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IMPROVING THE SAFETY LEVEL OF PYROTECHNIC ARTICLES TESTING IN VARIABLE CONDITIONS OF MICROCLIMATE

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Abstract

The related European directives in force stipulate that product testing shall be performed in conditions that reproduce as accurately as possible the real ones that may be encountered during their operation. These are products whose intended use are specified in the safety data sheet or within the instructions for use, and whose limits of the micro-climatic parameters that can be encountered (temperature, humidity, wind - for the outside ones, temperature, humidity, generation of restricted toxic compounds for interior ones) are known. In order to implement an integrated and complete solution for ensuring the compliance for measurement and determination of operational testing of pyrotechnic articles (categories F1, F2, F3 and F4), under high accuracy conditions in accordance with the methods and standards applied, there was used a multifunctional equipment purchased under within the research project code PN 16 43 03 04, developed within the Nucleu Program. The equipment type Rain Wise CC-3000 is designed for monitoring and recording micro-climate parameters and disposes of an incorporated software. Taking into account the applicable requirements in the field of pyrotechnic articles testing and the possibility of monitoring / determining micro-climate parameters specific for the test environment, for each type / category of pyrotechnic article tested may be established, on a scientific basis, the possible influence of external factors of the test environment, factors which may affect their proper operation, respectively: the wind (by its intensity and direction), ambient temperature, humidity, atmospheric pressure, nature and consistency / soil quality / launch platform on which the pyrotechnic article is placed before to actual testing.

Key words: microclimate, monitoring, pyrotechnic article, test, test infrastructure

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1. Introduction

According to the scientific literature, pyrotechnics is the science, technique and art of creating, maintaining and controlling fire. The studying, designing and the development of pyrotechnic compositions and devices or fireworks requires, in all situations, thorough theoretical and experimental studies (Ambekar et al., 2017; Blair et al., 2015; Pasculescu et al., 2014, 2015). Worldwide, the use of pyrotechnic articles has become more and more frequent in recent years, these products being used on celebrations of significant cultural and religious events, the most famous and commonly used being the fireworks. Pyrotechnics can also be used for special effects during concerts, theatre performances, movies and sports events, and even for rocket launching (Kovacs et al., 2017; Yin et al., 2014).

Microclimate is characterized by the physical parameters of air (temperature, humidity, motion, atmospheric pressure and radiant energy). Also, the microclimate specific to air layers from the ground surface is conditioned by the variations in heating, cooling, humidification and drying in micro-areas and it depends on the ground relief, the type of soil,

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vegetation etc. , being specific for distinct parts of a geographical land part (NUCLEU Project, 2017).

Our paper presents several microclimate determinations performed using Rain Wise CC-3000 high performance equipment, with different measurement schemes that have been established in accordance with the requirements of the applicable standards and procedural methodologies specific to the accredited laboratory performing the tests (PI-98).

2. Material and methods

According to legislation in force in the field of fireworks, the tests have to be performed in compliance with the manufacturer's instructions and other relevant instructions. Operation tracking test is performed visually or by means of video recordings using high performance cameras, respecting the safety distances specific to the type and categories of pyrotechnic articles tested. The functioning tests have been performed on an outside area located on site of the testing facility for civil use explosives and pyrotechnic articles from within the National Institute for R&D in Mine Safety and Protection to Explosion (INSEMEX) premises. The location is proper for testing such types and categories of pyrotechnic articles, it consists of a circular shaped concrete platform, provided with marking for the established location for positioning the pyrotechnic articles which shall be tested (Gheorghiosu et al., 2012) as well for the safety distances, located at 1, 8, and 15 m from the fireworks (category F1, F2, and F3) launch position (EU Directive, 2013). In case of pyrotechnic articles for professional use (category F4), these are tested according to the applicable standard testing method (EN Standard, 2013) respecting the safety distance indicated by the manufacturer or highlighted in the technical product specification. The main types of parameters of interest during the functioning tests of fireworks are represented by the following measurements and functional tests: ignition time, initial fuse time, integrity, function test, measurement of sound pressure level, and angle of ascent and height of effects, incandescent matter, and projected debris).

To determine the ascension height of the fireworks effects, two observation points are placed at the same level with the one of the concrete platform (Fig. 1). The testing infrastructure of which INSEMEX disposes is developed for performing the tests in compliance with the applicable standard method for pyrotechnic articles functioning test. The infrastructure consists of a concrete platform, of circular shape, provided with predetermined locations and markings in order to properly perform the functioning test, respectively: the location for launching pyrotechnic articles in the centre of the circular platform; the two locations P1 and P2, representing the observation points used for tracking the ascension effects in order to determine the effect's height, located at a distance of 50 m from the centre of the platform. They are disposed after two rectangular directions in order to monitor and determine the deviation angle in vertical plane generated during the functioning test. The three circular markings for the safety distances (located from the platform's centre at 1 m for F1, 8 m for F2 and 15 m for F3), on the circumference of which the sound-level measuring device type 2305 is located for measuring the impulse noise (S is 1 m for F 1, S is 8 m for F 2 and S is 15 m for F3). Also, the functioning test of pyrotechnic articles makes use of a state-of-the-art multifunctional equipment type Rain Wise CC-3000, designed for measuring and monitoring the parameters of the test environment (wind speed and direction, temperature, humidity, atmospheric pressure) as well as of the weather Oracle multi-display, mounted outdoor for the purpose of receiving, viewing and recording (for latter use) the data collected by the weather station.

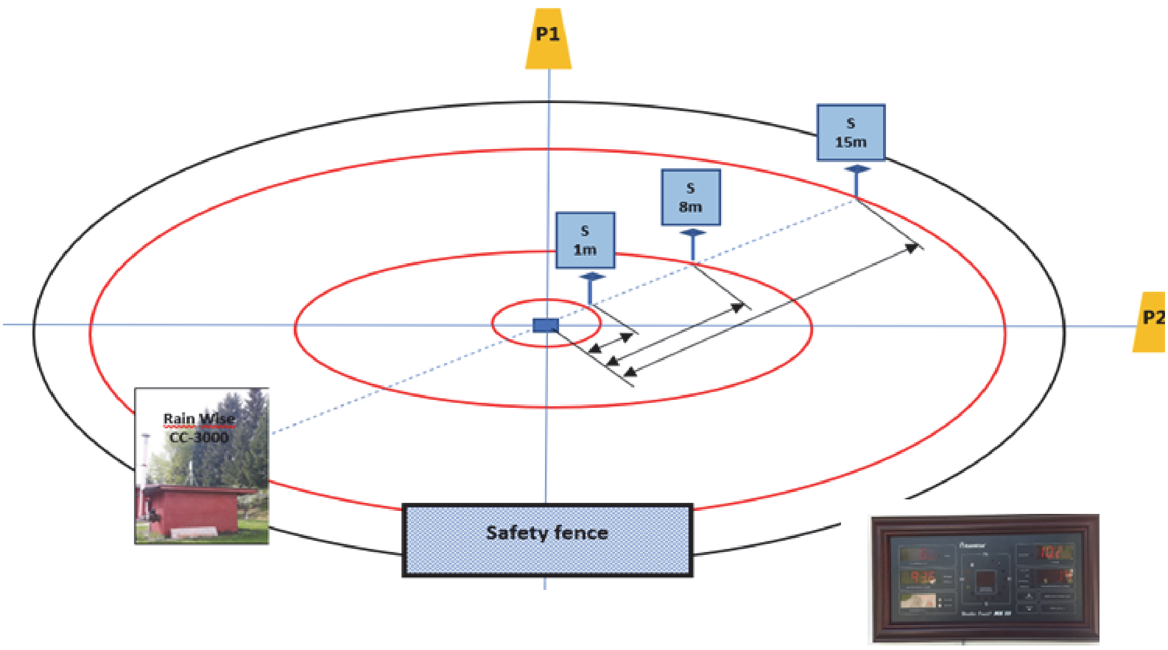

Fig. 1. Placement of specific measurement equipment for performing the functioning test of pyrotechnic articles

Fig. 2. Sample images taken during the functioning test of pyrotechnic articles type Festival of Peace BCS 100 and Thunder BCSZ 100

While performing the tests, the difficulty of monitoring the influence of the wind, which is manifested mainly on the pyrotechnic articles angle of ascent, affecting their height of effect should be taken into account. Also, the wind influences the sound pressure level and the smoke and gases propagation outside the safety areas, in its' blowing direction. Before starting the functioning test, there has to be fulfilled the condition for the wind speed not to exceed 5 m/s. During tests, the environmental parameters are analysed by measuring and determining the ones which have direct influence on the operation (wind velocity and temperature of the test environment) ensuring throughout the development of the test the compliance with the wind speed limit and the ones related to the temperature of the test environment (Leba et al., 2014). The minimum safety distance is the distance from any fireworks placement to the perimeter of the fireworks viewing area, called the exclusion zone. The calculated minimum safety distance should not be considered as the optimum safety distance, it is simply the minimum requirement based on certain conditions, estimates and assumptions known to generate an acceptable risk level (Pasculescu et al., 2019). The pyro-technician responsible for the fireworks display must aim to significantly exceed the calculated minimum distance in order to reduce as much as possible the risk of injury to persons and property. Also, the changes in weather conditions and inaccurate estimates or assumptions before and during the fireworks display should be taken into account. The information on the basis of which the pyro-technician should be able to estimate and calculate the minimum safety distance must be provided by the manufacturer or suppliers of the fireworks within the Product Data Sheet (EU Directive, 2013; Rus et al., 2017).

3. Experimental

The experimental program aimed for analyzing the results of the testing of the functioning of pyrotechnic articles, type battery, in category F2. In this respect, two types of products were tested, as presented in Fig. 2.

Before and during the performance of the tests, there were tracked and monitored the test environment parameters which had direct influence on the operation of the pyrotechnic articles (wind speed, temperature of the test environment, wind direction). In order to ensure accuracy of the values associated with the result indicators, the permanent monitoring of the conditions imposed by the applicable standard method was taken into account. A wind velocity lower than 5 m/s was recorded; the microphone of the sound level measurement equipment was placed in the test area at the required distance and at a 1 m height.

The correlation between the determined and measured value of the parameter of interest that characterizes the test environment directly determines the result by correcting the measured values with the value of the expanded uncertainty (considering both the uncertainty of the measurement equipment and the statistical uncertainty of the measurements performed). Therefore, the maximum value of the wind velocity parameter is corrected by the addition of the expanded uncertainty value; the minimum and maximum values of the temperature parameter are corrected by the subtraction or addition of the extended uncertainty of this parameter.

With regard to safety distances during functioning tests of pyrotechnic articles, for calculating the minimum safety distance to a firework's display, various factors have to be assessed, such as:

- the minimum safety distance (e.g. minimum distance for fireworks display under ideal conditions) and the minimum distance recommended by the manufacturer;
- wind effects;
- the effects of angular pyrotechnic articles (e.g. aerial bombs, candles) or the inclined terrain in the firing area;
- the effects of hazardous waste dropping;

Fig. 3. Location of RainWise CC-3000 multifunctional equipment

- the known effects and performance of pyrotechnic articles and any influence of the equipment used.

The minimum safety distance calculated shall be respected by all persons who are not directly involved in the organization of the fireworks display (e.g. other persons except pyro-technicians and safety staff) (Vasilescu et al., 2015).

No other person is allowed to be present inside the perimeter of these distances. The number of persons authorized in the minimum safety area has to be minimized so that to decrease the risk of exposure. For performing the functioning test of pyrotechnic articles (F1, F2, F3 and F4), in compliance with the applied standard methods, the specific equipment type RainWise CC-3000 was used, which is located on the roof, near the platform used for testing pyrotechnic articles (Fig. 3) (EN Standard, 2013, 2016; Gheorghiosu et al., 2013).

Multi-display Weather Oracle for the MKIII Weather Station was mounted outside the office building (Fig. 4), in order to receive data from the MKIII weather station via radio waves. Each measured parameter has a display, including a wind direction indicator.

Functional parameters:

- ✓ Time: displays either the current time or date;
- ✓ Temperature: displays the outdoor and indoor temperature as well as the temperature and dew temperature;
- ✓ Humidity: displays relative humidity and temperature-humidity index (THI); THI is a measure of relative heat, felt by man, taking into account the combination of temperature-humidity;
- ✓ Barometer: displays the atmospheric pressure and indicates whether the pressure drops, increases or is constant (the lights are extinguished);
- ✓ Rainfall: displays 2 counters for the amount of current or accumulated rainfall. They can be reset independently;
- ✓ Wind speed: displays the current wind speed wind direction and the wind rose.

The CC-3000 is a data logger and computer interface for Rainwise MK-IIII weather surveys station, with daily minimum values being registered at the end of each day.

Fig. 4. Location of Weather Oracle multi-display

4. Results and discussion

The requirement on the location for fireworks display (the place where the fireworks are to be launched) is determined by the size, access restrictions, and the surroundings of the location.

Generally speaking, fireworks with no breakages and debris (mines, roman candles, and other consumer fireworks in categories F1 ÷ F3) can be displayed in such locations. With regard to monitoring the effects of pyrotechnic articles at various ascension heights, relevant requirements should be specified in the technical safety data sheets of the products (Moraru et al., 2014).

The fireworks display site has to be suitable and to fulfil the relevant requirements for the categories of fireworks used, having to be solid and smooth, in accordance with the pyrotechnic product's safety requirements. A special attention must be given to adverse weather conditions, especially to wind direction and wind speed. Wind can have a considerable effect on the trajectory of bombs and missiles, on the way their debris fall and on the smoke propagation. If wind conditions can change the trajectory of shells, rockets and any ascendant trajectory objects they become hazardous to viewers or surrounding assets (Jitea et al., 2017; NUCLEU Project, 2017).

For the analysis of the microclimate parameters defining the test environment for pyrotechnic articles, their monitoring and determination at different time intervals should be considered. The statistical results are obtained by taking into account data transposed into status charts, respectively: variation of peak wind speed per day (Fig. 5), variation of wind speed and deviation per day (Fig. 6).

The displaying of fireworks is suspended or stopped when the following situations occur:

a) The wind starts blowing unusually in a different direction (unexpected intensity), fact which could endanger the public;
b) The wind is over 5 m / s and could endanger the safety of buildings, electrical installations, electrical communications and the public within the safety zone;
c) Sudden rainfall, fog, snowfall etc.;
d) Sudden (unexpected) accidents endangering human safety, such as tube blast, low-level explosions;
e) The coordinator of the fireworks decides this due to objective reasons.

Table 1 presents the estimation of the extensive measurement uncertainty associated with the test environment parameters which directly influence the test results (wind speed, test environment temperature)

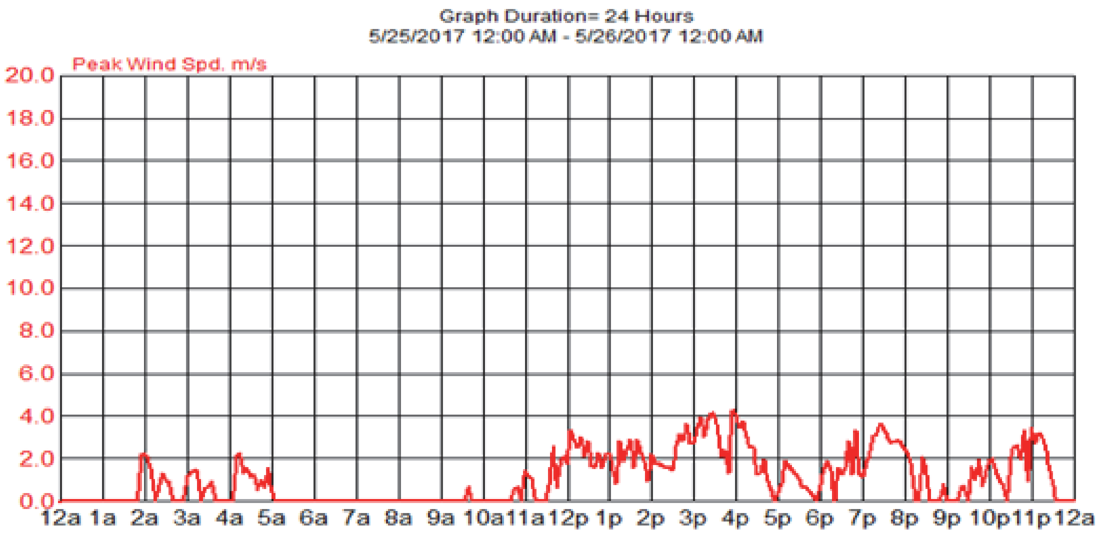

Fig. 5. Wind "peak" within a 24 hours period

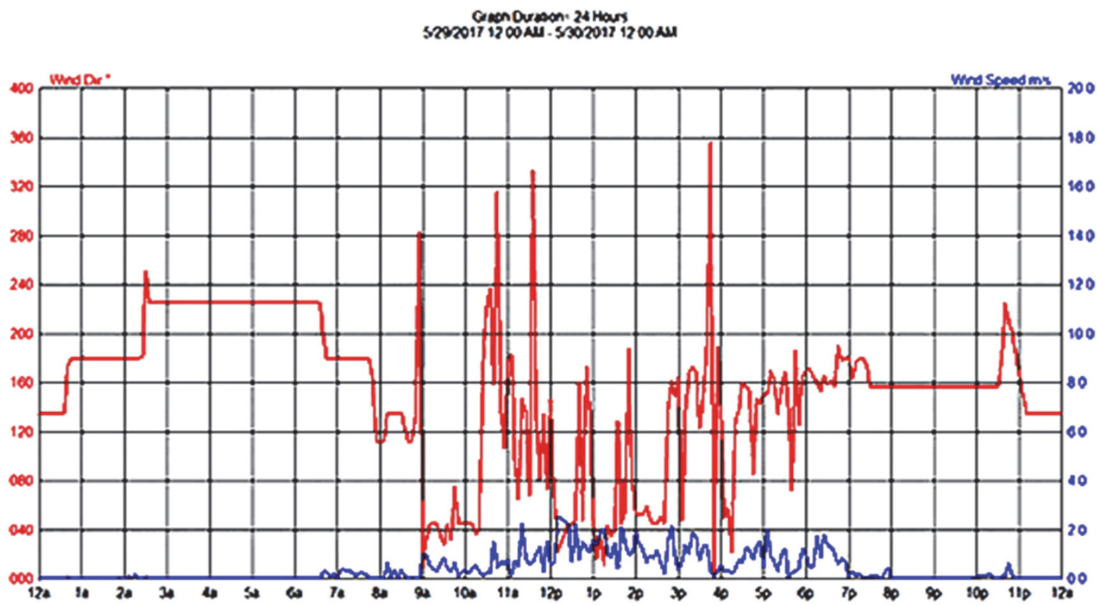

Fig. 6. Wind direction and speed within a 24 hours period

Table 1. The statistic adequacy of the result indicators

Statistical evaluation	***Non-statistical evaluation***	***Expression of extended uncertainty***
- The standard uncertainty of the average measurements; - Number of measurements, $n(X_i)$; - Arithmetic mean of results $n(X_i)$, $X_{med}=(\sum X_n)/n$; - Standard deviation, $s=[\sum(X_i\text{-}X_{med})^2/n\text{-}1]^{1/2}$.	- The uncertainty associated with the device, U(EM1); - Arithmetic mean of results, X_{med}; - Number of measurements, n; - Standard deviation, s; - The standard uncertainty, $U(X_{med})$.	- The calculation of compos uncertainty associated with sources of uncertainty identified and evaluated: $U_C(X)=[U(EM)^2+U(X_{med})^2]^{½}$ U(EM)= $U(X_{med})$= $U_C(X)$= - Calculating the expanded uncertainty: U= k x u_c , ($K_{95\%}$= 2) $U_e(X)=2xU_C(X)$= - Expression of the final result: Y = y±U (unit of measure);
Pyrotechnic article type Festival Of Peace BCS 100 		
n_v=3 Xv_{med}=1.5 m/s s_v=0.264575 n_t=3 Xt_{med}=8.33 ^{0}C s_t=1.527525 Result indicator: Noise level [dB], L_{AImax}: $114.2^{t=8.33\pm1.76\ [Celsius\ degree]}_{v=1.5\pm0.602 [m/s]}$ $113.8^{t=8.33\pm1.76\ [Celsius\ degree]}_{v=1.5\pm0.602 [m/s]}$ $114.1^{t=8.33\pm1.76\ [Celsius\ degree]}_{v=1.5\pm0.602 [m/s]}$	U(MKIII)=0.259807 $U(_{Xvmed})$=0.152753 U(MKIII)=0.038336 $U(_{Xtmed})$=0.881917 U(Sonometer)=0.3 dB $U(_{XLmed})$=0.10729	$U_C(X_t)$=0.301385 $U_e(X_t)=2xU_C(X_t)$=0.602 v = 1.5 ± 0.602 m/s $U_C(X_t)$=0.88275 $U_e(X_t)=2xU_C(X_t)$=1.7655 t = 8.33 ± 1.76 ^{0}C $U_C(X_L)$=0.318608 $U_e(X_L)=2xU_C(X_L)$=0.637216 L = 114.04 ± 0.637 dB
Pyrotechnic article type Thunder BCSZ 100 		
n_v=3 Xv_{med}=1.5 m/s s_v=0.264575 n_t=3 Xt_{med}=8.33 ^{0}C s_t=1.527525 Result indicator: Noise level [dB], L_{AImax}: $118.7^{t=8,33\pm1,76\ [Celsius\ degree]}_{v=1.5\pm0.602 [m/s]}$ $115.6^{t=8.33\pm1.76\ [Celsius\ degree]}_{v=1.5\pm0.602 [m/s]}$ $116.0^{t=8.33\pm1.76\ [Celsius\ degree]}_{v=1.5\pm0.602 [m/s]}$	U(MKIII)=0.259807 $U(_{Xvmed})$=0.152753 U(MKIII)=0.038336 $U(_{Xtmed})$=0.881917 U(Sonometer)=0.3 dB $U(_{XLmed})$=0.973539	$U_C(X_t)$=0.301385 $U_e(X_t)=2xU_C(X_t)$=0.602 v = 1.5 ± 0.602 m/s $U_C(X_t)$=0.88275 $U_e(X_t)=2xU_C(X_t)$=1.7655 t = 8.33 ± 1.76 ^{0}C $U_C(X_L)$=1.018714 $U_e(X_L)=2xU_C(X_L)$=2.037428 L = 116.76 ± 2.03 dB

5. Conclusions

The analysis of the main operating parameters of the pyrotechnic articles under variable micro-climate conditions took into account the documentation concerning the assessment of compliance with certain conditions.

These conditions are required by regulations in force and are firstly related to features which have to be verified during the performance of functioning tests (ascension or flight angle, ground movement, stability during operation, explosion height, acoustic pressure level, projected fragments, burning or incandescent fragments, flame extinction, combustion rate of pyrotechnic composition etc.).

Secondly, they are related to features to be verified after performing the functioning tests (arrow, integrity after functioning test etc.).

The studied aspects and results of the tests presented within this paper can be used as future guidelines for users dealing with pyrotechnical articles, so that to ensure the highest safety level possible during the functioning of fireworks.

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