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Warehousing of Dangerous Goods
Case: Explosives

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Dangerous goods are present everywhere in the modern world. They are obtained, processed, manufactured and finally transformed into everyday household commodities such as detergents, glues, paints and even food flavors and dyes. They are irreplaceable part of modern life, because chemicals production and consumption worldwide is constantly rising. However, not everyone is familiar with hidden hazards they possess.

This thesis aims at suggesting what is required to have a safe warehousing process of dangerous goods especially of explosives considering the nature of the goods. In order to answer to this question, the author describes first how dangerous goods are defined and classified. Research of this thesis is based on secondary data, which includes various European legislations, relevant literature and internet web-sites. All 9 classes of dangerous goods are briefly introduced with the emphasis on class 1 explosives. Handling of dangerous goods is a rather large topic and therefore the scope is limited to packaging and warehousing. In order to understand what is required from a safe warehouse of dangerous goods, the warehouse layout developed by the United Nations is discussed and real life examples are analyzed based on this model. Examples of accidents caused by explosives helped the author to define the main risks associated with explosives and to make suggestions and predictions for improvement and future of dangerous goods handling.

This thesis can be useful for those lacking knowledge about hazardous goods but planning to work in this field and companies considering to start dealing with hazardous goods. Even though the thesis is rather limited and the author was unable to provide primary data, the thesis is valid for those who are interested in dangerous goods in general, but if they require more profound and detailed information, they will need to make further research. The reliability is rather high, because the main sources of information are legislations developed by trustworthy European institutions such as the United Nations and Health and Safety Executive.

Keywords	Dangerous goods, explosives, packaging, warehousing

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List of abbreviations

ARIA	Analysis, Research and Information on Accidents Database operated by the French Ministry of Ecology, Sustainable Development and Energy
CLP	Classification, Labelling and Packaging Regulations by the European Union
COER	The Control of Explosives Regulations by Health and Safety Executive
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations by Health and Safety Executive
ECHA	European Chemical Agency
GHS	Globally Harmonized System of Classification and Labelling of Chemicals by the European Union
HSE	Health and Safety Executive, Great Britain
IBC	Intermediate Bulk Container
ITOER	Identification and Traceability of Explosives Regulations by Health and Safety Executive
LPG	Liquefied Petrol Gas
MARS	Major Accident Reporting System, provided by the Major Accident and Hazards Bureau (MAHB) of the European Commission's Joint Research Centre from EU, OECD and UNECE countries
MSER	Manufacture and Storage of Explosives Regulations by Health and Safety Executive
PPE	Personal Protective Equipment
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals Regulations of European Union
SDS	Safety Data Sheet
UN	The United Nations
UNECE	The United Nations Economic Commission for Europe

1 Introduction

Nowadays it is impossible to imagine a modern word without commodities containing a certain amount of chemicals. Solely in household keeping there is a big number of various consumer goods that consist of hazardous materials, such as washing powder, dishwasher detergents, soaps, shampoos, and almost every kind of modern household chemicals. Moreover, not only household commodities have suffered from chemicals intervention. Unfortunately people also encounter a huge amount of artificial-synthesized flavors, food grade dyes, additives and stabilizers. Even though, in comparison with industrial scale, household consumption of chemicals is rather minor, it is clear that chemicals are produced, transferred, stored and consumed worldwide. The European Chemical Industry Council Fact and Figure 2016 report states that European chemicals sales reached €555 billion in 2014, while worldwide consumption accounted for €3,232 billion, with China possessing the top ranking with €1,111 billion. According to the report the worldwide consumption increased by €81 billion from 2013, which depicts a growing trend in chemicals consumption (CEFIC, 2016). The statistical office of the European Union (Eurostat) states that the total production of chemicals in Europe peaked at 371 million tons in 2007. It fell by 8.4% and 12.8% in 2008 and 2009 respectively because of economic crisis. In 2011 the amount of chemicals produced decreased again and remained stable during 2011-2013 as can be seen in figure 1 (Eurostat, 2016).

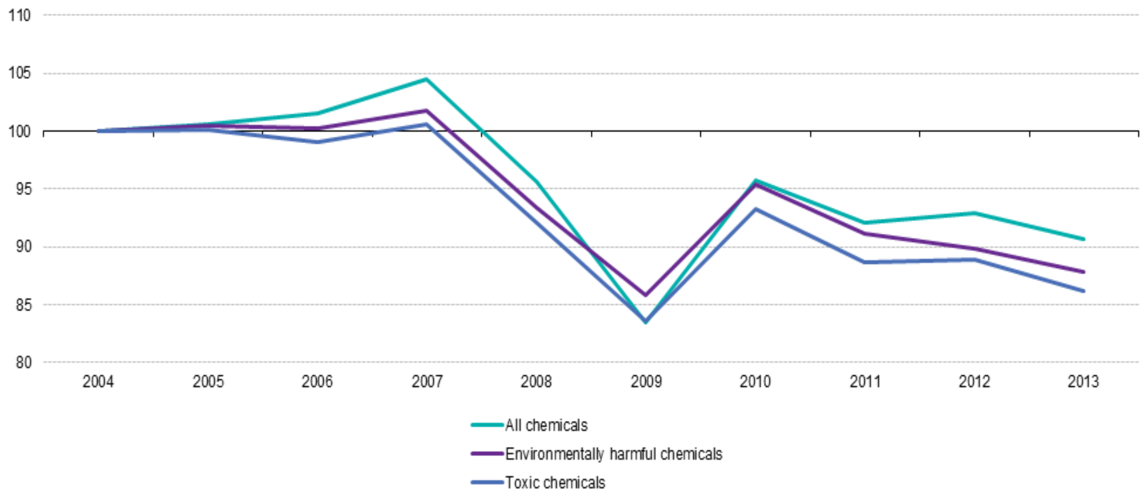

Figure 1. Production of chemicals in European Union 2004-2013 (Chemical production statistics, Eurostat, 2014)

The production of toxic chemicals reached its peak in 2007 and accounted for 235 million tones. During 2008 and 2013 the production decreased and fell to 202 million tons in 2013 (Eurostat, 2016). Explosives manufacturing account for 700000 tonnes and 1 million detonators in Europe (Federation of European Explosives Manufacturers, 2016). Even though in comparison with consumption, the amount of produced chemicals receded, the numbers are quite impressive.

There is probably no plant nowadays that does not use any chemicals at all, because hazards have become an irreplaceable part of almost all production nowadays and maintenance activities, such as cleaning. Even though not all chemicals have hazardous properties, it is still crucial that all of them arrive on site in proper conditions and doing no harm to people involved in dealing with them. This is important because even harmless chemicals can have dangerous chemical reaction with other substances if handled poorly. In this case manufacturers, occupiers, carriers and even governments have to cooperate to achieve the best outcome by providing proper packaging, storage and transportation for hazardous materials while they move through the supply chain. Moreover, nowadays eco-friendliness and high technology have already become a pet project and most economically successful countries are racing towards superiority in efficiency and safety of their business. However, it is a difficult question to answer when it comes to dealing with dangerous goods. No matter how automated and equipped might be a warehouse, there is always a possibility of emergency or even a disaster.

1.1 Objectives and research questions

The main objective of this thesis work is to explore dangerous goods packaging and warehousing in general with the emphasis on class 1 which is explosives. Real life examples will help to understand how efficient they are according to ideal warehousing model, developed by United Nations and whether packaging recommendations are usually met. This research will help to answer the question to which extent safe handling of dangerous goods can exist and how it is achieved. This thesis tries to define dangerous goods, their unique characteristics that influence the packaging, the way of storing and what can cause dangers during handling basically with the emphasis on class 1 explosives. The final objective is to suggest possible solutions for improvement of packaging and warehousing. In order to explore the topic efficiently the following questions were set:

What is understood under dangerous goods in general?

This chapter will help to obtain a basic understanding of the topic, because otherwise, it would be problematic to understand the issue profoundly and be able to critically analyze existing examples of dangerous goods packaging and warehousing.

What legislations control dangerous goods handling?

Acting in accordance with dangerous goods laws and legislation is a must for every company that deals with hazardous materials. The main regulations on packaging and warehousing in European Union will be explored.

How dangerous goods should be packaged and what consequences can poor packaging have? Does Class 1 demand any special packing requirements?

Proper packaging is one of the irreplaceable elements of safe warehousing, because if hazardous properties of goods are fully considered, the right packaging can eliminate various risks during the storage, that is why knowledge about dangerous goods packaging is needed to understand warehousing of hazardous goods.

How should dangerous goods warehouse look like to fulfill all the requirements?

The ideal model developed by the United Nations will be explored to understand what is considered to be the best layout, how safety requirement must be met, etc. Positive and negative examples among companies will be explored to understand what they do correctly and where they fail.

What risks arise within the dangerous goods warehouse and what possible improvements can be suggested?

In order to make proper suggestions, it is necessary to understand possible risks, that can be defined after exploring poor warehousing examples. Several suggestion of improvement will be made to an existing warehouse layout.

1.2 Methodology

The main methodology used in this thesis work is qualitative approach which was defined by Strauss and Corbin (1990) as "any kind of research that produces findings not arrived by any means of statistical procedures or other means of quantification". Qualitative research is focused on illuminating, understanding and extrapolating the situation (Hoepfl, 1997). The research includes secondary data obtained from corresponding legislations, literature, articles and relevant internet web-sites. Theoretical knowledge about dangerous goods and their characteristics was gathered to form a solid basis for the analysis. Legislations issued by the United Nations concerning dangerous goods are fundamental for the research. Dangerous goods packaging and warehousing rules developed by the United Nations will be researched and analyzed. Additional attention will be paid to class 1 explosives throughout the thesis. In order to explore how these regulations are implemented in life, examples of warehousing will be described. The examples will be analyzed in conformity with the United Nations regulations. The analysis will be followed by the conclusions from the particular situations and recommendations from the author.

The thesis reliability is rather high, because the information was obtained from the reliable sources, such as legislations and appropriate books and the results can be easily replicable. Trustworthy institutions such as the United Nations and Health and Safety Executive developed regulations that were the basis of the research. In order to reduce the subjectivity of the study which can decrease reliability, the author distinguishes theoretical information and common knowledge and the author's own thoughts throughout the text.

The research can also be considered as valid, because the text fully answers the research questions using the appropriate methodology which was selected to correspond to the nature of the thesis, which includes secondary data and more profound exploration of the topic. However, considering the narrow scope of the thesis, it is valid only for those who need information about dangerous goods on the general level. Those who need more detailed and deeper view on the topic, will have to make further research.

The author finds the research useful for those intending to start the career in dangerous goods warehousing and handling. It will also be useful for those who are incompetent about hazardous goods because the research will give them understanding about the topic. However, the topic itself is extremely large, considering the wide range of hazardous substances, which made the author unable to cover all the 9 classes in detail, because each class requires special conditions for packaging, storing and transportation. The thesis only briefly explores all 9 classes with the emphasis on class 1 explosives from the logistical point of view, specializing in warehousing activities and packaging. The thesis could have been more deep and concrete if the author had been able to obtain information from the primary sources. That is why those who need more profound knowledge about dangerous goods will find this thesis less valid. The author assumes they will find it more useful to explore the hazardous substances from the chemical or engineering point of view, which will help them understand the nature of dangerous goods.

1.3 Limitations

The geographical scope of this thesis is rather narrow. European Union regulations developed by the United Nations and Health and Safety Executive concerning dangerous goods are explored in the first place. However, the example of non European company case (Tainjin warehouse explosion, China) is also included because the author considered the case is worth mentioning because of its grave consequences even though it cannot be included in the thesis geographical limitations. The narrow geographical scope enables the author to widen the scope of dangerous goods explored. All 9 classes of hazardous materials will be briefly discussed along with general packaging and warehousing rules for dangerous goods. However, more emphasis will be laid on class 1 explosives.

The thesis work includes 5 parts. The introduction provides an overview of the topic and objectives of the research. In the chapter 2 theoretical basis regarding dangerous goods and corresponding legislations are described. Chapter 3 describes dangerous goods packaging rules, with additional attention to class 1 explosives. In chapter 4 hazardous goods warehousing system is explored and chapter 5 provides the analyses of cases. In the same chapter the author analyses to which extent dangerous goods warehouse can be safe and how warehousing of explosives differs from other dangerous goods classes. Chapter 6 summarizes the research and suggests possible improvements to existing warehouse layout.

2 Dangerous Goods

2.1 Classification of dangerous goods

In order to accomplish the main objective of this thesis work, it is necessary to explore what is understood under dangerous goods, their characteristics and what to expect when dealing with them.

Globally harmonized system of classification and labelling of chemicals (GHS) was firstly developed by the United Nations in 1992. This system divides chemicals by hazards they possess, assigns each class a label and relevant safety data sheet. GHS defines dangerous goods or hazardous materials as solids, liquids, or gases, both materials and manufactured products or mixtures of substances which possess hazardous properties. As a rule they have one of these properties: radioactivity, flammability, explosiveness, corrosiveness, oxidizing capacity, asphyxiation, bio hazardous nature, toxicity, pathogenic power or allergenic potency. These goods might also only contain hazardous materials, which can expose their hazardous properties under exceptional circumstances. The most common examples of dangerous goods are petrol, LPG (liquefied petrol gas), paints, pesticides and acids. They might cause explosions, fires and damage and serious injuries, such as poisoning, chemical burns and other health problems (Fox. 1999). The GHS makes hazardous properties available for people dealing with them in order to make each stage of supply chain safer and more effective when chemicals are involved (UNECE, 2016).

As a rule, the most dangerous materials are used in various industries and manufactures, however, goods that contain hazardous properties are used widely in households, for example paint, glue, cleaning fluids, washing powders and gardening products. These goods can gravely harm people, animals, infrastructure and the environment if they are not handled properly. This means that being dangerous substances, they fall under more dangerous conditions while being packed, transported and stored.

Companies dealing with their handling have to face a real challenge not to make already dangerous goods even more perilous. Regulatory regimes and legislations are supposed to control the handling of dangerous goods both locally and abroad. Packaging and warehousing of dangerous goods in Europe are controlled by the United Nations Globally Harmonized System of Classification and Labelling of Chemicals (2015), the United Nations Recommendations on the Transport of Dangerous Goods (2015), Health and Safety Executive "Chemical warehouse: the storage of packaged dangerous substances" (2009), followed by two European Union regulations: CLP (Classification, Labelling and Packaging) (2009) and REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) (2006). These regulations will be discussed more specifically later in this chapter.

As mentioned above, dangerous goods, if not handled properly, can cause grave danger to human health, animals, environment and infrastructure, thus in the beginning of 1992 United Nations firstly developed Globally Harmonized System of Classification and Labelling of Chemicals (GHS), a system of identifying hazardous materials. The GHS identifies inner hazards that various substances possess. Each class has its own graphic representation and marks. The classification system includes 9 classes of materials, with sub-classes for each one of them. The GHS explains dangerous properties of goods and provides guidance on handling of each class. GHS also describes possible logistics solutions for each class (GHS, 2015). This thesis will now briefly discuss 9 classes of hazardous materials shown in figure 2 in order to have the basic understanding of dangerous goods classification.

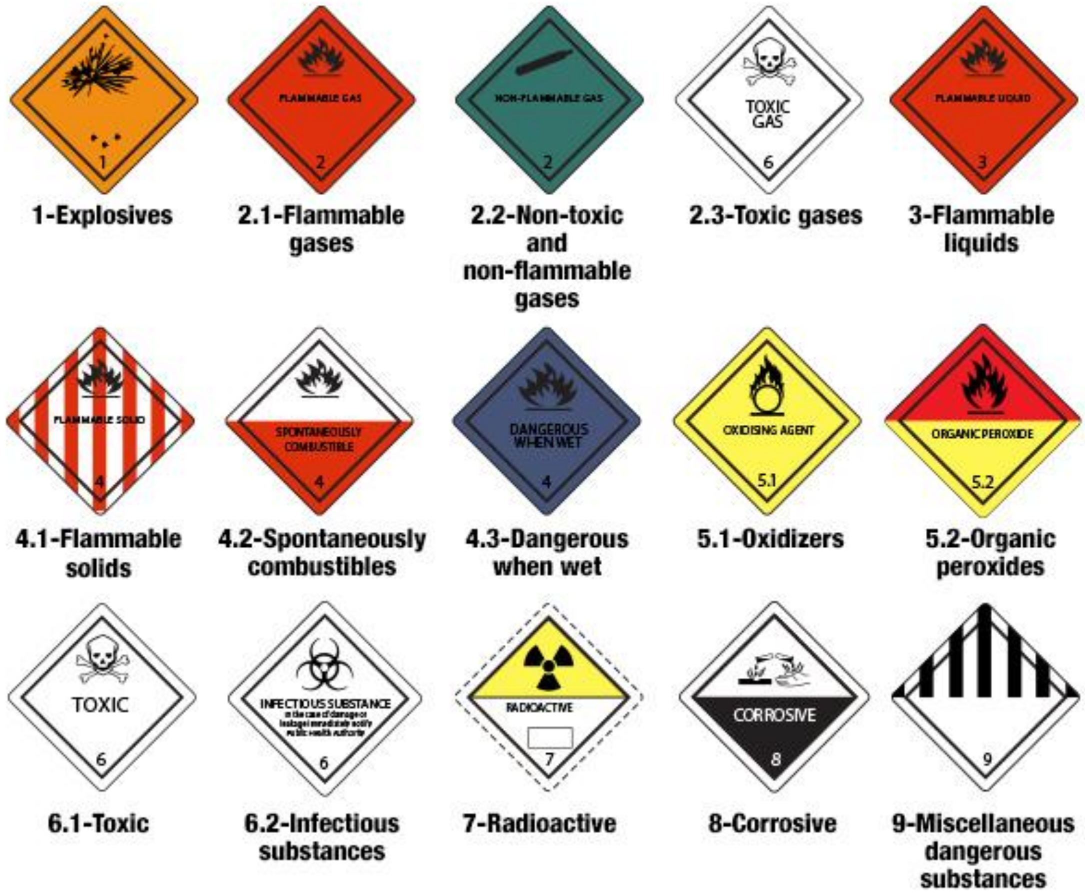

Figure 2. Dangerous goods classification (EuroSoft, 2016)

All 9 classes of United Nations Harmonized System of Classification and Labelling of Chemicals (GHS) are explained in more detail next.

CLASS 1 – explosives

Class 1 includes materials or substances that after a certain chemical reactions are able to conflagrate and exploit. Examples of such chemicals are gelignite, dynamite, nitropill, various detonators, ammunition, fireworks. The explosion can be caused only by a little contact between the explosive substance and small, but extremely sensitive detonator. Even though explosives are apt to behaving violently in specific circumstances, they are rather stable under normal conditions. This quality allows them to be transported by land and sea safely as long as they are not affected and disturbed at traffic accidents or they got hot during transportation.

According to Hazards Regulations 2014, issued by Health and Safety Executive, class 1 is divided into 6 hazard types describing potential behaviour of the explosives. Hazard type 1 produces a massive explosion as a result of any effect. Hazard type 2 produces a serious hazard projection, but is not able to explode as one like type 1. Type 3 is prone to ignition, produces a minor blast or both at the same time, but it is not able to engineer a massive explosion. Type 4 has a fire or slight explosion hazard with no projection. Type 5 includes very insensitive substances which are able to produce mass explosion, but the chance of it is really low. Subclass 6 is extremely insensitive and do not produce mass explosion. However, if the explosive is not kept in its classified package, lacks it or stored without considering its hazardous nature, the type may shift. For example, detonators, classified as type 4, can become type 1 if they are stored without packaging and close to each other. Black powder changes its type 1 to type 4 when stored in small portions of a few grams without confinement.

CLASS 2 – gases

Gasses are substances that can be of compressed, liquefied, dissolved or refrigerated liquefied condition. Examples of such chemicals are liquefied petroleum gas, acetylene, nitrogen, carbon dioxide, oxygen. They are able to have serious poisoning affect because of their flammability, toxicity and potential to causing asphyxiation and corrosiveness to people. Apart from physical dangers, gasses are able to cause chemical outcome, for example flammable and toxic gases.

CLASS 3 – flammable liquids

Flammable liquids are pure liquids, mixtures or liquids that contain solid parts and are able to produce a flammable vapour at temperatures maximum of 60-65 C. Examples of such chemicals are petrol, benzene, acetone, kerosene. These liquids are hazardous because they are volatile, combustible and are capable of conflagrating.

CLASS 4 – flammable solids; substances liable to spontaneous combustion; substances which emit flammable gases when in contact with water

Flammable solids are substances that are more liable to spontaneous combustion than ordinary combustible materials, such as wood and paper. Examples of such chemicals are sulphur, carbon, sodium, zinc dust, calcium carbide. As a rule, they burn with producing great heat. When they burn, they are able to produce toxic gasses and vapours.

CLASS 5 – oxidizing substances; organic peroxides

Oxidizers are dangerous substances which can start combustion as a result of chemical reaction. Examples of such chemicals are sodium nitrate, potassium chlorate, ammonium nitrate, methyl ethyl ketone peroxide. In the organic peroxides the molecule structure includes carbon linked to a double oxygen bond, which means fuel and oxygen are in the same molecule. As a rule they are stored in refrigerators in order to leave them inactive and control their temperature more effectively, as they are thermally unstable. When the temperatures become higher, organic peroxides will quickly decompose, which will end with massive explosion.

CLASS 6 – toxic substances; infectious substances

Toxic substances are those that are able to cause dire damage or be lethal to human when swallowed, inhaled or touched by skin. Examples of such chemicals are cyanide, methyl bromide and bromoacetone. Infectious substances contain pathogens, which are microorganisms: bacteria, viruses, parasites, fungi or others that are able to cause disease or death.

CLASS 7 – radioactive material

Radioactive substances contain redionuclides, which are unstable atoms that are able to change their structure spontaneously and randomly. Examples of such chemicals are uranium, plutonium, strontium. When the atoms change, they exhale radiation which leads to chemical radiation, which can injure human body in various ways, depending on the kind of radiation and duration of exposure.

CLASS 8 – corrosives

Corrosives are materials that produce chemical effects which affect other materials upon contact. Examples of such chemicals are hydrochloric acid, sulphuric acid, nitric acid, caustic soda. They are used to perform various transformations and effects in industry because they are extremely reactive.

CLASS 9 – miscellaneous dangerous goods

Miscellaneous goods are those that cause danger or hazard, but cannot be included in any class mentioned above or those substances that have several properties that belong to different classes. For example: explosive flares, colored smoke candles, flammable solid materials for heating food or providing warmth, fabric repair kits containing flammable liquids.Examples of these chemicals are dry ice, asbestos, hot bitumen, molten aluminium.

2.1.1 Classification of Explosives

In the paragraph above, explosives were explained as dangerous goods with classification provided by the United Nations. Now explosives will be explored as materials in order to have a better understanding of their hazardous properties. According to "Rock Blasting and Explosives Engineering" by Per-Anders Persson (1994), explosives can be classified according to their final user: military or civil. Military explosives are those that are used for military purposes, for example in manufacturing of bombs, torpedoes, shells, missiles, etc. They can be stored up for 10 to 20 years and handled differently from civil explosives, which are used for mining, engineering and rock blasting. In contrast to military explosives, civil are usually produced on site and thus their shelf life is not very long. However, military explosives transportation is more complicated, because it requires transportation in military vehicles or aircrafts.

Another classification of explosives is described in " High energy materials: propellants, explosives and pyrotechnics" (2010) by Jai Prakash Argawal. According to nature of explosives, they can be divided into high (detonating explosives), low (deflagrating explosives), pyrotechnics and commercial. High explosives are divided into primary, secondary and tertiary. Primary explosives react rapidly and produce high pressure during explosion. Primary explosives are extremely sensitive and are able to ignite even after little contact with other chemicals, sparks or fire, also as a result of friction or other impact. They detonate or burn very rapidly and are able to transmit detonation to other substances. These explosives are extremely dangerous and are usually stored in small quantities.

Secondary explosives are not really sensitive to mechanical influence, but in case of contact with high explosive, produce a massive blast. The key difference between primary and secondary explosives is that primary detonate as a result of inflammation, while secondary detonate after contacting with shock waves.

Tertiary explosives are little sensitive to fire or friction and cannot be initiated even using the primary explosive, instead they require a secondary explosive to act as an explosive booster. Low explosives burn slowly and regularly, thus the reaction is less shattering than from high explosives. Examples of low explosives are black powder, smokeless powder and propellants. Pyrotechnics is a mixture of combustible substances and oxidizer, which produces special effects. Commercial (civil) explosives are used for mining, construction and tunnel building.

2.2 Dangerous goods regulations

The processing of dangerous goods through the supply chain is controlled by different regulations. Each step, starting from the manufacturing falls under various legislations which are based on the United Nations Recommendations on the Transport of Dangerous Goods (2009). Even though the UN Recommendations are more a voluntary agreement than a law, they are the basis for the international regulations for handling of dangerous goods. This thesis focuses on packaging and warehousing, thus regulations that cover these stages of the supply chain are discussed more profoundly. Over time due to globalization of market and internationalization of trade, it became necessary to create classification that would be understood worldwide.

The Classification, Labeling and Packaging (CLP) was launched in 2009 and aligns existing EU legislation to the GHS (European Commission, 2016). The CLP supports GHS in its aim to make sure the same hazardous materials are named and labeled all over the world. Like GHS it was developed to facilitate trade and make process of hazardous substances safer. CLP states three main duties for suppliers: properly classify, label and pack the dangerous goods. Before dangerous goods are introduced to the market, it is necessary that the potential risks that might be caused by hazardous substances are identified. The CLP makes sure that everyone involved in the handling of dangerous goods are aware about hazardous properties of goods with the help of proper classification and labeling.

Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) came into force in 2007. REACH was developed in order to improve the protection of human health and environment which can arise while dealing with hazardous substances. REACH influences most companies in EU because it regulates not only industrial chemicals, but also those that are used in households, such as detergents, glues, etc. Moreover, even industries that do not work with chemicals directly, such as electronics, toys, textiles, etc. (Chemical Inspection & Regulation Service, 2012). According to REACH each company must identify and manage the risks, which is followed by the approval of the European Chemical Agency (ECHA) guaranteeing that chemicals can be used safely (ECHA, 2016).

Another important document is "Chemical Warehouse: The Storage of Packaged Dangerous Substances" developed by Health and Safety Executive(2009). It is not a legislation but a guidance for companies dealing with the storage of dangerous goods. It aims at reducing risks to people by advising on better design of premises and control measures.

2.2.1 Explosives regulations

There is a number of regulations regarding explosives in the European Union. The first regulation was The Explosives Act (1875) issued in the United Kingdom. This act applied mostly to gunpowder and other explosives, such as fireworks, fuzes, rockets, detonators, etc. This act prohibited selling gunpowder in public places (including children under 16), throwing fireworks publicly and processing gunpowder without permission. This act was followed by The Explosives Act 1923, as a supplement to 1875 version. It obliged occupiers to take precautions to prevent accidents at the premises, forbid any unauthorized entry to the premises and restrict employment of people under 18. Manufacture and Storage of Explosives Regulations (MSER) 2005 by the Safety and Health Executive covers the storage and handling of all explosive types.

The Control of Explosives Regulations (COER) defines duties for individuals with responsibility for explosives. Placing on the Market and Supervision of Transfers of Explosive Regulations (POMSTER, 1993) regulates safety requirements and controls of explosives. Dangerous Substances and Explosive Atmospheres Regulations (DSEAR, 2002) defines the minimum safety requirements at the work place related to risks arising from fire, explosion and other events in potentially explosive atmosphere. Identification and Traceability of Explosives Regulations (ITOER, 2010)controls tracing of explosives from the manufacturer through the supply chain to ensure they reach the final customer. Health and Safety Executive also helps to follow the origin of goods if they are stolen or lost. A new version of ITOER came into force in April 2013. Explosives Regulations 2014 were developed to help companies and individuals manufacturing, storing or processing explosives. They provide safety provisions and technical guidance.

3 Packaging of dangerous goods

3.1 General requisites for proper packaging

This thesis aims at exploring the storage of dangerous goods and proper packaging is probably the first step of efficient storing. If not packed correctly, dangerous situations can arise even before the goods leave the manufacturing site. The first part of Chapter 3 explores the general rules of proper packaging developed by the United Nations, while the second part looks deeper into the packaging rules for class 1 explosives.

According to Recommendation on Transport of Dangerous Goods by the United Nations (2011), dangerous goods packaging must be of good quality and be strong enough to prevent cargo from shaking during transportation, loading and unloading activities, such as placement and removal from the pallet, including any mechanical handling. In order to provide the safest packaging of dangerous goods, it is necessary to integrate both inner packaging and container properly. All national regulations covering packaging are based on the UN system, which requires packaging to meet standards before it can be allowed for transportation. Apart from proper material for packaging, it is a must to mark and label the good in order to warn about their hazardous properties. Sometimes goods require additional marks to warn about dangers that cannot be reflected by standard marks.

According to the United Nations Recommendations on Transport of Dangerous Goods (2011), dangerous goods must be packed in both inner and outer packages. Inner package must not break, get damaged and cause any leakage into outer package under normal conditions. Packages that are made of materials liable to break, such as some sorts of plastics, glass, porcelain must be placed into outer package with special material that will act as cushion between inner and outer package. In case of damage or leakage of the package, it is still possible to transport the goods in special salvage packaging. However, it is crucial to assure that the damaged package remains as steady as possible within a salvage package. In case of liquids, it is necessary to equip salvage packaging with special absorbent.

Chapter 5 of the Recommendations on Transport of Dangerous Goods states that the manufacturer or consigner is responsible for proper packaging before the goods are allowed to leave the production site. According to the recommendations, the manufacturer is responsible for assigning the proper UN marking to the goods. It includes the sequence numbers that indicate crucial information about the good. According to United Nations, a proper marking should be visible and easily legible, should not become damaged during weather changes and be of a contrasting colour to the surface of packaging. The consignor is also responsible for providing the following information on the UN marking: the shipping name, class, compatibility letter, subsidiary class, UN number, packing group, infectious substance category. An example of marking required by UN is shown in figure 3.

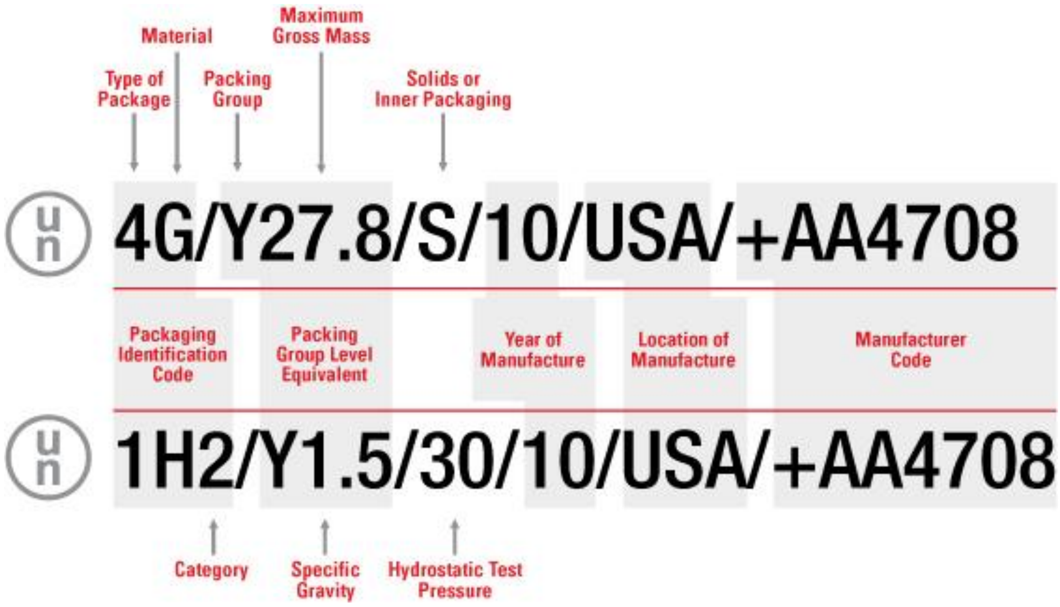

Figure 3. Dangerous goods marking example (Dangerous Goods, 2015)

Hazardous substances are labeled in order to be easier identified and to allow people to understand their dangerous properties and avoid them. Dangerous goods labels and explosives labels with sub-classes can be found under Appendix 1 and 2.

The United Nations in the Recommendation on Transport of Dangerous Goods (2011) states that the label must include the following information:

- The details of the supplier: full name, address and telephone number
- The actual quantity of substance
- Product identifiers
- If applicable hazard pictograms, signal words, precautions or other additional information.

Proper packaging must also be accompanied by a document called Safety Data Sheet (SDS). The example of SDS can be found in Appendix 3 and 4. of Globally Harmonized System of Classification and Labeling of Chemicals (GHS) by the United Nations requires SDS to ensure that suppliers provide enough information about the good and include the following:

- Date of preparation of SDS

- Name, address and contact information of the supplier
- Full product shipping name, UN number, class, subsidiary name and packing group
- Properties of substance: both chemical and physical, including its hazards
- Instructions and recommendations for handling, transportation and disposal
- First-aid in case of emergency, any precautions for the safe usage
- Fire-fighting and explosion control measures

3.1.1 Requisites for packaging explosives

In this section the author explores provisions for packaging of class 1 using the agreement concerning the International Carriage of Dangerous Goods by Road by the United Nations (2011) and Recommendations on the Transport of Dangerous Goods (2009) .

According to the Recommendations on Transport of Dangerous Goods, all packages designed for explosives must possess following qualities. The packages must protect the explosives and prevent them from contacting with other substances and eliminate the risk of inflammation under normal conditions. At the same time, the package itself must be safe to handle and resist any impact during loading and unloading activities.

The Recommendations on Transport of Dangerous Goods states several requirements for explosives packaging. Firstly, the closure devices, such as nails and staples must have a special covering if they are made of metal because it is crucial to prevent any contact between them. However, it is acceptable that a closure device have no covering, but in this case, the outer package must be able to protect explosive from the contact with metal. If the explosive is filled in the drum, the closure device must be equipped with a special gasket. In case of liquid explosives, it is a must to provide a double protection from the leakage in the closure device area.

It is important to ensure that explosive does no move or become interrupted in the package during transportation. This can be achieved by using inner packaging, special fittings and cushioning materials. In order to prevent friction and any contact between items in the package, it is necessary to separate them if they lack additional outer casing. Items can be separated using padding, trays or partitioning within the outer packaging. The packaging must be made of material compatible and impenetrable for the explosive. It is important because it prevents any chemical reaction between the explosive and packaging during transportation. Plastic packaging must not generate energy that will make explosives initiate. The difference in external and internal pressures between inner and outer package, influenced by the temperature change, must not cause any explosion. If the explosive is water soluble, the packaging must be water resistant.

According to the United Nations there are two cases when explosives do not require packaging. Large military explosives with or without means of initiation but containing more than two effective features can be handled without packaging. However, such explosives must be kept at least in crates or other possible handling to prevent them from becoming loose during transportation. In addition, it is possible to omit the packaging when the differences in internal and external pressure between the inner and outer packages can cause the explosive to blast or break through the package.

4 Warehousing of Dangerous Goods

4.1 United Nations recommendations of warehousing

The objective of this thesis was to make research about warehousing of dangerous goods. As described in chapter 3 even the most modern and safe warehouse will not be able to guarantee the best conditions for hazardous goods if the manufacturer fails to pack goods appropriately and provide proper documentation. However, if the initial steps are done correctly, the responsibility transfers to warehousing system and inner handling. It can be a real challenge, because many dangers and hazards can appear when storing dangerous goods, even if all safety requirements are met. People working in the warehouse are subject to dangers such as radiation, heat, missiles, smoke and fumes. However, there can also be hazards within the storage area, for example, decomposition of substances after having contacted with fire or oxygen and resulting in flames or leakage.

In order to help companies with this challenge, United Nations issued a guide called "Chemical Warehousing: The Storage of Packaged Dangerous Substances" (2009) which offers advice how to design the best layout, control risks and provide control measures. The document actually describes the ideal kind of a warehouse. However, the question arises to which extent dangerous goods warehouse can be safe in real life. In order to answer this question, it is necessary to explore what UN understands under proper dangerous goods warehouse and compare it with real life examples.

An example of proper warehouse design can be found under Appendix 5. According to the guide "Chemical Warehousing: The Storage of Packaged Dangerous Substances" (2009), the physical design of the warehouse should comply with following requirements. The warehouse must be one floor building without cellars and basements. Everything must be built using fire-resistant material while the inner premises should consist of separate sections, which are isolated from each other with the help of fire-proof partition walls. Each section should have its own entrance and fire extinguisher with electrical equipment kept outside the premises and protected from explosion. it is also important to provide the warehouse with easy access, especially in case of emergency by building several exits, because the accident might make one of them out of use.

The storing space should be designed the way to facilitate the handling operations. Containers should be kept safely and visibly so that any leaking container will be immediately noticed, removed and properly dealt with. The stacks must not prevent ventilation and complicate the escape in case of emergency. The most matching equipment should be used, which depends on what kind of goods is stored in the warehouse. Containers must be fixed properly to prevent accidental movement, as it might damage the containers and cause accidents. If aisles are narrow, it is advisable to use fork-lift trucks. Any vehicle engaged in handling of dangerous goods should be parked in safely, especially during loading and unloading. It is also necessary to prevent any possible collision between vehicles and containers, so the distances between aisles should be designed properly. Stack sizes should be limited in order to eliminate the possibility of overloading lower levels and the stability of the pile is maintained. It is also crucial that any unauthorized person must not be allowed into the warehouse in order to prevent any act of vandalism. The storage area should be locked and be accessible only for people with the appropriate level of authority.

4.2 Processing of dangerous goods within the warehouse

Processing of goods within any warehouse is an important activity, because if it is done poorly, the goods can be confused or lost. When it comes to dangerous goods, the error outcomes can be even more severe. This section was included in the thesis in order to depict not only how dangerous goods should be stored, but also handled within the warehouse.

When the goods enter the warehouse they must be received by a well-trained person who is aware of all possible risks and is able to choose the correct storage place to comply with hazardous properties of goods and the size of the package. Before sending the goods to the chosen place, it is important to check all the documents that come with the goods as well as the package for the presence of damages. Lucas Bergkamp in his book "The European Union REACH Regulations for Chemicals: Law and Practice" states that safety data sheet is the main tool of communication information about hazards and properties of goods. The safety data sheet (SDS) must be issued by every supplier and received before or the first time the goods enter the warehouse and checked properly. If SDS is not full or unsatisfactory, the goods must not be accepted into the premises and the immediate contact with the supplier is necessary. However, this will not be necessary if the premises are retail outlet or retail distribution warehouse and goods are in consumer packages (Bergkamp, 2013).

Health and Safety Executive in Chemical Warehousing states that if the good cannot be identified or the manufacturer failed to prove all the necessary documentation, the goods must not be sent into the storage area, but kept in the remote safe place until the supplier provides the lacking information. If the goods passed the initial checks and approved to be stored, they must be properly segregated in order to eliminate possible contacts which may lead to inflammation, explosion or dangerous chemical reaction between substances. The occupier is also supposed to prepare a register of each dangerous good entering the warehouse. He also ensures that all transit containers and correctly marked and assigned the right place in the warehouse in accordance with segregation of materials.

According to Chemical Warehousing by Health and Safety Executive, dangerous goods are usually stored in special intermediate bulk containers (IBCs) within the warehouse. IBC is usually used for industrial purposes, such as storing liquids, chemicals, solvents, pharmaceuticals, etc. IBCs are reusable and mounted on a pallet in order to be moved by a forklift within a warehouse. As a rule, dangerous goods and hazardous materials are shipped in IBCs even though previously they were designed for transportation only, but nowadays many chemical warehouses store hazardous substances exactly in IBCs. However, among strong advantages of IBCs, there are certain risks which may arise while keeping them in a warehouse. If IBC is disturbed by a fire, it can be easily damaged at the valve, which will cause leaking out and further escalation of a fire, which might result in absolute failure of the warehouse. Moreover, IBCs degrade faster when used for long-term storage instead of transportation, which was their initial role. This can also lead to leaking out and in case of contact with the source of ignition, initiate a fire.

There are other errors that may lead to IBC damage, such as stacking on uneven surfaces, using with substances that must be segregated, using for storage of waste or failure during transportation. As a rule, IBCs are made from cost-effective plastic material which is non-conductive to electricity. In order to eliminate the risks connected with IBCs, it is necessary that IBCs are properly labeled and handled properly depending in the class of materials being stored. If IBCs store flammable substances, it is advisable that the area is bunded in order to eliminate the risk of fire. If possible these areas should be outside and secured from vehicle damage.

4.3 Special requisites for warehousing of explosives

The most important point of safe storage of dangerous goods is proper segregation. According to Explosives Regulations 2014 by Health and Safety Executive, explosives that have different potential of ignition, are more likely to have a reaction when stored together. Explosives Regulations state following principles of proper segregation. The most important principle is to segregate explosives from other dangerous goods in a separated area, but if it is impossible, separate them with fire resistant walls or screens. It is also necessary to segregate explosives with massive potential hazard from minor potential, because in case of accidental ignition, the most sensitive substance will act as initiator of ignition (for example detonators and igniters should be separated from other explosives). Explosives should be kept in their original packaging designed for transportation and they are allowed to be removed only in an appropriate place. Stable explosives should be kept away from those that present increased hazard: explosives apt to have a reaction with water, explosives containing highly flammable, toxic or pyrophoric substances, explosives with uncertain behavior over time and waste explosives.

According to Explosives Regulations 2014 moving the explosives within the warehouse should also be considered because they can become close to the source of energy which can cause ignition. Moving explosives can also initiate ignition if explosives contact with other dangerous goods in case segregation rules are not met. That is why it is preferable to segregate moving explosives from moving of other goods and minimize the number of people involved in this activity. In order to provide safety movement it is crucial to prevent explosives from being dropped, collided with other goods or being accidently hit (for example, forklift hitting the container with explosives). Another important principle is to avoid mixing various types of explosives or explosives with other hazardous goods while moving on one vehicle within the warehouse. Additional protection should be provided in order to prevent explosives from accidental reaction with other elements that can increase their sensitivity.

The physical design of the warehouse should also be reconsidered. According to Explosives Regulations 2014, the warehouse should have additional entrances for vehicles transporting explosives, routes for employees carrying explosives and special loading and unloading areas for explosives. It is also crucial to ensure that the design of the warehouse is able to protect the goods properly from weather changes, including possessing a lightning conductor and guarantee that rooms assigned for explosives should not be used for storing other hazardous substances.

The Recommendation on the Transport of Dangerous Goods by the United Nations (2009) requires that compatibility groups of explosives should also be taken into account when arranging them in the warehouse. The best option is to handle various explosives separately, but unfortunately it is impossible because of practical reasons and economic costs. That is why compatibility groups were developed to determine to which extent explosives can be stored and transported in one consignment.

According to the Recommendations on the Transport of Dangerous Goods by the United Nations (2009), explosives are considered to be compatible if storing them together does not increase the chance of accident. That is why explosives were divided into groups named with a letter from A to L, N and S (I is omitted). Each group specifies safety provisions for transportation, storage and how to decrease a chance of accident that may arise from handling incompatible explosives together.

Group A includes the primary explosives. Substances in group B are primary explosives that do not contain more than two effective protective features. Group C explosives are propellants or deflagrating materials. Secondary explosives without means of initiation and propelling charge belong to group D. Group E includes secondary explosives without means of initiation, but with a propelling charge. Group F explosives are those that possess means of initiation and with or without propelling charge. Articles G are pyrotechnics or materials that contain pyrotechnics. H explosives contain white phosphorus and J substances contain flammable liquid or gel. Group K explosives include toxic chemical agent in its composition. Group L explosives possess a special risk and must be isolated from other groups. Possible hazard can originate from contact with water or hypergolic liquids. Group N includes extremely insensitive explosives. Explosives in group S are designed and packed so that there is no danger from friction and any hazard is restricted by the packaging. Figure5 indicates which explosive groups can be handled together and what specifics these reciprocities have.

Compatibility group	A	B	C	D	E	F	G	H	J	K	L	N	S
A	X												
B		X											X
C			X	X^6	X^6		X^1					X^4	X
D			X^6	X	X^6		X^1					X^4	X
E			X^6	X^6	X		X^1					X^4	X
F						X							X
G			X^1	X^1	X^1		X						X
J									X				X
K										X			X
L											X^2		
N			X^4	X^4	X^4							X^3	X^5
S		X	X	X	X	X	X	X	X	X		X^5	X

Figure 5. Explosives compatibility table (IMDG Code Compliance Centre, 2012)

- x indicates the groups that can be transported and stored together
- x^1 indicates that explosives in group G can be handled together with C, D and E
- x^2 - that goods from group L can be stored only with the goods from the same group
- x^3 - different extremely insensitive substances can be stored together if there is no risk of explosion between them, otherwise they must be treated as substances with extreme explosion hazard
- x^4 - group N explosives must be treated as group G when they are handled with groups C, D, E
- x^5 - the entire consignment must be treated as group N when explosives from groups N and S are stored or transported together
- x^6 - if a consignment includes substances from groups C, D, E, it must be treated as group E

4.4 Risks of warehousing

Unfortunately substances themselves are not always the cause of accidents. As a rule, discarded or used packaging, pallets, different rubbish can be ignited by accident and cause inflammation. These materials must not be kept within the warehouse. However, if the fire started after all, it will grow faster if incompatible goods stored together are involved in the accident. Moreover, the inflammation can affect even incombustible substances, for example toxics, which will be lifted away in the smoke or drifted with fire foam and cause harm to people and environment later on. The segregation of goods will decrease or even eliminate the possible risk of such escalation of danger. However, if the wide range of hazardous goods is kept within a warehouse, it might be impossible to store them individually.

There are several general causes of accidents in the warehouse. One of the most common is the lack of knowledge and information about the nature of goods and their hazardous properties. Human factor can also be responsible for grave dangers, for example the lack of training and awareness of safety requirements among workers. The design of warehouse itself can be a cause of incidents if designed and maintained incorrectly or insufficiently equipped, or example inadequate control of fire sources, electrical equipment and flammable materials. The most frequent and major risks in a warehouse of dangerous goods examined by the Health and Safety Executive in Chemical Warehousing (2009) are explained in the following paragraphs.

Ignition is probably the most typical accident in a chemical warehousing, as well as the most dangerous. So it is crucial to maintain proper control of possible sources of combustion, such as smoking of employees, maintenance work that include hot and fire work, electrical equipment, vicinity of hot pipes or lightning fixture, heating systems using flames, vehicles and machines, small appliances which can be a source of radio frequency energy. Also even accidental inflammations, for example combustion of in-disposed rubbish contaminated with oil or other minor source of fire can cause a disaster.

In case of poor and insufficient storage there is always a risk of leaking and spillages, which may result in grave destructions. In order to eliminate these risks the warehouse should be equipped with spillage control systems, which will help to prevent accidental spread of liquids. There are several ways of how to control the spillages, for example, using dry sand within the storage area, absorbent granules, sealing putties, etc. In case of leakage, the spoiled materials must be safely disposed using drums or bags that should always be available within the warehouse in case of emergency. The contaminated packages should be enclosed in special salvage drums (also known as over pack drums), which are able to store leaking drums or boxes.

In case of outdoor storage areas, spillages can be handled by special installations or bunds. The area should be designed with impenetrable and slightly sloped floor, which in case of leakage will make any liquid to flow down to a special contained place. It should also be as far as possible from combustible substances, which might cause fire. Corrosion, caused by rainwater can also be a ground for further damage of container and spillage of the substance. In order to withdraw the water from the container, an appropriate drainage system should be implemented. Putting containers on pallets will also reduce a chance of corrosion.

Segregation should also be taken into account when controlling the spillages. Liquids should be averted from penetrating into areas with incompatible materials. In order to prevent the leaked substances from reacting with other goods, it is necessary to incorporate bunded areas inside, in-rack bunds or dry trays beneath every pallet that in case of leakage will direct the liquid to the special area. In order to restrain the pool, it is necessary to incorporate the sills or proper drainage system into the storage area. However, if the spillage did happen, it is crucial to remove the contamination as fast as possible. People involved in cleaning operations must be fully equipped to protect them from possible health damages caused by leaked substance. The clothing must be resistant to substance and have no chemical reaction with it. If the clothing is contaminated, it is necessary to dispose of it after the cleaning is done. If allowed, it can be cleaned by special laundries or disposed as hazardous waste.

Apart from fire, explosion and spillage control, which will significantly decrease possible damage to human health, there are always risk of hazardous dusts and vapors that might be dangerous and even fatal. While working with dangerous substances employees should be equipped with personal protective equipment (PPE). PPE includes eye and skin protection, such as gloves, protective suites, overalls, helmets, goggles, etc. PPE also includes equipment, such as respiratory, eye and ear protection. The nature of hazardous materials determines the choice and fullness of PPE.

Various activities, machines and structured associated, but not directly involved in hazardous goods handling can also be a source of hazards. Possible risks can arise from additional hazardous goods storages, any other work areas or neighboring premises in the vicinity, extreme weather conditions, activities near the premises, such as traffic on the roads, presence of railways or airport, gas pipelines, voltage power lines, etc. Also other activities within the warehouse can have a significant effect, such as movement of vehicles and employees, loading and unloading activities, visitor access and portable sources of risks (matches, lighters, chemicals, etc.).

4.4.1 Risks associated with explosives

Sensitivity of explosives is probably the main source of risks associated with them. Sensitivity is the amount of friction, impact, heat, etc. which is necessary for explosive to ignite or explode (Cheret, 1993). All explosives are sensitive but the amount needed depends on the sub-class. Also primary explosives are rather sensitive to increase of temperature and can be stable at 75C, while secondary and tertiary explosives remain stable at 150C. Explosives sensitivity leads to the major risk which is ignition. Excluding possible sources of ignition will help to decrease a chance of fire outbreak. According to Explosives Regulations 2014 the most common sources of ignition are: naked lights and flames, heat and high temperature, electricity, friction, pressure and chemical incompatibility of certain substances. The risks associated with explosives originate from the main hazards from explosives, which are mass explosion or blast, accidental initiation, projection of fragments and debris, thermal radiation (Merrifield et.al, 1991).

According to Merrifield et.al (1991) the main hazards from detonable explosives is dangerous effect of detonation velocity. Explosives that detonate with high velocity produce significant shattering power, which form craters and cast fragments at high speed. Examples of high explosives are: PETN (8.26 km/s), Nitroglycerin (7.58 km/s), Picric acid (7.26 km/s). Another hazard is effect of blast waves, which result in release of energy. The damage produced by blast waves is expressed as a TNT equivalence. The TNT equivalence of examples mentioned above is 128 %, 148 % and 93 % relatively. The next hazard is effect of yield, which is depicted in the following equation:

Yield = Quantity * TNT Equivalence * efficiency, where efficiency depends on material quantity and type, mode of initiation.

5 Analysis of warehousing of dangerous goods

This chapter will explore and analyze two real life examples of dangerous goods warehouse and compares them to the ideal model and instructions of warehousing developed by the United Nations.

5.1 Senec Hazardous Goods Warehouse, Slovakia

Senec hazardous goods warehouse was built in 2006 by DSV, a company specializing in transportation and logistics and operating in more than 70 countries. The warehouse was constructed for DSV Slovakia and is located 20 km away from Bratislava. The location of the distribution centre is strategically efficient: 360 km to Prague, 60 km to Vienna International Airport and 220km to Budapest. The main part of the distribution centre was build a year before in 2005 and serves as a general warehouse. It occupies 3000 m^2 and offers 4130 pallet places. After having been constructed, the dangerous goods warehouse was added to the general warehouse and occupies 2200 $m^2$and has 2100 pallet places. The warehouse has 14 separated chambers: 6 rooms for flammable liquids and gasses, 6 rooms for other classes of dangerous goods and each room for goods preparation and safety needs (Goodman Senec Logistics Centre, 2016). The warehouse layout and goods allocation plan can be seen in the figures below.

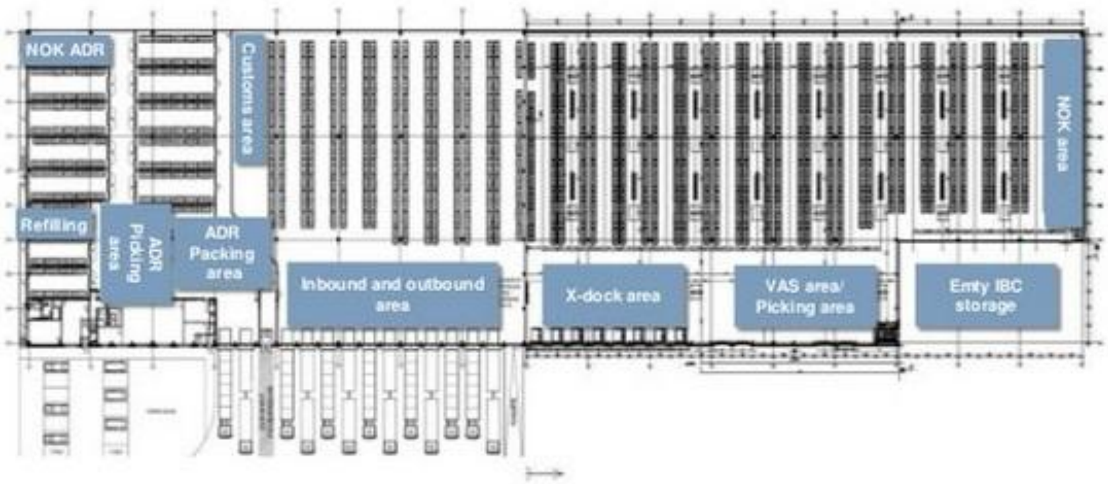

Figure 6. Warehouse layout: floor allocation plan. (Goodman Senec Logistics Centre, 2016).

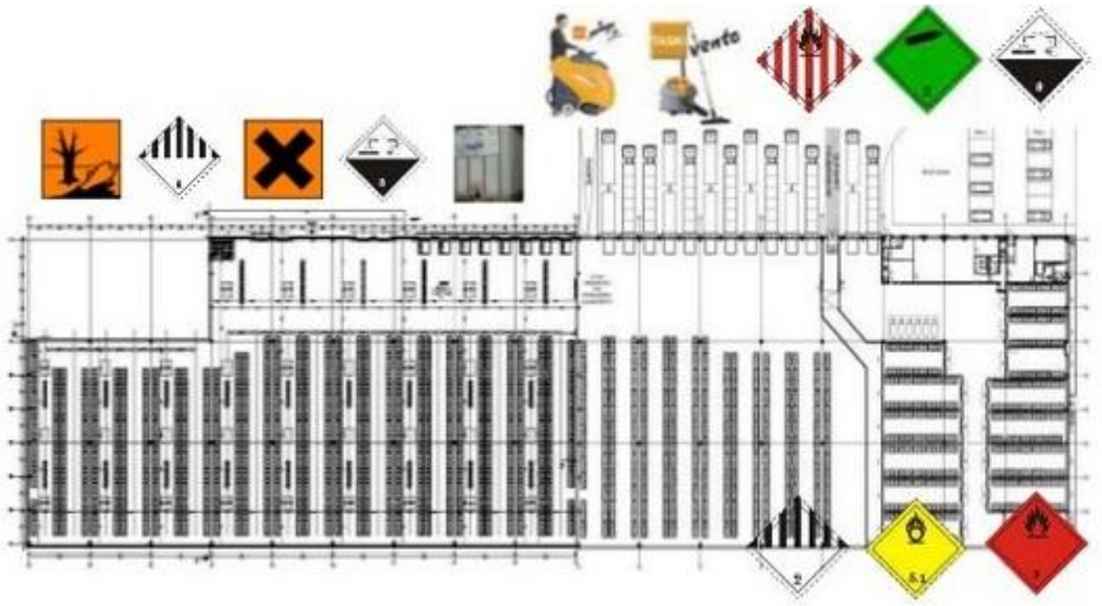

Figure 7. Warehouse layout: goods allocation plan (Goodman Senec Logistics Centre, 2016).

Senec's warehouse is fully equipped not only to handle hazardous goods properly, but also to provide security at work place. The warehouse was built in accordance with safety and emergency rules and is equipped with fire detection and alarm systems, which detect smoke both optically and thermally. Fire alarms are button shaped to facilitate their access and usage in case of emergency. The warehouse also has gas and vapor detection system and special signalization which comes into action the moment when gas concentration exceed the acceptable level. The ventilation system is automated and forces double air exchange per hour and during emergencies 10 times per hour. (Goodman Senec Logistics Centre, 2016).

In case of fire, the warehouse is equipped with both water and foam extinguishers. There are special foam sprinklers that are placed on every racking level which allows to immediately eliminate fire in the very place it appears. Outside the warehouse there are water hydrants and conservation pond. The doors of separated rooms where flammable materials are stored are shut automatically in case of fire. The floor is coated with antistatic cover and is resistant to chemical effect from any contact with hazardous materials. Senec warehouse can be referred to as a proper warehouse for dangerous goods because it provides necessary equipment and safety standards. Each room is separated, which fulfils the demands of segregation of hazardous goods. The doors between rooms are shut automatically in case of ignition, which might be crucial in case of a disaster. The detection system is hi-tech: apart from smoke detection, there are optical and thermal alarms. Both inbound and outbound activities are supported by bar-code scanning. (Goodman Senec Logistics Centre, 2016).However, even though nothing is mentioned about leakage risks, the warehouse proves to be reliable and well planned.

In comparison to the United Nations layout depicted in Appendix 5, Senec warehouse plan is rather similar. Various goods classes are allocated apart from each other in order to provide segregation. Senec is one-floor facility as recommended by the United Nations. Loading, packaging and empty IBCs areas are separated from the hazardous goods rooms.

The description above allows the author to assume that Senec warehouse is a positive example because according to the ideal model developed by the United Nations, it has:

- Diverse fire detection system
- Gas and vapor detection system
- Alarm system, both optical and thermal
- Automated ventilation system which provides air exchange on regular basis
- Availability of water and foam extinguishers
- Availability of foam sprinklers above every rack for immediate elimination of fire
- Chemically resistant floor
- Each room is separated, which enables proper material segregation

However, the author also defines some areas for improvement:

- Electrical equipment should be kept outside to prevent from explosion in case of fire
- Nothing is mentioned about leakage preventing - rows of containers with liquids should be kept on the surface with small angle, so that in case of spillage the liquid flows down and can be immediately noticed

5.2 Ruihai Logistics warehouse, China

This section will explore the negative example of dangerous goods warehousing. Probably the most notorious example poor warehousing is Chinese company Ruihai Logistics, which is responsible for the devastating Tainjin warehouse explosion. The company deals with dangerous goods within the port of Tainjin since 2011. Ruihai Logistics processes various kinds of hazardous materials, such as compressed air, flammable and corrosive substances, oxidizing agents and toxics. Even though the company handles such a various classes of dangerous goods, the tragedy did happen. Several warehouses are located within 46,000 m^2 site, including a fire pump and a fire pond. According to safety regulations, there must not be any public buildings in the close vicinity of the warehouse. However, the site was located less than one km away from public houses with locals unaware of their virtuous neighbor. The closest family was living only 600m away from the warehouse. Moreover, because of poor record keeping, the company was not able to identify and segregate the goods properly. The authorities claim that the company was functioning illegally because it received the license for dangerous goods handling less than two months before the explosion. This means that Ruihai logistics was lacking a license from October 2014 till June 2015 (Huang, 2015).

The mayhem began on the 12th of August 2015 when the fire was spotted on the site. The first attempts to stop the fire were not successful, as firefighters were not aware of hazardous properties of goods and even aggravated the situation. Later on two major explosions happened, which spread many kilometers away. They were followed by 8 smaller explosions, with the total energy outburst of 450 TNT. The disaster took life of 173 (95 of them were firefighters) people and injured 797 (The Guardian, 2015). The area with surrounding logistics companies was gravely damaged. The explosions left a huge crate and burned many vehicles in the port. Even a department store located 4 km away was reported to have its windows blown up. The cause of the explosion is still a riddle and most like remain unsolved. The problem is that no one knows exactly how much and what hazards were stored in the warehouse. It is only discovered that over 40 kinds of chemicals were stored in the warehouse. The disaster was also followed by a pollution: sodium cyanide was reported to have leaked in the sewers. After the first rains local people began suffering from burning feeling and rushes over their bodies. Thousands sticklebacks died and a threat of water contamination raised (Varandani, 2015).

This example shows clearly what disastrous consequences a poor design of a warehouse can have. The United Nations recommendations on proper warehousing allowed the author to analyze the case above and assume the disaster happened because of the following:

- Lack of goods segregation
- Clearly lack of automated fire and smoke detection system
- Lack of fire distinguishers suitable to all kind of goods
- Poor training of employees - failure to provide proper record keeping and unawareness of employees about hazardous properties of goods
- Lack of spillage prevention system, which resulted not only in leakage of substance from the container, but also into the sewers, which means the floor was not protected enough to prevent the liquid from further flowing

After having explored Senec's Warehouse example it is possible for the author to assume that dangerous goods warehousing have become safer and more reliable, even though accidents like Tainjin disaster still happen. Availability of model instructions from the United Nations and fast developing technologies makes it possible for organizations to build the proper warehouse. However, there is always a risk of external factors, such as human factor, nature disasters or other unexpected circumstances, but if employees are aware of them and prepared, the chances to decrease the negative consequences of possible accidents is rather high.

5.3 Accidents involving explosives

The following examples were chosen for analysis after exploring the ARIA (analysis, research and information on accidents) database. The database is operated by the French Ministry of Ecology, Sustainable Development and Energy and presents accidents happened at industrial facilities and had hazardous impact on environment (ARIA, 2016). The accidents listed describe cases in European Union since 1992. The following accidents were chosen because they correspond with one of the thesis objectives regarding dangerous goods warehousing.

5.3.1 Fireworks plant, Città Sant'Angelo, Italy.

The accident happened in a fireworks plant containing 11 small buildings used for production and warehousing covering around 300000 sqrm. (ARIA database, 2015). The warehouses were storing various dangerous goods, such as fireworks, black, aluminium, titanium powder, etc. The accident happened on the 25th of July 2013 in the storage area while three employees were moving fireworks from the warehouse to pick-up truck for internal transfer. The further accident investigation showed that fireworks transfer was the cause of explosion. The series of three explosion occurred in two buildings, followed by the two explosions in another buildings.

As a result 7 of 11 buildings were completely destroyed with others partially damaged with almost all the amount of fireworks involved in the disaster. Even though the mass explosions, emergency procedures were not initiated and the firefighters were called by the inhabitants of the area. Moreover, evacuation signal for employees was never given and they remained on site. The firefighting process was complicated because of plant layout and the arrangement of accesses. The only access was suitable for its purposes because it was large enough for letting firefighting equipment inside the plant.

The MARS Commission (Major Accident Reporting System managed by the Major Accident Hazards Bureau from the European Commission) identified several causes leading to the accident:

- Presence of non-authorised products
  The plant was storing products that were not allowed, including linked fireworks bombs already with a mortar. The Italian regulations prohibit fitting fireworks into mortars while they are produced or stored, only directly before fireworks performance. Moving assembled pyrotechnics is extremely dangerous, which proves why the transferring operations was the cause of accident.

- Storage of excessive quantities

  The domino effect happened because of small distance between the buildings, which was prohibited by Italian safety regulations. However, the safety distance decreases risks only if the amount of goods is not excessive. In this case, the domino effect was the result of explosion of excessive quantities of pyrotechnics.

- Unsafe operating conditions

  The lack of time for manufacturing operations forced employees to work in unsafe operating conditions. The time constraint caused by the demand for pyrotechnics in this time period and induced the employees to store excessive quantities and assemble fireworks at the production site.

- Poor plant design and layout

  The internal emergency procedure failed during the accident: the firefighters were not immediately called and employees were not evacuated. Poorly planned emergency accesses did not allow firefighters enter the site quickly.

- Disregard of warning signals

  Inspection done seven months before the accident had defined several weak points for this particular plant: lack of sufficient training of employees in case of emergencies and safe operational procedures; lack of sufficient emergency procedure itself: description of emergency system, communication during accidents, identifications of emergency situations, process of evacuation; deficiency of safe and proper locations of packages.

The accident resulted in 5 people being killed with 8 injured. The quantity of explosives substance released between 5 and 50 tons of TNT with the external losses accounted for between 0,5 and 2 million euros. These severe outcomes draw attention to the following points, which are crucial when dealing with explosives. Safety regulations must be considered in the first place, including quality, quantity and compatibility of goods stored within one area. Proper training of employees must be provided in order to decrease the human factor and make operations safer. Emergency procedures must be precise and well knows by employees. Warehouse design must prove quick and easy exit from the premises in case of accident. The premises must be built with appropriate material, so that in case of accident the amount of debris coming from damaged buildings is critical.

5.3.2 Oil storage depot, Buncefield, the UK

Another accident happened at Buncefield, UK in oil depot on the 11th of December 2005. The average amount of fuel stored is 150000 tones, which include gasoline, fuel oil and kerosene. The storage area includes three supply pipelines and two distribution lines. the first explosion was followed by a fire spread to 21 storage tanks and was heard in a distance of 160 km. The initial blast was later one followed by two additional explosions. Two days after the storage area was still in flames causing large leakage of product in retention areas. It order to stop the fire, it was decided to use special foam liquids which is known to be toxic for the environment.

During the 12th of December the fire was almost contained, but by the end of the day, the operation was abolished because of explosion risk. The operation lasted until December 14, when suddenly one more tank caught fire. Eventually the fire was extinguished only on the 15th of December. The investigation defined that the cause of accident was the explosion that happened because the liquid in the tank started to expand and overflow. Later on the explosive cloud covered the whole area of the site, even expanding beyond the territory. The automated level detection system in the tank was not working. When the liquid began to expand, no alarm was given.

When the accident happened, the fire fighters encountered following difficulties. The firefighting equipment was destroyed during explosion and the pumping station was destroyed which disabled the usage of water supply of the site. The site was also flooded with leaked substances from exploded tanks, which obstructed access to necessary installations within the site. These difficulties resulted in 800m radius damage with 43 people injured, the warehouse wall completely destroyed, including broken windows and doors, parked cars burned, loading section damaged along with control room. The environmental impact was also serious: the air was polluted, soil under the site and nearby water bodies were contaminated with fire foam. As a result, the reconstruction costs accounted for €37 million while the material loss was equivalent to €52 million.

5.4 Analysis of the cases and suggestions for improvements

After exploring the accidents, the author of the thesis can suggest several improvement ideas. Electronic monitoring of the alarms in the tanks can be implemented for more efficient control. This will eliminate the risk of overflowing and maintain the adequate level of substance in the tank. Tanks can also be equipped with inflammation detection system and detection of abnormalities, for example accidental opening of valves. The premises layout must not be an obstacle in case of emergency and hinder the access ways to safety installations.

The examples described in previous chapters prove that risks go hand in hand with dangerous goods. There will always be some human factor, technology breakdown or any kind of error which might lead to risks within the warehouse. In the chemical warehouse, absolute elimination of risks cannot be possible, because materials themselves are hazardous in nature. Even though it is impossible to remove the goods, which are the source of danger from the premises, it is still possible to segregate the goods in separate rooms and equip the premises with modern alarm and protection systems, improve the physical design of premises and provide employees with training.

On more general level, the author may suggest the following ways how to decrease explosives sensitivity during handling:

- Adapt the physical form of packages according to explosives sub-class: extremely dangerous explosives should be kept in small quantities, while insensitive substances can be stored in bigger packages, but not excessively large
- Pack explosives with cushioning material
- Provide encapsulation to prevent from contact with atmosphere and reaction with other goods
- Reduce the size of the package
- Separate the packages not only from other dangerous goods, but if possible explosives from different sub-classes, which his will decrease the risk of transmitting the fire to other packages in case of inflammation

Other ideas for improvements is aimed at warehousing of hazardous goods in general. Even though most warehouses today are automated and maintained using IT systems, which decreases human factor, it is necessary to take into account the possibility of equipment deterioration. Sprinkler systems should be tested once a year, fire prevention system should be examined by a specialized company also at least once a year. Companies that mix chemicals on their site, should always check whether their tanks are subject to corrosion. Following these simply suggestions, will decrease the technical risks dramatically. However, even though the main part of the warehouse is automated, there is always a number of employees operating the systems. Forklift operators and floor level workers should be retrained on the regular basis. Training evacuation can also be implemented once a year, in order to check how goods employees are prepared for possible accidents.

A proper design is the best tool when trying to limit the risks and control activities in the warehouse. No matter what class of goods are stored in the warehouse, they all have to have a proper safety system, which is not limited to simple fire alarm and extinguishers. Proper water supply is one of the important things to consider. As a rule, each warehouse has a sewage system, but this may not be enough in case of fire. Supplemental sewage system or pumps will help to provide additional water supply in case of emergency.

For larger warehouses, it may be necessary to install booster system, which will produce additional pressure in case of massive fire. If Tainjin warehouse had been equipped with booster system, it would have been able to avoid the disaster. Apart from traditional alarm system, visual alarms can be introduced. They are useful in warehouses and plant with high noise levels. Even though automated alarm system can be quite reliable, it is still advisable to equip the warehouse with fire hose reels or they substitute: fire hydrants. Introducing a system of conveyors instead of a forklift will eliminate the human error which may be caused by poor training of a forklift driver.

In the chemical warehouse, it is important to reduce the amount of other dangerous substances used for maintenance work in order to eliminate the risk of chemical contact between them. If possible, they should be substituted with less dangerous materials. For example, instead of using chlorinated solvent for degreasing, it is safer to use a detergent. Diesel can also replace petrol or kerosene, which are both flammable liquids. Other dangerous substances that usually come in powdered form can be replaced by the same substances but in the form of paste or solution. Reduction can be achieved by regular and immediate disposal of hazardous materials that are no longer in use.

Audit is another effective method how to improve the business. Michael B. Weinstein in his book Total Quality Safety Management and Auditing (1997) makes reference to ISO -10011-1 which defines audit as: "a systematic and independent examination to determine whether quality activities and related results comply with planned arrangement and whether these arrangements are implemented effectively and are suitable to achieve objectives". Michael B. Weinstein states that audit can be applicable to systems, programs, services, etc. within the organization. The audit can be both internal and external. In case of dangerous goods warehousing, external audit can be helpful if companies have recourse to organizations specializing at dealing with chemicals.

Administrative controls focus on changing the existing methods of work to make them more effective and improve the working environment. There are different ways of how to decrease risks at work. Health and Safety Executive in "Working with Substances Hazardous to Health" (2012) states that control measures should be properly combined with working ways to reduce hazards. It is required that standard operating procedure integrate proper equipment and proper way of using it, which combines instructions, trainings and supervision of employees at work. Employees should be trained how to handle the goods safer depending on their hazardous properties. It can also be advisable to reduce the number of people in the storage area and prohibit activities, such as eating, drinking, smoking and carrying any lightning devices at the work place. Personal protective equipment (PPE) include protective clothes, such as overalls, aprons, gloves, boots, helmets, etc. PPE also involves wearing protective equipment, such as dust masks, respirators, face shields, hearing protection, etc. (Working with Substances Hazardous to Health, 2012).

6 Conclusions

The findings of the thesis prove that handling of dangerous goods is a complicated process, which differs for each class. The qualities and specifics of goods must be taken into account before providing both packaging and warehousing. The main research question to which extent dangerous goods warehousing can be safe was answered positively. Detailed legislations and recommendation issued by authoritative bodies enables companies to provide the proper handling of hazardous goods on each stage of the supply chain. The availability and openness of information regarding hazardous goods helps people dealing with them to avoid risks and dangers.

Nowadays the existence of automated systems and high technologies make warehouses of dangerous goods safer and ready to react properly in case of emergency. However, there is still room for improvement and nowadays it is still impossible to eliminate human factor and technology errors. Possibly in the future, when computers become even more powerful and will be able to completely replace the human employees, it might be possible to eliminate risks fully. Even now there are famous companies that successfully implemented fully automated warehouses, for example: Zappos, which delivery time is 24 hours, Diapers.com, UPS Worldport, IKEA's "Distribuzione" which covers European region and processes 43 million items every year. (Digital Supply Chain, 2011). Amazon is already using 30,000 robots in its warehouses worldwide (Bloomberg Technology, 2016). Google is also working on implementing autonomous and remote controlled robots for moving cargo within the warehouse. (Business Insider, 2016). The further potential topic for research can be the warehouse of the future, which will be absolutely different from the warehouse of today. The technology evolution might make it possible to transfer extremely dangerous goods to store in the underground premises, where human employees will be replaced by robots. The machines will be fetching the goods from the underground and transferring them to final user in super safe containers. The premises will be coordinated by the powerful computer over ground. In case of accident, the risk of severe damage to people and environment will be seriously decreased. However, these innovations might look too far-fetched, but considering the speed of technology development, this can become possible in the next hundreds of years.

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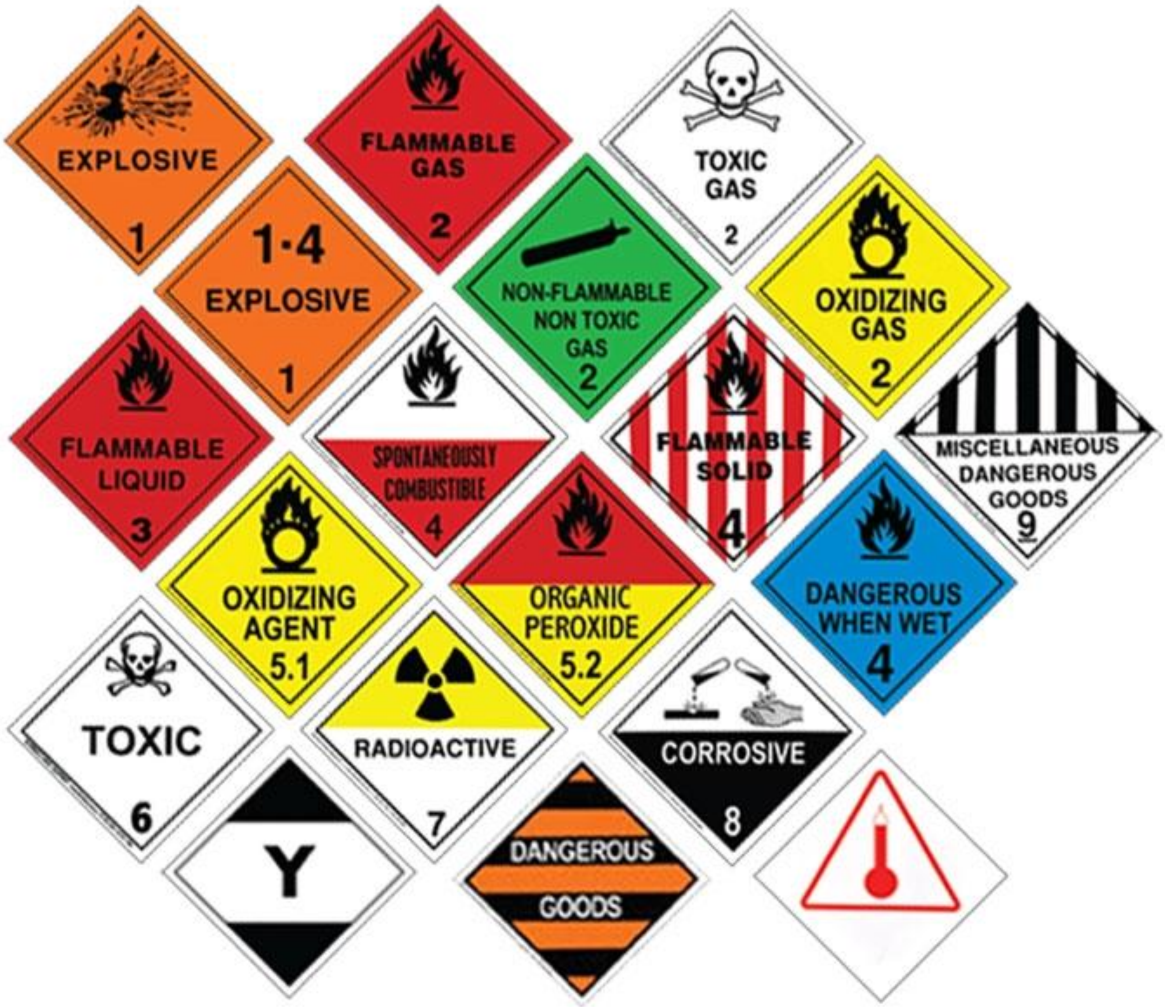
Dangerous goods labels



Explosives labels

Explosive Class 1.4

Explosive Class 1.1

Explosive Class 1.2

Explosive Class 1.3

Explosive Class 1

Explosive Class 1.5

Explosive Class 1.6

Safety Data Sheet

MATERIAL SAFETY DATA SHEET - 9 SECTIONS

SECTION 1 - PRODUCT INFORMATION

Product Name
Product Use
Manufacturer's Name
Physical and Mailing Address
Emergency Contact Phone Number

WHMIS Classification (optional)

Supplier's Name
Physical and Mailing Address
Emergency Contact Phone Number

SECTION 2 - HAZARDOUS INGREDIENTS

Hazardous Ingredients (very specific)

SECTION 3 - PHYSICAL DATA

Physical State (What does it look like? Is it a liquid, gas, or solid?)
What happens to it under a variety of circumstances? (i.e. heat, freezing, dropping, etc.)
Flammability and how to extinguish. Includes a wide variety of details concerning how easily this product

SECTION 4 - FIRE AND EXPLOSION DATA

will ignite / explode and how to deal with it.
How stabile is this product?

How it reacts under various conditions.

SECTION 5 - REACTIVITY DATA

Incompatibility with other substances.

Hazardous Decomposition Products

Information about how the product affects and enters the body. Immediate affect. Long term toxic affect.

SECTION 6 - TOXICOLOGICAL PROPERTIES

Exposure limits. In summery, immediate and long term affects to the human body.

SECTION 7 - PREVENTIVE MEASURES

Personal Protective Gear; ventilation, etc.; leak and spill info; waste disposal; handling and storage; special shipping instructions

SECTION 8 - FIRST AID MEASURES

Information for immediate first aid treatment. Usually always ends with "contact a Doctor"

SECTION 9 - PREPARATION INFORMATION / *Who prepared this and contact info*

Safety (Material) Data Sheet example

Material Safety Data Sheet

CALTEX

SECTION 1 PRODUCT AND COMPANY IDENTIFICATION

Delo Gold Ultra SAE 15W-40

Product Number(s): 500574
Company Identification
Chevron Pakistan Ltd
State Life Building No. 11, 1st Floor
Abdullah Haroon Road
Karachi 74400
Pakistan

Transportation Emergency Response
Pakistan: 0800-21-22-33, opcao 2
Health Emergency
Chevron Emergency Information Center: Located in the USA. International collect calls accepted. (800) 231-0623 or (510) 231-0623
Product Information
email : yhrizvi@chevrontexaco.com
Product Information: 92-21-565-2930 & 568-1371 EXT 257
MSDS Requests: 92-21-5215644

SECTION 2 COMPOSITION/ INFORMATION ON INGREDIENTS

COMPONENTS	CAS NUMBER	AMOUNT
Highly refined mineral oil (C15 - C50)	Mixture	70 - 99 %weight
Zinc alkyl dithiophosphate	68649-42-3	0.5 - 1.5 %weight
Calcium long chain alkaryl sulfonate	722503-69-7	0 - 0.75 %weight
Branched alkylphenol and Calcium branched alkylphenol	74499-35-7 & 132752-19-3	0.05 - 0.15 %weight

SECTION 3 HAZARDS IDENTIFICATION

IMMEDIATE HEALTH EFFECTS
Eye: Not expected to cause prolonged or significant eye irritation.
Skin: Contact with the skin is not expected to cause prolonged or significant irritation. Contact with the skin is not expected to cause an allergic skin response. Not expected to be harmful to internal organs if absorbed through the skin.
Ingestion: Not expected to be harmful if swallowed.
Inhalation: Not expected to be harmful if inhaled. Contains a petroleum-based mineral oil. May cause respiratory irritation or other pulmonary effects following prolonged or repeated inhalation of oil mist at airborne levels above the recommended mineral oil mist exposure limit. Symptoms of respiratory irritation may include coughing and difficulty breathing.

Dangerous goods warehouse layout by the United Nations