means of calculation involves use of the overpressure / scaled distance relationship to calculate overpressure (and hence noise) at the flashbanger masses specified in the draft CEN standards. These results are also presented in Table 8.

An equivalent treatment for Category 1 flashbangers produces distances for 140 dB(C) of 8.2 and 9.5 m for the barium nitrate (0.3 g) and potassium perchlorate (0.2 g) compositions, respectively, when the CEN 'testing' distance is 1 m. Figure 2, derived from the overpressure / scaled distance relationship, illustrates the distances from high energy bangers required for the noise to have reduced to 140 dB(C).

Previously published data[16] on the noise levels produced at the CEN testing distance of 15 m by commercially available Category 3 bangers using nitrate and perchlorate compositions have indicated that the perchlorate bangers should be ranked above the nitrate bangers in terms of potential noise hazards. However, for the Category 3 fireworks manufactured specifically for this study, the difference in performance of the two compositions is largely accounted for by the different net explosive content prescribed for each type.

The British Standard for Fireworks[1] states that BS Category 3 fireworks are for use in large open spaces and should not cause injury to people standing 25 m away. Advice is also given that people lighting these fireworks should wear suitable personal protection. It is noted from Table 8 that noise levels in excess of 140 dB(C) will occur at distances greater than 25 m from the firework for barium nitrate / aluminium bangers with 10 g of composition and for potassium perchlorate / aluminium bangers with 5 g of composition.

Conclusions

From this study, it is apparent that both CEN Category 2 and Category 3 bangers containing flash compositions are a major hazard if misused. Hearing damage to the user from these bangers could be severe, and noise hazards to bystanders could become unacceptable.

The noise generated by the two types of banger compositions investigated in this study has been found to be greater in the perchlorate bangers than the nitrate ones for flashbangers of equal net explosive content, but at the proposed

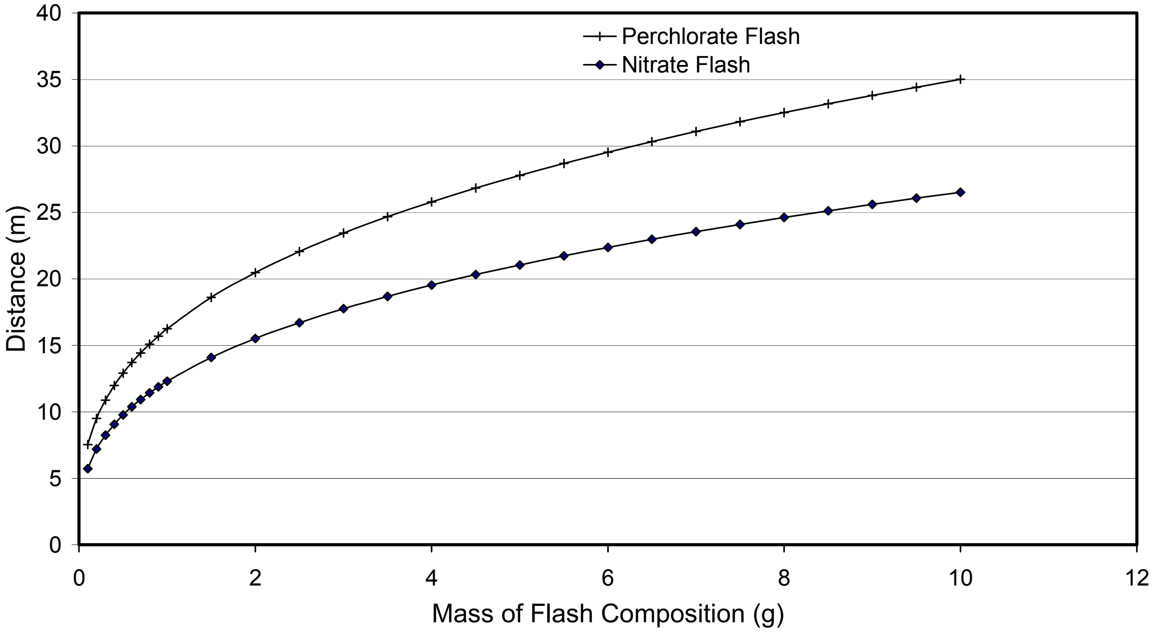

Figure 2. Distance required for the banger noise level to reduce to 140 dB(C).

CEN Standard net explosive contents for Category 2 and Category 3 bangers, the fireworks produce similar sound levels.

Acknowledgements

The study was funded by the UK Department of Trade and Industry and their permission to publish the results is gratefully acknowledged.

References

1) "British Standard, Fireworks, Part 1. Classification of Fireworks", BS7114: Part 1: 1988, British Standards Institution.

2) CEN is the Comité Européen de Normalisation.

3) R. J. Rapley, "European Standardisation of Fireworks CEN/TC/212, A Review of the Position as at June 1994", *Proc. 2nd Intl. Symp. on Fireworks*, October 24–28, 1994, Vancouver, Canada, pp 393–410.

4) R. K. Wharton and A. E. Jeffcock, "Evaluation of the Hazards Posed by High Energy Bangers. Part 2. Damage to Hand Simulants", accepted for publication in *J. Pyro.*

5) C. N. Kingery and G. Bulmash, "Airblast Parameters from TNT Spherical Air Burst and Hemispherical Surface Burst", ARBRL-TR-02555, US Army Armament Research and Development Center, BRL, Aberdeen Proving Ground, MD, USA, 1984

6) R. Merrifield, "Simplified Calculations of Blast Induced Injuries and Damage", Specialist Inspector Report No. 37, Health and Safety Executive, April 1993.

7) R. Wild, "Blast Waves Produced by a Pyrotechnic Flash Mixture Compared to those Produced by High Explosives", *18th Department of Defence Explosives Safety Seminar*, San Antonio, TX (1978) pp 727–739.

8) H. J. Yallop, "Explosion Investigation", *The Forensic Science Society*, Harrogate, England, 1980.

9) M. A. Cook, *The Science of High Explosives*, Robert E. Krieger Pub. Co. Inc., Huntington , NY, 1971.

10) L. V. De Yong, and G. Campanella, "A Study of Blast Characteristics of Several Primary Explosives and Pyrotechnic Compositions", *J. Haz. Mats*., Vol. 21 (1989) pp 125–133.

11) R. Merrifield, R. K. Wharton and S. A. Formby, "Potential Fire and Explosion Hazards of a Range of Loose Pyrotechnic Compositions", US Dept. of Defense, Explosives Safety Board, *27th Explosives Safety Seminar*, 20–22 August, 1996, Las Vegas.

12) E. Contestabile and R. A. Augsten, "Blast Pressure from Exploding Firework Mortars", *Proc. 19th Int'l Pyrotechnic Seminar,* Christchurch, New Zealand (1994) pp 135–152.

13) S. A. Formby and R. K. Wharton, "Blast Characteristics and TNT Equivalence Values for Some Commercial Explosives Detonated at Ground Level", *J. Haz. Mats.*, Vol. 50 (1996) pp 183–198.

14) K. L. and B. J. Kosanke, "Flash Powder Output Testing: Weak Confinement", *J. Pyro.,* No. 4 (1996) pp 5–14.

15) R. K. Wharton, P. M. Pitts and B. J. Thomson, "Measurement and Interpretation of the Peak Noise Levels Produced by a Range of Fireworks", *Proc. 19th Int'l Pyrotechnic Seminar*, Christchurch, New Zealand (1994) pp 483–500.

16) R. K. Wharton and H. J. Slater, "Further Studies of the Noise Levels Produced by Fireworks", *Pyrotechnica XVI*, (1995) pp 20–29.
