

## Lessons Learned from Recent Accidents in Fireworks Establishments

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This paper aims at analysing the technical, organizational and management aspects that are critical in a SMS for the control of major-accident hazards in the fireworks establishments.

Information and data are derived from the results of post-accident inspections carried out also by the authors. Information about further accidents and incidents come from public documents collected in e-MARS (Major Accident Reporting System by European Joint Research Centre), in ARIA (Accidents database by the French Ministry of Ecology) and in Infor.MO (Italian database for occupational accidents and injuries by INAIL Italian Workers' Compensation Authority).

The results present a useful basis to identify and prevent particular dangerous situations and could be exploit to provide guidance for improving the management safety through guidelines, good practices, specific training activities and appropriate audit.

### 1. Introduction

Accidents at fireworks depots and factories may have catastrophic consequences for workers, facilities, people and environment. Several studies about the causes and the dynamic of these accidents have been proposed for years, whilst the adequateness of the safety management system (SMS) has been questioned recently.

The aspects, connected with SMS, are very important in the case of fireworks facilities subjected to Seveso Regulation on the control of major-accident hazards involving dangerous substances. Risks associated with pyrotechnics had been considered in the amendment of Seveso II Directive (2003), after Enschede accident in the Netherlands (May 2000). The accident caused 22 deaths and the wounding of 1000 people, the most serious damage to a large area in the immediate vicinity of factory, including a residential area. The awareness of these dangers has been confirmed in the Seveso III Directive (2012).

#### 1.1 Background

Fireworks industry is one of the most vulnerable industry for frequency and severity of accidents. According to Baati et al. (2013), a deep knowledge and understanding of the stability and explosive properties of chemicals are crucial to assess the related risks and hazards and to design a safe process. For that reason, most studies in the scientific literature of fireworks safety are about reactivity and susceptibility of materials and mixture, such as Cagnina et al., 2013. Just a few papers focuses the issue of SMS adequateness.

Demichela (2007) proposed one of the first study about the causes of an explosion occurred in Italian firework facilities; she underlined as the production was not conformed to the rigorous controls and inspections as those required by a safety management system for major risk plants.

According to Pakkirisamy et al. (2014) accidents continue to occur due to non-availability of standard manufacturing equipment, tools, manufacturing procedures, and inadequate understanding of the thermochemistry of fireworks and their explosive nature. Ravi & Gandhinathan (2014) analyzed the accidents to improve safety culture, considering unsafe acts and conditions among the main causes for all accidents in fireworks industries. Blair et al. (2015) have presented a new approach to formulating pyrotechnic materials to increased safety levels as well as simplify logistics, storage and manufacture.

### 1.2 Recent severe accidents in Italy

In Italy, there is a growing concern about the high frequency of accidents at the fireworks plants that falls within the scope of the Seveso Directive on the control of major accident hazards. The dramatic events occurred in Italy in the last years in the firework facilities need attention by Public Authority and scientific community. This need stems from high frequency of occurrence of accidents in this type of activity and from catastrophic effects both for buildings and for workers. The last event in Modugno, as shown in Table 1, represents one of most serious accidents recorded at Seveso establishments.

*Table 1: Major accidents at Italian fireworks plants in the last three years*

Place	Date	N° fatalities
Città Sant'Angelo (Abruzzo)	25/07/2013	5
Tagliacozzo (Abruzzo)	09/07/2014	5
Belmonte Castello (Lazio)	28/02/2015	1
Modugno (Puglia)	24/07/2015	10

## 2. Objectives

The goal of this paper is to analyze the technical, organizational and management aspects that are critical in a SMS for the control of major-accident hazards in the fireworks establishments.

Lessons learned by the analysis of recent Italian accident and information collected in the European database are very useful to understand the causes of the accident and to suggest producers and tools to manage safety in firework establishments. Based on the statistical picture of recent accidents, the paper is aiming to define a few critical points to be checked during safety audits at fireworks establishments.

## 3. Materials and methods

To achieve the proposed objective, a comparison among technical, organizational and management causes of accidents occurred in fireworks establishments and explosive ones has to be made.

### 3.1 Materials

To conduct the analysis three different sources of information have been considered.

A first typology of information is related to the results deriving from reports formulated by a specific Commission designated by Public Authority to investigate principle causes of accidents occurred recently in Italian Seveso fireworks industries. These inspections have been directly carried out by the authors according to the regulations of the Seveso II and, after July 2015, of the Seveso III Directive. Direct experience of the authors offers the possibility of having immediate and comprehensive information that, used anonymously, constitute an important basis in research activities.

The results of these inspections have been compared to each other and with the data relating to other accidents drawn from public documents collected in two web databases: e-MARS, the Major Accident Reporting System at the EU Major Accident Hazard Bureau (MAHB) and ARIA, French Accident Database, at the Bureau for Analysis of Industrial risk and pollutions (BARPI). The purpose of the e-MARS is to facilitate the exchange of lessons learned from accidents and near misses involving dangerous substances in order to improve chemical accident prevention and mitigation of potential consequences. Reporting an event into e-MARS is compulsory for EU Member States when a Seveso establishment is involved and the event meets the criteria of a "major accident" as defined by Annex VI of the Seveso III Directive (2012/18/EU). ARIA, instead include accidents with and without major consequences, in any type of industry. The database contains a great number of accidents, both for fireworks facility and for ammunitions and explosives plants. According to the information extracted from the Italian database Infor.MO, which collects just events with casualties, occupational aspects have been evaluated. Infor.MO examines the injury dynamic, according to a systemic, standardized and interpretative methodology taking into account the sequence of events and the circumstances leading to the accidents. Data analyzed in the model are derived from the report of the fatal injuries collected by inspectors of Italian Competent Authority for health and safety at work.

### 3.2 Method

The first phase of the study has been focused on the collection of cases studies to be examined. Accidents occurred in factories and warehouses of fireworks were selected. Each report extracted by database described in § 3.1 has been carefully read and examined to detect and select the main causes of accidents assumed for the accidental event. Furthermore, results of reports elaborated by authors during Seveso inspections have been considered. All causes identified have been classified and was subsequently estimated

how many accidents were associated with the catalogued cases based on identification of specific factors. In this study, physical factors (mechanical, thermal, electrical), natural, chemical and organizational ones have been selected. The detail of the factors has been reported in the Table 2.

Table 2: Examined factors for accident's causes.

MECHANICAL FACTORS	THERMAL FACTORS	ELECTRICAL FACTORS	NATURAL FACTORS	CHEMICAL FACTORS	ORGANIZATIONAL FACTORS
Falls/collapse	Overheating airing	Electrostatic discharge	Storms/ Floods	Poor quality raw materials	Failure quality control
Inadequate tools/materials	Weld joint/ hot work	Short circuit	Heat waves	Unsuitable additive	Lack of knowledge or Insufficient procedures
Equipment's failure	Others	Others	Humidity/ Infiltration	Poor of cleaning	Non-application of known procedures
Accident by using forklifts			Others	Spontaneous combustion	Lack of PPE/ unsuitable clothing
Accident/breakdown of means of transport				Natural deterioration	Hurry/pressure for over-production/ lack of personnel
Use of unsuitable means of transport				Ageing of materials	Illegal activities
Others				Wastes not disposed	Use of legal depot
				Incompatibility	Malevolent intention
				Others	Layout Others

#### 4. Results

The comparison among information extrapolated by the analysis of inspections carried out by the authors in fireworks industry where the accidents occurred, and other incidents drawn in public documents collected in web database over described, has been made. The results, as reported in Figure 1, show that the principle cause of accidents is mainly due to management/organizational factors.

From all considered factors that are not organizational ones, the most important are chemical and mechanical factor. Among the analyzed chemical factors, there are the use poor quality raw materials that often do not meet the purity requirements, then the use of unknown additives for special effects, the lack of local cleaning or the degeneration of the materials themselves. Related to mechanical factors, accidents associated to failure of the equipment or the use of unsuitable tools are numerous.

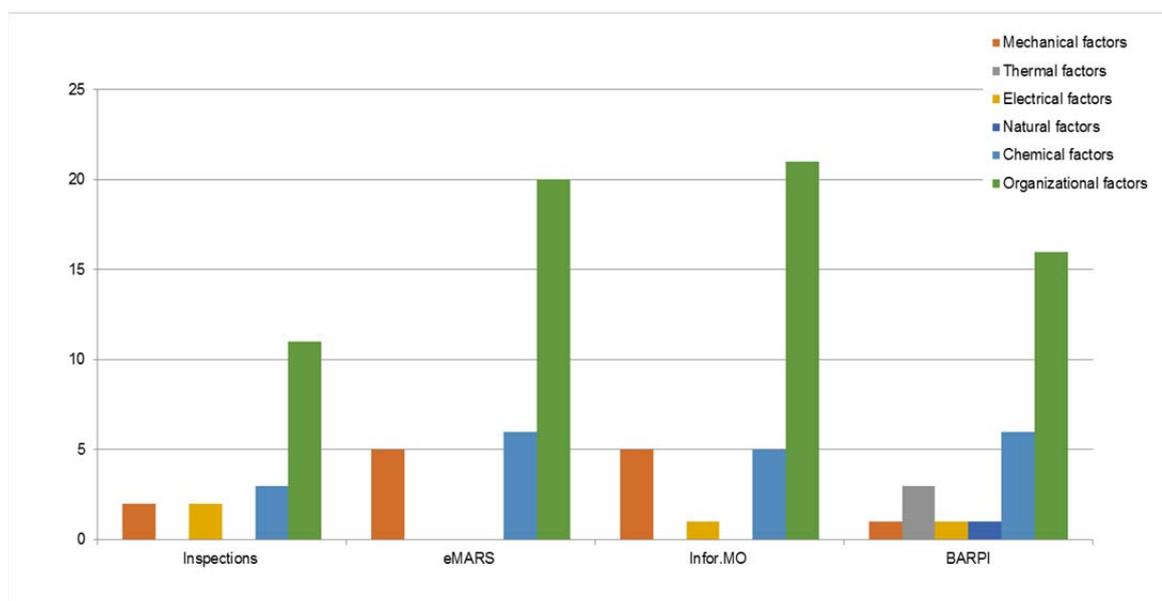


Figure 1: Factors from the reports extracted from the databases

The organizational factors underlying the accidents are shown in Table 3. The frequencies has been derived from all analyzed documents.

Table 3: Organizational factors.

Organizational factors	%
Ignorance/lack of procedures	39,71%
Non-application of known safety procedures	17,65%
Layout	13,24%
Other	13,24%
Lack DPI/Clothing unsuitable	7,35%
Failure quality control	4,41%
Fast/super production pressure/lack of staff	1,47%
Illegal activities	1,47%
Use of judicial deposit material	1,47%
Malicious intent	0,00%

The lack of knowledge or lack of implementation of safety procedures that should be applied in the company have been individuated as the principle aspect to consider in the analysis of accidental events. Furthermore, results show that the weight of the misapplication of known safety procedures is an organizational aspect that cannot be overlooked. By the analysis of accident's reports, many events are due to the "layout" of the factory that has been considered as the arrangement of the operating area and the distribution of buildings. The factor "Other", include training, information and communication issues. These elements, taken individually, do not have a significant weight in the analysis, but they have an important meaning if associated to more general organizational aspects, related to safety culture within the company.

The results obtained represent a useful tool to identify and prevent particular dangerous situations and could be exploited to develop guidance for improving the management of safety in the pyrotechnical establishments.

#### 4.1 Audits

In order to reduce the number of accidents and mitigate the effects of fatal injuries is necessary to stress the importance of audit in the management process. Inspections on the safety management systems for the control of major accident hazard are made according to Italian Decree (Decree 105/2015) by using a specific check-list. To support operators of firework establishments to control and manage risks, in this study a few suggestions to integrate internal audit have been proposed. Specific points that can be easily included in internal audit are reported in Table 4.

Table 4: Check list for internal audit.

SMS items according to the Seveso III Directive	Issues to be explored
Information, Education and Training	<ol style="list-style-type: none"> <li>1. Verify if IE&amp;T procedures define criteria to: <ul style="list-style-type: none"> <li>- involve workers</li> <li>- use correctly PPE</li> <li>- ensure traceability of IE&amp;T activities</li> <li>- individuate risks associated to substances</li> </ul> </li> </ol>
Risk Assessment	<ol style="list-style-type: none"> <li>1. Ensuring the complete assessment of risks associated to dangerous substances used and the storage of raw material and final products.</li> <li>2. Evaluate the risk associated to use of equipment</li> <li>3. Verify operative instructions to manage materials</li> <li>4. Verify procedures to prepare and manage final fireworks</li> </ol>
Operating Control	<ol style="list-style-type: none"> <li>1. Verify the correct airing of depots and control the humidity of operating areas</li> <li>2. Ensure a maintenance activities of operative conditions of equipment</li> <li>3. Use suitable clothing and ensure correct grounding equipment and devices</li> </ol>
Documentation and Reporting	<ol style="list-style-type: none"> <li>1. Verify implementation and correct update of procedures and operative instructions</li> </ol>

The first column of the Table 4 shows the items of SMS to be improved. The second column shows a few aspects that operators have to verify during the internal audit. These suggestions, obviously, may be adopted for improving the external audit procedure too.

## 5. Discussion & Conclusions

At fireworks establishments, it is essential to define specific procedures and operating instructions to increase the awareness of operators and workers about the high risk connected to the handling and processing of explosives and to highlight the weaknesses and possible improvements in the company. In order to reduce the number of accidents and at the same time mitigate the effects of fatal injuries is necessary to stress the importance that has the phase of audit. The internal audits by the operator and external ones by Authorities are an essential part of the management system. They ensure a higher level of safety and promote safety culture. The Seveso Directive is enforced just at larger fireworks workshops and depots, whilst, unfortunately, a number of establishments are under the safety thresholds and are not obliged by the Seveso Directive to adopt a safety management systems. They should voluntarily adopt at least the safety management system, exploiting the incentives for small sized enterprises, provided by national and regional programs for occupational safety and health.

The results of this paper derive from direct information collected by the authors and from reports retrieved from public databases. Inspection conducted by authors are few, whilst documents in the public domain are inhomogeneous, as implemented with different scopes and formats. Even though results are affected by these limits, they may be a good basis to develop operative tools to improve safety in similar plants. Further insights should be made taking into account the Seveso safety legislation and the security legislation in force, as well as the operative experience related to management aspects, such as the organization of safety, the monitoring of critical equipment, scheduled maintenance, education program and training.

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