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Analysis of Impact on Ambient Air Quality of Outdoor Firework Display During Chinese New Year 2013 in Hong Kong

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Abstract: Outdoor displays have been carried out for many years at Victoria Harbour in Hong Kong. These occur at least twice a year on China National Day (CND) and Chinese New Year (CNY) with a show time of about 23 minutes. The 2013 shows attracted many hundreds of thousands of people to watch on both sides of Victoria Harbour for about half an hour. An analysis of the ambient air quality data for 2013 provided by the Hong Kong Environmental Protection Department (HKEPD) was carried out to understand the impact on ambient air quality that may have resulted from the 2013 outdoor fireworks display during the CNY show. The data collected by HKEPD includes carbon monoxide (CO), nitrogen oxide (NO_x), nitrogen dioxide (NO_2), ozone (O_3), respirable suspended particulates (RSP or PM_{10}), fine suspended particulates (FSP or $PM_{2.5}$), and sulphur dioxide (SO_2). The analysis covers a period of 5 days, 2 days prior to and 2 days after the show during CNY 2013. Due to local air movement from east to west at Victoria Harbour and the high bursting of the fireworks display, the smoke that was generated by the fireworks was quickly dispersed. There was no significant impact on the ambient air quality based on the data collected. A trace of temporary smoke cloud was observed at the bursting height of the firing location.

Introduction

There are many questions concerning air pollution raised by environmental pressure groups, concerning outdoor fireworks. It is predominantly because firework displays generate light and sound that they draw the audience's attention. Some daytime fireworks even produce coloured smokes in the sky to create a colourful sky (rainbow) pattern. The majority of firework displays occur at night with music and different effects such as sparks, brocade, peony, dahlia, waterfall, etc. However these effects are normally accompanied by debris and smoke whether they are intended or not. Many reports[1,2,3] of the impact of firework displays on air quality have been presented. Debris is created when a paper shell bursts in the air, creating debris or un-burnt paper components or particles and in most cases, they are lightweight and non-hazardous. Smokes are part of the chemical reaction of firework compositions when ignited. The reactions produce different products together with the desired colours of light and sound in its specific chemical reactions, to give a specific effect. The specific effect is the major factor that draws the audience's attention. However the undesired side products, debris and unexpected smokes, can receive negative comments from the audience, and this is quite common at present. Environmental press groups recommend banning firework displays because of such by-products. On the other hand firework manufacturers have been working towards display fireworks with less visible smoke.

Hong Kong has had firework displays since the 19th century even though there are regulations prohibiting the sale and storage of fireworks. Leaving aside the reason for such prohibitions, fireworks are still one of the most important traditional and cultural items in Hong Kong, an international city whose population is more than 93% Chinese. Outdoor firework displays are therefore allowed on certain special occasions upon permission from a related authority of the Hong Kong government. Although there are small, personally arranged outdoor firework displays, the one organized at Hong Kong Victoria Harbour is the biggest and best-known event in Hong Kong, and probably in the world. A macro analysis of environmental monitoring data collected by the Hong Kong Environmental Department (HKEPD) of the Government of Hong Kong Special

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Administrative Region (HKSAR) around the shooting site was done to investigate the impact on the ambient air quality from this firework display. The data collected by HKEPD include carbon monoxide (CO), nitrogen oxide (NO_x), nitrogen dioxide (NO_2), ozone (O_3), respirable suspended particulates (RSP or PM_{10}), fine suspended particulates (FSP or $PM_{2.5}$), and sulphur dioxide (SO_2). The analysis covers a period of five days: two days prior to and two days after the show during CNY 2013, which fell on 11 February 2013, as indicated in Tables 1 and 2.

Table 1. *Firework display for CNY at Victoria Harbour on February 11, 2013*

Event	CNY
Date of display	11 February 2013
Time of display	20:00:00–20:23:06
NEC/kg	4467
Shell calibre/mm (inches)	75–173 (3–7)
Burst height/m	100–200
Weather	East wind 15 km h^{-1}

Table 2. *Weather recorded at Central Pier location (E) by Hong Kong Observatory*

Pressure/hPa	1020.0
Air temp./°C	17.2
Dew point/°C	13.8
Relative humidity (%)	80
Wind speed/km h^{-1}	15
Wind direction/weather	East wind, fine

Outdoor firework displays in Hong Kong

Hong Kong is a small city (1104 square kilometres) of more than 7.15 million people[4] occupying less than 25% of the developed land of Hong Kong Island, Lantau Island, the Kowloon Peninsula, and the New Territories, including more than 200 outlying islands. Between Hong Kong Island and the Kowloon Peninsula lies Victoria Harbour, one of the world's most renowned deep-water harbours (Figure 1). Since 1967, Hong Kong has prohibited the sale and storage of fireworks. Consumer fireworks cannot therefore be obtained in Hong Kong. Transportation from China to overseas is the biggest channel for exports from China.

Even before the establishment of the Hong Kong SAR in 1997, Hong Kong organized outdoor firework displays in public areas but special permits were required. It is difficult to obtain a permit due to the limited available area (high population density, 6620 people per square kilometre). Hong Kong Disneyland is the only place in Hong Kong currently allowing the firing of 3 inch shells within its premises based on a tight monitoring and control system. There are several other important events or festivals that allow outdoor firework displays performed each year in Hong Kong. These are New Year's Eve celebration, mostly organized at the beginning of the year; the second day of the Chinese New Year (Lunar Year), and China National Day which is October 1. Others were the East Asian Games which were held in 2009 and the 5th, 10th and 15th anniversaries of the establishment of The Government of Hong Kong SAR (handover), of which the latest was held on July 1, 2012.

in order to be able to track the impact of firework displays on the environment, the concentrations of air pollutants for two days prior to and after the display were analysed, making a total of a five day period of data for analysis. This was analysed, in order to evaluate the much longer term impact and to avoid any single and ad hoc weather changing impact. All environmental air pollutants were obtained from HKEPD[5] which continuously monitors the parameters at 14 monitoring stations. Since firework displays are fired from barges (Figure 2) in Victoria Harbour, the data monitored from the nearest four stations were selected for analysis.

Figure 1. *Hong Kong Victoria Harbour and 4 monitoring stations, (A) (right) to (D) (left), source: map from Google*

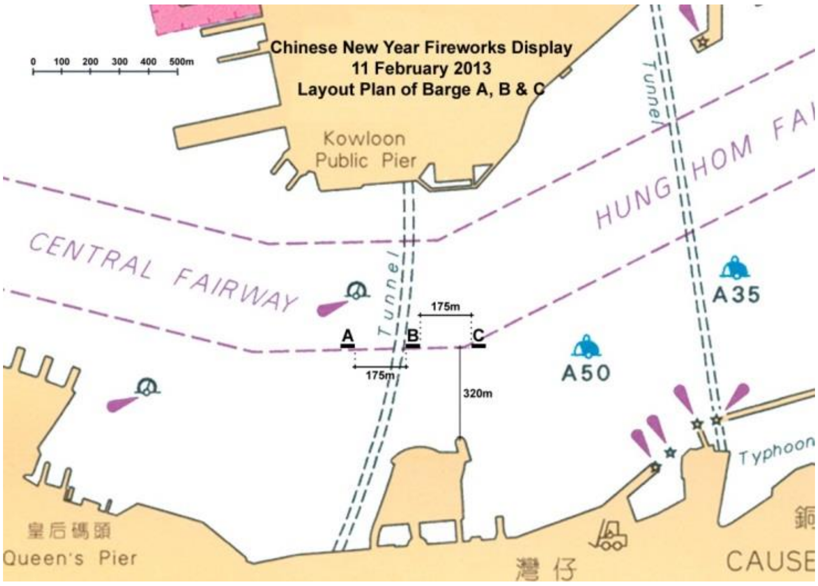

Figure 2. *Firework display layout plan of barges A, B and C at Victoria Harbour*

These stations are all located on Hong Kong Island and are, from east to west, (A) Eastern Station, (B) Causeway Bay Station, (C) Central Station and (D) Central Western Station, as indicated (right to left) in Figure 1. An observatory station, (E), is used to measure wind speed, relative humidity and temperature at Central Pier, located in the middle of stations (B) and (C), directly adjacent to the shooting site.

Data collected by Hong Kong Environmental Protection Department

The five monitoring stations are located in residential areas at different heights. Some are close to main traffic routes and some are on top of buildings. They are located to represent the best environments for monitoring ambient air without adverse impact from either individual incidence or personnel interruptions. The exact locations and nearby environments are shown in Figures 3 to 7.

Monitoring stations

(A) Eastern (General Station) – Figure 3

- Location: Sai Wan Ho Fire Station, 20 Wai Hang Street, Eastern, Hong Kong Island
- Sampling Height: 28 meters from sea level
- Distance from shooting site: 3000 metres (approximately)

(B) Causeway Bay (Roadside Station) – Figure 4

- Location: No. 1 Yee Wo Street, Causeway Bay, Hong Kong Island
- Sampling Height: 6.5 meters from sea level
- Distance from shooting site: 800 metres (approximately)

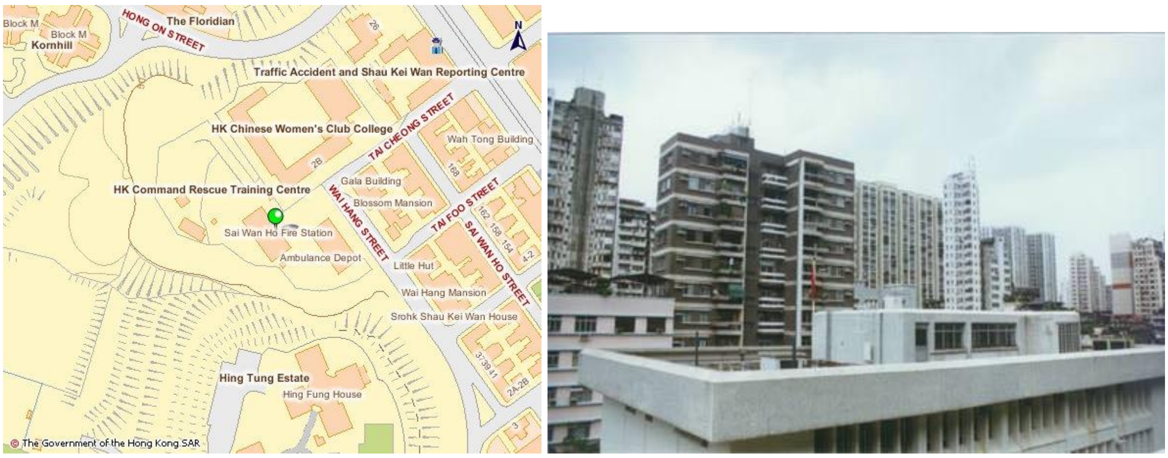

Figure 3. *Eastern Station*

(C) Central (Roadside Station) – Figure 5

- Location: Junction of Des Voeux Road and Chater Road, Hong Kong Island
- Sampling Height: 8.5 meters from sea level
- Distance from shooting site: 1500 metres (approximately)

(D) Central Western (General Station) – Figure 6

- Location: Sai Ying Pun Community Complex, 2 High Street, Central & Western, Hong Kong Island
- Sampling Height: 82 meters from sea level

__Figure 4__. Causeway Bay Station

__Figure 5__. Central Station

__Figure 6__. Central Western Station

***Figure 7**. Landmarks viewed from Central Pier pointing to shooting site (east)*

- Distance from shooting site: 2000 metres (approximately)

(E) Central Pier – Figure 7

- Location: Latitude N – $22^0$17'20", Longitude E – $114^0$09'21", Elevation of ground (above sea level) – 19m
- Address: Pier at the Central District of Hong Kong Island

Key air pollutants

Key air pollutants that were monitored by HKEPD included Respirable Suspended Particulates (RSP or PM10),* Total Suspended Particulates (TSP), nitrogen oxides (NO_x), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), and later, Fine Suspended Particulates (FSP or $PM_{2.5}$)* were added, which are commonly used as references by other countries such as the European Union, USA, UK, Thailand, etc. They were monitored from 2005 to date at monitoring stations (A) to (D) (Figure 1), while monitoring point (E) was used for wind speed, temperature measurement and relative humidity. These measuring locations are the closest to the shooting site.

Monitoring equipment used by EPD

Air quality monitoring goes on 24 hours a day, 7 days a week, on average hourly. Most equipment used for gaseous pollutants such as RSP (PM_{10}) and FSP ($PM_{2.5}$) determines them continuously by automatic analysers. The list of equipment employed for monitoring is summarized in Table 3.[6]

Annual important events

Hong Kong is an international city where multicultural activities are commonly held. With the majority of the population being Chinese, firework displays are common. Besides the two main firework display events in Hong Kong every year (*Chinese New Year (CNY)* – the second day of

Table 3. *Equipment being used by HKEPD for measuring ambient air qualities*

Pollutants	Measurement principle	Equipment
SO_2	UV fluorescence	TECO 43A, API 100E, TECO 43I
NO, NO_2, NO_X	Chemiluminescence	API 200A
O_3	UV absorption	API 400, API 400A
SO_2, NO_2, O_3	Differential optical absorption spectroscopy	Opsis AR 500 System
CO	Non-dispersive IR absorption with gas filter correlation	TECO 48C, API 300
TSP	Gravimetric	General metal works GS2310
RSP (PM_{10})	a) Gravimetric b) Oscillating microbalance	Graseby Andersen PM10 R&P TEOM Series 1400a-AB-PM10 Thermo Scientific TEOM 1405-DF
FSP ($PM_{2.5}$)	a) Gravimetric b) Oscillating microbalance	Thermo Scientific Partisol-Plus 2025 R&P TEOM Series 1400a-AB-PM2.5 Thermo Scientific TEOM 1405-DF

the Lunar Year (Chinese New Year) which is always either in January or February of the year and *China National Day (CND)* – October 1) there are some other irregular or less frequent firework display events such as the East Asian Games, celebration of Tsing Ma Bridge, etc. For the sake of continuity and repeatable measurements, the analysis includes the CNY and CND only.

Discussion

The outdoor firework display was performed at 20:00. It was fired at Victoria Harbour, the deepest bay of Hong Kong between Kowloon Peninsula and Hong Kong Island because the shooting site is large with a sufficient safety zone. The show could be seen along both sides of the harbour. In fact the HK firework display at Chinese New Year has become a tourist attraction. It was attended by about 300 000 to 600 000 people standing on both sides of the harbour. The distance between both sides of the harbour is about 1000 m. The location provides a clear safe zone when marine control of boats is enforced during the show. The mortar racks were installed on the barges A, B and C. (Sometimes there may be 4 to 5 barges depending on the scale of the show.) These barges were then brought to the designated location (Figure 2), and anchored. The display was of 23 minutes 6 seconds duration. During the performance there were 12 themes playing continuously and synchronized fireworks launching with music or songs.

During the show, as normal, there were smokes and debris produced at around 100 to 200 meters height above sea level because 90% of the fireworks used were cakes and aerial shells fired from the barges. Fireworks fired at water level were seldom used due to the water surface not being still and the long distance view from both sides of the harbour. The pollutant monitoring data were extracted for a period of five days, i.e. two days before the display and two days after, to show the continuation of the background level. Therefore there were five consecutive days of data (or 120 hours) showing the ambient air quality at the four stations (A) to (D). The wind speed, temperature and relative humidity were obtained from the HK Observatory. This was used to compare the effects of weather changes, if any.

Since the show took place at 20:00 on February 11, 2013, the monitoring pollutant data are shown at the 68th hour in all parts of Figure 8. There are four charts marked from (A) to (D) indicating the monitoring station location, East to West. The red arrow indicates the exact the time of the performance in charts (B) and (C) which were the nearest stations to the firework display. The weather conditions such as temperature, relative humidity and wind speed were recorded at the nearest location (E), Central Pier by Hong Kong Observatory,[7] and are shown in Table 2.

Analysis of individual outdoor firework displays

The monitoring data of all key pollutants at stations (A), (B), (C) and (D) during CNY 2013 are shown in Figure 8. These pollutants were sulphur dioxide (SO_2), Respirable Suspended Particulates (RSP or PM_{10}), Fine Suspended Particulates (FSP or $PM_{2.5}$), nitrogen oxides (NO_x), nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3). All units of measurement are μg m^{-3} except for CO which is 10 μg m^{-3}. Some data were missed due to mechanical breakdown. The red arrow indicates the time the performance started.

Chinese New Year (CNY) 2013

The five days of pollutant data are shown in Figure 8, from February 9 to 13, 2013 (120 hours, Sunday to Thursday) with the display performed on February 11, 2013 (Tuesday) at 20:00 for a period of 23 minutes 6 seconds (show time at the 68th hour on x-axis). The measured data recorded at stations (A) and (D) are flat and low meaning that pollutants were low and normal. This was because these two stations were far away from the central area where the densest population and commercial activities

Table 4. *Hong Kong Air Quality Objectives (AQOs)*[8]

Pollutant/μg m^{-3}	Average time				
	1 hour	8 hours	24 hours	3 months	1 year
Sulphur dioxide (SO_2)	800		350		80
Total suspended particulates (TSP)			260		80
Respirable suspended particulates (RSP or PM_{10})			180		55
Nitrogen dioxide (NO_2)	300		150		80
Carbon monoxide (CO)	30 000	10 000			
Ozone (O_3)	240				
Lead (Pb)				1.5	

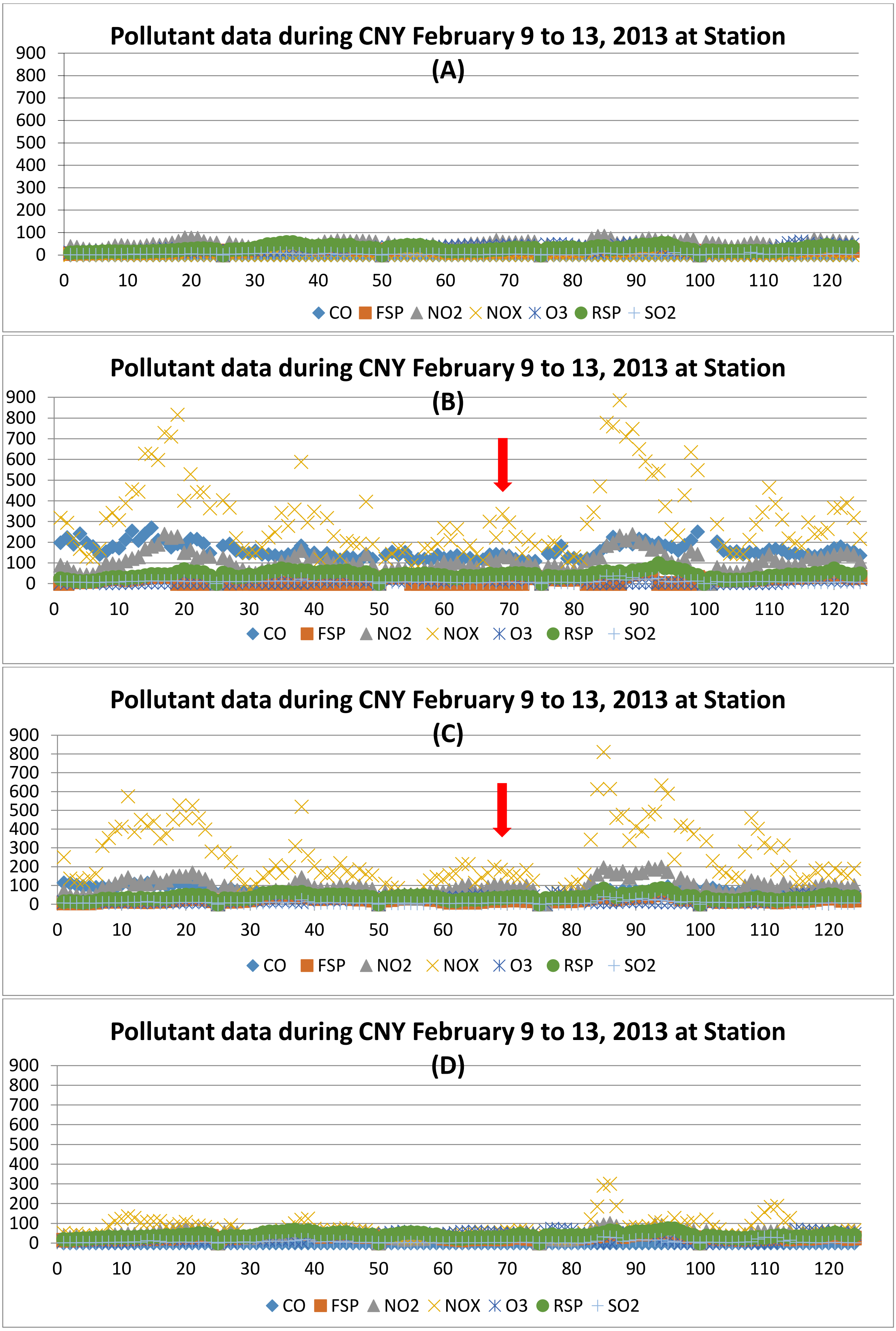

Figure 8*. Pollutant data during CNY February 9 to 13 at Stations (A) to (D) (top to bottom). All units of measurement are µg m⁻³ except for CO which is 10 µg m⁻³.*

Table 5. *Highest hourly pollutant concentrations measured in Hong Kong 2013*

Pollutant, (μg/m^3)	AQO / 1 hour	Highest hourly pollutant at Stations			
		A	B	C	D
Sulphur dioxide (SO_2)	800	89	105	133	200
Total suspended particulates (TSP)		NA	NA	NA	NA
Respirable suspended particulates (RSP or PM_{10})		251	227	252	180
Fine suspended particulates (FSP or PM2.6=5)		128	175	155	198
Nitrogen dioxide (NO_2)	300	230	454	468	266
Nitric oxide (NOx)		NA	824	1025	545
Nitrogen oxide (NO)		NA	1570	1899	1030
Carbon monoxide (CO)	30 000	NA	4070	2680	NA
Ozone (O_3)	240	192	120	124	258
Lead (Pb)		NA	NA	1.5	NA

were. From stations (B) and (C), the two stations located at the local commercial and shopping district, the data show larger variation. However the charts showed an increase of pollutants from the 35^{th} hour but not at the 68^{th} to 69^{th} hour when the firework display was performed.

The wind speed was 15 km h^{-1} blowing from east to west. The chart for station (D) which was in the downwind direction did not show visible smoke nor any adverse effect at or after the 69^{th} hour.

As shown in Table 4, there are key pollutant monitoring data for the whole year in Hong Kong before 2014. This is an average of measurements all around the areas (14 monitoring stations) measured in Hong Kong. It showed the firework display at CNY 2013 did not have any adverse effect on ambient air quality.

The highest hourly pollutant concentrations measured in 2013 are shown in Table 5. This was the highest hourly data among all measurements in Hong Kong for the whole of 2013. When looking at the stations (B) and (C) in Figure 8 while the firework display was going on at 20:00, February 11, 2013, the key pollutant measurements are all below the highest record for the year. From the other point of view, the highest hourly pollutant data in Table 5 were not caused by the firework display events at CNY.

Conclusions and recommendations

The impact on ambient air quality was negligible for firework displays during CNY 2013 in Hong Kong. Analysis of ambient air quality around the shooting site was very similar to that for the previous four years (2010 to 2013).[9] The changes in key air pollutants are shown in Table 6. One could argue that the monitoring data were not specific to the

Figure 9*. 2013 Fireworks Display at Victoria Harbour of Hong Kong*

Table 6. *Changes of concentration levels of key air pollutants from 2010 to 2013 of Hong Kong*

Pollutant, µg m^{-3}	*	2013	2012	2011	2010
RSP (PM_{10})	G	50	42	48	45
	R	56	53	61	60
FSP ($PM_{2.5}$)	G	32	28	34	29
	R	37	33	39	36
NO_x	G	110	90	91	94
	R	320	312	326	318
NO_2	G	60	51	53	52
	R	120	119	122	117
SO_2	G	12	11	13	12
	R	11	10	12	10
O_3	G	30	40	41	39
CO	G	850	733	669	693
	R	950	1011	955	1066

firework display because the data were not good enough. However the ambient air quality was also affected by many factors such as transportation, population, wind direction, wind speed, humidity, etc. It was not possible to isolate the firework display factor and conclude there was an impact by shooting fireworks. Furthermore the public showed more interest in the change in measured data regarding ambient air quality. So using this analysis could possibly reflect that there was negligible impact on the surroundings.

From Figure 8, there was another observation from stations (B) and (C) which were close to the shooting site and to a busy shopping area. The background ambient air pollutant level was already high compared to stations (A) and (D) throughout the five days monitored. When compared to national requirements, the quality was acceptable.

Lastly and most important, the right selection and management of the firing site is a critical factor. Hong Kong Victoria Harbour (Figure 9) is an excellent venue for firework displays. The buildings located on both sides of the harbour provide a good viewing location and an excellent air cleaning pathway. For this reason the impact on ambient air from the display was acceptable. However this was a local case study and it does not imply all displays would have similar observations. It would be worth comparing in detail with more specific measurement data. However with thoughtful and careful planning of firework displays, the positive contribution from firework displays to society and the public is far greater than the negative one.

Notes

*RSP (PM_10) refers to respiratory suspended particulates having particle sizes equal to or less than 10 microns. FSP ($PM_{2.5}$) refers to the fine suspended particulates having particle sizes equal to or less than 2.5 microns.

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Towards the New Pyrotechnics Directive 2013/29/EU – an Impact Assessment

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Abstract: *With the coming into force of the new European Directive 2013/29/EU (Official Journal of the European Union L 178/27; 28.6.2013) pyrotechnic articles are regulated in view of making them available on the Union market. This Directive is a recast of the current Directive 2007/23/EC (Official Journal of the European Union L 154/1; 14.6.2007) regarding the placing on the market of pyrotechnic articles and will replace it entirely by July 1st, 2015. In comparison with the current Directive, the complexity and level of detail are increased in the recast version. Furthermore, a variety of new requirements are implemented, which influence the activities of the economic operators and notified bodies. This contribution describes the relevant changes from the viewpoint of the notified body Bundesanstalt für Materialforschung und -prüfung (BAM), and gives an impact assessment of the new requirements and corresponding suggestions for solutions to problems. The illustrated reforms are not all-embracing, but reflect the most important decisions and consequences.*

Background to the recast

The following illustrates briefly the reasons and the motivation of the European Commission (COM) for setting up a recast of the Pyrotechnics Directive.[1,2] The information presented in this chapter was taken from the published executive summary regarding the impact assessment of the new legislative framework (NLF) alignment package of the COM from 2011.[3]

EU Directives follow mainly two overarching objectives: First, they should ensure that articles made available in Europe safeguard public interests like health and safety, consumer and environmental protection at a high (and preferably uniform) level. Second, they should form the basis for the free movement of articles within the EU by applying harmonized requirements. However, stocktaking of the COM from 2004 revealed several shortcomings and the fact that these goals were not achieved. In conclusion, the following were observed:

- A significant number of non-compliant products still reaching the market,
- The performance of certain notified bodies (NBs) was not satisfactory, and
- Inconsistencies exist throughout the legislation making its application unnecessarily complicated for manufacturers and authorities.

Within the frame of a public consultation at that time 92% of the overall economic operators (manufacturers, importers and distributors) considered that their specific sector was affected by non-complying products. Generally speaking, non-compliance can be potentially harmful for product users in view of the above mentioned public interests and it hampers the competitiveness of compliant firms. Non-compliant economic operators can gain significant cost advantages (e.g. by avoiding costly conformity assessment procedures) in comparison with those who apply harmonized Union legislation or standards. This problem increases with less effective market surveillance in the Member States of the EU.

In addition, the executive summary of COM[3] reveals that 84% of the economic operators, 68% of the NBs and 53% of the public authorities had significant problems with the quality of services of the NBs in general. This was explained by the lack of necessary competence of certain NBs to carry out conformity assessments in a proper way (in spite of being accredited against respective standards). Another reason for the concerning and sometimes

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poor quality of the work of certain NBs is that, in order to issue their certificates at significantly lower rates, these NBs do not put the required level of effort into their assessment or into the application of procedures. This can be achieved e.g. by elimination or reduction of on-site controls or relaxed requirements regarding the frequency of periodic audits/inspections to considerably reduce the costs of assessments.

In consequence, and as part of the reaction of COM towards these concerning observations, the “New Legislative Framework” (NLF) was adopted as part of the goods package with the aim of minimizing the observed shortcomings. It consists of two complementary instruments:

- Regulation (EC) No 765/2008 on accreditation and market surveillance (NLF Regulation)[4]
- Decision No 768/2008/EC establishing a common framework for the marketing of products (NLF Decision)[5]

The NLF Regulation provides immediate legal force and effect and has been in force since January 1st, 2010. In contrast to this regulation, the NLF Decision has no immediate legal effect on the Member States or the economic operators. The NLF Decision basically sets the overarching frame for the requirements of the economic operators and NBs, which must be implemented in (existing) regulations. For this reason, COM identified a group of EU Directives for product harmonization (the so-called NLF-package), where all single Directives are horizontally aligned to the NLF Decision. This NLF-package consists of the following 10 Directives:

1. Pyrotechnic Articles Directive: Directive 2007/23/EC on the placing on the market of pyrotechnic articles
2. Civil Explosives Directive: Directive 93/15/EEC on the harmonisation of the provisions relating to the placing on the market and supervision of explosives for civil use
3. ATEX Directive: Directive 94/9/EC on the approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres
4. Lifts Directive: Directive 95/16/EC of 29 June 1995 on the approximation of the laws of the Member States relating to lifts
5. Pressure Equipment Directive (PED): Directive 97/23/EC on the approximation of the laws of the Member States concerning pressure equipment
6. Measuring Instruments Directive (MID): Directive 2004/22/EC on measuring instruments
7. Electromagnetic Compatibility Directive (EMC): Directive 2004/108/EC on the approximation of the laws of the Member States relating to electromagnetic compatibility and repealing Directive 89/336/EEC
8. Low Voltage Directive (LVD): Directive 2006/95/EEC on the harmonisation of the laws of Member States relating to electrical equipment designed for use within certain voltage limits
9. Non-automatic Weighing Instruments Directive (NAWI): Directive 2009/23/EC on non-automatic weighing instruments
10. Simple Pressure Vessels Directive (SPVD): Directive 2009/105/EC relating to simple pressure vessels

With this background the pyrotechnics recast Directive 2013/29/EU[1] was published and entirely replaces the Directive 2007/23/EC[2] by July 1st, 2015.

Impact assessment and solution approaches

Several questions arise for the concerned economic operators, NBs and market surveillance authorities when existing Directives are replaced by new recast versions. One of the focus points is the situation of the certificates issued under the old Directive. This aspect is treated as a kind of ‘inventory keeping’, where certificates issued under Directive 2007/23/EC[2] shall remain valid under the Directive 2013/29/EU,[1] as well. Nevertheless, the requirements according to the new Directive apply, which differ to some extent in comparison with the old Directive (as shown further down this article). This situation could lead to ambiguities between all involved parties, such as economic operators, NBs and market surveillance authorities, e.g. when labelling details according to 2007/23/EC[2] as part of the respective conformity assessment certificates at that time differ from the requirements of the new Directive 2013/29/EU.[1] This requires an extensive knowledge and information exchange between the parties involved, especially with the market surveillance authorities. From the point of view of the NBs, this information exchange was already initiated with the competent EU board regarding market surveillance ADCO-PA (Administrative Coordination Working Group – Pyrotechnic articles).

As explained earlier in the text, the provisions of the new Directive 2013/29/EU[1] will be applicable by July 1st, 2015. A specific topic is the newly formulated essential safety requirement (ESR) number 4 in the Annex I to this Directive, which had to be adopted by the Member States by July 4th,

2013. According to the old ESR 4 (Annex of 2007/23/EC[2]) all pyrotechnic articles must not contain commercial blasting agents, except for black powder or flash composition and military explosives. However, several types of pyrotechnic articles, particularly those for vehicles such as airbag gas generators but also squibs/bullet hits, contain small amounts of commercial blasting agents and military explosives and have been placed on the market for many years. As these substances cannot be adequately replaced for their intended purpose, a modification was necessary:

Pyrotechnic articles must not contain detonative explosives other than black powder and flash composition, except for pyrotechnic articles of categories P1, P2, T2 and fireworks of category F4 meeting the following conditions:

(a) the detonative explosive cannot be easily extracted from the pyrotechnic article;

(b) for category P1, the pyrotechnic article cannot function in a detonative manner, or cannot, as designed and manufactured, initiate secondary explosives;

(c) for categories F4, T2 and P2, the pyrotechnic article is designed and intended not to function in a detonative manner, or, if designed to detonate, it cannot as designed and manufactured initiate secondary explosives.

According to this new requirement ESR no. 4, detonative explosives other than black powder and flash composition are still prohibited within the categories F1–F3 and T1, but under due consideration of the given properties and further tests these substances are not explicitly excluded any more for articles of the categories P1–P2, F4 and T2 (which would include airbag gas generators and squibs).

In order to prove that the requirement ESR 4 (c) is met, appropriate test and evaluation methods must be developed. Amongst others, the following aspects need clarification:

- Which secondary explosive has to be taken? Which form, shape and mass of this explosive are suitable?
- Test configuration (direct contact or not etc.)?
- Experimental proof as part of EU type-examination only (performed by or on behalf of the NBs) or also as part of subsequent QS batch tests (performed by manufacturers)?

The respective European committee for standardization CEN/TC 212 Pyrotechnic articles and the Forum of Pyrotechnic NBs (coordination group between the notified bodies and the COM) currently deal with these aspects. Respective task forces with intense involvement of BAM recently developed test and assessment criteria for the experimental investigation of ESR 4 (c). It is expected that these tests and assessment criteria will be implemented in the future into the corresponding product standards for display fireworks (F4), theatrical pyrotechnic articles (T2) and all other pyrotechnic articles (P1–P2). Parts of these tests and assessment criteria were already published by BAM within the *Journal of Pyrotechnics* ("Assessment of Explosives in Squibs").[6]

In addition to this requirement, the question whether a detonative explosive cannot be easily extracted from the pyrotechnic article (ESR 4 (a)) needs thorough consideration and clarification.

The new Directive 2013/29/EU[1] doesn't apply any more to the placing on the market alone, but now comprises the entire procedure of making available on the market. This means any supply of a pyrotechnic article for distribution, consumption or use on the Union market in the course of a commercial activity, whether in return for payment or free of charge. One has to keep in mind that the old Directive was just limited to the placing on the market, which basically means the first making available of a pyrotechnic article on the Union market. With this formulation the entire chain of trade is covered.

Furthermore, it stands out that the extent or coverage of the Directive 2013/29/EU[1] was considerably increased, by a factor of nearly 3 concerning just the number of pages. This is mainly due to the fact that the obligations for all economic operators were strongly worded with an increased level of detail. This can be illustrated very well by an exemplary focus on the obligations of the distributors. Whereas the old Directive nearly neglected these specific obligations, the new Directive set up requirements within an entire article consisting of 5 paragraphs. Amongst others, the following aspects must be now acknowledged by the distributers from July 2015 on:

- Are the instructions and safety information in a language which can be easily understood by consumers and other end-users in the Member State in which the pyrotechnic article is to be made available on the market? What happens by the way if the distributer comes to a different conclusion regarding the required easy understandability for articles that successfully passed conformity assessment procedures?
- Verification of the labelling regarding the required details on the manufacturer and importer

- In case of a reason or suspicion of (formal) non-conformity to report to the competent national authorities of the Member States in which they made the pyrotechnic article available on the market to that effect, giving details, in particular, of the non-compliance and of any corrective measures taken.

As pointed out, the obligations of the manufacturers were also increased. They shall, when deemed appropriate in the view of potential risks for the health and safety of consumers, carry out sample testing of pyrotechnic articles that were already made available on the market and investigate regarding the non-conforming pyrotechnic articles. This needs further clarification, as the manufacturer already declared conformity to the Directive, and specific tests and assessments were also already carried by NBs (e.g. EU type-test and possibly batch tests) and the manufacturer (e.g. batch tests) himself. When articles are already made available on the Market, do the manufacturers have to repurchase their own articles for the purpose of these additional tests?

From the viewpoint of the fireworks industry an important aspect was “lifted” to a higher requirement level within the Directive 2013/29/EU.[1] The so-called “Lex Malta” in Article 2 g confirms further on that fireworks which are built by a manufacturer for his own use and approved for use exclusively in its territory by the Member State in which the manufacturer is established, and which remain in the territory of that Member State, don’t fall under the comprehensive scope of the Directive. Or in other words: conformity assessment procedures, aligned with extensive testing, are not mandatory in these cases. However, the interpretation of this will likely differ quite strongly in the Member states. The following brief example highlights this aspect: A manufacturer of professional fireworks sets up a display show and shoots these fireworks (without selling them, see Figure 1):

- Would this qualify as “own use”?
- Would such evaluation be dependent on the location (own company’s or public ground) or on the finances (audience pays or not)?
- Is the actual place of production important for this assessment (e.g. manufacturing site and lines within the EU or outside such as PR China)?
- How is this seen in the context of the definition of “making available on the market” itself (…means …use on the Union market in the course of a commercial activity, whether in return for payment or free of charge)? This definition might contradict the “Lex Malta” clause.

Figure 1. Fireworks display in Malta 2012 (source: Lohrer; BAM).

With regard to one of the main reasons for the recast of the Directive, the problematic care and diligence of certain NBs as pointed out by COM[3] (see earlier in the text), the Directive 2013/29/EU[1] contains an increased number of requirements towards being notified in the first place. According to Article 25 (6), such a body shall be capable of carrying out all the conformity assessment tasks assigned to it by Annex II and in relation to which it has been notified, whether those tasks are carried out by the conformity assessment body itself or on its behalf and under its responsibility. This strict requirement is flanked by the respective requirements of the latest “The Blue Guide” – on the implementation of EU product rules.[7] It is here specifically stated that, in cases of subcontracting to bodies in third countries, the notified body must have appropriate facilities and staff to be able to verify test results in the EU. In addition, if accreditation is the chosen path for notification, it must cover the subsidiary companies of notified bodies to which they have recourse. These requirements set the bar quite high for all NBs, as the respective harmonized standards require a large amount of testing capabilities (wide test grounds, comprehensive equipment etc.). A notification alone, as commonly done in the past and under the current Directive, on the basis of conformity assessments carried out by subcontracted tests labs (“stamping” of test reports), appears to be against the new provisions of the Directive 2013/29/EU.[1] Furthermore, COM considered the strong need due to incidents in the past to require the NBs to participate in, or ensure that their personnel responsible for carrying out the conformity assessment tasks are informed of, the relevant standardization activities and the activities of the notified body coordination group (forum of NBs). The NBs are additionally required to apply as general guidance the administrative decisions and documents produced as a result of the work of that group.

With focus on the reporting obligations of the NBs an important aspect was added, which possibly has its reason in the lack of care and diligence of some NBs (observed by COM[3]). In accordance with article 35 (2), NBs shall provide the other bodies notified under this Directive carrying out similar conformity assessment activities covering the same pyrotechnic articles with relevant information on issues relating to negative and, on request, positive conformity assessment results. This is an interesting statement, as it requires all NBs to report to the other NBs all negative conformity assessment procedures, which is not limited to EU type-examinations (module B), but also includes QS-related modules (such as C2, D, and E). A further motivation of COM to set up such requirements might have been the attempt to minimize hawking activities of manufacturers trying to spot the weakest part of the chain between the NBs. Within this "negative" reporting procedure, however, many things are not clear and need further consideration and clarification, such as:

- *What information is provided?* This depends on the respective conformity assessment module. After a negative EU type-examination for example traceability information such as registration and lot numbers are not issued, whereas after a negative module C2 assessment such details present valuable and useful information. This has to be considered with due care, taken into account the confidentiality aspects between the manufacturers and the NBs.
- *When is the information to be provided to the others?* Do the NBs have to report right away after the performed negative tests? Do they have to consider periods for objection for the manufacturer (which could take weeks and would contradict one possible aim of this reporting procedure to reduce the likelihood of the manufacturers to look for another NBs meanwhile for the same unchanged articles)?
- *How is the information provided?* Is a simple email to the other NBs enough or is there a need to feed databases?
- *Consequences arising from these negative reports?* How to proceed for example, if one NB receives the negative assessment report prior or during a testing procedure for possibly the same article?

Another direct consequence of this procedure is the fact that a certain approval statistic between the NBs is generated, which reveals if (and how many) products were negatively assessed by the NBs. Possible out of balance scenarios for identical articles and procedures between the NBs might be minimized with this measure.

These above mentioned concerns are currently discussed within the forum of NBs and one can expect a harmonized operation procedure regarding this negative assessment reporting obligation in the near future.

Another change comes with the labelling requirements given in the new Directive 2013/29/EU.[1] The new provisions now explicitly require the registration number for traceability as part of the article label and in addition the product, batch or serial number.

Unfortunately, the COM missed the opportunity to require a clear traceability of the articles to the specific batch that was tested. Due to the fact that the article number in addition to the registration number was considered as sufficient, the necessary link to the tested batch is still not always given.

Unfortunately, one important aspect regarding labelling of display fireworks remained unchanged in the new Directive. The COM kept the opinion to require a minimum safety distance on the label of display fireworks (and professional theatrical pyrotechnics, as well). This mandatory fixed value on the label of the display fireworks to be applied by users with specialist knowledge leaves no flexibility for the intended use. In addition, the term "safe distance" is misleading and not all-embracing. As recently shown by T. Smith and C. Lohrer[8] and C. Lohrer,[9] the philosophies of defining a "safe distance" differ significantly in Europe and other parts of the world. How can a NB assess or determine such a "safe distance" within a conformity assessment procedure (the respective certificates apply throughout the entire EU) with all the differing safety distance regulations? Distances for articles might be acceptable in Spain, but not in the Netherlands etc. Even if it were possible to find one approach for the entire EU, it could only be based on a standard use such as vertical firing, no windy conditions, no difficult terrain properties (just to name a few). The conditions onsite will, however, differ. There will be wind (considering direction and speed), rain or humidity, angling of the tubes, terrain elevation, houses etc. All of these factors will lead to either an increased or decreased applicable safety distance compared with the mandatory fixed value on the label. This will likely confuse the enforcement bodies onsite, responsible for the permission of such displays. The flexible and sensible approaches according to the applicable EU Standards for display fireworks and professional theatrical pyrotechnics were not considered during this recast. Within the testing and assessment of such articles according to these standards, only the relevant performance parameters will be recorded and displayed on the label. These values are the basis for the safety distance calculations in the Member states.

Figure 2. Airbag testing at BAM (source: Waschki/Dengel; BAM).

Promising experiences with such flexible systems (no fixed distances on display fireworks) already existed in the UK and in Germany before the implementation of the Directive 2007/23/EC[2] and had proven their sensible applicability in daily life.

The minimum labelling requirements for pyrotechnic articles for automotive purposes changed as well. As for fireworks for example, the product, batch or serial number is now mandatory. In addition, information towards the identification of manufacturer and importer must be accompanied by the address (single contact point). Figure 2 illustrates airbag testing during conformity assessment procedures at BAM.

The new Directive 2013/29/EU[1] pays more attention to formal aspects than the old Directive 2007/23/EC.[2] Examples for these observations are the detailed requirements on the conformity declarations and formal non-compliances.

Manufacturers must, at the end of the conformity assessment procedures (e.g. finished module B EU type-examination and QS according module D), draw up an EU declaration of conformity and affix the CE marking. Annex III of the Directive 2013/29/EU[1] gives now the minimum information that is necessary within such conformity declarations (not exhaustive):

- Registration number,
- Product, batch or serial number,
- Name and address of the manufacturer,
- Notified body issuing the certificate,
- References to the Directive and the corresponding standards, etc.

This is directly linked to article 42 dealing with formal non-compliant products. Even if pyrotechnic articles are technically safe and in compliance with the ESR of the Directive 2013/29/EU[1] (Annex I), they will be considered formally non-compliant, if one or more of the following aspects are observed (not exhaustive):

- the CE marking has not or falsely been affixed,
- the identification number of the notified body, where that body is involved in the production control phase, has not or falsely been affixed,
- the EU declaration of conformity has not or falsely been drawn up,
- the technical documentation is either not available or not complete, etc.

In consequence of such formal non-compliance, the national authorities shall take all appropriate measures to restrict or prohibit the pyrotechnic article being made available on the market or ensure that it is recalled or withdrawn from the market.

Another relevant change concerned one of the applicable types of conformity assessment procedures. The module C (conformity to type, Annex II of 2007/23/EC[2]) was substituted by module C2 (conformity to type based on internal production control plus supervised product checks at random intervals, Annex II of 2013/29/EU[1]), which reveals higher or stricter requirements as it focuses also on internal production related aspects. It is therefore like module C + product checks at random intervals, or with other words “module D - light”. For more details refer to the Blue Guide.[7] As a consequence of this required assessment of the internal production control, the procedures and guidelines of the forum of NBs in the EU must be updated and changed accordingly. Several questions regarding this new conformity assessment procedure must be answered, such as:

- Are tests performed at the time of delivery of these articles in the EU sufficient (such as container deliveries from China)? This procedure is currently performed by NBs within module C testing, but would likely not satisfy the mandatory assessment of the internal production control that requires direct access to the production lines
- Are type or batch tests performed?
- What constitutes random intervals?

Currently the forum of NBs works on a harmonized applicable procedure to cover the obligations of module C2. The result will likely be published again by the COM after internal clearance.

The last but not least relevant change that is highlighted here deals with the application process for articles submitted to the EU type examination (module B). Manufacturers must submit for application, amongst others, the detailed technical documentation which shall include an adequate analysis and assessment of the risk(s). As commonly known, one specific risk is the product of a certain expected hazard multiplied with its expected frequency. As shown by several studies in the past (one method was presented by T. Smith[10]), adequate risk assessments are comprehensive and require detailed information on many aspects that are not fully known at the beginning of the conformity assessment procedure, such as:

- type of expected failure (e.g. in-mortar explosion, blind shell on ground, blind stars on ground, burning matter, …),
- conditions of use (e.g. angling mortar, short mortars, insufficient mortar materials, …),
- environmental conditions (e.g. wind directions & speed, rain & humidity, temperature, dried grass, …),
- surrounding conditions (terrain type and location itself, elevation, buildings nearby, …).

And again, even if all sensible scenarios were foreseeable prior to type testing and certain risks in terms of precise values are generated, how are they assessed? There are no commonly accepted threshold values of risks applicable to the entire EU. Each Member state applies its own criteria and assessments and acceptable limits. It is therefore impossible for a NB to find an adequate risk assessment that fits for all EU member states. This must also be seen in the context of the differing safety distance approaches in the EU as discussed earlier in the text. It therefore remains unclear how this new requirement can be adequately treated by the manufacturers and NBs (e.g. by the application of harmonized standards alone or further measures in addition necessary?)

Conclusions

The European Directive relating to the making available on the market of pyrotechnic articles (recast) comprises several new obligations for the economic operators, market surveillance authorities and notified bodies in this field. Some of these changes are considered helpful and necessary by the authors of this paper, such as the new ESR 4 and the additional labelling number (product, batch or serial). Other new obligations will likely complicate the entire procedure of making available of pyrotechnics on the EU market and it is expected that problems during the first months or years(s) of application of the new Directive will occur in Europe. In order to minimise misinterpretations and problems, an intensive knowledge and information exchange between the above mentioned involved parties is necessary and partly already initiated (notified bodies and market surveillance authorities aim at informing each other on a regular basis during the year).

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The European Regulation Concerning the Registration, Evaluation, Authorization and Restriction of Chemicals

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Abstract: The European regulation n°1907/2006 of 18 December 2006 – commonly referred to as "REACH" – states the mandatory registration and evaluation of chemical substances marketed, manufactured or imported in quantities of more than one ton per year on the European market. This obligation not only applies to chemical substances but also to articles which contain chemical substances when they must be considered as associations of articles and chemical substances according to REACH, meaning that their chemical composition determines their function to a greater degree than or the same degree as the special shape, surface or design they are given during production.

In its "Guidance on requirements for substances in articles" (RIP 3.8), the European Chemical Agency (ECHA) mentions fireworks as examples of such associations of articles and chemical substances. The professional experts of CEN/TC 212 who developed the European standards for fireworks under a mandate of the European Commission disagree firmly with this statement. As a consequence they decided to react with their own arguments.

The present paper gives an overview of the arguments of the professional experts of CEN/TC 212, and recalls their previous attempt to promote them at the level of the European Commission and the opening they were given by return that might lead to possible specific action of the European Commission "*including, in particular in the Guidance on requirements for substances in articles."* In that perspective and following the same approach that was adopted for ammunition by the European Defence Agency, they decided to prepare a professional guidance document in which they would express clearly their position in contradiction with ECHA's position. Such document is intended to be presented to the European Commission in order to obtain its support and, consequently, a modification of ECHA's position.

A task group was created by CEN/TC 212 to do so before the end of 2015.

Introduction

The European regulation n°1907/2006 of 18 December 2006 – commonly referred to as "REACH" – states the mandatory registration and evaluation of chemical substances marketed, manufactured or imported in quantities of more than one tonne per year in the European Economic Area, and the obtaining of special authorizations for using substances of very high concern. It maintains the pre-existing system of restriction on use.

Although REACH is mostly intended for substances and mixtures of substances, it also extends to articles which contain chemical substances and mixtures of substances when their chemical composition determines their function to a greater degree than or the same degree as the special shape, surface or design they are given during production. In that case, according to REACH, these articles are called "associations of article and substance". In the opposite case, they are simply called "articles" and are not submitted to the requirements of REACH.

All manufacturers and importers must identify and manage the risks of the substances and/or associations of article and substance they market. For substances produced or imported in quantities over 1 tonne per year and per company, they must

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demonstrate the manner they do so in a registration dossier which must be submitted to the European Chemicals Agency (ECHA). ECHA checks that the registration dossier complies with the REACH regulation and must approve the manufacturers' test proposals and ensure that they are limited to what is strictly necessary and sufficient.

Such a process is quite complex and expensive. So, in the case of articles which contain chemical substances and mixtures of substances, it is of importance to check whether these articles are "articles" or "associations of article and substance". REACH gives some help to manufacturers and importers by considering that the function of a product is "determined by what its producer/supplier wants it to be used for and what the person acquiring it expects it to do". As a consequence, the first step is always to use such understanding of the function of an article to determine it. Such determination must be thoroughly carried out and clearly justified.

In its "Guidance on requirements for substances in articles" (RIP 3.8), ECHA provides complementary tools to complete such determination process and, for "borderline cases" – meaning cases for which the function of the article cannot reliably lead to a decision on whether the article is an "article" or an "association of article and substance" – flow charts and examples of application.

REACH and Fireworks

Among the examples given in the last version of its "Guidance on requirements for substances in articles" (RIP 3.8), ECHA mentions fireworks, considers they are articles that "explode and make colours" and, from such understanding of their function, concludes that they are associations of articles and substances.

A group of experts who developed European harmonized standards for fireworks under a mandate of the European Commission firmly expressed their disagreement with such a conclusion and then, at its plenary meeting of July 2nd, 2014 the technical committee of CEN (the European Standardization Committee) – CEN/TC 212 – in charge of the development of those standards decided to activate a task group to prepare a road map to promote its position regarding fireworks as articles according to REACH, instead of associations of articles and substances.

As far as the function of a product is "determined by what its producer/supplier wants it to be used for and what the person acquiring it expects it to do", the function of a firework is undeniably to generate an artistic visual and/or aural effect in the air, on the ground, on the surface of water or underneath it, and during a given time.

The artistic visual effects are not only based on a varied set of colours, but also on the various luminous shapes which are traced either (1) by burning objects ("stars") and incandescent slag particles ejected from the fireworks or (2) by the flames and/or showers of sparks and hot gases projected from the fireworks. In the first case, combustion is initiated inside the firework casing and proceeds outside; in the second case, combustion remains strictly internal.

If colours are undoubtedly important, it is mainly the variety of luminous shapes and modulated sounds which makes fireworks shows attractive and answers the creative needs of firers. A fireworks show which was solely based on the use of coloured shells would be particularly monotonous, even with a high intensity of firing. Then, one must consider the fact that firers will first choose the fireworks for the shape and extension of the visual effects which will be traced in space and time in the air, above the ground or the surface of water.

Colours depends on the chemical formula of the pyrotechnic composition, but the shape and extension of the visual effects result from the specific design of the firework and/or the shape and surface of the pyrotechnic units (e.g. stars) contained in the firework.

Firstly, the shape (spherical, cylindrical, tubular, etc.) stars are given by their manufacturing process (rolling, pressing, casting, extrusion, etc.) allows these unitary effects to burn regularly with a stable colour and/or constant tracing tail. In the same manner, "crossette" effects are obtained by stars which are given a specific shape so that they burn and break abruptly after a few seconds into fragments which trace a cross-like figure in the air.

Without being compacted to these typical shapes, pyrotechnic compositions would exhibit a violent and erratic burning and even deflagrate in a great number of cases. Colours would quickly tend to turn white due to the high temperature of the flame which would inevitably be a consequence of the strong increase of the burning rate.

Secondly, it is the manner in which stars are arranged, clustered and/or disassociated inside the shells which leads to such varied shapes in the air as a dahlia, a peony, a ring, a heart, a cross, etc... or a combination of those.

Similarly, as concerns aural effects, a maroon only gives a report when its composition is kept within its casing during a sufficiently long time after ignition to reach deflagration and if its ignition charge is sufficiently powerful. A cracker only bangs when its composition is tightly confined by its cardboard casing. If not, the composition of maroons and crackers will simply make a puff and a part of it will be dispersed without being ignited.

The design is even more important for pyrotechnic whistles where the burning composition generates no sound if it is not charged into a tube in such a specific manner that it is stimulated as an organ pipe. Similar dependence on design is observed for other aural effects like humming or crackling.

More generally, colours and sounds can be generated by means of a large variety of pyrotechnic compositions the chemical formulas of which may be very different. But none of them can burn in such a way that it gives its visual or aural effect if it is not used with an appropriate design of product.

It is in fact this appropriate design which makes a shell spread its stars in multiple trajectories to trace a flower, a ring, a rainfall, etc. in the air whatever the colour and then the chemical formula of the pyrotechnic composition, and which differentiates it from a fountain, a mine, a Bengal flame, a roman candle...

It is only its design which makes a fountain throw a shower of sparks as a water fountain or waterfall does, which a shell will never do. And happily a fountain does not explode when it is correctly manufactured!

It is again because of its design a roman candle generates a sequence of varied and possibly different effects or a mine throws a powerful narrow or fan-type jet of burning stars, etc...

To conclude, it is mainly the design of fireworks which assures the variety of effects and makes possible the high number of their artistic space-time combinations which characterize fireworks shows.

All the above arguments lead the experts of CEN/TC 212 to conclude that, **from the point of view of REACH, fireworks are – in their large majority – articles and not substances in special containers. This statement means they are given a specific shape, surface or design which determines their function to a greater degree than does their chemical composition.**

Generic types according to the European harmonized standards for fireworks

When they developed the European Standards for Consumer and Professional Fireworks, the experts of Working Groups 1 and 2 of CEN/TC 212 had to differentiate fireworks in *"sets of articles with a common, very general, design feature and/or with a common characteristic effect"* to characterize their impact on public and users safety. They named these sets by the term "generic types" and deducted from the general essential safety requirements of the European Directives 2007/23/EC and 2013/29/EU specific requirements for such generic types.

All the differences between generic types are based on design and performance characteristics, never on chemical formulations and peculiarities.

As authorized by the Directives 2007/23/EC and 2013/29/EU, they also considered the interest of grouping "pyrotechnic articles that are similar in design, function or behaviour" in product families which could be submitted together to type-examination and testing. Colours have only been considered as variants within a family, but not as a distinctive parameter influencing the safety approach required by the above-mentioned Directives.

All generic types of fireworks have then very different respective designs. These designs are unique for a given generic type; on the contrary, a given colour can be generated by various pyrotechnic compositions and their corresponding chemical formulas may differ significantly. This observation reinforces the conclusion according to which the design of fireworks is generally more important than their chemical composition.

Previous attempt to prove fireworks are articles according to REACH

In 2010, the European Commission started a public consultation regarding the review of the scope of REACH according to its Article 138, No. 6:

"By 1 June 2012 the Commission shall carry out a review to assess whether or not to amend the scope of this Regulation to avoid overlaps with other relevant Community provisions. On the basis of that review, the Commission may, if appropriate, present a legislative proposal."

In the same year, a group of experts of CEN/TC 212 WG2 examined the possible overlaps between REACH and the European Directive 2007/23/EC and prepared a document to bring to light such overlaps. This document was accompanied by an annex which demonstrated thoroughly that most pyrotechnic articles – and, among them, fireworks – were articles according to REACH and should not be considered as packaged substances.

The document and its annex were sent together on November 30th, 2010 by CEN/TC 212 to the Head of

Unit “Chemicals and nanomaterials” of DG Environment D3, the Head of Unit “Chemicals – REACH” of DG Enterprise and Industry G1, the Head of Unit “Chemicals - Classification & Labelling, Specific Products, Competitiveness” of DG Enterprise and Industry G2 and the Executive Director of the European Chemicals Agency. At the same time, they were posted on the ReachScope web link that was opened to gather all the documents contributing to the review of the scope of REACH.

The answer of the European Commission came on March 22nd, 2013 with the following conclusions:

“The Commission has concluded that REACH functions well and delivers on all objectives that at present can be assessed.

Some needs for adjustments have been identified, but balanced against the interest of ensuring legislative stability and predictability, the Commission will not propose any changes to the enacting terms of REACH.

There is a reference to pyrotechnic articles in the accompanying Commission Staff Working Document:

Pyrotechnic articles: The Commission services concluded that certain pyrotechnic articles, considered as mixtures under REACH, might be subject to a double regulatory burden, at least as far as communication of the information in the supply chain is concerned. In such a case both obligations under REACH and under the Pyrotechnic Articles Directive5 would apply at the same time. According to the current ECHA guidance on requirements for substances in articles, a majority of pyrotechnic articles should be regarded as packaged mixtures, whereas they are regarded as articles by the technical experts in the responsible CEN Technical Committee (TC 212) and also by some competent authorities of the Member States. The Commission services will investigate whether this issue requires specific action, including, in particular in the Guidance on requirements for substances in articles.”

In parallel, ECHA only acknowledged receipt of the document and its annex, but never replied to it nor changed their guidance on requirements for substances in articles.

The European Commission has not yet started the investigation that is mentioned in the last sentence of its conclusions but, in a recent letter to the European Fireworks Association (EUFIAS), it has declared its intention to do so before the end of 2015 and to organize a meeting between some professional experts and ECHA in its presence. To prepare this meeting, it has asked for more information about the present situation of fireworks versus REACH in the various Members States of the European Union and for a more detailed presentation of the arguments developed by the professional experts.

The experience of military ammunition

REACH is based on the principle that the downstream manufacturers, importers and users have an obligation to manufacture, to market and to use substances whose hazardous effects for human health or the environment are correctly controlled. According to REACH itself, the evaluation of these hazardous effects is therefore now the responsibility of the manufacturers and importers concerned (and not the States as under the previous system).

REACH introduces an unprecedented change in the way information is exchanged on the substances throughout the supply chain. Each actor must now reinforce the traceability of the substances he uses and ensure that its uses fall within the exposure scenarios taken into account by the suppliers.

It is then the responsibility of the manufacturers or importers to determine whether the public and the users of their products are exposed to the hazardous effects of the substances that are included in the products they place on the European market.

Having understood this main transfer of responsibilities from the States to the economic actors and to ensure that REACH is uniformly applied in the ammunition field (including rockets and missiles), the French defence manufacturers decided to write a **professional guide** in which they would give their evaluation of the possible chemical hazards linked to the substances included inside their products and show their common agreement on the status of the different types of ammunition regarding REACH.

Such a professional guide would be the reference document for the whole of the ammunition profession acting in a coherent and cohesive manner with respect to all third party requests. It might, if necessary, be presented as a supporting document during controls by the French Administration, as well as to insurance companies and customers who would request it.

A group of experts coming from the French defence industry started discussions in October 2008, in the presence of representatives of the French Ministry of Defence, and published their guide in November 2009. A second edition appeared necessary to include new types of ammunition and follow some significant modifications of the ECHA “Guidance on requirements for substances in articles" (RIP 3.8); it was published in April 2013.

The professional guide starts from the function of every type of ammunition and shows that the function of most of them is determined by their specific shape, surface or design to a greater degree than does their chemical composition. According to REACH, such products are articles and not associations of article and substance.

Some few articles that intentionally reject chemical substances without transformation were identified and treated as borderline cases according to the flowcharts of the ECHA "Guidance on requirements for substances in articles". Indeed, such articles were considered as associations of articles and substances according to REACH. Doing so, the professional guide of the French Defence Industries shows that their conclusions were not based on preconceived opinions, but fair and thorough analysis of the function of every type of ammunition as expected by the Armies acquiring it.

The French Ministry of Defence has accepted this professional guide and promoted it within the European Defence Agency (EDA). Its translation in English was circulated to the Defence Industries and Ministries of the other European countries and they decided at a very large majority (and unanimously by the community of industrialists) to make it their reference guide for ammunition, whatever ECHA may think of it. EDA's position was eventually supported by the European Commission.

Why not follow the same approach for fireworks?

Work proposal

The Task Group "REACH and fireworks" which CEN/TC 212 activated on July 2nd, 2014, and EUFIAS have decided to combine their efforts to **write a European professional guide for fireworks** by analogy with the above example of military ammunition.

Such a professional guide should be supported by all national and European associations of manufacturers and importers as well as notified bodies. These associations and notified bodies are then invited to participate in the writing of that guide either directly during specific meetings or by reviewing its successive drafts, making comments, modifications and additions (where appropriate).

The generic types that are defined by the European harmonized standards for consumer and professional fireworks will serve as a basis for the technical analysis of functions versus shape, volume, design and chemical composition. It is foreseeable with a high confidence level that such analysis will show that the functions of most generic types are more determined by the three first characteristics than the fourth one.

This guide will also include specific application of the flow charts of the ECHA "Guidance on requirements for substances in articles" to each generic type of fireworks, in order to confirm the conclusion that is suggested by its function regarding its status as "article" or "association of article and substance" and then to prevent any critic for not having considered fireworks as "borderline cases".

After completion, this professional guide will be sent to the European Commission so that it decides to give mandate to CEN/TC 212 and ECHA for "*specific action, including, in particular in the Guidance on requirements for substances in articles*". The Task Group "REACH and fireworks" of CEN/TC 212 and EUFIAS already informed the European Commission that such a professional guide will be part of the documents which will be submitted to discussion at the meeting to be planned by the European Commission by the end of 2015

A first meeting will be planned in Paris at the beginning of September 2015 to review a first draft of the professional guide for fireworks. Any European who is interested in taking part in this meeting is invited to send his/her application to the convenor of the Task Group at the following e-mail address pthebault@pyroconsultant.com

Notes and references

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6. European Standard EN 16262-1:2012, Pyrotechnic Articles, Fireworks, Category 4, Part 1: Terminology.

Firework Salute Sound Characteristics and Perception: Background and Theory

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Abstract: The aesthetics of the sound produced by exploding firework salutes is not well addressed in the scientific literature. This paper presents a brief summary of what is known about impulse sounds as it may apply to exploding firework salutes. Also included are three hypotheses relating to the aural and physical perception of such sounds by humans, in the hopes that someone will test and expand on them.

Introduction

In most instances, the sound accompanying an explosion is a nuisance, an undesirable consequence of using explosives to do work. However, in fireworks, the sound from an explosion is often the primary effect being sought; and it is sought for its entertainment value; one might even say, for its aesthetic value. Accordingly, the acoustic characteristics of the air-blast waves produced by fireworks and how they are perceived by the audience are important. Unfortunately, the aesthetic quality of blast waves is a subject that has not been well reported in the scientific literature. It is the authors' hope that this discussion of the human perception of the sound produced by exploding firework salutes may stimulate a scientific investigation of the subject.

Background information

The explosive sound produced by a salute is technically referred to as an impulse sound because it is an event of very short duration. Figure 1 is an illustration of an idealized blast-pressure wave from an explosion.

An air-blast wave is a shock wave; as such, it travels faster than the speed of sound in air. Prior to the arrival of the leading edge of the blast wave at the location of the observer, there is no deviation from ambient atmospheric pressure (i.e., there is no precursor to the sound of the explosion). Upon arrival of the blast wave, there is a near instantaneous jump in air pressure from ambient to

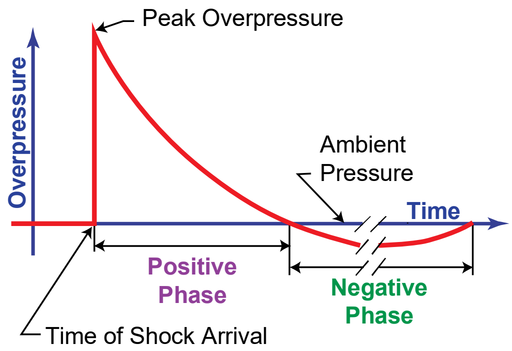

***Figure 1**. Illustration of an idealized air-blast wave from an explosion.*

the peak overpressure of the blast wave. Thereafter, the pressure returns relatively slowly, but still quickly, back to ambient air pressure. This first portion of the blast wave is referred to as its positive phase, and it lasts approximately 0.1 millisecond for a 1½ inch (38 mm) firecracker at close range (i.e., roughly a few feet or a meter), to approximately 3 milliseconds for a 3 inch (76 mm) aerial salute at typical spectator distances (i.e., roughly a few hundred feet or a hundred meters). Following the positive phase, there is a negative phase, which, at close range, is much less extreme in magnitude, but it lasts somewhat longer than the positive phase. For powerful explosions, there may be another much weaker positive phase following the negative phase. Figure 2 shows the blast wave recorded from an exploding 3 inch (75 mm) test firework salute at a distance of 4 feet (1.2 m), with the salute suspended and the air-blast detector mounted approximately 5 feet (1.5 m) above the

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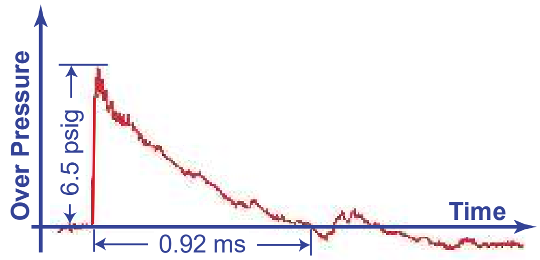

Figure 2. *Example of the air-blast wave from a 3 inch test salute recorded at a distance of 4 feet.*

ground. (The detector used in this and the other salute examples was a free-field piezoelectric blast gauge aimed directly at the exploding salute. The units of overpressure in this and the other salute examples is pounds per square inch gauge (psig), which is the pressure above ambient atmospheric pressure, where 1 psig corresponds to 6.89 kPa overpressure. The data were recorded using a digital oscilloscope.)

Air-blast waves from all explosions have a similar shape. For detonations, the reaction rate of the explosive charge is sufficiently high to immediately produce a shock wave in air. For deflagrations and mechanical explosions, air shock waves are often produced as the result of the process sometimes described as 'shocking-up'. This process is illustrated in Figure 3.[1a]

Any sufficiently great pressure pulse in air, regardless of its initial shape (e.g., see 'Initial' in Figure 3), will naturally evolve into a shock wave, which is explained as follows. All parts of the pressure pulse move away from the source at the speed of sound. However, the high-pressure pulse compresses the air, with the higher pressure portions of the pulse compressing the air to a greater extent than the lower pressure portions of the pulse. The act of compressing the air results in its momentarily being heated to a higher temperature, where the extent of the heating is a function of the amount of compression. Because the speed of sound increases with temperature, this means that the higher pressure portions of the pulse travel at a greater speed than the lower pressure portions of the pulse. This has the effect of the higher pressure portions of the pulse starting to catch up to the leading lower pressure part of the

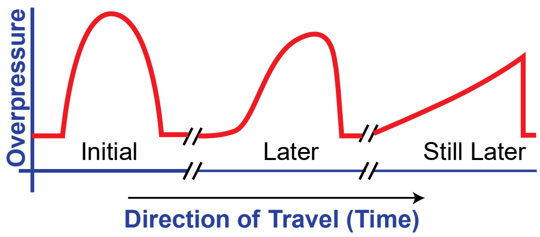

Figure 3*. Illustration of the 'shocking-up' process for a high-pressure pulse in air.*

pulse (see 'Later' in Figure 3). This process continues until the pressure pulse has transformed itself into a shock wave with the standard shape (see 'Still Later' in Figure 3).

As an acoustic wave propagates away from its source, it experiences attenuation, the total of which (A_t) can be considered to be the sum of the three sources of attenuation.[2]

$$A_t = A_s + A_a + A_e \qquad (1)$$

Here A_s, described as the geometric spreading attenuation, is simply due to the air-blast wave spreading out geometrically as it expands in the atmosphere. The second term, A_a, described as the atmospheric absorption attenuation, is a function of the thermodynamic properties of the atmosphere, which affects most strongly the higher frequency components of the blast waveform. For example, under the atmospheric conditions of 1 atm (14.7 psi) pressure, a temperature of 20 °C (68 °F) and 50% relative humidity, the atmospheric attenuation coefficients for sounds of 125, 500, 2000 and 8000 Hz are 0.445, 2.73, 9.86 and 104 dB/100 m, respectively.[2] The third term in Equation 1, A_e, is the attenuation from everything else, including ground effects.

While a blast (i.e., shock) wave is not strictly an acoustic (i.e., sound) wave, blast waves too experience similar attenuation as they travel away from their source (and blast waves do eventually degrade into acoustic waves). For example, blast waves also experience geometric spreading attenuation (A_s) and atmospheric absorption attenuation (A_a). There is, however, a significant difference in the atmospheric absorption attenuation of blast waves, for as long as they remain shock waves. The attenuation of the high frequency components (in a Fourier sense) can be

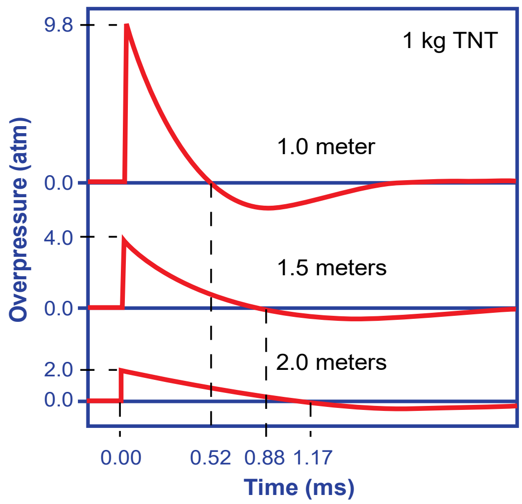

Figure 4. *Illustration of the attenuation of a powerful air-shock wave over a very short distance.*

significantly offset by the continuing 'shocking-up' process.

The net effect from these sources of attenuation is for the peak overpressure to rapidly decrease and the duration of its positive phase to increase. This is illustrated in Figure 4, even for very short distances from an exploding 1 kg charge of TNT.[1b] (In this figure, time zero was set to correspond to the arrival of the blast wave at the location of the recording blast gauge.)

Figure 5 illustrates the air-blast wave from an exploding 3 inch (75 mm) firework salute recorded at a distance of 370 feet (110 m). The salute was suspended, and the air-blast detector was mounted approximately 5 feet (1.5 m) above the surface of the ground. (Again in this figure, time zero was set to correspond to the arrival of the blast wave at the location of the recording blast gauge.)

Comparing Figures 2 and 5, note the great reduction in peak overpressure, 6.5 psig (45 kPa) versus 0.046 psig (0.32 kPa). Also there is an increase in the duration of positive phase, 0.9 ms versus 3 ms. In addition, the magnitude of the negative phase in Figure 5 is increased relative to its positive phase, giving this blast wave somewhat more nearly the appearance of a single cycle of a sine wave. It is thought that this is an indication that the initial air-blast wave has substantially degraded from a shock wave into a sound wave. Eventually, as air-blast waves propagate even farther from their source, they lose much of the sharpness of their leading edges.

Probably the most important characteristics of a salute, as heard by the audience at a firework display, are its loudness, its tonal quality (mellow boom versus a sharp crack sound), and the physical sensation as felt by spectators (what is sometimes described as a 'chest thump'). Each of these characteristics is a subjective response to the air-blast wave as perceived personally by spectators.

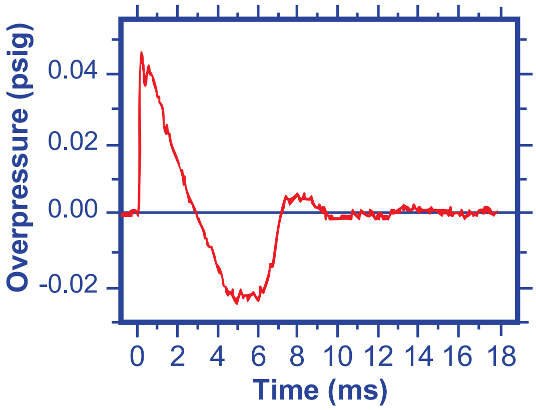

Figure 5*. Example of air-blast wave recorded at a distance of 370 feet from a 3 inch firework salute exploded near ground level.*

As subjective responses, they are not amenable to direct physical measurement using scientific instruments. For that reason, in the research of the perception of salute sounds, it is necessary to include human observers, during testing, to provide their personal ratings of the characteristics of salute sounds. Additionally, during testing, measurements using scientific instruments are needed to define the physical parameters of the sounds to which the panel of human observers are exposed. In that way, it should be possible to correlate the perceived responses of the test subjects to a range of air-blast waves of differing physical parameters. In the text that follows, the three characteristics of salute explosions will be considered in somewhat more detail.

Loudness

Sound pressure level (SPL) is measured in decibels (dB) and is related to the pressure (P) of a sound wave, in comparison with a reference sound pressure (P_0), as indicated in Equation 2.[3]

$$\mathrm{SPL} = 20 \log_{10} (P/P_0) \qquad (2)$$

In Equation 2, for the purpose of this discussion, P_0 is the standard reference pressure of 0.0002 microbar (root mean square). This reference pressure is generally accepted as the minimum audible sound for humans at 1000 Hz.[3] When converting to pressures measured in pounds per square inch, P_0 becomes 2.9×10^{-9} psi, and Equation 2 can be rewritten as,

$$\mathrm{SPL} = 170.8 + 20 \log_{10} P \qquad (3)$$

At the reference frequency of 1000 Hz, over the range of intensity from the threshold of hearing to the threshold of feeling, sound pressure levels in decibels are arbitrarily set equal to 'loudness levels' (L_N) with the units of phons[3], i.e.,

$$L_N \text{ (in phons)} = \mathrm{SPL} \text{ (in decibels)} \qquad (4)$$

Over the range of loudness level from 40 to 100 phons, 'loudness' (N), with units of sones, as perceived by human subjects under ideal conditions, is related to loudness level as shown in Equation 5.[3]

$$\mathrm{Log}_{10} N = 0.03 (L_N) - 1.2 \qquad (5)$$

By substitution from Equation 4,

$$\mathrm{Log}_{10} N = 0.03 (\mathrm{SPL}) - 1.2 \qquad (6)$$

Then solving for 'loudness' (N, in sones),

$$N = 10^{(0.03)(\mathrm{SPL}) - 1.2} \qquad (7)$$

Loudness is expressed in a linear scale, such that at the reference frequency of 1000 Hz, a sound with a loudness (N), which is twice that of another sound, is heard (i.e., perceived) to be twice as loud by a typical observer under ideal conditions. In terms of decibels (at the reference frequency of 1000 Hz and in the range from 40 to 100 dB), each increase of 10 dB corresponds to a doubling of the loudness of the sound. Accordingly, from Equation 7, sounds of 40, 50 and 60 dB will be perceived as having loudness (N) of 1, 2 and 4 sones, respectively.

At typical spectator distances (roughly 400 feet, 110 m), the sounds from firework salutes are substantially greater than 100 dB and are not even remotely close to pure 1000 Hz tones. Thus, test subjects are likely to respond differently than the above theory suggests. Nonetheless, as a hypothesis for testing, one might start by assuming that the perception of even these very loud impulse sounds follows the same general relationships described above. Indeed, if that were the case, it would be relatively easy to characterize the perceived loudness of the sounds of salutes (as a function of distance from the source), using data recorded with standard sound measuring instruments.

Tonal quality

For non-impulse sounds of sufficient duration, the frequency of the wave form fundamentally determines the tone or pitch of the sound, with high frequencies being heard as high-pitched sounds and low frequencies heard as low pitched sounds. The reciprocal of frequency is the 'period' of the wave, which is the time duration of one complete air-pressure cycle of the sound wave. Thus, for non-impulse sounds of sufficient duration, short period (i.e., high frequency) sounds are heard as being high pitched, whereas long period sounds are heard as being low pitched.

Even for pure tones, the sound must persist for some interval of time before its pitch will be perceived by a human observer. If the sound persists for only a very short time, it will be heard simply as a 'click', devoid of any sensation of pitch.[4a] If the tone persists a little longer, it will still be heard primarily as a click, but now with at least some minimal tonal quality (i.e., perceived as a somewhat high or low pitched click). The length of time that the tone must persist for it to begin to be perceived as having some tonal quality is called the 'click-pitch threshold', and that length of time depends on the frequency of the tone. Table 1 presents information on the approximate click-pitch threshold times for pure tones of various frequencies (the table values are derived from data in reference 4a). Note that, while the number of cycles the tone must persist for it to have some perceived tonal quality decreases for lower frequency tones, the corresponding required time duration that the tone must persist increases.

Table 1. *Approximate 'click-pitch threshold' for various frequency tones*[4a]

Frequency (Hz)	Period (ms)	Click-pitch threshold (ms)	Number of cycles
2000	0.5	3.5	7.0
1000	1.0	3.5	3.5
500	2.0	6	3.0
250	4.0	11	2.7
125	8.0	18	2.2

Based on the air-blast wave form shown in Figure 5, the period of the wave (i.e., the time duration of its positive plus negative phases) is approximately 7 milliseconds, corresponding to a frequency of approximately 140 Hz (i.e., 140 cycles per second). Using the information in Table 1, the click-pitch threshold for such a sound requires a duration of approximately 16 milliseconds (or roughly 2.3 cycles) for there to be a perceived tonal quality to the sound. Accordingly, essentially no tonal quality would be expected for the blast wave from the explosion recorded in Figure 5. However, to the contrary, as a matter of common experience, there is at least some minimal perceived tonal quality associated with such explosions. For example, consider the sound produced by two explosions occurring near ground level. The first is the explosion of a standard 1.5 inch (38 mm) firecracker at a distance of several feet (roughly 2 m), and the second is the explosion of a 3 inch (75 mm) salute at a distance of a few hundred feet (roughly 100 m). Both explosions will produce an air-blast wave of roughly 0.05 psi (0.34 kPa) peak overpressure. However, the period (the duration of positive plus negative phases) of the salute's blast wave will be approximately 35 times longer than that of the firecracker (roughly 7 ms versus 0.2 ms). Certainly there is a perceived tonal difference between the sounds of the two explosions, with the salute explosion sounding much more mellow than the firecracker. Almost certainly the difference in tonal quality of these two explosions is the result of the great difference in the periods of their air-blast waves, even though both are less than the click-pitch threshold.

It should be noted that when salutes explode high in the air and the observer's ear is several feet (roughly 2 m) above the ground, there will be a significant delay between the arrival time of the air-blast wave coming directly from the salute and the arrival time of the same blast wave after its having been reflected off the ground. This produces an overall effect of the blast wave going through what appears to be two cycles rather than only one. Figure 6 is the recorded blast wave from a test salute exploding approximately 400 feet (120 m) in the air with the sound detecting instrument positioned approximately 5 feet (1.5 m) above the

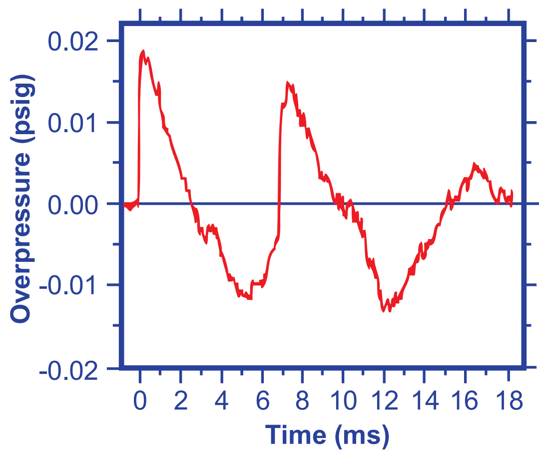

Figure 6. Example of an air-blast wave recorded a few feet above the ground, from a salute exploding high in the air.

ground. In this case, the total duration of the blast wave is approximately 16 milliseconds, thus approximately equalling the click-pitch threshold for an approximately 140 Hz sound.

There is another potential complicating factor with respect to the perception of salute sounds. For non-impulse sounds, there is an interrelationship between the perceived loudness and the perceived pitch of those sounds. Specifically, loud tones less than roughly 1500 Hz are perceived to have slightly lower pitches, while loud tones greater than roughly 1500 Hz are perceived to have slightly higher pitches.[4b] Thus, in salute testing, there may be some degree of interplay between a spectator's perception of loudness and the tonal quality of exploding salutes.

It can be assumed that the combined duration of positive and negative phases of an air-blast wave is analogous to the period of a repeating wave form. Despite the duration of the impulse sounds from salutes often being less than the click-pitch threshold, as a test hypothesis, and with all else being equal, impulse sounds with long phases can be anticipated to be heard as somewhat more 'mellow booms', as compared with short phase sounds, which are expected to be heard more nearly as 'sharp crack' sounds.

Physical sensation

The physical response of an object to air-blast pressure waves depends on peak overpressure, the duration of positive phase, and the 'critical time' of the object (which can be estimated to be one quarter of the reciprocal of resonant frequency of the object[1c]). When the duration of positive phase is much longer than the critical time of an object, the physical response of that object is approximately proportional to the air-blast wave's peak overpressure, whereas, when the duration of positive phase is shorter than the critical time of an object, the response is approximately proportional to the blast wave's pressure impulse (i.e., the area under the pressure *versus* time blast wave curve). In the case of the human body, it would seem that the duration of the positive phase of a salute sound is likely to be shorter than the critical time of most of one's more massive body parts. Thus, as another test hypothesis in a study of the perception of salute blast waves, it can be presumed that the physical sensation felt by the observers will correlate with the pressure impulse of the blast wave. That is to say, for two equally loud sounds, the one with the longer positive phase will be felt by observers to produce a greater pressure sensation (i.e., chest thump).

Conclusions

In summary, three possible hypotheses for a study of salute sound perception by humans are:

1. The perceived loudness of a salute sound will approximately follow Equation 7, above.
2. For salute sounds of approximately equal loudness, those with a longer phase duration will be heard as being more mellow in tonal quality.
3. For two salute sounds with the same peak overpressure, the one with the longer positive phase will be felt by observers to produce a greater blast-pressure sensation (i.e., chest thump).

Acknowledgements

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Flame Projectors for Show Effects – Investigations of Thermal Radiation for Assessing Safety Distances

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Abstract: The use of flames as part of shows is state of the art. Besides pyrotechnic flame projectors, the use of projectors that produce flames by burning various gases, liquids and dusts is significantly increasing. In this study infrared radiation in the wavelength range from 7.5 to 14 microns was measured for several systems (flame projectors) and set in relation to known human pain threshold levels. From this relation safety distances been determined for a static scenario (audience watching show) and compared with those of approved pyrotechnic articles.

Introduction

When flames are assessed with regards to the setting of safety distances at stage and music shows usually only visual dimensions of the flames in combination with a safety margin are taken as the basis for the determination of the corresponding safety distances. This refers to pyrotechnic article effects as well as for flames generated by the combustions of flammable gases, fluids and non-explosive solids (dusts, e.g. Lycopodium or cork dust).

The generation of flames is associated with the emission of thermal radiation, which is the predominant key factor in the hazard analysis for spectators and actors on stage, as well.

The thermal radiation of the projectors was measured and set in relation to the processes known from the human pain threshold levels. From these relations safe distances for a static scenario were finally confirmed by a test person.

Background

The hazard of thermal radiation has been treated in various studies regarding labor safety and accident simulations. However, different values of human pain threshold levels are reported. The thermal radiation dose, i.e. consideration of the exposure time as well, is more suitable for an assessment of hazards to persons by the consideration of flame projectors. In this study, the thermal radiation dose and the pain threshold or the limit for the time-independent thermal radiation from ref. 1 are considered as a reference.

From the different critical irradiances for humans, documented in the literature, the following were used as a reference:

Maximum irradiation (independent of time) $q = 1.7$ kW m^2 [ref. 1]

Pain threshold for a contact time of 3 sec $q = 12.6$ kW m^2 [ref. 2]

The draft standard prEN 16263-3: 2012 (other pyrotechnic articles according to 2007/23/EC and 2013/29/EU)[3] gives a limit on the thermal radiation for the assignment of articles to the category P1 of $D \leq 125$ [(kW/m^2)$^{4/3}$ * s] at reference time ≤120 s or $q_m \leq 1, 0$ kW m^{-2} at a reference time >120 s (where q_m is the thermal radiation at the safety distance and D is the thermal radiation dose).

The calculation of the thermal radiation dose was performed according to ref. 3 according to the following formula:

Thermal radiation dose $D = q^{4/3} * t$ (1)

Where D = thermal radiation dose (kW s m^{-2})

q = thermal radiation (kW m^{-2})

t = duration (s)

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Measurements

The measurements to determine the thermal radiation were carried out by using an infrared camera (VarioCam®HD, company InfraTec) with the following technical specification:

- Spectral range: : 7.5–14 µm
- Infrared frame rate 30–240 Hz
- Temperature range −40 to 2000 °C
- Thermal resolution: 0.05 K
- Measurement certainty:
  - ± 1.5 K (0–100)°C;
  - 1.5 % (<0 and >100)°C

The experiments were performed in an indoor venue of sufficient dimensions to realize air interchange but also minimize any influence of weather conditions.

The study included several pyrotechnic flame projectors (pyrotechnic articles for stage use with a national German approval) and the following non-pyrotechnic projectors which use different media to produce flames:

- Gas – propane (flashpoint 97 °C); Figure 1
- Liquid – Isoparaffin (flashpoint 62 °C min.), Figure 2
- Solid – lycopodium (particle size range of about 35 microns, bulk density 300g dm^{-3}, tetrahedral shape), Figure 3.

For all flame projectors the lifetime and heights of the flames were measured during investigations depending of the performance spectrum of the flame projectors.

In the case of gas systems, the number of simultaneously used nozzles (projectors and corresponding flames side by side) was varied up to four.

***Figure 1**. Flame projector (gases, propane).*

***Figure 2**. Flame projector (liquid, Isoparaffin).*

***Figure 3**. Flame projector (solid/dust, lycopodium).*

For the evaluation or comparison of the thermal radiation values, the maximum values (hot spot) and the data related to the whole radiation area values were determined for each measurement. For the assessment of the hazards, the maximum value (hot spot) of thermal radiation was the focus of this study.

For further interpretation of the generated values the emission factor plays a key role and must be determined for each material that is investigated. A material-related assignment of an emission factor to any flame is difficult and often not sufficiently precise. For this study, an emission factor of 0.90 was used as an average and basis due to the lack of further analysis of the flame compositions.

***Table 1**. Radiation data from flame projectors at 15 m distance*

Flame projector type	Max. thermal radiation q_{max} (kW m^{-2})	Max. thermal radiation dose D_{max} (kW s m^{-2})
Propane	0.8–1.2	0.87–3.66 (4.19 for 4 parallel flames)
Isoparaffin	0.9–1.3	0.95–2.24
Lycopodium	1.2–1.4	1.67–2.65
Pyrotechnic flame projector no. 1	0.9	0.50
Pyrotechnic flame projector no. 2	0.8	1.85
Pyrotechnic flame projector no. 3	1.4	3.20
Pyrotechnic flame projector no. 4	0.9	0.34
Pyrotechnic flame projector without any approval	1.1	0.56

Results of thermal radiation measurements

Table 1 summarizes the results measured at 15 m distance to the single flames regarding the thermal radiation and the calculated thermal radiation doses (radiation multiplied by its exposure time). For propane, the results are given separately with four parallel flames.

Table 1 reveals that the range of the maximum thermal radiations for projectors with gas and isoparaffin are comparable. Considering the thermal radiation dose the influence of system parameters is seen more clearly.

For the propane flame projector the differences between the thermal radiation dose of the single flame and the four parallel flames are quite small. This is due to the fact that the thermal spheres of the flames overlap only minimally. The resulting differences in the safety distance are shown in Table 3.

Human exposure limits to thermal radiation

Two fundamental approaches to determining the stress or pain thresholds regarding thermal radiation can be found in the corresponding literature: The limits of thermal radiation (irradiance/thermal flux) were determined by thermal radiation dose. The data from ref. 2 are used as examples for further considerations and are partly summarized in Table 2.

***Table 2**. Pain thresholds taken from ref. 2*

Radiation intensity q (kW m^{-2})	Temperature pain threshold (°C)	Exposure time t until pain threshold (s)
4.2	45.1	13
5.2	45.3	10
6.3	46.5	8
8.4	47.1	5.5
12.6	48.3	3

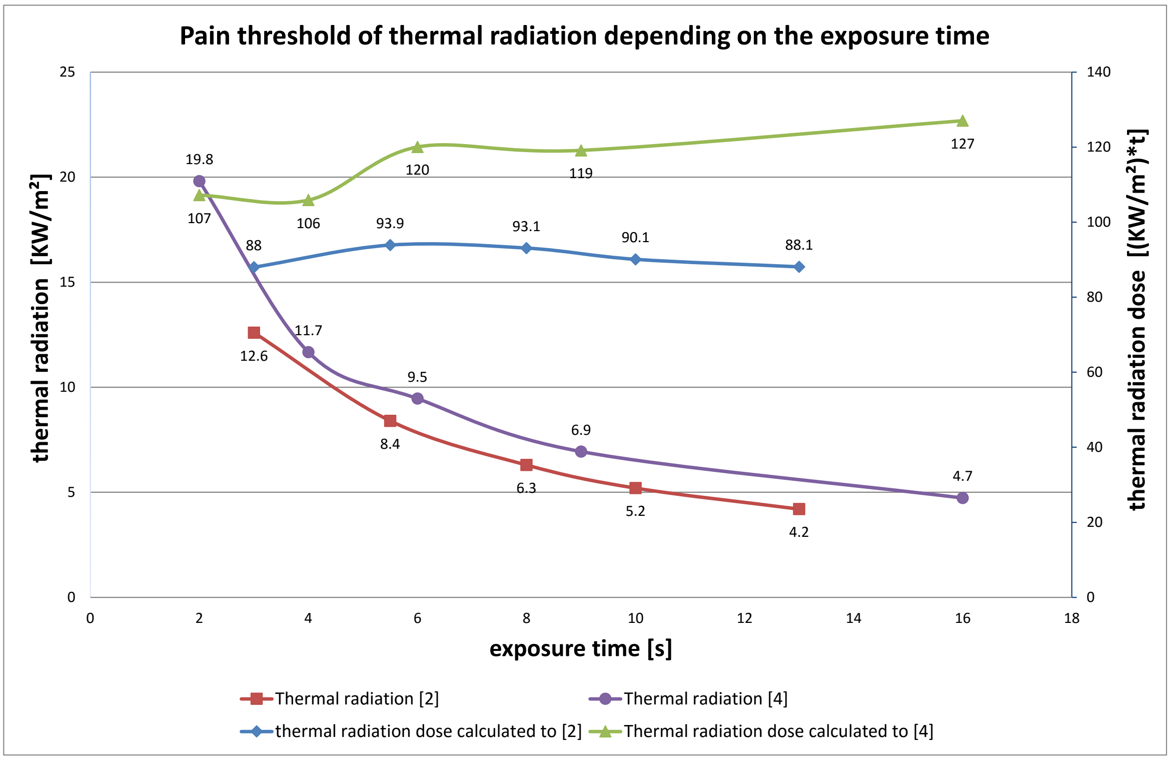
Figure 4 shows the relationship of the pain threshold for thermal radiation and exposure time of the flame (red curve). The blue curve represents the thermal radiation dose, which has been calculated from the thermal radiation values and the exposure times from ref. 2. The purple curve represents the thermal radiation from ref. 4. The green curve represents the thermal radiation dose, calculated from ref. 4.

It can be seen that the approach is sufficiently accurate, since the results in this graph (blue curve) can be seen as an approximately straight line (regardless of the exposure). The advantage of using the thermal radiation dose is that a fixed limit value can be set.

Assessment of safety distances

The pain thresholds were defined on the basis of thermal radiation limits given in ref. 1 with 1.7 kW m^{-2} and according to ref. 2 with 12.6 kW m^{-2}. The reference value of 12.6 kW m^{-2} with a contact time of 3 s (ref. 2) was chosen

***Figure 4**. Calculated thermal radiation (doses) from the literature (ref. 2 and 4)*



because the duration of the flame columns mostly lied between 0.5 and 4.0 seconds. Thus, a reasonable comparison is given.

For the determination of the safety distances on the basis of the thermal radiation dose taken from ref. 2, the average value of 91 kW s m^{-2} was used (see blue curve in Figure 4). This approach is conservative in terms of thermal radiation doses. Using the limits prescribed in ref. 3 or 4, the commitment averaged limits for the thermal radiation dose were calculated to be 125 kW s m^{-2} and respectively 117 kW s m^{-2}.

Starting from the assumption that the radiation decreases with the square of the distance, the safety distance may be calculated using the following formula:

$$r = \sqrt{\left(\frac{D}{D_G}\right) \times R^2} \qquad (2)$$

Where r = safety distance (m)

D = thermal radiation dose (kW s m^{-2})

D_G = pain threshold based on thermal radiation dose (kW s m^{-2})

R = measuring distance (m)

If using the approach according to ref. 1 with 1.7 kW m^{-2} (without regard to the exposure time) the safety distance r[a] of 12.5 m has been calculated.

According to the approach of ref. 2 with 12.6 kW m^{-2} and an exposure time of 3 s a safety distance r[b] of 5.0 m has been calculated for propane.

Substituting the linearized pain threshold of the thermal radiation dose of 91 kW s m^{-2} according to ref. 2 and the real lifetime of the flames, the result of real safety distance r[c].

A summary of the safety distances is shown in Table 3. These safety distances are based on the maximum thermal radiation or thermal radiation dose.

It should also be mentioned that the given maximum value of thermal radiation (hot-spot) has been adopted for the entire lifetime of the flame. As this is not the case in real terms, the calculated safety distances follow a conservative assessment.

On the base of thermal radiation dose, the influences of flame projector parameters on the safety distance are clearly recognizable.

Assessment of the calculated safety distances based on studies with a test person

The calculated safety distances based on the measured thermal radiation and ref. 1 and 2 were demonstrated with tests with a human test person.

__Table 3__. Summary of the calculated safety distances/maximum values with (2) (1 – only one measurement; 2 – four burner with maximum flame size and lifetime)

Flame projectors	Safety distances			
	$r^{[a]}$ (m)	$r^{[b]}$ (m)	$r^{[c]}$ (m)	Safety distance according to old BAM approval
Propane	12.5	5.0	3.0 3.5^{2}	
Isoparaffin	13.0	5.0	2.5	
Lycopodium	13.0	5.0	3.0	
Pyrotechnic flame projector no. 1	11.0	4.0	1.5	radial 2 m effect direction 3 m
Pyrotechnic flame projector no. 2	10.5	4.0	2.5	radial 2.5 m effect direction 3 m
Pyrotechnic flame projector no. 3	14.0	5.5	3.0	radial 3 m effect direction 5 m
Pyrotechnic flame projector no. 4	11.0	4.0	1.0^{1}	radial 8 m effect direction 40 m
Pyrotechnic flame projector without any approval	12.0	4.5	1.5	–

The thermal imaging camera was used to record the change in the skin temperature of the subject and the heat radiation of flame projectors. In addition to the detection of the surface temperature of the skin, the subjective feelings from the subjects were also documented.

All experiments were carried out with the uncovered torso of the test person.

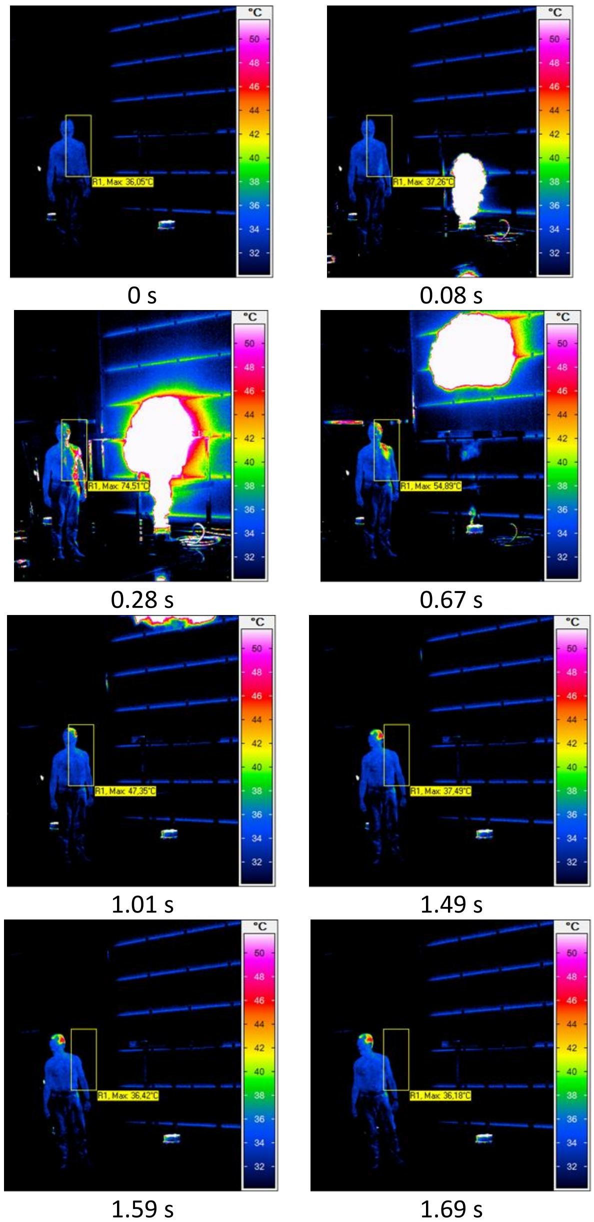
Under identical parameters, the flame projectors (propane, Isoparaffin and Lycopodium) and the distances between the flame and the subject were varied. As distances 5 m, 3 m, 2 m and 1 m have been selected. For each distance (with the exception that described next series) at least three experiments were carried out.

For illustration the following sequence of IR images from a series of tests with a propane flame and a distance between the test person and the flame of 1 m are used (Figure 5).

The thermal radiation dose of the flame was 1.3 kW s m^{-2} in this experiment. This would lead to a safety distance $r^{[c]}$ = 1.7 m. The calculated safety distance was much higher than the distance in this experiment, which was reflected by the feelings of the test person. The thermal radiation at this distance was perceived by the tester as clearly painful (permanent damage to the skin, however, was not observed thereafter). For this reason, the series was stopped after two attempts.

The listed maximum temperatures of the measuring field on the body in these frames show mainly the reflected thermal radiant from the skin. To assess the actual (deep) heating, the difference between the initial skin temperature and skin temperature must disappear after the flame exposure. After the disappearance of the flames an increase in temperature of 0.13 K was observed. The prolonged heating of the hair on the head of the test person to recognize the color detachment

__Figure 5__. Sequence of IR images at a distance of 1 m flame (propane flame)



(green–yellow–red), indicates a significantly better absorption of thermal radiation by hair/scalp/air. A stronger deterioration of this area has not been detected by the test person in the subjective perception. A slightly longer-lasting feeling of heat was observed by the tester.

By increasing the distance between the test person and the flame the thermal perception of the tester was significantly reduced.

To determine the effect of the number of flames on the acceptable pain feelings also a comparative study series has been carried out with one and four flames.

The thermal feeling when being exposed to four gas flames was only slightly more pronounced than with one flame. This perception was also reflected in the barely measurable difference in skin temperature immediately after extinguishing the flame.

The differences in the emitted thermal radiation doses between propane, Isoparaffin and lycopodium, as indicated in Table 1, also correspond to the subjective feelings of the test person. The propane gas flame is more easily perceived as "warmer".

Conclusions

Infrared radiation in the wavelength range from 7.5 to 14 microns of various systems (flame projectors) was measured and set in relation to known threshold levels of pain for persons from the literature. From this relation safety distances have been determined for a static scenario (audience watching show).

The results of this study show that the thermal radiation dose should be the basis for the determination of safety distances. The exposure time has an indisputable impact on the hazards. In this respect the specific limit of 91 kW s m^{-2} (ref. 2) is proposed as the basis for the calculation. The use of pain thresholds/limits based on thermal radiation values unrelated to the exposure time as described in ref. 1 are not suitable for the determination of real safety distances to flame projectors.

The effectiveness of the developed method for calculating the safety distance $r^{[c]}$ has been verified by studies with a test person. The safety distances thereafter determined reflect the subjective feelings of the test person. The method can be regarded as a useful means for calculating safety distances with regard to the effect of thermal radiation from flame projectors on persons.

Notes and references

The author himself was the human subject. The aim of the investigation was the development of national regulation in view of the heat radiation when flame projectors be used. All other national regulations were be fulfilled.

1 UBA Bericht “Ermittlung und Berechnung von Störfallablaufszenarien nach Maßgabe der 3. Störfallverwaltungsvorschrift“; Forschungs- und Entwicklungsvorhaben 297 48 428, Band 2, S. 194, Umweltbundesamt, Februar 2000.

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4 American Institute of Chemical Engineers, Center for Chemical Process Safety. Guideline for evaluation the characteristics of vapor cloud explosions, flash fires, and BLEVES, 1994.

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