Display Fireworks And Stage Pyrotechnics In Use – Which Distances Are 'Safe' In Germany And Other Parts Of the EU?

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Abstract: *Display fireworks and theatrical pyrotechnic articles are widely used in the EU by persons with specialist knowledge for local festivities, events, concerts and various music shows. According to the European Directive 2013/29/EU relating to the making available on the Union market of pyrotechnic articles, these articles are categorized as fireworks of category F4 and theatrical pyrotechnic articles of category T2, respectively. Before these pyrotechnic articles may be made available on the market, manufacturers must ensure that they satisfy the essential safety requirements (ESR) of this Directive. By application of the standard series EN 16261 for F4 articles and EN 16256 for T2 articles an assumption of conformity to the ESR is triggered. Both standards do not specify minimum safety distances to the spectators or to the audience, but give guidance to the Member States for setting up their own regulations for defining the safety distances by means of measured article-dependent performance parameters or construction properties. These safety distances differ between the Member States due to the cultural differences and various methods of calculation. This paper explains the procedures for defining safety distances for F4 and T2 in Germany. Respective advantages and disadvantages are pointed out, and results for identical items, categorized as F4 and T2, illustrate the current measures. In addition, a brief overview of the corresponding regulations regarding display fireworks in some other European Member states is presented. The different approaches are compared with each other by calculating the respective safety distances for identical articles.*

Introduction

With the coming into force of the new European Directive 2013/29/EU[1] of the European Parliament and of the Council of 12 June 2013 on the harmonisation of the laws of the Member States relating to the making available on the market of pyrotechnic articles (recast), fireworks and theatrical pyrotechnic articles are subject to certain conformity assessment procedures to demonstrate conformity to the essential safety requirements (ESR) of this Directive. An overview on these general procedures, though under the former Directive 2007/23/EC[2], was already given by Kurth[3], Ramón[4] and Lohrer *et al*.[5,6]

Fireworks and theatrical pyrotechnic articles are categorized depending on the potential hazard and intended use into the categories F1–F4 and T1–T2. Article 10 of the Directive 2013/29/EU[1] specifies the minimum label requirements for fireworks articles. For category F4 fireworks, which present a high hazard, which are intended for use only by persons with specialist knowledge (commonly known as fireworks for professional use) and whose noise level is not harmful to human health, the information regarding the minimum safety distance(s) is mandatory on the label. The same requirements exist for theatrical pyrotechnic articles of the category T2 (for stage use which are intended for use only by persons with specialist knowledge).

In the recent years the standard series EN 16261[7] for display fireworks (F4) and EN 16256[8] for theatrical pyrotechnic articles (T1/T2) were developed by the corresponding working groups (WGs) 2 and 3 of the Technical Committee CEN/TC 212 of the European Committee for Standardization (CEN). By application of these standard series a formal assumption of conformity to the ESR is triggered. However, the corresponding standard series don't give guidance on how to set or calculate the required minimum safety distances for F4 and T2 articles. These decisions taken by the WGs 2 and 3 at that time were mainly due to differing safety philosophies in the EU Member States: It was challenging at that time to harmonize the understandings of a 'safe' distance (if existing at all) throughout all

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participating Member States. One simple example illustrating this situation is the assessment of flash bangers. Whereas some countries allow the use of such articles only for persons with a special permit, others countries accept their use even in close proximity to persons. Furthermore, in some countries it is common and part of the festivity to run through a curtain of sparks emitted by articles, whereas in other countries people would try to sue the manufacturers or display operators if sparks should hit the audience. The general use of fireworks and the corresponding measures for safe use depend strongly on cultural aspects specific to all different regions in Europe. After long discussions a consensus regarding a specific approach or calculation procedure applicable to all EU Member States was *not* reached.

It was decided by the WG experts to measure and display the relevant performance parameters on the label of the pyrotechnic articles concerned and leave it up to the Member States to define their own regulations for minimum safety distances by means of measured type- and article-dependent performance parameter or construction aspects. It is therefore expected that these calculation procedures will differ between the Member States due to the cultural differences and various methods of calculation.

According to the standard series EN 16261[7] and EN 16256,[8] the following performance parameters were generally identified to be relevant for the determination of the minimum safety distances within the Member States in Europe for articles of the categories F4 and T2:

- effect distance (or burst height),
- sound pressure level (SPL) including the measuring distance,
- the hazardous debris distance (if existing), and
- information on incandescent particles returning to the level from which the device was fired (if existing).

In addition to these four general performance parameters, the following category- and type-dependent parameters are given:

- radial effect distance (only for T2, and where applicable per type),
- effect range (only for aquatic fireworks of the category F4),
- overall duration (only for aerial wheels of the category F4), and
- maximum firing angle (only for articles/tubes placed at an angle other than vertical of the category F4).

The focus of this work is to present the respective requirements for setting safety distances for display fireworks and theatrical pyrotechnic articles according to the German regulations and guidelines. In addition, a brief overview on the safety distance procedures within some other European Member States regarding display fireworks and a comparison between these procedures is illustrated, as well.

Legal requirements in Germany

General aspects

The approaches for setting safety distances in Germany are purely deterministic depending on major expected hazards, without consideration of any probabilistic behavior. In other words: The safety distances are based on the idea that the article will malfunction (with a probability of 100%), and in case of a shell will fall to the ground without bursting in the sky ('blind shell'). Comparable deterministic concepts can be found in several other EU Member States, such as France, Italy, The Netherlands, Portugal and Spain. However, these methods are in contrast for example to the assessment philosophy in the United Kingdom, where risk based systems (i.e. hazards in combination with their expected frequencies) are taken into account.

The following approaches are published by BAM as application guidelines.[9,10] They originate from long-term experience, R&D activities and comprehensive accident investigations, carried out with all involved parties such as manufacturers, pyrotechnicians, enforcement bodies and the notified body BAM. Even though not mandatory, they are currently applied by the vast majority of persons with specialist knowledge and the enforcement bodies in the field, sometimes with slight technical changes. Nevertheless, it is expected that future legislation in Germany regarding the safety distances for display fireworks and theatrical pyrotechnics will adopt these approaches in the same way without major technical changes.

The resulting values of the calculations of the minimum safety distances at 'standardized' conditions of use and testing (see below) have to be displayed on the label of the F4 and T2 articles by the manufacturers (refer to article 10 of 2013/29/EU[1] and article 12 of 2007/23/EC[2], respectively).

However, the applicable distances determined by persons with specialist knowledge in Germany may deviate from those depending on the specific conditions of use (wind, inclination angle etc.).

Display fireworks of the category F4

Standardized conditions of use and testing

The distances displayed in Table 1 refer only to a 'standard' use in which they were tested, i.e. vertical orientation of the mortars, firing level equal to level of audience and wind less than 9 m s^{-1} at a representative location at a height of 2 m.

As already pointed out earlier, conditions of use might lead to different values in application, e.g. depending on wind, angle of orientation, elevated shooting locations etc. These influences on the safety distances are illustrated in the following.

Influence of inclination angle

If the fireworks articles are used at an angle, the safety distances according to Table 2 apply:

In the direction opposite to the firing direction the safety distance may be reduced by a maximum of 40%.

Influence of wind

Fireworks articles or respective units which are ejected into the air are prone to drift due to wind force. In case of wind speeds >9 m s^{-1} but ≤13 m s^{-1} the safety distances in the direction of the wind (including those after assessment of inclination angle) must be increased by 100%. If the wind speed exceeds 13 m s^{-1} the safety distances in the direction of the wind (including the ones after assessment of inclination angle) must be increased by 200%.

These increased values however don't apply to ground fireworks (refer to entry no. 1 of Table 1).

In the direction opposite to the wind direction the safety distance may be reduced by a maximum of 40%.

Influence of the height of buildings

If display fireworks are fired from the roofs of buildings, then the respective height is added to the burst and effect heights of the articles falling under no. 2–4 and 8 of Table 1. The corresponding adjustments due to inclination angle and wind have to be made in addition afterwards.

Table 1. *Safety distances of display fireworks in Germany under standardized conditions*

No.	Fireworks articles	Safety distances to the audience
1	Ground fireworks	20 m; in case of lance work the maximum distance of the single articles applies
2	Shells and bombettes with caliber ≥50 mm (also out of mines, Roman candles, shot tubes)	80% of the burst height, at least 800 × (caliber in mm)
3	Shells and bombettes with report as main effect (also out of mines, Roman candles, shot tubes)	100% of the burst height, at least 1000 × (caliber in mm)
4	Rockets and aerial wheels	200 m in shooting direction, 125 m to the audience and all other directions
5	Miscellaneous fireworks with effect-/burst heights <30 m which do NOT belong to numbers 2–4	30 m
6	Miscellaneous fireworks with effect-/burst heights >30 m which do NOT belong to numbers 2–4	50 m
7	Aquatic shells	1.5 × maximal effect distance plus 2 × radial effect width
8	Daylight shells without burning matter/effects	80% of the burst height

Table 2. *Safety distances for display fireworks in dependence on the inclination angle for fireworks falling under the numbers 2–4 and 8 of Table 1.*

Inclination angle from the vertical	Increase of safety distance
5–10°	40%
11–15°	60%
16–20%	80%
>20%	Single case evaluation necessary

Influence of terrain elevations

If the display fireworks are fired from elevated terrains with slopes ≥20%, the safety distance of the articles falling under no. 2–4 and 8 of Table 1 has to be increased by 20%. The corresponding adjustments due to inclination angle and wind have to be made in addition afterwards. In case of almost vertical slopes (such as buildings), the previous clause applies.

Theatrical pyrotechnics of the category T2

The basis for the calculation of the safety distances for theatrical pyrotechnic articles of the category T2 is the assessment of the effect dimensions (e.g. how far do the sparks go) and the sound pressure level. The effect dimensions comprise the effect distance and the radial effect distance. According to EN 16256[8], the following definitions apply:

Effect distance: maximum distance of the effect in the direction of firing measured from the base of the article.

Radial effect distance: maximum distance of the effect in any direction except in the direction of firing.

Minimum safety distance (MSD_{ED}): minimum distance of persons or flammable materials or obstructions from the article in the direction of the effect to reduce the risk to as low as reasonably practicable.

Minimum radial safety distance (MSD_{RED}): minimum distance of persons or flammable materials or obstructions to the article, in any direction except the direction of firing, to reduce the risk to as low as reasonably practicable.

NOTE: There might be different safety distances for persons who are protected from the effects by protective equipment and those without protective equipment. This is often the case on stages where the artists are closer to the effect than the audience and therefore need special protection.

The T2 procedure is generally identical with the setting of safety distances for theatrical pyrotechnic articles of the category T1 within conformity assessment procedures applying EN 16256[8].

Standardized conditions of use and testing

The minimum safety distances given in the following refer again only to a 'standard' use in which they were tested, i.e. vertical orientation of the articles, firing level equal to level of audience and wind less than 9 m s^{-1} at a representative location at a height of 2 m (if at all applicable at a theatrical venue, e.g. indoors/outdoors).

The minimum safety distances based on effect dimensions (MSD_{effect}; contains the distances in effect and radial effect directions) for articles of category T2 shall be calculated in effect and radial effect directions based on formula (1):

$$MSD_{effect} = 1.3 \times L \quad (1)$$

where L is the maximum length measured during testing based on effect dimensions, debris, and burning or incandescent matter.

In addition, the minimum safety distance based on sound pressure level (MSD_{SPL}; contains the distances in effect and radial effect directions) can be estimated by using the formula (2), based on the requirement that 120 dB (AI_{max}) shall not be exceeded outside the safety distance:

$$MSD_{SPL} = 10^{(\log(r_{measurement}) - \frac{(SPL_{threshold} - SPL_{measurement})}{20})} \quad (2)$$

where $r_{measurement}$ = distance of sound pressure meter to the pyrotechnic article [m]

$SPL_{threshold}$ = sound pressure level threshold of = 120 dB(AI_{max})

$SPL_{measurement}$ = sound pressure level measured at $r_{measurement}$ in dB(AI_{max})

The resulting minimum safety distance (in effect and radial effect direction) equals the maximum of both values MSD_{effect} and MSD_{SPL}.

Influence of inclination angle

The placement of the articles under an angle towards the audience is permitted under the following conditions as displayed in Figure 1 in combination with formula (3):

$$MSD_{resulting} = MSD_{ED} \times \cos(\alpha) + MSD_{RED} \times \cos(90° - \alpha) \quad (3)$$

$MSD_{resulting}$ = resulting minimum safety distance to the audience and α = inclination angle [°].

Influence of wind

The effects and ejected units from theatrical pyrotechnic articles are prone to drift due to wind force. In case of wind speeds >9 m s^{-1} but ≤13 m s^{-1} the safety distances in the direction of the wind (including those after assessment of inclination angle) must be increased by 100% for articles having an effect or burst height of >30 m under standardized conditions of use. If the wind speed exceeds 13 m s^{-1} the safety distances in

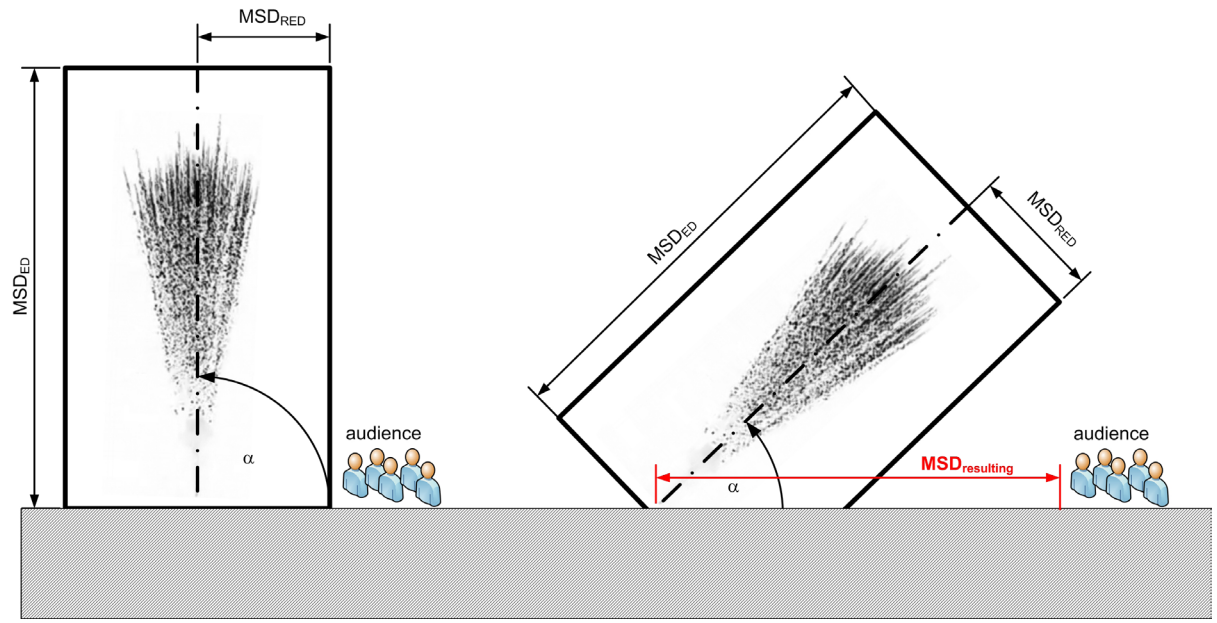

Figure 1. *Resulting minimum safety distances to the audience for theatrical pyrotechnic articles T2 placed at an angle towards the audience.*

the direction of the wind (including those after assessment of inclination angle) must be increased by 200% for articles having an effect or burst height of >30 m under standardized conditions of use.

Specific bouquet effects

For articles that produce wide bouquet effects at large altitudes (e.g. Crossette) it is permitted to reduce the resulting minimum safety distance to the audience near the ground down to 2 m. This, however, is only after thorough case-by-case assessments by the persons with specialist knowledge of the possible resulting hazards, such as falling debris or burning/incandescent matter, blind stars, low burst heights, radial effect distances at that height and sound pressure level (the requirement of 120 dB(AI_{max}) still applies, as well).

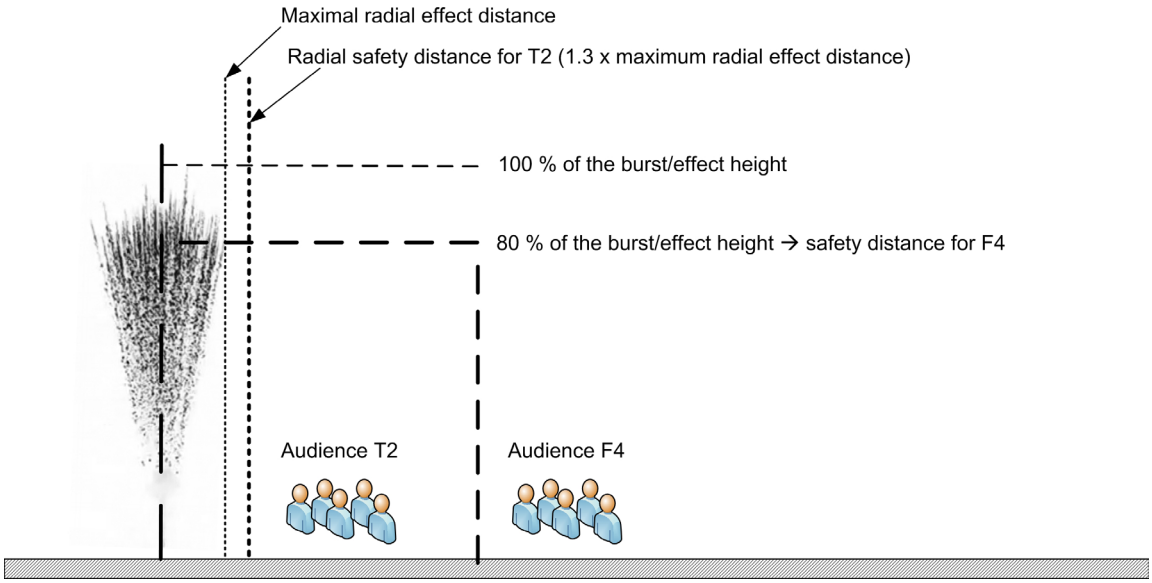

Figure 2. *Exemplary safety distances of a mine – based on effect dimensions for display fireworks F4 and theatrical pyrotechnic articles T2 in Germany.*

Conceptual differences for F4 and T2 in Germany

As displayed above, the concepts of safety distances for theatrical pyrotechnic articles and display fireworks differ significantly. Where in the latter case the safety distance to the audience is predominantly based on effect/burst height (direction shifted by 90° from the horizontal in case of standardized use) and caliber, the safety distances for theatrical pyrotechnics are always defined in each single direction (i.e. firing direction and radial). For example: A F4 mine (caliber >50 mm) consisting of bombettes would have a safety distance to the audience equal to 80% of the burst heights of the bombettes (though, at least 800 × caliber in mm). However, another mine categorized as a T2 theatrical pyrotechnic article would have a radial safety distance to the audience depending on the maximum radial effect

Table 3. *Safety distances to the audience for identical articles categorized asT2 and F4 in direct comparison*

Type of article	Effect/burst height [m]	Radial effect distance [m]	MSD_{RED} for T2 [m]	MSD for F4 [m]
Comet (star)	100	<1	f(SPL) ~10 m*	50
Comet (bombette)	100	<1	f(SPL) ~20 m*	80
Mine (stars only)	70	10	13	50
Fountain/jet	10	3	4	30
Airburst	9	7	10	20
Rotating effect (saxon)	5	5	7	20

*Estimated distance at which 120 dB(AImax) are reached.

Table 4. *Specific testing requirements for theatrical pyrotechnic articles and display fireworks in the EU*

Specific standard testing requirements	**T2:** refer to EN 16256 (T2)[8]		F4: refer to EN16261 (F4)[7]	
Minimum number of items to be type tested on function (destructive)	30 pcs.		9 pcs.	
Minimum number of items to be dismantled during type tests (destructive)	3		0	
Measurement of effect width/radial effect distance during type and batch tests	Yes		No	
Minimum number of items to be batch tested on function (sample size depending on lot size)	Lot size	Sample size	Lot size	Sample size
	2–15	1	2–25	1
	16–25	2		
	26–90	3	26–150	2
	91–150	5		
	151–500	8	151–500	3
	501–1200	13	501–1200	8
Relevant performance parameter values of the single results within a permitted tolerance (in %) of the measured average during batch tests	±20%		±30%*	
Functioning of articles	Complete and 100%		'As intended' by manufacturer†	
Criteria for testing 'similar' items (variants) within a product family‡	All family variants are tested for function unless they differ only in color effects		Not all variants of a product family need to be tested (e.g. min and max)	

* Except otherwise justified by manufacturer; therefore > ±30 % possible.
† Therefore <100% possible.
‡ Guidelines published by the European Commission for grouping articles that are similar in design, function or behavior into product families.[11]

distance, which is usually much smaller than the burst height (considering the sound pressure level is not dominating, see Figure 2).

Table 3 illustrates this discrepancy between safety distances to the audiences for further articles that could likely be categorized either as F4 or T2.

In addition, the permitted inclination of articles and their effects towards the audience in case of T2 is different to the conditions of use for display fireworks.

These differences in the assessment of articles falling under F4 and T2 can be justified with the tightened testing criteria for T2 in comparison with F4. This is displayed in Table 4.

As displayed above, the criteria for passing the type and batch tests are significantly stricter for T2 articles in comparison with F4 articles. Therefore, and as a rule of thumb, theatrical pyrotechnics might be generally considered to be of a better quality than regular display fireworks due to the intended close proximity use. In consequence, it appears to be justifiable to apply smaller 'safe' distances to the audience in comparison with display fireworks.

The situation for display fireworks in other EU Member States

General remarks

The procedures that are briefly described in the following for the countries France (FR), Spain (ES), The Netherlands (NL), Italy (IT) and Portugal (PT) are neither complete nor all-embracing. The focus of this work was on some specific article types used and tested under 'standardized conditions'. The safety distances displayed here are defined from the article/effect to the audience. Safety distances to buildings or other objects, which might deviate, are not taken into account. The assessment of adjustments which might be necessary for the respective 'non-standard use', such as tilted mortars, wind, elevated shooting locations etc. was also not part of this study.

These values and procedures presented below were to the best knowledge of the author up-to-date when writing this contribution.

With the exception of the UK, all other countries which are part of this study apply deterministic approaches for setting safety distances. In these cases, the potential hazards (the article will malfunction in a certain way) are taken as the only basis for setting the respective safety distances. Any assessment regarding a certain probability of malfunctioning is not carried out.

France

The French system[12] for determining safety distances is quite comparable to the described German procedures. It is also based on performance data (effect/burst height), construction aspects (caliber), effects (stars/visual and report/aural) and the actual generic type of the fireworks. A compendium of some relevant requirements is given in Table 5.

Portugal

In contrast to the systems in Germany and France, the procedures in Portugal[13] to set the safety distances for display fireworks comprise only

Table 5. *Safety distances of display fireworks in France under standardized conditions*

No.	Fireworks articles	Safety distances to the audience
1	Shells (except report shells)	80% of the burst height, at least 800 × (caliber in mm)
2	Shells with report as main effect	100% of the burst height, at least 800 × (caliber in mm)
3	Rockets	150 % of burst height. If these results are in between the following ranges, then the upper range limit applies as the MSD: 0–25 m: 25 m 25–50 m: 50 m 50–100 m: 100 m >100 m: values rounded to the next 10 m.
4	Mines (stars only)	100% of the effect height, at least 800 × (caliber in mm)
5	Roman candles (stars only)	50% of effect height
6	Fountain (small effect width)	effect distance, at least 15 m
7	Shot tube (comet)	50% of effect height
8	Shot tube (bombette)	80% of the burst height, at least 800 × (caliber in mm)
9	Ground fireworks (without movement)	effect distance, at least 15 m

the information regarding the firework types and respective calibers. For rockets, the calibers apply to the rocket motors. Performance parameters such as effect/burst heights are not taken into account. The relevant type-dependient safety distances are given in Table 6 and Table 7.

Italy

The Italian system[14] distinguishes between ground and aerial effects depending on the type of fireworks and the respective caliber. It is therefore comparable with the Portuguese system. Some relevant details for this study are presented in Table 8.

The Netherlands

The Dutch regulations[15] also depend on the firework type/effect and the relevant construction property caliber. Table 9 displays an extract of these approaches.

Spain

The concept idea in Spain[16] is more or less in line with the regulations in Italy, Portugal and The Netherlands, as it considers the types/effects and the caliber of the display fireworks. Performance parameters like effect/burst height are not taken into account. A summary is given in Table 10.

United Kingdom (UK)

As already pointed out, the situation in the UK differs significantly from the other countries presented in work. The legislator in the UK declined to define fixed distances or specific procedures on how to calculate these values for display fireworks. Whereas in the other countries deterministic approaches are the preferred choice (purely focusing on some expected hazards), risk based assessments have to be carried out by the persons with specialist knowledge on a case-by-cases basis in the UK. Within a risk assessment, not only the expected hazards are taken into account, but also their expected frequencies (probability of occurrence). In other words: 'what could happen and how often'?

The Health and Safety Executive (HSE) requires each person with specialist knowledge to make an appropriate risk assessment based on things like: properties of the fireworks (e.g. type, effect, caliber, debris, long-burning stars,), environmental conditions (e.g. wind, rain/humidity) proximity to flammable materials, audience or performers,

Table 6. *Safety distances of display fireworks (except rockets) in Portugal under standardized conditions*

No.	Caliber of fireworks (except rockets) [mm]	Safety distances to the audience [m]
1	10	3
2	15	5
3	20	6
4	30	9
5	40	20
6	50	25
7	60	48
8	75	60
9	100	80
10	125	100
11	150	120
12	200	160
13	250	200

Table 7. *Safety distances of display rockets in Portugal under standardized conditions*

No.	Caliber of the rocket motors [mm]	Safety distances to the audience [m]
1	<15	75
2	16	80
3	17	85
4	18	90
5	20	100
6	22	110
7	25	125
8	26	130
9	28	140

Table 8. *Safety distances of display fireworks in Italy under standardized conditions*

No.	Type of fireworks	Safety distances to the audience [m]
1	Waterfalls, fountains, wheels	30
2	Shot tubes: caliber <25 mm caliber 25–50 mm caliber 50–110 mm	 40 50 100
3	Cylindrical shells and rockets: caliber <110 mm caliber 110–130 mm caliber 130–210 mm	 100 150 200
4	Spherical shells: caliber <130 mm caliber 130–220 mm caliber 220–400 mm	 100 150 200

Table 9. *Safety distances of display fireworks in the Netherlands under standardized conditions*

No.	Type of fireworks	Safety distances to the audience [m]
1	Rockets (away from audience)	125
2	Lance work	15
3	Ground fireworks (e.g. fountains)	30
4	Roman candles (≤2 inch ≈ 50.8 mm)	75
5	Mines: caliber ≤4 inch (101.6 mm) caliber 4–6 inch (101.6–152.4 mm)	 60 100
6	Shells: caliber <3 inch (<76.2 mm) caliber >3 inch (>76.2 mm) caliber >4 inch (>101.6 mm) caliber >5 inch (>127 mm) caliber >6 inch (>152.4 mm) caliber >8 inch (>203.2 mm) caliber >10 inch (>254 mm) caliber >12 inch (>304.8 mm) caliber >18 inch (>457.2 mm) caliber >24 inch (>609.6 mm)	 120 165 200 230 265 325 390 455 645 845

consideration of buildings and amenities close by etc. Based on that the appropriate safety distances are identified and applied by the persons with specialist knowledge. This decision can be based on the experience of that person, or other measures might be taken into account (e.g. using specialized software like ShellCalc©[17,18] or noise level calculations), as well.

Table 10. *Safety distances of display fireworks in Spain under standardized conditions*

No.	Type of fireworks	Safety distances to the audience [m]
1	Ground fireworks (no projected items): caliber 20 mm caliber 30 mm caliber 40 mm caliber 50 mm caliber 60 mm caliber 70 mm	 10 12 14 20 30 40
2	Shells, mines (with report effects): caliber 50 mm caliber 60 mm caliber 75 mm caliber 100 mm caliber 120 mm caliber 125 mm caliber 150 mm caliber 175 mm caliber 180 mm caliber 200 mm caliber 250 mm caliber 300 mm caliber 350 mm	 25 36 45 60 72 75 120 140 145 200 250 300 350
3	Mines (stars only, no report effect): aliber < 50 mm caliber < 75 mm caliber < 100 mm caliber < 120 mm caliber < 150 mm	 25 35 50 60 75
4	Roman candles, shot tubes: caliber < 50 mm caliber < 60 mm caliber < 70 mm	 25 48 56
5	Rockets	50

Comparison between the presented deterministic approaches for display fireworks – discussion and interpretation

Based on the information provided in the previous clauses, a comparison between the deterministic procedures of the countries Germany, France, Spain, The Netherlands, Italy and Portugal is displayed for some relevant display fireworks articles (category F4). The detailed information is given in Table 11. The resulting safety distances to the audience are based on 'standardized' conditions of testing and use as described earlier in the text. Relevant and frequently used fireworks types were chosen combined with exemplary calibers and estimated/calculated effect and burst heights. For each fireworks type and caliber or effect/burst height, the respective extreme values are highlighted (maximum in **bold face**; minimum in *italic)* in Table 11. For the case of spherical shells of Peony type, the single values are in addition displayed in Figure 3.

With regards to Figure 3 one has to keep in mind that in some systems (France and Germany) the influence of the respective caliber might be dominated by the burst height, which is not displayed on the abscissa. However, this information can be taken from Table 11.

The differences between the single approaches are remarkable. This, however, was expected due to the different cultural events and histories regarding festivities and fireworks displays within the countries concerned.

Table 11. *Safety distances of display fireworks in some European countries under standardized conditions*

Type of article	Nominal caliber	Burst/effect height*	Resulting safety distances to the audience in 'standard' conditions					
			DE	**FR**	**ES**	**NL**	**IT**	**PT**
	[mm]	[m]	**[m]**	**[m]**	**[m]**	**[m]**	**[m]**	**[m]**
Spherical Shell-Peony	75	136	109	109	*45*	**120**	100	60
(stars as main effect)	100	184	147	147	*60*	**165**	100	80
	150	240	192	192	*120*	**230**	150	*120*
	200	285	228	228	200	**265**	*150*	160
Spherical Shell- Salute	75	136	**136**	**136**	*45*	120	100	60
(report as main effect)	100	184	**184**	**184**	*60*	165	100	80
	150	240	**240**	**240**	*120*	230	150	*120*
	200	285	**285**	**285**	200	265	*150*	160
Mine	50	25	30	40	*25*	**60**	50	*25*
(stars as effect)	75	50	50	60	*35*	60	**100**	60
Roman candle	30	50	50	25	25	**75**	50	*9*
(stars as effect)	60	75	50	*38*	48	**120**	100	48
Fountain	30	25	**30**	15	12	**30**	**30**	*9*
(small effect width)	40	50	**50**	*15*	14	30	30	20
Shot tube	30	25	30	13	25	**75**	50	*9*
(Comet/star effect)	45	75	50	38	*25*	**75**	50	*25*
Shot tube	30	75	50	60	25	**75**	50	*9*
(Bombette/report effect)	45	75	60	60	*25*	**75**	50	*25*
Rocket	15	70	**125**	110	*50*	**125**	100	75
(caliber for rocket motor)	20	150	125	**230**	*50*	125	100	100
Ground fireworks	20	10	20	15	10	**30**	**30**	*6*
(no movement)								

* Estimated; for shells using ShellCalc© v5.1.8 (0 m s^{-1} wind, 0 m elevation, terrain 2, other entries default or zero)

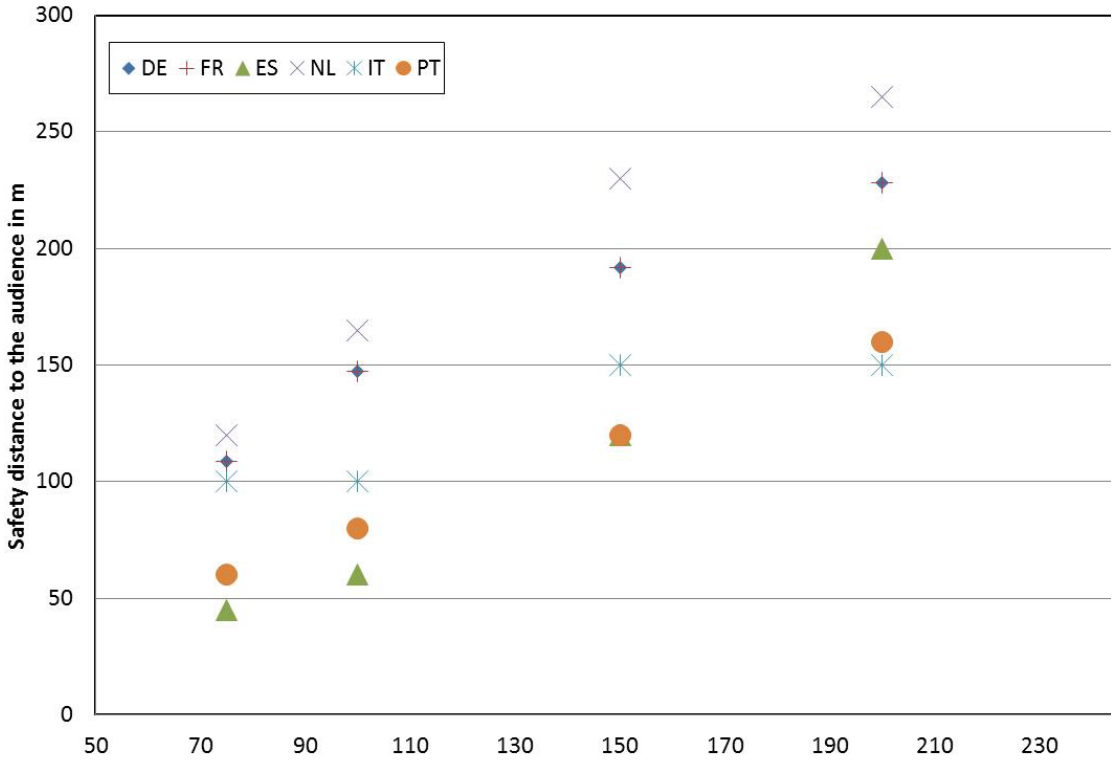

Figure 3. *Resulting safety distances to the audience for spherical shells (type Peony) of different calibers in comparison between the individual deterministic approaches.*

By taking a closer look at Table 11 it is noticeable that the approaches of Spain and Portugal in no cases revealed a specific maximum of the single safety distances for the chosen fireworks articles. However, the approach from The Netherlands showed in 14 out of these 21 exemplary cases maximal values for the safety distances in comparison with the other systems (in some cases together with other countries).

In contrast, both systems of The Netherlands and Germany revealed in no cases respective minimal values for the safety distances in comparison with the other systems. This, however, was reached by Spain in 13 cases and by Portugal in 10 cases (in some cases parallel).

These findings might lead to the conclusion that the system from The Netherlands could be evaluated as the most conservative approach for defining safety distances for display fireworks between these investigated countries under standardized conditions. In consequence, the reverse finding might also be justifiable, in a way the safety distances in Spain and Portugal in many cases are not considered as conservative. This is most likely due to the very specific fireworks culture in these countries, combined with the significantly different social acceptance of fireworks and their effects in these countries.

The presented approaches for the determination of safety distances under standardized conditions of use and testing (e.g. vertical orientation, no wind) might be put into three different general groups, depending on the type and number of parameters influencing the respective safety distances (Table 12).

The necessary information needed to apply the respective systems generally increases with these group numbers.

All of the three systems from The Netherlands, Spain and Portugal that were identified in this work that lead to extreme values (min and max) for safety distances as presented above would belong to the first group, which generally requires the least amount of information necessary for the assessment and calculation. The main advantage of the approaches of this group, and partly of the second group as well, is the fact that these approaches are simple and handy to apply by the persons with specialist knowledge and in the same way by the enforcement bodies responsible for the granting of permission of the fireworks displays. Another important advantage of this philosophy of group 1 is the fact that these approaches are independent from any performance parameters that

Table 12. *Overview of the relevant influence parameters for setting safety distances in the selected European countries*

Group	Relevant parameter	Applied by
1	Type of article/effect (e.g. shell) and constructional properties (e.g. caliber)	Italy, Spain, Portugal and The Netherlands
2	Type of article/effect, constructional properties and performance parameter (e.g. burst/effect height)	France and Germany
3	Type of article/effect, constructional properties, several performance parameters (e.g. burst/effect heights, debris, long burning stars) and risk assessment (hazard x frequency)	United Kingdom

need to be measured during type and batch testing. Recent investigations regarding the measurement of burst/effect heights for display fireworks revealed significant discrepancies between several test methods, procedures and equipment that are commonly used in the field.[19] In these cases one has to expect comparatively high measurement uncertainties for the values of burst/effect heights in general. However, on the negative side, one might identify the possibility of over- and under-estimating certain hazards in comparison with risk based approaches that require more information on the articles and surrounding conditions. This might be due to neglecting certain hazards (such as explosion of the shell on the ground after falling down or explosion directly inside the mortar, burning matter on ground) or considering unrealistic functioning or behavior.

In conclusion, all approaches for setting safety distances for display fireworks have advantages and weak points in their application in daily life. These respective systems must, however, be seen in the context of the situation in each single country due to different cultural aspects and social acceptance of fireworks and their corresponding effects. The term 'safe' is and will always be assessed differently by the respective countries. Simple examples highlighting these differences are the question of what is 'loud' (being exposed to a certain sound pressure level) and the presence of sparks (being exposed to effect sparks or some incandescent matter/fallout). Each system and approach presented in this work has its own eligibility and justification for being applied in the respective countries.

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