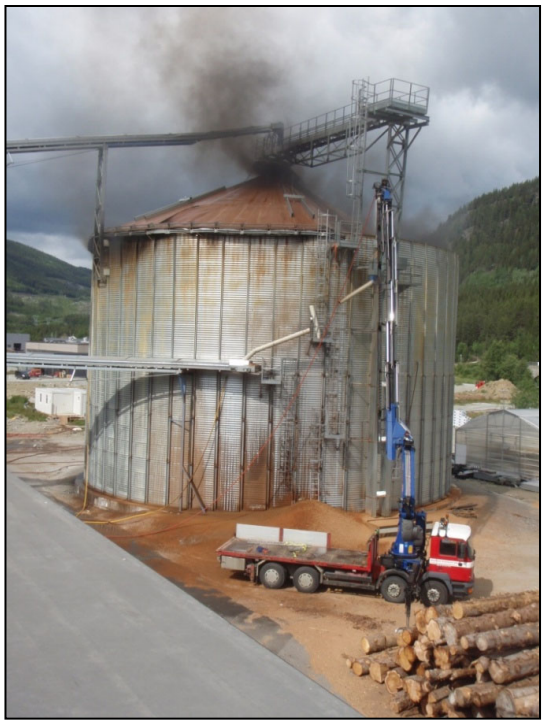
Silo Fire Suppression and Prevention Workshop-Part 1

Introduction and experimental work, Personal safety considerations Silo firefighting strategy

Henry Persson
RISE Fire Research 2019



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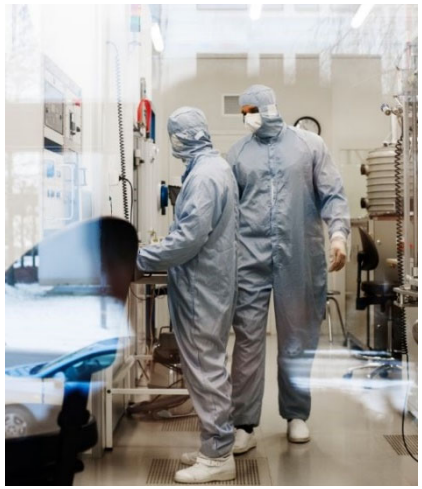
RISE in brief

- RISE Research Institutes of Sweden
- 2,700 employees.
- Turnover approx. SEK 2.7 billion (2017).
- Runs 100s of test and demonstration facilities



RISE Fire Research

Borås-Sweden

Trondheim-Norway

Staff: About 155 persons (120 Sweden, 35 Norway)

Testing and research areas:

- Materials and building constructions
- Industrial fire protection
- Tunnel and underground safety
- Maritime and off-shore safety
- Vehicle fire safety
- Fire investigations
- Fire simulations
- etc.

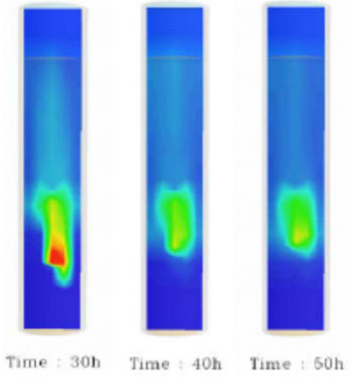
More information can be found on https://www.sp.se/fireresearch

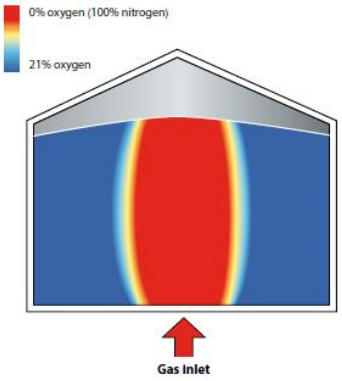
RISE Fuel Storage Safety (FSS)

An international Center of Expertise for fire safety during storage and handling of liquid or gaseous fuels, solid biofuels and recycling of waste material involving research, innovation and knowledge transfer

Content of presentations

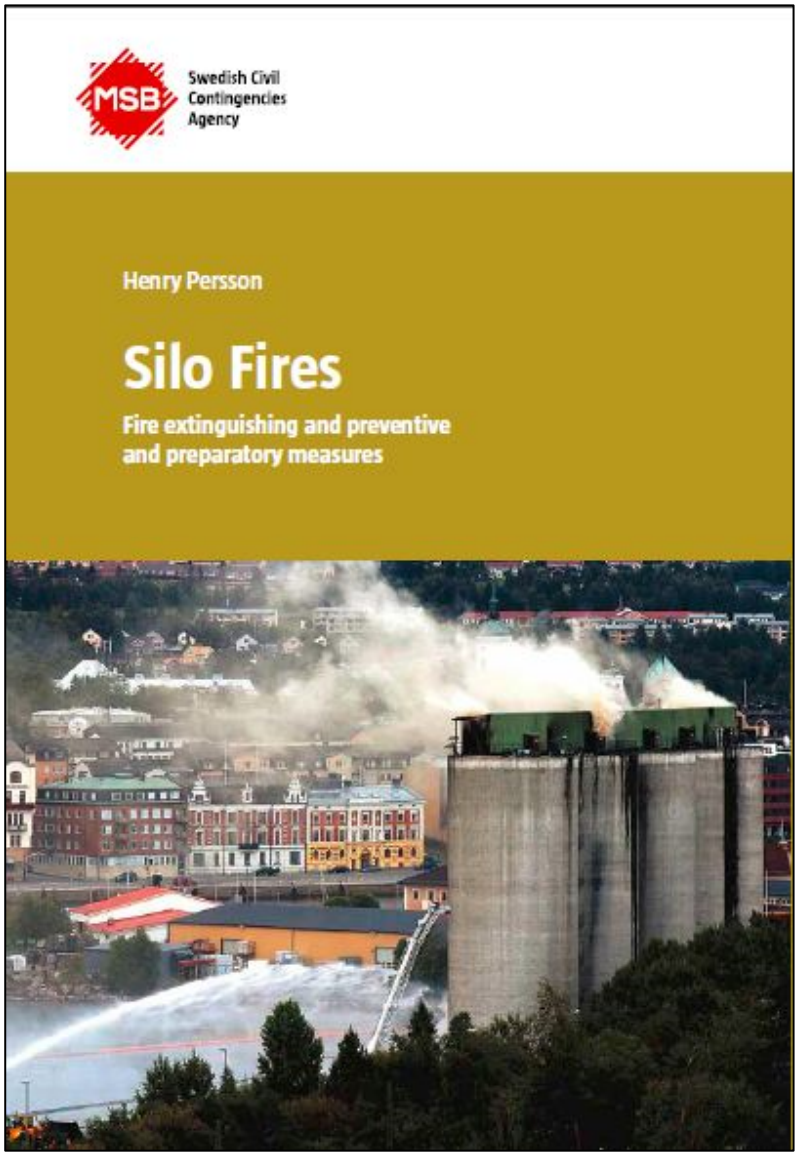
- Background to silo firefighting recommendations
- Self-heating in wood pellets
- Experimental work on silo fires
- Personal safety considerations
- Silo firefighting strategy
- Alternative firefighting strategy
- Practical experience from silo fires
- Preventative and preparatory measures





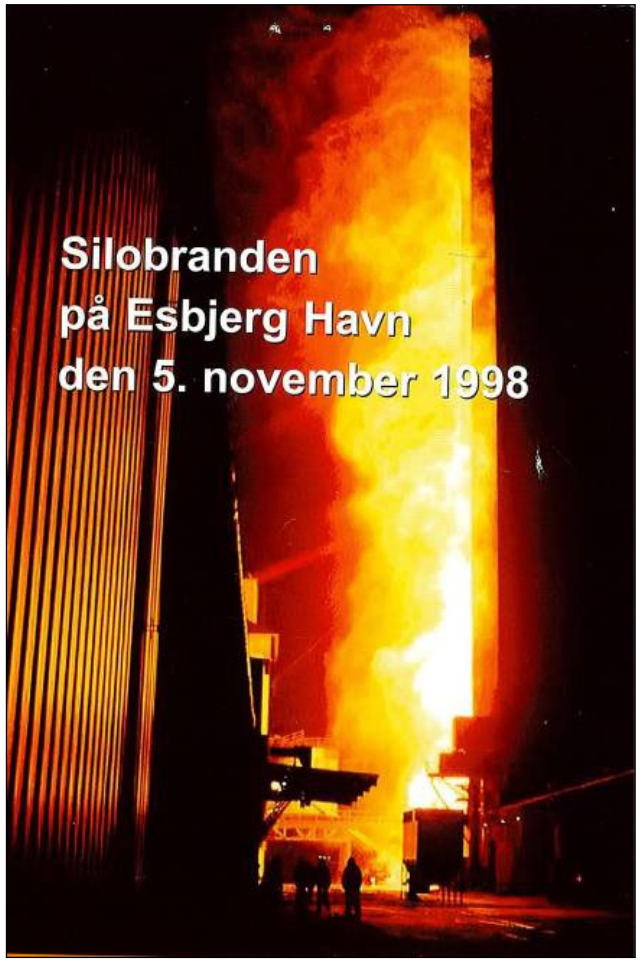
Background to silo firefighting recommendations

- Swedish Civil Contingency Agency (MSB) initiated a study
- Litterature review published 2004 (in Swedish)
- Firefighting of silo fires often a failure
- Several experimental projects to improve understanding of self-heating and fire development.
- Study of real fire incidents



Published 2012

Esbjerg-Denmark 1998



Grain silo converted for wood pellets

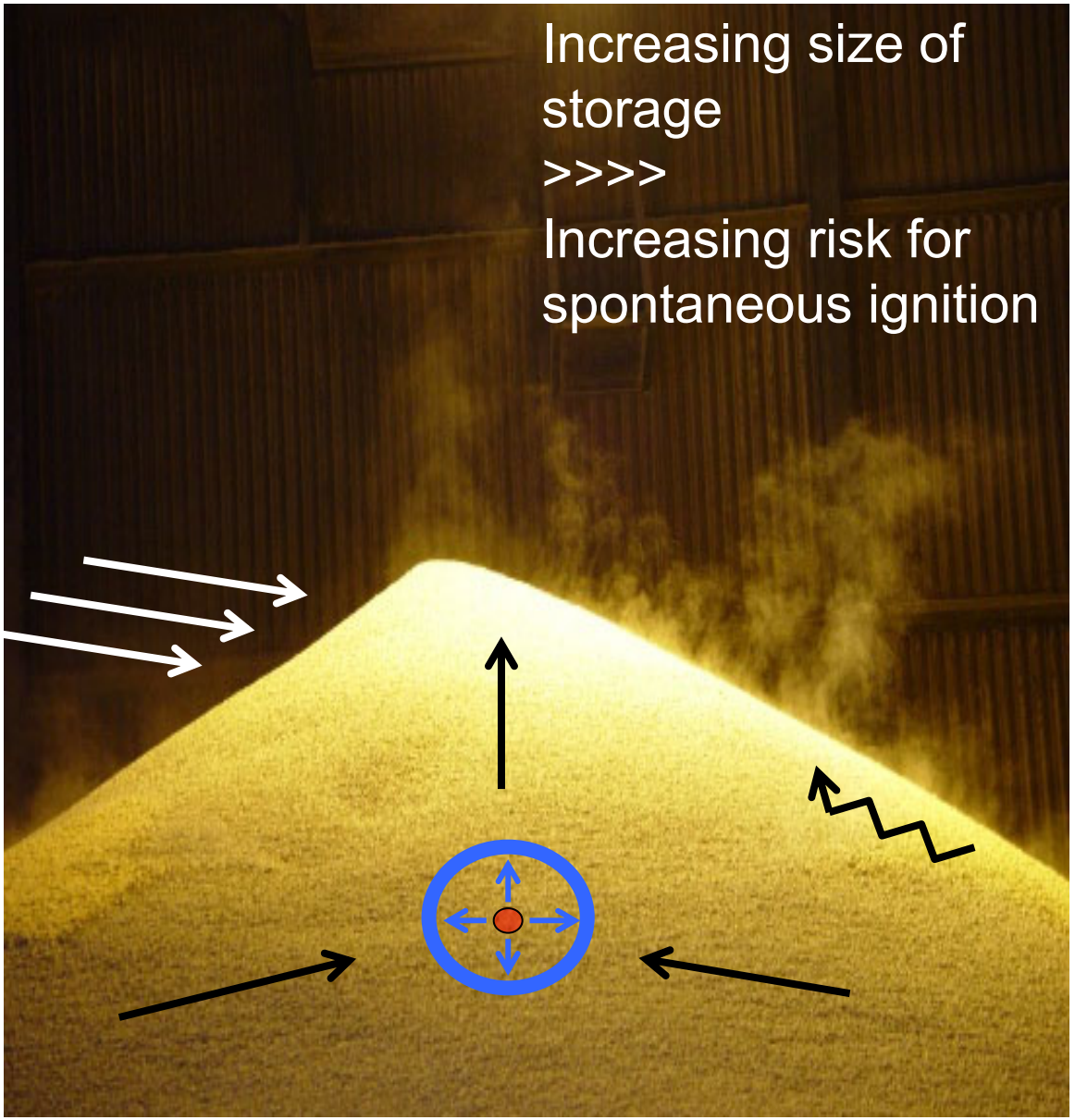
85 m high silo, 23 cells×2000 m^3

Spontaneous ignition

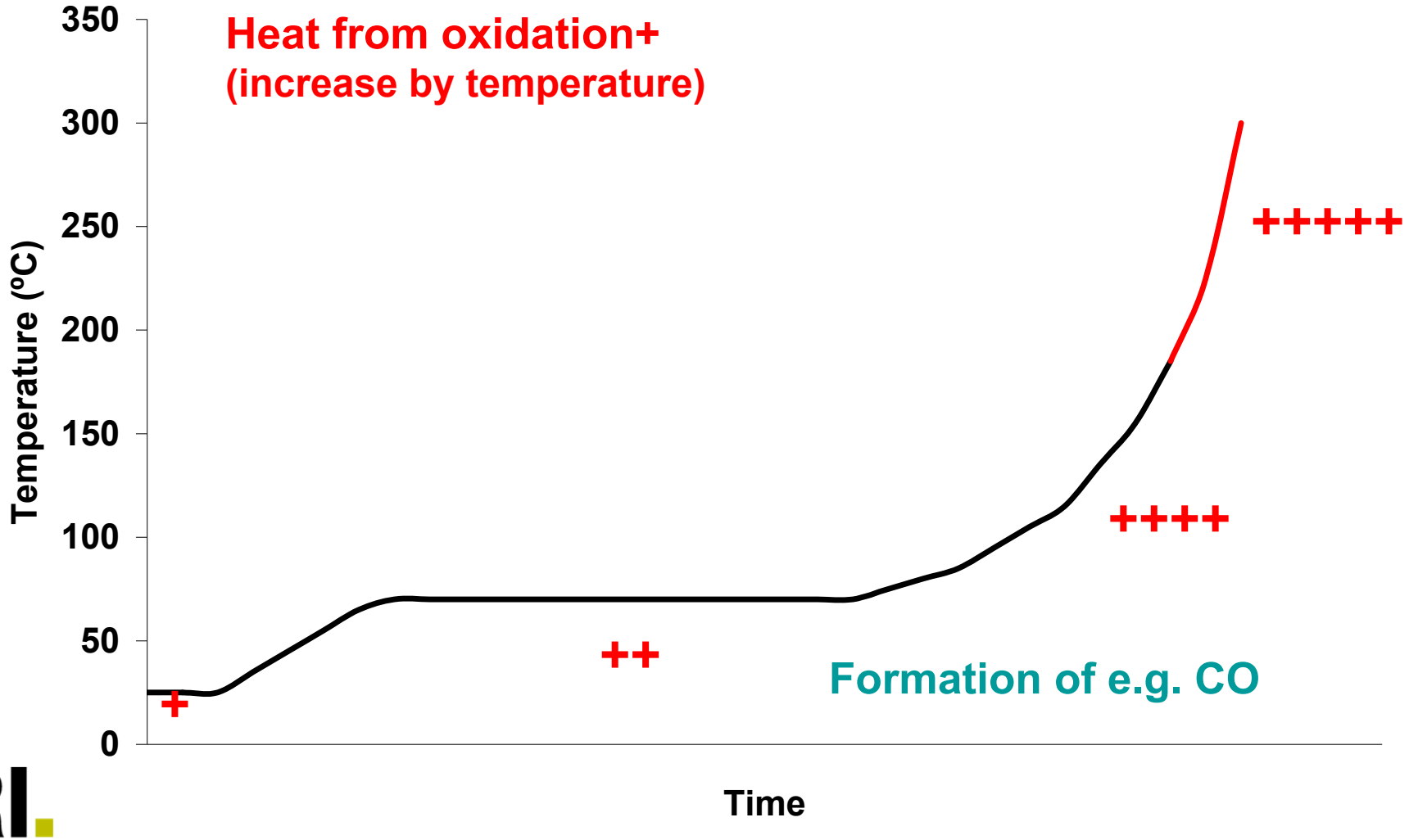
Non-successful extinguishment, complete loss of silo

Increasing size and complexity of storage

Self-heating and spontaneous ignition common cause of fires during storage



Self-heating and spontaneous ignition



Self-ignition!

Self-heating in wood pellets

- Microbiological activity generally not significant (as in e.g. piles of wood chips)
- Heat from oxidation of wood constituents
- Oxidation of unsaturated fatty acids proposed to be major heat source
- Self-heating often seen shortly after production
- Some fuel qualities show higher heating activity and can during unfavorable conditions lead to spontaneous ignition

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Silo fire tests in laboratory scale

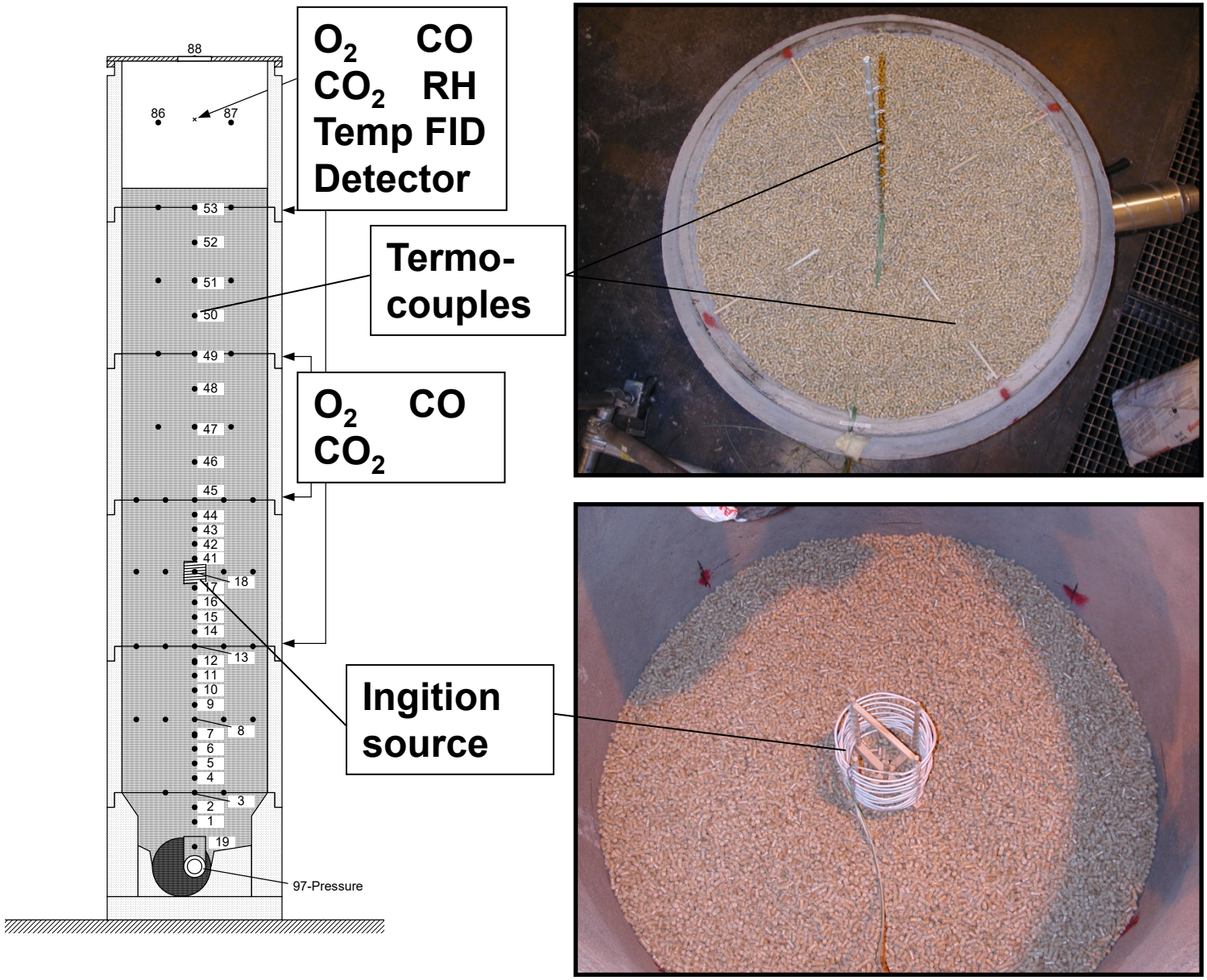
- Further silo fires resulting in total loss
- Need to understand the fire development in a silo fire
- Verify the extinguishing process using gas injection at silo base
- Wood pellets used as bulk material
- Co-funding from WPAC

- Silo fire in 3 of 5 silos
- Filled with wood pellets.
- Spontaneous ignition
- Total loss

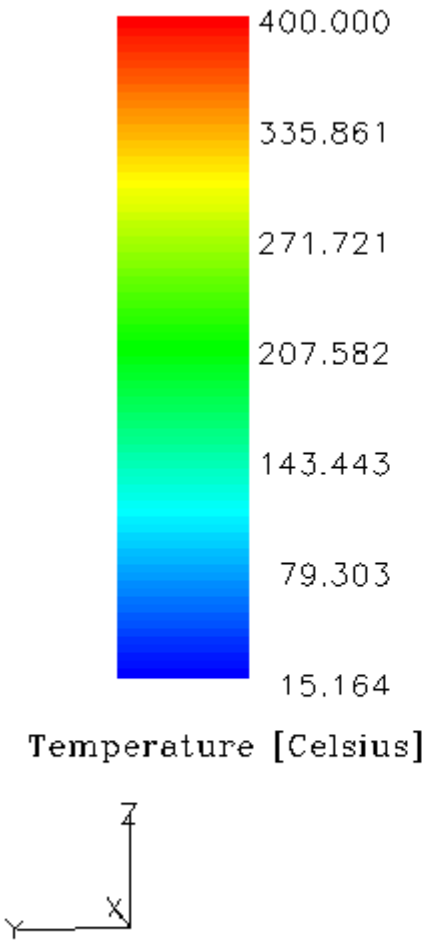
Silo fire tests in laboratory scale (2006)

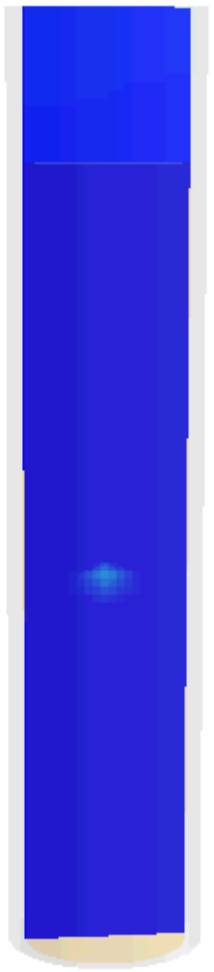
- 1 m in diameter
- 6 m high

Test arrangement and instrumentation



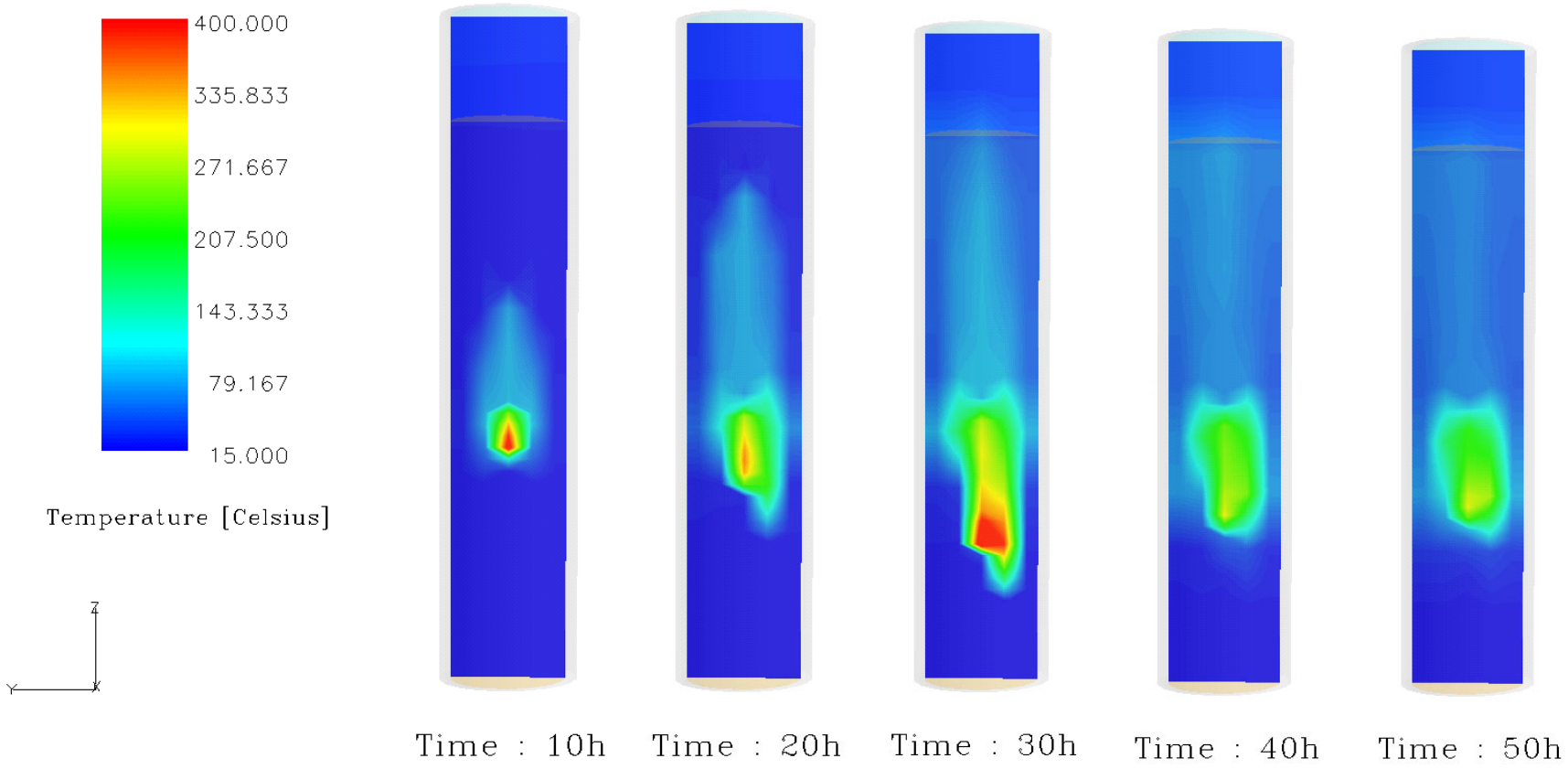
Temperature- (and gas) distribution in the silo



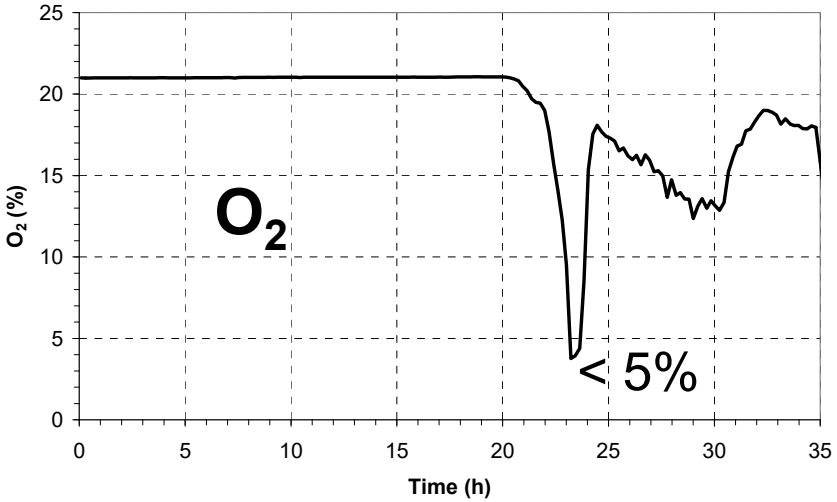


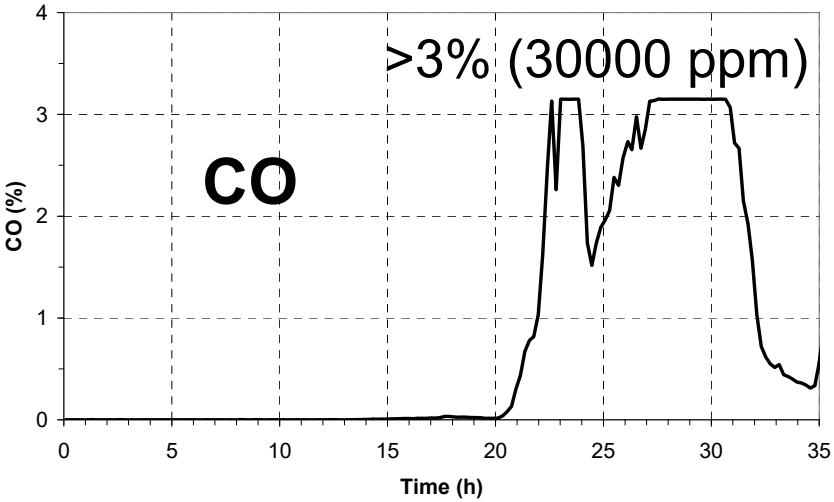
Time : 1h

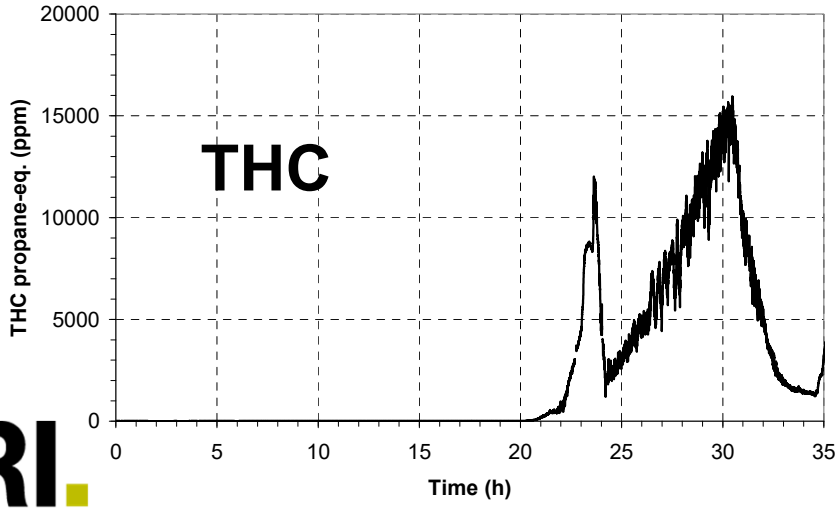
Temperature- (and gas) distribution in the silo

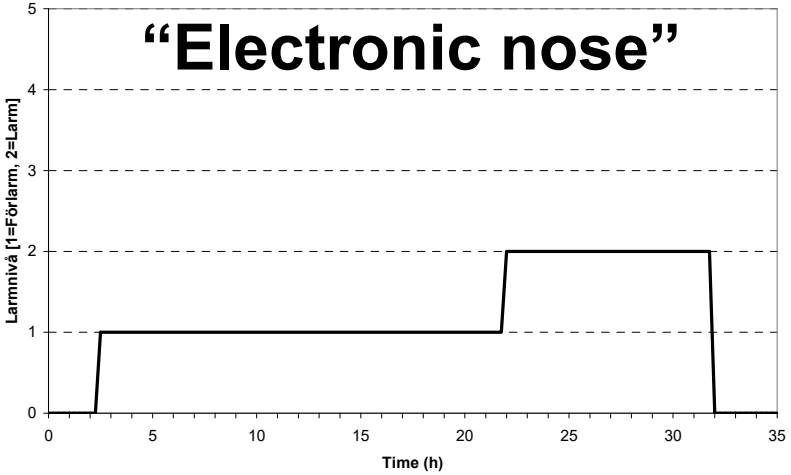


Detection in the silo headspace – possible after >20 tim



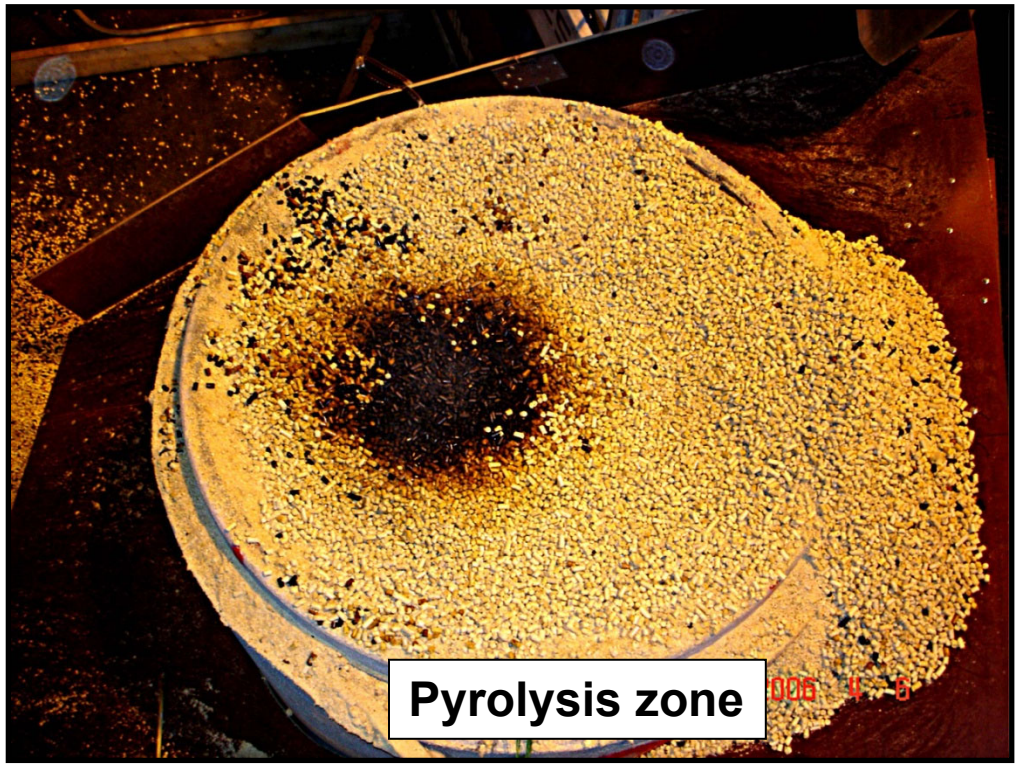






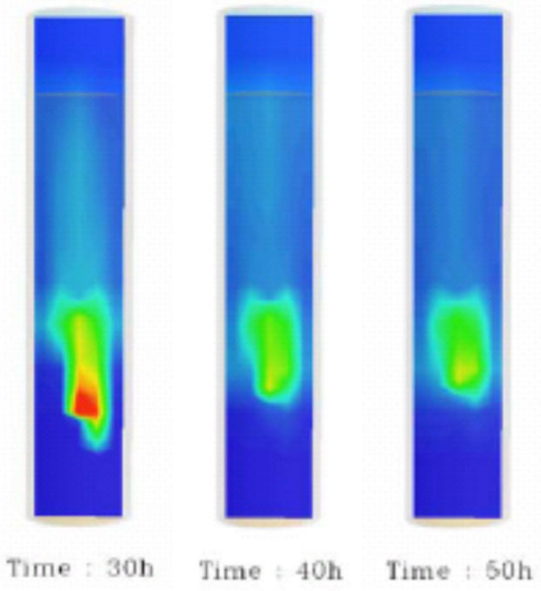
Time scale 0-35 h

Observations after the test



Conclusions from extinguishment tests

- Control of smouldering nest within some hours in an airtight silo
- Total extinguishment shall not be expected
- Gas injection at the silo base provides a possibility that the entire bulk is flushed with inert gas
- Creates a possibility to monitor the extinguishment in the silo headspace
- Proposed dimensioning
  - 5-10 kg/m^2 h
  - 5-15 kg/m^3



Personal safety considerations

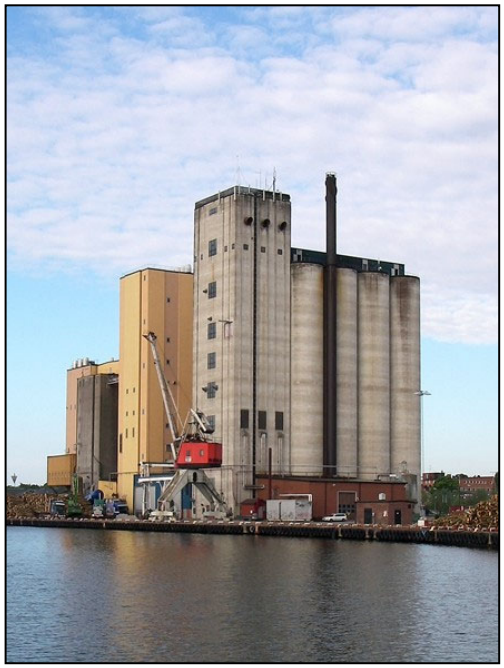
Typical concentrations measured in silo premises

Carbon monoxide:

- **Often >100 ppm (max 15 min exposure-Sweden)**
  In some cases >1000 ppm
- **Inside headspace, oxidation 0,5 - 1 % (5000-10000 ppm)**
- **Inside headspace during fire 3 - >10 %**
  1,4 % deadly within 5 minutes

Oxygen:

- **Low oxygen conc., 0-10% during fire**
  7 % incapacitation < 1 minute



Personal safety considerations

Measure oxygen and carbon monoxid (CO)

Combination of high CO-concentration and
low oxygen concentration extremely dangerous

- Not enought to measure oxygen concentration!
- Use personal measuring instruments/detectors

Personal safety considerations

Risk for gas and dust explosions

- Large amount of pyrolysis gases inside silo headspace
- Probably lack of oxygen
- Dispersion of accumulated dust layers
- Possibly exposed ignition source
  - If a hatch is opened, the combustion gases will be mixed with oxygen and form a flammable gas mixture
  - If ignition source is availabe (glowing, electrical equipment, static electricity) this might ignite the flammable gas

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CO flammable between 12,5-74%

Do not use carbon dioxide!

- **Generation of static electricity during discharge- might cause gas explosion in silo headspace!**

- **Might form combustible gases** (carbon monoxide and hydrogen) at 650-700 ºC in atmospheres with lack of oxygen and availability of pure carbon and water

$$C+CO_2 <<>> 2\ CO$$

$$C+H_2O <<>> H_2+CO$$

- Ice formation in pipes if pressure is below 5,2 bar
- Vaporizer require a powerful heat source

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Gas and dust explosions

Small silos as dangerous as large silos!

Safety considerations during silo fires

Think twice before action!

It may be better to do nothing at all for the moment

The goal is a safe fire mitigation operation

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Silo firefighting strategy

Preplanning is half the work!

- Preplanning of emergency operation in cooperation with the fire brigade and nitrogen gas/equipment provider
- Shall include a risk assessment for the firefighting operation
- Preparatory measures (will identify critical needs)
- Risk assessment of the entire plant will also identify preventative measures

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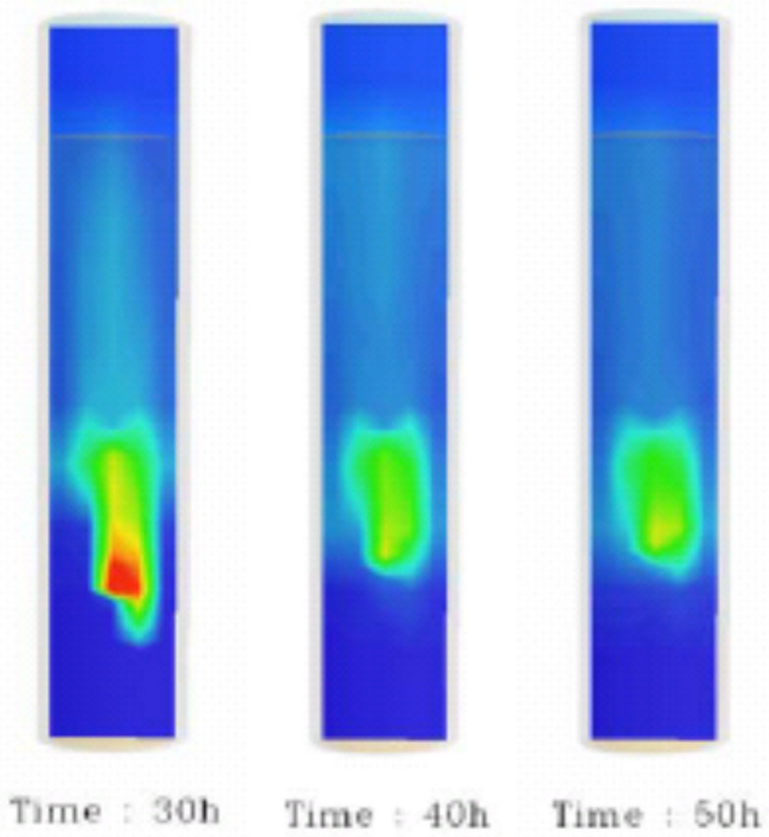
Silo firefighting strategy

Primary fire fighting tactics

- Inert the silo with nitrogen from the base of the silo
- If necessary, inject nitrogen to the silo headspace during the initial phase of the operation

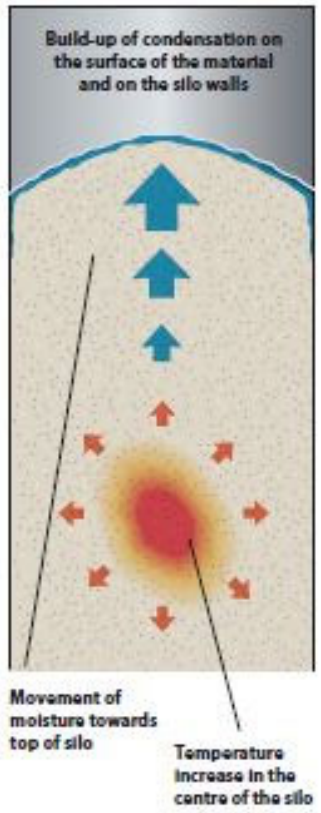
But first…..



Silo firefighting strategy

Identify the type of silo and possible fire scenario

- Type of silo, bulk material, degree of filling
- What observations has been done
- Self-heating situation or a verified fire
- Suspected surface fire of deep-seated smouldering fire
- Conveying systems connected to the silo
- Silo equipped with forced ventilation system



Silo firefighting strategy

Make a first risk assessment and establish rules for access

- Consider risk for high concentrations of Carbon monoxide (CO) or low concentrations of Oxygen (O_2)
- High concentrations might also occur in adjacent spaces, e.g. control rooms, staff areas
- Verify by measurement of both CO and O_2
- If any doubts, use full protective gear and a SBCA (self contained breathing apparatus)

Silo firefighting strategy

Scenario 1: Most likely a self-heating situation

- If possible, start discharge the silo to break-up the zone of warm material
- Measure CO and O_2 in the silo headspace
  - (requires an analysis instrument for high CO-concentrations (%-scale)
- Intensify the control of the discharged material
- If hot, miscoloured or smouldering material is noticed, stop discharge immediately and prepare for inerting the silo as soon as possible.

Silo firefighting strategy

Scenario 2: Verified fire, DO NOT OPEN THE SILO!

- Do not open the silo or try to discharge without having the fire under control. There is a significat risk for a gas- and/or dust explosion and an uncontrolled fire escalation.

Silo firefighting strategy

DO NOT OPEN THE SILO!

Silo firefighting strategy

DO NOT OPEN THE SILO!

One Person Dead and Three Injured in Dust Explosion at Woodworking Plant

Date: January 24, 2019
Location: Anzegem, West Flanders (Belgium)
Address: Nijverheidslaan 9, 8570

Type: Dust Explosion

Fuel: Wood Dust
Industry: Door and Window Manifacturing (Wood Products)
Equipment: Silo

Company: Groep Pouleyn
Database Incidents: None Recorded

Loss: One Dead, Three Injured
Capital Cost: Unknown

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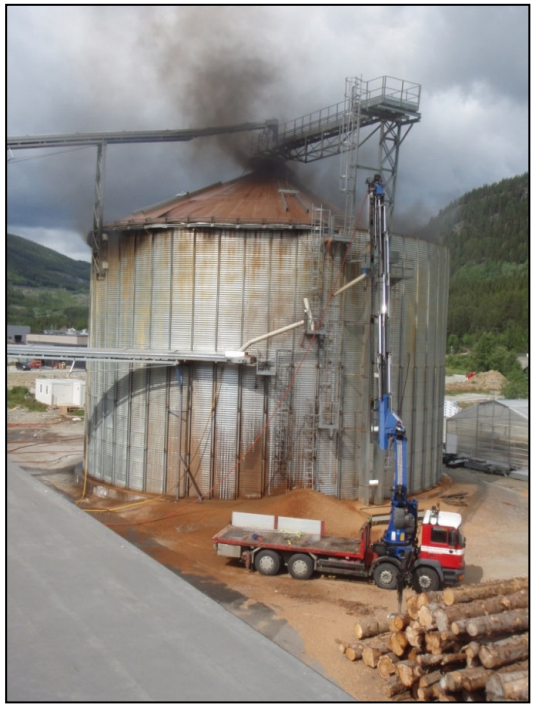
DUST SAFETY SCIENCE.COM

Silo firefighting strategy

Make a first risk assessment and establish rules for access

Risk for gas- and/or dust explosion

- If there is a verified fire with smoke development, significant water condensation from the silo headspace, etc., the risk for a gas explosion in the silo heaspace should be considered as high
- Avoid work at the silo top
- Consider to increase the risk area at ground level
- Consider inerting of the silo headspace



Silo firefighting strategy

Minimize air entrainment into the silo

- Shut down any ventilation system, close/seal all openings
- During nitrogen injection, ensure there is a pressure relief arrangement at the silo headspace, while preventing inflow of air.
- If the silo has an superstructure, the smoke gases should be guided outdoors if possible (contains a lot of tar)

Think of a kettle barbecue!

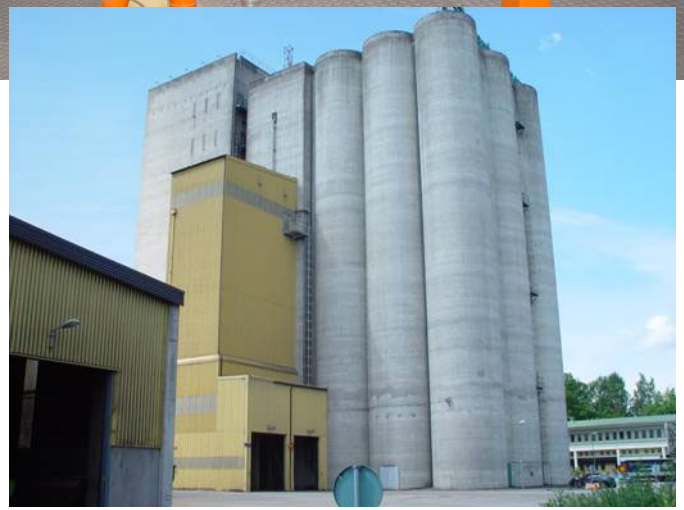
Silo firefighting strategy

Minimize air entrainment

- Shut down any mechanical ventilation
- Close/seal all ventilation openings/leakages
- Close/seal inlet and discharge valves

Silo firefighting strategy

Minimize air entrainment



Silo firefighting strategy

Request nitrogen and gas evaporator equipment

- Arrange delivery of liquid nitrogen, gas evaporator and a cryogenic tank
- The evaporator unit is required to evaporate the liquid nitrogen before injected into the silo
- The cryogenic tank facilitates a continous inerting during the entire suppression and discharge operation
- Arrange the equipment in a safe location and avoid blockage of neccesary transports, e.g. during the discharge process
- Consider a fixed gas system or establish a mutual aid organisation if supply of equipment and gas is a problem

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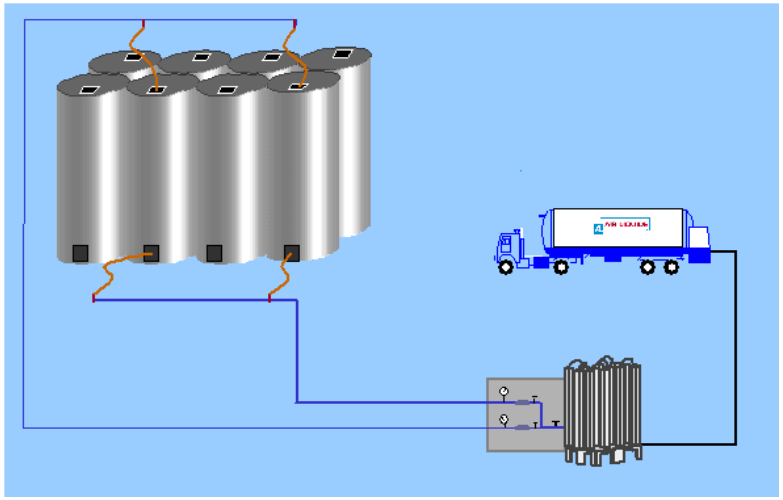
Silo firefighting strategy

Tanker truck, a cryogenic tank and an evaporator equipment for a continous supply of inert gas

Silo firefighting strategy

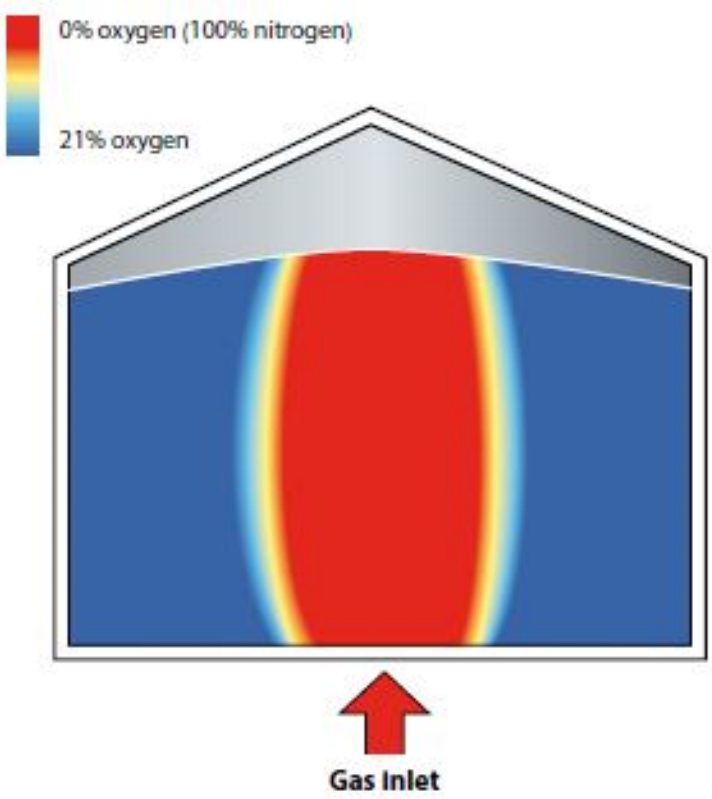
Prepare for inerting at the silo base (and possibly the silo headspace)

- Gas injection at the base of the silo provides the safest and most effective inerting operation.
- An gas injection rate of 5 kg/m^2 h, provides a filling velocity of approx. 8 m/tim at 50% porosity
- Calculate for a total gas consumption of at least 5-15 kg/m^3 (gross volume)

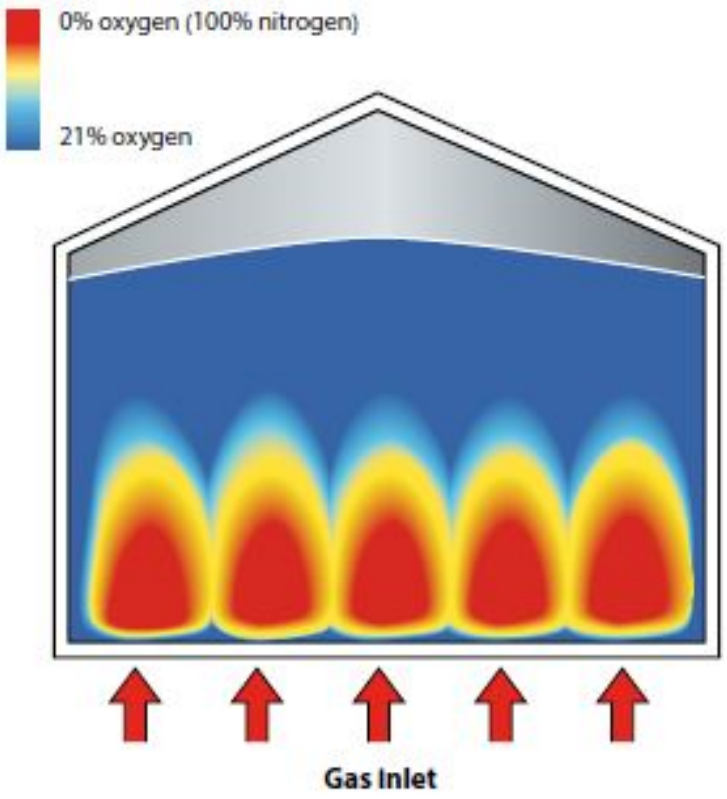


Gas distribution in large diameter silos

- Gas injection will create problems at large diameter silos without a fixed gas distribution system



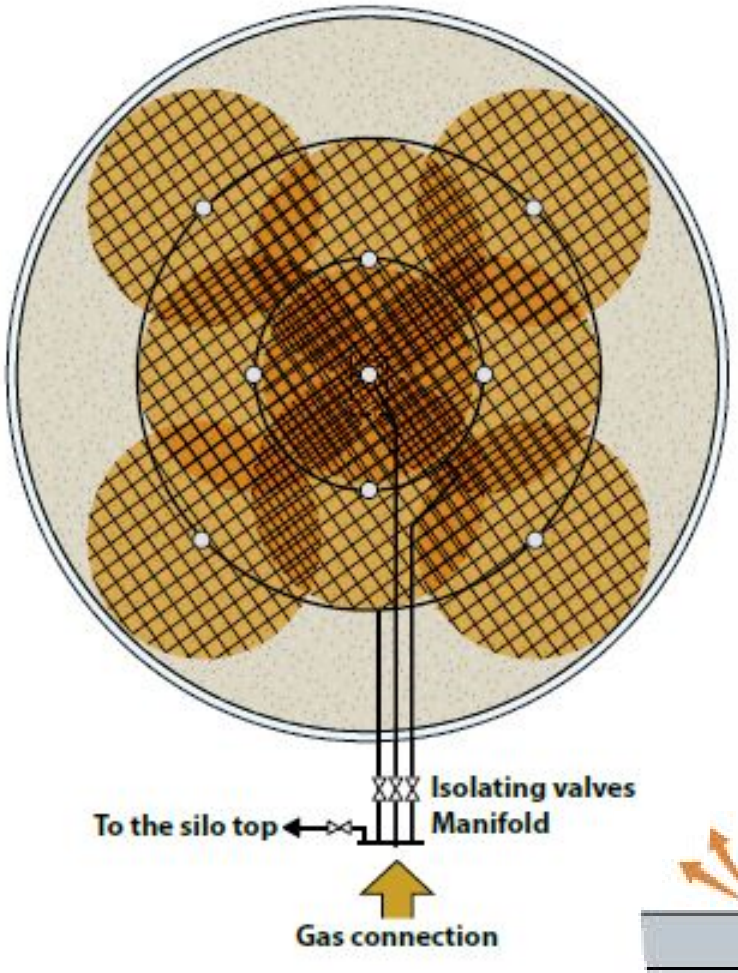
Single gas inlet

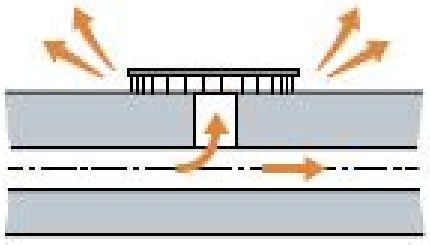


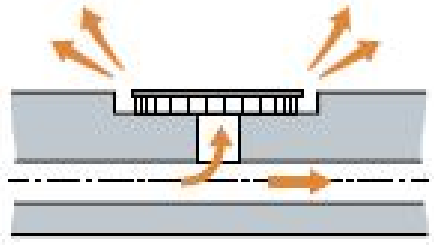
Distributed gas inlets

Gas distribution in large diameter silos

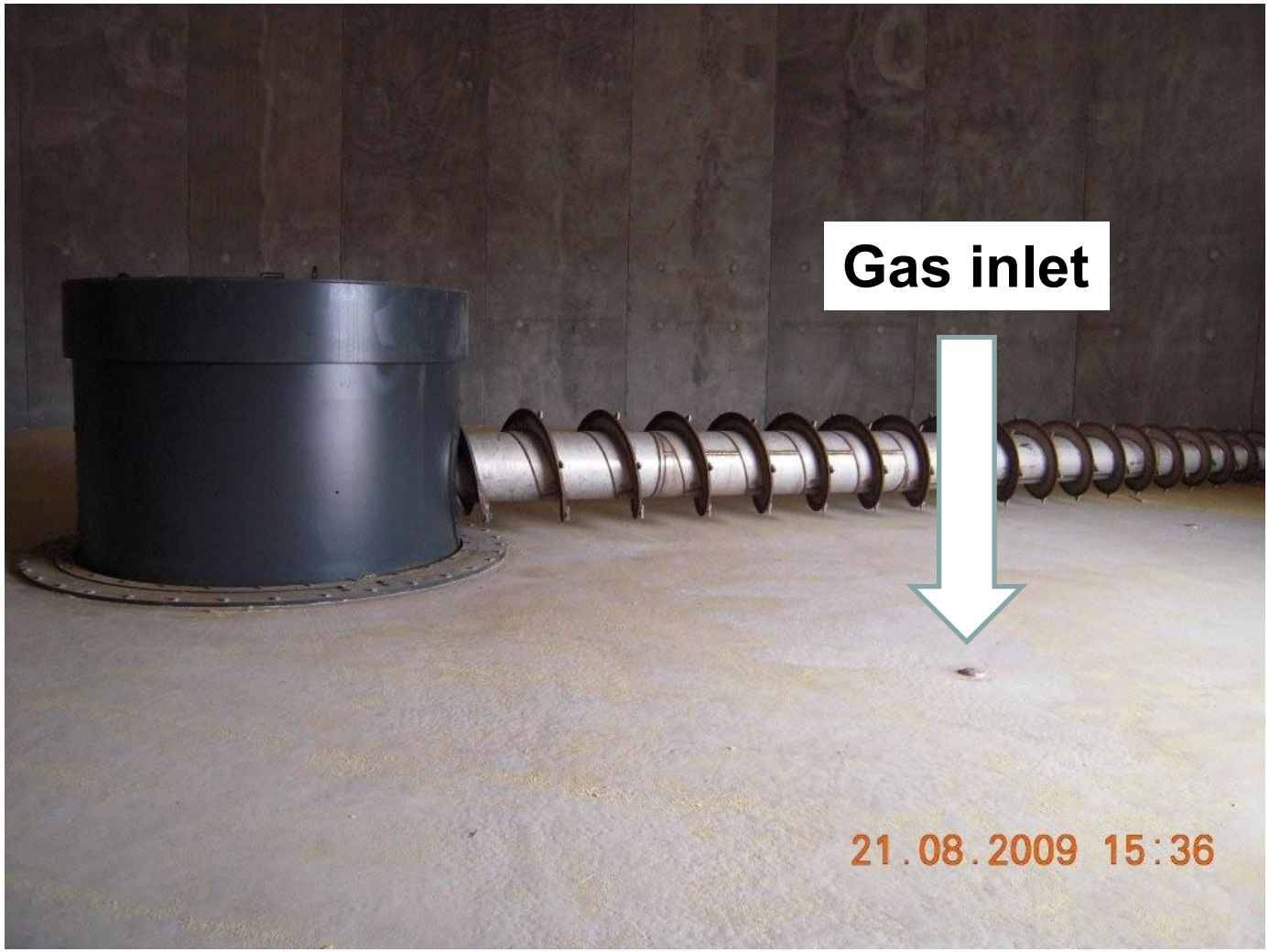
Diagram of gas supply system



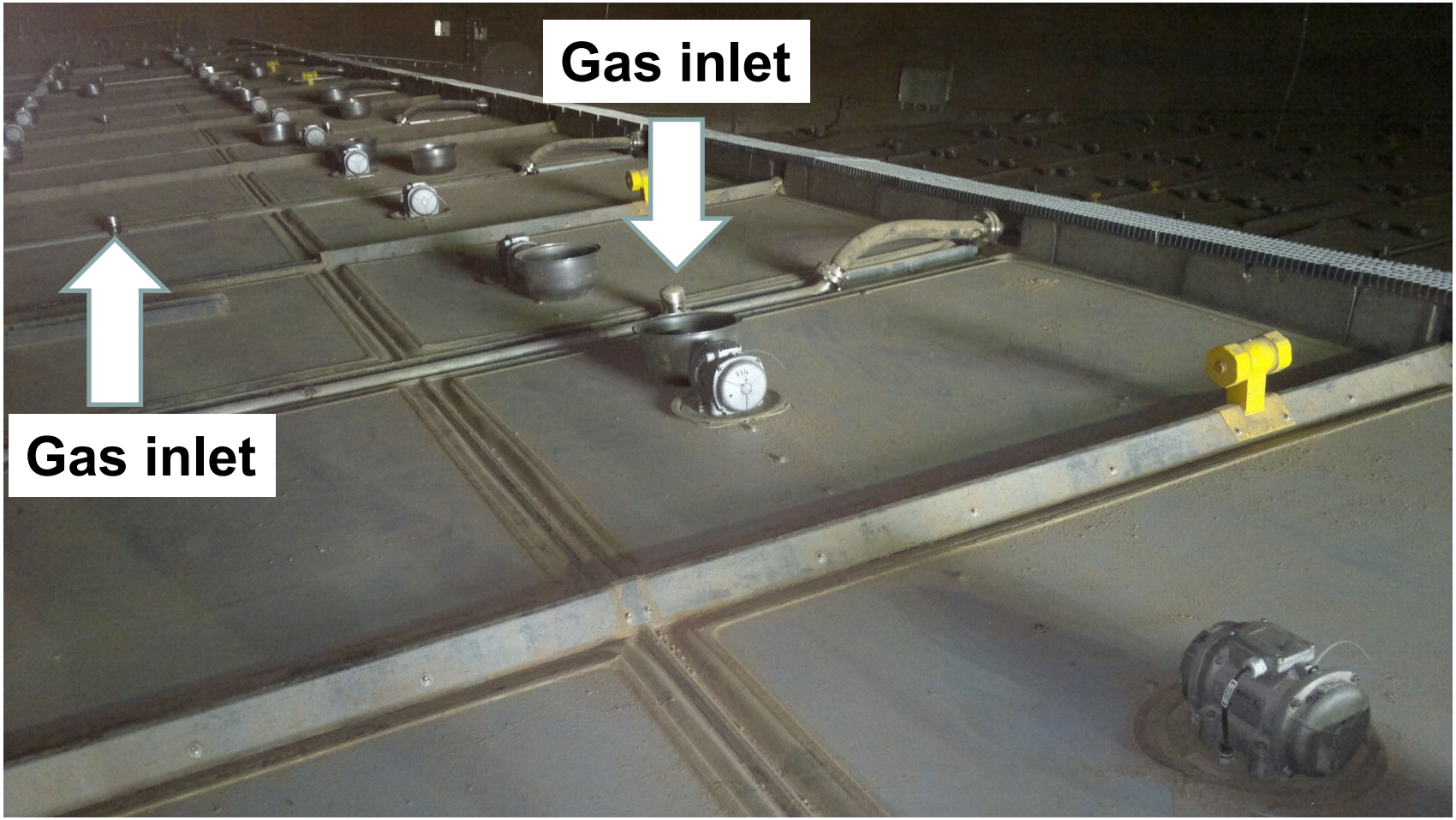




Gas distribution in large diameter silos

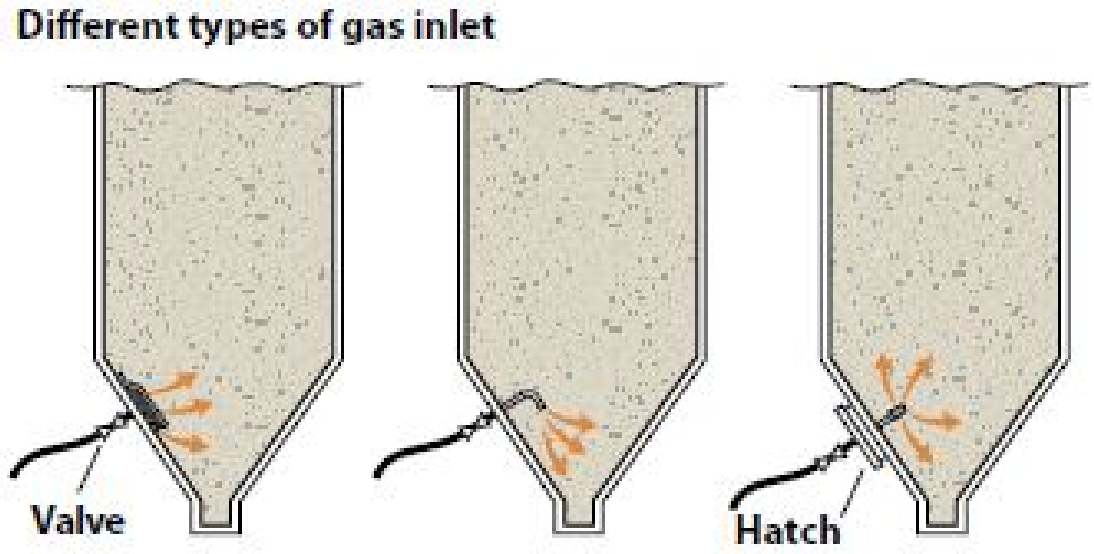


Gas distribution in large diameter silos



Gas injection in small diameter silos

- Do not locate the inlet directly along the silo wall



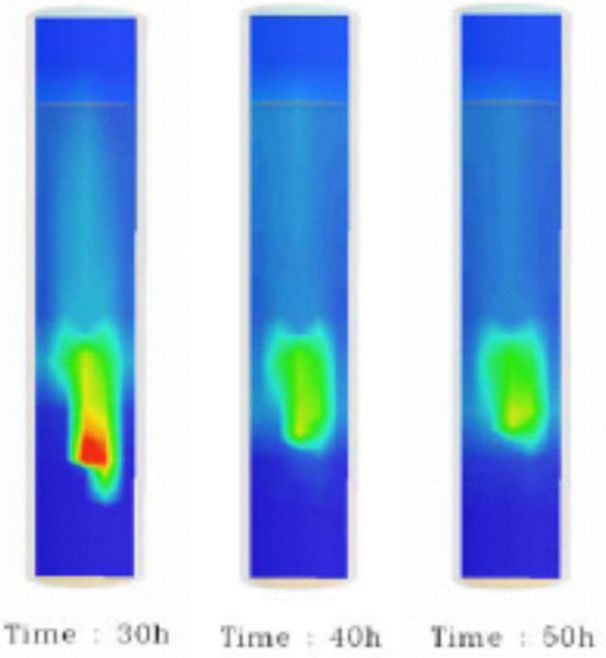
Gas injection in small diameter silos

- If the silo is not prepared for gas injection, manufacture one/several lances and arrange perforations in the silo wall for the lances at suitable locations
- Will create problems at large diameter silos
- Safety aspects!

Silo firefighting strategy

Measure gas concentration and temperature in the silo headspace (if possible)

- Gas (CO och O_2) and temperature measurements to monitor the fire suppression process
- Provides a basis for a continued risk assessment, also during the discharge operation
- Gas analyzer capable of measuring very high CO concentrations (min 10%=100 000 ppm)
- Fixed samplingsline to ground level



Silo firefighting strategy

Start gas injection as soon as possible

- A low flow rate of gas can often be extracted directly from the gas truck
- **If significant risk** for explosion or open fire in the silo headspace (e.g. high oxygen content) injection if nitrogen into the silo headspace should be considered
- Start gas injection at the base of the silo at a flowrate of 5 kg/m^2 h (lower for wood dust).
- Allow the gas injection to continue and monitor the suppression process visually and by measurements in the silo headspace.

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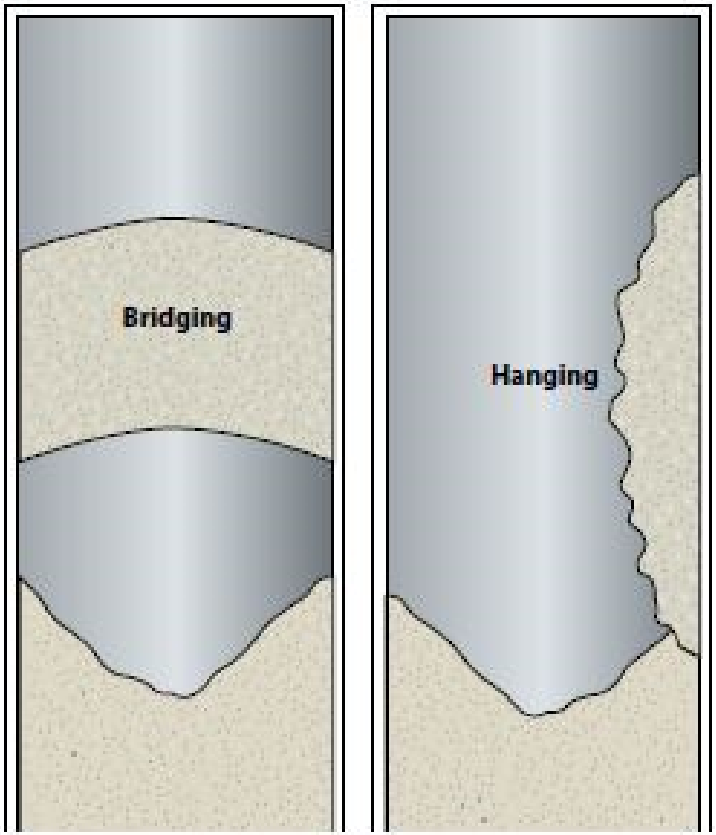
Silo firefighting strategy

Start the discharge when the silo is completely inerted and the smouldering fire is judged to be controlled.

- The oxygen content in the silo headspace should be below about 5% and the concentration of CO significantly reduced.
- The conditions shall be monitored during the entire discharge process
- Firefighting personell with full protective gear and SCBA should preferably control the discharge process along the entire conveying system

Silo firefighting strategy

- Smouldered material might ”glue together” and block discharge openings
- Check for hangings or bridging inside the silo



Silo firefighting strategy

Discharge might take several days or even weeks

- Calculate for a maximum discharge rate only 25-50% of normal capacity (often even far lower)
- Plan for exchange of personal, need for large number of air bottles for the SCBA-units, etc.
- Injection of nitrogen should continue during the entire discharge process, although the gas flow rate could possibly be reduced.
- If located at a power plant, consider the possibility combust the non-affected material directly

Silo firefighting strategy

Large area required for handling of discharged material

- Monitor the discharged material for reignition
- Unload discharged material in elongated piles and if possible, try to sort non-affected material from discolored or charred material.

Silo Fire Suppression and Prevention Workshop-Part 1

Thank you, questions?