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Solid biofuels — Safe handling and storage of solid biofuel pellets in commercial and industrial applications

Biocombustibles solides — Manutention et stockage en toute sécurité des granulés de biocombustibles solides dans des applications commerciales et industrielles

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Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 238, *Solid biofuels*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

There is a continuous global growth in production, storage, handling, bulk transport and use of solid biofuels especially in the form of pelletized biofuels.

The handling and storage of solid biofuels and their physical characteristics can lead to a risk for fire and/or explosion, but also health risks, for example intoxication due to exposure to carbon monoxide (CO), asphyxiation due to oxygen depletion, and allergic reactions.

There is a risk of injury or fatality associated with pellet storage so the implementation of safety measures is important. The possibility of fire and explosion incidents is a clear indicator that safety is to be prioritized, first of all for human safety but also because interruptions in energy supply will have significant consequences. The market confidence in solid biofuels as a reliable energy source will be jeopardized, and financial losses due to business interruptions could occur. Difficulty to obtain insurance coverage will also increase.

This document provides support, advice and guidance to facility owners, logistics providers, equipment suppliers/manufacturers, consultants, authorities and insurance providers to assess and mitigate risk when handling and storing solid biofuel pellets. General guidance is provided for personnel safety protection and personal precautions in accordance with generally accepted work safety requirements. As part of the determination and assessment of risks for solid biofuels, applicable quality standards and related test methods are discussed and recommendations for additional methodologies are indicated. As made of living materials, solid biofuels are subject to degradation such as ageing and moisture contamination causing variability in reactivity which requires margins in risks assessments. One shipment of solid biofuels may have substantially different physical and chemical characteristics in terms of self-heating and off-gassing than another, and therefore diligent monitoring, frequent testing and house-keeping are recommended.

Solid biofuels — Safe handling and storage of solid biofuel pellets in commercial and industrial applications

1 Scope

This document provides principles and requirements for safe handling and storage of solid biofuels pellets in commercial and industrial applications. This document is using a risk-based approach to determine what safety measures should be considered.

Facilities with a storage capacity <100 t are covered by ISO 20023. Generally, for end-user facilities with a storage capacity of <1 000 t, ISO 20023 could also be applicable if storage principle and facility complexity is in-line with the objectives of ISO 20023.

This document covers the handling and storage process of pellets in the following applications:

— at a pellet production plant from the outlet of the cooler unit until loaded for transportation;

— at a commercial distributor from the receiving station until loaded for transportation; and

— at an industrial end-user from the receiving station until fed into the fuel preparation or combustion process.

Although unloading and loading of e.g. vessels, trains or trucks are included in the operational envelops defined above, the safety aspect of the transportation itself is beyond the scope of this document.

This document also gives specific guidance on detection and suppression systems and preparatory measures to enable safe and efficient firefighting operations. Guidance on the management of fire and explosion incidents is also specified.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 12100, *Safety of machinery — General principles for design — Risk assessment and risk reduction*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1 General terms

3.1.1
biofuel pellet
biofuel made with or without additives in the form of cubiform, polyhedral, polyhydric or cylindrical units with a diameter up to 25 mm, produced by compressing biomass

Note 1 to entry: Usually the biomass has been milled before densification.

Note 2 to entry: See also non-woody pellet and wood pellet.

[SOURCE: ISO 16559:2014, 4.31]

3.1.2
combustible dust
finely divided solid particles, 500 μm or less in nominal size, which may form explosive mixtures with air at standard atmospheric pressure and temperatures

Note 1 to entry: This includes dust and grit as defined in ISO 4225.

Note 2 to entry: The term 'solid particles' is intended to address particles in the solid phase but does not preclude a hollow particle.

[SOURCE: ISO/IEC 80079-20-2:2016, 3.1]

3.1.3
combustible flyings
solid particles, including fibres, where one dimension is greater than 500 μm in nominal size, which may form an explosive mixture with air at standard atmospheric pressure and temperature

Note 1 to entry: The ratio of length to width is 3 or more.

[SOURCE: ISO/IEC 80079-20-2:2016, 3.2, modified — Note 2 deleted.]

3.1.4
fines
small sized particles in fuel below a certain pre-defined size, here less than 3,15 mm

[SOURCE: ISO 16559:2014, 4.90, modified — "usually" replaced by "here" to indicate exact limit.]

3.1.5
ignition source
source of energy that initiates combustion

[SOURCE: ISO 13943:2008, 4.189]

3.1.6
product safety data sheet
specification sheet defining physical aspects, characteristics and health and safety data for a product

3.1.7
self-heating
exothermic reaction within a material resulting in a rise in temperature in the material

[SOURCE: ISO 4880:1997, 55]

3.1.8
self-ignition
ignition resulting from *self-heating* (3.1.7)

[SOURCE: ISO 4880:1997, 56]

3.1.9
smouldering
slow combustion of a material without light being visible and generally evidenced by an increase in temperature and/or by smoke

[SOURCE: ISO 4880:1997, 58]

3.1.10
wood pellet
biofuel made from woody biomass with or without additives in the form of cubiform, polyhedral, polyhydric or cylindrical units, random length and typically 3,15 mm to 40 mm, a diameter up to 25 mm and with broken ends

Note 1 to entry: The raw material for wood pellets is woody biomass in accordance with Table 1 of ISO 17225-1. Pellets are usually manufactured in a die, with total moisture content usually less than 10 % of their mass wet basis.

Note 2 to entry: The woody biomass used as feedstock for pellet making is milled to size in accordance with customer specification. Determination of the particle size distribution of the constituent of pellets is done by ISO 17830.

[SOURCE: ISO 16559:2014, 4.228]

3.2 Risk management

3.2.1
accident
incident resulting in fatality, disease, injury or other damage

[SOURCE: ISO 21101:2014, 3.25]

3.2.2
emergency
serious situation requiring immediate action

[SOURCE: ISO/TR 21102:2013, 2.8]

3.2.3
fail-safe
term applied to equipment or a system so designed that, in the event of failure or malfunction of any part of the system, devices are automatically activated to stabilize or secure the safety of the operation

[SOURCE: ISO 13628-7:2005, 3.1.49]

3.2.4
failure mode and effect analysis
FMEA
analytically derived identification of the conceivable equipment failure modes and the potential adverse effects of those modes on the system and mission

Note 1 to entry: It is primarily used as a design tool for review of critical components.

[SOURCE: ISO/TS 16901:2015, 3.11]

3.2.5
harm
injury or damage to the health of people or animals or damage to property or the environment

[SOURCE: ISO/IEC Guide 51:2014, 3.1, modified — "or animals" added.]

3.2.6
hazard
potential source of *harm* (3.2.5)

[SOURCE: ISO/IEC Guide 51:2014, 3.2]

3.2.7
hazardous event
event that can cause *harm* (3.2.5)

[SOURCE: ISO/IEC Guide 51:2014, 3.3]

3.2.8
hazardous situation
circumstance in which people or animals, property or the environment is/are exposed to one or more *hazards* (3.2.6)

[SOURCE: ISO/IEC Guide 51:2014, 3.4, modified — "or animals" added.]

3.2.9
hazard and operability study
HAZOP
systematic approach by an interdisciplinary team to identify *hazards* (3.2.6) and operability problems occurring as a result of deviations from the intended range of process conditions

Note 1 to entry: All four steps are in place and recorded to manage a hazard completely.

[SOURCE: ISO/TS 16901:2015, 3.16]

3.2.10
incident
event or occurrence, which can, but does not necessarily, create a *risk* (3.2.14) of *harm* (3.2.5), including possible risks due to shearing, crushing, falling, impact, trapping, fire, electric shock, exposure to weather etc.

[SOURCE: ISO/TS 25740-1:2011, 3.13]

3.2.11
inherently safe design
measures taken to eliminate *hazards* (3.2.6) and/or to reduce *risks* (3.2.14) by changing the design or operating characteristics of the product or system

[SOURCE: ISO/IEC Guide 51:2014, 3.5]

3.2.12
intended use
use in accordance with information provided with a product or system, or, in the absence of such information, by generally understood patterns of usage

[SOURCE: ISO/IEC Guide 51:2014, 3.6]

3.2.13
reasonably foreseeable misuse
use of a product or system in a way not intended by the supplier, but which can result from readily predictable human behaviour

[SOURCE: ISO/IEC Guide 51:2014, 3.7, modified — Note 1 to entry and Note 2 to entry has been deleted.]

3.2.14
risk
combination of the probability of occurrence of *harm* (3.2.5) and the severity of that harm

Note 1 to entry: The probability of occurrence includes the exposure to a hazardous situation, the occurrence of a hazardous event and the possibility to avoid or limit the harm.

[SOURCE: ISO/IEC Guide 51:2014, 3.9]

3.2.15
risk analysis
systematic use of available information to identify *hazards* (3.2.6) and to estimate the *risk* (3.2.14)

[SOURCE: ISO/IEC Guide 51:2014, 3.10]

3.2.16
risk assessment
overall process comprising a *risk analysis* (3.2.15) and a *risk evaluation* (3.2.20)

[SOURCE: ISO/IEC Guide 51:2014, 3.11]

3.2.17
risk control
process of decision-making for managing and/or reducing *risk* (3.2.14); its implementation, enforcement and re-evaluation from time to time, using the results of *risk assessment* (3.2.16) as one input

3.2.18
risk criteria
terms of reference against which the significance of a *risk* (3.2.14) is evaluated

Note 1 to entry: Risk criteria are based on organizational objectives, and external and internal context.

Note 2 to entry: Risk criteria can be derived from standards, laws, policies and other requirements.

[SOURCE: ISO/IEC Guide 73:2009, 3.3.1.3]

3.2.19
risk estimation
process of assigning values to the probability of occurrence of events and their consequences

[SOURCE: ISO 13824:2009, 3.15]

3.2.20
risk evaluation
procedure based on the *risk analysis* (3.2.15) to determine whether tolerable *risk* (3.2.14) has been exceeded

[SOURCE: ISO/IEC Guide 51:2014, 3.12]

3.2.21
risk management
coordinated activities to direct and control an organization with regard to *risk* (3.2.14)

[SOURCE: ISO/IEC Guide 73:2009, 2.1]

3.2.22
risk reduction measure
protective measure
action or means to eliminate *hazards* (3.2.6) or reduce *risks* (3.2.14)

[SOURCE: ISO/IEC Guide 51:2014, 3.13, modified — Example has been removed.]

3.2.23
residual risk
risks (3.2.14) remaining after *risk reduction measures* (3.2.22) have been implemented

[SOURCE: ISO/IEC Guide 51:2014, 3.8]

3.2.24
safety
freedom from *risk* (3.2.14) which is not tolerable

[SOURCE: ISO/IEC Guide 51:2014, 3.14]

3.2.25
significant hazard
hazard (3.2.6) which has been identified and which requires specific action to eliminate or to reduce *risk* (3.2.14) according to the *risk management* (3.2.21)

3.2.26
tolerable risk
level of *risk* (3.2.14) that is accepted in a given context based on the current values of society

Note 1 to entry: For the purposes of this document, the terms "acceptable risk" and "tolerable risk" are considered to be synonymous.

[SOURCE: ISO/IEC Guide 51:2014, 3.15]

3.3 Storage, handling and operation

3.3.1
mechanical bridging
process of forming stable bridges in a bulk storage of solids where large particles mechanically interlock and form an obstruction, preventing the discharging of the material

Note 1 to entry: Bridging is also called arching.

3.3.2
cohesive bridging
process of forming stable bridges in a bulk storage of solids when particles bond together due to effects of moisture, fines concentration, particle shape, temperature, etc. and form an obstruction, preventing the discharging of the material

Note 1 to entry: Bridging is also called arching.

3.3.3
bulk material
amount of material within which component parts are not initially distinguishable on the macroscopic level

[SOURCE: ISO 11648-1:2003, 3.1.1]

3.3.4
bunker
vessel for the storage of materials, with the main section having vertical walls and the lowermost portion usually constructed in the form of a hopper

Note 1 to entry: Large bunkers are often used at power plants for short term fuel storage before the combustion furnace.

[SOURCE: ISO 1213-1:1993, 9.1.6, modified — "bin" deleted, Note 1 to entry added.]

3.3.5
bunker floor
steel construction above the *bunker* (3.3.4) to support the conveyor system and a steel grating to allow entrance for maintenance

3.3.6
bunker covering
construction covering the *bunker floor* (3.3.5) to aid the *bunker* (3.3.4) ventilation system to create an airflow from the *bunker house* (3.3.7) into the bunker

Note 1 to entry: The bunker covering will reduce dust dispersion into the bunker house and the environment during filling but also reduce the risk of foreign objects falling into the bunker during e.g. maintenance work inside the bunker house.

3.3.7
bunker house
building construction covering the *bunker* (3.3.4), the bunker floor *bunker floor* (3.3.5) and the conveyor system, protecting it against precipitation and preventing dispersion of dust to the environment

3.3.8
core flow
material flow that is confined to a column immediately surrounding the vertical axis through the outlet and in which the material on the surface slides in towards the downward-moving column

[SOURCE: ISO 1213-1:1993, 10.1.15]

3.3.9
funnel flow
flow that occurs during gravity storage when bulk material sloughs off the surface of the material and discharges through a vertical channel which forms within the material in the bin whenever material is drawn from the outlet

Note 1 to entry: Material adjacent to the bin walls remains stationary.

Note 2 to entry: Core flow is sometimes used instead of funnel flow.

[SOURCE: ISO 15117-1:2004, 3.15, modified — Note 2 to entry included.]

3.3.10
hopper
container for a loose bulk material such as grain, rock, or rubbish, typically one that tapers downward and is able to discharge its contents at the bottom

3.3.11
maintenance manual
document detailing the disciplines and procedures to be followed to maintain an item of equipment, complete machine or system in good working order

Note 1 to entry: A maintenance manual will detail periodic checks and replacement of parts, type of lubricant and protective processes and the period of time between each check. It will include instructions on how to locate faults, carry out repairs and the replacement of components. It may also include a detailed list of the components which go together to make the complete unit, and their reference numbers and quantity required to assist purchase of replacements as required.

[SOURCE: ISO/TR 11065:1992, 385, modified — Part of definition moved as Note 1 to entry.]

3.3.12
mass flow
flow in which all the contents of a bin, silo or bunker are in motion, so that there is substantially uniform velocity of flow across the whole cross-section of the material

[SOURCE: ISO 1213-1:1993, 10.1.14, modified — "(in bunkers)" deleted in heading; bin, silo or added.]

3.3.13
operation manual
collection of documents that provide the information necessary to familiarize the personnel with the operation and maintenance of a facility, system or item of equipment

[SOURCE: ISO 26870:2009, 3.11, modified — and maintenance deleted in heading.]

3.3.14
personal protection equipment
PPE
equipment that can include, but is not limited to, clothing, gloves, helmets, footwear and face protection

[SOURCE: ISO/TR 21808:2009, 2.1]

3.3.15
powered mobile handling equipment
equipment provided with some form of self-propulsion ordinarily under the direct control of an operator

Note 1 to entry: Powered mobile handling equipment includes, earthmoving machinery (e.g. rollers, graders, scrapers, skid steer loader), wheel loaders and wheel loader equipment, trucks, excavators, mobile cranes, hoists, elevating work platforms, concrete placement booms, reach stackers and forklifts, and trains and wagons.

3.3.16
ratholing
discharging of material taking place only in a flow channel formed above the outlet of a silo, *bunker* (3.3.4) or *hopper* (3.3.10)

Note 1 to entry: The reason for ratholing is the material being cohesive leading to the material outside the formed channel will not flow into it, stopping the outflow once the central flow channel is emptied.

Note 2 to entry: Ratholing is also called piping.

Note 3 to entry: See also definition on funnel flow, 3.3.9.

3.3.17
SCBA
self contained breathing apparatus
generic term for respiratory protective devices, designed for the wearer to carry a source of supplying air, oxygen or breathable gas to be consumed in breathing

[SOURCE: ISO 16972:2010, A.267]

3.3.18
screw conveyor
auger conveyor
mechanism that uses a rotating helical screw blade, usually within a tube, to move liquid or granular materials

3.3.19
silo
structure for the storage of a volume of *bulk material* (3.3.3)

[SOURCE: ISO 6707-1:2014, 3.2.20, modified — "loose" material has been replaced by "bulk" material, "large" has been deleted.]

3.3.20
warehouse
flat storage
A-frame storage
building or structure for storage, such as garages, storage buildings and freight depots

3.4 Extinguishing media, extinguishing systems and detection

3.4.1
Compressed Air Foam
CAF
homogenous foam produced by the combination of water, foam concentrate, and air or nitrogen under pressure

[SOURCE: ISO 7076-5:2014, 3.5]

3.4.2
Compressed Air Foam System
CAFS
system in which a foam concentrate and air are continuously added under pressure to the water being discharged from a fire-fighting pump

[SOURCE: ISO 7076-6:2016, 3.5]

3.4.3
foam expansion ratio
ratio of the volume of foam to the volume of the foam solution from which it was made

[SOURCE: ISO 7076-2:2012, 3.4]

3.4.4
gas detection system
system which monitors spaces for the presence and concentration of relevant gasses (e.g. flammable and toxic gases, oxygen concentration) and initiates alarm and control actions at predetermined concentrations

Note 1 to entry: There are also personal mobile gas monitoring devices that could be applicable (G.2.5).

[SOURCE: ISO 10418:2003, 3.1.20, modified — "on an offshore installation" deleted, and "toxic" included, Note 1 to entry added.]

3.4.5
high expansion foam
foam which has an expansion greater than 200

[SOURCE: ISO 7076-4:2016, 3.1]

3.4.6
ignition source detection system
system consisting of one or more devices capable of detecting the presence of active ignition sources or warm or overheated material

Note 1 to entry: Highly sensitive detector to detect sparks, hot or glowing particles in e.g. pneumatic and mechanical conveying systems.

4 Guidance on how to use this document

The purpose of this document is to help designers, purchasers of handling systems, and operators along the pellet supply chains to ensure that safety hazards and adverse effects to the quality of the pellets that can influence safety are avoided. It uses a risk-based approach to determine what safety measures should be considered.

The requirements stated in this document as mandatory are additional wood pellet specific requirements that shall be included in the company's existing safety management system.

Users of this document are responsible for identifying local regulations.

The supply chain includes handling and storage at the pellet producers, commercial distributors/storages and end-users, which could be large scale industrial applications (e.g. power plants), medium size boilers and distributors/traders delivering to small scale boilers for private use.

The characteristics of pellets might vary depending on used raw material and production process. Information about a specific pellet brand, with respect to quality, safety and health aspects during handling and storage, is found in quality specifications and safety data sheets published by the suppliers.

The document is focused both on design and operation. Clause 5 outlines the general risk management process to be applied to identify possible risks and to assess the need for risk reduction/risk control measures for each specific facility. Clauses 6 to 11 provides further detailed information on specific risks and hazards, safe operation and maintenance and specific safety measures for different types of handling and storage that determine what safety measures shall be considered for each individual facility.

Storage capacity is not the only parameter on which to decide which safety measures are necessary. The pellet yearly turnover and the complexity of the on-site handling will most likely be equally or more important than storage capacity. This will include the number, type and size of of conveying systems as well as number, type and size of storage units, etc.

The overall risk management process is therefore essential to ensure that all safety measures applicable to each individual facility configuration and operational as well as maintenance requirements are satisfied.

Further descriptions of the solid biofuel pellets supply chain and general safety issues for unit operations are described in Annex A.

An example of a risk assessment in a commercial medium size wood pellet store is presented in Annex H.

5 Risk management

5.1 General

To improve the safety during handling and storage of solid biofuel pellets, both the design and operation shall be considered. Safety is the responsibility of everyone directly or indirectly involved in operation and maintenance of a facility, here limited to the scope of this document.

For identified hazards the following hierarchy of priority should be followed as a minimum:

1. Elimination
2. Substitution
3. Engineering controls
4. Administrative controls
5. Personal protective equipment (PPE)

As the top item is most effective, this process shall be adressed both during design, operation and maintenance and much can be achieved already during design.

For the operational management of occupational health and safety, the Plan-Do-Check-Act (PDCA) model according to ISO 45001 should be used.

Figure 1 illustrates the steps to follow when assessing the risk and how it relates to risk management.

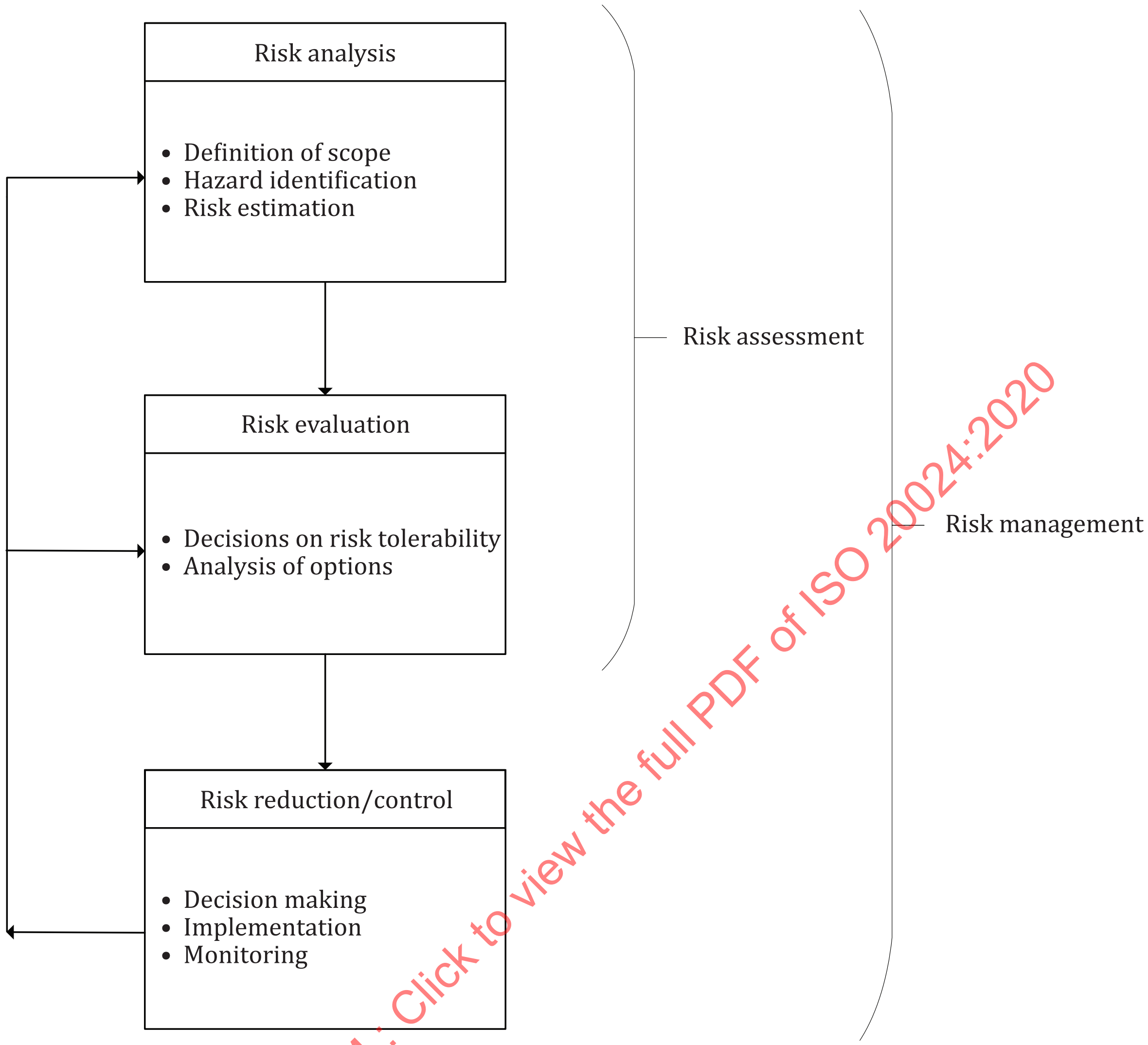


Figure 1 — Risk management

The risk management process includes a risk analysis and a risk evaluation which form the basis for the risk assessment and what risk reduction/control measures are required for each specific operation.

Risk management includes design, construction, operation, preventive and remedial maintenance as well as preplanning of emergency procedures. Specific information/guidance can be found for conveyor systems (Clause 8), silos (Clause 9), bunkers (Clause 10) and warehouse storage (Clause 11) and related annexes. The risk management shall be documented for guidance, training and record keeping purposes.

The documentation shall describe and justify the measures taken but also include aspects not considered applicable or relevant.

The person responsible for the risk management process shall have verifiable competence to conduct a fire and explosion risk assessment; the level of competency required should be commensurate with the complexity of the facility to be assessed, i.e.:

— good understanding of solid biofuels;

— good understanding of the equipment and processes used for the production and along the supply chain of biofuel pellets;

— good understanding of fire related aspects of building control and function and appropriately trained and/or experienced in fire safety and fire protection issues;

— appropriate knowledge of national fire and safety regulations and the requirements of other enforcing bodies and stakeholders (i.e. insurers) and knowledge of relevant national and local codes and experience of application;

— any other specific competence requirements regulated by any local regulations.

5.2 Introduction to the risk management process

5.2.1 General

Management of risks include a number of steps and sub-steps as shown in Figure 2. In 5.2.2 to 5.2.6 the different parts of risk management are defined and described.

5.2.2 Definition of scope

When performing a risk analysis, it is necessary to define the scope, i.e. the system that is to be included in the analysis. This includes definition of the boundary of the system and to identify user, intended use and reasonably foreseeable misuse. Assumptions and limitations for the analysis should also be defined. Technical, environmental, organisational and other aspects relevant for the problem/system should be included.

5.2.3 Hazard identification

Hazard identification involves systematic review of the system under study to identify the type of inherent hazards that are present together with the ways in which they could be realized. Different hazards and sources of risks should be identified and the type of hazard they pose analysed. Hazard identification methods fall mainly into three categories:

a) comparative methods (e.g. checklists, hazard indices and reviews of historical data);

b) fundamental methods, that are structured to stimulate a group of people to apply foresight in conjunction with their knowledge to the task of identifying hazards (e.g. HAZOP [hazard and operability study] and FMEA [failure mode and effect analysis]);

c) inductive reasoning techniques (for example, event tree logic diagrams).

The significance of the sources of risks shall be analysed by an initial evaluation, based on a consequence analysis. The aim of this analysis is to decide whether:

1) actions should be taken to eliminate or reduce the hazard;

2) the analysis can be terminated due to the insignificance of hazard;

3) the analysis should be continued with a risk estimation.

There are many factors influencing the the risk management, e.g. the storage capacity, annual pellet turnover and complexity of on-site handling and to consider all the variables that could be valid for a particular facility. At least, the hazards mentioned in Clause 6 and relevant parts of Clauses 8 to 11 shall be considered in the hazard identification process. In Clause 7, there are requirements for safe operation and maintenance, which also shall be considered.

5.2.4 Risk estimation

Risk estimation should examine the initiating events or circumstances, the sequence of events that are of concern, any mitigating features and the nature and frequency of the possible deleterious consequences of the individual hazards to produce a measure of the level of the risk being analysed. The measures could address humans, animals, property or environmental risks and should include an indication of the uncertainty associated with the estimates. The risk estimation process can be described by the following steps:

a) frequency analysis used to estimate the likelihood of each undesired event identified during the hazard identification stage. To estimate event frequencies three different approaches are commonly used: relevant historical data, analytical or simulation techniques and expert judgement;

b) consequence analysis is used to estimate the likely impact should the undesired event occur;

c) risk calculations where risk should be expressed in the most suitable term, e.g.: individual risk, e.g. predicted frequency of mortality, frequency versus consequence plots (F-N curves), the statistically expected loss rate in terms of casualties, economic loss or environmental damage, the distribution of the risk of a specific damage level.

5.2.5 Risk evaluation

After risk estimation has been completed, risk evaluation shall be carried out in accordance with ISO 12100 to determine if risk reduction is required. If risk reduction is required, then appropriate measures shall be selected and applied.

5.2.6 Risk reduction/control

Based on the risk evaluation, measures should be taken to achieve a tolerable risk level. Where hazard or hazardous situations with multiple risks have been identified, care should be taken to prevent risk reduction measures chosen to reduce one risk from resulting in another intolerable risk. Risk reduction can be divided in measures taken during design and during the use phase, respectively. The measures shall in turn be divided into different steps or parts and shall be taken in the specific order:

a) Risk reduction measures during design:

   1) Inherently safe design

   2) Guards and protective devices

   3) Information/instruction for use

b) Risk reduction during the use phase:

   1) Additional protective devices

   2) Training

   3) Organization of work, application of equipment and supervision

   4) Personal protective equipment

In Figure 2 the process of risk management is shown, with the iterative process of risk reduction and, if applicable, risk assessment.

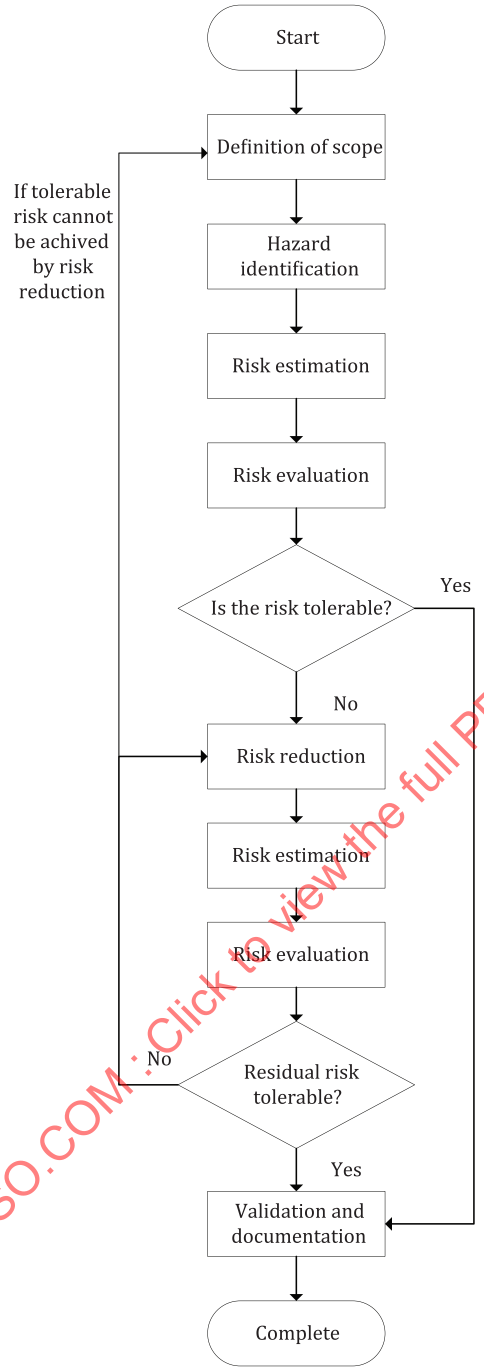


Figure 2 — Iterative process of risk assessment and risk reduction (after ISO/IEC Guide 51:2014)

An example of a risk assessment is presented for a commercial, medium size wood pellet store with relatively low complexity is shown in Annex H.

6 Requirements for design and construction

6.1 General

This clause describes requirements for the general design and construction while additional requirements are described for specific objects in Clauses 8 to 11.

Requirements for safe operations and maintenance are described in Clause 7.

6.2 Specific risk considerations for handling of solid biofuel pellets

The following hazards conditions are common in all operations involving solid biofuel pellets during production, handling, transportation and storage and shall be considered as a minimum during the risk management process: Dust explosion, fire, pyrolysis gas explosions (which is a result of smouldering fires), off-gassing of toxic gases, areas with low oxygen concentrations, high walls of pellets in storage facilities collapsing (such as an avalanche) on personnel and mobile handling equipment. The main hazards to the quality and value of the pellets are; physical degradation (for example, breakdown); contamination by water (which could result in fungi growth), humidity, extraneous materials. Only those quality related hazards that are directly related to safety will be further discussed in this document.

The equipment and facility shall be constructed in such a way that risks are minimized. All aspects of a facility shall, to the extent possible, follow the fail-safe principle meaning that a single failure shall not cause a secondary catastrophic failure to happen.

NOTE This can be achieved by inter-locking, power backup, dumping of materials by gravity, etc.

The equipment shall cause minimal degradation to the pellets and should protect the material from the elements and keep it away from ignition sources.

Design and construction of facilities (including commissioning and hand-over) and operational, preventive and remedial maintenance and emergency procedures shall be such as to minimize the exposure to risk related to the following:

a) Combustible or potentially explosive dust,

   Solid biofuel pellets always contain dust which can easily become airborne. Dust smaller than 500 µm are explosive if in sufficiently high concentration and in contact with an ignition source (see 6.2 h). All wood dust shall be assumed combustible until demonstrated otherwise for example by appropriate and representative testing. Fine dust generated during handling has a propensity to settle on flat surfaces in layers on beams, motor casings, cabinets, railings, floors, lamp shades, etc. The ignition temperature for dust in layers is comparatively low compared to that of a dust cloud in contact with a hot surface. Since a layer will start glowing when exposed to a hot surface for a longer period of time the temperature will rise significantly hence creating a massive ignition source for a dust cloud (see 6.2 b). All areas of an operation involving handling or storing of solid biofuel pellets where explosive dust or gases can be present, shall be divided and classified in risk zones. Risk zones shall indicate local contexts where national or regional regulations (e.g. ATEX directives, NFPA standards) are present (See Annex C).

b) Self-heating,

   Solid biofuel pellets and related dust have a propensity to self-heat during storage, particularly relatively shortly after production, or at elevated moisture content (e.g. due to water intrusion) and elevated ambient temperature (see B.2). The heating can be considerable depending on the quality of the pellets and can in some cases develop into smouldering requiring fire extinguishing intervention and emergency discharge. Temperature monitoring of the surface and inside the stored bulk is important to obtain indications of self-heating. Measurements of CO just above the bulk surface could provide additional information. Possibilities for emergency discharge shall be considered.

   It should also be noted that layers of dust from wood pellets on a warm surface could start a self-heating process and thereby cause ignition even below the determined minimum ignition temperature (MIT) of a dust layer (see Annex C).

c) Danger of dust emission to the environment and exposure of workers and others in the vicinity of the facility,

The amount and characteristics of fine dust lofted in the air is a health risk when inhaled and some type of wood dust can be carcinogenic (NTP, 2016). Efforts to control dust exposure shall be planned and implemented during the design stage.

d) Exposure of operators to asphyxiation or intoxication,

Solid biofuel pellets release gases such as carbon monoxide (CO) and carbon dioxide (CO_2) in combination with rapid oxygen depletion. Small amounts of methane and hydrogen as well as malodorous hydrocarbons are also released (see 7.5 and D.2).

e) Avalanches,

Solid biofuel pellets have in general a high flowability similar to grain but can under certain circumstances cause high walls of pellets, or bridging and ratholing when stored in silos or bunkers with gravity bottom feed. Engulfment or burial can easily happen if entering a storage bin during discharge. Life-saving with life-line and “cofferdam” (a barrier to prevent burial of personnel by pellets) is one of the few options to save life in such cases.

f) Machinery,

Machinery involving moving parts (in normal operation and in case of malfunction) can involve a significant risk for personnel injuries and suitable risk reducing guarding measures shall be considered. The requirements of ISO 12100 (safety of machinery) as well as any local regulations shall be fulfilled.

g) Moving vehicles,

Moving vehicles, in normal operation but in particular in case of e.g. emergency discharge of a storage due to self-heating or fire, can involve a significant risk for personnel injuries. The main risk factors are the many vehicles (e.g. wheel loaders, trucks) in operation, reduced visibility due to smoke, reduced visibility due to drivers using SCBA-equipment. Suitable risk reducing measures shall be considered.

h) Fire hazards,

Both pellets and dry wood dust pose a fire hazard and ignition sources shall be avoided. There are a number of potential ignition sources along the path of the pellets which shall be considered during risk zone classification (see 6.2 a and Annex C). These ignition sources can be present both during normal operation and/or in case of malfunction, and needs to be considered during design and commissioning but also during operation:

— Hot surfaces (e.g. lamp shades, lamp bulbs, overheated ball bearings and motor casings, driers, overheated rollers (idlers) and guide rollers, exhaust stems in moving equipment);

— Self-heating (exothermic reactions) (both in storage of bulk material and in dust deposits on heated surfaces);

— Flames, hot gases and hot particles (including e.g. external fires, hot work during maintenance, transport of smouldering material, gas from vehicle exhaust systems);

— Mechanically generated sparks (friction, abrasion, impact);

— Electrical apparatus;

— Stray electric currents;

— Static electricity (e.g. spark discharge, propagating brush discharge);

— Lightning.

6.3 Risk areas

There are several typical areas where the solid biofuel pellets can cause hazardous conditions for personnel or be subject to quality degradation (which could influence safety) along the chain of handling.

Below are some examples of areas (but not limited to) in which these risks will be found:

a) Ship cargo holds, stairwells, enclosed storages, enclosed rooms (asphyxiation, envelopment);

b) Pellet off-loading and transport system (ship unloader, train unloader, transfer points, conveyor systems, etc.)(explosive atmosphere, personal injuries, etc);

c) Storage facilities (self-heating, off-gassing, oxygen depletion, explosive atmosphere);

d) Powered mobile handling equipment (fire and explosion, personnel injuries);

In connection with pellet quality, the designer shall assess the design to identify the following:

e) Places where contamination in the form of e.g. precipitation or extraneous materials can enter the pellets (during handling and storage);

f) Places where the pellets are subject to impact or breakdown;

g) Places where segregation can occur causing fines to become separated or concentrated.

For each of these, the designer shall make an assessment of the likely level of impact on the quality where this can be of significance for safety, and put in place appropriate measures to ensure that the quality is not reduced to an unacceptable level to the cargo owner.

The main places where these risks will usually be found will include:

— Open ship hold (contamination by precipitation);

— Ship unloader (degradation by impact and crushing);

— Conveyor transfer points (degradation by impact, excessive drop height);

— Feeder systems such as conveyor systems, drag chain feeders (degradation by pressure or attrition);

— Reclaim by handling equipment such as front loaders and trucks driving over wood pellets causing degradation and contamination.

6.4 General requirements and recommendations for safe handling

The design of facilities and equipment as well as operational guidelines (see Clause 7) can eliminate or minimize the risk for hazardous conditions during handling and storage of solid biofuel pellets. Below, some general aspects of importance are listed while more specific aspects related to certain objects (conveyors, silos, bunkers and warehouses) are presented in Clauses 8 to 11.

a) General design and construction considerations should avoid dust generation, dust settlement, material build up, etc.

   — Beams, ledges and structures, which cannot be regularly cleaned and are located inside buildings for handling and storage of biofuel pellets, shall have a cover with a sharp top angle of <60° to deflect accumulation of any build-up of dust.

   — “Dead spots” enabling accumulation of dust shall be minimized. Cover beam girders with sheet metal or fill with materials such as styrofoam to block accumulation of dust on flanges.

   — Locations of potential deposits or accretions shall be easily accessible.

   — Install monitoring and mitigating measures for early stage detection and mitigation.

b) Processes that create dust can be avoided by the following means:

— Using enclosed conveying routes, enclosed transfer points and/or dust removal systems

— Minimizing the number of transfer points and their drop heights and/or impact on pellets

c) Accessibility for regular inspections

d) Accessibility for housekeeping

e) Accessibility for firefighting

f) Accessibility/possibility for emergency discharge of storage

g) Preparatory measures should be considered during the design and construction phase of the plant in order to gain the prevention of fires or as they could be important to reduce the consequences of a fire/explosion incident (see 8.3, 9.3, 10.3 and 11.3 for details).

h) Explosion relief systems, if necessary combined with explosion isolation components, will reduce the risk of transfer of an explosion and fire along a conveyor and secondary explosions in connected equipment. The pressure relief should be guided outdoors (see 8.3.2).

i) Areas where dust becomes lofted during handling and the occurrence of explosive dust/air mixtures cannot be fully avoided shall be classified in risk zones/areas. Within the zones, only equipment (electrical or mechanical) approved for the relevant zone shall be used (see Annex C).

j) All identified risk zones/areas shall be clearly identified by signs and warning symbols.

k) Electrical equipment and lightning protection. Do not use halogen or other lighting fixtures with hot surfaces. The enclosures of electrical equipment shall have a proper classification with respect to protection against personal safety, foreign objects, ingress of water and explosion protection.

l) Risk for accumulation of gases from off-gassing or pyrolysis gases (CO, CO_2) in locations adjacent to storage facilities (e.g. offices, lunch rooms, and meeting rooms), in particular during self-heating or fire situations.

Further information about risks associated with dust is given in Annex C and some guidance on handling of emergency situations (e.g. self-heating, fire) is summarized in Annex D.

7 Requirements for safe operation and maintenance

7.1 General

The following requirements, when applicable based on the risk assessment, shall become part of the operations and maintenance manuals.

7.2 General requirement for operation, maintenance and manuals

Operation and maintenance of a facility shall be organized such that hazardous situations are avoided and in the event emergency situations occur there shall be evacuation and first aid instructions in place for what to do in case of injury and shut-down procedures for minimizing damage. Typical situations which historically are known to cause injuries and even fatalities are confined space entry, dust and gas explosions, limbs and clothing caught in machinery, electric shock, exposure to hot surfaces, tripping over debris etc.

To avoid such incidents, the employer shall ensure that each worker receives adequate safety and health training, in particular in the form of information and instructions specific to his workstation or job:

— on recruitment,

— in the event of a transfer or a change of job,

— in the event of the introduction of new work equipment or a change in equipment,

— in the event of the introduction of any new technology.

The training shall be adapted to take account of new or changed risks, and repeated periodically if necessary.

Personnel should regularly be informed about the risks related to confined spaces and also be equipped with personal gas detectors measuring both CO and oxygen (O_2) content as exposure to high/low concentrations can occur under normal operation conditions.

During operation and maintenance, it is important to apply strict rules about lock-out of machinery, both mechanically and electrically, before e.g. any obstructions are cleared or other maintenance work is conducted. These rules shall also include lock-out of fire/explosion detection and suppression systems and ensure that they are reactivated before any operation commence. However, detection systems relevant for security should still be active if possible.

7.3 Documentation of operation procedures

The following documents shall be compiled at a facility handling and storing solid biofuel pellets and where necessary be available and maintained to be current.

a) Procedures and guidelines:

  — daily procedures including start-up and shutdown routines;

  — emergency procedures;

  — housekeeping procedures;

  — outline of operator training;

  — worksafe guidelines from local/national authorities;

  — log and reporting requirement (operational conditions, incidents/abnormal conditions, accidents);

  — reporting structure of organization;

  — safe behaviour;

b) Maintenance manual:

  — preventive maintenance routines (e.g. regular control of bearings);

  — remedial maintenance routines (e.g. access to critical spare-parts to enable a fast replacement);

c) safety guidelines for visitors and contractors working on-site (e.g. orientation plans, rules for entry of confined spaces, lock-out of machinery);

d) Properties of the solid biofuel pellets produced and/or handled by any facility (product safety data sheet):

  — identification;

  — hazard identification;

  — composition;

  — physical properties;

  — chemical properties;

  — self-heating properties;

— off-gassing and oxygen depletion properties;

— safety characteristics of dust (see Annex C);

— toxicological information.

Examples of specific aspects to consider during normal operation and include in the documentation/manuals are described in 7.4 while aspects on emergency procedures are handled in 7.5.

7.4 Safety during operation

7.4.1 Operation

Regular visual inspection of the entire handling system shall be performed, to identify dust accumulation, spilled material or indications of malfunction or damaged equipment requiring maintenance. The use of a handheld IR (Infrared) camera or IR-thermometer is recommended as this increase the possibilities to detect heated material/equipment.

Limit the storage time and apply the first-in-first-out principle as far as possible. Seek to avoid mixture of fuel with different type, qualities and moisture content in order to avoid stratified heating in boundary layers due to dust content, particle size etc.

Visual inspections, after taking the necessary safety precautions, of stored pellets shall be performed regularly, i.e. noting any tendencies of vapour formation. Such inspections shall be done also upon entry of delivered fuel into storage.

For storage with an expected storage time of more than 3-4 weeks without any transfer operations, control of the pellet properties loaded into the storage should be considered, e.g. tendency to self-heating

NOTE A method to determine the tendency to self-heating is being developed and ISO 20049-1[1)] is currently under development within ISO/TC 238/WG 7.

Regular monitoring of stored pellets should be conducted using mobile and/or fixed sensors for temperature and/or gas detection (see Annex G). As the storage facilities and storage conditions can vary considerably, monitoring of the rate of change of the bulk temperature (and/or gas concentration) are often more important than a specific threshold as an abnormal increasing rate of change indicate some form of changed conditions and a possible problem.

For intermediate storages which every week have a transfer to the stock or reclaiming, temperature monitoring of the moved pellets (at inlet and/or outlet) is recommended.

Keeping good track of normal conditions is therefore essential to learn more about the specific storage and to have the possibility to detect any abnormal situation in an early stage. In such situation suitable safety precautions shall be taken, e.g. removal, inertization or cooling of the fuel (see Annex D for further guidance). Upon emptying, the storage shall be cleaned of pellets and dust before refilling. Intermediate storages need to be emptied and cleaned regularly (preferably at least once a year), to avoid accumulation of dust.

When handling and storage of pellets in bags or big-bags on pallets, the main risk is related to the stability, in particular if the pallets are stacked on height. A damage of a pallet on low level can result in the collapse of the entire pallet stack with risk for personnel injuries.

Log lists of relevant actions related to the operation and reporting routines of any incidents including follow-up measures shall be kept and continuously updated.

7.4.2 Housekeeping

Dust accumulations present both a significant explosion hazard (see Annex C) but also a health risk, and technical/organizational measures shall be taken to avoid the exposure of personnel to dust. A routine

1) Stage at the time of publication: ISO/FDIS 20049-1:2020.

for checking dust dispersion/dust build up shall therefore be set in place. A cleaning plan shall be kept and maintained for regular removal of dust; it shall be based on frequency of cleaning or max dust layer.

A dust layer exceeding 0,5 mm to 1 mm in general or dust layer exceeding 3 mm covering more than 5 % of a given work area shall be considered as a potentially hazardous condition for dust explosion.

NOTE 1 It has proven successful to mark potential accretion areas in colour and when the coloured marking is no longer visible, it is an indication that cleaning should take place without delay (VGB, 2013).

NOTE 2 A "given work area" is considered to be an area of the workplace, whose boundaries are defined by the various physical structures around it, which can enclose, contain, or compartmentalize the area. These structures can include walls, floors, ceilings, process equipment, or any combination of these which have the effect of either fully or partially enclosing, containing, or compartmentalizing that work area within the facility. The greater the extent of confinement, enclosure, or containment in an area where dust has accumulated, the greater the risk that an explosion can occur.

Large wall surfaces with rough surface texture could be painted with gloss antistatic paint in order to avoid accumulation of dust and to minimize generation of electrostatic build-up.

Vacuum cleaners shall be certified for use in explosive atmosphere as recommended by local regulations. Due to the risk of raising dust, cleaning shall not be performed with compressed air or high pressure cleaners.

Fine dust will create a health risk and special attention should be given airborne dust since concentrations of wood dust above 1 mg/m^3 is considered as a danger level. Exposure can be a cause for asthma, effects to skin and eyes. and and can be carcinogenic. Personnel regularly exposed to dust, e.g. those working with house-keeping, operation and maintenance shall have access to respiratory protective equipment and it shall be worn when relevant.

7.4.3 Maintenance

A maintenance plan for all key mechanical equipment, e.g. conveyors, valves, various monitoring equipment, fire detection and fire protection equipment shall be kept and updated. Certified equipment shall be maintained and inspected in accordance with recommendations by suppliers and current maintenance plan to ensure safe performance.

To avoid intrusion of precipitation in stores, the building envelope shall be properly constructed and regularly inspected for defects. Rain gutters should also be regularly inspected to ensure proper function, as blockage can lead to intrusion of water into the building.

The preventative maintenance routine shall include checking the grounding of casings of motors, fans and other conductive objects. The resistance to ground or between objects shall be <1 MΩ to prevent the risk of sparking due to static discharge. A conductive object can be earthed by a direct conductive path to earth or by bonding it to another conductive object that is already connected to the earth. Some objects are inherently bonded or inherently earthed because of their contact with earth. The maximum resistance shall also include interconnecting parts e.g. flexible's and piping, belt material and drive wheels or flexible and equipment. IEC TS 60079-32-1 provides further information.

Workplaces in potentially explosive areas shall be checked before the start of work by a qualified person and only opened after application of the corresponding release procedure.

Systems in potentially explosive areas shall be checked by a qualified person before first activation and repeatedly checked at regular intervals.

If explosive dust/air mixtures are avoided by permanent or occasional inerting of an enclosed system, an additional risk assessment shall be performed including the additional risk for low oxygen areas for operating and maintenance personnel.

Emptying and cleaning of certain equipment (e.g. running certain conveyors free of material, emptying and cleaning of storage) shall be done in advance of a longer operationally stand-still or maintenance period.

Hot work (welding, cutting, brazing, machining with high-speed tools and other work exerting heat or sparks) shall only be conducted after receiving a written permission from an authorized person at the facility. Before starting the work, necessary precautions should be made to eliminate any combustible material in the area of work. Fire extinguishing equipment shall be available and ready for use and the work shall be monitored by one or several fire guards. Lock-out of fire/explosion detection systems can be necessary to avoid activation. The permission procedures shall also ensure that the system is reactivated before any operation commence again. Spills of lubricants like oil and grease as well as hydraulic oils shall be removed to prevent them becoming a catalyst for self-heating.

Closed pellet stores (especially silos and bunkers) shall only be entered for repair or maintenance after it has been confirmed by specific measurements that the gas concentrations of O_2 and CO provide a safe access.

WARNING — Do not measure oxygen concentration only, both O_2 and CO shall be measured (see D.2.2).

The work shall always be conducted by the company of a second person who stays outside the hazard zone as an additional safety measure and with a safety rope attached to the entering person. The attendant should always have eye contact or at least voice contact with the person inside the store.

7.4.4 Guidelines for visitors/contractors

7.4.5 Guidelines for contractors

Contractors' staff shall be informed regarding rules for:

- wearing personal protective equipment (PPE) (helmet, protective glasses, noise protection, protective shoes, reflective clothing, respiratory protective equipment, or any other specific PPE relevant for the facility.);
- areas involving specific hazards;
- entering confined spaces. A specific permission, education and training shall be required as well as the use of mobile gas detectors for at least O_2 and CO, and having escort of a second person on the outside of the entrance to the confined space;
- activities involving any hot work. A specific permission, education and training shall be required as well as having escort of a fire guard equipped with extinguishing equipment;
- action in case of a fire or other emergency situation, evacuation routes and location of “Point of assembly”;
- any other specific safety considerations relevant for the facility.

The contractor(s) shall receive the information both verbally but also in written form and shall confirm this with a signature.

7.4.6 Guidelines for visitors

Visitors shall not be allowed to enter any operational areas of the facility without escort of an employe assuring that the visitors are not entering any dangerous areas. Prior to entering the operational areas, all visitors shall be informed to always stay together with the escort person and follow given advices. All visitors shall as a minimum be wearing a helmet, reflective clothing, protective glasses, but also noise protection, or any other PPE as deemed necessary for the visit.

7.5 Pre-planning of emergency operations

Where applicable, pre-planning and preparation of checklists shall be made in cooperation between the operator and the fire and rescue services to cover possible scenarios. Typical incidents that shall be considered are:

— activation of ignition source detection systems in the conveying system,

— fire detection in the conveying system,

— indicated self-heating in a storage,

— confirmed fire in storage,

— activation of any explosion protection system in the plant,

— rescue of people from confined spaces.

The pre-fire planning shall include:

— Structure of emergency organization with contact details (e.g. mobile telephone number, private telephone number) to both all involved internal personnel and to external key persons (fire and rescue services, suppliers of inert gas and related equipment, freight companies, health and environmental authorities, etc.).

— A general risk assessment and safety rules for various expected incident scenarios and at least the six scenarios mentioned above.

— Procedure for how to perform an updated, on-site risk assessment related to the specific object and incident scenario.

— Immediate actions (preferably as a check list) to minimize the risk for the involved personnel (see below) and reduce the consequences of the incident.

— Need for warning signs and warning systems, equipment to cordon off certain areas.

— Expected duration of a fire (or explosion) incident and actions with respect to this (smaller incidents can be handled during some hours while a fire in a silo can take several days or even weeks).

— Preparations, equipment and routines for emergency discharge of storage in case of indicated self-heating or fire.

— Emergency shut down procedures for certain equipment.

— Instructions for handling of extinguishing media and contaminated material.

— Education and training of personnel for various incident scenarios (including both operator personnel, fire and rescue personnel and if relevant, key suppliers of extinguishing equipment/media).

— Routines for regular updates of the emergency procedures.

— Regular inspection and replenishment of first-aid materials.

Further details to include/consider in the pre-planning work for various equipment/locations are also mentioned in Clauses 8 to 11, and a general guidance on how to manage various emergency situations is presented in Annex D.

The pre-planning document shall also include necessary drawings and photos of the plant to visualize where various fire protection systems are installed, id-numbers of various sensors, location of water hydrants with information about maximum flow rate and pressure, emergency routes and exits within buildings and along conveyor systems, detailed construction drawings of certain equipment, etc.

7.6 Personnel risks

The following risks for personal injuries shall be considered, both during pre-planning of various possible emergency situations and during an ongoing emergency operation but is not limited to:

— exposure to toxic gases (for example, high concentrations of CO as a result of off-gassing or a self-heating/fire situation);

— areas with low O_2 concentration;

— use of inert gases during the inerting/firefighting operation (asphyxiation, exposure to cold liquefied gas);

— effects of explosions (considering both dust and gas explosions), injuries from operating explosion vents or construction parts thrown away by the explosion, risks and effects of secondary explosions;

— rapid propagation of fires and explosions in constricted spaces such as conveyor tunnels/galleries and access corridors, in particular if having steep pitch;

— backdraft (for example if opening up a silo with an ongoing smouldering fire);

— work inside confined spaces and the risk of engulfment or burial of personnel;

— instability of structure (for example, structure for elevated conveyors, collapse of silos) during fire;

— working at heights.

8 Conveyor system and transfer points

8.1 General

Typical causes of fires, specifically in conveyor systems (A.4.3), are often hot surfaces (e.g. overloading, insufficient lubrication, damaged track supporting rollers (idlers), guide rollers and internally positioned ball bearings, overheated electric motor casing, overheated brakes, belt slip, skewing of belts, friction of the belts, high speed, friction against material deposits), or forming of sparks (e.g. high speed (relative speed >1 m/s), inappropriate matching of materials, lack of or insufficient equipotential bonding causing electrostatic sparks, faults in electric devices and utilities, extraneous materials). These features shall be included in the risk assessment.

In 8.2 and 8.3, more specific aspects are listed which, as a minimum shall be considered and documented during the risk management process (Clauses 5 and 6) and implemented as possible risk reduction/risk control measures, if considered relevant or necessary, during the design and construction phase of the conveyings systems on the plant. If the risk assessment indicates that a specific measure should be implemented in the design, further information, recommendations and requirements are given in 8.4.

8.2 Detection

The following risk reduction/risk control measures shall be considered:

— Temperature monitoring of incoming material to identify abnormally warm pellets (i.e. pellets having a temperature exceeding those experienced during normal operation).

— Ignition source detection system for incoming material and in transfer points to identify hot or glowing material on the conveyor system (8.3.1).

— Motion sensing device to detect belt slipping, belt slow down or jammed conveyor, e.g. due to material build-up or blockage in transfer points.

— Measurement of the electric current consumption to detect overload in the drive.

— Sensors to detect belt misalignment.

— Vibration sensors to detect bad bearings in the drivers, rollers, etc.

— Temperature monitoring to identify hot bearings in the drivers, rollers, etc.

— Detection system along the conveyor system to identify open fire (e.g. linear temperature detection cables, flame detectors, etc.).

— Camera surveillance of areas not regularly attended by personnel.

— Interlocking of the selected detection system(s) to securely shutdown the conveyor in case of conditions that could result in a fire incident (8.4.2).

— Activation of a safe way of preventing the material being fed into a storage.

The selection of detection system should consider the possibility for maintenance and testing during operation. The ignition criteria of the material being transported shall also be considered during selection of detection system. Further information on various monitoring and detection systems is given in Annex G.

8.3 Preparatory measures

8.3.1 Fire protection

The following risk reduction/risk control measures shall be considered:

— Prohibition of vehicle parking and storage of combustible material under conveyors.

— Use of fire-resistant and dissipative belts (Cat 2B or Cat 4A according to ISO 340 and ISO 284).

— Possibilities for visual inspection, house-keeping and maintenance and manual firefighting.

— Accessibility to each installed sprinkler/spray nozzle, fire detector for inspection and maintenance via suitable hatches, alternatively via easy removal of the nozzle/detector for inspection and maintenance on the outside of the conveyor.

— Ignition source detection system connected to a quick activating water injection system in transfer points.

— Possibilities for material rejection in case of detection of abnormally warm, hot or glowing material on the conveyor at transfer points into a silo or flat storage.

— Preparation for emptying the conveyor system on unplanned standstill.

— Protection of covered conveyors located indoors by an automatic sprinkler system or water mist system.

— Sprinkler protection of conveyers located outdoors which are totally enclosed or partially open, made of non-combustible material and elevated above the ground.

— A deluge water spray system in conveyor galleries having a steep pitch, or for similar conditions, where the fire spread could be faster than the operation of conventional automatic sprinklers.

— A deluge water spray system in areas where fast response or immediate large area cooling is desired due to high values, unusual potential for severe loss or high frequency of fires.

— In addition to a deluge water spray system, compartmentation of large conveyor galleries in combination with fire ventilation in order to reduce the risk for a rapid fire spread.

— Interlocking of conveyors to safe shut down automatically on sprinkler water flow or fire detection (8.4.2).

— Fixed stand pipe systems with connections for the use of the fire and rescue service for additional or final firefighting.

— Access/escape possibilities at least at both ends of the conveyor system for the operating and firefighting personnel.

— Emergency lightning installed in all parts of a covered system/galleries.

— Warning/alarm systems (light/sound) available at suitable locations in all parts of the system to ensure an early evacuation.

— Push buttons for manual activation of the fire alarm as well as fire hose reels and/or fire extinguishers available at suitable locations.

— Separate conveyors to be used for emergency discharge (8.4.3).

8.3.2 Explosion protection

The following risk reduction/risk control measures shall be considered:

The risk of explosion predominately results from dust generation. If not conflicting with any local regulations, and based on a risk area classification (see Annex C), the following explosion protection measures shall be considered:

— Conveyor system construction to reduce the generation of dust (8.4.4).

— Use of covered conveyor structures designed to minimise the spreading of dust, accumulation of dust inside the structure and connection of transfer points to a dust collecting system.

— Certified explosion protection equipment installed to be corresponding with the explosion risk area classification along the conveyor system based on all operating conditions including start/stop of the equipment and maintenance.

— Enclosed/covered conveyors, including e.g. dust extraction systems equipped with explosion relief systems as part of the measures to limit the explosion overpressure to avoid flying debris.

— Type, size and location of explosion vents designed to ensure an effective pressure relief and prevent the risk for injury of personnel when activated.

— Guiding the pressure relief from an explosion to the outside of the building or using certified flameless indoor explosion venting devices (8.4.4).

— Explosion isolating systems (as a complement or alternative to explosion vents) to avoid transfer of an explosion and fire along a conveyor which could result in secondary explosions in connected equipment.

— Explosion suppression systems (as a complement or alternative to explosion vents or explosion isolation systems).

— Explosion-proof design (as a complement or alternative to other explosion protection measures).

— Interlocking of conveyors to shut down automatically on explosion detection (8.4.2).

— Cleaning of dust deposits using a suitable vacuum cleaning system certified for use in explosive atmospheres or by using a low pressure water cleaning system (8.4.4).

— Specific consideration of the risk for dust explosion and suitable relevant explosion protection measures for conveyors intended for emergency discharge.

8.4 Additional information, recommendation and requirements on design and protection of conveyor systems

8.4.1 General

If it has been determined via the risk assessment process that a specific risk reduction/control measure described in 8.2 and 8.3 needs to be included, this clause provides additional information, recommendations and requirements.

8.4.2 Detection systems

Ignition source detection system for incoming material and in transfer points to identify hot or glowing material on the conveyor system can also be connected to a quick activating water injection and/or a material rejection system (see 8.4.3).

Ignition source detection systems should be interlocked to securely shutdown the conveyor in case of conditions that could result in a fire incident. The shutdown sequence should also include all contributing transport system to the stopped conveyor. The shutdown sequence should also be designed in a way so that the risk of fire is not increased due to the stop itself.

Temperature monitoring system to identify hot bearings in the drivers, rollers, etc can be obtained by using linear temperature detection cables, or if the conveyor bearings are not enclosed, by using an IR camera or an IR thermometer.

Detection system along the conveyor system to identify open fire (for example, linear temperature detection cables, flame detectors, etc.) is of particular importance for long, covered conveyors. A detection system can be replaced by an automatic sprinkler system for certain applications (see 8.4.3).

8.4.3 Fire protection

At certain locations, e.g. before the discharge into a silo, the activation of a detection system should also activate a safe way of preventing the material being fed into the silo, e.g. by designing a safe way of feeding the material to an abort or a safe side dump (see 8.3.1). Depending on the physical layout and material flow, it can be practical to reverse the direction of a conveyor for disposal of aborted material. Conveyors transporting aborted material should be running dry before shutting down.

Open indoor conveyors might not need a specific sprinkler protection system if the building is protected by a ceiling mounted automatic sprinkler system designed to also cover the conveyor system.

Visual inspection, house-keeping and maintenance and manual firefighting of conveyor systems can be made possible e.g. by making them accessible on both sides, adding walkways on both sides for elevated conveyors, and installing vacuum cleaning systems).

In case of repeated activations of an ignition source detections system, the system should shut down the conveyor system.

In case of cold climate where freezing could occur, a dry type or pre-action system shall be considered as an alternative to automatic sprinkler system. For dry pipe systems, the filling time shall be considered.

Deluge systems intended to protect conveyor galleries with steep pitch, where rapid fire spread could be expected or there is a potential for severe loss or high frequency of fires, shall cover the entire belt system, including the return belt. Filling time for a dry pipe system shall be considered.

Fixed stand pipe systems with connections for the use of the fire and rescue service shall have connections for fire hoses at suitable locations along the entire conveyor system.

If ignition source detection system with extinguishing is installed, manual activation of the extinguishing system via push buttons at suitable locations should be considered. Also a manual activation of the system should result in a safe shutdown sequence of the conveyor system as described in 8.4.2.

Conveyors to be used for emergency discharge shall be designed to endure transport of hot and smouldering material and be accessible to allow visual supervision and manual water application or equipped with a suitable ignition source/fire detection system combined with a fixed water application system to extinguish any smouldering material discharged onto the conveyor. A separate conveyor for emergency discharge should be considered if several storage units are connected to the ordinary conveyor for discharge.

NOTE For more details on sprinkler design for conveyor protection, see e.g. FM Global Data sheet 7-11 (FM Global, 2015) or NFPA 15.

8.4.4 Explosion protection

The conveyor system should be constructed to reduce the generation of dust by minimizing the number of transfer points and their drop heights.

Conveyor structures should be covered to minimise the spreading of dust, and constructed so the dust accumulation inside the structure is minimised. Transfer points should be connected to a dust collecting system or equivalent measures to reduce the dust emission.

All equipment installed along the conveyor system shall be certified to correspond with the explosion risk area classification. The risk area classification shall be based on all operating conditions including start/stop of the equipment and maintenance.

Enclosed/covered conveyors, including e.g. dust extraction systems should be equipped with explosion relief systems as part of the measures to limit the explosion overpressure to avoid flying debris.

The type, size and location of explosion vents should be chosen such that it ensures an effective pressure relief but also prevent the risk for injury of personnel when activated, e.g. prevent passage in front of the vent and/or using a flame arrester at the vent opening.

If conveyors are located indoors, the pressure relief from an explosion shall be guided to the outside of the building or using certified flameless indoor explosion venting devices. In such case, the strength of the building structure shall be considered.

Cleaning of dust deposits should be made using a suitable vacuum cleaning system certified for use in explosive atmospheres or by using a low-pressure water cleaning system. Compressed air or high-pressure water cleaning system shall not be used.

Conveyor systems for emergency discharge need special consideration with relation to the risk of fire and explosions as the discharged material will contain smouldering material which could result in open flames when the material is exposed to the air.

9 Silos

9.1 General

Typical causes of fire in silo storage of pellets are often related to

— self-heating (See Annex B) of the pellets;

— hot material introduced into the silo via the conveyor system;

— mechanical failures of e.g. discharge equipment at the bottom of the silo.

Explosions inside the silo headspace can be a result of

— smouldering material introduced into the silo via the conveyor system which can ignite a dust cloud generated inside the silo during filling;

— the consequence of a primary explosion in the conveyor system causing a secondary explosion inside the silo;

— smouldering fire inside the silo, generating high concentrations of combustible gases (CO, unburnt hydrocarbon) leading to a gas explosion.

In 9.2 and 9.3, more specific aspects are listed which, as a minimum shall be considered during the risk management process (see Clauses 5 and 6) and implemented as possible risk reduction/risk control measures, if considered relevant or necessary, during the design and construction phase of the silo storage. If the risk assessment indicates that a specific measure should be implemented in the design, further information, recommendations and requirements are given in 9.4. Guidelines for handling of various emergency situations are presented in Annex D.

9.2 Detection and temperature and gas monitoring

The following risk reduction/risk control measures shall be considered:

— ignition source detection system monitoring the pellets flow into the silo to identify warm, hot or glowing material along the incoming conveyor system (9.3.1.1);

— monitoring of gas composition or gas concentration in the silo headspace and close to the discharge outlet;

— monitoring of temperatures inside the bulk by temperature sensor cables suspended from the silo roof;

— ignition source detection system monitoring the pellets flow from the silo discharge opening to identify warm, hot or glowing material for control of the discharged material to the conveyor system (see 9.3.1.1);

— video surveillance of areas not regularly attended by personnel.

Some further information on various monitoring and detection systems are given in Annex G.

9.3 Preparatory measures

9.3.1 Fire protection

9.3.1.1 General design of silo

The following risk reduction/risk control measures shall be considered:

— A minimum distance between individual silos and adjacent buildings to ensure good accessibility and possibilities for preparations for emergency discharge in the case of fire.

— Air tightness of the general silo construction, except specific ventilation arrangements (see below), to restrict air entrainment into the bulk material but also to minimize the leakage of inert gas in case of an extinguishing operation.

— Internal construction of the silo (e.g. steel beams in the roof) to prevent accumulation of dust.

— Roof construction to withstand the load from temperature detection cables attached to the roof and to minimize water condensation leading to risk of water falling into the pellets.

— Flooring top layer material to minimize risks of spark generation with mobile handling equipment.

— Minimize the risk for bridging and ratholing.

— Installation of nominally airtight valves at both inlet and discharge outlet.

— Closed and sealed doors, openings, hatches, in particular located below the maximum filling level to minimize the possibility for unintentional air entrainment.

— Prevention of backgassing or backfire into the silo from a furnace directly connected to a silo.

— Possibilities to close ventilation arrangements based on free convection or turn off and close forced ventilation systems in case of a fire situation.

— Provide sufficient height to allow free fall of the pellets at a suitable location, both before the silo inlet and after the discharge outlet to allow the installation of ignition source detectors, preferably in combination with either a suppression system or a quickly acting material rejecting arrangement.

— Arrangement and routines to lessen the dust generation from the impact of pellets falling from the top of the silo (see A.5.2.1).

— Arrangements for emergency discharge designed for handling discharged hot/smouldering/burning material.

— A specific storage area available for handling the discharged hot/smouldering/burning material.

9.3.1.2 Inert gas system for fire suppression/prevention

The following risk reduction/risk control measures shall be considered:

— Fixed inert gas distribution system at the base of the silo for inerting of the bulk material (see 9.4.3.2).

— Installation of a pressure/vacuum venting valve (or other similar arrangement) with a venting capacity corresponding to the gas flow rate used during the inerting operation of the silo.

— Fixed inert gas distribution system for protection of the silo headspace (see 9.4.3.3). CO_2 should not be used as extinguishing media unless using a vaporizer to guarantee a gaseous form of the CO_2 due to the risk of explosion, see D.2.3.2.

— Arrangement of fixed gas sampling lines from silo headspace to a safe location where gas analysis instruments can be located during a fire situation.

— Fixed deluge (water)/foam/CAF system mounted in the silo ceiling for the protection of the silo headspace in case of an open fire situation.

— Fixed stand pipe systems with connections for the use by the fire and rescue service for additional or final firefighting.

— Injection of inert gas to reduce the oxygen concentration inside the silo for fire prevention.

— Forced ventilation system for control of the bulk temperature (Annex E).

NOTE Using large quantities of water will cause swelling of the pellets and could endanger the entire silo construction due to the forces generated, see Annex D.

9.3.2 Explosion protection

During normal operation, the risk of explosion is predominately connected to dust explosions. This could e.g. be due to incoming smouldering material, igniting the dust cloud generated during the free fall into the silo. During a smouldering fire situation inside the silo, e.g. caused by self-heating, there is a significant risk of gas accumulation (for example CO and unburnt hydrocarbons) which could result in a gas explosion.

In addition to the explosion protection measures mentioned in 8.3.2, the following additional risk reduction/risk control measures shall be considered:

— Equipment installed at a silo in a risk classified area to be certified according to the explosion risk classification of the specific area/equipment.

— Explosion relief arrangement on the silo construction to prevent the explosion pressure to exceed the maximum design pressure for the overall silo construction.

— Preparations to seal the vent openings after release to minimize air entrainment and loss of inert gas during the inerting operation of the silo. If self closing explosion vents are used, vacuum venting valves have to be installed as the cooling of the hot gases following the combustion can create a vacuum in the silo, resulting in a deformation. The flow capacity of the venting valves shall be designed in relation to the volume and strength of the silo.

9.4 Additional information, recommendation and requirements on design and protection of silos

9.4.1 General

If it has been determined via the risk assessment process that a specific risk reduction/control measure described in 9.2 and 9.3 needs to be included, this clause provides additional information, recommendations and requirements.

9.4.2 Detection systems

Monitoring of the pellet bulk inside a silo could be made by monitoring the gas composition using gas detection system, or the gas concentration using CO/CO_2 detectors. The measurements should be made in the silo headspace and preferably also close to the discharge outlet.

When monitoring the temperature inside the bulk by temperature sensor cables suspended from the silo roof, the vertical spacing of the individual temperature sensors on each cable should not exceed 3 m. The number of sensor cables and spacing between the individual cables should be based on the specific conditions, e.g. silo diameter, construction of silo roof, duration of storage. The design of the roof need to withstand the load from temperature detection cables attached to the roof as a result of the flowing pellets during filling and discharge.

NOTE The sensor cables can be attached to the silo bottom (with a breakable connection) or by other means fastened to keep the cables in their vertical position during filling.

9.4.3 Fire protection systems

9.4.3.1 General design

The general silo construction (wall, roof, connection between the wall and roof, connection between the wall and the silo foundation) shall be as airtight as possible to restrict air entrainment into the bulk material but also to minimize the leakage of inert gas in case of an extinguishing operation.

Construct the silo so that the risk for bridging and ratholing is minimized.

Both the silo inlet and discharge outlet should be provided with nominally airtight valves. The inlet valve should close automatically in case of fire detection in the feeding conveyor system in order to prevent the spread of an external fire into the silo. Both the inlet and outlet valve should close automatically in case of fire detection at the discharge outlet.

Doors, openings, hatches, in particular located below the maximum filling level shall be closed and sealed to minimize the possibility for unintentional air entrainment which could cause localized self-heating and ignition.

Ventilation of the silo head space, either based on free convection or forced ventilation, shall be possible to close or turn off and close in the case of a fire situation. The valves should be nominally airtight and shall be remotely controlled and locally by hand. In case the silo is ventilated via free convection through an annular gap between the silo wall and and roof, some arrangement should to be installed making it possible to close the gap.

If the silo is equipped with a ventilation system for cooling of the bulk material, this system shall also be possible to turn off and air intakes/outlets possible to close and seal (see also 9.4.3.6).

If the silo is directly connected to a furnace, suitable prevention measures of backgassing or backfire due to underpressure caused by a forced ventilation system shall be considered.

When the ventilation systems are turned off and closed, there shall be a pressure/vacuum venting valve (or other similar arrangement) with a venting capacity corresponding to the gas flow rate used during the inerting operation of the silo.

To allow the installation of an ignition source detector, both at the inlet of the silo and at the discharge outlet from the silo, chutes should be arranged creating a free fall of the pellets. The chutes should be located between the conveyor for incoming material and the silo opening or at a suitable location before the silo inlet as well as between the discharge opening and the discharge conveyor or at a suitable location after the silo outlet. This will allow the ignition source detectors to be installed in combination with either

— a quick activating water injection system or

— a quick acting material rejecting arrangement (rejection material should then be guided to a safe collecting area).

As an alternative to a free fall outlet, choke feed can be used as discharge mechanism, which does not imply free falling (dust generation). Temperature monitoring can be made with surface measurement and subsequent ignition source detection.

To lessen the dust generation from the impact of pellets falling from the top of the silo, it is recommended not to empty a silo completely, except for cleaning. The impact from pellets falling on pellets from low height is much less than pellets falling on concrete or steel boom. There are also so called “bean ladders”, “grain ladders” or “filling tubes”, positioned in the center of silos providing a slide or step-wise avalanche from top to bottom (A.5.2).

Preparations for emergency discharge should be made by installation of a separate conveyor system designed for handling the discharged hot/smouldering/burning material. This is of particular importance if several silos are served by only one conveyor system (see NOTE below). If the ordinary discharge conveyor system is planned to be used, this shall be equipped with an enhanced fire protection (8.3.1).

A specific storage area shall be available for handling the discharged hot/smouldering/burning material. The location should be carefully selected considering the possible risks for nearby objects, neighbouring activities, dominant wind directions, etc. The storage area should include possibilities to collect any extinguishing media.

NOTE There are many examples of silo fires where the lack of emergency discharge preparations has created great problems to discharge the silo in a controlled manner, and in several cases this has resulted in a total loss of both the pellets and the silo. The complexity and problems increase if only one conveyor is used for multiple silos as there will be a risk for fire spread. Accessibility to the conveyor for firefighting personnel will also be more difficult if the conveyor system is located in a culvert below the silo(s). A separate discharge possibility from each silo is therefore strongly recommended.

9.4.3.2 Inert gas system for bulk material

The fixed inert gas distribution system shall be installed at the base of the silo for inerting of the bulk material. The number of gas distribution inlets and design of the pipe arrangement shall be based on the silo cross section area.

The gas supply and the gas distribution system should be designed to provide a flow rate of not less than 5 kg/m^2 (silo cross section area) per hour. The flow and pressure calculation should assume that the silo is full of pellets having the lowest anticipated permeability.

The inlet opening/connection to the gas distribution system shall be sealed when not in operation to avoid air/moisture entrainment into the silo.

The gas distribution system shall be possible to flush with water during maintenance of the silo and shall therefore have an inclination towards the point of drainage.

The gas injection openings/nozzles at the silo bottom shall be designed to prevent blocking or clogging of the bulk material.

The pressure relief opening/valve shall be arranged in the silo headspace and designed to be capable of evacuating a gas flow corresponding to the injected inert gas flow. The opening should be designed as a check valve, allowing outflow of gas by preventing inflow of air/oxygen unless a significant underpressure is obtained inside the silo (for example due to a rapid temperature decrease, see 9.3.2).

Arrangement of fixed gas sampling lines from silo headspace to a safe location during a fire situation should be considered as this will provide a possibility to monitor the inerting and fire suppression process. The instruments should preferably be capable of measuring O_2 and CO/CO_2 (%-scale).

9.4.3.3 Fire protection of silo headspace

The piping and gas inlets for the inert gas distribution system should be located in the upper part of the silo wall to avoid damage to the pipe system in case of an explosion. The number of inlets should be based on the silo cross section area and the gas inlet dimension should ensure a low inlet velocity to avoid dust formation. CO_2 shall not be used as extinguishing media (see NOTE 1).

The gas supply and the gas distribution system should be designed to provide a flow rate of not less than 1 to 3 kg/m^2 (silo cross section area) per hour.

The gas injection openings/nozzles at the silo headspace shall be located as far away as possible from the pressure relief opening (see 9.3.1.2) in order to reduce the inert gas loss as much as possible. The openings/nozzles shall be located such that they are not covered by the bulk material at maximum fill level and designed so they not get blocked or clogged by dust.

A fixed deluge (water)/foam/CAF system can be mounted in the silo ceiling as a complement to the inert gas system for the protection of the silo headspace in case of an open fire situation. Such system is important, in particular in large diameter silos or silos equipped with explosion vents which, after an explosion, can be very difficult to seal effectively making it difficult or even impossible to obtain an extinguishing effect using only inert gas. Using a foam system with high quality of expanded foam (e.g. applied as CAF) will reduce the use of water and provide a foam blanket on the top or the material reducing the entrainment of oxygen into the bulk material (see NOTE 2).

Because of the risk of a gas/dust explosion, manual foam application is not recommended due to injection of air through the openings. If manual foam application is required, openings shall be positioned such that the foam can be applied to form a uniform layer covering the entire top layer of the pellets in the silo. The openings shall be designed to limit the air entrainment as much as possible.

A fixed stand pipe system with connections for the use by the fire and rescue service for additional or final firefighting should be consided. The pipe system should have connections for fire hoses at suitable locations at the access platforms at the silo top. Access/escape routes for the firefighting personnel shall be considered.

NOTE 1 The use of CO_2 as extinguishing media is not recommended as the silo headspace is likely to have an explosive atmosphere due the generation of pyrolysis gases. The discharge of CO_2 is known to generate electrostatic charge which could generate a spark and cause an explosion inside the silo headspace (see D.2.3.2).

NOTE 2 Using large quantities of water will cause swelling of the pellets and could endanger the entire silo construction due to the forces generated, see Annex D.

9.4.3.4 Inert gas system for fire prevention

If there is an increased risk for self-heating and spontaneous ignition and/or that the consequences of a fire situation is unacceptable, injection of inert gas to reduce the oxygen concentration inside the silo should be considered.

The inert gas supply shall be connected to the gas distribution system at the base of the silo (see 9.4.3.2) and have a capacity enough to keep the oxygen concentration in the bulk material below about 10 %.

As an alternative to using liquefied nitrogen for producing nitrogen gas (see 9.4.3.5), a nitrogen gas generator could be installed, normally generating a mixture of about 95 % nitrogen and 5 % oxygen. Also here, the capacity should be enough to keep the oxygen concentration below 10 % (see NOTE 1 and NOTE 2).

In order to limit the needed capacity of nitrogen, in particular for large diameter silos, the gas distribution system could be divided into a number of sections, applying the gas to one section for a number of hours before switching to the next section, etc.

A gas analyser measuring the oxygen concentration in the silo head space shall be used to ensure the system performance. A mobile gas analyser could be used if the measurement frequency is ensured by being part of the operational procedures.

NOTE 1 An oxygen concentration of <10 % is expected to be enough for prevention purpose, while an oxygen concentration of maximum 5 % in the silo headspace is recommended as the aim in a firefighting situation.

NOTE 2 EN 16750 can provide further guidance on the design, installation and maintenance of fixed oxygen reduction systems.

9.4.3.5 Inert gas supply

The inert gas supply for the protection/inerting system of the bulk material and/or the headspace should be based on either

a) a mobile tank with liquid nitrogen for the inert gas in combination with a mobile vaporization unit which is connected to the gas distribution systems (bottom and headspace) in an emergency situation,

b) an onsite fixed tank with liquid nitrogen and a fixed vaporization unit,

c) an inert gas generator system connected to the gas distribution systems (limited capacity and too high oxygen content in the gas could be a problem for extinguishing operations).

For the connection of a mobile gas supply unit to the gas distribution system (bulk and headspace system), a connection manifold shall be located at a suitable position on the outside of the silo.

For supply of inert gas from external suppliers using e.g. road transport of mobile tanks, the procedures and capacity requirements of an inerting operation, shall be thoroughly coordinated with the supplier to ensure adequate supply.

NOTE Batteries of N_2 cylinders would only be an alternative for very small silos or as the first step of an inertisation operation until further gas supply can be obtained.

9.4.3.6 Cooling of bulk material by forced ventilation

In certain parts of the world, the solid biofuel pellets have a high initial temperature due to hot weather, often combined with a pellet production using reactive raw material with high amount of oxidative substances. In order to control the bulk temperature, a forced ventilation system could be used in these situations. The following aspects shall then be considered (see also Annex E).

The ventilation air flow shall be generated by strong fans supplying and distributing the air through gaps in the bottom of the silos, or for small diameter silos, through perforated metal sheets in the discharge cone of the silo. Venting of the cooling air is done through dampers at the top of the silos.

The temperature in the bulk shall be monitored with a number of temperature sensor cables (see 9.4.2). The sensor configuration shall to be designed with consideration given to the thermal conductivity characteristics, the permeability and variance in permeability, ventilation fan capacity and the geometry of the fresh air inlets.

The temperature monitoring system will present a picture of the temperature distribution in the bulk material and shall give alarm if any temperature sensor exceeds a predetermined level. In such cases, the heat generated by self-heating is higher than the cooling capacity and emergency actions shall be considered.

The fans are normally controlled by the temperature monitoring system which turns on and off to maintain the temperature within predetermined margins. In certain installations, the fans can run continuously and are switched off only if the inlet ventilation air temperature exceeds the temperature of the bulk material.

The fan capacity shall be based on the bulk permeability of the material and the geometry of the silo. The fan capacity shall be high enough to provide enough cooling. If the fan capacity is too low, the ventilation can make the situation worse, as the increased oxygen supply into the material will increase the oxidation process and thereby result in a temperature escalation rather than to temperature decrease. Therefore, the fans should have a backup power supply in case of a failure of the normal supply.

A high humidity in the inlet air can cause problems and in order to avoid this, the ventilation shall be turned off if the relative humidity exceeds e.g. 80 % or a dehumidifier system shall be installed.

The ventilation system could be combined with the injection of inert gas (see 9.4.3.2) if the temperature rises above critical values. In this situation the ventilation system shall be designed to ensure that the air supply is completely blocked to facilitate the inerting operation (see D.4).

9.4.4 Explosion protection

Equipment installed in a risk classified area shall be certified according to the explosion risk classification of the storage during different operational procedures e.g. filling, discharge or maintenance.

If the silo construction is not designed to withstand the full explosion pressure, the silo shall be equipped with relief arrangement to prevent the explosion pressure to exceed the maximum design pressure for the overall silo construction.

For silos having walls of corrugated steel plates, the attachment of the roof to the silo wall or the roof construction itself is often a week point and shall be considered in the calculations and during the design of the pressure relief arrangement (see NOTE).

Preparations shall be made to seal the vent openings after release to minimize air entrainment and loss of inert gas during the inerting operation of the silo.

NOTE There are several examples (in particular from explosions in large diameter silos) where entire silo roof has acted as an explosion vent by lifting from the silo wall construction and then fall back again, even if the roof was equipped with certified explosion vents. In certain occasions, a part of the roof has also been thrown away, falling down to the ground beside the silo wall. This prevents an effective inerting process as it might be impossible to reduce the oxygen concentration in the silo headspace.

10 Large scale bunkers

10.1 General

The size and shape of bunkers can vary considerably, from small underground bunkers for local heating plants to large bunkers in large scale power plants (see Annex A). The description in Clause 10 is primarily focused on large scale bunkers, although certain aspects could also be valid for small size bunkers. In certain small scale applications, ISO 20023 might be more relevant.

Typical causes of fire in bunker storage of pellets are often related to:

— Various external ignition sources (e.g. lighting, electric equipment, hot work).

— Smouldering material introduced into the bunker via the conveyor system.

— Self-heating of the pellets (mainly if the pellets are stored for a long time, e.g. during outage or idle periods).

— Back-fires from boiler unit or mechanical failures of e.g. discharge equipment at the bottom of the bunker.

Explosions in the bunker can be a result of:

— smouldering material brought into the bunker via the conveyor system which can ignite a dust cloud generated inside the bunker during filling,

— the consequence of a primary explosion in the conveyor system or dust extraction system causing a secondary explosion inside the bunker,

— a smouldering fire inside the bunker, generating high concentrations of combustible gases (CO, unburnt hydrocarbon), leading to a gas explosion.

In 10.2 and 10.3, a listing of more specific aspects is presented which, as a minimum shall be considered during the risk management process (see Clauses 5 and 6) and implemented as possible risk reduction/risk control measures, if considered relevant or necessary, during the design and construction phase of the bunker storage. If the risk assessment indicates that a specific measure should be implemented in the design, further information, recommendations and requirements are given in 10.4. Guidelines for handling of various emergency situations are presented in Annex D.

10.2 Detection and temperature and gas monitoring in bunkers

The following risk reduction/risk control measures shall be considered:

— Ignition source detection system monitoring the pellets flow into the bunker to identify warm, hot or glowing material along the conveyors for incoming pellets (see 10.3.1.1).

— Monitoring of gas composition or gas concentration in the bunker or in the bunker dust extraction system and close to the discharge outlet.

— An aspirating monitoring system in the bunker house.

— A dust monitoring system located in the bunker house.

— Monitoring of temperatures inside the bulk by temperature sensor cables suspended from the the bunker floor.

— Ignition source detection system monitoring the pellets flow from the bunker discharge opening to identify warm, hot or glowing material for control of the discharged material to the conveyor system (see 10.3.1.1).

— Video surveillance of areas not regularly attended by personnel.

Some further information on various monitoring and detection systems are given in Annex G.

10.3 Preparatory measures

10.3.1 Fire protection

10.3.1.1 General design of bunker

The following risk reduction/risk control measures shall be considered:

- Air tightness of the general bunker construction, except specific ventilation arrangements (see below) to restrict air entrainment into the bulk material.
- Closed and sealed doors, openings, hatches, etc., in particular located below the maximum filling level, to minimize the possibility for unintentional air entrainment.
- Minimize the risk for bridging and ratholing.
- Limitation of the production of dust.
- Internal construction of the bunker to prevent accumulation of dust.
- Bunker floor construction to withstand the load from temperature detection cables as a result of the flowing pellets.
- Subdivision of large bunkers with a solid wall construction up to the bunker floor.
- Provide sufficient height to allow free fall of the pellets at a suitable location, both before the bunker inlet and after the discharge outlet to allow the installation of ignition source detectors, preferably in combination with either a suppression system or a quickly acting material rejecting arrangement.
- Possibilities to turn off and/or close ventilation arrangements of the bunker house.
- Installation of nominally airtight valves at the bunker discharge outlets.
- Arrangements and routines for emptying of the bunker content in case of an unplanned shut down.
- Arrangements and routines for emergency discharge designed for handling the discharged hot/smouldering/burning material.
- A specific storage area available for handling the discharged hot/smouldering/burning material.

10.3.1.2 Bunker house and bunker protection

The following risk reduction/risk control measures shall be considered:

- Fixed deluge (water)/foam/CAF system for the protection of the bunker house.
- Fixed deluge foam/CAF or high expansion foam system for the protection of the bunker (below the bunker floor).
- Fixed inert gas distribution system for inerting the bulk material in the bunker.
- Fixed stand pipe systems with connections for the use by the fire and rescue service for additional or final firefighting.

10.3.2 Explosion protection

During normal operation, the risk of explosion is predominately connected to dust explosions. This could e.g. be due to incoming smouldering material, igniting the dust cloud generated during the free fall into the bunker. During a smouldering fire situation inside the bunker, gas accumulation (for example, CO and unburnt hydrocarbons) could result in a gas explosion.

In addition to the explosion protection measures mentioned in 8.3.2, the following additional risk reduction/risk control measures shall be considered:

— Equipment installed at a bunker in a risk classified area shall be certified according to the risk classification of the specific area/equipment.

— Explosion relief arrangements at the bunker house.

— Explosion relief arrangements in the dust extraction system.

— Preparations to seal the vent openings after release to minimize air entrainment and loss of foam and/or inert gas during an fire fighting operation. If self closing explosion vents are used, vacuum venting valves have to be installed as the cooling of the hot gases following the combustion can create a vacuum in the bunker/bunker house, resulting in a deformation. The flow capacity of the venting valves shall be designed in relation to the volume and strength of the bunker/bunker house.

10.4 Additional information, recommendation and requirements on design and protection of bunkers

10.4.1 General

If it has been determined via the risk assessment process that a specific risk reduction/control measure described in 10.2 and 10.3 needs to be included, this clause provides additional information, recommendations and requirements.

10.4.2 Detection systems

Monitoring of the pellet bulk inside a bunker could be made by monitoring the gas composition using gas detection system, or the gas concentration using CO/CO_2 detectors. The measurements should be made both below the bunker floor and close to the discharge outlet.

For monitoring of the bunker house, an aspirating gas detection system could possibly provide the best coverage of the entire space due to the size and influence of ventilation.

When monitoring the temperature inside the bulk by temperature sensor cables suspended from the bunker floor, the vertical spacing of the individual temperature sensors on each cable should not exceed 3 m. The number of sensor cables and spacing between the individual cables should be based on the specific conditions, e.g. the bunker area, any subdivisions of the bunker, construction of bunker floor, duration of storage.

A dust monitoring system located in the bunker house could be used to indicate that the dust extraction system works properly and/or indicate a change in quality of received pellets.

NOTE Control that the bunker floor construction is designed to withstand the load from temperature detection cables as a result of the flowing pellets during filling and discharge, if installed.

Some further information on various monitoring and detection systems are given in Annex G.

10.4.3 Fire protection systems

10.4.3.1 General design of bunker

The general wall construction of the bunker construction shall be as airtight as possible below the maximum filling level to restrict air entrainment into the bulk material. Doors, openings, hatches located below the maximum filling level shall be closed and sealed to minimize the possibility for unintentional air entrainment which could cause localized self-heating and ignition.

The design should seek to limit the production of dust and the internal construction of the bunker and bunker house should be designed to prevent accumulation of dust. To reduce dust contamination of the bunker house during filling and to prevent objects from falling into the bunker during operation, a bunker covering should be installed on the topside of the bunker floor construction. Except for the inlet air openings, this construction shall be made as airtight as possible. The inlet opening shall allow clean air from the bunker house to replace the air extracted from the inside of the bunker by the dust extraction system. The openings should be designed and located such that a downward airflow of at least 0,5 m/s is obtained and that the airflow is collecting the generated dust as efficiently as possible. Openings for filling the bunker from the conveyor system should be sealed in a flexible manner by using e.g. a “brush” system.

Ventilation of the bunker house, based on the bunker dust extraction system or any other forced ventilation system or free convection, shall be possible to turn off or close, e.g. in case of a fire situation. The valves should be nominally airtight and shall be remotely controlled and locally by hand.

In large bunkers with several discharge outlets, each part of the bunker should be subdivided with a solid wall construction up to the bunker floor to reduce the likelihood for spread of smouldering fires between various sections of the bunker. Each discharge outlet should be provided with nominally airtight valves.

To allow the installation of an ignition source detector, both at the inlet of the bunker and at the discharge outlet from the bunker, chutes can be arranged creating a free fall of the pellets. The chutes should be located between the conveyor for incoming material and the bunker opening or at a suitable location before the bunker inlet as well as between the discharge opening and the discharge conveyor or at a suitable location after the bunker outlet. This will allow the ignition source detectors to be installed in combination with either

— a quick activating water injection system or

— a quick acting material rejecting arrangement (rejection material should then be guided to a safe collecting area).

As an alternative to a free fall outlet, choke feed can be used as discharge mechanism, which does not imply free falling (dust generation). Temperature monitoring should be made with surface measurement and subsequent ignition source detection.

Preparations for emergency discharge should be made by installation of a separate conveyor system designed for handling the discharged hot/smouldering/burning material. This is of particular importance if the bunker is located underground and/or several bunkers are served by only one conveyor system. If the ordinary discharge conveyor system is planned to be used, this shall be equipped with an enhanced fire protection (see 8.3.1).

A specific storage area shall be available for handling the discharged hot/smouldering/burning material. The location should be carefully selected considering the possible risks/problems for nearby objects, neighbouring activities, dominant wind directions, etc. The storage area should include possibilities to collect any extinguishing media.

10.4.3.2 Bunker house protection

For the protection of the bunker house (above the bunker floor,) a fixed deluge (water)/foam/CAF system should be installed in the bunker house ceiling to control/suppress glowing embers or an open fire in the conveyor system, electrical cables or other objects. The use of a foam system with high quality of expanded foam (e.g. applied as CAF) is preferred as the foam will reduce the amount of water. The foam that is flowing down through various openings in the bunker floor into the bunker will also partly cover and protect the pellet surface.

NOTE Using large quantities of water only will cause swelling of the pellets and could cause bridging or ratholing and even endanger the entire bunker construction due to the forces generated (see Annex D).

10.4.3.3 Bunker protection

For the protection of the bunker (below the bunker floor), a fixed deluge foam/CAF or high expansion foam system should be installed at suitable locations in or below the bunker floor to ensure a full coverage of the pellet surface which will control/suppress glowing embers or an open surface fire. If the bunker is subdivided by separating walls, the deluge system should also be sectioned allowing activating of selected sections. The use of a foam system with high quality of expanded foam (e.g. applied as CAF) is preferred as this will protect the pellet surface, reduce the penetration of oxygen into the bulk material and reduce the amount of water. When the surface is covered with foam, additional foam application can be made in suitable intervals.

If a high expansion foam system is considered, the foam generators should be arranged so that fresh outside air is used for foam generation. Ventilation openings from the bunker and the bunker house to the outside shall be available having a capacity corresponding to the foam generation capacity. Further guidance can be obtained in EN 13565-2 and NFPA 11. An alternative could be to use a high expansion foam system designed for the use of inside (contaminated) air.

Fixed stand pipe systems with connections for the use by the fire and rescue service for additional or final firefighting in a fire situation should be installed. The pipe system should have connections for fire hoses at suitable locations close to all entry points to the bunker house. Access/escape possibilities for the firefighting personnel shall be considered.

NOTE In case of a well-developed fire at the activation of the high expansion foam system, there can be problems with fast foam breakdown due to hot and foam destructive gases in bunker house/headspace. The use of high expansion foam can also create problems for the fire & rescue service to access the bunker house for e.g. additional manual extinguishing operations.

10.4.3.4 Inert gas system for fire suppression

An inert gas system could be considered as a complement to the protection of the bunker using a foam system described in 10.4.3.3. The inert system would aid the control of a smouldering fire deep inside the stored bulk material as it would prevent oxygen supply to the fire. This option would in particular be important if there are no possibilities for a specific emergency discharge. The general principles for silo protection should be followed, and the system design should be made according to applicable parts of 9.3.1.2 and 9.4.3.2, and the extinguishing operation following the recommendations in D.4.

If using inert gas as a complement for fire suppression, it is important to realize that the gas will also penetrate the foam layer and reduce the oxygen concentration in the bunker house. Any personnel entering the bunker house shall therefore wear SCBA-equipment (Self Contained Breathing Apparatus) as the oxygen concentrationcan be very low even if the fire appears to be controlled or extinguished.

10.4.3.5 Gas supply

Various alternatives for inert gas supply are described in 9.4.3.5.

10.4.4 Explosion protection

Equipment installed and used in a risk classified area shall be certified according to the explosion risk classification of the storage during different operational procedures e.g. filling, discharge or maintenance.

Explosions relief arrangements of the bunker, bunker house and dust extraction system should be designed to prevent an explosion pressure to exceed the design pressure for each enclosure. The type, size and location of explosion vents shall be chosen such that it ensures an effective pressure relief but also prevent the risk for injury of personnel when activated, e.g. prevent passage in front of the vent and/or using a flame arrester at the vent opening. The pressure relief should preferably be guided outdoors to a safe area, or if not possible, using a certified flameless indoor explosion venting device. In such case, the strength of the building structure shall be considered.

If the bunker is protected by an inert gas system, preparations should be made to seal the the vent openings after release to minimize air entrainment and loss of inert gas during the inerting operation of the bunker.

11 Warehouse

11.1 General

Typical causes of fires in a warehouse storage of pellets are often related to self-heating (see Annex B) of the pellets, self-heating/smouldering in underground discharge system or smouldering material brought into the storage via the conveyor system.

Also other equipment inside the storage, e.g. conveyor systems in the ceiling for the incoming pellets or various discharge systems in the floor construction for automated discharge could be potential ignition sources (see 8.1).

There are also possibilities for external ignition sources, e.g. related to hot surfaces or fires in wheel loaders or other external equipment used inside the storage for discharging the pellets.

Explosions inside the warehouse could be a result of:

— smouldering material introduced into the warehouse via the conveyor system which can ignite a dust cloud generated during filling;

— a consequence of a primary explosion in the conveyor system causing a secondary explosion inside the warehouse;

— a deep-seated smouldering fire in the stored material generating high concentrations of combustible gases (CO, unburnt hydrocarbon) which could ignite and cause a rapid fire spread and/or a gas explosion;

— a consequence of a primary explosion caused by mobile handling equipment or other equipment.

In 11.2 and 11.3, a listing of more specific aspects is presented which, as a minimum shall be considered during the risk management process (see Clauses 5 and 6) and implemented as possible risk reduction/risk control measures, if considered relevant or necessary, during the design and construction phase of the warehouse. If the risk assessment indicates that a specific measure should be implemented in the design, further information, recommendations and requirements are given in 11.4. Guidelines for handling of various emergency situations are presented in Annex D.

11.2 Detection

The following risk reduction/risk control measures shall be considered:

— Ignition source detection system at transfer points to identify warm, hot or glowing material along the conveyors for incoming pellets.

— Monitoring of gas composition or gas concentration inside the warehouse.

— Monitoring of temperatures of the bulk material.

— An ignition source detection system to identify warm, hot or glowing material in the discharged pellets.

— Monitoring of gas composition or gas concentration in automated underground discharge system.

— Fire detection/extinguishing system in the engine compartment of wheel loaders as well as a portable dry chemical fire extinguisher (min 6 kg) easily accessible for the driver.

— Video surveillance of areas not regularly attended by personnel.

11.3 Preparatory measures

11.3.1 Fire protection

The following risk reduction/risk control measures shall be considered:

— Air tightness of the general warehouse wall construction of the warehouse to restrict air entrainment into the bulk material.

— Internal construction of the warehouse designed to prevent accumulation of dust.

— Several door openings for discharge of large warehouses.

— Subdivision of the warehouse with concrete walls.

— Smooth, flat surface to minimize risks of spark generation with mobile handling equipment.

— Roof construction to withstand the load from temperature detection cables attached to the roof.

— If using a conveyer system for filling and/or discharge of the warehouse, provide sufficient height to allow free fall of the pellets at a suitable location, before the the the warehouse inlet and after the discharge outlet to allow the installation of ignition source detectors preferably in combination with either a suppression system or a quickly acting material rejecting arrangement.

— A specific storage area available for handling the discharged hot/smouldering/burning material.

— Fixed deluge (water)/foam/CAF system installed in the warehouse ceiling for the protection of the bulk in case of risk for ignition due to glowing embers, etc. or to control/suppress an open surface fire.

— Fixed stand pipe system with connections for use by the fire and rescue service for additional or final firefighting.

— IR camera to detect hot material or smouldering material in the bulk material during filling and discharge.

— SCBA-equipment (Self Contained Breathing Apparatus) for wheel loader drivers.

11.3.2 Explosion protection

During normal operation, the risk of explosion is predominately connected to dust explosions. This could be due to incoming smouldering material, igniting the dust cloud generated during the free fall into the storage for example. During a smouldering fire situation inside the pellet stack, gas accumulation (e.g. CO and unburnt hydrocarbons) could result in a gas explosion in enclosed areas, e.g. in an underground discharge system.

In addition to the explosion protection measures mentioned in 8.3.2, the following additional risk reduction/risk control measures shall be considered:

— Equipment installed in a warehouse in a risk classified area to be certified according to the explosion risk classification of the specific area/equipment

— Wheel loaders designed to work in dusty environment.

— Explosion relief arrangements in enclosed areas where there is a risk for dust- or gas explosions.

11.4 Additional information, recommendation and requirements on design and protection of warehouse

11.4.1 Detection systems

Monitoring of the pellet bulk inside a warehouse could be made by monitoring the gas composition using gas detection system, or the gas concentration using CO/CO_2 detectors. The measurements should preferably also include any automated underground discharge system. Due to the size and influence of ventilation, an aspirating monitoring system would possibly provide the best coverage of the entire warehouse volume. It should be noted that the use of powered mobile handling equipment inside the storage can disturb a gas detection system and cause false unwanted alarms.

Temperature monitoring of the bulk material close to the surface could be made by using spears with temperature sensors which are introduced into the pile while monitoring deeper into the pile requires the use of temperature sensor cables suspended from the warehouse roof. The vertical spacing of the individual temperature sensors on each such cable should not exceed 3 m. The number of sensor cables (or spears) and spacing between the individual cables should be based on the specific conditions, e.g. size of warehouse, construction of warehouse roof, duration of storage. The sensor cables should be attached to the warehouse floor or kept in position by some other arrangement in order to keep the cables in their vertical position during filling. If the discharge is made by use of wheel loaders, it shall be possible to easily move the sensor cables to a safe position during the discharge operation.

As fire in the engine compartment of all wheel loaders could be a potential ignitions source for igniting dust and the stored pellets, a fire detection system (and fixed extinguishing system) should preferably be installed in the engine compartment of wheel loaders operating inside the warehouse.

The detection system for monitoring the discharged material should be installed at first possible location, for example in the first transfer point of the conveyor system if using an automated underground discharge system or, below the hopper outlet to the main discharge conveyor system if using a wheel loader for discharge.

Some further information on various monitoring and detection systems are given in Annex G.

NOTE Control that the roof construction is deigned to withstand the load from temperature detection cables attached to the roof as a result of the flowing pellets during filling and discharge, if installed.

11.4.2 Fire protection

Design the general wall construction of the warehouse construction to be as airtight as possible below the maximum filling level to restrict air entrainment into the bulk material. Large stores should preferably have several door openings for discharge along its perimeter to enable adequate reclaiming, also in case of emergency. Doors, openings, hatches located below the maximum filling level shall be closed and sealed when not in use to minimize the possibility for unintentional air entrainment into the pellet bulk which could cause localized self-heating and ignition.

For large stores, subdivision with concrete walls should be considered to enable to separate different batches from each other (avoids mixing of different qualities and conditions) and provide possiblities to discharge the specific batch causing problem. It also reduces the likelihood for spread of smouldering fires inside the bulk. The layout of the separate storage areas shall not obstruct movement of pellets and mobile handling equipment.

The internal construction of the warehouse (e.g. steel beams in the roof) shall be designed to prevent accumulation of dust.

An inlet chute creating a free fall of the incoming pellets should be arranged between the feeding conveyor and the distribution conveyor over warehouse or at a suitable location before the distribution conveyer to allow the installation of a ignition source detector in combination with either

— a quick activating water injection system,

— a quick acting material rejecting valve,

— a possibility to reverse the distribution conveyor for rejection (rejection material shall then be guided to a safe collecting area).

A specific storage area shall be available for handling the discharged hot/smouldering/burning material. The location should be carefully selected considering the possible risks for nearby objects, neighbouring activities, dominant wind directions, etc. The storage area should include possibilities to collect any extinguishing media.

The protection of the pile/piles of pellets can be obtained by installation of fixed deluge foam/CAF system in the warehouse ceiling to ensure full coverage of the pellet surface which can control/suppress glowing embers or an open surface fire. If the warehouse is subdivided by separating walls, the deluge system should also be sectioned allowing activation of selected sections. A foam system producing a high quality of expanded foam (e.g. applied as CAF) should be used as this will protect the pellet surface, reduce the penetration of oxygen into the bulk material and reduce the amount of water. When the surface is covered with foam, additional foam application can be made in suitable intervals.

As a complement (or alternative) to the fixed fire protection system, a fixed stand pipe system with connections at suitable locations inside the warehouse should be installed for the use of the fire and rescue service. This will be important during emergency discharge of pellets to quickly extinguish any smouldering/burning pellets as the inner part of the pile is exposed. If there is no fixed foam system installed to protect the overall surface of the pile(s), there should also be suitable foam concentrate, foam proportioning equipment, and foam branches/foam monitors available to cover the pellets with a layer of a foam. The use of a mobile CAF system would be the best option. The stand pipe system should have connections for fire hoses at suitable locations, possibly both inside and outside the warehouse. Access/escape possibilities for the firefighting personnel shall be considered.

There should be access to mobile IR camera to detect any hot material or smouldering material in the bulk material during discharge.

SCBA-equipment (Self Contained Breathing Apparatus) shall be available and used by the wheel loader drives and other personnel entering areas affected by smoke gases. It is important that all personnel have relevant education and regular training to use the SCBA equipment.

11.4.3 Explosion protection

Equipment installed in and used in a risk classified area shall be certified according to the explosion risk classification of the storage during different operational procedures e.g. filling, discharge or maintenance.

Wheel loaders should be designed to work in dusty environment, e.g. having shielded hot surfaces, non-spark generating material in wheel loader bucket, equipped with a fire detection and fire extinguishing system.

Explosions relief arrangements shall be installed in enclosed areas where there is a risk for dust or gas explosions. The type, size and location of explosion vents shall be chosen such that it ensures an effective pressure relief but also prevent the risk for injury of personnel when activated.

Annex A
(informative)

Description of solid biofuel pellets supply chain and general safety guidelines for unit operations

A.1 Introduction

The supply chain includes handling and storage at the pellet producers, commercial distributors/storages and end-users, which could be large scale industrial applications (e.g. power plants), medium size boilers and distributors/traders delivering to small scale boilers for private use. The supply chain for biofuel pellets can involve water borne, rail or road transportation.

As the size of storage, the yearly turn-over and complexity can vary considerably this document is using a risk based approach to determine what safety measures should be considered. It is therefore essential for the user of this document to have knowledge and experience corresponding with the complexity of the facility to determine which clauses are applicable to the facility being considered.

Section A.2 is an orientation of unit operations in typical supply chains for solid biofuel pellets.

Section A.3 to A.5 provides more specifics on the major unit operations in generic supply chains for solid biofuel pellets.

An example of a risk assessment is presented for a commercial medium size wood pellet store with relatively low complexity is shown in Annex H.

A.2 Description of the solid biofuel pellets supply chain

A.2.1 Producers

This clause contains a brief description of the process equipment, which can constitute a pellet production line after the pellet presses as illustrated in Figure A.1. All unit operations in the supply chain in the Figure A.1 has a number and is referenced in the text.

The operations in the supply chain are:

— Following the pellet presses (1), the pellets are cooled by air flow (2).

— The dust and pellet debris of the cooled pellets are removed in a screen or sieve (3).

— The pellets are hereafter transported by conveyor (4) to a storage (5) which can be a silo or a warehouse.

— From the storage, the pellets are either

  — Loaded to bulk transport (6-10) (either via a trader (see A.2.2) or directly to a residential/small scale end user (see ISO 20023) or an industrial end user (see A.2.3). (The bulk transport can be by truck, rail or ship); or

  — Packed in bags and stored prior to transport (11-12).

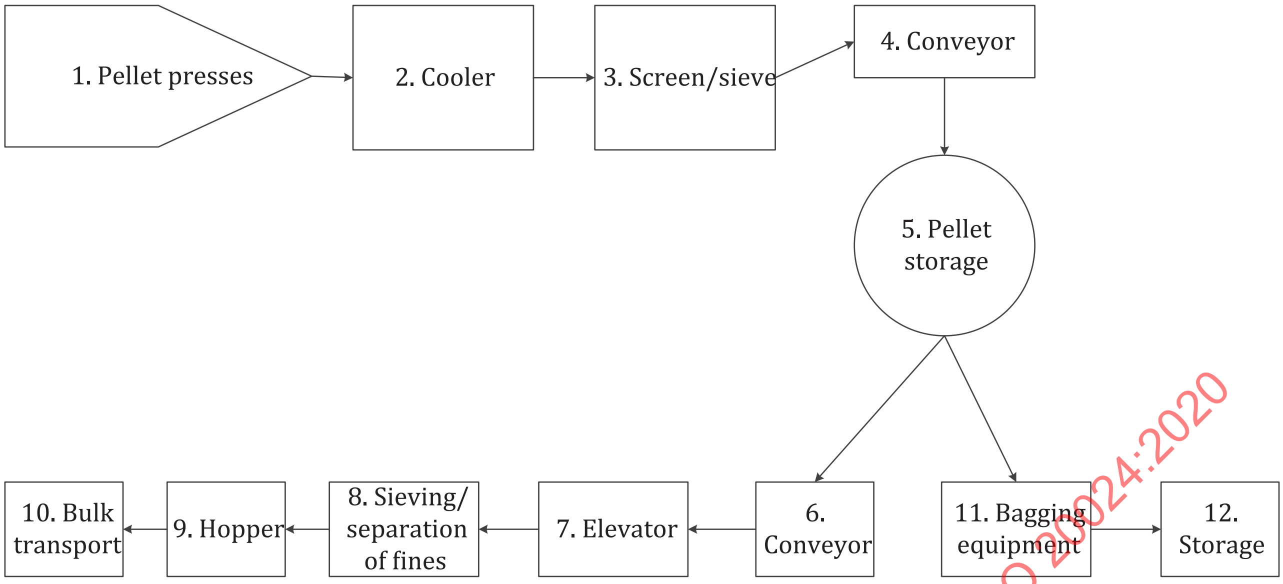


Figure A.1 — Example of the handling stages of solid biofuel pellets at a production site.

A.2.2 Commercial distributor/storage

The solid biofuel pellets are loaded from the storage facility at the production site. Many commercial traders operate a storage directly by themselves or by using a service provider. Silos or flat storages are common and Figure A.2 show the usual steps of handling the solid biofuel pellets for the transfer into the traders storage, and for the reclaiming of the solid biofuel pellets to be distributed to the end user.

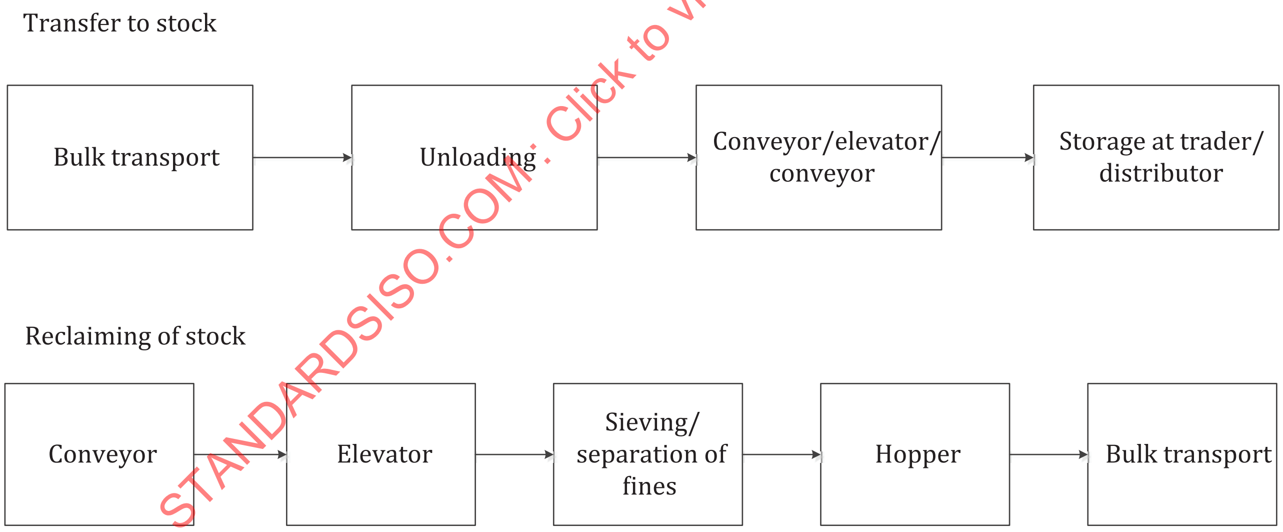
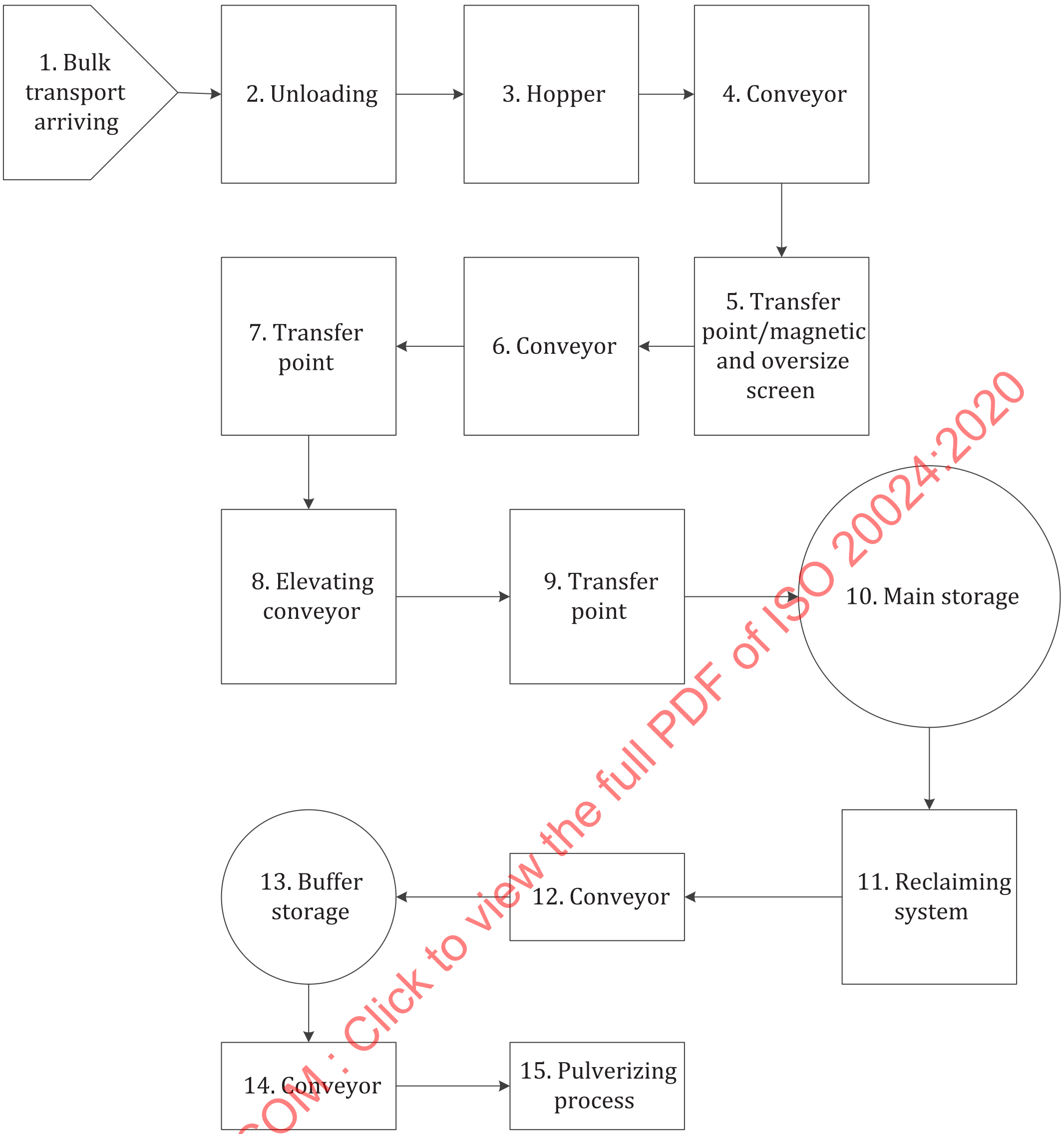


Figure A.2 — Example of handling stages for transport and storage of solid biofuel pellets between production and the end-user via a trader/distributor

A.2.3 Industrial end-user

This clause contains a brief description of the main facilities, processes, and equipment, which can constitute a pellet handling line at an end-user, see Figure A.3.



Key

1	bulk transport arriving at receiving station
2 and 3	unloading and hopper, where the pellets are transferred to the first conveyor belt
4 to 9	conveyor system, with sections connection via transfer points
5	magnetic separator and oversize screen for removal of extraneous materials
10	main storage facility (silo/dome; warehouse)
11	reclaiming system (gravity feed, mechanized discharge with screw conveyor or chain scraper or, reclaim by powered mobile handling equipment such as wheel loader
12 and 14	conveyor system, with sections connected via transfer points
13	smaller buffer storage (silo, bunker) to supply the boiler or pulverizing unit at boiler house
15	pulverizing process (not part of this document)

Figure A.3 — Example of handling stages at a power plant

Based on the concept of a large scale power plant, (e.g. coal fired power plant converted into pellets), the following can form the outline of the pellet handling system. Each item (1-14) in Figure A.3 consists of one or more unit operations and related equipment which are further described in A.3-A.5.

NOTE Further important guidance related to both design, construction and operation can be obtained in e.g. the publication "Fire and Explosion Protection in Biomass Powerplants" issued by VGB (VGB, 2013) and "Safe handling and storage of biomass in thermal power stations" issued by Energy Institute, UK (Energy Institute, 2016). Although focused on large power stations, there are many general aspects that are relevant also for smaller facilities.

A.3 Receiving station

A.3.1 Seaport loading or unloading

A.3.1.1 General information

Large volumes of pellets are transported by ship as part of the overall supply chain. Although the transport itself is not a part of this document, loading and unloading is included. The following information is mainly describing the unloading process but much of the information is also valid for the loading process and should be considered in applicable parts. Successful loading and unloading activities require the co-operation of the ship's crew, port authorities, stevedores and others who can be involved.

Loading and unloading should be performed with minimal degradation of the pellets and due regard for the environment.

The choice of loading/unloading equipment and operational practice should minimise the emission of fugitive dust, spillage of pellets and contamination (including moisture). Loading and unloading (or discharge) should be done in accordance with IMSBC Code under the IMO SOLAS Convention (IMO) and local regulations stipulated by port authorities and found in applicable port handbook or guidelines.

Gases such as CO and CO_2 are liberated in large amounts from pellets in enclosed spaces such as a ship hold. The IMSBC Code prescribe closed hatch covers during ocean transportation which brings the oxygen level down to almost zero and is an effective method making the hold atmosphere inert, which constitute a fatal risk for personnel. Proper, preferably forced ventilation, and verification of acceptable conditions by use of both CO and O_2 meters is extremely important before entering a ship hold. Natural ventilation to acceptable level of a large ship hold and stairwells can take up to 24 h depending on the number of air exchanges. Bulk movement of pellets can also engulf personnel. Access to the hold should therefore be strictly controlled, and assessments of the risk to personnel entering the hold should be made.

Mobile handling equipment are often used in the ship holds to assist in unloading as well as during mop-up and cleaning. Special operating procedures should be in place to minimize the exposure of personnel to dust and marginal air quality. The type of mobile equipment and the operating procedures should also aim to minimise the duration of, and the fire risk associated with, these activities.

Safety of work onboard ships are regulated by the IMO, local regulations as well as local worksafe guidelines as they relate to:

- the type(s) of ship to be unloaded and ship configuration; e.g. gearless, gantry cranes, deck cranes, self-unloader, type of hatch covers, etc.;
- the properties of the pellets (bulk and physio-chemical) and any other material to be handled by the machine;
- requirement to minimise dust emissions;
- noise levels;
- requirement to minimise pellet degradation;

— exposure risk (dust, CO and oxygen depletion) if mobile equipment with operator is used in the cargo hold during unloading.

The IMSBC code (IMO, section 3) prescribe ventilation of cargo hold headspace and stairways prior to personnel entering such spaces. Such ventilation is often done immediately after the ship has arrived weather permitting and should always be followed by gas inspection before unloading is allowed to begin. The gas inspection should involve measurement of both CO- and O_2-concentration as a minimum.

A.3.1.2 Grab cranes

Cranes with grabs are commonly used for unloading ships to receiving hoppers on the dock or in some cases unloading is done from one ship to another ship or barge. The crane can be the gear onboard the unloading ship or the crane can be mobile on wheels or rail or on a barge or stationary on the dock. If the cargo is received on land it is usually dropped in a hopper, sometimes with fans generating under-pressure to suppress the dust generated in combination with dust collection. The hopper may be fitted with a grate for removal of tramp material. All unit operations during loading and unloading should be focused on minimizing the damage to the pellets and to minimize the generation and disbursement of dust.

Receiving hoppers should be of conducting material so no insulative cladding should be used to ensure the pellets and dust is in contact with dissipative surfaces when landing.

Equipment should be installed to detect hot or smouldering material at the discharge of the hopper together with means to extinguishing or cooling or alternatively eject material (see also A.4.2). Good practice is also to do temperature spot checking of cargo with manual IR sensor before as well as during unloading. Some commercial supply contract has a maximum acceptable temperature of the cargo for acceptance into a facility. If temperature is exceeding maximum allowable temperature the cargo may have to be cooled and if not practical it may have to be unloaded on the dock for aeration and cooling.

A.3.1.3 Continuous Ship Unloader (CSU)

The main types of continuous ship unloaders (CSU) are outlined below.

- Screw conveyor:
  - Screw conveyor unloaders typically include a counter-rotating head at the end of a vertical screw conveyor, feeding further belt or screw conveyors in the boom, and a discharge conveyor. They are typically rail-mounted on a quayside.
  - Advantages: High throughput rates, enclosed unloading system.
  - Disadvantages: High power consumption, finite length of screws results in bearings within the boom and arm. Large extraneous materials can also block the screws. Also the fines content will increase due to high impact on the wood pellets by the screw (see A.4.3.7).
- Vacuum unloaders:
  - Vacuum unloaders comprise a suction nozzle, large filter vessel, connecting pipe, air movers and a discharge conveyor. The air movers induce a flow of air sufficient to transport the pellets from the suction nozzle, through the connecting pipe and into the filter vessel where the pellets are detrained from the air and passed, typically through rotary valve, into the discharge conveyor. They can be either wheel or rail mounted on a quayside.
  - Advantages: enclosed unloading system, no moving parts within the fuel.
  - Disadvantages: explosion risk in filter housing, degradation of pellets at high air velocities and high energy consumption.
- Bucket wheel / bucket elevator:
  - Buckets are mounted either on an adjustable arm or on a wheel. Due to their size, bucket wheel elevators are typically rail mounted on a quayside.

  - Advantages: high throughput, access under hatches on larger ships.
  - Disadvantages: This is a less preferred conveyor due to its relatively high explosion risk, and creates significant dust emissions from bucket wheel unloaders and transfer points within the unloader.
- Sandwich Belt and self-unloading ships (into hopper):
  - These ships comprise of several holds mounted above a discharge conveyor. A sandwich-belt arrangement is used to convey the pellets up the bow of the ship and along a boom to a discharge point; typically a hopper.
  - Advantages: Do not require dedicated unloading systems.
  - Disadvantages: Small capacity of ship, no segregation between cargo and personnel around conveyor in ship's hold, dust emissions between hold and conveyor can be significant.

A.3.2 Train unloading

A.3.2.1 General

Railcars used for transportation of solid biofuel pellets are covered, usually the grain-type, with manually or pneumatically operated bottom gates for discharge of cargo. The railcars are usually divided into 3 or 4 internal hoppers, each emptying through separate bottom gates. Other types include rotating railcars with closed bottom and removable or hinged top covers which open up when the entire car is turned over.

A.3.2.2 Rail receiving hopper

The capacity of a rail unloading hopper can vary between a single wagon and an entire train. The top of the hopper is typically at ground level, with the hopper and reclaim mechanism (usually screw or chain conveyors) below ground level.

Rail receiving hoppers should be located under cover to protect the pellets and handling equipment from moisture ingress. Floor surfaces should be profiled such that any liquid drains away from the hopper to minimise contamination.

Receiving hoppers should be of conducting material so no insulative cladding should be used to ensure the pellets and dust is in contact with dissipative surfaces when landing. Due to the risk of derailment, rail reception are not typically fitted with coarse grid as a first stage of tramp removal, but are fitted with air extraction systems to remove dust from the air displaced by the fuel. Angled baffles may be used to improve the performance of the air extraction system.

Occupancy of the rail reception area should be minimised at the point of discharge and adequate Personal Protection Equipment (PPE) provided.

The accumulation of dust should be avoided to prevent the formation of dust layers as they present fire and explosion hazards. Suitable measures include internal conductive cladding in relevant areas, installation of shedding plates, air extraction systems, the provision of cleaning equipment and where necessary, access for cleaning activities.

Fire detection and suppression equipment should be fitted as required by the necessary assessments. Detection and abortion of hot incoming material is advisable in order to avoid loading overheated material into storage facility. Suitable detection system would be IR sensor not sensitive to daylight (see Annex G).

A.3.3 Lorry (truck) unloading

A.3.3.1 General

Lorries (trucks) used for transportation of solid biofuel pellets are covered and usually have hydraulic systems for unloading the cargo into a receiving hopper or directly onto the floor inside a warehouse.

A.3.3.2 Lorry (truck) receiving hopper

The lorry (truck) receiving hopper is typically at ground level with the reclaim mechanism (belt conveyor, chain conveyor or screw feed) below the ground level.

Lorry (truck) reception hoppers should be located under cover to protect the pellets and handling equipment from moisture ingress. Floor surfaces should be profiled such that any liquid drains away from the hopper to minimise contamination.

Hoppers should be fitted with coarse grid as a first stage of tramp removal and an air extraction system remove dust from the air displaced by the fuel. Angled baffles may be used to improve the performance of the air extraction system.

Receiving hoppers should be of conducting material, so no insulative cladding should be used to ensure the pellets and dust is in contact with dissipative surfaces when landing.

Lorries should be earthed before discharge commences. Occupancy should be minimised at the point of discharge and adequate PPE provided.

The accumulation of dust layers should be avoided as they present fire and explosion hazards. Suitable measures include internal conductive cladding in relevant areas, installation of shedding plates, air extraction systems, the provision of cleaning equipment and where necessary, access for cleaning activities.

Fire detection and suppression equipment should be fitted as required by the necessary assessments. Detection and abortion of hot incoming material is advisable in order to avoid loading overheated material into storage facility. Suitable detection system would be an IR sensor not sensitive to daylight (see Annex G). Depending on the operation at the receiving hopper a manual handheld detector can be sufficient.

A.3.3.3 Moving receiving systems

Several different types of systems are used for receiving wood pellets delivered by lorry (truck). Some are using moving floors or belt on ground level on which the pellets are dumped from the vehicle. For further transportation into a storage. Dust extraction systems are recommended to keep the dust concentration in the area as low as possible.

A.3.4 Dust handling

Minimizing the generation of dust and an effective dust handling is important for the overall safety. Annex C provides further information about the risks with dust and recommendation on prevention and mitigation of dust explosions.

A.4 Conveyor system

A.4.1 General

A.4.1.1 Conveyor design

Wood pellets are subject to impact and attrition during transportation by conveyor due to drop and friction. All conveying systems that encourage impacts or rubbing, wedging or grinding actions should be avoided. To protect pellets, from e.g. precipitation and contamination and to minimize dusting to the environment, conveying system should be covered.

When designing a conveying system consider the following general aspects:

— The optimum length of a conveyor should be determined by not only the distance and geometry of transportation but also by the load of the material and size of the drive motor. The number of drops and the height of the drops should be kept at a minimum (see A.4.3.2). Risk for spreading burning or smouldering material during emergency. Specific conveyors designed to handle hot or smouldering material should preferably be used for emergency discharge.

— Extraneous materials can act as an ignition source. Extraneous material separators such as magnet separator should be used for extraction before the pellets are entering e.g. storage or pulverizers.

— Consider the need for compartment and partitioning in the design.

— Design the conveying system for reduced motion speed to prevent sparks due to contact between moving parts (not applicable for a belt conveyor for example).

— Spaces where accumulation of dust can occur should be avoided. Avoid hot surfaces. Machine components which can become hot during operation should be shielded to avoid contact with dust.

— Rollers (idlers) with ball bearings or bushings under constant load should have dust-proof in-capsulation and location in high wear applications should be equipped with e.g. linear cable detectors, thermocouples, be monitored with IR heat sensors or camera (see G.2.8).

— Guide-rollers and idlers for conveyors should be made of conducting material such as metal to dissipate static electricity generated by friction.

— Transfer points should preferably have dust collection and impact limiting deflecting devices (see A.4.3.2).

— Consideration should be given to incline angle of belt conveyors and surface friction such that material cannot avalanche. Maximum incline depends on the characteristics of the wood pellets (diameter, length, surface friction) and can be experimentally determined. However, a common guideline is 21° to 25° on a flat profile belt but may be steeper if the belt is profiled with ribs.

— Belt should preferably be made of non-static material.

— Belt should preferably be made of fire retardant material.

— Conveyor systems should have shutdown sequencing starting upstream.

— In certain locations it is beneficial to be able to reverse direction of conveyor belts in emergency situations for dumping of burning or smouldering.

— Automatic sampling stations are often required for high volume handling of wood pellets. The sampling station can be integrated with part of the conveyor system or located in conjunction with a transfer point. Some stations are semi-automatic or even manual and special precautions has to be taken to protect operators from injury.

A.4.1.2 Protection of indoor conveyor systems

Use non-combustible covers.

Do not position conveyors above each other (either parallel or crossing over) if the area is protected by automatic sprinkler at the ceiling.

Avoid conveyors passing a fire wall. If such passing is necessary, suitable protection measures should be installed to ensure the fire wall rating.

Hanging skirts above conveyors for blocking dust from spreading should be of electrostatically dissipative material and properly grounded.

Do not store combustibles under indoor conveyor belts that are more than 1,2 m wide unless a non-combustible barrier and automatic sprinkler protection suitable for the hazard is provided below the conveyor.

A.4.1.3 Protection of outdoor conveyor systems

Use non-combustible enclosures and insulation for conveyor galleries, tunnels, etc. Vertical rough surfaces with a propensity to collect dust should be painted. Preferably with antistatic paint.

Combustible insulation should be covered with fire retardant coating or replaced by non-combustible insulation.

General protection of conveyor steel constructions against impact from traffic, snow, landslides, etc.

A.4.1.4 Operation and maintenance

Video surveillance of areas not regularly attended by personnel.

Preventive maintenance should include scheduled lubrication, exchange of moving parts such as ball bearings, bushings, levels etc.

Conduct regular inspections of conveyor galleries to ensure there is no build-up of dust settlement or debris beside or under the conveyor. Use a handheld IR-camera to detect friction against material/dust accumulation, metal-to-metal, over-heating of bearings, skewing, etc. Fixed IR cameras can be installed for overall monitoring of hot spots at unit operation areas where overheating can occur of equipment or hot particles can land such as collection bins etc.

A.4.2 Detection system

To achieve and safeguard the operation, the installation of sufficient fire and smouldering detection systems should be considered at critical logistic transfer points. Fixed IR cameras can be installed for overall monitoring of hot spots at unit operation areas where overheating can occur of equipment or hot particles can land such as collection bins etc. Early detection is always the most efficient way to minimize the consequences of a fire. Ignition source detection systems connected to a quick activating extinguishing system or a possibility for material rejection should be considered to be installed in transport systems. This will reduce the risk of ignition in silos or flat storage through external ignition sources, such as sparks, friction heat etc. (see further information in Annex G). Also the installation of areal open flame sensors or proximity sensors to detect broken or jammed belts should be considered.

A.4.3 Conveyor types

A.4.3.1 Belt conveyors

There are several types of belt conveyors on the market such as standard open belt, folded belt and tube belt types. Tubular belt conveyors can include both vertical and horizontal parts and therefore minimize the number of transfer points. Belt conveyers are generally having a low power consumption, causes no or minimum damage to the product from the conveying (but there could be damages related to the transfer points) and extended conveying distances are possible (up to 1 000 m for a single belt). However, spill (waste) could occur due to return belt part and transfer points need special attention for dust control and spills.

Apart from the conventional conveying type belts there is also a vertical twin belt conveyor for unloading ships. This type is not yet widely used due to some drawbacks for example the ship cannot be completely emptied and additional wheel loader is needed (more than for grab or pneumatic unloading). Also the feeding device can introduce damage to the pellets. The unloading capacities are on the other hand large, up to 1 500 t/h.

A.4.3.2 Belt transfer points

Since a belt is running with speeds up to 3 m/s the transfer point design is critical as the pellets is dropping down from one belt onto the running second belt.

During free fall transfer the pellets velocity will be increased which cause induced air flow. The latter causes the dust getting airborne. Methods are available to “bootstrap” the flow of pellets by minimizing the amount of entrained air in the flow. Examples are the “spoon hood type transfer” and the “Dust Suppression Hopper (DSH), which reduce the dust formation significantly during free fall transfer.

A.4.3.3 Bucket elevators

For vertical conveying of bulk materials, the bucket elevator is widely used. Bucket elevators without proper misalignment and temperature sensors and interlock are however known to have a high rate of fires and explosions and special care should be taken to make sure proper design. Due to the nature of solid biofuel pellets (i.e. risk for fire and dust explosion) the elevator is more and more declined in new projects since there have been many incidents also in other wood industries. It is possible to mitigate these hazards by monitoring devices for belt skew, belt misalignment or blockage, and insulation of the elevator with for example rotary feeders and suppression systems.

Efforts have been made to re-design the elevators, solving the main problems such as speed of the belt and the feeding of the pellets at the bottom. These developments are not yet widely available on the market.

A.4.3.4 Pendulum Bucket Elevators

A variant of the bucket elevator is the Pendulum Bucket Elevator. Here the buckets are able to spin and can also be used for horizontal conveying. The benefit is that the belt speed can be low since the buckets are tipped at the discharge point and emptying on gravity only. The capacities are lower than that of the standard elevator but the advantage is that damage to the product is minimized. This type of equipment is widely used for handling of delicate products. This technology is not common in the pellet industry due to the many moving parts and the abrasive nature of handling products.

A.4.3.5 Special belt conveyors

For vertical/inclines conveying special belts are available. These belts are equipped with flexible cheeks preventing the product from falling off the belt sideways. The belt is divided into compartments creating a chain of segregated parcels. For conveying vertical the pockets are bucket shaped rather than flat.

A.4.3.6 Chain conveyors

Chain elevators are typically transporting horizontally but can be configured to transport also on an inclining slope. Since these units are completely closed, the product inside is protected from external influences. Thus the dust is contained. Chain conveyors can be equipped with dust suppression system and venting to handle products with entrained dust in smaller applications.

As an average, the speed of the chains is around 1 m/s; hence more or less gentle for the pellets. An important parameter is the loading of the chain. The pellets damage will increase in case of overfeeding. The vertical chain conveying will therefore create more damage (fines and dust) than the horizontal and inclined chain conveyor. A special model of this chain type conveyor is the disk tube. Here the pellets are trapped between discs equally spaced on a chain and pulled forward.

With this system, bends are possible both horizontally and vertically. Capacity is limited to around 90 m^3/h, which is somewhat low for the most pellets application.

A.4.3.7 Screw conveying

Screw conveyors are used in a variety of applications such as transporting product from a hopper or storage over a distance of up to 20 m. Flat bottom silos can have a sweeping screw conveyor feeding pellets to the center gate leading to an underground conveyor system. Screw conveyors are also used for feeding boilers.

Screw conveyor are most suitable for short distances, and a completely closed and dust tight construction is possible. Inclined and vertical conveying is possible but will result in increased damage of the pellets. Screw conveyors require special design for minimum pellet damage by optimum the clearance and reduced RPM. They might be difficult to run completely empty and will create noise in combination with pellets handling.

A.4.3.8 Pneumatic conveying

Pneumatic conveying is sometimes used for unloading wood pellets from ships or barges into a power plant. It can also be used for transportation of pellets inside a power plant. The pellets are entrained in the airstream and moving at high speed and any bend of the airstream will cause the pellets to collide with the pipe wall which generates dust. The pellets are extracted from the air stream by a separator using gravity. Since a power plant is usually grinding the pellets to dust the degradation is in itself not a problem, but the conveying system is not suitable as a primary system for long term storage. As the dust is transported at high speed it becomes electrostatically charged unless the pipe and receiving collector is made of dissipative material (usually metal). It is important to make sure the pathway is properly designed to avoid ignition of the dust.

Pneumatic conveying systems are closed minimizing spills and protecting the pellets, the layout is flexible due to random routing with short bends and the transfer point can be completely dust tight. However, the power consumption is 10-20 times higher than for belt conveyors and special attention should be taken for wear parts like rotary valves, pip bends, etc.

A.4.4 Dust handling

Minimizing the generation of dust and an effective dust handling is important for the overall safety. Annex C provides further information about the risks with dust and recommendation on prevention and mitigation of dust explosions.

A.5 Storage facility

A.5.1 General design considerations

When selecting the type (silo or flat storage) and size of storage, the following should be considered as a minimum:

— Type of operation (e.g. pellet producer, short term storage at harbour, long term storage in harbour, main storage at power/heating plant, intermediate storage at pellets distributor, etc.).

— Minimum required storage capacity. The angle of repose for the specific pellet will determine the degree of filling the silo can take. This can be found in the product safety data sheet or similar product specification.

— Typical quantities during filling and discharge (for example, a truck load, a set of rail cars, a transatlantic shipload).

— Expected turn-over (i.e. min/normal/max storage time).

— Type of pellets to be stored (from one source or many different types and sources). Mixing of pellets with substantially different permeability can contribute to self-heating (see B.2).

— The need for automated handling.

— The land area available for the handling and storage. The location and the distance between silos needs to allow fire and rescue vehicles to safely access the area.

— Location (neighbourhood activities).

— Accessibility and options for material handling including a sufficiently large lay down area in case of problems such as self-heating or fire (e.g. only storage facility or at a power/heating plant where the pellets can be combusted). The possibility for emergency discharge is important to consider and installation of a separate conveyor system designed for handling the discharged hot/smouldering/burning material is strongly recommended. This is of particular importance if several silos or bunkers are served by only one conveyor system.

A.5.2 Silos and domes

A.5.2.1 General

Silos can be used for short term as well as long term storage of wood pellets although long term is generally not recommended for freshly produced pellets unless proper ventilation and cooling is provided. Silo storage lends itself to a high degree of automation in terms of handling as well as conditioning of storage conditions as well as monitoring from a safety perspective. However, visual inspection of the product can only be done from the top and cannot be done safely since the headspace accumulate off-gasses and is subject to severe oxygen depletion.

As a consequence there is a need to consider alternative measures to monitor the storage, for example installing temperature sensor cables suspended from the silo to control the temperature inside the bulk material and some form of gas detectors and humidity sensors in the silo head space. The need for various detection systems will vary depending on the size of the silo and the normal turnover/storage time. In general, a detection system at the inlet and discharge outlet (transfer points conveyor-silo) should be considered.

For small silos with a very quick turn-over (hours up to some days), for example, for intermediate storage, no additional detection system might be necessary.

For small to medium size silos, where the pellets are stored for a few days to a few weeks, a Multi-Gas-Detector (MGD) or CO gas detection should be considered. If the degree of ventilation is high (for example, via a dust extraction system), a temperature monitoring systems for the bulk material should be considered, e.g. temperature sensor cables suspended from the silo roof.

For small/medium/large size silos where the pellets can be stored for up to several months, both a gas detection system (Multi Gas Detector-MGD or CO/CO_2) and temperature monitoring systems for the bulk material should be considered. In large diameter silos, an aspirating gas detection system would be preferable to ensure coverage of the entire headspace volume. Also the number of temperature sensor cables should be extended to cover the entire bulk material.

It is also important to design the silo such that the risk for bridging and ratholing is avoided. The risk for problems increases with smaller silo diameters, if the bulk contains large amounts of dust and fines, and also in a self-heating/fire situation where moisture and smouldering can cause agglomeration of the material. During free fall of pellets from the top there is a natural segregation of pellets and the entrained dust. The pellets roll down the slope of the pile in the silo due to gravity, and congregate around the periphery of the pile while the dust is accumulating at the center of the pile. This contributes to the bridging and ratholing of the material. It also results in un-homogeneous flow of the pellets out of the silo and in some cases becomes a quality issue for a shipment. Besides geometry, quality of product and distribution of pellets and fines, issues with the flow of material inside a silo (e.g. bridging, ratholing) are closely related to the sequence of filling and discharge operations (D.2.5.4). The segregation is eliminated if the silo has a so called “bean ladder”, “grain ladder” or “filling tube”, positioned in the center of silo providing a slide or step-wise avalanche from top to bottom. The segregation can also be eliminated or at least minimized by installing an inverse cone just below the intake at the top of the silo. The cone will spread the dust and pellets more evenly towards the periphery and if the diameter is correctly designed the mixture of pellets and dust will be disbursed evenly in the pile. This eliminates most of the risk of stratification and also makes the material flow out of the silo more even and in addition eliminates most of the risk of bridging and ratholing.

In case of an emergency situation (self-heating/fire in the bulk, a dust/gas explosion in the silo head space), there are very limited possibilities for a rapid discharge. Instead the situation has to be kept under control by the use of a fixed inert gas system installed both at the silo bottom and in the silo head space to avoid further escalation and to allow discharge using the ordinary discharge system. However, in complex facilities, it might be relevant to design and install a separate emergency discharge system (see NOTE).

NOTE There are many examples of silo fires where the lack of emergency discharge has created great problems to discharge the silo in a controlled manner, and in several cases this has resulted in a total loss of both the pellets and the silo. The complexity and problems increases if only one conveyor is used for multiple silos as there will be a risk for fire spread. Accessibility to the conveyor for firefighting personnel will also be more difficult if the conveyor system is located in a culvert below the silo(s). A separate discharge possibility from each silo is therefore strongly recommended.

A.5.2.2 Type of silos

A.5.2.2.1 Large diameter freestanding silos

Large diameter freestanding silos are all flat-bottomed and built on a flat concrete construction with a discharge conveyor system in a culvert below the floor. The main bulk volume is discharged by gravity through one or several gates until the bulk materials angle of repose is reached. Complete discharge is then usually obtained using a circulating reclaiming screw conveyor feeding the material in to the center where the gate is located. For very large diameter silos, where a sweeping screw conveyor is not technically feasible, the final discharge can be obtained by the use of several parallel conveyors systems below the floor construction allowing several discharge gates, minimizing the remaining material. However, the final discharge requires the use of a wheel loader for a complete discharge. Another alternative is to use a vibrating floor construction which allows a complete discharge without manual operations.

There are three different construction principles for large diameter silos.

— Steel silos where the wall construction is made of a welded steel or by curved segments of corrugated steel plates bolted together. The wall construction is not able to withstand any uneven load towards the wall, which means that the silo should be evenly discharged by gravity through gates in the center at the bottom of the silo. The roof is also a steel construction attached to the silo wall. The roof can be equipped with explosion panels (see NOTE).

— Silos with a concrete wall construction, either by use of concrete wall elements attached together to form a circular wall or by conventional molding/slip molding of the silo wall. As the wall construction is stronger, it is able to withstand an uneven load towards the wall. These silos often have a large door opening in the wall making it possible to enter with a wheel loader for e.g. final discharge of the silo. The roof is a steel construction attached to the silo wall. The roof can be equipped with explosion panels (see NOTE).

— Dome silos are constructed of a thin reinforced concrete shell having a half-spherical shape. The outer surface of the dome consists of a reinforced PVC airform, which during the initial construction phase is inflated with a fan system. The inside of the PVC airform is then covered with a spray-applied foam insulation to a determined thickness followed by steel reinforcement and a shotcrete application to obtain the necessary thickness of the concrete shell. Due to the construction method, a dome silo is generally more airtight than a steel silo.The construction is very strong and can withstand overpressures of about 1 bar and the roof construction can carry a significant load.

NOTE There are examples from explosions in large diameter silos where entire silo roof has acted as an explosion vent by lifting from the silo wall construction and then fall back again, even if the roof was equipped with explosion vents. In certain occasions, a part of the roof has also been thrown away, falling down to the ground beside the silo wall. This will prevent an effective inerting process as it might be impossible to reduce the oxygen concentration in the silo headspace.

A.5.2.2.2 Tower silos

Often very high concrete construction (commonly 25 m to 50 m, but could be significant higher) with many individual silo cells (often 4 m to 12 m in diameter) connected to a large unit involving 10 to

30 individual cells. Existing tower silos are often built for handling and storage of grain, animal feed, etc. In certain applications tower silos are also used for pellet storage.

Tower silos are discharged by gravity and have a conical/sloping bottom towards a discharge opening positioned above a conveyor system, often common for several silo cells.

A.5.2.2.3 Small and medium size silos

— Freestanding steel silos (often 3 m to 10 m diameter, 5 m to 15 m high), with a gravity discharge through a conical hopper.

— Rectangular silo construction (either gravity discharge through several conical hoppers or by a screw/chain conveyor along one rectangular hopper).

For this type of silos, the silo walls are sometimes treated with low friction coating, for example polytetrafluoroethylene (PTFE), to improve the flow and reduce tendencies for hangings and bridging.

A.5.3 Bunkers

A.5.3.1 Small size bunkers

Small size bunkers for pellet storage, often referred to as “pellet bunker”, is fuel storage usually located under earth or in the basement with an access door to enter from one vertical side made out of concrete or steel. The bunker can either be filled up by tipping from a truck but mostly by blowing in the pellets through connectors from a silo truck.

There are also underground stores which have only a manhole pit but no vertical access door.

Many of these bunkers/pellet stores have a limited size and capacity and is covered by ISO 20023.

A.5.3.2 Medium and large size bunkers

Bunkers are usually used as a last short term buffer storage before the pellets are transferred into the boiler, in some cases via a milling unit. The construction is similar to a rectangular silo construction with one or several conical hoppers where the pellets by free flow are discharged via rotary valves or by a screw conveyor at the bottom. The difference compared to a silo is that a bunker has an open top construction and is therefore integrated in a separate building (bunker house) covering the entire bunker. The pellets are normally charged into the bunker by a belt conveyer running along the bunker house on top of the bunker allowing the pellets to be discharged into the bunker at any position. As this filling process generates a lot of dust, it is recommended to install a bunker covering, i.e. a cover construction, which together with an air extracting system reduces the dust spread to the bunker house. The bunker covering also reduces the risk for extraneous materials to fall into the pellets.

In general, the turn-over of the pellets is relatively short, but as for silos, the need for temperature monitoring inside the bulk, gas monitoring in the bunker and bunker house is important to consider. It is also important to have a ignition source detection system on the conveyor for the incoming pellets. Due to the dust generation, a thorough zone classification of the entire bunker house and the equipment installed in the bunker and bunker house is vital. Accumulated dust on surfaces inside the bunker house/bunker should be minimized as far as possible by constructive measures e.g. minimizing horizontal surface area on beams. The bunker house and the equipment will need special attention in relation to house-keeping and maintenance and a dust monitoring system can be useful to verify that the dust extractions system works properly.

Although the turn-over is short, the need/possibilities for an emergency discharge due to an unplanned shut down or an emergency situation should be considered. A fixed fire protection system (foam, CAFS) will most likely be necessary to protect the bunker house and the top of the bunker while the need for an inerting system for the bulk material inside the bunker depends on the emergency discharge possibilities.

A.5.4 Warehouse

The main advantage with a warehouse is that it is probably cheaper to build compared to a silo with similar capacity and that it provides a degree of flexibility, e.g. possibility to store various pellets qualities in separate areas in the storage. The storage also provides good possibilities for visual inspections of the stored pellets. The warehouse has also some advantages in a self-heating/fire situation, as there might be a possibility to discharge the specific area of pellets causing the problem.

The main disadvantage is that a warehouse in general requires more manpower during normal operation. The discharge of pellets is mainly made by using wheel loaders moving the pellets from the pile to a hopper, sieve or bunker for further conveying to a loading station or a boiler system for example. Another disadvantage is the dust formation. Although the filling of the storage is mainly automated using a belt conveyor system along the ceiling, the drop from the conveyor down to the floor/pellet pile results in dust formation. Some form of dust suppression system should therefore be considered. Also the discharge using a wheel loader generates dust, in particular when discharging the bucket into the hopper. Accumulated dust on surfaces inside the warehouse should be minimized as far as possible by constructive measures, for example minimizing horizontal surface area on beams combined with cleaning procedures. Overall, the normal operation in a warehouse can cause a dusty environment, which combined with possible off-gassing from the pellets, needs to be considered both from a health point of view and from a fire/explosions point of view.

If the warehouse is large and used for seasonal storage without any divisions into separate piles, visual inspections only will not be sufficient to ensure detection of any self-heating tendencies in the pile. To monitor the surface or near surface temperature, IR sensor could be used. In some cases, the control could be complemented/improved by using spears with a temperature sensor with is manually introduced into the pile. However, this requires personnel to walk in top of the piles, which is associated with risks (such as off-gassing, dust and envelopment) but also the problem that the spears will only provide temperature measurements 1-2 m into the pile. To monitor the temperature conditions in the entire bulk, installing temperature sensor cables suspended from the warehouse ceiling might therefore be necessary. This can cause practical problems during discharge using the wheel loader, but there are practical examples where the temperature lines can be moved out of the area as discharge continues (see Annex G). As for silo storage, it might also be necessary to install smoke and gas detection systems as well as humidity sensors in the warehouse ceiling.

As mentioned above, the discharge process of a warehouse often involves the use of a wheel loader, which can contain several potential ignition sources. These should be eliminated before operating if the building is zone classified. This might need special measures for the individual components (for example, exhaust system, engine, lights), which are potential ignition sources. There might also be specific requirements related to the use of equipment in classified zones, including maintenance and inspections procedures.

Annex B
(informative)

Self-heating and off-gassing

B.1 Introduction

This annex gives a brief description of the phenomenas of self-heating as well as off-gassing which are important to consider during handling and storage of biofuel pellets. The text is based on some parts of Clauses 3 and 4 in the IEA Guidelines (IEA, 2013). For both a wider knowledge and more details, please read the full IEA document. Even further information can also be obtained from The Pellet Handbook (Obernberger and Thek, 2010). Off-gassing is a consequence of self-heating and early detection of off-gassing, particularly CO, is an indication of chemical reaction in a pile of pellets. See Annex E for one method for prevention of self-heating in silos and thereby also off-gassing.

B.2 General description of the self-heating phenomena

Self-heating is a well-recognized problem, which has been observed for many different materials and different conditions. The most well-known material prone to self-heating and spontaneous combustions is probably oil soaked rags. However, any material that can either decompose or be oxidized by air can under certain circumstances exothermically reach spontaneous combustion (Babrauskas, 2003). Self-heating can be seen as the first step in a process that might finally result in spontaneous combustion. Babrauskas (Babrauskas, 2003) defines these steps as:

a) Self-heating: an increase in temperature due to exothermal reactions in the fuel.

b) Thermal runaway: self-heating which rapidly accelerates to high temperatures.

c) Spontaneous combustion: smouldering glow or flaming by thermal runaway.

This means that by these definitions spontaneous combustion could, but does not have to, mean open flames. Open flames can develop when the reaction front reaches a surface open to air or when gases produced in the bulk material mix with air in the head space of the silo and ignite. Open flames are seldom present inside the pile of material since the voids between pellets are normally smaller than the quenching diameter. Since the spread of the reaction front is affected by the availability of oxygen, the spread is not always symmetrical, but follows the oxygen, which can lead to strange smouldering patterns in a pile of material. Due to the importance of the relationship between the heating and cooling processes, self-heating often is most pronounced in the centre of a pile, but other factors have a strong influence. Thermal convection within a pile is driving the heat upwards, and e.g. mixing of pellets with different bulk permeability causing inhomogeneity such as stratification with dust layers inside the pile blocking the natural convection, wet spots, and non-symmetrical availability of oxygen, results in that the self-heating may not always occur in the center of the pile. If storing material in a pile, there is a risk of development of open flames when material is removed from the pile, allowing oxygen to come closer to the parts where a smouldering process might be occurring.

In materials prone to self-heating, the self-heating process occurs throughout all of the material. The temperature rise is then controlled by the removal of heat. The heating processes increases with increasing temperature, but there are also different processes active in different temperature ranges. A system where the ambient temperature is such that the temperature of the material will increase until ignition (if nothing is changed) is called a supercritical system. A system where the ambient temperature and other conditions are such that the cooling is larger than the generated heat is called a subcritical system. This means that increasing thermal conductivity or decreasing the heat of reaction will decrease the propensity for self-heating. The processes, however, depend differently on the dimensions of the storage. The generation of heat is proportional to the volume of the material, while the cooling is proportional to the exposed surface area. Therefore, the self-heating tendency is proportional to the volume/surface ratio.

Self-heating in biomass is a well-recognised phenomenon (Kubler, 1987). The materials are generally porous and susceptible to heat generating processes from biological metabolic reactions (microbiological growth), exothermic chemical reactions (chemical oxidation) and heat-producing physical processes (e.g. moisture absorption) and are thus prone to self-heating and spontaneous ignition. These three processes can act alone or in combination, where the dominating process depends on the conditions, e.g. temperature and moisture content. The oxidation reactions involved take place on the surface of the material particles (involving solid phase reactions) meaning that the problem of self-heating and spontaneous combustion arises for porous material with a large surface area to volume ratio. Cell respiration can continue for some time after harvesting, as an exothermic process. This process stops if the material is dried and will not restart when rewetted. Oxidation of fatty acids in sawdust and other moist fuels is accelerated by microbial activity with mesophilic bacteria and fungi up to approximately 40 °C and by thermophilic bacteria up to approximately 70 °C. Above this temperature chemical oxidation becomes dominant and further raises the temperature, in many cases up to an uncontrolled temperature range.

As mentioned above, self-heating occurs in many different materials (for example, most organic substances, agricultural products, and foodstuff), but it becomes a problem only if the generated heat cannot be transported away without increasing the temperature in the material. This cooling process is dependent on the properties of the material, the size and shape of the storage and the ambient conditions.

The humidity of the material can affect the self-heating risk in different ways. For high water contents the water will either absorb heat or evaporate to such extent that the self-heating is limited. At the other end, increasing the water content above approximately 16 % can start biological processes (Krause, 2009). For dry materials, such as biopellets, addition of water leads to temperature rise due to the heat of adsorption/condensation. The reasons could be a leakage of rain water in the roof or that the bulk storage is cooled by forced ventilation using air with high humidity. The thermal conductivity of porous material is significantly affected by the moisture content, especially for material at temperatures 60 °C to 100 °C (Sjöström and Blomqvist, 2014). It is important to realize that different types of solid biomass fuels, e.g. different types of biomass pellets, behave very differently when it comes to self-heating and off-gassing when stored. Dry solid biofuels such as wood pellets, briquettes and other dry solid biofuels require protected storage to keep the structure and low moisture content of the fuel. This can be done in silos or indoors, e.g. in A-frame buildings. The raw material for fuel pellet production is normally wood (sawdust, planer shavings, chips, harvest residue etc.). Wood is a complex material and contains cellulose, hemicellulose and lignin and some extractive compounds such as terpenes, fatty and resin acids and phenols, etc. Different kinds of tree species have different amounts of these compounds; and also seasonal variation can occur.

A number of serious incidents of self-heating and spontaneous ignition of wood pellets in storage have occurred (Persson and Blomqvist, 2004; Lönnermark et al., 2008). There are examples of fires caused by self-heating both in silos and in flat storage facilities. There is also a fire risk from various external ignition sources in storage and especially connected to the handling and transport of pellets.

Biofuel pellets are inherently sterile (contains no bacteria, yeast or mold) due to severe exposure to heat during drying, fractionation during hammer milling and pressure during extrusion to pellets. The combined effect of relatively high temperature regimes in pellet production and the low moisture content of the resultant pellets are sufficient to limit the biological activities. However, if contaminated by water after production, wood pellets may be subject to microbial growth causing self-heating and off-gassing. Biofuel pellets are also subject to oxidation as well as hydro-dynamic moisture migration in piles which causes self-heating and off-gassing.

Self-heating of fuel pellets does, however, occur in large-scale storage and also in some cases in smaller piles stored at normal ambient temperatures. For wood pellets, the tendency for self-heating seems to vary between different qualities of pellets and is most pronounced relatively shortly after production. It has been observed that during storage of pellets the temperature in the pile or silo can increase a few days or even hours after production. The temperature can vary, depending on the pellets raw material and mostly about 60 °C to 65 °C (Arshadi and Gref, 2005; Arshadi et al., 2009). The temperature increase can sometimes be higher (for certain pellet qualities up to 90 °C), but at such temperatures the risk of a run-away temperature resulting in a spontaneous ignition will increase, especially if the volume of the pile is large or the pellets are stored in a silo. The most common procedure for handling such temperatures is to distribute the pellets in thin layers over the pile surface to allow maximum cooling. Filling a silo at a high filling rate with these types of pellets will limit the cooling possibilities and increase the risk of a run-away temperature situation. Mixing of pellets of different moisture content is another potential source of heat production as heat is produced in the process of balancing out the moisture in the pile.

Part of the heat production is most probably due to low temperature oxidation of easily oxidised components in the material. It has been suggested that a high content of unsaturated fatty acids in the fuel increases the problem with low temperature oxidation and self-heating of wood pellets (Arshadi and Gref, 2005). The oxidation process is very complicated. The oxidation reactions are chain reactions (radical reactions). In these reactions the fatty acids in pellets are oxidized to aldehydes and ketones, accompanied by the generation of heat, i.e. it is an exothermic process. Further oxidation of these aldehydes and ketones will produce low molecular carboxylic acids (Arshadi and Gref, 2005) . These volatile organic compounds have been detected during pellet storage. Fresh pine sawdust contains high amounts of unsaturated fatty acids.

In addition, absorption of moisture in pellets is an exothermic process, i.e. it generates heat. There are two phenomenon involved: condensation heat and differential heat. Pellets are hygroscopic and can, at high air humidity, absorb water vapour from the air, especially if the pellet surface temperature is lower than that of the air (Arshadi et al., 2009). Once absorbed, water vapour condensates on the pellet surface which then causes the release of condensation heat.

Differential heat of sorption is released when the moisture content increases in the interval from initial set point up to the fibre saturation point. The condensation heat released is much larger than that of differential heat when moisture is absorbed from air.

When pellets with propensity to exhibit one or more of the heat generating processes are stored in a large volume, the temperature will increase within the pile, which can lead to spontaneous ignition in pellet storage facilities. The main risks resulting from the self-heating process of stored pellets are the following, in the order of occurrence:

— Release of asphyxiating gas (primarily CO_2) and toxic gas like CO as well as irritating gases such as aldehydes and terpenes (see also B.3). Spontaneous ignition resulting in pyrolysis of bulk material and release of pyrolysis/combustion gases.

— Gas and/or dust explosion, typically as a result of personnel approaching top compartment of a silo in a fire rescue work, see also D.2.4, D.2.5.2.

— Surface fire and spread of fire, typically as a result of an explosion in a silo.

B.3 General description of the off-gassing phenomena

B.3.1 General

Off-gassing refers to the emission of different volatile compounds by solid biofuel pellets along the supply chain, that is, from manufacturing to customers use. The kind of raw material, its treatment prior to production, as well as the pellets manufacturing conditions can have an influence on the off-gassing characteristics and the gases emitted. The compounds observed can be divided into condensable gases and non-condensable gases. Directly related to the generation of condensable and non-condensable gases is the depletion of oxygen.

However, the mechanisms that cause off-gassing and how these mechanisms are influenced by raw material characteristics, process parameters, and storage conditions are currently not well known. Self-heating is generally considered a pre-cursor to off-gassing. Lignocellulosic biomass, such as solid biofuel pellets undergo chemical oxidation (sometimes called auto-oxidation), and under certain moist circumstances can also be subject to microbial decomposition, producing heat and non-condensable gases (CO, CO_2, CH_4, H_2) as well as condensable gases (VOC). In addition, biomass suffers mechanical degradation producing fine dust particles, which represents a health risk if inhaled and a safety risk for fires and explosions Obernberger and Thek, 2010). Self-heating is correlated to auto-oxidation (Arshadi et al., 2009; Svedberg et al., 2004; Arshadi and Gref, 2005) of fatty acids and resin acids which contributes to the emission of condensable as well as non-condensable gases. The higher the content of extractives the higher the content of off-gassing.

B.3.2 Condensable gases

B.3.2.1 General

In high temperatures, drying resins and fatty acids migrate to the surface of wood particles where they become more prone to hydrolysis and oxidation (Nielsen, 2009). These chemical processes change the constituents of the molecular structure of the biomass and generates VOC such as aldehydes, ketones, carboxylic acids and terpenes, some of which contributes to the characteristic smell of wood in various stages of aging (Back and Allen, 2000).

B.3.2.2 Health considerations of condensable gasses

Emission of aldehydes is a health issue. Pentanal and hexanal are emitted at high levels from stored pellets. Hexanal is known to be a substance that can causes skin irritation and affect the upper airways. It can enter the body by skin contact or inhalation, and therefore, it can be considered an occupational and domestic health hazard (Svedberg et al., 2004). Guidelines issued by national and regional authorities and information provided in Safety Data Sheets by pellet manufacturers should be consulted for more details regarding Occupational Exposure Limits (OEL). Table B.1 shows exposure limits for some aldehydes:

Table B.1 — Permissible exposure limits (PEL) and short-term exposure limit (STEL) for some common aldehydes (AFS 2018:1)

Aldehyde	CAS nr	PEL (work day)	STEL (for 15 min)
Acetaldehyde	75-07-0	25 ppm (45 mg/m^3)	50 ppm (90 mg/m^3)
Formaldehyde	50-00-0	0,3 ppm (0,37 mg/m^3)	0,6 ppm (0,74 mg/m^3)
Furfural	98-01-01	2 ppm (8 mg/m^3)	5 ppm (20 mg/m^3)
Glutaraldehyde	111-30-8	—	0,1 ppm (0,4 mg/m^3)

The Bibliography provides a comprehensive list of documents from research on emissions from condensable gases. Areas where condensable gas emissions occur should be ventilated properly to keep the concentrations below stipulated OEL. Workplaces should be organized such that personnel does not have to spend more time than necessary in such areas, even if the concentrations are below OEL. Occupational hygienists should assess areas where emissions are known to occur and the Operating Plan or similar document should include guidelines for personnel to minimize the exposure time.

B.3.3 Non-condensable gases

B.3.3.1 General

The main types of non-condensable gases emitted from lignocellulosic biomass during storage are CO, CO_2 and CH_4. It is important to know the amount and rate when designing a particular storage system safely.

As with the condensable gases, the off-gassing characteristics can vary based on the type and origin of the material, the way it was produced, moisture content, etc. As these non-condensable gases result in oxygen depletion and can in some case be poisonous, sufficient ventilation of storage rooms is necessary. This is particularly the case for CO_2, which is heavier than air and can therefore tend to settle in a storage bunker or flow to lower placed fuel discharge areas.

NOTE A test method to determine off-gassing from and oxygen depletion by solid biofuel pellets is currently under development within ISO/TC 238/WG 7(ISO TS/WD 20048-1).

B.3.3.2 Non-condensable gasses health considerations

CO is a product of autoxidation processes of fats contained in biomass and the emissions are often correlated to hexanal (Svedberg et al., 2004). CO is a noxious substance with a 245 times stronger chemical affinity to haemoglobin, the blood protein carrying oxygen to the tissue in the human body, than oxygen. Yet, its rate of binding to this protein is 20 % slower than the binding rate to oxygen (NRC, 2010). When there is a high concentration of CO present in the environment and a low concentration of oxygen, the haemoglobin binds to CO, forming carboxyhaemoglobin (COHb). The presence of COHb not only causes less oxygen to be bound to haemoglobin, it also influences the oxyhaemoglobin dissociation, with the end result that the tissue oxygen partial pressure decreases causing tissue hypoxia (NRC, 2010). Normal levels for COHb in our bodies are 0,5 to 0,8 %, while smoking can present concentrations as high as 8 %. The lethal threshold level is considered to be 40 % (NRC, 2010). The following effects on human health are known (NRC, 2010):

— an exposure to CO above 420 ppm for 10 min or 150 ppm for 30 min can cause irreversible or serious, long lasting adverse health effects, or an impaired ability to escape, including susceptible individuals (people suffering cardiovascular diseases);

— an exposure above 1 700 ppm for 10 min, 600 ppm for 30 min, or 330 ppm for 60 min can cause life-threatening health effects or fatality.

CO_2 displaces air (oxygen) which causes asphyxiation. Symptoms of high or prolonged exposure to CO_2 and lack of oxygen are headache, increased heart rate, dizziness, fatigue, rapid breathing, visual and hearing dysfunction:

— above 2 % CO_2 in the blood - feeling of heaviness in the chest and/or more frequent and deeper respirations;

— at 3 % CO_2 - the breathing rate doubles;

— at 5 % CO_2 - the breathing is four times the normal rate.

At levels exceeding the above, concentration CO_2 is directly toxic. Thus, proper ventilation of storage rooms and lower placed fuel discharge areas is essential.

Emission of CH_4 (methane) from wood pellets is not toxic but, together with CO_2 increases the risk for asphyxiation by displacing air (oxygen). Due to oxygen depletion, possible health effects of inhaling methane at high concentrations are increased breathing and pulse rates, lack of muscular coordination, emotional upset, nausea and vomiting, loss of consciousness, respiratory collapse and fatality.

B.3.3.3 Oxygen depletion

Auto-oxidation as referred to above in section B.3 is causing rapid depletion of oxygen in enclosed storage spaces for wood pellets. Therefore, it is recommended to maintain a minimum oxygen level of 19,5 % and monitor the level of CO at the same time. The International Maritime Organization (IMO) forbids entry to spaces unless there is a minimum of 20,7 % oxygen in combination with a maximum of 100 ppm CO (Obernberger and Thek, 2010). Safety guidelines available today to avoid CO poisoning consider a proper ventilation of the area, the use of gas meters for both CO and O_2, the use of self-contained breathing apparatus when the levels of these gases are not in the safe range (Obernberger and Thek, 2010).

Lack of oxygen spontaneously increases the rate of breathing which in an environment with concentration of CO, rapidly escalates the intake of the toxic CO referred to as hyper-ventilation (or hypo-ventilation). Breathing in atmospheres with less than 5 % oxygen causes unconsciousness within just a few cycles of breathing and is extremely dangerous. About 20 % of the oxygen intake goes to the brain, which is very sensitive to oxygen deprivation. Oxygen levels in enclosed headspaces such as in ship holds and large enclosed storages without ventilation can go to 5 % oxygen level within a matter of a few days. In fact the IMO regulations prescribe closed hatch covers during ocean voyages with the intent to bring the oxygen level as low as possible to eliminate the risk of fires in ship holds (IMO. 1974). Careful attention should be given to the oxygen level in combination with CO. Oxygen depletion is sometimes even more dangerous. Oxygen content in air is 20,9 % at sea level. Attention should be given to the prescribed minimum acceptable level of 19,5 % oxygen which allows for a possibility of 1,4 % of other gases of which some can be CO_2 and some CO. 1,4 % is the same as 14 000 ppm of which a significant portion can mask the presence of CO (compare health exposure risk with potential fatal outcome at 1 700 ppm level as indicated in B.3.3.2). Simultaneous measurement of oxygen and CO concentrations in enclosed spaces is paramount.

Annex C
(informative)

Dust as a fire and explosion hazard and mitigation of risks

C.1 Introduction

Annex C provides guidelines useful for improved safety when designing as well as operating and maintaining facilities where dust from solid biofuel pellets is present. This document explains the context and risks involved as well as common measures for minimizing the exposure during handling and storage of solid biofuel pellets where dust is generated.

All areas of an operation involving handling or storing of solid biofuel pellets where potentially explosive dust or gases can be present should be divided and classified in risk zones where national or regional regulations should be considered (see C.5). Risk and consequence reduction measures should be considered both during design and operation.

The terms “combustible dust” and “explosible dust” can in general be considered interchangeable, so also “explosibility” and “combustibility”. In this document, the terms “combustible dust” and “combustibility” are used.

Some of the specific characteristics on materials given in this document for illustration purpose may or may not apply in individual cases and it is advisable to rely on information in the product safety data sheet provided by the manufacturer of the solid biofuel pellets in question.

C.2 Classification of dust and explosions

C.2.1 General

During handling and storage, solid biofuel pellets are releasing fragments of various sizes due to attrition and impact. The amount of fragments released depends on the durability of the product. There is also fines and dust inherently entrained in solid biofuel pellets from production. Absorption of moisture during handling and storage gradually break down solid biofuel pellets and also have a significant impact on the combustibility characteristics. In addition, ageing of solid biofuel pellets tend to decrease the durability due to changes of the chemical and mechanical structure of the material. The more handling and drops the more fragments are generated.

Dust generated during production, handling and storage of solid biofuel pellets can have very different shapes and sizes. Dust originating from sawdust and sanding operations are typically spherical while dust originating from shavings and hammer milled feedstock are typically flat. Dust from pellets is typically compressed with a large surface area (sometimes referred to as “two-dimensional”). The definitions of combustible dust can be slightly different in various standards and guidelines but the general accepted definition, which is also used in this document, is particles less than 500 µm (3.1.1). The smaller particles, the larger are the risk. Particles less than 100 µm can travel a distance before settling as a layer and dust less than 1 µm can stay in the air for almost unlimited time and travel a long distance. Dust can therefore accumulate and create layers in places far from the source inside as well as outside a manufacturing plant if not contained properly. Flyings on the other hand is defined as particles large enough not to easily catch fire, typically >500 µm.

Based on its characteristics, dust can be classified as either "primary" or "secondary" and is characterized as follows:

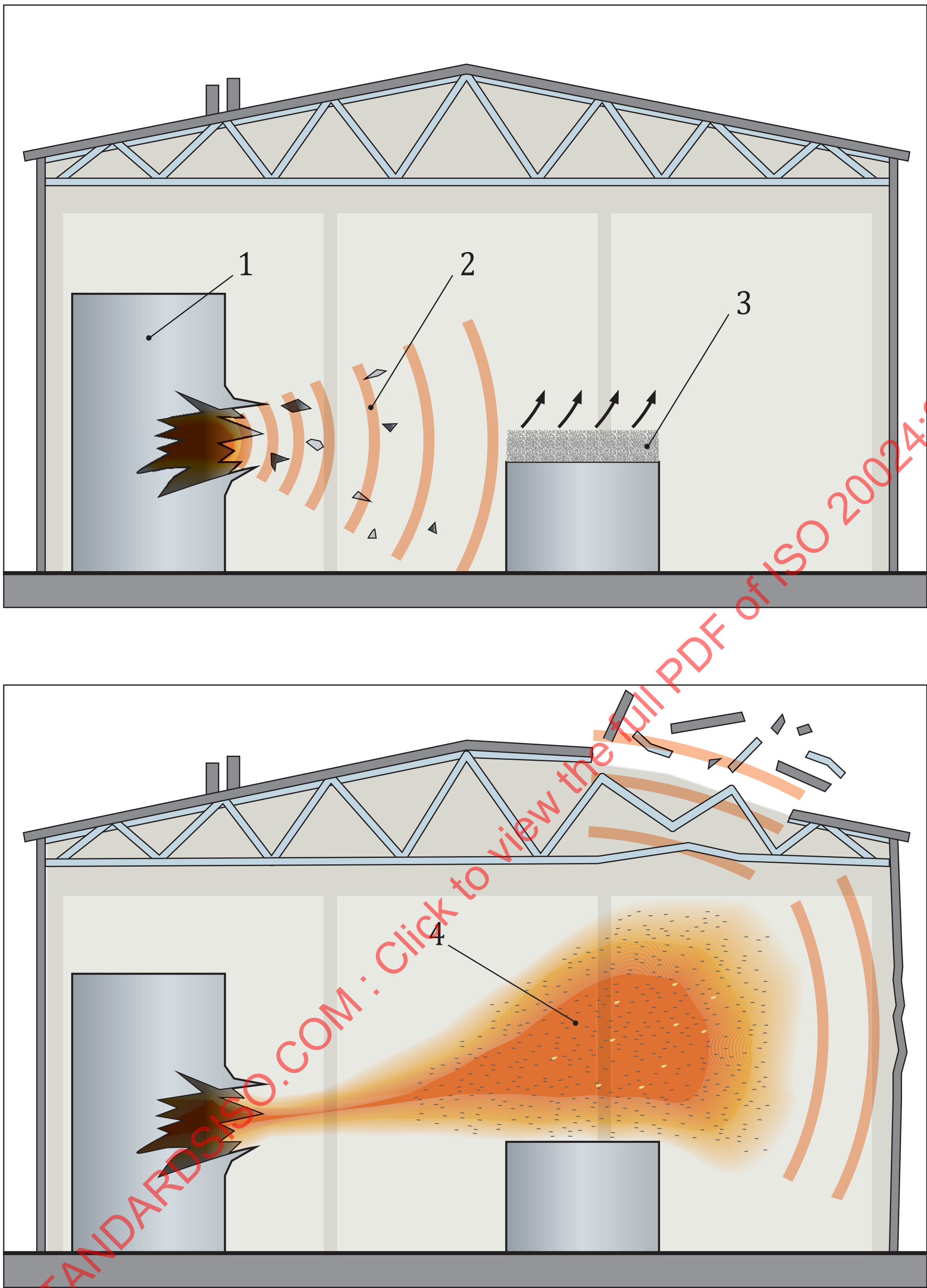
— Primary dust: generated during production or other work processes and is found on floors and surfaces near or below the dust producing or waste handling equipment. Primary dust is the source for secondary dusts. While primary dusts can consist primarily of greener, moister and coarser particulates, unmanaged primary dusts releases over time finer and drier secondary dust if not promptly abated.

— Secondary dust: fine and dry particulates broadly dispersed and often settled on surfaces away from the production or handling area such as rafters, ceilings, and beam, ductwork, walls, joints, machinery, cabinets and even walls with rough surfaces.

Explosions are also classified as "primary" or "secondary" and are characterized as follows:

— Primary explosion: event typically occurring in a dust collection system or processing equipment where a dust layer or cloud can easily form and is directly subject to an ignition source such as spark, electrostatic discharge, hot particle or flame.

— Secondary explosion: event occurring when a dust layer is disturbed and form a dust cloud and is ignited by a primary explosion (also called deflagration) which means burning material is disbursed at very high speed. Burning material can hit objects and personnel and cause major damage or injuries. Figure C.1 illustrates the progression of a primary explosion to a secondary explosion.



Key

1 primary explosion

2 blast wave

3 dust layer is entrained and dust cloud formed

4 extensive secondary explosion can result

Figure C.1 — Principle of the development of a limited primary explosion to one or several large secondary explosions

A high temperature (C.4.2) or a significant energy (C.4.4) for dust from solid biofuel pellets is required to ignite dust suspended in air. In addition, the concentration of dust needs to exceed a minimum explosible concentration (C.4.8).

A rule of thumb is that a concentration blocking a lamp with a light output of 400 lumen (corresponding to a 25 W incandescent lamp or 6,6 W LED) at a distance of 2 m indicate the risk for explosion. This high dust concentration is found only in certain areas like e.g. enclosed hoppers or bins and specific areas in bunkers.

The temperature required for igniting a dust layer is considerably lower for a dust cloud (C.4.3), the thicker the layer the lower the ignition temperature is due to the extremely low thermal conductivity of wood materials. Dust layers of several mm is often found in operating facilities and present a major risk since hot particles can easily land on dust layers and cause ignition.

C.2.2 Determination of particle size distribution

Handling facilities for biofuel pellets have several unit operations (unloading, conveyer transfer points, bucket elevators, moving of material with front loader, loading into storage space, loading of vehicles etc. – see A.2). Each operation can generate and accumulate dust with different particle size distribution. It is advisable to establish knowledge of particle size distribution of the dust from locations where dust is known to accumulate to make sure samples taken for test purposes are representative when establishing reference values for dust combustibility of the material being handled. Determination of particle size distribution of the fines and dust to be tested should be done in accordance with ISO 17827-2.

Solid biofuel pellets are often crushed in pulverizers or hammer mills into a fine dust before combustion. There are also computer aided image analyzers available, which not only provide the particle size distribution but also the shape distribution, which is of value when optimizing combustion performance during energy conversion.

C.3 Testing for dust explosibility and related fire safety characteristics

C.3.1 General

Testing dust for explosibility requires specialized equipment not normally found in industrial test laboratories. Each laboratory needs special accreditation and is inspected on a regular basis. The nature of the test procedures also requires specially trained personnel and safety precautions. Several parameters are required to fully assess the risk with dust. C.4 provides an orientation of the more common tests. All materials sent to an explosion laboratory for testing are inherently classified as hazardous upon arrival and is handled and stored accordingly by the laboratory.

C.3.2 Sampling and sample preparation of dust for testing purposes

Testing of dust sampled “as is” with large particles and high moisture content will not necessarily give reliable combustibility data for safe design of a facility. Also, using characteristics of “wood flour” often found in handbooks are not necessarily representative of the dust from solid biofuel pellets. Testing of the dust from a specific facility is therefore the best way to determine the combustibility characteristics of the dust. The following sections provide references to test methods for determination of the most important parameters for safe operation, maintenance, design of handling equipment and storage facilities (C.4).

Samples for testing should always be collected from dust layers, preferably accumulated “secondary“ dust (C.2), which have the highest propensity to catch fire or explode. However, dust can easily be transported long distances depending on particle size and shape within a facility by air circulation, therefore it is sometimes difficult to collect or assemble a representative sample for testing. Risk assessment and risk zone assessment (C.5) related to equipment located in an area and should be considered when selecting samples for testing. Dust from a bag-house for integrated dust collection from several different unit operations may be representative and suitable for testing.

In the event sufficient amount of representative dust cannot be obtained for testing, dust may be produced by grinding in such cases. Dust should be produced from pellets made from similar feedstock, or if that is not possible, dust should be produced from the feedstock intended to be used for manufacturing of the solid biofuel pellets. However, dust from grinding, sawmilling and sanding operations can be different from dust from solid biofuel pellets (C.2).

C.3.3 Shipment of dust samples for testing

Since moisture is affecting the combustibility of the dust, and thus the test results, it is important to protect samples from ingression of moisture from the atmosphere. Samples should be packed in hermetically sealed containers.

Test samples should be screened to size to conform with the specified particle size distribution specified by the respective test method. In case such screening cannot be done prior to shipment, the laboratory should be contacted to confirm if such screening can be done by the laboratory.

The amount of sample required for testing depends on the type of tests requested. Most of the tests mentioned in C.4 are iterative and require many individual tests to determine the representative parametric value. The laboratory should be consulted to estimate the required amount.

For suitable packaging and labelling of sample, contact the laboratory. International and national regulations require any shipment of hazardous material to be accompanied by instructions and commercial documents and a product safety data sheet if available defining the expected characteristics and health aspect of the material.

C.4 Determining safety characteristics of combustible dusts

C.4.1 General

Dust is tested in both suspended form and in form of layer since the reactivity is very different for the two states. The reactivity of dust is tested in specialized laboratories normally not found in commercial test laboratories. The laboratories are typically compliant with ISO/IEC 17025. The product safety data sheet issued by the manufacturer normally provides specifics for each particular brand of solid biofuel pellets.

The explosibility characteristics of solid biofuel pellets depends on moisture content as well as particle size distribution of the test samples. The ASTM Standards (e.g. ASTM E1226) and NFPA guidelines (e.g. NFPA 68) prescribe 95 % minus 200 mesh (<75 µm) particle size and <5 % moisture for testing of samples and defined reproducibility and repeatability ranges. ISO/IEC 80079-20-2 does not stipulate strict values for moisture and particle size distribution, nor does it provide reproducibility or repeatability ranges. This means that moisture and size distribution as well as the test method needs to be recorded in the test report. Using different test methods may therefore not necessarily yield comparable results.

The following sections provide an orientation for design purposes of the main parameters used for characterization of solid biofuel pellets and related dust. The referenced standards provide detailed descriptions of testing procedures.

C.4.2 Determination of Minimum Ignition Temperature (MIT) for dust cloud

The ignition behaviour of dust clouds on a heated surface is described by the minimum ignition temperature (MIT) of dust clouds – also called auto-ignition of dust clouds. It is defined as the lowest temperature at which a hot surface trigger ignition of a mixture of dust and air under specified test conditions (ISO/IEC 80079-20-2 or ASTM E1491). The test method is using a Godbert-Greenwald (GG) or BAM apparatus prescribed in the test methods.

C.4.3 Determination of auto-ignition temperature (T_L) for dust layer

Determination of the auto-ignition temperature of a layer of dust (T_L) should be done under prescribed conditions in accordance with the ISO/IEC 80079-20-2 or the ASTM E2021 Standards by heating the dust of a specific thickness using a heating plate until it ignites. Using different thickness allows for extrapolation to other thicknesses.

C.4.4 Determination of Minimum Ignition Energy (MIE)

Determination of the Minimum Ignition Energy (MIE) should be done using a Hartmann tube under prescribed conditions in accordance with ISO/IEC 80079-20-2 or ASTM E2019. MIE is a measure of how much electrostatic discharge energy is required to ignite a dust cloud and can vary in a wide range depending on moisture, particle size and shape.

C.4.5 Determination of Maximum Explosibility Pressure for dust cloud (p_{MAX})

Determination of the Maximum Explosibility Pressure (p_{MAX}) should be done using a Siwek explosion chamber under prescribed conditions in accordance with ISO/IEC 80079-20-2 or ASTM E1226. Dust is turbulated, ignited and exploded in an enclosed chamber. p_{MAX} is a measure of how much pressure in bar that can be expected during an explosion. p_{MAX} is one of the key parameters used when designing explosion venting.

C.4.6 Determination of maximum explosion pressure rate ($\mathrm{d}p/\mathrm{d}t_{\mathrm{MAX}}$)

The determination of the deflagration index (K_{ST}) should be done using a Siwek explosion chamber under prescribed conditions in accordance with ISO/IEC 80079-20-2 or ASTM E1226. Dust is turbulated, ignited and exploded in an enclosed chamber. $\mathrm{d}p/\mathrm{d}t_{\mathrm{MAX}}$ is a measure of the maximum pressure rate in bar/s during an explosion.

C.4.7 Determination of deflagration index for dust cloud (K_{ST})

The deflagration index (K_{ST}) is a calculated value based on the $\mathrm{d}p/\mathrm{d}t_{\mathrm{MAX}}$ and should be done in accordance with ASTM E1226 and NFPA 68 or EN 14034-2 as per Formula (C.1). K_{ST} is a measure of maximum pressure rise in bar·m/s during an explosion.

$$K_{\mathrm{ST}} = {}^{\mathrm{d}p}\!/_{\mathrm{d}t}{}_{\mathrm{MAX}}\ V^{1/3} \tag{C.1}$$

where

p is the pressure in bar;

t is the time in s;

V is the volume in m^3;

C.4.8 Determination of Minimum Explosible Concentration (MEC)

Determination of the Minimum Explosible Concentration (MEC) should be done using a Siwek explosion chamber under prescribed conditions in accordance with ISO/IEC 80079-20-2 or ASTM E1515. Dust is turbulated, ignited and exploded in an enclosed chamber. MEC is a measure of the minimum concentration of dust in $\mathrm{g/m}^3$ required for an explosion to happen if ignited. Since it is one of the critical parameters in dust control the rule of thumb is to select a value lower than the actual measured value for design purposes.

C.4.9 Determination of Limiting Oxygen Concentration (LOC)

Determination of Limiting Oxygen Concentration (LOC) should be done using a Siwek explosion chamber under prescribed conditions in accordance with ISO/IEC 80079-20-2 or ASTM E1515. Dust is turbulated, ignited and exploded in an enclosed chamber. LOC is a measure of minimum concentration of oxygen in % required for an explosion to happen if ignited. This fundamental parameter is used for securing safe atmosphere in storages, ship cargo holds etc. and can be used for estimating requirement of inert gas for inertisation of headspace in large silos.

C.4.10 Determination of Direct Current (DC) resistivity

Dust from wood has very high Direct Current (DC) resistivity and is therefore prone to accumulation of triboelectric charges when material is transported in non-conductive conduits or conduits, which are not properly grounded. If conduits or pipes are grounded the charges bleed off to the conducting surface and pose little or no threat. Feed pipes, hoppers, conduits carrying solid biofuel pellets, particularly at high speed, should always be grounded. If sectionalized, each element should be either directly grounded or at least bonded to a grounded element. Grounding is one of the most important safety considerations in design of handling facilities. This applies also to hose systems for stationary as well as Electro Statically Dissipative (ESD) mobile vacuum systems compliant with IEC 61340-5-1, IEC 61340-5-2 and related ESD approved detergent is used. Comprehensive rules for grounding and bonding are stipulated in various standards (IEC 60079-14, IEC TS 60079-32-1, EN 1127-1) and national or regional codes (Article 250 - Grounding and Bonding (NFPA 70)).

The ASTM D257 specifies methods for determination of both volume and surface DC resistivity and ISO/IEC 80079-20-2 specifies a simplified method for volume resistivity of materials. DC resistivity for dust with moisture content and particle size distribution as stipulated for testing in accordance to ASTM.

C.4.11 Determination of thermal conductivity

Solid biofuel pellets and related dust has a very low thermal conductivity. This means for example that hot spots in a pile propagate very slowly which in turn means that heat is concentrated in a relatively small area for an extended period of time leading to gasification of highly volatile gases, which if subjected to spark or electrostatic discharge, can result in smouldering or open flame fire. The thermal conductivity depends on moisture content, ambient temperature and convection or ventilation in a pile. The permeability of solid biofuel pellets in bulk is a function of void in the pile (geometry of pellets and the amount of entrained fines). The ISO 8301 and ASTM C518 Standards specify methods for determination of thermal conductivity, which is used for calculating maximum distance between temperature sensors in large storages.

C.4.12 Determination of flammability of dust from solid biofuel pellets

Flammability is a measure of how fast a fire or smouldering can propagate in materials and is measured as mm per minute and is primarily used for determination of packaging requirements during transportation. The UN MTC Test N.1 (UN, 2013b) is prescribing the test methodology. The material under test is loaded in a 250 mm long mould with a grove and ignited in one end. The travelling distance for the fire or smouldering is measured after 2 min. If the distance is 200 mm or less, the material is classified as non-flammable.

C.5 Risk area classification

C.5.1 General

Fire and explosion hazards arising from handling and storing materials with combustible dust are attributed to normal chemical and physical processes in the material as well as ambient conditions such as temperature, humidity and access to oxygen (air) in the local area. The risk is directly related to particle size distribution, the amount of material accumulated in an area as well as the residence time for the material when accumulated, either layered or in suspended form. Regular housekeeping is paramount to combat risk.

Several standards are summarized in the following sections to provide guidelines for minimizing the risk in an area with flammable vapours, gases and areas with dust and flyings.

C.5.2 Comparison of the Class/Division and the Zone classification methods

There are two main methods developed for classification as follows:

a) The US Code of Federal Regulation CFR 1910.307 Hazardous for classified locations provides a framework in USA for risk area classification and is referred to as the Class and Division method. The US National Fire Protection Association (NFPA) has codified the classification in the National Electrical Code (NFPA 70), which is based on risk assessment under normal as well as abnormal operating conditions. NEC has established Class I for environments with release of gas and vapour, Class II for environment with release of dust and Class III with release of flyings. Each Class has subcategories called Division 1 or 2 depending on severity of the release. The normal designation for North American facilities handling and storing solid biofuel pellets is Class II, Division 1 (see Table C.1).

   Canada has adopted the Class and Division method with some modifications and is published as Canadian Electrical Code (CEC) by Canadian Standards Association (CSA) as CSA–C22.2 No 60079-X-16.

   The Class and Division classification method is a voluntary classification system in North America.

b) The European Directive 1999/92/EC provides legal and binding framework in Europe for risk area classification.

   The ATEX classification method has been adopted by the European Committee for Electrotechnical Standardization and is based on frequency and duration of explosive dust atmosphere in the form of a cloud of dust in air, sometimes referred to as the European Zone method with designations Zone 20, 21 and 22 for dust (and Zone 0 or 1 or 2 for gases, vapours and liquids).

   The standards in the European countries for classification of explosive dust areas are based on the European CENELEC standard EN 60079-10-2, which is based on the international IEC standard, IEC 60079-10-2).

   The Zone classification method is mandatory in all EU countries.

Table C.1 summarizes and compare the definitions of risk area for the North American and European classification methods. There are differences in the coverage with more specific operating conditions for release defined in the North American method while the European method is focused on the frequency/duration of the release.

Table C.1 — Comparison of the North American and European risk area definitions

Classification criteria for release of dust and flyings			
NFPA 70 (NEC)/CEC		EN 60079-10-2	
Definition of conditions	**Class/Division**	**Zone**	**Definition of conditions**
A location in which combustible dust is in the air under normal operating conditions in quantities sufficient to produce explosive or ignitable mixtures, or	Class II, Divison 1	20	A place in which an explosive dust atmosphere, in the form of a cloud of combustible dust in air, is present continuously, or for long periods or frequently.
where mechanical failure or abnormal operation of machinery or equipment can cause such explosive or ignitable mixtures to be produced, and can also provide a source of ignition through simultaneous failure of electrical equipment, through of protection		21	A place in which an explosive dust atmosphere, in the form of a cloud of combustible dust in air, is likely to occur in normal operation occasionally.
in which Group E combustible dusts may be present in quantities sufficient to be hazardous.			
A location in which combustible dust due to abnormal operations may be present in the air in quantities sufficient to produce explosive or ignitable mixtures, or	Class II, Divison 2	22	Area in which an explosive dust atmosphere, in the form of a cloud of combustible dust in air, is not likely to occur in normal operation but, if it does occur, will persist for a short period only.
where combustible dust accumulations are present but are normally insufficient to interfere with normal operation of electrical equipment or other apparatus, but could as a result if infrequent malfunctioning of handling or processing equipment become suspended in the air, or			
in which combustible dust accumulation on, in or in the vicinity of the electrical equipment could be sufficient to interfere with the safe dissipation of heat from electrical equipment, or could be ignitable by abnormal operation or failure of electrical equipment.			
A location because of the presence of easily ignitable fibres or where materials producing combustible flyings are handled, manufactured or used, but in which such fiber-flyings are not likely to be in suspension in the air in quantities sufficient to produce ignitable mixtures.	Class III, Divison 1	Not applicable	Not applicable
A location in which easily ignitable fibers/flyings are stored or handled other than in the process of manufacture.	Class III, Divison 2		

C.5.3 Combustible material Group classification

Combustible materials which can cause an explosive dust atmosphere are classified in Groups under the North American as well as the European methods. They both cover the same materials but with different designations. Table C.2 summarize both systems for the Group classification. Group III according to the European standard (based on international IEC standard), is subdivided in subgroups according to the table.

Table C.2 — Material Group classification by the European and North American methods

Combustible dust and flyings	Material Group designation	
	Europe *	North America
Atmosphere containing flyings	IIIA	
Atmosphere containing non-conductive dust	IIIB **	
Atmosphere containing conductive dust	IIIC	
Electrically conductive dust		E
Carbonaceous dust		F
Agricultural dust		G **

* Classification according to IEC 60079-10-2 and EN 60079-10-2.

** Includes dust from wood pellets.

The risk varies for the subgroups, such that equipment classified IIIA can be used in dust atmospheres classified IIIA, equipment classified IIIB can be used in dust atmospheres classified IIIA and IIIB, and equipment classified IIIC can be used in dust atmospheres classified IIIA, IIIB and IIIC.

C.6 Safety certification related to dust

During design, installation and operation of equipment in areas classified as potentially hazardous (C.5) there are various regulations to consider. In order to mitigate risk in operations handling and storing biofuels, the equipment (primarily electrical equipment) could require a legally binding or voluntary safety certification depending on the jurisdiction. In Europe, the ATEX Directive 2014/34 EU, provides a legal and binding framework for equipment used in explosive atmospheres. Certifications of equipment are based on internationally recognized standards, which in turn form a basis for regionally or locally adapted standards and guidelines. The certification procedure is specific for each region involving organizations accredited or notified specifically to test, evaluate, inspect, approve, audit and issuing safety certification for equipment. These certifying organizations typically have to conform with ISO/IEC 17025, ISO/IEC 17020 and/or ISO/IEC 17021-1.

In addition to standards with requirements on the equipment itself, there are a number of standards or codes related to the installation and use of explosion protected equipment, including IEC 60079-14, IEC 60079-17 and IEC 60079-19.

The three globally dominating safety standard schemes for equipment are IEC, NEC and ATEX. All three have somewhat different requirements for regulatory compliance although much of the protective techniques prescribed are similar and are in there own right providing a high level of protection in hazardous conditions. There is a continuous effort under way to harmonize the standards and certification procedures worldwide. Overlap between old and new safety standards makes certification somewhat complex. Consultation with experts on safety certification is therefore recommended to verify which standards are in effect and best suited for a particular application.

The IEC 60079 and ISO 80079 series of standards specifies the protection techniques suitable for electrical and non-electrical explosion protected equipment, respectively, and are also the basis for IECEx as well as ATEX safety certification. ATEX also requires certification of protective systems. The NEC (NFPA 70) code also covers all types of equipment and the working environment. The NEC (CEC in Canada) code for safety certification is traditionally used in North America although the IEC code is gradually becoming accepted also in North America in certain industrial sectors. As part of the global harmonization effort the Ingress Protection (IP) code is now included as an alternative under the NEC code. ATEX is however not accepted and is not used in North America.

The protective heavy-duty industrial enclosures specified by the National Electrical Manufacturers Association (NEMA) are dominating the industry in North America.

The IEC 60079 and ISO 80079 series of standards are widespread in the world outside Europe and North America. Acceptance for explosion protected equipment according to these standards is gradually gaining in such parts of the world.

Issuing regulations for the working environment is typically the responsibility of the regional or local health and safety authorities. Plant owners or operators are responsible for complying with the applicable regulations. In Europe, Directive 1999/92/EC is implemented by the national authorities. In USA the Occupational Safety and Health Administration (OSHA) has the regulatory authority. In Canada, Health Canada and the provincial counterparts has the authority to regulate the workplace safety. In many jurisdictions the producer of tradable commodities like wood pellets are required to publish a product safety data sheet which in combination with equipment and workplace safety considerations provide a basis for a safe environment. In most jurisdictions risk area classification (C.5.2) is required as part of the workplace certification.

C.7 Prevention and mitigation of fires and explosions

C.7.1 General

Prevention and mitigation of explosions involves a number of considerations related to design, operation and maintenance of a facility for handling and storing solid biofuel pellets. To better understand the physics of fires and explosions more effectively in order to prevent and mitigate incidents in progress, each subsection hereunder is referencing the combustibility parameters described in C.4 and as provided by the supplier of solid biofuel pellets in their respective product safety data sheet. The required declaration in a product safety data sheet on combustibility is stipulated in the (UN, 2013a) or REACH (Directive 2008/1272/EC).

Many dust explosions in the industry start with a small fire in a layer of dust due to the relatively low auto-ignition temperature. The parameters necessary to be present for a fire to start is listed below. If the conditions for a fire is also combined with two more parameters, dispersion of the combustible material (dust) and a confinement, there is a potential for an explosion, a so called primary explosion.

a) Basic conditions for a fire:

- fuel (accumulated dust);
- oxygen (air);
- heat (e.g. friction, hot surface).

b) Basic conditions for an explosion:

- fuel (accumulated dust);
- oxygen (air);
- ignition source (spark, small open flame);
- dispersion of fuel (forming a dust cloud);
- confinement (room, machine enclosure).

If the dust cloud is ignited, the explosion produces a pressure wave which dislocate and is lifting layers of dust from trusses, beam, floor etc. If the suspended dust reach a concentration above the MEC, the primary explosion will develop in to a so called secondary explosion (see Figure C.1).

The burning fuel is landing and adhering to exposed surfaces and usually causes significant damage and injury. Dust explosions normally propagate with subsonic speed (deflagration). The speed of deflagration can be magnified when the pressure wave is passing though constricted spaces such as tunnels and ducts.

It is important to eliminate the initial step of this escalating process by diligent housekeeping to minimize the accumulation of dust in layers (see C.7.2.2).

C.7.2 Precautionary ignition avoidance

C.7.2.1 General

The precautionary measures for ignition avoidance are related primarily to the parameters listed below and relates to a combination of design, operation and maintenance considerations. In addition, material characteristics of the biofuel play an important role. Some fuel qualities such as chemical composition and fines content represent more risk than others.

Parameters to control (see C.4)	TC, MIE, MEC, LOC, TL

C.7.2.2 Operation and maintenance

Housekeeping by means of sweeping floors and vacuuming areas where dust tend to accumulate is of primary importance and should be done on a continuous basis, preferably with dedicated personnel focused on controlling the dust. Even a thin layer of dust in the floor can be enough to create a combustible cloud of dust (see Figure C.2). Layers of secondary dust (see C.2) should not exceed a thickness of 3 mm (see further detailed guidelines in NFPA 499).

Key

1 1 mm layer of dust of bulk density 500 kg/m³

2 dust dispered evenly in the entire enclosure

3 dust dispersed evenly to 1 m height

Figure C.2 — Illustration of how a thin dust layer can create a combustible dust cloud

Smoking should be prohibited in areas handling and storing wood pellets.

Electrostatically certified mobile vacuum cleaners approved for use with combustible dusts should be used to pick up dust and spilled material.

The use of compressed air is normally prohibited inside operating plants unless production machinery is shut down and effective ignition sources are excluded.

Compressed air can be used for cleaning moving inactive machinery when parked in separated area. Dust accumulating on engine or exhaust system surfaces can reach temperatures close to or above TL level and represents a hazard. Mobile equipment with internal combustion engines should be equipped with automatic built-in fire extinguishers in the engine compartment. The temperature of hot components in the engine compartment should be monitored to set-off alarm when exceeded. Wheel loaders with buckets or scraping blades for moving solid biofuel pellets should be equipped with edge of electrostatically dissipating material to avoid sparks to develop.

Some jurisdictions may prescribe electrostatically dissipative clothing. Hard-toe work shoes with ESD (Electro-Statically Dissipative) certified soles are available and recommended.

All electrical ground connections should be checked as part of the regular maintenance program.

The protective window for ignition source detectors needs to be cleaned on a regular basis.

Hot work such as welding and grinding should be conducted in accordance with local safety guidelines.

C.7.2.3 Inertisation

Explosions and fires can be prevented if the oxygen content is kept below the Limiting Oxygen Concentration (LOC) as indicated for the material in question. A safety margin of 2 % to 4 % below the LOC is recommended. Control of the oxygen concentration can be achieved in several different ways such as inertisation with nitrogen, steam or oxygen deprived exhaust gas. This may apply to reactors, pulverisers, hammer mills, mixers, dryers, cyclones, dust collectors, conveyors, screw feeders, bucket elevators, hoppers, silos etc. If inertisation is used it is important to make sure the vessel does not contain air pockets or that the inertisation media is not by-passing space volumes on its way through a system. Equally important is that air locks such as vessels filled with material do not develop ratholes or channels through which air could penetrate an inerted space volume. It is also important to consider the personal safety and monitor the oxygen concentration as this low oxygen content very quickly can cause loss of consciousness (see D.2.3.1).

It should be pointed out however that smouldering can continue even below the LOC in wood materials once the material has been ignited and is hot enough due to the fact that wood contains over 40 % chemically bound oxygen which at high temperature is sufficient to sustain smouldering.

C.7.2.4 Dust collection

Baghouses and cyclones are notorious for fires and explosions. Wood particles have an electrical DC resistance of 10^{12} Ω compared to coal dust with 10^{6} Ω. Particles with high electrical resistance have a propensity to accumulate electrical charge on the surface such as tribo-electric charge when travelling at high speed. If the conduit in which they travel cannot bleed off electrons from the passing particles the stream of particles will become increasingly charged (see MIE in C.4.4) and can result in a sudden electrostatic discharge. If the concentration of particles is sufficiently high (see MEC in C.4.8) the particles can ignite if there is sufficient oxygen (air) present (see LOC in C.4.9). Ducts and pipes leading to baghouses as well as mounting structures for filter bags should be properly grounded to effectively bleed off any build-up of electrical charge.

Baghouses and cyclones are very effective for separating airborne dust in areas where dust is generated. However, hot particles entering the baghouse are known to initiate fires and explosions. The same is true for fragments of metals and stones when entering the baghouse, as they can cause sparks to initiate fires and explosions. The in-feed to baghouses and cyclones should be protected by sensors to extinguish or deflect hot particles and fragments (see C.7.2.7). Baghouses and cyclones should be equipped with explosion panels facing outside buildings and away from areas where people can be present. Also suppression systems and/or explosion isolation systems could be considered.

Dust from baghouses are suitable as samples for conducting combustibility testing as described in C.3.2.

C.7.2.5 Dust concentration limitation and dilution

Exhaust air from dust collection systems should not be re-circulated back in to a building if the dust is deemed to cause a health risk (see 6.2 c) or to represent a deflagration hazard.

Hoods and enclosures should be designed and located such that wood dust or particles generated will fall, be projected, or be drawn into the hood or enclosure so as to minimize fugitive dust emissions without interfering with the safe and satisfactory operation of machines and other equipment. All hoods and enclosures should be of non-combustible construction unless protected with automatic sprinklers.

In dust transportation systems fans should if possible, be placed on the clean side of the filter. Fans placed in a dust loaded part of the system should be designed and certified for the application.

C.7.2.6 Ignition source detection and extinguishing

Ignition source detection systems are usually connected to a deluge water system, inertisation system (for example, nitrogen flooding), steam snuffing or abort gate to extinguish or divert an ignition source to a safe area. The sensitivity level of the detection system can usually be set to a practical level which means that smaller sparks can be detected but may not have sufficient energy to ignite material in its path and therefore would not initiate an extinguishing operation to avoid unnecessary disruption of a production line. Spark detection systems may be used in situations when the sparks are transported at about the same speed as the material and the distance between the detector and the extinguishing devise should be such that the extinguishing devise is given sufficient time to react to avoid the spark to by-pass. For further information on detection systems see Annex G.

C.7.2.7 Dust suppression

Water, mist or chemical palliatives may be sprayed over areas where dust is generated or accumulated. However, water or mist is degrading the calorific content of biofuels and may also introduce fungi and smoldering (see B.2) and can only be used in extremely small amounts using a fine spray or atomizer. The use of chemicals is not acceptable in many cases since it can be seen as a contaminant and could have serious consequences during handling, storage and combustion. In addition, anything deposited on the surface of pellets can leave traces on conveyor belts, hoppers, inside rail cars or trucks as well as on the walls in ship holds. Cleaning of such surfaces can be very expensive and may be prohibited, since it could contaminate other commodities transported through the same system.

The other approach for dust suppression is to blend a binder in the feedstock used for pellets and briquettes and thereby increasing the durability of the solid biofuel pellets to minimize the generation of dust.

However, the simplest method is to avoid products being dropped on hard surfaces and thereby avoid in-elastic impact. When products are dropped on the product itself, the impact is elastic and therefore generates less dust. A consideration is to avoid emptying silos completely and always leave some product at the bottom.

C.7.3 Measures to minimize explosion effects

C.7.3.1 General

The precautionary measures for minimizing explosion effects (constructive measures) are related primarily to the parameters listed below and relates to a combination of design, operation and maintenance considerations. In addition, material characteristics of the biofuel play an important role. Some fuel qualities such as chemical composition and fines content represent more risk than others.

Parameters to control (see C.4)	MIE, MEC, LOC, p_{MAX}, dp/dt_{MAX}, K_{ST}

C.7.3.2 Explosion pressure proof design

Explosion containment is the fundamental and most desirable level of design, but is often prohibitively expensive and, in many cases, not practical. In addition, pressure piling can occur in certain design configurations with linked vessels. The objective is to design equipment in such a way as to withstand the maximum explosion pressure p_{MAX} and explosion pressure rate dp/dt_{MAX} as established by testing in single vessel configuration.

C.7.3.3 Explosion isolation

Propagation of an explosion travelling through a pipe or duct can be stopped by means of fast acting valves effectively cutting off the path of the pressure wave (NFPA 654:2017 section 7.1.6.1). The valves can be passive or active. The passive valve is designed to use the increased pressure to shut itself close and resets itself when the pressure has fallen. The active valves have a sensing devise closing the valve in milliseconds after detection of a pressure increase. An alternative active valve design is releasing compressed air at high speed and high pressure within milliseconds and pinches a sleeve, which shuts off the pathway. Yet another design is using chemical suppressant to stop the progression of a deflagration pressure wave or flame front.

Another concept is using a fast acting abort or diverter gate, which deflects the media in the pipe or duct out of the system to a safe location. The gate is activated either by over-pressure, over-temperature or by an ignition source detector upstream from the gate.

A flap valve may be used to protect from back-pressure caused by an explosion downstream from the valve. The valve is open in the forward direction but the flap falls and closes quickly when the backward pressure exceeds the forward pressure in the pipe or duct (NFPA 69:2017 section 12.2.3).

Flame resistant components (e.g. tested and certified rotary valves) can prevent explosion propagation into other parts of the facility.

C.7.3.4 Explosion suppression

It typically takes 30-100 ms for the pressure in an enclosure from an explosion to become destructive. In order to suppress an explosion the pressure has to be detected early enough to initiate release of a suppressant to stop the development of a fireball inside the enclosure. Also, the rate of release has to be sufficiently fast to extinguish all flames before destructive overpressure develops. Explosion suppression is expensive and is typically only used when

— it is not possible to protect by means of explosion containment or relief venting, or

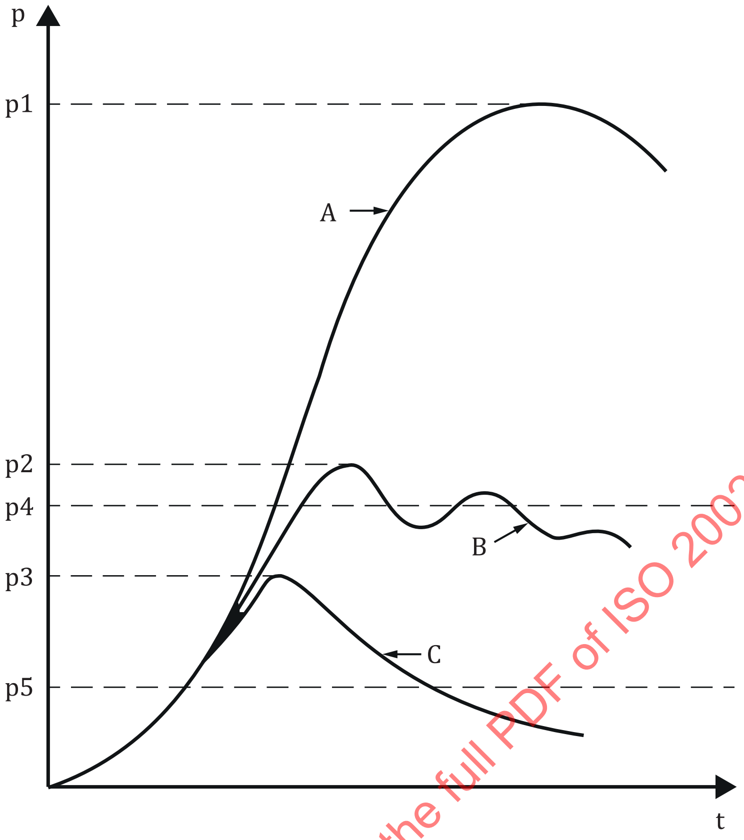
— when explosion venting cannot be done to a safe location, or

— the capacity of the venting cannot be achieved.

Sometimes explosion suppression safe-guarding is used in combination with explosion venting to protect the integrity of an enclosure.

C.7.3.5 Explosion venting

Explosion venting is a protective measure to eliminate pressure to build above the pressure for which the enclosure is designed and discharge the pressure wave in a safe place to avoid injury and damage to equipment. Weak areas, so called explosion panels, of the enclosure especially designed to break open at a predetermined pressure relieve the pressure. Figure C.3 illustrates the principles of explosion venting. Curve A illustrate the “normal” progression of the pressure wave. The “Strength of vessel” is the maximum pressure for which the vessel (enclosure) is designed, including access doors, manhole covers etc. Curve C illustrates the reduced pressure after the explosion panels of sufficient size have ruptured. Curve B illustrates the reduced pressure after smaller size explosion panels have ruptured.



Key

t time
p pressure
A unvented
B not appropriate vent dimension
C large vent
p1 max pressure
p2 reduced pressure for not appropriate vent
p3 reduced pressure for large vent
p4 strength of vessel (design pressure)
p5 vent opening pressure (static)

Figure C.3 — Principle of explosion venting

The K_{ST} and p_{max} values representative of the dust likely to be contained in the enclosure are essential for calculating the size as well as the p_{stat} (rupture pressure) characteristics of the material in the explosion panels.

Annex D
(informative)

Safety aspects and guidance on handling various emergency situations

D.1 Introduction

This annex provides guidance on the handling of various types of emergency situations and could be used in the pre-planning and preparations of checklists and to define a procedure for a continuous update of the risk assessment during an ongoing incident (7.5). Such emergency situations can involve fires in conveying systems, self-heating, a suspected fire or a confirmed fire, explosions but also rescue of people in confined spaces. As the possibilities for handling these situations will differ depending on the type of facility, the recommendations are divided into various objects following the main Clauses 8 to 11 in this document covering fire situations in conveyor systems, storage in silos, bunkers and warehouses.

These kinds of emergency situations can also generate severe risk for personal injuries, and therefore the first part of the annex is covering safety risks. The pre-planning is based on a risk assessment considering possible safety aspects as far as possible. However, it is also important to recognize that the specific emergency situation is a unique event and the risk assessment is therefore to be evaluated continuously during the entire operation, to handle the risks associated with the upcoming situations during the work.

Annex D also provides some general information about various extinguishing medias that can be useful in the planning process and during the firefighting operation.

D.2 Safety aspects in emergency situations

D.2.1 General

This section of Annex D is focused on safety aspects which are important to consider in emergency situations involving self-heating and/or fire situations. The presentation of various safety aspects/most acute risks mentioned below are based on a silo fire situation as this is perhaps one of the most complex situations to handle. A silo fire creates a number of risks that can cause serious injuries or fatality, both for plant personnel and emergency services personnel. Although focused on silo fire, similar risks will also be present in many of the other fire scenarios covered by this document.

Additional information on safety aspects related to off-gassing and dust and gas explosions can also be found in Annex B and and in the MSB silo handbook (MSB, 2013), IEA guidelines (IEA, 2013), and The Pellet Handbook (Obernberger and Thek, 2010).

D.2.2 Formation of carbon monoxide (CO) and carbon dioxide (CO_2)

As described in B.3.3.3, auto-oxidation is causing rapid depletion of oxygen in enclosed storage spaces for wood pellets. Even before self-heating or a fire can be detected, the formation of CO spreading through the plant can cause serious risks. CO is completely odour-free and therefore impossible to detect without special CO detectors. Measurements in facilities have shown that CO concentrations of >100 ppm can exist under normal conditions inside silo superstructures or passageways at silo bottoms. Concentrations of >1 000 ppm have been observed in these locations in connection with fires. In ship holds of ships arriving in port to discharge wood pellets after long sea voyages CO concentrations of 5 000-10 000 ppm (0,5-1 %) has been measured combined with oxygen concentrations of 5 % to 10 %

(Svedberg et al., 2008). Ventilation is therefore extremely important before personnel are allowed to enter (see B.3.3.2).

In the silo headspace, the gas concentrations can be significantly higher and CO concentrations of 5 000-10 000 ppm (0,5 % to 1,0 %) have been measured in cases of increased oxidation of the pellets. In the event of a fire, the CO concentration in the silo headspace can exceed 10 %, which creates a very serious threat (see NOTE below). In connection with oxidation/self-heating or fires, very high concentrations of CO_2, in some cases over 30 % and unburned hydrocarbons can be formed, which further increases the risks.

It is important not to exclusively rely on oxygen concentration measurements. Air normally contains about 21 % oxygen and accepting a concentration of e.g. 20 % oxygen as acceptable could lead to very serious consequences. If the reduced oxygen concentration consists of CO, this would correspond to about 10 000 ppm, which quickly could lead to unconsciousness and fatality.

Therefore, it is recommended to maintain a minimum oxygen level of 19,5 % and monitor the level of CO at the same time. The International Maritime Organization (IMO) forbids entry to spaces unless there is a minimum of 20,7 % oxygen in combination with a maximum of 100 ppm CO (IMO). Safety guidelines available today to avoid CO poisoning consider a proper ventilation of the area, the use of gas meters for both CO and O_2, the use of self-contained breathing apparatus when the levels of these gases are not in the safe range.

NOTE Carbon monoxide (CO) is an odour-free gas that has the same density as air. The Swedish Work Environment Authority has set a Permissible Exposure Limit (PEL) of 35 ppm for 8 h and 100 ppm for 15 min in working environment. The PEL limits may vary somewhat from one region to another. Exposure to 1 400-1 700 ppm for 30 min or 6 000-8 000 ppm for 5 min leads to loss of consciousness. Exposure to 2 500-4 000 ppm for 30 min or 12 000-16 000 ppm for 5 min is fatal. 10 000 ppm corresponds to 1 % of volume. CO concentration between 12,5-74 % is flammable.

D.2.3 Risks of using nitrogen and CO_2 as extinguishing agents

D.2.3.1 Nitrogen

Handling of nitrogen brings risks since it lowers the oxygen level in the air and can thereby lead to suffocation. Depending on local regulations, these prescribe a minimum oxygen level ranging from 19,5 to 20 % and respiratory equipment should be used if the level is lower than 18 % (consult your local authorities). If nitrogen is released into the open, for example during filling from the tanker vehicle to a mobile gas tank, the gas is quickly dispersed since it weighs about the same as air, which would pose no danger. In contrast, nitrogen can remain present for a long time in closed areas that have been inerted or adjacent enclosures, e.g. conveyor culverts below a silo. This means that the oxygen level could be very low, which can quickly cause loss of consciousness.

Examples of critical exposure times are shown in Table D.1.

Table D.1 — Examples of critical exposure times

Oxygen concentration	Leads to unconsciousness after
7 %	1 min
5 %	20 s
3,5 %	15 s

During the firefighting operation, there is also probably a combination of very high CO and CO_2 concentrations, as well as low oxygen levels due to the fire, which makes the environment very dangerous.

It is therefore necessary to continuously control the CO and oxygen concentrations in the facility in the event of a fire. In the affected areas (at the bottom and top of the silo superstructure), all persons should wear complete respiratory gear. In connected areas (control rooms, personnel areas, stairwells, elevators etc.), increased gas concentrations can also be present, which makes it necessary to wear respiratory gear here as well unless continuous measurements guarantee a safe work environment.

An additional risk that should be taken into account is frostbite injuries that can occur when handling liquid nitrogen. Hoses between the tank and vaporizer and the vaporizer itself can become extremely cold since liquid nitrogen has a temperature of −196 °C and these surfaces should therefore not be touched without protective gloves. Mounting of the equipment and filling etc. should be handled by trained personnel, such as the gas provider's service personnel, and it is important to assure that emergency response personnel are informed of the required safety instructions. Even if the risk of hose breakage is very low, unauthorized personnel should never stay in the vicinity of equipment and hoses containing liquid nitrogen.

Liquid nitrogen or very cold nitrogen can also on direct contact cause damage to certain materials, such as non-alloy ("black") steel, plastics, rubber etc. In contrast, brass, copper and aluminium can withstand such contact relatively well.

Regarding the gas distribution from the vaporizer to the injection point on the silo, it is important to ensure that no leakage or hose breakage occurs. When the nitrogen is distributed in gaseous form, the gas pressure is normally only a few bars, but it is important to make sure that the vaporizer's capacity is not exceeded, as this could result in the very low nitrogen temperatures causing damage to the hoses.

In regards to inerting the silo headspace, nitrogen has the benefit of not causing any problems related to static electricity since it is injected in gaseous form as long as the vaporizator’s capacity is not exceeded.

D.2.3.2 Carbon dioxide (CO_2)

CO_2 is a traditional extinguishing agent that is used in portable fire extinguishers and for fixed fire protection systems in enclosed spaces. Due to the high pressure, the gas is in liquid form inside the storage vessel. Typical applications are the extinguishing of small spill fires and extinguishing of fires in electrical equipment, computer rooms, etc. The extinguishing effect is mainly due to the displacement of the oxygen concentration in combination with a certain degree of cooling. When dealing with silos, there are however serious disadvantages of using CO_2. Historically, CO_2 has been the extinguishing agent used for silo firefighting. A large number of these responses, however, have experienced problems that in several cases have led to failure. There is also a risk that using CO_2 can make the fire worse if used in certain situations.

The following summarizes the reasons why CO_2 should not be used in firefighting.

The most important safety aspect is that CO_2 has a strong tendency to build-up of static electricity caused by the liquid CO_2 flowing out through the discharge nozzle and forming ice crystals. As a smouldering fire inside a silo will generate large amount of pyrolysis gases, the atmosphere inside the silo head space is very likely to be flammable (see D.2.4). Electrostatic discharge from the ice crystals could then ignite flammable gas mixtures in the silo headspace and cause a powerful explosion. Several standards gives warnings about the use of CO_2 in potentially explosive atmospheres (BS 5306-4, NFPA 12) and there are several examples of situations where application of CO_2 have caused explosions and in some incidents fatal damage, both using fixed systems and during manual application from gas bottles through hatches in to the silo headspace (Hedlund, 2018).

Another serious risk is that CO_2, in the conditions generally found in a smouldering silo fire, could contribute to an increased production of CO. At temperatures above 650 °C to 700 °C in combination with limited oxygen supply, CO can be formed from CO_2 through the reaction $C + CO_2 \leftrightarrow 2CO$, where the biomass contributes with the carbon. In such cases, the addition of CO_2 from an inerting operation contributes to the production of the flammable gas CO. The use of CO_2 could therefore result in a more severe fire growth instead of providing a fire extinguishing effect.

Another problem when using CO_2 is that it can cause serious practical problems. CO_2 is a liquefied gas and the pressure in the tank depends on the surrounding temperature. An attribute of CO_2 that often creates problems is that CO_2 cannot exist in liquid form at a pressure below 5,2 bar. Instead, the liquid freezes into a solid (carbonic ice). This means that feeding liquid CO_2 through a hose or pipe system requires maintaining a pressure of at least 5,2 bars in the entire gas feeding line to avoid ice from forming and blocking the passage. In fixed extinguishing systems, this minimum pressure is guaranteed by customized nozzles but maintaining the pressure is difficult when feeding the gas to the silo headspace, usually through a fire hose with some type of open pipe at the end. One solution that is normally used in these situations is to apply a very high flow rate so that the pressure drop in the hose maintains a high pressure. However, this usually results in ice formations at the end of the hose where the pressure is not high enough, which eventually leads to total blockage of the hose. At this stage, the hose upstream the blockage, contains a mixture of CO_2 in liquid and gaseous form and, due to heating from the surrounding, the pressure in the hose will increase quickly, which can lead to hose breakage. To avoid this, the hose can be disconnect from the pressure tank/tank vehicle and allow depressurizing backwards. This is a very risky operation that leads to the formation of a CO_2 cloud when the gas in the hose flows out. The action also involves great risks both in terms of;

— hose breakage,

— the hose whipping around when disconnected and

— poisonous CO_2 (see NOTE below).

Problems with ice forming also occur if you try to feed liquid CO_2 directly into the bulk material, e.g. at the bottom of the silo. As soon as the gas exits the hose or feeding pipe, the pressure drops and the gas freezes. This results in heavy ice formation in the bulk material, which leads to the blocking of the porosity of the bulk material, which then prevents continued application of gas.

A possibility to reduce the problems with ice formation and static electricity is to use a vaporizer to ensure that the gas is discharged into the silo in gaseous form. Due to the relatively high boiling point of CO_2, such a vaporizer will require a powerful external heat source.

NOTE CO_2 is an odour-free gas that is about 1,5 times heavier than air, which can pose serious safety risks since it accumulates at low levels. CO_2 is not only reducing the oxygen concentrations as nitrogen does, but it also affects the respiratory function. National and regional authorities usually stipulate limits of 5 000 ppm per 8 h of work and the limit for 15 min of exposure is 10 000 ppm (10 000 ppm = 1 %). When using CO_2 as an extinguishing media, the design concentration is very high, probably at least 30 % to 50 %. Loss of consciousness and cramps occur at concentrations of 20 % to 30 % in less than a minute.

D.2.4 Dust and gas explosions

The normal handling of materials in silo plants generates always more or less dust formation, which eventually covers all horizontal surfaces and construction components with dust.

If any of this dust is dispersed to a cloud and there is an ignition source present, a dust explosion could occur. This "primary" explosion often leads to additional dust whirling up and causing a "secondary" explosion, which is often significantly more powerful than the primary explosion.

Even a thin layer of dust could create a significant risk. A 1 mm thick dust layer with a bulk density of 500 kg/m^3 provides a dust concentration of 500 g/m^3 if whirled up to 1 m height and 100 g/m^3 if whirled up to 5 m height. Since the flammability range for many types of dust varies from about 50 g/m^3 to about 2 000 g/m^3, the risk of explosion is apparent (see also C.2 and C.7).

During an ongoing smouldering fire in a silo, a high volume of flammable pyrolysis gases consisting of CO and different types of unburned hydrocarbons is formed. At temperatures above about 700 °C, a reaction with water can also occur, the so called water-gas reaction, $C + H_2O \rightarrow H_2 + CO$ which results in the production of hydrogen and further CO. Water is present, both chemically bound in the stored organic materials, but water is also produced as a result of the combustion process or could be added through an extinguishing operation using water based firefighting agents. Altogether, a silo fire entails a significant risk that there is a flammable gas mixture in the silo headspace.

This can lead to a very powerful gas explosion if the gas is ignited, by e.g. unprotected electrical equipment, static electricity or drilling in the top of the silo as part of the extinguishing attempt. A small gas explosion can also serve as a "primary explosion" that causes a significantly more powerful secondary dust explosion.

Past accidents show that gas and dust explosions can lead to very extensive damage. The entire silo roof could be thrown off and the risk of injury/fatality for persons on the roof is very high. There are significant risks in the form of falling construction parts etc. for persons and equipment on the ground as well. The risk of gas and dust explosions is the same for large and small silos.

Since the risk of gas and dust explosions is the most serious danger associated with silo fires, it is important to make on-site risk assessment to establish which risk areas should be cordoned off, where to place extinguishing equipment etc. As part of the fire fighting strategy it is important to assume the risk of an explosion in the headspace is always present. The risk assessment is therefore to be continuously updated based on e.g. results from gas measurements in the silo headspace and visual observations. Conditions are likely to change during the time extinguishing and discharge of material is under way and explosions can happen any time.

It is therefore extremely important to minimize the risk for dust and gas explosions and the suggested extinguishing technique of inerting with nitrogen gas has many advantages. Using gas provides a very controlled course of action as the gas is primarily injected at the bottom of the silo and the risk of lofting dust is minimal. When inerting silos containing powdered material such as wood powder, it is important to start the gas injection with a low gas flow in order to avoid generation of a dust cloud that could result in a dust explosion. There is currently no “safe” gas flow limit established since it depends on the following parameters:

— powder density,

— permeablity of the powder,

— fill level of powder in the silo,

— how the gas is distributed inside the silo (number of gas inlets).

When working on the top of the silo (sealing openings, mounting measurement instruments, arranging ventilation/pressure relief, preparing for the inertization, etc.), it is very important to not generate any ignition source, flammable gas mixture or dust formation. In a developed pyrolysis fire (apparent smoke formation, etc.), high concentrations are formed of CO and different types of unburned hydrocarbon which could be within the flammability range. If the oxygen concentration in the silo headspace is high enough (over 5-10 %), the gases can ignite if there is a suitable ignition source. In these situations, it is important to realize that there is a risk of explosion. Minimum Oxygen Concentration (MOC), (see Annex C) for wood powder alone is around 10 % and the mixture with hydrocarbon can have an even lower MOC.

Attempting to use LEL (Lower Explosion Limit) monitoring instruments to measure the concentration of flammable pyrolysis gases inside e.g. the silo headspace, to assess the risk of explosion is not recommended. These instruments are calibrated for one specific gas, usually methane or propane, which means that correction factors is to be applied in order to measure any other gas. These correction factors vary between 0,5 to 3,0 and since the composition of the gas mixture is unknown, the error could be significant and result in a completely incorrect assessment.

If the risk of explosion is considered to be high, continued work should be minimized until the silo headspace has been inerted.

Regardless of the decision to use an inerting procedure or some alternative extinguishing method, it is very important to carry out this procedure in a safe way so that the operation itself does not create a gas or dust explosion inside the silo. This applies to all silos regardless of size.

D.2.5 Other health hazards

D.2.5.1 Rapid fire escalation

A silo fire can rapidly escalate and become uncontrollable due to a number of factors. The design of the silo can include openings in the roof or, part of the roof or explosion panels can have released due to an explosion. This will allow oxygen to enter the headspace and feeding a fire or smouldering in the material. This will in turn increase the generation of pyrolysis gas, which can explode or increase the fire intensity and the risk for a total collapse of the roof structure. The best action to maintain control is to inject foam (CAF or low/medium expansion foam) and cover the entire top layer of material to block oxygen. A silo can easily be lost if the condition in the headspace is not kept under control.

Another situation that could cause a rapid fire escalation and maybe also a dust explosion is in a silo during emergency discharge. If the silo is not properly inerted during the discharge and smouldering material suddenly becomes exposed e.g. due to collapse of hanging or bridging material inside a silo, the generated dust could ignite and cause a rapid fire development/dust explosion.

A rapid fire development could also occur during emergency discharge in a warehouse fire caused by self-heating. When the seat of the smouldering fire is reached, the increased supply of oxygen will turn the smouldering into a flaming fire and also increase the generation of flammable pyrolysis gases. The fire will most likely also spread glowing embers which, together with increased exposure of heat radiation, could start fires on top of the entire stack, causing a very rapid fire development. It is therefore very important to have firefighters in standby positions to have full control of the situation during discharge. Having the possibility to activate a foam/CAF deluge system to cover the entire surface of the stack will increase the possibilities to avoid a total loss. It is also important to realize that the visibility inside the warehouse could be very limited due to smoke generation which could hamper the possibilities for a manual firefighting even further. The high concentrations of smoke gases and reduced viability is also to be considered for the personal involved in the discharge operation, e.g. wheel loaders, and SCBA equipment is important to use.

D.2.5.2 Backdraft

A backdraft situation could occur in a silo fire if, e.g. an emergency discharge is made without prior inerting of the bulk by cutting up a hole in the silo wall to allow the material to flow out on the ground. The silo could then contain high concentrations of hot pyrolysis gases and when opening up the silo, the outflow of the hot gas will be replaced by fresh air. This will create a flammable concentration and if ignited (which is very likely), the ignition will cause a powerful expansion of the gases (explosion) creating a jet flame from the opening which could both injure firefighting personnel and ignite adjacent objects. There are examples of jet flames reaching a length of about 50 m causing ignition of surroundings and also spreading glowing embers starting fire, for example on the silo top.

Similar situations could also occur in situation when opening an enclosed space/object where there is a possibility for combustion gases to accumulate.

D.2.5.3 Instability of structure

In many cases conveyors, walking bridges, etc are supported by a silo (or a warehouse) construction. In case the silo/warehouse is damaged by the fire, this could also result in a collapse of such supporting structure. The use of large volumes of water in a silo fire could also cause damage to the structure. Solid biofuel pellets expand up to about 3 times when wetted which will cause a very powerful expansion tearing the silo wall apart. Even if a swelling material is not stored in the silo, using large amounts of water could damage the silo construction due to the high static pressure against the silo wall caused by the accumulated water. Depending on the specific design, swelling of pellets could also cause problems in a warehouse or a bunker.

D.2.5.4 Ratholing, bridging

In general, solid biofuel pellets behave as a free-flowing material and is usually not creating any problems during discharge from a silo. Depending on the silo construction, for example flat bottom or the angle of a conical bottom, the material flow can be defined as mass flow or funnel flow. Mass flow indicates when the entire bulk material across the whole cross section of the silo is moving downwards during discharge. The bottom material is discharged by means of a circulating screw conveyor (reclaimer) or in small diameter silos having a very steep conical outlet. Funnel flow (also called core flow) indicate when the material sloughs off the surface of the material and discharges through a vertical channel formed within the material down towards the discharge outlet.

If the flowability of the bulk material is reduced, e.g. due to a high content of fines or moist material, ratholing or bridging could occur. Ratholing indicates that the funnel runs empty due to the material outside the funnel will not flow causing the discharge to stop. Bridging occurs if e.g. cohesive bulk material forms a stable bridge inside the entire silo or locally over the discharge outlet, preventing further discharge.

Besides geometry, quality of product and distribution of pellets and fines, issues with the flow of material inside a silo (e.g. bridging, ratholing) are closely related to the sequence of filling and discharge operations. As most silos have a centric discharge, some even equipped with a discharge cone, filling and discharge of product cause quite different pressure levels inside the product. During filling of a silo, the pressure at the bottom of the silo increases rapidly. Because the incoming product settles down in layers, the friction between product and the silo wall has only very little relevance. During discharge, the friction between silo wall and the down coming product increases, causing a reduction in pressure at the silo bottom, while increasing the vertical loads at the silo wall.

Reduced pressure also reduces the likelihood of compaction and agglomeration of the product, even if stored for a longer period. Consequentially, the likelihood of material flow related issues like bridging and core flow can be reduced by means of thoughtful silo operation.

Both bridging and ratholing could cause severe problems and is likely to occur in a fire situation, particularly in smaller diameter silos and if water is used as extinguishing media. The work to break up the stuck material could be risky and needs specific risk considerations (see 6.2 e and 9.3.1).

Similar problems could also occur in large diameter silos or in flat storage where steep, high walls of pellets could occur causing the risk for an avalance of pellets and the risk for burial of personnel. Work close to such wall of pellets is very dangerous and appropriate safety precautions is to be taken.

D.3 Conveyors-Actions in case of fire/explosion incidents

In case of a fire or explosion incident, follow the general checklist in the pre-planning document including e.g. the following actions;

- Follow the risk assessment procedure to define any specific safety precautions related to the actual fire situation. The risk assessment is then be evaluated continuously during the entire operation, to handle the risks associated with the work.
- Ensure that the conveyor system has shut down.
- If a particular conveyor is designed to run free of material via a rejection valve to an emergency pile before shut down, it is also important to inspect the pile for any sign of discoloured, hot or smouldering material.
- Ensure that any sprinkler/water spray/water deluge system is activated.
- Close all valves at transfer points, e.g. inlet to a silo.
- Consider the fact that the fire spread inside covered conveyors can be very rapid, in particular if having a steep pitch.
- Localize the fire and start the additional manual firefighting attack as soon as possible. Use of hand-held thermal imaging cameras can be very useful in localizing the seat of the fire in covered conveyors.
- If there is a risk for dust generation, apply the water/extinguishing media as gently as possible.
- Check/supervise all transfer points and systems along the conveying line to verify any possible fire spread, in particular into any storage (silos, bunkers or flat storage) further downstream, from the location of the fire.
- In case of an explosion in the conveyor system, fire spread could occur at long distances, both upstream and downstream the location of the explosion.

— Consider the risk for additional explosions and secondary explosions.

D.4 Handling of self-heating and fire incidents in silos

D.4.1 Actions in a self-heating situation

In case of an identified self-heating situation, follow the checklist in pre-planning document, including e.g. the following actions:

— Follow the risk assessment procedure to define any specific safety precautions related to the actual fire situation. The risk assessment is then to be evaluated continuously during the entire operation, to handle the risks associated with the work.

— If possible, start discharging the silo to break up the zone of warm material.

— If occurring at a power or heating plant using the wood pellets as fuel, transfer the pellets directly to the furnace if possible.

— If occurring at a storage facility, transfer the pellets to another silo or flat storage. An alternative, if available, could also be to transfer the pellets back to the original silo. If no other option, transfer the pellets to a storage area prepared for emergency discharge.

— Intensify the control of the discharged material to ensure that the self-heating has not yet resulted in a spontaneous ignition. If hot, miscoloured or smouldering material is noticed, the discharge should immediately be terminated and the silo should be inerted (see D.4.2.1).

NOTE As it can be difficult to judge the extent of an indicated self-heating process, it is important that the fire rescue services always is notified prior to any discharge actions is initiated.

D.4.2 Firefighting operation and emergency discharge

D.4.2.1 Spontaneous ignition inside the bulk material

If a smouldering fire in the bulk material has been confirmed or the suspicion of a fire is very strong, initiate the inerting operation of the silo as soon as possible.

Follow the checklist in pre-planning document, including e.g. the following actions;

— Follow the risk assessment procedure to define any specific safety precautions related to the actual fire situation. The risk assessment is then to be evaluated continuously during the entire operation, to handle the risks associated with the work, both regarding risk for gas or dust explosions or the probability for high concentrations of toxic combustion gases or low oxygen concentration due to the use of inert gas and oxygen consumption by the fire.

— Close all openings in the silo (including inlet and discharge valves).

— Turn off any ventilation system and close or seal all ventilation openings.

— Ensure that there is a pressure relief arrangement at the silo headspace to allow the outflow of combustion gases and the excess gas when inert gas injection is started but preventing inflow (unless there is a significant negative pressure in the silo).

— Do not open the silo; this could result in a very fast fire development and/or explosion.

— Do not use water unless there is an open fire (see below).

— Start the injection of inert gas at the silo bottom as soon as possible.

— If there is a significant risk for a gas or dust explosion in the silo headspace, inject inert gas also directly to the silo headspace until safe conditions are reached. (see also D.4.2.2).

— Continuously follow the gas concentration readings in the silo headspace. Keep the O_2 concentration below 5 %..

— Start discharge only when the fire is judged to be under control (significantly reduced levels of CO and CO_2 in the silo headspace). This can take many hours. (During a fire situation, a CO-analyser capable of measuring the concentration in the %-range, preferably up to 5 % to 10 % is recommended).

— Continue gas injection at the silo bottom during the entire discharge process and ensure that O_2 concentration is kept below 5 % in silo headspace during discharge.

— If O_2 level is exceeding 5 %, stop discharge until O_2 level is below 5 % again.

— During discharge, it is important to have a continuous control of the discharged material and possibilities to extinguish any smouldering material. The discharge process can encounter problems by e.g. blockage of discharge opening due to large lumps of charred material which require manual intervention.

— The discharged material should preferably be transferred by a separate conveyor system to the outside of the silo for further transport to the designated storage area intended for emergency discharge. If possible, sort the unaffected pellets from those showing a sign of being involved in the smouldering process.

— If the main conveyor system is used for discharge, supervise all transfer points and conveyor(s) to prohibit any possible fire spread. In such case, it is important to design this conveyor for transfer of hot/smouldering material.

— During discharge, continuously control the tendencies to hangings or bridging inside the silo, in particular in small diameter silos.

For additional information, see Annex B.

D.4.2.2 Open fire in silo headspace

An open fire in the silo headspace can occur due to incoming smouldering material that was not detected along the incoming conveyor system. Another reason could be ignition of the pyrolysis gases generated by a smouldering fire deep inside the bulk (often resulting in a gas explosion followed by an open fire). A fire could also be a combination of an open fire on the surface of the bulk material surface and a fire in the pyrolysis gases. The following recommendations should be considered:

— The fire could get intensive and threat the silo roof construction and exposed parts of the silo wall, in particular if the headspace is ventilated, e.g. due to the explosions panels have opened and are not of self-closing design.

— If inerting of the silo headspace is estimated to take too long time or will be inefficient due to ventilations openings, foam (or water) could be used to control the open fire. (Using water will cause swelling of the pellets and could endanger the entire silo construction due to the forces generated, see D.2.5.3).

— Preferably use a fixed installed (water)/foam/CAF sprinkler system in the silo headspace (see 9.4.3.3) in order to avoid the need for fire-fighting personnel at the top of the silo and thereby further openings and increased ventilation to enable a manual application of foam/(water). Application of foam is preferred as this will protect the pellet surface, reduce the penetration of oxygen into the bulk material and reduce the amount of water (and thereby reduce the swelling effect of pellets). When the surface is covered with foam, application can be made in suitable intervals.

— Application of high expansion foam could be an alternative method in some situations but might not be fully effective due to limited spread across a large diameter silo, large differences in height of the bulk material, and fast foam breakdown due to hot and foam destructive gases in the silo headspace. There could also be problems to arrange the high expansion foam generating system due to height difference between the ground and the point of application in the silo headspace.

— A mobile IR camera could be very useful to detect any remaining fires, hot spots or glowing embers on the bulk surface after the main extinguishing operation.

— When the surface fire has been controlled, the entire silo is to be inerted according to D.4.2.1 before the discharge is started as fires inside the bulk material in most situations cannot be extinguished from the headspace.

Further guidance on silo firefighting is given by MSB (MSB, 2013).

D.5 Handling of self-heating and fire incidents in large scale bunkers

D.5.1 Actions in a self-heating situation

In case of an identified self-heating situation, follow the checklist in pre-planning document, including e.g. the following actions:

— Follow the risk assessment procedure to define any specific safety precautions related to the self-heating situation. The risk assessment is then to be evaluated continuously during the entire operation, to handle the risks associated with the work, both regarding risk for gas or dust explosions or the probability for high concentrations of toxic combustion gases or low oxygen concentration.

— If possible, start discharging the relevant bunker section directly to the furnace if possible.

— If no other option, transfer the pellets to a storage area prepared for emergency discharge.

— Intensify the control of the discharged material to ensure that the self-heating has not yet resulted in a spontaneous ignition. If hot, miscoloured or smouldering material is noticed, the discharge should immediately be terminated and the bunker section should be covered with foam and preferably also inerted (see D.5.2).

NOTE As it can be difficult to judge the extent of an indicated self-heating process, it is important that the fire rescue services always is notified prior to any discharge actions is initiated.

D.5.2 Actions in a fire situation in the bunker house or in the bunker

In case of an identified fire, follow the checklist in pre-planning document, including e.g. the following actions;

— Follow the risk assessment procedure to define any specific safety precautions related to the actual fire situation. The risk assessment is then to be evaluated continuously during the entire operation, to handle the risks associated with the work, both regarding risk for gas or dust explosions or the probability for high concentrations of toxic combustion gases or low oxygen concentration.

— Initiate the firefighting operation as soon as possible as the fire could develop quickly and threat the bunker covering roof construction, exposed parts of the bunker wall and conveying systems and other installations located in the bunker house above the bunker covering roof.

— Depending on the location of the main fire, activate the fixed installed (water)/foam/CAF sprinkler system in the bunker house or the system below the bunker covering roof (see 10.3 and 10.4). Application of foam is preferred, in particular if the bulk material in the bunker is involved, as this will protect the pellet surface, reduce the penetration of oxygen into the bulk material and reduce the amount of water (and thereby reduce the swelling effect of pellets). When the surface is covered with foam, application can be made in suitable intervals.

— A mobile IR camera could be very useful to detect any remaining fires, hot spots or glowing embers on the bulk surface after the main extinguishing operation.

— When the surface fire is under controlled, the entire bunker should preferably be inerted using the system described in 10.4.3.4 before the discharge is started, in particular if the fire scenario is believed to also involve smouldering fires deep inside the bulk material. Such fires inside the bulk material will be very difficult to extinguish from the headspace by just foam application.

NOTE A complete inerting operation is perhaps not necessary if the pellets, without any risk for fire spread or explosions, can be feed directly into to furnace for combustion or to a safe storage area using a designated emergency discharge conveyor system.

D.6 Handling of self-heating and fire incidents in warehouses

D.6.1 Actions in a self-heating situation using an underground discharge system

In case of an identified self-heating situation, follow the checklist in the pre-planning document, including e.g. the following actions;

— Follow the risk assessment procedure to define any specific safety precautions related to the actual fire situation. The risk assessment is then to be evaluated continuously during the entire operation, to handle the risks associated with the work, both regarding risk for gas or dust explosions or the probability for high concentrations of CO or low oxygen concentration.

— Start discharging, if possible reclaiming pellets as close to the identified position of heated pellets as possible, to break up the zone of warm material.

— Intensify the control of the discharged material to ensure that the self-heating has not yet resulted in a spontaneous ignition.

— If hot, discoloured or smouldering material is noticed or there is a “fire smell”, the discharge should immediately be terminated. Stop any ventilation system connected to the discharge conveyor system to avoid supply of air/oxygen into the conveyer system and into the bulk storage and prepare for emergency discharge and firefighting.

NOTE As it can be difficult to judge the extent of an indicated self-heating process, it is important that the fire rescue services always is notified prior to any discharge actions is initiated.

D.6.2 Actions in a self-heating situation using wheel loader discharge

In case of an identified self-heating situation, follow the checklist in the pre-planning document, including for example, the following actions;

— Follow the risk assessment procedure to define any specific safety precautions related to the self-heating situation. The risk assessment is then to be evaluated continuously during the entire operation, to handle the risks associated with the work, both regarding risk for gas or dust explosions or the probability for high concentrations of CO or low oxygen concentration. Specifically consider the risk for a fast fire development in case the self-heating has already resulted in a smouldering fire.

— Ensure that first hand firefighting equipment is readily available, e.g. fire hoses connected to a hydrant system and positioned at suitable locations (do not have to be filled with water at this stage).

— Start discharging the pile of warm material using e.g. a wheel loader.

— Ensure that there is a continuous control of both the remaining bulk material and the discharged material, e.g. using an IR camera, to ensure that the self-heating has not resulted in a spontaneous ignition.

— If the warehouse is located at a power/heating plant, transfer the pellets directly to the furnace if possible.

— If the warehouse is part of a storage facility, transfer the pellets to another flat storage or silo. If no other option, transfer the pellets to a storage area prepared for emergency discharge.

— If the temperature in the pile is indicating an increasing temperature or hot, miscoloured or smouldering material is noticed, or there is a "fire smell", stop the discharge immediately and prepare for emergency discharge and firefighting.

D.6.3 Firefighting operation and discharge in warehouses

If a smouldering fire in the bulk material has been confirmed or the suspicion of a fire is very strong, it is important to prepare safety precautions before discharge commences. Follow the checklist in pre-planning document, including e.g. the following actions;

— Follow the risk assessment procedure to define any specific safety precautions related to the actual fire situation. The risk assessment is then to be evaluated continuously during the entire operation, to handle the risks associated with the work, both regarding the risk for very high concentrations of toxic combustion gases and low oxygen concentration inside the storage, the risk for a fast fire development, possible reduced visibility due to smoke generation and wheel loader traffic.

— Prepare for an extinguishing operation, by arranging water supply both for manual firefighting and, if relevant, for the use of the fixed (water)/foam deluge system at the roof.

— If possible, also prepare for manual foam application of the bulk material.

— Do not start unloading until there are firefighting personnel equipped with SCBA in stand by positions at the pile.

— Also the wheel loader drivers should be equipped with SCBA.

— Be very observant on changes in smoke or smell or if increased temperatures (using e.g. IR-camera) could be noticed at any location.

— In case of increased smoke generation, apply a layer of foam (e.g. CAFS or medium expansion foam) over the entire pile of pellets to reduce air entrainment into the pile and reduce the risk for fire spread in case of a cascade of glowing embers. This could preferably be made either using mobile foam branches/monitors but also by using a foam deluge system. Reapply foam as required to maintain a continuous foam layer on the pile.

— Start any roof ventilation system if dust or smoke gases hamper the discharge operation (e.g. visibility).

— In case of detection of hot or smouldering material, apply water to the affected area to avoid any open fires.

— Discharge the material to the designated storage area intended for emergency discharge. Sort the unaffected pellets from those showing a sign of being involved in the smouldering process. During the entire discharge operation, it is important to have a continuous control of the discharged material and possibilities to extinguish any smouldering material.

— In case of significant open flames in the pile which cannot be easily extinguished, stop the discharge process. Activate the deluge system in parallel with manual firefighting.

— Adjust the discharge operation, such that the situation can be kept under control until the discharge is completed.

D.7 Extinguishing media

D.7.1 Nitrogen (CAS 7727-37-9)

Boiling point: −196 °C

Gas Density at 1,013 bar and 15 °C: 1,185 kg/m^3

Specific volume at 1,013 bar and 15 °C: 0,844 m^3/kg

Relative density (air = 1,0) at 1,013 bar and 15 °C: 0,97

(reference: https://encyclopedia.airliquide.com/)

Specific safety data can be found on the product safety data sheet from the supplier and safety aspects to consider when used as an extinguishing media is given in D.2.3.1.

D.7.2 Carbon dioxide (CO2)(CAS Number 124-38-9)

Boiling point (sublimation point): −78,5 °C

Gas Density at 1,013 bar and 15 °C: 1,87 kg/m^3

Specific volume at 1,013 bar and 15 °C: 0,534 m^3/kg

Relative density (air = 1,0) at 1,013 bar and 15 °C: 1,53

(reference: https://encyclopedia.airliquide.com/)

Specific safety data can be found on the product safety data sheet from the supplier and safety aspects to consider when used as an extinguishing media is given in D.2.3.2.

D.7.3 Foam

D.7.3.1 General

Foam is generated by mixing a foam concentrate with water to form a foam solution (premix) which is feeding the foam generation equipment. Depending on type of foam concentrate and the type of foam generating equipment, various types of finished foam can be generated.

D.7.3.2 Types of foam concentrates

The main use for foam is for extinguishment of flammable liquids (often designated “Class B-fuels”). There are various types of foam concentrates, so called “Class B foam” concentrates, normally designated “AFFF”, “FFFP”, “3F” and “Detergent”, were the two first types are so called “film-forming foams” and are containing fluoro-surfactants (per- and polyfluoroalkyl substances (PFAS)). The latter two are so called “fluorine free foams”, which are not filmforming and do not contain fluoro-surfactants. The concentrates are normally used at a nominal concentration of 1 % to 6 % depending on their formulation.

There are also foams with the main purpose to be used for extinguishment of “class A-materials”, i.e. solid materials that also can form a smouldering fire, e.g. paper, wood, textiles. These foam concentrates are designated “Class A foam”.

Class A foam usually contains a mixture of surfactants that are both ”oleophilic” (attracted to oil) and ”hydrophilic” (attracted to water). This means that the generated class A foam has an affinity to hydrocarbons, which provides ideal conditions for the water to soak the carbon layer that are usually formed on typical class A-materials. In contrast to Class B foam concentrates (traditional firefighting foam), class A foam was developed to be used at much lower concentrations, normally between 0,1 % and 1,0 %.

From an environmental point of view, it is recommended to only use foam concentrates of type Class A foam, or fluorine free foams (Detergent or 3F) for firefighting of solid biofuels. Foams containing fluoro-surfactants should be avoided as they are causing a long term environmental impact and might require collection and incineration of the collected waste water following a fire incident. Fluoro-surfactants could also pollute ground water and thereby also cause health issues.

D.7.3.3 Types of generated foam

Depending on the foam generation equipment, the foam could be expanded to various degrees. The degree of expansion of the foam is called "expansion ratio" and is expressed as the volume of the generated foam in relation to the volume of the foam solution used to for the foam generation. The generated foam is grouped into three categories,

— Low Expansion Foam (LEX) expansion ratio <20

— Medium Expansion Foam (MEX) expansion ratio 20 to <200

— High Expansion Foam (HEX) expansion ratio 200 and above

To obtain the various expansion ratios, different types of foam generation equipment is used, e.g. a low expansion foam branch, a medium expansion branch or a high expansion foam generator. The LEX and MEX foam generation is normally using "air aspirating foam equipment" (air is aspirated into the foam branch by a venturi effect generated of the foam solution). The high expansion foam generator is normally using a fan to feed enough air to generate the higher expansion. LEX and MEX are normally used to cover a horizontal fuel surface, while the HEX is normally used to fill an entire enclosure with foam (e.g. a machinery room on a ship, aircraft hangar).

CAFS is another type of foam generating equipment which uses compressed air to create a foam that is called CAF. Water and foam are mixed together using foam proportioning equipment designed for significantly lower proportioning ratios than used in traditional foam equipment normally, 0,1 to 1 % when using class A foam concentrates. Following the foam proportioning, pressurized air from a separate compressor is mixed into the premix solution generating homogeneous foam with small and stable bubbles. The generated (expanded) foam is then distributed through hoses to the fireman operating the hose and could be applied without any use of a foam nozzle. As the hose contains expanded foam, the weight is significantly less compared to using water and thereby much easier to maneuver. The expansion ratio can be varied to generate low- or medium expansion foam and the foam can also be generated to be very "stable" resulting in properties similar to "shaving crème". This gives several advantages, e.g. the possibility to apply the foam also on leaning or vertical surfaces. The drainage rate (the loss of water from the generated foam) is also low resulting in less water damage (e.g. wetting and swelling effect of pellets).

D.7.4 Water

Water is the most common fire extinguishing media and can be applied in many different ways, by manual application through fire hoses and firefighting nozzles or via fixed systems to supply sprinklers or water mist systems.

NOTE Avoid the use of a powerful solid stream water jet as it could expose smouldering fires close to the surface combined with creating a dust cloud which could be ignited and cause a dust explosion.

The use of water mist systems reduces the amount of water as the cooling effect is improved by a more effective evaporation of the fine droplets. However, the small droplets are more sensitive to airflow and should only be considered in enclosures with a low or moderate ceiling height. Sprinklers are generally using higher flow rates, produces larger drops, resulting in a better penetration and wetting capability.

Various water based systems are also used in conveyor systems, e.g. as quick acting valves for transfer points, sprinkler/water mist systems for conveyor protection.

If possible, water application in large amounts should be avoided in closed storage for biofuel pellets, e.g. in silos, bunkers, as the water is causing the pellets to swell which could cause bridging or even rupture the entire silo construction due to the swelling forces (see D.2.5.3).

D.7.5 Sand

In case of an uncontrolled fire in large piles of bulk material where water or other extinguishing medias are not available or not possible to use, using sand to cover the pile could be an alternative. This is an method which is relatively frequently used for e.g. fires in large piles of waste. This will require large quantities of sand and the use of wheel loaders and long-range excavators.

Annex E
(informative)

Ventilation for cooling of bulk material

In some countries, a modern storage facility for pellets could also contain a forced ventilation system for controlling the thermal conditions in the stored pellets. However, in areas with high relative air humidity, the effects of injecting outside air into the storage have to be considered in view of the equilibrium moisture concentration (EMC) characteristics of pellets. An increased humidity in the pellets will contribute to increased microbial activity. Humid air can also make the pellets swell. Furthermore, in the case of high ambient temperature as compared to the temperature in the pellets, the thermal content of the injected water vapour will contribute to the heating of the pellets. In other words, under certain circumstances, ventilating storage with air containing high relative humidity may in fact lead to temperature escalation in the storage rather than to temperature decrease. In order to avoid this uncontrolled condition, the ventilation system should include a dehumidifier to control the amount of moisture injected into the storage.

In order to control the bulk temperature in large silos, ventilation is increasingly used in North America. In many cases the solid biofuel pellets have a high initial temperature due to hot weather, combined with a pellet production using reactive raw material with high oxidative substances. The ventilation air flow is generated by strong fans and the air is always distributed through gaps in the bottom of the silos. Venting is done through dampers at the top of the silos. The temperature is monitored with a number of temperature cables, where the sensor configuration needs to be designed with consideration given to the thermal conductivity characteristics, the permeability and variance in permeability, ventilation fan capacity and the geometry of the fresh air inlets. The temperature monitoring system will present a picture of the temperature distribution in the bulk material and will give alarm when the temperature exceeds a certain level, e.g. 45 °C. The fans are normally controlled by the temperature monitoring system which turns on and off to maintain the temperature within predetermined margins. In some installations, the fans run continuously and are switched off only if the inlet ventilation air temperature exceeds the temperature of the bulk material. Service companies supplying cable temperature monitoring systems may also offer remote 24/7 service via internet providing temperature logging as well as several alarm settings communicated to the local operator of silos. Various safety measures are in place to make sure loss of power and/or communication is not jeopardizing safe operations. This allows for very efficient monitoring and eliminates the risk of mistakes by the silo operator in terms of loss of attention.

Storage of biofuel pellets with different bulk permeability may cause stratification of heat in a silo which may lead to escalation of temperature. Filling biofuel pellets with segregated fines or dust from railcars or ocean vessels into a bulk storage may cause layers of material which may obstruct convection or air flow in a pile and may also result in temperature escalation. The ventilation fan capacity has to be sized for worst case scenario in view of variations in permeability in the pile. If the fan capacity is too low, the ventilation could make the situation worse, as the increased oxygen supply into the material will increase the oxidation process and thereby result in a temperature escalation rather than a temperature decrease. Due to this, the fans normally have a backup power supply in case of a failure of the normal supply. As mentioned, a high humidity in the inlet air could cause problems and in order to avoid this, it could be necessary to turn off the ventilation if the relative humidity exceeds e.g. 80 % or to install a dehumidifier system.

The ventilation system can be combined with the injection of inert gas if the temperature rises above critical values. In this situation it is extremely important to design the ventilation system so that the air supply can be completely blocked to facilitate the inerting operation.

Besides forced ventilation, cooling of solid biofuel pellets can be achieved by circulating the material to another silo. In some installations, external conveyor systems in combination with aeration of the material through gentle drops between conveyor belts are used (see also D.4.1).

Annex F
(informative)

Principle design of inert gas distribution system and inlet openings

F.1 General

This clause summarises some brief information about the design of the inert gas distribution system in a silo and is based on part of the recommendations on given by MSB (MSB, 2013 [chapter 7]). For both a wider knowledge and more details, please read the full publication.

It should also be noticed that these recommendations are based on experience, tests and simulations with solid biofuel pellets as bulk material and that experience from tests and real fires is limited to silos with relatively small diameters.

F.2 Inert gas supply

Liquid nitrogen is considered to be the main alternative to be selected as inert gas due to availability and risk factors (see D.2.2).

There are two main options for the supply of liquid nitrogen:

— liquid nitrogen delivered by truck or rail

— stationary installation of liquid nitrogen supply

NOTE There are also possibilities to use bottles of compressed nitrogen but is from a practical point of view limited to inert very small enclosures. There are also possibilities to use a nitrogen gas generator, producing a gas mixture of about 95 % nitrogen and 5 % oxygen but the main application is for fire prevention rather than fire suppression (see 9.4.3.4). The limitation of such equipment is related to the remaining oxygen concentration in the gas which will make the gas less efficient for fire suppression and that the capacity of such gas generator is limited compared to the supply of liquid nitrogen.

In addition to the supply of liquid gas, either using a mobile tank or a fixed installed tank, there is also need for a vaporizer unit ensuring that the gas is delivered in gaseous form into the silo, and equipped with necessary pressure relief valves, pressure regulators, low temperature sensors, etc. When using a fixed installation, all piping is fixed and made of stainless steel. In case of a mobile supply, the various units (temporary storage tank, vaporizer unit, gas distribution system at the protected silo) are often connected by using flexible hoses suitable for handling liquid gas and/or cold vaporized gas.

A fixed system is preferable as the equipment is in place allowing a fast response to a fire incident while a mobile equipment could be acceptable providing that all required equipment and delivery of nitrogen can be secured in a reasonable short time in an emergency situation.

To ensure a safe handling and operation of the gas equipment, independent on using a mobile or fixed system, the entire system should be designed by professional companies.

F.3 Fixed gas distribution system at the silo bottom

All silos should preferably be prepared for an extinguishing operation by having a gas distribution pipe system already installed at the silo bottom. There are two primary purposes of such a system, one being to facilitate a quick response for the fire & rescue service and the other being to assure that gas is evenly distributed so the entire silo is inerted. The importance of efficient gas distribution increases

