Performance evaluation of pyrotechnic articles for maritime use

Ilie-Ciprian Jitea[1*], *Cristian* Rădeanu [1], *Ladislau* Radermacher[2], and *Petru* Jurj[1]

[1]National Institute for Research and Development in Mine Safety and Protection to Explosion – INSEMEX Petroşani Department of Safety Explosives and Pyrotechnic Articles, 32 34 G-ral Vasile Milea St., 332047 - Petroşani, Hunedoara County, Romania
[2] University of Petrosani, Hunedoara County, Romania

Abstract. This paper presents a performance evaluation of maritime pyrotechnic articles, including hand flares and buoyant smoke signals, subjected to simulated operational stress conditions. Testing included thermal cycling (-30°C to +65°C), 24-hour water immersion, and exposure to heptane vapours to replicate emergency maritime scenarios. A total of 216 samples were analyzed using dedicated equipment such as climate chambers and controlled ignition enclosures. Most articles operated within required parameters, yet several units exhibited ignition failure after immersion and unintentional ignition of flammable vapours, raising safety concerns. Structural degradation, delayed ignition, and reduced signal duration were also noted in some specimens. These results confirm that current type-approval and certification practices may not adequately reflect real-world conditions. The findings support the need for updated testing protocols, regular re-certification, and independent laboratory validation. By enhancing testing methodologies and aligning them with realistic operating conditions, this paper contributes to the improvement of product safety and reliability for maritime distress signalling devices.

1 Introduction

Maritime pyrotechnic articles are indispensable elements of on board safety systems across marine transport, offshore platforms, and search and rescue operations. Devices such as hand flares, buoyant smoke signals, and parachute rockets serve a singular, life-critical purpose: to visibly alert and guide rescuers in emergency situations at sea. Their successful operation, especially in harsh maritime environments, can determine the difference between survival and disaster.

Despite mandatory certification requirements under international frameworks such as the International Maritime Organization (IMO) conventions and Directive 2014/90/EU on marine equipment, field evidence continues to expose reliability gaps. As highlighted by the JAHARP2021-08 project, a significant portion of CE-marked products tested including those bearing the Wheel mark applied following successful IMO-type approval, figure 1,

* Corresponding author: ciprian.jitea@insemex.ro

exhibited either inconsistent functionality or safety and critical failures, even when sampled directly from the European market [1].

Fig.1. Wheel Mark and CE-marked hand flare

Some articles did not ignite, others ignited unsafely (e.g. igniting heptane vapors), and many demonstrated poor resistance to environmental stressors like water immersion and extreme temperature variation.

This paper builds upon those concerns by conducting a targeted performance evaluation of hand flares and buoyant smoke signals. Unlike type-approval testing, often limited and conducted under optimal conditions, our approach simulates real world operational stress: thermal cycling, 24-hour immersion, and exposure to flammable atmospheres. The goal is to assess not just nominal functionality, but the consistency and safety of activation when users are most vulnerable, such as during storms, cold temperatures, or fuel leaks.
Furthermore, our methodology aligns with modern regulatory perspectives that advocate for performance-based validation over formal compliance alone. As the JAHARP project underscored, the reliance on outdated type, approval reports (some over 15 years old) and a lack of EU-accredited testing facilities leave substantial gaps in market surveillance and product accountability [2].

By identifying functional deviations, failure mechanisms, and safety risks through a controlled yet rigorous protocol, this work aims to inform both product development and regulatory enforcement. The results serve as a resource for manufacturers, market surveillance authorities, and emergency service providers, contributing to improved reliability of distress signals and, ultimately, higher safety standards in maritime operations [3,4].

2 Testing protocol and equipment

The tested specimens were provided by the Federal Maritime and Hydrographic Agency (BSH), Germany, within its role as an EU market-surveillance authority. They included products from different manufacturers available on the European market, ensuring representative coverage of the types currently in use.

The evaluation of pyrotechnic articles for maritime use was conducted using a standardized protocol designed to simulate extreme operational environments. Twelve pyrotechnic article types (6 hand flares and 6 buoyant smoke signals) were subjected to a comprehensive test protocol covering multiple operational and environmental scenarios. Three specimens per type were tested under each condition, resulting in a total of 216 evaluated samples. Each pyrotechnic type was subjected to a structured testing sequence that included, among other procedures, thermal cycling, 24-hour water immersion, and exposure to flammable vapours (heptane), in order to assess functional reliability and operational safety [5,6].

2.1 Equipment used

The following specialized equipment was employed:
- Climate chamber capable of maintaining temperatures from -30°C to +65°C, used for thermal cycling and temperature conditioning, figure 2.

Fig.2. Climate chamber used for thermal cycling and temperature conditioning (-30°C to +65°C).

- Immersion tanks with a depth of one meter, equipped with a metal support frame for securing buoyant smoke signals during submersion, were used to simulate prolonged exposure to seawater, figure 3.

Fig.3. Buoyant smoke signals mounted on a support frame for 24-hour immersion testing in a 1 meter deep tank.

- Precision timing and measurement instruments for recording ignition delay, duration of combustion, and smoke visibility.
- Controlled ignition enclosure designed for the safe testing of flammable vapors such as heptane to assess unintended ignition risks, figure 4.

Fig.4. Controlled ignition enclosure used to assess flammable vapor ignition risks.

2.2 Testing conditions

All pyrotechnic samples, including hand flares and buoyant smoke signals, were subjected to the following test stages:

• Thermal cycling where samples underwent a sequence of high- and low-temperature exposures, cycling between -30°C and +65°C, to simulate extreme maritime environments.

• Water immersion the devices were fully submerged in water at a depth of one meter for 24 hours to assess waterproofing and post-immersion operability.

• Functional testing, after conditioning, the articles were ignited under controlled conditions to evaluate proper functioning (ignition success, burn time, and signal visibility).

• Ignition safety testing, the samples were exposed to a controlled heptane vapor environment to examine unintended ignition potential.

This multi-stage protocol was designed not only to assess whether devices met standard requirements, but also to uncover latent failure modes that may arise under realistic maritime conditions. Observations recorded during these tests served as the basis for subsequent analysis and interpretation [7].

3 Test results and analysis

The performance evaluation was carried out to determine how maritime pyrotechnic articles respond to simulated operational and environmental stress conditions. Each test was designed to reveal potential functional limitations and safety concerns under conditions aligned with international regulatory requirements.

3.1 Performance under temperature cycling

Thermal cycling was performed between -30°C and +65°C, reflecting the extreme temperature ranges that distress signals may encounter during transport, storage, or emergency use in maritime environments. The devices were conditioned in climate chambers through multiple cycles, figure 5, after which ignition and signal functionality were tested.

Fig.5. Both types of tested articles, hand flares and buoyant smoke signals, undergoing thermal cycling inside the climate chamber.

Most of the tested hand flares and buoyant smoke signals maintained consistent performance following this procedure. They ignited reliably and produced the required visual signals (light or smoke) for durations compatible with safety standards.

However, a limited number of samples demonstrated functional degradation after cycling:

- Delayed ignition was observed in some flares, requiring longer activation times than specified.
- In rare cases, complete ignition failure occurred after exposure to low temperatures, indicating possible contraction or malfunction of internal ignition components.
- Signal duration was slightly reduced in several smoke signals, which could compromise visibility during real emergency scenarios.

These findings suggest that while the majority of units are robust against temperature fluctuations, certain products may require design adjustments to ensure full operational consistency under extreme conditions.

According to Directive 2014/90/EU, pyrotechnic distress signals must maintain operational reliability after temperature conditioning. The observed ignition delays and occasional failures indicate that some tested products did not fully comply with these requirements, highlighting design limitations not covered by current type-approval reports.

3.2 Performance after water immersion

To simulate accidental immersion or extended exposure to wet environments, all samples were submerged in water at a depth of one meter, figure 6, for 24 hours. After removal, each article was inspected for visible water ingress and tested for functionality.

Fig.6. Hand flares on a metal support frame immediately after completion of the 24 hour immersion test in a 1 meter deep tank

The immersion test revealed that:

- A majority of units maintained full functionality and ignited without issue.
- A notable minority failed to ignite or exhibited unreliable ignition, indicating that water ingress had likely affected the ignition mechanism or internal charge.
- In some cases, mechanical damage was evident, such as swelling or detachment of components, possibly due to inadequate sealing or absorption of moisture.

This highlights the importance of robust waterproofing in the design of distress signals, especially when they are expected to operate reliably in emergency maritime environments where full submersion is likely [8].

The immersion test revealed that:

- A majority of units maintained full functionality and ignited without issue.
- A notable minority failed to ignite or exhibited unreliable ignition, indicating that water ingress had likely affected the ignition mechanism or internal charge.
- In some cases, mechanical damage was evident, such as swelling or detachment of components, possibly due to inadequate sealing or absorption of moisture.

This highlights the importance of robust waterproofing in the design of distress signals, especially when they are expected to operate reliably in emergency maritime environments where full submersion is likely.

IMO Resolutions and Directive 2014/90/EU specify that distress signals must retain full functionality after immersion. The ignition failures and visible mechanical damage recorded in our tests demonstrate that a fraction of products available on the European market do not consistently meet this mandatory requirement.

3.3 Heptane exposure and ignition risk

To evaluate accidental ignition risks, selected pyrotechnic articles were exposed to heptane vapors in a controlled testing enclosure. This simulated a high-risk environment where flammable substances are present, such as near fuel spills or engine compartments.

The safety evaluation found that:

- Most devices did not ignite heptane vapors and behaved as expected when operated according to procedure.
- However, some hand flares ignited heptane upon activation, raising critical safety concerns, figure 7.

Fig.7. Hand flare igniting heptane vapours during activation.

- Additionally, there were cases where combustion extended to the housing or handle, posing a risk of injury to the user, figure 8.

Fig.8. Hand flare exhibiting combustion damage to housing and handle.

- In one instance, the ignitor sleeve detached from the main body during ignition, indicating structural failure under standard use conditions, figure 9.

Fig.9. Ignitor sleeve detached from hand flare body during activation.

These results emphasize the necessity of incorporating vapor-safe ignition systems and flame containment features. In emergency situations where fuel vapors may be present, even a low probability of unintended ignition constitutes an unacceptable risk, table 1.

Table 1. Summary of Key Issues Identified During Testing

Issue Observed	Affected Article Type	Test Condition	Notes
Ignition failure after immersion	Hand flares, smoke signals	24-hour water immersion	Linked to poor sealing or water ingress
Heptane vapor ignition	Hand flares	Flammable vapor exposure	Caused by hot particles during activation
Structural failure (sleeve detachment)	Hand flares	Functional test	Sleeve detached upon activation
Housing or handle combustion	Hand flares	Flammable vapor exposure	Risk of user injury observed
Short signal duration	Both types	Thermal cycling	Possibly related to degraded formulation or insulation loss
Delayed ignition	Both types	Thermal cycling	Response time exceeded normal limits

Current maritime equipment standards require safe use in environments where fuel vapours may be present. The ignition of heptane vapours by certain hand flares directly contradicts this safety principle, raising concerns that existing type-approvals may overlook critical operational risks.

4 Discussions

The testing campaign outlined in this study has provided clear evidence that the operational reliability of pyrotechnic distress signals remains inconsistent across different manufacturers and product batches. While the majority of hand flares and buoyant smoke signals passed functional tests following thermal and immersion conditioning, the presence of ignition failures and safety hazards in several samples is cause for concern.

The ignition issues observed after immersion and thermal cycling highlight potential vulnerabilities in the sealing and composition of ignition systems. Even if most products meet the baseline performance criteria, isolated failures are unacceptable given the life-critical role these devices play in maritime emergencies. These concerns are aligned with findings from the JAHARP2021-08 project, which identified widespread non-compliance and structural deficiencies even among CE-marked and supposedly certified equipment.

These results suggest that there may be discrepancies between certified compliance and real-world performance. Although the products formally meet IMO and Directive 2014/90/EU documentation, our findings show that under practical stress conditions some units encounter difficulties in meeting safety expectations, particularly regarding waterproofing, thermal resilience, and ignition safety. This emphasizes the importance of updating certification protocols to better reflect operational realities.

A particularly alarming result was the unintended ignition of heptane vapors by some flares. This not only poses a serious threat to users in the vicinity of fuel spills or enclosed spaces, but also suggests that current ignition systems may lack sufficient insulation and vapor safety. The JAHARP study similarly reported that flare handles occasionally caught fire or disintegrated, leading to increased injury risks. These findings collectively support the need for revised ignition designs that prevent external flame exposure and eliminate potential contact with flammable vapors [9,10].

From a regulatory and market surveillance perspective, our analysis findings emphasize systemic issues:

- Many type approvals are based on outdated test reports, some exceeding 15–20 years;
- No EU, accredited laboratories exist for full scale testing of marine distress signals, often requiring reliance on fireworks labs or in-house manufacturer testing;
- Batch control and production quality checks appear insufficient, as demonstrated by high failure rates during independent testing.

Moreover, the logistical challenges associated with testing these devices, including transportation as dangerous goods and limited availability of compliant testing infrastructure make ongoing surveillance and third-party verification both costly and inefficient. Nevertheless, as the JAHARP project concluded, the safety of maritime personnel cannot be compromised due to administrative or logistical constraints.

This discussion reinforces the importance of establishing:

- Harmonized, up-to-date performance standards for maritime pyrotechnics;
- Mandatory re-certification procedures at regular intervals;
- Independent, accredited testing facilities capable of verifying performance across the full range of environmental and safety conditions.
- Finally, the conditioning of sample, through thermal cycling, submersion, and exposure to volatile substances, proves to be not just a validation step, but a necessary filter to reveal latent design or manufacturing flaws. Future product approvals and regulatory frameworks should integrate such rigorous evaluation methods to better ensure the safety, reliability, and effectiveness of maritime distress signals in real world scenarios.

5 Conclusions

This paper has presented a structured performance evaluation of hand flares and buoyant smoke signals under simulated maritime conditions. The results confirm that while many articles meet basic functional requirements, several critical safety and reliability issues persist across different products and manufacturers.

Failures observed after water immersion, inconsistencies following thermal cycling, and unintended ignition of heptane vapors underline the need for more rigorous product design and testing practices. These findings are consistent with those reported in the JAHARP2021-08 project, which highlighted widespread non-compliance even among CE-marked pyrotechnic articles available on the European market.

The most pressing concerns identified include:

- Ignition failures following prolonged exposure to water;
- Structural degradation and component detachment;
- Lack of protection against flammable vapor ignition;

Absence of regular re-evaluation for type-approved products.

This paper supports the view that current certification and batch control mechanisms are not sufficient to ensure consistent product quality and operational safety. Periodic re-testing, updated performance criteria, and independent verification must become standard practice for maritime distress signals.

Future work should focus on refining material compositions and ignition mechanisms, strengthening the regulatory framework, and expanding accredited testing infrastructure. By aligning testing procedures with realistic operating scenarios and international safety objectives, the reliability and effectiveness of pyrotechnic articles can be significantly improved, ultimately enhancing safety at sea.

Part of this work was carried out through the ”Nucleu” Program within the National Plan for Research, Development and Innovation 2022-2027, with the support of the Romanian Ministry of Education and Research – National Authority for Research, project no. 23 32 02 03, title: Development of monitoring methods to reduce environmental impact from the use of explosive materials, pyrotechnic articles, and application of blasting technologies. Also, part of te results were obtained using the Installation of National Interest - IOSIN-PCDIEx within INCD INSEMEX Petroșani, supported through public funding allocated by the Ministry of Education and Research - National Research Authority

References

1. Ilie-Ciprian Jitea, Cristian Rădeanu, Bogdan Garaliu-Bușoi, Ștefan Ilici, Robert Laszlo, Development of Testing Infrastructure For Maritime Pyrotechnic Articles, Annals of the University of Petroşani, Mechanical Engineering, 26 (2024), 21-30
2. Cristian Rădeanu, Attila Kovacs, Daniela Rus, Ilie - Ciprian Jitea, Dragos Gabriel Vasilescu, Increase in the security quality in use of professional pyrotechnic articles falling in category F4. 8th International Multidisciplinary Scientific Symposium „UNIVERSITARIA SIMPRO” 11-13 October 2018,Conference ProceedingsISSN–L 1842 – 4449ISSN 2344 –4754, Pag. 125÷13
3. Ciprian Jitea, Attila Kovacs, Gabriel Vasilescu, Edward Gheorghiosu, Daniela Rus and Sorin Bordoş, Prospective analysis of ambiental and weather effects on conform displaying of fireworks. 8th International Conference on Manufacturing Science and Education – MSE 2017 “Trends in New Industrial Revolution” 09 August 2017, Volume 121 (2017) MATEC Web Conf., 121 (2017) 11011
4. Daniela Rus, Gabriel Vasilescu, Attila Kovacs, Edward Gheorghiosu, Ciprian Jitea, Informatical (it) platform for the certification of explosives and pyrotehnical products. Environmental Engineering and Management Journal June 2017, Vol.16, No. 6, 1361-1366
5. Kovacs, A., Vasilescu, G., Gheorghiosu, E., Rus, D., Jitea, I.-C., & Bordos, S. (2017). Appropriate management of preventing actions on health and safety for testing activities of high explosives in confined environment. Quality-Access to Success, 18, 93–96.
6. Darabont, D.-C., Moraru, R. I., Antonov, A. E., & Bejinariu, C. (2017). Managing new and emerging risks in the context of ISO 45001 standard. Quality-Access to Success, 18, 11–14.
7. Bejinariu, C., Darabont, D.-C., Baciu, E.-R., Georgescu, I.-S., Bernevig-Sava, M.-A., Baciu, C. (2017). Considerations on Applying the Method for Assessing the Level of Safety at Work. Sustainability, 9(7), 1263. https://doi.org/10.3390/su9071263
8. Explosives regulations. (2014). Explosives regulations 2014: safety provisions: guidance on regulations. Merseyside: Health and Safety Executive, HSE Books.
9. DIRECTIVE 2014/90/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 July 2014 on marine equipment and repealing Council Directive 96/98/EC
10. Law no.126 of december 27,1995*) on the regime of explosives and Technical Standards with subsequent additions and amendments.