



European Guideline

CFPA-E No 31:2013 F

Protection against self-ignition
and explosions in handling and storage
of silage and fodder in farms





Foreword

The European fire protection associations have decided to produce common guidelines in order to achieve similar interpretation in European countries and to give examples of acceptable solutions, concepts and models. The Confederation of Fire Protection Associations in Europe (CFPA E) has the aim to facilitate and support fire protection work in European countries.

The market imposes new demands for quality and safety. Today, fire protection forms an integral part of a modern strategy for survival and competitiveness.

This guideline is primarily intended for farmers or those responsible for safety in farms. It is also addressed to personnel who, one way or the other has to relate to risk and safety in farms. The guideline does not include the actions by the fire brigade and the risks the fire fighters are exposed to by flames breaking out from the smouldering fires in the silos or explosions thereof. It is emphasized that it is necessary to make the guideline available to farmers with little expertise in the field of risk assessment and fire protection.

The proposals within this guideline have been produced by Norsk brannvernforening and the author is Kjell Schmidt Pedersen from Norway.

This Guideline has been compiled by Guidelines Commission and adopted by all fire protection associations in the Confederation of Fire Protection Associations Europe.

These guidelines reflect best practice developed by the countries of CFPA Europe. Where the guidelines and national requirement conflict, national requirements must apply.

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1 Introduction

As a result of extensive rationalisation, mechanisation and increase of the size of production buildings and installations fire and explosion risks on farms have increased.

The European farmers' need for knowledge and qualified guidance has increased over the last few years due to the fact that the responsibility for safety within buildings and installations that is required by legislation rests on the farmers or owners themselves.

The CFPA E Guidelines Commission has issued a Guideline concerning fire prevention and protection for farmers in general but this Guideline, Guideline No. 17:2008 "Fire safety in farm buildings" does not include explosions or self-ignition due to handling of hay, straw, silage and fodder.

The fire statistics for the different European countries do not reveal any particular risk for dust explosion for ordinary sized farm units. The risk for self-ignition is however clearly revealed in the statistics. If the units extend in size and activity the risk for dust explosion may become significant, because the activity may include large silos for storage, vertical and horizontal transport lines and to some extent milling installations.

The commission has hence identified a need for guidance concerning prevention and protection against these risks to provide a more comprehensive guidance for farmers.

The typical users of this guideline and Guideline No. 17 are the farmers themselves and the personnel given any responsibility by the farmers. This fact is taken into consideration in establishing the guideline.

Both physical and organizational measures can be applied to reduce the risk to an acceptable level.

2 Fire and explosion risk exposures for farms

The intention is that this guideline and Guideline No. 17:2008 together will cover the fire and explosion risks exposure and needed prevention measures for farms in general.

As Guideline No. 17:2008 points out, the farm activity implies specific fire and explosion risks elements and calls for specific prevention measures. Such risks include:

- The exposure of animals and hence the evacuation challenges.
- The risks concerning the specific environment on farms (high humidity, dusty atmosphere, acidic waste, presence and storage of manure).
- The presence of the staff members at all times (living next door to the working facilities).
- Handling and storage of grain, straw and fodder leading to self-ignition fires and explosion risks.
- Driving and parking of vehicles and machinery indoors and outdoors.



- Extended use of electrical appliances (e.g. high pressure cleaners, ventilation fans, mobile heating lamps/units, electrical fly catchers, mobile working lamps up to 500 W) and distribution of electrical power.
- Different activities with inherent different risks establishing a need for separation between buildings and some activities inside buildings.
- Large amounts of combustible materials of different properties.
- The use of radiant gas burners.

3 Scope of this guideline

The aim of this guideline is to give farmers themselves an adequate understanding of the phenomena of self-ignition and explosion and the prevention measures they can take to achieve an acceptable level of safety. This guideline will together with Guideline 17:2008 comprise comprehensive guidance for farmers when it comes to fire and explosion safety. The target group for this guideline is the farmers themselves and not fire safety experts. The guideline will, however, point out some prevention measures that must be further exercised by appropriate expertise.

This guideline will be inadequate for personnel seeking general knowledge about the phenomena and personnel working with these phenomena in other occupancies. In general one can refer to extensive international literature about these risks and appropriate prevention and protection measures.

Although dust explosions very seldom occur in normal sized farm units the phenomena is included in this guideline to include large farming units that could be exposed to this type of risk.

Large agricultural units are not included in this guideline because they are not considered to be included in a farming context, but in an industrial context. Such units include large storage silos, receiving-, transport- and milling facilities. Chapter 7 will refer to international literature covering these units and activities.

It is important for the fire brigade to be well prepared to meet any risks in connection with silo fires due to self-ignition. The risks will include ignition of unburned fire gases and explosions due to accidental oxygen supply to a glowing or smouldering fire. Toxic gases released from the silo could also present a threat to fire fighters. Some of the literature references given in chapter 7 will include description of risks and possible measures for prevention and protection.

4 Definitions

The core terminology used in this field will be defined in this chapter, including designations for farming activity and equipment, fire and dust explosion phenomena and protective measures and equipment.

Bales of hay: Packed hay in bales covered with a plastic membrane.



Combustible material: Material that does not satisfy the criteria for non-combustible material according to standardized testing.

Explosion: A rapid combustion process resulting in increased temperatures and pressure.

Explosion limits: Upper and lower limits for concentrations of combustible gas or dust in air able to ignite with resulting flame propagation through the mixture .

Fire separation wall: Wall separating sections of a building in such a manner that a fire will not spread from the section in which it starts to other sections.

Flaming fire: A combustion process with an open flame, where the fuel is in a gaseous state.

Ignition: The start of combustion.

Inert gas: Non- combustible gas that could be applied as an extinguishing agent or a prevention measure by dilution of air/oxygen.

Mesophile and thermophile micro-organisms: Micro-organisms with optimum growth conditions at 20 – 40 °C and 45 – 65 °C, respectively.

Pressure relief: Ventilation from closed rooms by holes, openings, hatches or destroyed areas in case of an explosion.

Self-ignition: Ignition of a material without any external heat energy supply.

Silage: Fermented fodder

Smoke: Visible mixture of solid or fluid particles in gas produced by combustion or pyrolysis.

Smouldering fire: Combustion on the surface within pores and cavities of solid materials without flames and visible light emission.

5 Self-ignition fires and dust explosion mechanisms

It is important to some degree to understand the phenomena and the mechanisms involved in the events one shall take measures against. A short explanation of the mechanisms/physics involved in self-ignition and dust explosions in hay, straw, silage and fodder is given below. The explosion risk in ordinary farm activity is small and dust explosions are rare. Explosions in ordinary farm activities mostly involve gas explosions in connection with oxygen-limiting silos and seldom dust explosions. The mechanisms of dust explosions are, however, included here because the possibility of their occurrence can increase in the future, due to change in farming activities.



5.1 Self-ignition

A significant number of fires in farms are caused by self ignition in straw, grain and fodder. This occurs due to heat development in a bulk of the material that contains moisture and where good insulation conditions exist. In some countries it is estimated that 5 – 10 % of all fires in farming buildings originate from self ignition.

Such self-heating implies an increase of the bulk temperature without any supply of heat energy from the surroundings. Self-heating in wet agricultural material will sometimes lead to self ignition. The material's own respiration can lead to a heat accumulation up to 40 °C, if the moisture content is high enough. The most important source of self-heating in agricultural material is activity by microbiological activity caused by fungus and bacteria. Growth of fungus requires less moisture than growth of bacteria. At first a group of micro-organisms with maximum activity close to 40 °C (mesophile) start to grow. This group will not survive temperatures above 50 °C. Further heat accumulation up to 70°C is caused by so-called thermophile micro-organisms and is a well known process in composting. The mesophile organisms are dominated by fungus and the thermophile by bacteria. Bacteria and traces of fungus exist normally in the air and on surfaces of solid particles and materials. At temperatures above 70-80 °C exothermic (heat producing) chemical reactions take over. This will not necessarily lead to self-ignition.

A necessary requirement for self ignition is a moisture content of 20 % or higher, provided that the air supply is sufficient. Moisture content below 13 % in hay and straw will not start any biological activity and hence there is no heat development. Moisture content between 13 and 20 % will normally not lead to high enough temperatures to cause self-ignition.

Moisture content below 15% in straw during loading for storage indoors will prevent self-ignition but decrease the quality of the straw as fodder. In addition to the moisture content a number of factors will influence the process of starting any self ignition. Such factors are:

- The tightness of the storage or packing of the straw
- Type of straw
- Seed and plant oil content in the straw
- Size of the different units such as straw bales
- Aeration between the straw bales and aeration or draft in the storage room

If the temperature is exceeding 80 °C as a result of microbiological activity chemical reactions could lead to further heat accumulation. The active core could be a very limited area within the straw bales or pile.

If the temperature is kept at a high level for some time the active area will dry and in some cases development of a highly combustible core will occur, which could contain flammable gases. The drying process can reach a state where the heat insulation around the active core can collapse. This could also occur if canals or pores are created in the straw as a result of movement in the straw or penetration of the straw by an object. The particular gases will hence be released and give off a particular odour similar to rotten apples. If air is allowed into the core it can self ignite. The temperature is then estimated to have reached 100 °C. From this point on the development is quite rapid. At 200-250 °C smoke will be visible on the surface. A smouldering fire could take



place in the bulk of the material that could continue for many hours. The smouldering fire could expand in the bulk for hours and eventually die out or surface on the outside of the bulk. The next step is the outbreak of a flaming fire.

Hay, straw and fodder could be stored in bales outdoors and indoors and as bulk in silos. As the volume of the stored material increases the probability of heat accumulation increases and hence the ability of the bulk to self-ignite. This is due to heat accumulation deep in the core of a well heat insulated area. The air admission possibility in the bulk increases the possibility of oxidation of the bulk material and hence the possibility for self-ignition and smouldering fire. This fact calls for air tight silos.

5.2 Dust explosion

A dust explosion occurs when small particles (dust) of combustible material is well distributed in air at a sufficient concentration, start to burn. A dust explosion is in principle a very rapid combustion of a dust cloud. The combustion is rapid due to the presence of a large surface area of the combustible material. A large area is simultaneously in contact with air when the combustion starts. If this occurs within a container or a room the combustion will create a rapid build up of heat and consequently a rapid increase in pressure inside the room or container. This could eventually lead to rupture of the containing surfaces. If the combustion occurs in a part of a larger room or outdoors this could result in small or large pressure waves to propagate. Both rapid combustion in a container and propagating large pressure waves can be a threat to the environment.

Dust explosions need the following conditions:

- Small particles of combustible material. The material could be natural organic material like sugar, flour, grain, fodder, straw, coal, wood or synthetic materials or metal powder of magnesium, iron aluminium and zinc.
- The particles must be finely distributed in air or oxygen as a dust cloud. That could occur if a bulk of dust is whirled up in the air.
- The concentration of the particles must be within the explosion limits for the material. For grain, straw and fodder that implies non-visibility conditions (you can not see your own hand).
- Sufficient ignition energy must be present to start the combustion.

The ignition sources could be:

- Release of electrostatic energy created by particles themselves being whirled up.
- Glowing fires in piles of combustible material
- Open flames like from a lighter or match.
- Hot surfaces with temperatures up to 400 – 500 °C.
- Mechanical energy transformed to heat as a result of a mechanical impact to a solid surface giving off solid particles and hence heated surface of the area involved. Examples of this could be a metal object falling into the silo during loading of material to be stored. This is dependant of the size and type of metal and the impact energy.



- Electrical discharges or arcing that could be created by the material itself sliding against the process equipment.

Secondary dust explosions can occur. These may be created by whirling up dust piles or layers outside the primary explosion container, room or area. The secondary pressure build up could be higher than the primary due to the increased energy supplied to the awaiting material. Large areas of deposited dust layers will hence be a risk for secondary explosions giving large pressure waves. A fire in dust indoors could lead to the disturbance of dust layers resulting in an explosion.

6 Self-ignition fire and explosion risks involved and prevention measures to be taken by farmers

6.1 Self-ignition fires

6.1.1 The activities and areas constituting a risk

Due to mechanisms described above in chapter 5, combustible material like straw, grain and fodder have to be stored in piles or bulk to constitute a risk for self-ignition fires. Such storage could be in the following manner in farms:

- Bulk storage in silos.
- Bulk storage indoors as bales of hay or piles.
- Bales of hay stored outdoors.

6.1.2 Protective measures to avoid the start and growth of a fire

Protective measures for bulk storage indoors in bales or piles

- The moisture content of the material must be lower than 15 % and not be exposed to increase of moisture during storage.
- The bales should not be packed too hard. Too hard packing will lead to a need for increasing the aeration around the bales.
- The bales must be stored in such a manner that measurements of the temperature are possible.
- Bales with a high content of plant oil seeds must be closely monitored
- The bales must be stored in such a manner that moving the bales outdoor is easy in case of temperature increase within the bales.
- Collapse of the bales or decrease in volume indicates imminent risk for self ignition.
- Some bales should be monitored for temperature increase. The packed hay should be checked twice a day for six weeks after baling. One practical solution is to use a probe and thermometer to accurately determine the temperature inside a stack of hay. A simple temperature probe can be made in the farm workshop from a 10-foot piece of 3/4-inch diameter iron pipe. One should drill eight 3/16-inch diameter holes about three inches from



one end then hammer that end of the pipe together to form a sharp edge. Commercial temperature probes are available, but are often too short to monitor the maximum interior temperature zone within a hay stack.

- Any change of draft around the bales should be avoided.
- Be aware of any peculiar smell, like from rotten apples. This could indicate that a self-ignition is on the way. Be alert when the bales are opened and have extinguishing equipment at hand.
- Do not stack on top of, or against, steam pipes or heaters,

The following indicators could be used when monitoring the temperature in the bales:

- Temperatures below 40 °C: no sign of self-ignition
- Temperatures between 60 and 80 °C: consideration to call the fire brigade
- Temperatures of 100 °C or higher: a self-ignition fire is under way.

Protective measures for bulk storage in bales outdoors

Outdoor storage is much safer than indoors. If there is any doubt about the bales' ability for self-ignition, outdoor storage should be applied. Outdoor storage gives the possibility to choose how close to buildings the bales should be stored, depending on the calculated risk acceptance.

Protective measures for bulk storage in silos

Silos of different types are used for the bulk storage of different material for different activities. In this context the silos are storing hay and silage as fodder for livestock on ordinary farms and will be either of the conventional type or the oxygen-limiting/ controlled atmosphere type. The most common building mode for the conventional type of silos is the use of concrete staves and steel bands/sheets. Conventional silos can also be constructed in wood, tile blocks or steel.

While the conventional silo is constructed to minimize the free flow of air into the storage area, the oxygen-limiting silo is designed as a solid construction to be nearly air-tight. They can be build of insulated steel shells, poured concrete or fiberglass.

The conventional silo is constructed with an unloading chute that runs vertically on the exterior of the silo and an open top or loosely constructed dome. The oxygen-limiting silo has no unloading chute, but two-way pressure relief valves on the roof, roof hatches and access doors at ground level with safety interlocks. The two way pressure relief valves compensate interior pressure changes due to temperature variations.

Different construction characteristics and contents of the two types can result in different fire causes and personnel hazards.

To avoid self-ignition care must be taken to ensure the proper moisture and distribution of the silage. In the first three weeks of the storage of the silage oxygen is consumed in the fermentation process and heat is produced. After this the silage is supposed to reach a steady state. If the



process continues, the temperature can rise to a level necessary to produce self ignition. In some documented cases self ignition has occurred after two years.

Fires are much less common in the oxygen-limiting silos than in conventional types, but the consequences are much higher. If any of the latches or doors are left even partially open or the construction is subject to leakage, air will enter the stored material and hasten the self-ignition process. Carbon monoxide (CO) is produced and if an ignition source is produced or changes occur in the incomplete combustion an explosion may occur.

Sources of ignition could be:

- Lightning due to the fact that the silos are the tallest structure on the farm. A lightning rod protection system will reduce the risk.
- Mechanical heat of friction can occur if loading or unloading belts, pulleys or shafts can have mechanical failure and overheating. This calls for good maintenance of the equipment, according to the maintenance manual .
- Arcing and overheating of old or modified electrical motors. New motors have sufficient safety devices.
- Static electricity, which may occur during loading or unloading of the silo.
-

Means of preventing silo fires are:

- Silos should be inspected at least once a year and any damage repaired. One should look for structural weaknesses and any cracks should be sealed to avoid air coming into contact with the stored material.
- Checking of doors to ensure that they fit properly. Any doors showing signs of decay should be replaced.
- The crops must be harvested with the proper moisture content and be properly distributed inside the silo. Proper distribution gives better compaction and keeps air from reaching the feed.
- When the silo is empty the unloader system should be inspected and repaired. Belts, bearings, wiring and motors should be checked and any damage repaired.
- Inspect and lubricate the unloader lift cable to prevent a dropped unloader. If the cable shows any indications of kink, cut or corrosion it should be replaced. Examine the power cable for damaged insulation and terminals.
- Bonding and earthing metal components.

6.1.3 Measures for safe handling of a smouldering fire

Any signs that a fire is developing should result in alerting the fire brigade, both in the case of indoor hay ball storage and silo storage. The risks involved and the need for appropriate and professional handling is evident and hence should exclude any action by the farmers themselves.



The chance of explosion due to production of carbon-monoxide in the case of a fire in the silo has been explained above. In addition it must be emphasized that oxygen-limiting silos may explode if water or foam is sprayed through the top hatch or if the hatch is opened.

After notifying the fire brigade farmers should attempt to close the bottom of the chute to limit air movement through it. Non-combustible materials should be used to close the chute.

The farmers should wet the area around the construction on fire and move livestock and machinery from adjacent buildings.

6.2 Explosions

The explosion risks can be divided in two:

- The risk of gas explosions as a result of smouldering or glowing fires within oxygen-limiting silos.
- Gas and dust explosions in connection with the operation of oxygen-limiting silos.

6.2.1 *The risk of gas explosions in oxygen-limiting silos.*

Fires are much less common in oxygen-limiting silos than in conventional types, but the consequences can be much higher. If any of the latches or doors are left even partially open or the construction is subject to leakage, air will enter the stored material and hasten the self ignition process. Carbon monoxide (CO) is produced during the smouldering or glowing fire and the gas collect in the vapour space of the silo. As the flammable range of carbon monoxide is very wide, 12,5 – 74 %, the potential for a back-draft like explosion is very high. If an ignition source is produced or changes occur in the incomplete combustion an explosion may occur.

It must be emphasized that oxygen-limiting silos may explode if water or foam is sprayed through the top hatch or if the hatch is opened. This could happen as a result of fire fighting and attempt to cool down the silo. Water can hence enter the roof openings and air is drawn into the silo from outside. The carbon monoxide concentration can be brought into the right proportion for an explosion. The source of ignition is the heat of combustion that is already occurring. Any attempt to enter into the oxygen-limiting silo during a fire can result in an explosion.

6.2.2 *The risk of dust explosions in oxygen-limiting silos.*

Grain dust is normally not considered to be a fire threat within oxygen-limiting silos. In some cases, however, due to fire operations from outside, the dust has been suspended in the right proportions to allow a dust explosion. The ignition source is the already existing fire in the silo.



6.2.3 Measures to avoid explosion in oxygen-limiting silos.

Since the risk of explosion occurs during fires in the silos it is recommended that farmers leave all fire operations and fire fighting to the fire brigade. The measures left to the farmers is to avoid any self-ignition fire as described above, detect any fire that is occurring, alert the fire brigade and make the fire scene available for the fire brigade on their arrival.

6.2.4 Measures to reduce the risk of dust explosions on farms

The risk of dust explosions in normal farming activity is very low and can be controlled by measures described under chapter 5 concerning the mechanisms of dust explosions. In general good housekeeping by removing any dust deposits, earthing of machinery in contact with organic dust and avoiding the use of spark producing material in mixing, piping and transport equipment.

The risk of dust explosions in connection with agricultural handling and storage of grain, hay, fodder is, however, to a large extent present in the agricultural industry which receives, transports, mills, mixes, stores, and delivers large quantities of dust producing material like grains and fodder. For safe handling in the agricultural industry it is recommended that the literature and guidelines referred to in chapter 7.2 are studied.

7 References

7.1 Literature as background for this guideline

- 1 Henry Persson; Brand i silo. Brandsläckning samt förebyggande og förberedande åtgärder. Myndigheten for samhällsskydd og beredskap. ISBN 978-91-7383-220-5. September 2012. (In Swedish)
- 2 LBK-anbefaling 06.01.06. Anbefalinger fra landbrukets brannvernkomité vedrørende selvantennelse i høy og halm. (In Norwegian)
- 3 Timothy G. Prather; Silo fires: Prevention and Control. Conventional and sealed silos. The University of Tennessee. Agricultural Extension Service. PB 1307. October 1988.
- 4 U.S. Fire Administration/Technical Report Series. Special Report: The Hazards associated with Agricultural Silo Fires. USFA-TR-096/April 1998.
- 5 Rolf K. Eckhoff; Dust explosions in the process industries. Gulf Professional Publishing. 2003.
- 6 VdS; Inertierung von Silos im Brandfall. VdS 2154: 2008-01 (04). (In German).



7.2 Recommended literature for the industry exposed to self-ignition and dust explosion risks

- 1 Rolf K. Eckhoff; Dust explosions in the process industries. Gulf Professional Publishing. 2003.
- 2 Henry Persson; Brand i silo. Brandsläckning samt förebyggande og förberedande åtgärder. Myndigheten for samhälsskydd og beredskap. ISBN 978-91-7383-220-5. September 2012. (In Swedish).
- 3 Stanley S. Grossel, Robert G. Zalosh; Guidelines for safe handling of powders and bulk solids. American Institute of Chemical Engineers. Center for Chemical Process Safety. 2004.
- 4 Avi Levy; Handbook of conveying and handling of particulate solids. Elsevier 2001.

8 European Guidelines

Fire

- Guideline No 1:2002 F - Internal fire protection control
- Guideline No 2:2013 F - Panic & emergency exit devices
- Guideline No 3:2011 F - Certification of thermographers
- Guideline No 4:2010 F - Introduction to qualitative fire risk assessment
- Guideline No 5:2003 F - Guidance signs, emergency lighting and general lighting
- Guideline No 6:2011 F - Fire safety in care homes for the elderly
- Guideline No 7:2011 F - Safety distance between waste containers and buildings
- Guideline No 8:2004 F - Preventing arson – information to young people
- Guideline No 9:2012 F - Fire safety in restaurants
- Guideline No 10:2008 F - Smoke alarms in the home
- Guideline No 11:2005 F - Recommended numbers of fire protection trained staff
- Guideline No 12:2012 F - Fire safety basics for hot work operatives
- Guideline No 13:2006 F - Fire protection documentation
- Guideline No 14:2007 F - Fire protection in information technology facilities
- Guideline No 15:2012 F - Fire safety in guest harbours and marinas
- Guideline No 16:2008 F - Fire protection in offices
- Guideline No 17:2008 F - Fire safety in farm buildings
- Guideline No 18:2013 F - Fire protection on chemical manufacturing sites
- Guideline No 19:2009 F - Fire safety engineering concerning evacuation from buildings
- Guideline No 20:2012 F - Fire safety in camping sites
- Guideline No 21:2012 F - Fire prevention on construction sites
- Guideline No 22:2012 F - Wind turbines – Fire protection guideline
- Guideline No 23:2010 F - Securing the operational readiness of fire control system
- Guideline No 24:2010 F - Fire safe homes
- Guideline No 25:2010 F - Emergency plan
- Guideline No 26:2010 F - Fire protection of temporary buildings on construction sites
- Guideline No 27:2011 F - Fire safety in apartment buildings



- Guideline No 28:2012 F - Fire safety in laboratories
- Guideline No 29:2013 F - Protection of paintings: transport, exhibition and storage
- Guideline No 30:2013 F - Managing Fire Protection of Historic Buildings
- Guideline No 31:2013 F - Protection against self-ignition and explosions in handling and storage of silage and fodder in farms

Natural hazards

- Guideline No 1:2012 N - Protection against flood
- Guideline No 2:2013 N - Business Resilience – An introduction to protecting your business
- Guideline No 3:2013 N - Protection of buildings against wind damage
- Guideline No 4:2013 N - Lightning protection

Security

- Guideline No 1:2010 S - Arson document
- Guideline No 2:2010 S - Protection of empty buildings
- Guideline No 3:2010 S - Security system for empty buildings
- Guideline No 4:2010 S - Guidance on key holder selections and duties