1000 FREDERICK LANE, MORGANTOWN, WV 26508 • 304.285.5916

Industrial Silo Fire and Subsequent Explosion Kills One Firefighter and Critically Injures Another - Iowa

Executive Summary

On January 5, 2019, an industrial silo fire and subsequent explosion killed a 33-year-old lieutenant and critically injured a 23-year-old firefighter. At 05:46 hours, Battalion 1 (B1), Ladder 54 (L54), Ladder 59 (L59), Engine 46 (E46), Ambulance 1 (A1), and Ambulance 2 (A2) were dispatched to a reported fire in the "germ pit" area of silo #2 at a corn processing facility. L54 and A2 were the first units on-scene at 05:52 hours followed by B1 at 05:53 hours. B1 established Command and set up the command post about 500ft upriver while L54 continued to silo #2 and performed a size-up. A unified command structure was developed at the command post between the fire department and facility representatives. Facility employees informed Command that contractors had been working to remove an obstruction in the silo before the fire was discovered. Size-up from L54 revealed a smoldering silage fire in the bottom of silo #2. A tactical plan was initiated deploying L54's 1¾-inch hoseline from the below grade conveyor area, directing the water up into the silo. This plan was ineffective as L54 crews observed that air was being drawn/sucked into the silo and there was still active fire inside. This effort was abandoned at 06:42 hours and an alternative plan was developed involving flowing water through a 2ft-by-2ft access hatch on top of the silo using L54 as a standpipe and 50ft of 3-inch hose. At 07:55 hours, L54 was put into position next to the silo configuration and connected to the water supply from a hydrant. Command arranged the position of the firefighters for the operation as companies (CO1, CO2, and CO3) for task-level assignment and communication purposes. At 08:04 hours, a CO1 firefighter was positioned in L54's bucket to operate the standpipe, CO2 firefighters were positioned at

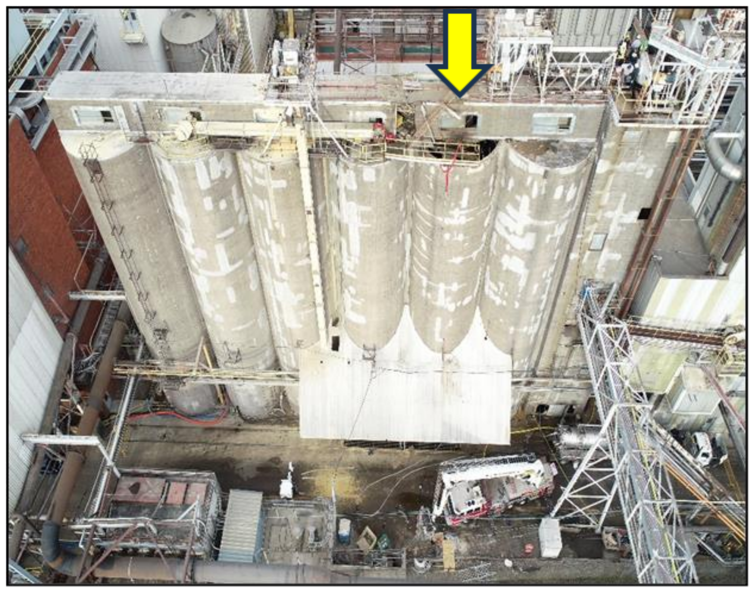

Photo 1: Six silos at a corn processing facility. Yellow arrow shows silo #2 whose top exploded approximately 3 hours after a corn pellet fire was discovered at the bottom of the silo.
(Courtesy of the fire department)

the bottom of the silo to monitor progress, and CO3 lieutenant (deceased firefighter) and CO3 firefighter (critically injured firefighter) were positioned at the top of the silo to flow water. At 08:44 hours, after ten minutes of flowing water into the top of the silo, the hoseline was moved around to saturate more product. This resulted in an explosion at the top of the silo which caused CO3 lieutenant to fall 85ft from the edge of the silo, landing on a fiberglass awning below, and then onto the ground. The explosion also catapulted CO3 firefighter into the air who then fell into silo #2, landing on the still smoldering pellets. After both were transported to the hospital, firefighting operations resumed, changing tactics multiple times, until the fire was fully extinguished at 15:15 hours. CO3 lieutenant died and the CO3 firefighter was hospitalized for three weeks before being discharged from the hospital on January 25, 2019.

Contributing Factors

- *Smoldering propagation due to chemical reaction/self-ignition of silage*
- *Emergency planning at corn processing facility*
- *Fire suppression tactics and pre-incident planning*
- *Explosion due to application of water through the top hatches of silo*

Key Recommendations

Fire departments should:

- *Train fire officers and firefighters on the hazards associated with different types of silos and the appropriate firefighting tactics, including any unique hazards posed by the silo contents.*
- *Develop a pre-incident plan for all high-hazard occupancies in their jurisdictions.*

Governing municipalities (federal, state, regional/county, and local) should:

- *Ensure the applicable fire and life safety codes are enforced at high-hazard occupancies such as agricultural and/or food processing facilities.*

Agricultural and/or food processing facilities should:

- *Properly operate and maintain their silos and implement the applicable requirements of NFPA 61, Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities.*

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Introduction

On January 5, 2019, an industrial silo fire and subsequent explosion killed a 33-year-old lieutenant and critically injured a 23-year-old firefighter. On January 30, 2019, the U.S. Fire Administration (USFA) notified the National Institute for Occupational Safety and Health (NIOSH) of this incident. On February 16 – 22, 2019, two investigators representing the NIOSH Fire Fighter Fatality Investigation and Prevention Program (FFFIPP) traveled to Iowa to investigate this incident. The NIOSH investigators conducted interviews with command officers, fire officers, firefighters, fire investigators, and other emergency personnel who were on-scene at the time of the incident. Also, NIOSH investigators inspected the personal protective equipment (PPE) used by the firefighters as well as other equipment used at the incident. The investigators reviewed fire department standard operating guidelines (SOGs), training records, dispatch records, witness statements, investigation documents, and the county medical examiner’s report.

Fire Department

The career fire department in this incident has a 36 square mile jurisdiction, serves a population of 26,500 residents, annually responds to an average of 4,600 calls, and provides emergency medical services (EMS). The fire department maintains three stations with each being designated as a company (e.g. Company 1). The jurisdiction is divided into territories for each station and the location of fire and EMS calls dictates which station responds per department SOGs and Box Alarm assignments.

The fire department is comprised of 45 uniformed personnel and maintains three shifts: A, B, and C. Each shift is staffed by 14 personnel, with a minimum of 11 on-duty per shift, across the three fire stations. Shifts operate on a 24-hour schedule from 07:00 to 07:00 the following day. Each shift is assigned one battalion chief, three lieutenants, five engineers, and seven firefighters. The fire department’s leadership contains a fire chief and two assistant chiefs who serve as the training/EMS director and the Fire Marshal/city safety director.

The fire department has four divisions:

- EMS division provides basic and advanced life support.
- Building & Neighborhood Services division provides fire and life safety inspections and enforcement of building codes for the jurisdiction as well as public education. This division utilizes both the 2018 International Building Code (IBC) and the International Fire Code (IFC) as part of the city’s building ordinances.

- Investigations division maintains several arson investigators to determine cause and origin of fires.
- Training division provides initial training and continuing skills development for all firefighters in accordance with NFPA 1001, fire officers, and EMS personnel.

The fire department and its operations are established by local ordinances. These ordinances include direction on auto-aid and mutual aid agreements, training, compensation, appointment and duties of the fire chief, designation of fire inspectors, and authorization to provide emergency ambulance and rescue services. The fire department has a comprehensive set of internal written policies and guidelines that provide direction for incident command, general incident responses, communications, emergency operations, and general administration.

Training, Education, and Professional Development

The fire department maintains a training division that provides initial training and continuing skills development for all firefighters, fire officers, and EMS personnel. The initial training for recruits consists of six weeks of daily academy type training for a total of 240 hours. Recruits are then given 50 hours of general knowledge testing, address tests, and skill drills that are completed during their first 10 months on shift. The fire department written policies provide professional development requirements for driver operators and other skills.

The fire department utilizes Iowa's requirements for recruitment, selection, promotion, and retention for all civil service classified employees. Local ordinance dictates the requirements for promotion to firefighter first class. This ordinance states that fire department employees shall obtain certification as a Fire Fighter I, Fire Fighter II, and Iowa paramedic before they can obtain promotion from probationary member. Local ordinance dictates that the fire chief shall be appointed by the city administrator with approval of the local council.

B1 (incident commander) had 27 years of total fire service experience at the fire department with the last eight years as battalion chief of B-Shift. He maintained training in the incident command system and held numerous certifications as Fire Fighter I, Fire Fighter II, Incident Safety Officer, Leadership I, Leadership II, Leadership III, Fire Investigator, Fire and Emergency Services Instructor, Fire Officer I, Fire Officer II, Fire Apparatus Driver/Operator Aerial and Pumper Apparatus, Iowa and Illinois State Emergency Medical Paramedic provider, and Iowa Fire Service Training Bureau Instructor/Evaluator.

CO3 lieutenant (deceased firefighter) had 12 years of total fire service with the department holding the ranks of firefighter, engineer, and lieutenant. He maintained training in the incident command system and held numerous certifications as Fire Fighter I, Fire Fighter II, Incident Safety Officer, Leadership I, Leadership II, Leadership III, Fire Investigator, Fire and Emergency Services Instructor, Fire Officer I, Fire Officer II, Fire Apparatus Driver/Operator Aerial and Pumper Apparatus, Iowa and Illinois State Emergency Medical Paramedic provider.

CO3 firefighter (critically injured firefighter) joined the department in November 2017 and at the time of the incident was almost two years on the job. He maintained training in the incident command system and held numerous certifications as Fire Fighter I, Fire Fighter II, and Iowa and Illinois State Emergency Medical Paramedic provider.

Apparatus, Staffing, and Communications

At 05:46 hours, the following units were dispatched for a fire in silo #2, the "germ pit" area, of the corn processing facility:

Apparatus	Staffing	Arrival On-Scene
Ladder 54 (L54)	3	05:52
Ambulance 2 (A2)	1	05:52
Battalion 1 (B1)	1	05:53
Ladder 59 (L59)	3	05:54
Ambulance 1 (A1)	1	05:54
Engine 46 (E46)	2	05:59

The county Public Safety Answering Point (PSAP) dispatches for eight EMS agencies, 17 fire departments, and four law enforcement agencies (three police departments and a sheriff's office). The PSAP is staffed by a communications director, a technical system manager, and 16 telecommunicators which include shift supervisors. At the time of the incident, the PSAP operated a VHF (analog) system with one repeater. However, the PSAP also operates tactical fireground channels that are not repeated or recorded due to ranges. The fire department has nine apparatus that are equipped with mobile repeaters as areas of the jurisdiction have limited radio coverage. Fire departments are dispatched on two channels.

Silo Construction, Characteristics, and Maintenance

Silos are used for the preservation, storage, and disbursement of organic materials such as foodstuff. Silos can also be used for storage of materials such as coal and powdered mixes. There are three types of vertical or upright silos in the agricultural industry [Murphy and Arble 2000; Arble and Murphy 1988; NIOSH 2012].

1. **Conventional silos** are typically constructed of concrete staves with pretensioned steel hoops. They can also be constructed of brick, glazed tiles, and wood. They either feature a fabricated domed roof for weather protection or are open at the top. They often feature an external unloading chute with their silage unloaded from the top.
2. **Oxygen-limiting silos or "sealed" silos** have design features to limit the exposure of the silage to outside air which creates an oxygen deficient environment inside. They are often constructed of poured reinforced concrete, concrete staves, or enamel-coated steel. They do not have outside chutes and typically have bottom unloaders that remove the silage from the bottom using augers and conveyor systems. Fill and unloading hatches are sealed with clamps and gaskets to limit airflow.
3. **Modified oxygen-limiting silos** are those that were used as an oxygen-limiting silo but have been converted to a conventional silo.

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Based on the construction and limited access points for oxygen, the NIOSH investigators believed the incident silo to be oxygen-limiting or "sealed".

Incident Silo Characteristics

The corn processing facility used six side-by-side silos (**See Photo 1**) for temporary storage of products and byproducts prior to loading onto river barges for transport. The silos were 94.5ft tall, 24ft in diameter, and each could hold up to 500 tons of product. The rebar-reinforced concrete walls were 13-inches thick, and a 7-inch concrete "cap" covered each silo. Silos #1 and #2 contained corn gluten feed pellets, silos #3 through #5 contained a "germ" product, and silo #6 contained earthen material in silica form (**See Diagram 1**). At the time of the incident, silo #2 contained only two to four tons of corn gluten feed pellets.

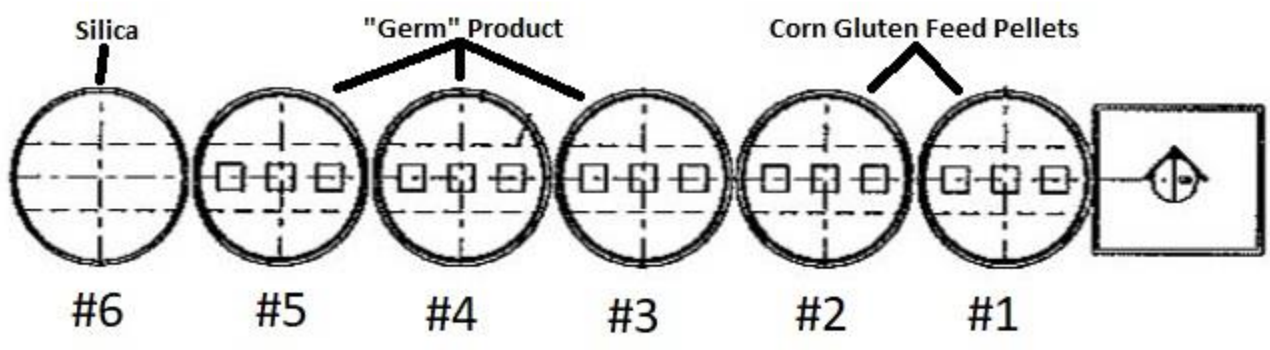

Diagram 1. Silo configuration from above with labeled silage.
(Courtesy of the fire department)

The six silos were connected by two conveyor systems: one above and one below the silos. The conveyor system above the silos was a raised hallway known as a headhouse that moved product into each silo [Exponent 2019]. The headhouse for silo #2 (the incident silo) had two access hatches that measured 1ft-by-1ft, and a slide gate for conveyor discharge that measured 2ft-by-2ft. The conveyor system underneath the silo (a conveyor tunnel) moved products from the silo to the river barges for transport. Silo #2 contained three lower discharge slide gates, each measuring 8 inches-by-12 inches, flowed products onto the conveyor tunnel. Each slide gate also had an access/inspection port. Silo #2 also had a side access hatch (2ft-by-3ft) which was approximately 13ft off the ground [Exponent 2019]. Finally, there was a fiberglass awning on the river-facing side of the silo configuration which spanned from silo #2 to #4.

Recent Silo Maintenance

Three months prior to this incident, the corn processing facility discovered an agglomerated mass of pellets, known as a "bridge," that was approximately 15 – 20ft thick near the bottom of silo #2. The bridge hindered the flow of the corn gluten feed pellets from the silo to the lower discharge gates. Over a three-month period, the facility hired several contractors to remove the pellet bridge and clean the silo. These contractors used a series of methods to break-up the bridge including high pressure air, drills, and water hoses. The residual water and product were vacuumed out of the lower conveyor system by a suction truck. The contractors were successful in reducing the size of the bridge but were not able to completely remove it.

On January 4, 2019, the contractor crews reportedly left the side access hatch of silo #2 open overnight. When the contractor crews returned on the morning of the incident, they reported observing white smoke pushing out and smoldering/burned material falling from the discharge slide gates. Upon arrival of the facility supervisor, they entered the conveyor tunnel and discovered over 6ft of burning product from the bottom of the silo to the floor of the tunnel. The facility supervisor notified security to call 9-1-1 to report a fire in the germ pit area.

Incident Timeline

The following timeline is a summary of events that occurred as the incident evolved shortly after 05:30 hours on Saturday, January 5, 2019. Not all incident events are included in this timeline. The times are to the minute and were taken from the fire departments' *National Fire Incident Reporting System* (NFIRS) fire reports, dispatch log, on-scene accountability documentation, and interview notes.

Time January 5, 2019	Fireground Operations, Response, and Details
05:30 – 05:44 Hours	• Contractor crews discover white smoke pushing out and smoldering/burned material falling from the discharge slide gates of silo #2. • Facility notified and directed security to call 9-1-1.
05:45 Hours	• PSAP receives a 9-1-1 call from a security guard at the corn processing facility reporting a fire in the "germ pit" area of the refinery.
05:46 Hours	• Fire units are dispatched to the corn processing facility for a report of a fire in the "germ pit" refinery area. • B1, L54, L59, E46, A1, and A2 dispatched.

05:52 Hours	• L54 and A2 arrives on-scene.
	  • Escorted to incident area by facility security.
	  • L54 begins a scene size-up with facility employees.

05:53 Hours	• B1 arrives on-scene. • Establishes Command and sets up the command post 500ft away from the incident silo.
05:54 – 06:08 Hours	• A facility supervisor debriefs Command on the incident. • Command requests A1 to report to command post and perform incident accountability. • Command requests all fire units on-scene to switch to Fireground #3 tactical channel for incident communications. • Command, fire units, and facility employees decide on plan to flow water into the silo from a bottom access/inspection port.

Time	Fireground Operations, Response, and Details
	• L54 deploys a 1¾-inch hoseline to the bottom of the silo and begins flowing water.
06:21 Hours	• Water supply secured by L59 and E46 from hydrant to L54 using 300ft lay of 5-inch supply line.
06:36 Hours	• Facility command requests the contractor crew to bring their suction truck to the incident area to remove the water and extinguished product from the conveyor tunnel where the L54 crew is working.

06:42 Hours	• Command requests a status report.
	  • L54 looks into the silo and observes air being drawn/sucked in and that there is still active fire inside. L54 responds to Command that they do not think the water application is working.
	  • Handline is shut down and L54 exits the conveyor tunnel.
	  • L54 noted that a side access hatch was present on the river-facing side of the silo, about 13ft above the ground.
	  • Command asked the facility supervisor if this hatch could be used to flow water into the silo. The facility supervisor declined stating that it may be too dangerous.

06:47 Hours	• Contractor crew's suction truck arrives on-scene.
06:48 – 07:08 Hours	• Tactic changed to flowing water through an access hatch on top of the silo using L59. • Contractor crew's suction truck enters the incident area, stages parallel against the silo configuration, and begins to vacuum up the water and product that was running out of the bottom of the silo. • L59 is not able to reach the catwalk and is requested to be removed.
07:09 Hours	• Command develops new strategy to use L54 as a standpipe to allow a hoseline to apply water through top of the silo.
07:10 Hours	• Battalion 2 (B2) arrives on-scene due to shift change and is debriefed at the command post.
07:20 – 07:42 Hours	• Fire department shift change transpires with four firefighters arriving on-scene and four others leaving. • CO3 lieutenant (deceased firefighter) is one of the four firefighters who arrives on-scene.

Time	Fireground Operations, Response, and Details
07:55 Hours	• L54 put into position next to the silo configuration and reconnected to the water supply from the hydrant.

08:04 – 08:21 Hours	• Command arranges position of firefighters for the operation as companies (CO1, CO2, and CO3) for task-level assignment and communication purposes.
	  • CO1 in L54's bucket to operate the standpipe.
	  • CO2 at the bottom of the silo to monitor progress.
	  • CO3 lieutenant and firefighter flow water into top of silo.

08:22 Hours	• CO3 lieutenant and firefighter reach the catwalk.
	  • Light, lazy white smoke and aerosolized dust observed on top of the silo and coming from the headhouse.
	  • 50ft section of 3-inch hoseline without a nozzle connected to the standpipe in L54's bucket.
	  • The CO3 firefighters drop the hose into the access hatch and observe light, grey smoke pushing out of the hatch but no heat.

08:28 Hours	• CO3 lieutenant and firefighter radio to Command that they are in position and request their hoseline to be charged. • After beginning to flow water into the silo, the surrounding smoke and dust begin to suck back into the silo.
08:34 Hours	• Command transfers from B1 to B2 with all fire units notified of the change by radio. • B1 departs the scene. • CO2 firefighters enter the conveyor tunnel and note warm water flowing from the bottom of the silo.
08:44 Hours	• CO2 firefighters check the conveyor tunnel again and note that the water is now cool with no smoke or steam observed. • They radio CO3 lieutenant for a status check on the top of the silo. • An order is given to move the hoseline around to saturate more product. • Upon moving the hoseline, CO3 lieutenant observes a puff of smoke.
08:45 Hours	• A very loud low tone compression/explosion sound is heard from the top of the silo. • CO2 firefighters hear a sudden roar from above and observe a pressurized "white-out" of steam and white smoke in the conveyor tunnel. • Concrete debris begin to rain down in the incident area.

Time	Fireground Operations, Response, and Details
	• Command observes CO3 lieutenant fall from the edge of the silo, land on the fiberglass awning below, and then onto the ground. ◦ A CO2 firefighter immediately performs patient assessment and resuscitation efforts while a Mayday is called.

08:49 Hours	• Command requests an additional ambulance be sent to the scene and an emergency medical helicopter.
	  ◦ Command updates the PSAP that CPR is in progress for a firefighter who experienced a fall from height.
	  ◦ CO3 lieutenant transported to a local hospital.
	• Accountability performed which identifies the CO3 firefighter as missing.
	• CO2 firefighters respond to the top of the silo area to search for CO3 firefighter with nothing found.

08:51 Hours	• B1 receives a telephone call from the facility command requesting him to return.
	  ◦ B1 briefed on the situation by the facility command.
	  ◦ Command transferred from B2 to B1.

08:52 – 09:26 Hours	• Contractor crew members, firefighters, and B2 open a side access hatch on silo and observe CO3 firefighter, semi-conscious, sitting on silage on the opposite silo wall from the access hatch.
09:27 Hours	• Command requests a second ambulance and helicopter for a fall victim who they were extracting from inside the silo. • CO3 firefighter crawls to the opening, is secured in a stokes basket, is lowered to a stretcher of a waiting ambulance, and transported to a landing zone.
09:31 – 15:15 Hours	• Additional fire units from a mutual aid department arrive on-scene and begin firefighting operations, changing tactics multiple times until the fire is fully extinguished.
15:27 Hours	• Incident declared under control, fire investigators on-scene.
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14:24 Hours	• All units cleared from the corn processing facility.

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Personal Protective Equipment

At the time of the incident, both firefighters were wearing full structural firefighting turnout gear. Both firefighters were wearing a NIOSH Approved® MSA Model G1, 45-minute, 4500 psi SCBA. The SCBAs were taken to the NIOSH's National Personal Protective Technology Laboratory (NPPTL) in Morgantown, West Virginia for evaluation and testing. Testing was conducted on February 26, 2019. No evidence was identified to suggest that the SCBA units inspected and evaluated contributed to the fatality or near miss. NIOSH determined that there was no need for corrective action with regards to the approval holder or users of SCBAs manufactured under the approval numbers granted to these products [NIOSH 2019]. The entire evaluation, NPPTL Report Number TN-22941, is available on the NIOSH website.

Weather Conditions

At 05:52 hours on January 5, 2019, the outdoor temperature was 32°F, dewpoint was 32°F, the wind was out of the southwest at 5 mph, there had been no precipitation in the last 24 hours, and conditions were fair [Weather Underground 2019].

Investigation

At 05:45 hours, the PSAP received a 9-1-1 call from a security guard at the corn processing facility reporting a fire in the "germ pit" area of the refinery. The security guard requested responding fire units meet him at the main entrance and they would be escorted to the incident area of the facility.
At 05:46 hours, B1, L54, L59, E46, A1, and A2 were dispatched to a fire in silo #2, the "germ pit" area of the corn processing facility. L54 and A2 arrived on-scene at 05:52 hours and were escorted to the incident area by a security guard. B1 arrived on-scene at 05:53 hours and followed L54 to the incident area. B1 established Command and setup the command post 500ft away from the incident silo (**See Photo 2**). Upon arrival at the incident area, L54's crew began a scene size-up with facility employees.

A facility supervisor met Command at the command post to provide a briefing on the events leading up to the incident and what was known about the fire. He explained that over a period of three months, the facility hired a contractor to remove a bridge of pellets that formed and clean silo #2. At 05:30 hours that morning, the contractor crew noticed smoldering/burned material and a fire in the silo which prompted the facility to call 9-1-1. Command radioed to A1 requesting that upon arrival, they report to the command post and perform accountability for the incident. Command also requested all fire units on-scene to switch over to Fireground #3 tactical channel for all incident communications. L59, A1, and E46 arrived between 05:54 and 05:59 hours.

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Photo 2. Location of silo #2 in relation to command post.
(Courtesy of the fire department)

After completing their size-up, L54 reported to the command post to discuss their plan for fire suppression in the silo. The facility supervisor explained that there was some "germ" product in the bottom of the silo which they believed was on fire. He explained that they believed the product was on the sides of the silo as opposed to being level at the bottom. In response, L54 noted that a plate (over an access/inspection port) had been removed from the bottom of the silo just before the conveyor system. The facility supervisor agreed that this location would be safe to flow water into the silo and noted that the conveyor system was shut down.

The L54 crew returned to the incident area and deployed a 1¾-inch hoseline to the bottom of the silo to begin flowing water. They began extinguishing the smoldering materials that had fallen around the conveyor system and then directed the water into the silo through the access/inspection port to put out the fire. Command requested the location of the nearest hydrant from the facility supervisor, which was determined to be West of the silo. At approximately 06:09 hours, Command requested that L59 assist E46 in securing a water supply from the hydrant to L54. While the water supply was being secured, L54 crews continued to apply water into the bottom of the silo, flowing 90 – 100 gallons per minute. L59 and E46 confirmed to Command that a water supply was secured to L54 at 06:21 hours. This was accomplished with a 300ft lay of 5-inch supply line. Command then requested L59 and E46 crews to report to the command post.

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A unified command structure was developed at the command post with the addition of the facility command and safety officer. At 06:36 hours, the facility command requested the contractor crew bring their suction truck to the incident area to remove the water and extinguished product from the conveyor tunnel where the L54 crew was working. Command requested a status report. L54 looked into the silo and noticed that air was being drawn/sucked in and that there was still active fire inside. L54 responded to Command that they did not think the water application was working. They decided to shut the handline down and return to the command post, exiting the conveyor tunnel at 06:42 hours. L54 noted that a side access hatch was present on the river-facing side of the silo, about 13ft above the ground. Command asked the facility supervisor if this hatch could be utilized to flow water into the silo. The facility supervisor stated that it may be too dangerous to open the hatch because the facility was unaware of what was behind it and was concerned about burning "germ" product spilling onto who opens the hatch. The contractor crew's suction truck arrived on-scene at 06:47 hours.

At the command post, it was decided the fire suppression tactic would change to flowing water through an access hatch on top of the silo. The plan was to setup L59 and use its standpipe to run hose above the catwalk on top of the silo. This was estimated to require 200ft of 3-inch hose if L59 could reach the catwalk. Command requested L59 and E46 to shut down and move the supply line from L54 to position L59. The contractor crew's suction truck then entered the incident area and staged parallel against the silo configuration. The truck began to vacuum up the water and product that was running out of the bottom of the silo so that the conveyor system did not flood. Upon staging, Command was notified that L59 was not able to reach the catwalk. In response, Command requested that L59 be removed from the incident area and L54 return. At 07:09 hours, Command entered the incident area to conduct a new size-up of the silo and develop a strategy. He observed a landing near the top of the silo which he believed L54 could reach. This area would be just short of the top of the silo but was about 10-15ft from the catwalk.

At 07:10 hours, B2 arrived on-scene due to shift change and proceeded to the command post to relieve B1 of Command. He was briefed on the current status of the incident and the new plan of using L54 as a standpipe to allow a hoseline to flow water into the top of the silo. The facility safety officer showed B2 a hand drawing of the silo showing the amount of product he believed was still in the silo. He also explained that the bottom of the silo discharge was open to allow water to flow through. Between 07:20 and 07:42 hours, fire department shift change was transpiring with four firefighters arriving on-scene and with four others leaving. This shift change included the arrival of CO3 lieutenant (deceased firefighter).

L59 was stowed at 07:24 hours. At 07:55 hours, L54 was put into position next to the silo configuration and reconnected to the water supply from the hydrant. Command arranged the position of the firefighters for the operation as companies (CO1, CO2, and CO3) for task-level assignment and communication purposes. At 08:04 hours, a CO1 firefighter was positioned in L54's bucket to operate the standpipe while CO3 lieutenant and CO3 firefighter (critically injured firefighter) were taken by the facility safety officer up a set of stairs to reach the catwalk. Light, lazy white smoke and aerosolized dust was observed on top of the silo and coming from the headhouse. Due to the smoke, the facility employee did not reach the catwalk and both CO3 lieutenant and firefighter went on air using their SCBAs. CO2 firefighters were positioned at the bottom of the silo to monitor progress of the operation.

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At 08:22 hours, the CO3 lieutenant and firefighter reached the catwalk. Their 50ft section of 3-inch hoseline without a nozzle was connected to the standpipe in L54's bucket by the CO1 firefighter. The CO3 firefighters dropped the hose into the access hatch on top of the silo. It was down far enough that it would not push out of the hatch when charged. They noticed light, grey smoke pushing out of the hatch but no heat. At 08:28 hours, the CO3 lieutenant and firefighter radioed to Command that they were in position and requested their hoseline to be charged. After beginning to flow water into the silo, the surrounding smoke and dust began to suck back into the silo. At 08:34 hours, Command was transferred from B1 to B2 with all fire units being notified of the change by radio. B1 departed the scene. CO2 firefighters entered the conveyor tunnel and noted warm water flowing from the bottom of the silo. They reported to Command that they believed the operation was working. While working in the headhouse, both the CO3 lieutenant and firefighter used their SCBAs.

At 08:44 hours, CO2 firefighters checked the conveyor tunnel again and noted that the water was now cool with no smoke or steam observed. They radioed CO3 lieutenant for a status check on the top of the silo. An order was given to move the hoseline around to saturate more product. Upon moving the hoseline, CO3 lieutenant observed a puff of smoke. CO2 firefighters then heard a sudden roar from above and observed a pressurized "white-out" of steam and white smoke in the conveyor tunnel. At the same time, Command walked to L54 and a very loud low tone compression/explosion sound was heard from the top of the silo at 08:45 hours. Concrete debris began to rain down in the incident area. Command then observed CO3 lieutenant fall from the edge of the silo, land on the fiberglass awning below, and then onto the ground. A CO2 firefighter immediately performed patient assessment and resuscitation efforts while a Mayday was called. At 08:49 hours, Command requested an additional ambulance be sent to the scene and an emergency medical helicopter. Command updated the PSAP that CPR was in progress for a firefighter who suffered from a long fall. CO3 lieutenant was then transported to a local hospital. At this time, all firefighting operations stopped and the CO1 firefighter brought L54's bucket to the ground. Accountability was performed which resulted in noting that the CO3 firefighter was missing. CO2 firefighters responded to the top of the silo area using access stairs to search. They were unable to locate the missing CO3 firefighter.

At 08:51 hours, B1 received a telephone call from the facility command requesting him to return because there "had been an accident." Upon his arrival on-scene, he was briefed on the situation by the facility command, noting that one firefighter was transported to the hospital and another was missing. Command was transferred from B2 to B1. During the search for CO3 firefighter, B2 noted that there was very little amount of concrete debris on ground. Most of the roof materials after the explosion had fallen inward into the silo. Thinking the missing firefighter may be inside the silo, B2 requested the facility safety officer to arrange for a crane to drop a basket into the silo to conduct a search.

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A member of the contractor crew then updated B2 about the side access hatch on the silo that could be used to aid the search (**See Photo 3 and 4**). Upon opening the hatch, they observed the semi-conscious CO3 firefighter sitting on the silage against the inside silo wall. They did not observe any fire in the silo. A second ambulance and helicopter were requested by Command at 09:27 hours. Command noted to the PSAP that they had a fall victim who was talking and that ongoing efforts were underway for extracting the victim from inside the silo. Firefighters began unbolting the side access hatch to gain a larger opening. CO3 firefighter then crawled to the opening and was secured in a stokes basket which was lowered to a stretcher of a waiting ambulance. CO3 firefighter was then transported to the landing zone for the helicopter for transport to a local hospital.

Photo 3 and 4. Location and ladder configuration used to locate and rescue CO3 firefighter from inside silo #2.
(Courtesy of the fire department)

After both firefighters were transported, facility employees noted that smoke had begun to emanate from the bottom of the silo again. Additional fire units from a mutual aid department arrived on-scene at 09:31 hours and began firefighting operations, changing tactics multiple times until the fire was fully extinguished at 15:15 hours. The incident was declared under control at 15:27 hours.

Fire Origin and Explosion Cause

Fire:

NIOSH investigators interviewed corn processing facility employees who noted that multiple incipient stage fires had occurred in the silos over the past 10 years. Silage is a fermented feed that is made from high moisture plant materials such as grass, corn, or maize using the oxygen excluding conditions of a silo. When a silo is filled with these materials, the aerobic respiration from the silage eventually produces heat and consumes oxygen in the silo, resulting in fermentation. The fermentation process also produces heat and preservative acids until the silage become stable. When the silage is stored at the recommended moisture content, the water present helps absorb the heat generated and prevents overheating. But if the silage is too dry, the heat cannot dissipate fast enough and the internal temperature in the silage could rise until spontaneous combustion occurs. The oxygen in the silo could support a smoldering fire which in most silo fires, spreads slowly (days, weeks, or months) until it reaches the top of the silage [Murphy and Arble 2000].

Explosion:

An independent root cause investigation, which included an engineering analysis, was conducted by a third-party private organization in 2019. The third-party organization developed two explosion hypotheses as potential causes for the incident: a combustible dust explosion and a combustible gas explosion [Exponent 2019]. According to NIOSH [1986]:

- Combustible dust explosions may occur if dust inside the silo becomes suspended, oxygen is sufficient, and is ignited by the heat of the smoldering fire in the silage.
- Combustible gas explosions may occur in a silo when sufficient oxygen and an ignition source is introduced into the explosive atmosphere in the silo headspace which is produced by the accumulation of combustible gases from the smoldering fire in the silage.

The organization identified the root cause of the explosion to be *the application of water through the top hatches of the silo in an attempt to suppress the fire*. A literature review and engineering analysis determined that suppression activities that apply water to a smoldering silo fire have the potential to exacerbate the explosion hazards present [Exponent 2019]. Open hatches and the application of water can entrain oxygen into the silo headspace. For a combustible gas explosion, the introduction of oxygen can bring the atmosphere into the explosive range and an ignition source, such as the smoldering fire in the silage, can cause an explosion [NIOSH 1986]. Further, the application of water can stir up dust within the silage and cause it to become suspended in an explosive concentration [OSHA 2013].

Contributing Factors

Occupational injuries and fatalities are often the result of one or more contributing factors or key events in a larger sequence of events that ultimately result in injuries or fatalities. NIOSH investigators identified the following items as key contributing factors in this incident that ultimately led to the fatality and near miss:

- Smoldering propagation due to chemical reaction/self-ignition of silage
- Emergency planning at corn processing facility
- Fire suppression tactics and pre-incident planning
- Explosion due to application of water through the top hatches of silo

Cause of Death

According to the county medical examiner report, the cause of death of CO3 lieutenant was blunt force and injuries to the chest and abdomen because of a fall from a grain bin following an explosion.

Recommendations

Fire departments should:

Recommendation #1: Train fire officers and firefighters on the hazards associated with different types of silos and the appropriate firefighting tactics, including any unique hazards posed by the silo contents.

Discussion: None of the firefighters interviewed by NIOSH investigators noted training in the specific hazards associated with silos or the appropriate firefighting tactics for silo fires. The fire department did not have any written guidelines for silo fires. Additionally, the corn processing facility employees did not communicate the hazards presented by the incident silo's contents or the appropriate fire suppression methods as dictated by an occupancy fire safety plan.

Since 1985, NIOSH has investigated five incidents of firefighter fatalities and injuries resulting from silo fires and explosions. For each incident, NIOSH recommended that firefighters be trained on the hazards associated with and the appropriate firefighting tactics for silos [NIOSH 1985; NIOSH 2004; NIOSH 2006; NIOSH 2011; NIOSH 2012]. The existing literature on silo fires and explosions has remained unchanged for more than 40 years based upon the science of the conditions created by the design and contents. Typical firefighting tactics can unintentionally create the conditions for an explosion in a silo by creating dust clouds, introducing air, applying incompatible extinguishing methods, and using equipment that can become an ignition source [OSHA 2013]. Additionally, the building characteristics of silos can present vulnerabilities that require special consideration and planning for firefighting activities [NFPA 2021].

Fire departments can develop training from available resources or requisition existing training. Silo fire and emergency trainings are available through fire academies and private fire training organizations. Fire departments can develop SOGs using the information and response techniques learned from these trainings.

<u>Silo Hazards</u>

The fermentation process naturally forms various gases in the silo, such as carbon dioxide. When silage burns, the organic compounds also release hazardous gases such as carbon monoxide, nitric oxide, nitrogen dioxide, and nitrogen tetroxide. Many of these gases are flammable, maintain an explosive range, and can accelerate the burning of combustible materials. Additionally, chemical additives are often added to silage such as corn. These include urea, anhydrous ammonia, and organic acid preservatives [Murphy and Arble 2000; Arble and Murphy 1988]. According to USFA, the presence of these gases should be considered by firefighters especially in an oxygen-limiting silo [1998].

One of the most dangerous hazards presented by silos is a combustible dust explosion. Since 1980, there have been over 200 combustible dust incidents at industrial facilities that have led to the deaths and injuries of workers [OSHA 2024]. Combustible dust is a solid material composed of distinct particles which present a fire or explosion hazard when suspended in air or some other oxidizing medium over a range of concentration. Dust explosions often occur in a series where the first explosion stirs the dust settled in other areas of the confined space and results in additional explosions that are larger and stronger. These dusts are often byproducts of organic materials that are finely ground. For a dust explosion to occur, five conditions must be present [IFSTA 2016]:

- Combustible dust is suspended in air
- Particle concentration is within explosive range
- Ignition source is present
- Dust is in a confined space
- Oxygen content is sufficient to support combustion.

The possibility of a combustible dust explosion is a critical hazard that dictates modifying firefighting tactics. The explosibility of a dust cloud is impossible to measure during an incident. Gas meters that measure explosive and flammability ranges cannot measure these ranges for combustible dusts [OSHA 2013]. Silos also present a hazard of structural collapse and the integrity of the silo throughout an incident should be considered.

Firefighting Tactical Considerations

One of the most important factors for firefighters to consider with silo fires is time. Time is especially important when dealing with an oxygen-limiting silo whose design reduces the ingress of oxygen to support combustion.

Unlike when other dry materials and flammable structures burn, silo fires burn slowly (days, weeks, months). As such, there is often ample time at the scene to analyze the situation and develop a plan for extinguishing the fire [Murphy and Arble 2000; Arble and Murphy 1988; NIOSH 2011]. This includes time to meet with facility owners and collect all pertinent information regarding the silo (**See Appendix One**).

An enclosed silo fire, by design, will likely be a ventilation limited fire. Therefore, the same tactical considerations for any ventilation limited structure fire would apply. It is most effective to fight the fire on its own level. It is most effective to fight the fire from the intake portion of the flow path. It is ineffective and a high hazard tactic to fight the fire from the exhaust portion of a flow path. The hazard from a ventilation limited fire can increase rapidly with the introduction of air [Madrzykowski and Weinschenk 2018].

There are several firefighting tactical considerations for fires in oxygen-limiting silos [Hill and Rickenbach 2015; Murphy and Arble 2000; Arble and Murphy 1988; OSHA 2011a, OSHA 2011b, OSHA 2013, NFPA 2022] that fire departments can implement around size-up and hazard recognition, extinguishment actions, and safety considerations:

Size-up and Hazard Recognition:

- Determine the type of silo, location of silo unloading opening, utility shutdowns (lockout/tagout), all additional openings, and location of exposures.
- Determine the content type and amount in the silo.
- Determine the length of time the silo fire has lasted.
    - Fire burning for an extended period can create void spaces in the contents.
- Observe smoke conditions and location (if present).
    - Smoke emitting from the top hatches of an oxygen-limiting silo dictates that the top hatches should not be closed or secured.
- Utilize a thermal imaging device to determine location and amount of smoldering silage.
- Establish a collapse zone around the silo.

Extinguishment Actions:

- All firefighting activities that introduce air into the silo must be <u>avoided</u>.
    - No attempt should be made to enter, breach, or directly extinguish fire in the silo.
    - Water or foam should not be directed onto the fire through the top hatches.
    - Attempting to drown the fire with a deluge of water is not effective as the water will not penetrate deeply into the silage, but run off towards and down the inside walls (water follows the path of least resistance), by-passing the hot areas of silage.
- Allowing an oxygen limiting silo to smother itself out by not opening the top or bottom hatches for two weeks has been shown to be effective in some cases.
    - Facility may have to partially or completely empty the silo with extinguishment of silage after removal from the silo.
- Consult with silo manufacturer for step-by-step instructions or recommendations on how to extinguish fires in their silos.

Safety Considerations:

- Any attempt to extinguish a fire inside an oxygen-limiting silo may introduce oxygen into the silo (via natural oxygen ingress through openings or through water), increasing the risk of causing the suspension of combustible dust resulting in an explosion or backdraft type of situation.
- Firefighters should stay off an oxygen-limiting silo that is shaking, noisy, hot, smoking heavily, or that has been opened (allowing oxygen ingress) within the past few days.
- Silos are considered permit-required confined spaces due to being large enough to bodily enter, have limited access, has a potential for a hazardous atmosphere, and contains a potential for engulfment.
    - Silos may contain Immediately Dangerous to Life and Health (IDLH) atmosphere due to the presence of combustible gases, dust, vapors, and toxic agents in accordance with 29 CFR 1910.272.
    - Silos should be treated as a confined space and any planned entry should utilize considerations provided in NFPA 350, *Guide for Safe Confined Space Entry and Work*.

Recommendation #2: Develop a pre-incident plan for all high-hazard occupancies in their jurisdictions.

Discussion: At this incident, the fire department maintained a specialized Box Alarm assignment for high-hazard occupancies in their jurisdiction, including the corn processing facility. The policy dictated which fire and EMS units from each station would respond to emergencies at the facility including fire, EMS, and safety incidents. Directions for responses were further detailed for specific routine call areas in the facility the emergency was reported and what entrances responding units should utilize.

A pre-incident plan is defined as a document developed by gathering general and detailed data that is used by responding personnel in effectively managing emergencies for the protection of occupants, participants, responding personnel, property, and the environment [NFPA 1660 2024]. A pre-incident plan identifies deviations from normal operations and can be complex and formal, or simply a notation about a particular problem, such as the presence of flammable liquids, explosive hazards, modifications to structural building components, or structural damage from a previous fire [NIOSH 1999]. In addition, NFPA 1660 outlines steps involved in developing, maintaining, and using a pre-incident plan by breaking the incident down into planning, implementation, and execution phases. In the planning phase, for example, it covers factors such as physical elements and site considerations, occupant considerations, protection systems and water supplies, hydrant locations, and special hazard considerations. Building characteristics that are important to record include type of construction, materials used, occupancy, fuel load, and unusual or distinguishing characteristics [NFPA 1660 2024].

<u>Group H-2 Occupancies: Combustible Dusts</u>

In this incident, the corn processing facility produced and stored corn gluten feed pellets. Agricultural products, such as these pellets, generate dust which can form explosible mixtures in air. The independent root cause investigation of this incident included an explosibility study for the pellets stored in the incident silo. The study confirmed that the dust generated from the pellets is combustible with consistent explosibility parameters of similar corn-based products [Exponent 2019]. Facilities that produce and store combustible dusts are classified as Group H-2 high-hazard occupancies by the 2018 IBC. Section 307.4 provides this designation for buildings and structures containing combustible dusts that pose a deflagration hazard. This includes where combustible dusts are manufactured and generated in a manner that the concentration creates a fire or explosion hazard [IBC 2018].

Fire departments should identify combustible dust hazards in advance as part of their routine pre-incident planning to identify appropriate firefighting actions and avoid creating additional hazards for fire department and corn processing facility staff that are onsite during a fire or other emergency. Pre-incident planning for industrial facilities allows fire departments to engage with employees to collect facility-specific information that would not be otherwise obvious upon arrival for an emergency. All locations where combustible dusts are generated and stored should be identified. Pre-incident plans should also include information developed with facility employees such as compatible extinguishing agents and appropriate fire suppression methods. Pre-incident planning also allows for routine training activities and drills with high-hazard occupancy facilities and their employees [OSHA 2013].

Governing municipalities (federal, state, regional/county, and local) should:

Recommendation #3: Ensure the applicable fire and life safety codes are enforced at high-hazard occupancies such as agricultural and/or food processing facilities.

Discussion: NIOSH investigators interviewed corn processing facility employees who noted that multiple incipient stage fires had occurred in the silos over the past 10 years. The fire department in this incident maintains a Building & Neighborhood Services division. As provided in NFPA 1030, personnel in this division provide fire and life safety inspections and enforcement of building codes for the jurisdiction. This division utilizes both the 2018 IBC and the IFC as part of the city's building ordinances. The AHJ is responsible for training and certifying inspection and code enforcement personnel to ensure that the appropriate fire and building safety codes are utilized and enforced [IFSTA 2016].

NFPA 1730, *Standard on Organization and Deployment of Fire Prevention Inspection and Code Enforcement, Plan Review, Investigation, and Public Education Operations*, Chapter 6 states that fire prevention inspection and code enforcement shall be conducted to ensure compliance with adopted codes and standards. The AHJ shall determine the minimum resources, personnel, and equipment levels necessary to perform code enforcement and inspection activities. Additionally, NFPA 1730 [2019] states that existing occupancy fire prevention inspection and code enforcement inspection frequencies shall not be less than those specified below for each occupancy risk classification:

- High: Annually
- Moderate: Biennially
- Low: Triennially
- Critical Infrastructure: Per AHJ.

Although the recommended inspection frequency for an occupancy such as the one in this incident is annually, fire departments, in cooperation with their AHJ, can perform additional fire and life safety inspections and enforcement to enhance their ability to identify potential compliance and emergency response issues.

<u>Group H-2 Occupancies: Fire and Life Safety Codes</u>

The 2018 IBC provides fire and life safety requirements which dictate design and engineering controls based on occupancy and use. For example, table 414.5.1 explains that explosion venting and prevention systems are required for structures containing combustible dusts generated during manufacturing and processing. Section 2203 of the 2018 IFC provides the requirements for operations that manufacture, process, and generate potentially combustible dust. These include completing a dust hazard analysis for new and existing facilities and maintaining housekeeping procedures for preventing the accumulation of combustible dusts in the interior of buildings.

These requirements also include physical identification of hazards. Previous NIOSH reports involving silo fires and explosions recommended that facilities install placards on the exterior of silos that include information on the type of silo, emergency contact for the facility, and proper fire suppression tactics (**See Diagram 2**). Specifically, these reports recommended placards that clearly state "DANGER - Sealed Silo – Water Contributes to Explosion of Sealed Silos" or some variation [NIOSH 2004; NIOSH 2011; NIOSH 2012].

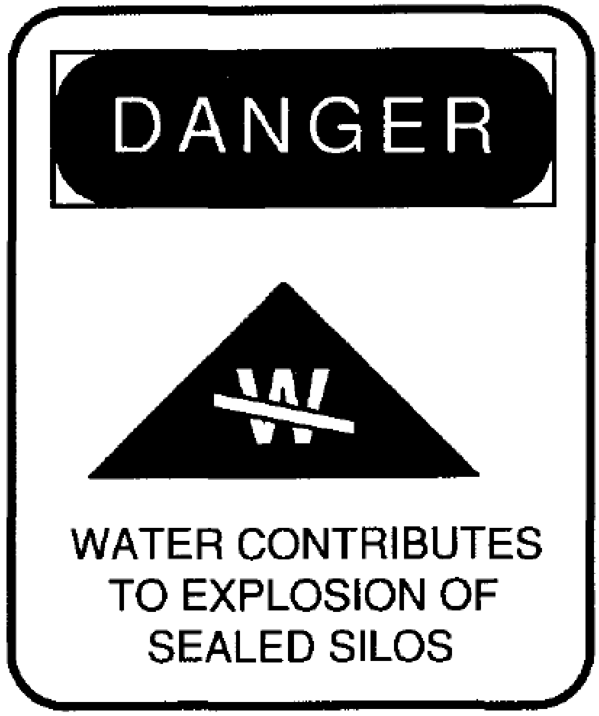

Diagram 2. Example warning placard. ***(Courtesy of the Northeast Regional Agricultural Engineering Service)***

The 2018 IFC provides fire and life safety requirements based on occupancy and use. Section 403.7 dictates that all Group H occupancies shall have and maintain an approved fire safety and evacuation plan. Fire safety plan requirements include a list of all major fire hazards associated with the normal use and occupancy of the premises. The IFC also dictates that employees of the occupancy be appraised of fire hazards associated with the processes and materials they are working with, through training and availability of Safety Data Sheets. This also includes requirements for each employee to be instructed in the proper procedures for preventing fires and responsibilities in the event of a fire [IFC 2018].

The fire safety plan requirements allow for facility employees to communicate hazards to the responding fire department in the event of an emergency. This includes specific hazards and precautions that firefighters should be aware of when selecting fire suppression tactics. This would include precautions for combustible dust and explosions in silos.

Agricultural and/or food processing facilities should:

Recommendation #4: Properly operate and maintain their silos and implement the applicable requirements of NFPA 61, Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities.

Discussion: The corn processing facility discovered a 15 – 20ft thick bridge of pellets near the bottom of silo #2 three months prior to this incident. The bridge prevented the flow of the corn gluten feed pellets from some of the silo's discharges. The facility hired contractors to remove the bridge of pellets and clean the silo.

Facilities should routinely inspect and maintain all equipment to ensure safe operation and condition. This includes using the silo manufacturer's recommended proper maintenance procedures to ensure the integrity of their oxygen-limiting features [NIOSH 2004]. In this incident, the contractor crew left hatches open overnight which allowed for the ingress of oxygen that supported smoldering combustion of the silage.

NFPA 61 provides requirements for agricultural and food processing facilities to manage and mitigate fire and explosion hazards of combustible dusts or related particulate solids. The standard explains that owners and operators of these facilities should identify fire and explosion hazards associated with their facility and their potential consequences. They should manage and communicate these hazards to their employees. One of the main methods described by NFPA 61 to manage these hazards is for the facility to develop and implement a written housekeeping program to reduce the accumulations of agricultural dust. This may include the use of dust collection (vacuum) equipment. The standard also provides requirements for explosion prevention, relief, and venting devices and systems [NFPA 61 2020].

NFPA 61 provides that wet or dry standpipes shall be provided in all operating areas of headhouses and storage galleries that are over 50ft above grade. Additionally, the standard advises facilities to consider the installation of spark/ember detection and extinguishing systems [NFPA 61 2020].

Post-Incident Fire Department Prevention Actions

After this incident, the fire department implemented changes to incident response and fireground operations. These changes were based on the department's critique of the incident on January 5, 2019.

- **Industrial Fire Response SOG**
  The fire department training/EMS director and management developed and finalized this SOG to provide personnel and fire officers a consistent operating guideline when responding to structural type fires and other emergencies within industrial settings, such as the corn processing facility in this incident (**See Appendix Two**).
- **Training with High-Risk Occupancy Facilities**
  Since the development and implementation of the Industrial Fire Response SOG, the fire department routinely trains with high-risk occupancy facilities in their jurisdiction as part of their pre-incident planning. This includes simulated responses that incorporate facility employees and management to ensure appropriate hazard communications and effective incident stabilization with facility-specific hazards.

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Investigator Information

This incident was investigated by Dr. Thomas Hales, Investigator, and Matt Bowyer, General Engineer, with the Fire Fighter Fatality Investigation and Prevention Program, Surveillance and Field Investigations Branch, Division of Safety Research, NIOSH located in Morgantown, WV. This investigation report was authored by Dr. Wesley R. Attwood, Investigator and Program Advisor, with the Fire Fighter Fatality Investigation and Prevention Program, Surveillance and Field Investigations Branch, Division of Safety Research, NIOSH located in Pittsburgh, PA.

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Dan Madrzykowski and Keith Stakes from the Fire Safety Research Institute, part of the UL Research Institutes, provided an expert review of the investigation report. A subject matter expert review was provided by Eric J. Rickenbach of RescueTechs, LLC and Tim Zehnder, Business and Community Education Coordinator for Fire Training at the Mid-Plains Community College. The NFPA Emergency Response & Responder Safety Division and KC Elliott, Epidemiologist, NIOSH Office of Agriculture Safety and Health, also provided a technical review.

Additional Information

Underwriters Laboratories (UL)

The Fire Safety Research Institute (FSRI), part of the UL Research Institutes, continues to work with fire departments and fire service organizations to conduct research on fire dynamics, fire safety issues, and fire ground operations. Access to reports from completed studies and information from on-going studies can be found at https://fsri.org. Access to free online training on evidence-based firefighting (more than 30 course modules in all) can be found at https://training.fsri.org.

Disclaimer

The information in this report is based upon dispatch records, audio recordings, witness statements, and other information that was made available to the National Institute for Occupational Safety and Health (NIOSH). Information gathered from witnesses may be affected by recall bias. The facts, contributing factors, and recommendations contained in this report are based on the totality of the information gathered during the investigation process. This report was prepared after the event occurred, includes information from appropriate subject matter experts, and is not intended to place blame on those involved in the incident. Mention of any company or product does not constitute endorsement by NIOSH, Centers for Disease Control and Prevention (CDC). In addition, citations to websites external to NIOSH do not constitute NIOSH endorsement of the sponsoring organizations or their programs or products. Furthermore, NIOSH is not responsible for the content of these websites. All web addresses referenced in this document were accessible as of the publication date. *NIOSH Approved is a certification mark of the U.S. Department of Health and Human Services (HHS) registered in the United States and several international jurisdictions.*

Appendix One
Silo Initial Assessment Worksheet
(*Courtesy of RescueTechs, LLC*)

TYPE OF INCIDENT:	FIRE?	RESCUE?	RECOVERY?	COLLAPSE?
FARM LOCATION:				
FARM OWNER/POC:			PHONE #	

CRITICAL INITIAL MANAGEMENT ITEMS:

_____ 1. ESTABLISH INCIDENT MANAGEMENT SYSTEM, PERSONNEL ACCOUNTABILITY SYSTEM, AND DESIGNATE SAFETY OFFICER.
_____ 2. ESTABLISH APPROPRIATE SAFETY ZONES. (CONSIDER MOVING ANIMALS DEPENDING ON SITUATION.)
_____ 3. MEET WITH FARM OWNER/MANAGER – ESTABLISH LIAISON OFFICER.
_____ 4. OVERALL SCENE ASSESSMENT.
_____ 5. EVALUATE AND PRIORITIZE LIFE SAFETY ISSUES.
_____ 6. EVALUATE EXPOSURE ISSUES (BUILDINGS, EQUIPMENT, FEED, LIVESTOCK, ETC.).
_____ 7. LOCK-OUT / TAG-OUT OF EQUIPMENT COMPLETED? CAN THE UNLOADER BE LIFTED?
_____ 8. REQUEST APPROPRIATE RESOURCES.

Personnel operating in the immediate area of the silo shall be using proper PPE, including SCBA, and conducting air monitoring.

SILO MANUFACTURER (& PHONE #)	CONTACTED?
SILO SERVICE COMPANY (& PHONE #)	CONTACTED?
WHAT AND WHEN WAS THE LAST SILO AND/OR UNLOADER MAINTENANCE/REPAIR?	

TYPE (AS ORIGINALLY CONSTRUCTED): _____ CONVENTIONAL _____ OXYGEN LIMITING

CONSTRUCTION: _____ STEEL _____ CONCRETE STAVE _____ POURED CONCRETE

_____ OTHER (IDENTIFY): _____ ANY TYPE OF LINING OR BAG?

YEAR CONSTRUCTED:	DIMENSIONS: DIAMETER: ___________ HEIGHT: ___________

WAS THIS SILO MODIFIED IN ANY MANNER? _____YES _____NO

IF YES, HOW?

TYPE OF UNLOADING SYSTEM: _____ TOP UNLOADER _____ BOTTOM UNLOADER _____ NONE/MANUAL

POWER SUPPLY? _____ ELECTRIC _____ HYDRAULIC POWER SUPPLY SECURED? _____ YES _____ NO

DOES THIS SILO HAVE A "BIG JIM" OR "LITTLE DAVID" STYLE UNLOADING SYSTEM? _____ YES _____ NO

MATERIAL IN SILO: ____ CORN SILAGE ____ HAY/RYE CROP SILAGE ____ SORGHUM

____ HIGH MOISTURE GRAIN ____ OTHER (SPECIFY): ______________________________

HOW FULL IS SILO?	ARE THERE 2 DIFFERENT MATERIALS IN THE SILO?	
DATE LAST FILLED?	WAS NEW MATERIAL PUT ON TOP OF OLD? ____YES _____NO	IF YES, HOW FULL WAS SILO PRIOR TO LAST FILLING?
IF FILLED WITHIN LAST 2 MONTHS – WHAT WAS THE MOISTURE PERCENTAGE AT TIME OF FILLING? ______%	WAS UNLOADER DRAWING HIGH AMPERAGE DURING NORMAL UNLOADING OPERATIONS? _____YES _____NO	
WHAT IS THE STATUS OF ANY DOORS, HATCHES, OR OTHER OPENINGS (OPEN, CLOSED, LATCHED, ETC.)?		
WAS ANY TYPE OF FUMIGATION, OTHER PESTICIDE, OR OTHER CHEMICAL CONTROL USED INSIDE? IF YES, WHAT & WHEN?		

Appendix Two

Example Industrial Fire Response SOG

(*Courtesy of the fire department*)

PURPOSE:

This standard operating procedure/guideline addresses operations in the industrial setting.
To provide a suggested, standard, and consistent operating guideline to aid emergency responders in the discharge of their duties when responding to structural type fire/other situations within the industrial setting.

SCOPE:

This SOG pertains to all personnel in this organization.

PROCEDURES/GUIDELINES & INFORMATION:

Fire Operations:

Typical positions and initial actions are listed below:

- Standard company operations assign basic fire ground functions and activities to companies based upon the capability and characteristics of each type of unit.
- Standard company operations assign major fire ground functions to the particular company who can best accomplish the operation.
- Standard company operations integrate the efforts of engine, ladder, and rescue companies to achieve effective rescue, fire control, and loss control activities.
- Standard company operations increase the awareness and confidence of company members in the standard performance of other companies operating on the fire ground.
- Standard company operations reduce the amount and detail of orders required to get companies into action on the fire ground.

Typical positions and initial actions are listed below:

Level I Staging:

- First-arriving unit:
  - Shall report to the most appropriate position on scene to carry out the duties specified in Responsibilities of Command.
  - If in a hydrant area and in lieu of orders to the contrary, the first-arriving engine company shall proceed to the most convenient hydrant and lay (or be prepared to lay) the appropriate size hose line(s) should the type of incident necessitate water.
  - If in a no hydrant area, and in lieu of orders to the contrary, the first-arriving engine company shall lay (or be prepared to lay) the appropriate size hose line(s) to the incident scene in such a manner as to allow for the establishment of a continuous water supply to the incident should the type of incident necessitate water.

- If in a no hydrant area and in lieu of orders to the contrary, the first-arriving tanker shall hook up and prepare to pump to any lines laid by the first-arriving engine, should the type of incident necessitate water.
- In lieu of orders to the contrary, the first-arriving truck company shall report to the same location as the first-arriving company. If an obvious rescue situation exists at another location, the first-arriving truck company may proceed to that location while advising the incident commander of the situation.

- All Other Units:
    - In lieu of orders to the contrary, all other units shall remain outside of the incident scene.
    - In lieu of orders to the contrary, all other units shall proceed to a convenient location (at a hydrant if available) approximately one block from the scene. Upon arrival at this location, unit commanders shall transmit, "(Unit ID) is staged (ID the location)." This message will inform the incident commander that the unit is ready for assignment.
    - No unit shall commit itself to any operation without having received orders or approval from Command.
    - Unit commanders shall not request assignments from staging.

Initial Actions:

- Command and the first arriving unit– will stage at the designated entry of the property meeting with the facilities supervisor or management.
- Other Units – staged for assignments once the Incident Action Plan (IAP) is set.

<u>Responding to and operating at emergency incidents in the industrial setting:</u>

Industrial fires present unique problems to firefighters accustomed to operating at ground level, single family residences primarily those of access, rescue, fire control, exposure protection, ventilation, and personnel safety. Industrial fire operations present their own set of challenges and can vary greatly from high-rise, commercial and residential fire responses.

INDUSTRIAL INCIDENT OVERVIEW

Access to the building or area is complicated by the possibility of falling glass, by building or structure setbacks, collapse of the buildings and structures, construction is a problem and access is often limited to only one face of the building. Access to floors beyond the reach of aerials is limited to stairwells and catwalks that can be open areas or confined areas. Access may possibly only be made through other areas of production, storage or manufacturing. The location of the stairwells may, or may not be at the unburned/damaged portion of the floor, and may cause the fire fighters to enter directly into the hazardous area rather than from the 'outside in' as we are accustomed.

Rescue of those trapped in the involved area is slow, and if they are too high to be evacuated by aerials, rescue is compounded by the necessity of using the stairs or catwalks and possibly going through the hazardous areas to reach them. Damage to the structures will make access and rescue very difficult.

Fire Control is compounded both by the inevitable delayed response to the affected areas of the property. With limited access and definite delayed access, the problem may expand widely and rapidly as an IAP is developed and implemented.

Facility it is difficult and even impossible to know and understand what takes place in the industrial setting. The number of unknown hazards within the industrial setting is not known and can change at a moment's notice. The layout of the facility, product, processing and the number of employees make this response one of the most dangerous for the fire department.

IMMEDIATE TACTICAL PRIORITIES

The TACTICAL OBJECTIVES in an industrial fire are:

1. **Assess the current situation for large scale evacuations of the industrial area.** We may not be able to control the issue in time to prevent a larger issue within the property. We must protect and setup ingress and egress into the area.
2. **Rescue any immediately threatened occupants.** An aggressive offensive, coordinated attack/rescue has proven to be the most effective tactical option in the majority large scale incidents and situations and rescue, in most cases, should be limited to those in immediate danger in the area.
3. **Stop the production of life-threatening heat and smoke by extinguishing the fire.** Continuous relief of heat and smoke and proper application of water on the fire floor(s) until extinguishment.

IMMEDIATE PRIORITIES

The initial arriving units to a fire in the industrial setting should be concerned with obtaining the following information at a minimum:

1. Requesting additional resources if there is evidence of a confirmed fire. I.e. auto-aid, mutual-aid, Rapid Intervention Team, safety officer to the scene. Think of additional alarms- what is needed now and possibly later.
2. Arriving battalion chief with the first on scene company will meet and establish command at the entry point of the industrial business to start the information gathering phase of the incident.
3. Command with first arriving company will meet with the site supervisor, security or the industrial incident commander at the entry point of the facility prior to entering or committing to any area within the facility.
4. All other incoming units will stage outside of the property in Level 1 staging.
5. A clear working knowledge of the incident will be obtained by the incident commander, company officer and the facility representatives before moving to the area of the incident with the following questions answered as completely as possible-
    a) What is the current issue?
    b) What unseen risks are you (plant personnel) aware of to the fire department responders?

c) What are the past and current facts?
d) How time sensitive is this issue at this point?
e) How long ago did this occur?
f) When did it start?
g) When was this issue discovered?
h) What was done to this point? Who has been involved with this so far?
i) Who is currently involved?
j) What is currently being done?
k) How do we mitigate this incident?
l) Is this a Fire/HazMat issue?
m) Who or what other agencies have been notified of this situation?
n) What happens if nothing more is done to mitigate this issue at this time?
o) What are the best- and worst-case scenarios?
p) Who has knowledge of this incident? Site staff? Contractors? Who are the key players? Who is going to be part of the Unified Command Structure? (identify by name and what role they play at the facility- This person or their replacement will stay with the fire department IC for the entirety of the incident—No exceptions)
q) What are the risks to the employees inside the facility both now and later?
r) Are evacuations needed or underway? Shelter in place? Evacuation will be the fire department Incident Commanders decision.

6. The newly formed Unified Command Staff (incident commander, facility reps) will proceed to the area of the reported incident while forming an IAP. At this point a dedicated safety officer will be appointed enroute to the scene or called to the scene. This safety officer position must be staffed throughout the incident! (Is there a need for multiple safety officers?)
7. On arriving in the area an IAP will be formed and agreed upon. The IAP will be in written format at the Incident Command Post.
8. The IAP will be enacted with a staffed safety officer position on site or on the way to the scene through the use of call-back. (Can potentially be filled with Auto-Aid Chief or officer on scene from fire department)
9. Providing or verifying that a continuous water supply is present and sustainable.
10. Stand-pipe and/or sprinkler system supplied
11. Elevated aerial to make our own stand-pipe
12. Lock-out tag-out steps taken by SOG --
13. Drawing, schematics or computer images for clear understanding of the area with regards to ingress and egress.
14. As the incident allows, a complete safety briefing for all involved crews.
15. Enact the IAP within the scope of the ICS system providing for firefighter safety, survival, accountability and welfare.