Two Volunteer Fire Fighters Die After an Explosion While Attempting to Extinguish a Fire in a Coal Storage Silo – South Dakota

Executive Summary

On September 15, 2011 a 20-year-old male, and a 22-year-old male, both volunteer fire fighters, were killed while attempting to extinguish a fire in a coal storage silo. After removing approximately 80 of the 100 tons of coal inside the silo, the two victims attempted to extinguish the fire by applying water through an access hatch on top of the 50 foot silo. An explosion occurred destroying the silo and killing the two victims. A third fire fighter working inside the structure at the base of the silo was seriously injured.

Coal storage silo after explosion
(NIOSH Photo)

Contributing Factors

- *Silo design*
- *Unique explosive characteristics of coal (Bituminous, Sub-Bituminous including Powder River Basin Coal)*
- *Fire fighting tactics for silo fires.*

Key Recommendations

- *Fire departments should review, revise and enforce standard operating guidelines (SOGs) for structural fire fighting that address silos containing combustible particles*
- *Fire departments should train officers and fire fighters on the hazards associated with different types of silos and the appropriate fire fighting tactics including any special hazards posed by the silo contents*
- *Fire departments should ensure that pre-emergency planning is completed for all types of silos located within fire department jurisdictions.*

Additionally, governing municipalities, manufacturers, and designers of coal storage silos should:

- *consider requiring that placards with hazard warnings and appropriate fire fighting guidelines be placed on silos*

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- *ensure that silos are constructed so that the contents flow without becoming trapped (stagnant) and to limit the introduction of air into the silo.*

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Introduction

On September 15, 2011 a 20-year-old male, and a 22-year-old male, both volunteer fire fighters, were killed while attempting to extinguish a fire in a coal storage silo. On September 16, 2011 the United States Fire Administration (USFA) notified the National Institute for Occupational Safety and Health (NIOSH) of this incident. On September 20-23, 2011, a Safety and Occupational Health Specialist and a General Engineer, traveled to South Dakota to conduct meetings and interviews with the fire department, representatives of the state's fire marshal's office, personnel who constructed the coal silo, and personnel who constructed a similar coal silo in a nearby community. The investigators reviewed the injured fire fighter's training records, the incident commander's training records, the department's training requirements, and blue prints of the coal bin. The department did not have any standard operating procedures at the time the investigation was conducted.

Fire Department

This volunteer department consists of 19 uniformed fire fighters. The department has 1 station and serves a population of 150 people in a community that covers approximately 9,000 acres. The department also provides mutual aid to the jurisdiction adjoining their community.

Training and Experience

The state has no minimum training requirements for fire fighters. The fire department was created to protect the life and property of this community in 1999. In 2009 the department received a Federal Emergency Management Agency (FEMA) grant that allowed them to put all of their members through state certified training that meets the curriculum for NFPA Fire Fighter I and II.

Both victims received training to NFPA Fire Fighter I and II, Incident Command System (ICS) 100 and 200, wildland firefighting, and methamphetamine laboratory fire suppression tactics.

The Chief, who was the Incident Commander, has received training on topics such as Fire Fighter I and II, and Incident Command System 100, 200, 300, and 700.

Coal Storage Silo

The farming operations of the community require them to keep the temperature of their barns consistent throughout the year. This can be very difficult and expensive due to the harsh winter climate in the region. Coal fired boilers are more economical than gas or electric and have had great success in similar situations, using water heated to 180-degrees to provide heat for the livestock barns and for other facilities on the farm.

The silo design is critical to store coal safely. Bulk coal in storage is very hazardous due to the ability of coal to produce its own heat. Coal releases heat slowly through oxidation which requires the silo to be designed to limit the introduction of air into the stored coal.

Construction of the concrete coal storage silo and boiler room on the incident site began in the fall of 2007 and was completed in the spring of 2008. Plans were drafted by an engineering firm and the storage silo was constructed by using precast, reinforced concrete panels. The panels were lifted and set into place. The panels were secured together with a series of metal anchoring plates and angle iron that were cast into the panels and welded together once in place (see Photo 1). Concrete sampling during the construction phase (after the required curing period) showed the strength of the concrete to be in excess of 8,000 psi.

The panels were 10 feet tall x 17 feet 8 inches wide. They were 10 inches thick and consisted of a two-inch sheet of foam in the middle of the concrete for insulation. The coal storage silo was assembled by stacking five panels on top of one another to a height of 50 feet. A metal funnel with a major diameter of 17 feet 8 inches, and a minor diameter of 20 inches was fabricated on site using ¼-inch sheet metal. It was lowered into the bottom of the square-shaped silo with a crane and supported by a series of metal legs and struts to provide an uninterrupted flow for the coal (see Photo 2). The open corners were enclosed with sheet metal transition panels cut to fit the corners and sloped down to meet the funnel at its major diameter where the funnel contacted the walls of the storage bin. A ring of ¼-inch metal approximately 4 inches wide wrapped around between the corners (see Photo 1). The funnel and the corners were attached to the silo with a weld along the walls. The corners were attached to the funnel with a slip joint. This connecting slip joint was sealed with a polyurethane caulking (see Photo 3).

The storage silo was covered with a 17-foot 8-inch square precast concrete panel that was 10 inches thick. It was not structurally connected to the walls of the storage bin. The lid had an access hole that was 24 inches x 24 inches in the southwest corner (see Photo 4). The underside of the lid, and approximately 2 feet down around the top of the interior of the storage bin, was sprayed with 2 inches of foam to safeguard against condensation.

The concrete storage silo attached to the building housing the 10 million BTU boiler through an 8 x 8 foot doorway. The funnel dumped into an enclosed metal tray that housed two 4 inch metal augers that transferred the coal to the boiler through the doorway (see Photos 5 and 6).

The concrete storage silo was loaded through a system that consisted of a trough where trucks could dump the coal. Inside the trough was a rubber belt and metal cup conveyor that transported the coal up to the top of the storage silo and extended into an enclosed chute approximately 12 feet above the top surface of the lid (see Photo 7). This type of conveyor system is a typical one used for grain.

One of the primary concerns for the bulk storage of coal is its ability to produce its own heat. The storage of bulk coal, whether inside a silo or stockpiled on the ground, releases heat slowly through oxidation. It is possible for enough heat to be released over a period of time to raise the coal temperature to self-ignition or spontaneous combustion. Such fires can be very stubborn to extinguish because of the amount of coal involved (often hundreds of tons) and the difficulty of getting to the seat of the fire. Moreover, bituminous coal in either the smoldering or flaming stage may produce copious amounts of methane and carbon monoxide gases. Methane is not a concern with sub-bituminous (PBR) coals.[1,2]

In addition to their toxicity, these gases are highly explosive in certain concentrations, and can further complicate efforts to fight this type of coal fire. Even the most universal firefighting substance, water, cannot always be used because of the possibility of a steam explosion.[1] Water contributes to the exothermic reaction of coal increasing the fire problem.

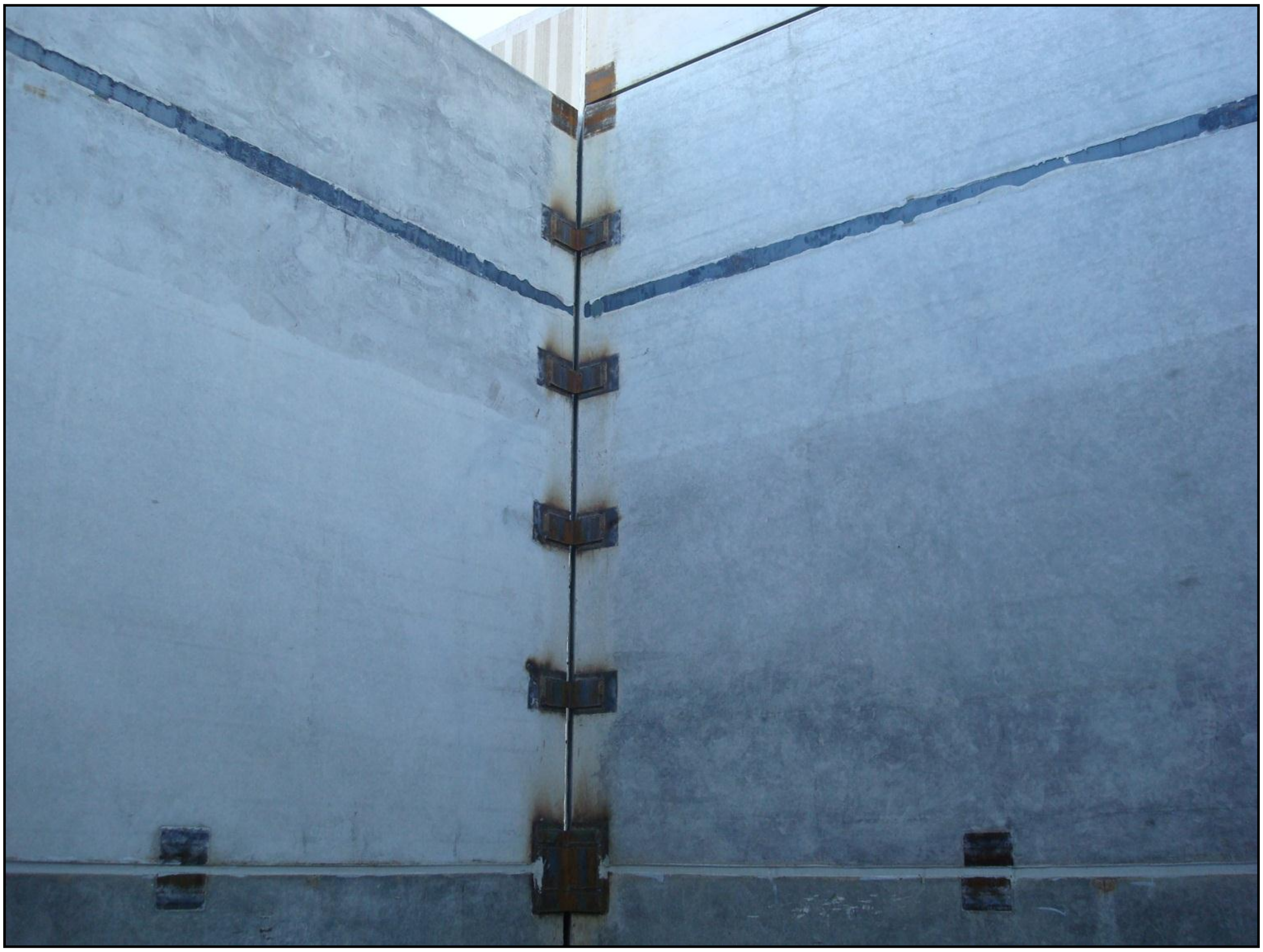

Photo 1. Weld points to hold the panels together in a similar silo. The black metal strip going around the top two sections in the picture is the 4-inch weld strip for the sheet metal funnel transition panels for the corners.
(NIOSH photo.)

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Photo 2. The metal funnel of a similar silo and its associated supports.
(NIOSH photo.)

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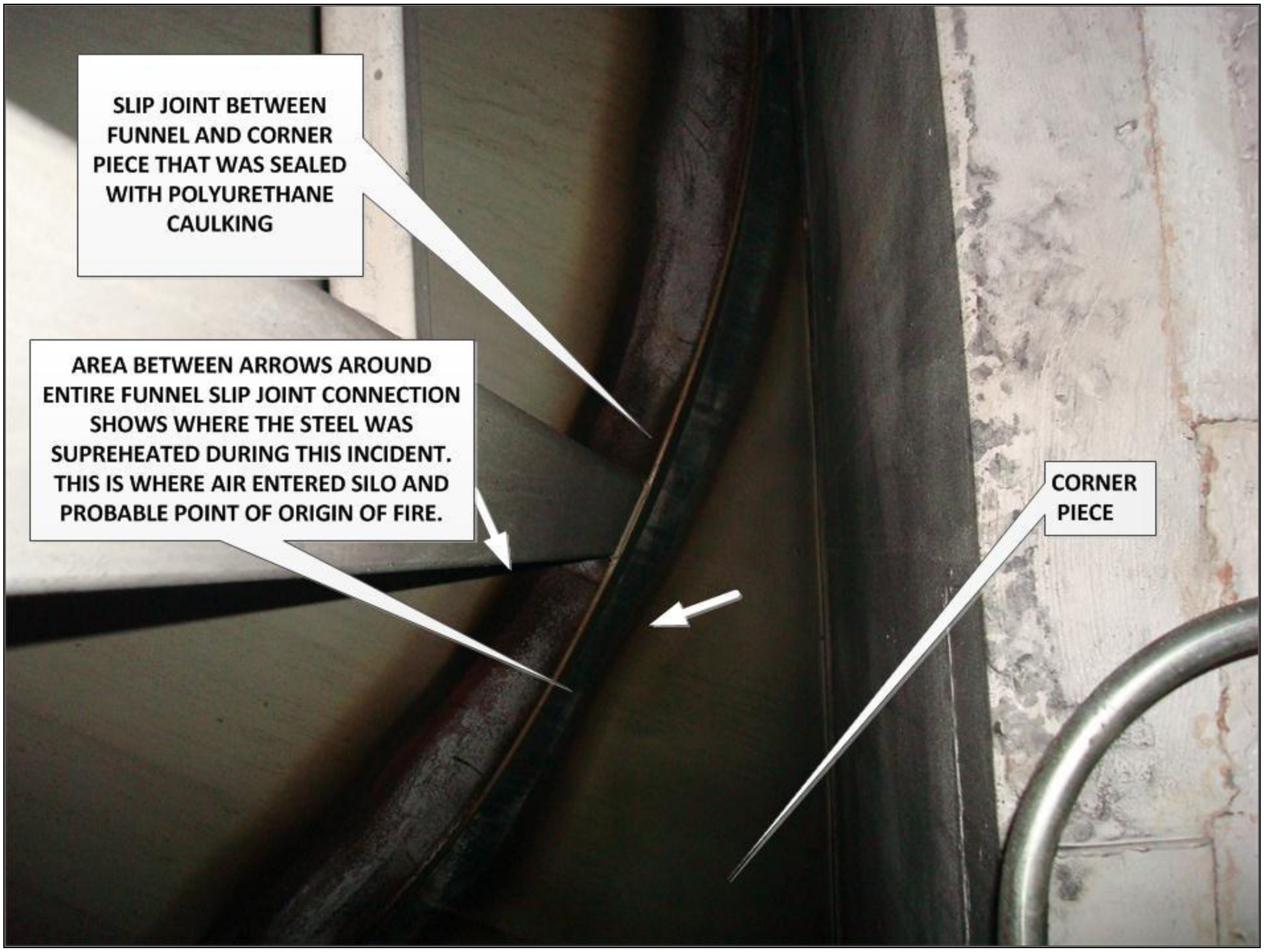

Photo 3. Shows lines of demarcation where fire was burning inside silo around the slip joint between the funnel and the corner pieces. *(NIOSH photo.)*

Recent Storage Operations

The storage silo has a reported storage capacity of approximately 175 tons. The silo was filled with approximately 100 tons of Powder River Basin coal two days prior to the incident occurring.

Powder River Basin Coal (PRB)

Operators familiar with the unique requirements of burning PRB coal say that it is not a case of "if" you will have a PRB coal fire, it's "when." Idle bunkers and silos that contain PRB coal should be monitored frequently for signs of spontaneous combustion by using CO monitors, infrared scanning, or temperature scanning. Some plants make bunkers or silos of PRB coal inert with carbon dioxide (CO^2) when they are expected to sit idle. For this practice to be effective, the enclosure must be completely sealed, especially the bottom cone, because CO^2 is about 1.5 times heavier than air. The amount of

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CO^2 needed to effectively render an enclosure inert is 3.3 lbs per ft^3. A silo measuring 22 feet in diameter and 55 feet high would require 3.2 tons of CO^2. A bulk supply of CO^2 and an extensive piping system for bunkers and silos may be necessary to implement this system. CO^2 is used as a preventive step for fire. However, it is very unlikely that such a CO^2 system would be able to suppress a fire in a coal silo.

When raw coal is loaded into a bunker or silo, size segregation begins to take place. Large chunks of coal tend to roll out to the periphery of the bin, while smaller chunks and fines stay in the center. This size segregation facilitates air migration up along the sides of the bunker or silo. It also presents a practical firefighting challenge when applying water from above: Water tends to “rathole” or follow the path of least resistance through voids and can bypass the seat of the fire. Dealing with a fire inside a bunker or silo is dangerous and must be addressed with the correct equipment and training. There are three recommended methods for fighting a silo or bunker fire: using a fixed system installed inside the enclosure, using a special tool called a piercing rod, or the use of both. Experience indicates that the very best method of attack is to get the extinguishing agent directly to the seat of the fire.[2,3] it is imperative that the extinguishing agent is a micelle encapsulator agent, such as F-500, and not water or foam. A micelle encapsualtor acts as a chemical barrier around the fuel and not as a blanket layer over top of the fuel as regular foam does. This technology eliminates the combustibility section of the fire tetrahedeon.

The risk of fire is present wherever coal is used and stored. The probability of stockpiled or stored coal self-igniting is greater as the coal ranking decreases. Anthracite coal, as found in the east, is the highest ranking coal and is easily handled. Lower rank coals, which are found in the west, tend to be very fragile, resulting in faster degradation and particle size reduction during the handling process which leads to spontaneous combustion. Powder River Basin (PRB) Coal is sub-bituminous coal from the west that has a BTU range of 8,000-8,800. [4] PRB is notorious for the spontaneous heating hazards it presents due to the high moisture and oxygen content in the coal. The explosibility of sub-bituminous PBR coal can be up to two times greater that bituminous coal.[5] If an explosion occurs, PRB coal will experience a faster rate of pressure rise. [6] PBR coal has a known propensity to self-ignite while idle in storage bins and silos. In this instance, the coal was trucked into the community from an adjoining state.

Equipment and Personnel

The First Alarm was at 0759 hours. All department personnel responded and arrived on the site just after the alarm was sounded. The fire happened on community property where all of the volunteer department personnel were working, facilitating the rapid response to the alarm.

The responding equipment included:
Engine 1, Fire Chief
Tanker 1, Fire fighter
Brush Truck 1, Fire Fighter
The remaining 16 fire fighters, including the two victims, responded on foot to the fire scene.

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Timeline

- **0759 Hours**
  The coal storage silo was showing smoke from an access port on top of it. The fire station is located just across the road and members were there within seconds.

- **0820 Hours**
  Members climbed to the top of the silo and flowed 1500 gallons of water through the access port on top. They were also operating a handline inside the building at this time to cool down the metal funnel at the bottom of the silo.

- **0850 hours**
  Members flowed 300 gallons of foam through the top access port.

- **0905 to 0943 hours**
  Members unloaded coal by using two grain augers. They removed approximately 80 tons of coal before they had to quit due the coal being too hot. This left approximately 20 tons of coal inside the silo.

- **0943 to 0947 hours**
  The two victims took an aerial lift up to the top of the silo in an attempt to extinguish the fire with an 1 ¾ inch handline.

- **0947 to 0951 hours**
  The two victims flowed water through the access port on top of the silo.

- **0951 hours**
  An explosion took place blowing both of the victims, the top, and several side panels off of the silo.

Personal Protective Equipment

The fire fighters were not wearing any protective clothing or equipment at the time of the incident.

Weather and Road Conditions

The conditions at the time the incident occurred were clear and sunny with the temperature approximately 60 degrees Fahrenheit. The wind was between 5 miles per hour with gusts up to 18 miles per hour from the South to Southwest.

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Investigation

On September 15, 2011 a 20-year-old male, and a 22-year-old male, both volunteer fire fighters, were killed while attempting to extinguish a fire in a coal storage silo. At approximately 0759 hours the department was notified that the coal storage silo had smoke showing from the access port on top of the bin. The fire department has a tanker, an engine, and a brush truck located at their station adjacent to the boiler room and coal storage silo. All apparatus arrived within seconds and personnel climbed the silo with a 150 foot 1 ¾-inch pre-connect handline off of the engine to the top of the structure. At approximately 0820 hours, members flowed approximately 1500 gallons of water (amount in the tanker) through the top access panel in an attempt to extinguish the fire inside of the storage silo (Photo 4). The 1500 gallons of water had little effect on the fire. At the same time, members used a 1 ¾-inch handline, connected to the brush truck, inside the boiler room to flow water onto the underside of the funnel in an attempt to cool it down. *Note: Members recalled noticing that the metal had discolored due to the heat at the funnel slip joint (see Photo 3).*

With the tanker was emptied, the department secured water from an on-site storage tank. They then deployed a 1 inch line to the roof of the storage silo. Fire fighters were still on the roof of the silo at this time and applied approximately 300 gallons of foam through the access port on to the burning coal pile. At this point, the smoke conditions subsided and fire department members and community personnel worked on removing the coal from the storage bin. They removed an access panel on the outside of the funnel where it dumped into the tray housing the augers. They used a grain auger to remove the coal to a portable tank inside the boiler room (Photos 5 & 6). Another grain auger transported the coal outside and into awaiting trucks. The trucks then hauled it away to another location in the community where it could cool down.

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Photo 4. Shows access panel on top of silo where the victims were flowing water at time of explosion.
(NIOSH photo.)

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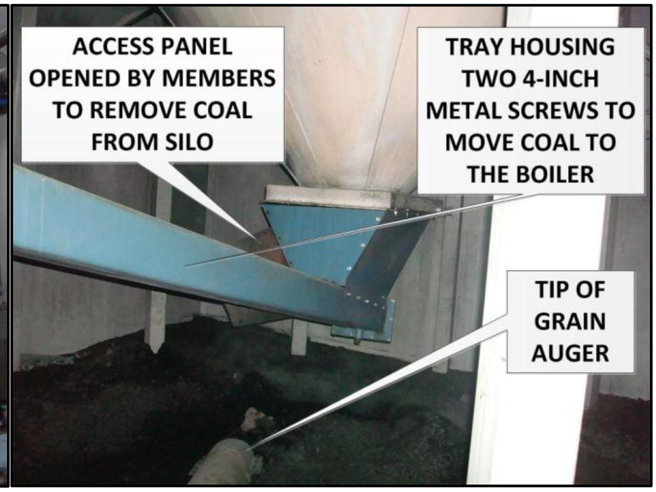

Photo 5. Grain auger used to remove coal before explosion.
(NIOSH photo.)

Photo 6. Bottom of funnel after explosion.
(NIOSH photo.)

From approximately 0905 hours to 0943 hours there were no fire fighters on the roof of the silo. All members worked to remove approximately 80 tons of coal from the bottom of the storage bin. The last 20 tons were so hot that they feared it would ruin the augers and possibly the truck beds transporting it, forcing them to cease removing the coal with the augers.

At approximately 0943 hours, department members decided to attempt to extinguish the fire from the access hole on top of the storage bin. The victims used an aerial lift to get to the top of the silo, walked out onto the silo roof, and flowed an 1 ¾-inch handline through the access port. For approximately 4 minutes, they flowed water and then the explosion occurred. The force of the explosion was so great that several of the vertical panels on the sides of the silo were blown off. The roof panel of the silo, with the victims standing on it, was blown into the air. Members immediately responded to provide aid to the victims who were crushed by the debris. They were transported to a local hospital where they were pronounced dead. A third fire fighter working inside the silo at the base of the coal chute was seriously injured.

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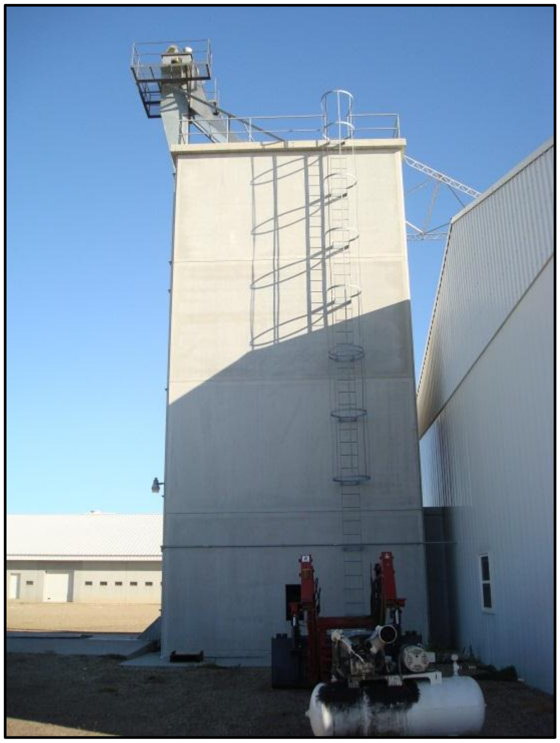

Photo 7. Coal storage silo similar to the one involved in fatal explosion.
(NIOSH Photo)

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 the injury or fatality. NIOSH investigators identified the following items as key contributing factors in this incident that ultimately led to the fatalities:

- *Silo design*
- *Unique explosive characteristics of coal (Bituminous, Sub-Bituminous including Powder River basin Coal)*
- *Fire fighting tactics for silo fires.*

Cause of Death

The cause of death for both victims was multiple blunt force trauma.

Recommendations

Recommendation #1: Fire departments should review, revise and enforce standard operating guidelines (SOGs) for structural fire fighting that addresses oxygen-limiting silos.

Discussion: Standard operating guidelines (SOGs) are organizational directives or plans that establish how the organization will react in various situations to increase the effectiveness and ensure the safety of the fire fighting team. Standard fireground guidelines include, but are not limited to: basic command functions; delegation of command responsibility; communications and dispatching; fire ground safety; tactics; initial resource deployment; and designation of roles and responsibilities of companies and units. SOGs should be comprehensive and encompass training, fire protection agreement plans, and procedures for those incidents involving mutual and automatic aid. SOGs should be written, periodically reviewed, and enforced.[7] Important elements that should be incorporated into SOGs for conducting operations on an oxygen-limiting silo fire include: [8,9]

- Confirm pre-plan information on arrival
- Do not use water or traditional fire fighting foam; however, micelle encapsulator fire extinguishing agent, such as F-500, should be used.
- If the top hatches are open, fire fighters should not close them if there is smoke coming out from the top, especially if the silo is vibrating or making unusual sounds
- Lockout and tagout the electrical service to the silo
- Roof hatches should be safe to close if the silo has been quiet for several days and there has been no smoke coming from the hatches. The hatch should be closed, but not securely, to permit the relief of any pressure that may build up
- Establish a collapse zone around the silo at least 1 and ½ times the height of the silo, keep unauthorized personnel away from the area, inspect for extension and protect adjacent exposures
- Ensure that all responders wear the appropriate personal protective clothing and equipment
- Some silos have external valves to inject carbon dioxide or liquid nitrogen from compressed gas cylinders to help control the fire
- If the silo still continues to burn, seek assistance from the industry or subject matter expert.

In this incident, the fire department did not have any SOGs which could have provided tactical guidance.

Recommendation #2: Fire departments should train officers and fire fighters on the hazards associated with different types of silos and the appropriate fire fighting tactics.

Discussion: There are two types of upright silos: conventional and oxygen-limiting or "sealed" silos. Conventional silos are typically used to store corn, hay or other foodstuff for livestock feed. These silos provide for the preservation, storage and disbursement of the feedstock. Conventional silos usually have outside doors located on the silo wall. Conventional silos are normally unloaded from the top. Oxygen-limiting silos are sealed to prevent oxygen from entering the silo. Both types of silos can be found on farms. It is critical for fire fighters to recognize the type of silo involved prior to beginning any fire fighting operations.

The greatest hazard of a fire in a silo where combustible particles are stored is the risk of an explosion. These silos are constructed of steel or concrete and have tightly sealed openings and hatches. When the hatches are closed and the silo is filled, the oxygen concentration should be insufficient to support a fire. Any attempt to extinguish a fire in an oxygen limiting silo may introduce oxygen into the silo, increasing the risk for a back-draft or explosion.

Smoke emitting from the top hatches of an oxygen-limiting silo dictates that the top hatches should not be closed and secured. Fire fighters should stay off an oxygen-limiting silo that is shaking, hot, noisy, smoking heavily, or that has been opened within the past few days. If the structure is quiet, motionless and cool, has not been opened recently and is smoking minimally, fire fighters should close the bottom unloader door and top hatches. Do not lock down these roof hatches, as they allow the silo to vent itself. [10] Always seek assistance from the silo manufacturer or field representative.

In all cases, fire fighters and incident commanders should practice proper risk management including a full risk management analysis following the guidelines listed in *NFPA 1500 Standard on Fire Department Occupational Safety and Health Program*, Chapter 4.2, Risk Management Plan.[11] Fire departments should be aware of and develop ways to safely control and extinguish the contents of silos within their jurisdiction. Fire departments should identify the different types of silos within their jurisdictions and develop risk management plans that address the specific potential hazards present and include the components of a risk management plan listed in Chapter 4.2.3:

- Risk identification – actual and potential hazards
- Risk evaluation – the likelihood of occurrence of a given hazard and the severity of its consequences
- Establishment of priorities for action – the degree of a hazard based upon the frequency and risk of occurrence
- Risk control techniques – solutions for elimination or mitigation of potential hazards. Key controls are explosion venting.
- Risk management monitoring – evaluation of the effectiveness of risk control techniques.

Recommendation #3: Fire departments should ensure that pre-emergency planning is completed for all types of silos located within fire department jurisdictions.

Discussion: Pre-emergency planning, pre-planning, and pre-incident planning are all terms that mean essentially the same thing. By first identifying target hazards (e.g., oxygen-limiting silos present high risk to life safety and property and unique hazards of silos contents) within a department's jurisdiction, the fire department can prioritize and begin to establish pre-emergency plans for those target hazards before an incident occurs. Pre-emergency planning enhances effective and safe operations and helps save lives and protect property. The pre-incident plan should not be confused with fire inspections which monitor code compliance. Pre-incident planning assumes an incident will occur and is one of the most valuable tools available for aiding responding fire fighters in effectively controlling an emergency.

In conducting pre-emergency planning for silos, fire departments must recognize the basic silo types as well as the construction features, materials used, presence of loading devices, other distinguishing characteristics, and the hazards associated with each type. They should include the identification and availability of special fire fighting equipment, apparatus, extinguishing agent and also rapid intervention and confined space rescue teams. Pre-emergency planning should identify the type of silo, the age of the silo, structural integrity of the silo, type of material normally stored in the silo, the hazards of the material stored in the silo, roof structural integrity, and the silo interior layout. Whenever possible, silos should be inspected during the construction phase to aid in assessing the different types of construction, materials, etc. The silo manufacturer should be consulted to insure that accurate information is obtained. Some silo manufacturers have step-by-step instructions on how to extinguish fires within their silos.[10]

NFPA 1620, Standard for Pre-Incident Planning can be used to establish a pre-incident plan for silos within their jurisdiction so as to minimize the risk to emergency responders.[12]

Recommendation #4: Fire departments should ensure that their members wear protective clothing and equipment based on an assessment of the hazards in operating areas to which firefighters are likely to be exposed.

Fire fighters should use protective clothing and equipment that meet the applicable requirements of NFPA 1971, Standard on Protective Ensemble for Structural Fire Fighting whenever the member may be exposed to the hazards for which it is provided.[11,13]

During this incident, fire fighters did not wear any protective equipment.

Recommendation #5: Fire departments should ensure that a separate Incident Safety Officer, independent from the Incident Commander, is appointed at each structure fire.

Discussion: According to NFPA 1561 Standard on Emergency Services Incident Management System, 2008 Edition, paragraph 5.3, "The Incident Commander shall have overall authority for management of the incident (5.3.1) and the Incident Commander shall ensure that adequate safety measures are in place (5.3.2)." This shall include overall responsibility for the safety and health of all personnel and for other persons operating within the incident management system. While the Incident Commander (IC) is in overall command at the scene, certain functions must be delegated to ensure adequate scene management is accomplished.[14] According to NFPA 1500 Standard on Fire Department Occupational Safety and Health Program, 2007 Edition, "as incidents escalate in size and complexity, the Incident Commander shall divide the incident into tactical-level management units and assign an incident safety officer (ISO) to assess the incident scene for hazards or potential hazards (8.1.6)."[11] These standards indicate that the IC is in overall command at the scene, but acknowledge that oversight of all operations is difficult. On-scene fire fighter health and safety is best preserved by delegating the function of safety and health oversight to the ISO. Additionally, the IC relies upon fire fighters and the ISO to relay feedback on fireground conditions in order to make timely, informed decisions regarding risk versus gain and offensive versus defensive operations. The safety of all personnel on the fireground is directly impacted by clear, concise, and timely communications among mutual aid fire departments, sector command, the ISO, and IC.

Chapter 6 of NFPA 1521, *Standard for Fire Department Safety Officer*, defines the role of the ISO at an incident scene and identifies duties such as: recon of the fireground and reporting pertinent information back to the Incident Commander; ensuring the department's accountability system is in place and operational; monitoring radio transmissions and identifying barriers to effective communications; and ensuring established safety zones, collapse zones, hot zones, and other designated hazard areas are communicated to all members on scene.[15] Larger fire departments may assign one or more full-time staff officers as safety officers who respond to working fires. In smaller departments, every officer should be prepared to function as the ISO when assigned by the IC. The presence of a safety officer does not diminish the responsibility of individual fire fighters and fire officers for safety. The ISO adds a higher level of attention and expertise to help the fire fighters and fire officers. The ISO must have particular expertise in analyzing safety hazards and must know the particular uses and limitations of protective equipment.[16]

In addition, active risk identification, evaluation, mitigation and pre-planning must take place at every incident, not just during silo fires by the member designated as the safety officer.

Recommendation #6: Municipalities should consider requiring that placards with hazard warnings and appropriate fire fighting guidelines be placed on silos.

Discussion: Information regarding the type of silo would be invaluable to fire fighters should an incident occur. Placards should be placed on silos warning fire fighters that the silo is an oxygen-limiting silo, and the placard should include information regarding the proper extinguishing techniques. The placard should also warn fire fighters not to use water to extinguish an oxygen-limiting silo fire, and have emergency contact information available. The placard should state "DANGER – Sealed Silo – Water Contributes to Explosion of Sealed Silos."[1]

Recommendation #7: Manufacturers and designers of coal storage silos should ensure that they are constructed to limit the introduction of oxygen into the silo.

One of the primary concerns for the bulk storage of coal is its ability to produce its own heat. The storage of bulk coal, whether inside a silo or stockpiled on the ground, releases heat slowly through oxidation. It is possible for enough heat to be released over a period of time to raise the coal temperature to self-ignition or spontaneous combustion. Such fires can be very stubborn to extinguish because of the amount of coal involved (often hundreds of tons) and the difficulty of getting to the seat of the fire. Moreover, bituminous coal in either the smoldering or flaming stage may produce large amounts of methane and carbon monoxide gases. Methane is not a concern with sub-bituminous

(PBR) coals. In addition to their toxicity, these gases are highly explosive in certain concentrations, and can further complicate efforts to fight this type of coal fire. Even the most universal firefighting substance, water, cannot always be used because of the possibility of a steam explosion.[7]

The probability of stockpiled or stored coal self-igniting is greater as the coal ranking decreases. Anthracite and bituminous coal, as found in the east, is the highest ranking coal and is easily handled. Lower rank coals, which are found in the west, tend to be very fragile, resulting in faster degradation and particle size reduction during the handling process which leads to spontaneous combustion. Powder River Basin (PRB) Coal is subbituminous coal from the west that is notorious for the hazards it presents regarding fires and explosions. The explosibility of subbituminous PBR coal can be up to two times greater that bituminous coal.[5]

Age, type, composition, temperature, and moisture content all factor in to the susceptibility of a spontaneous combustion occurring while coal is in storage. Provisions must be made to monitor lower grade coal stored in a silo, bunker or stockpile to reduce the occurrence of spontaneous combustion. Typically PBR coal should not be inactively stored for more than 14 days.[5] Coal should be stored so that air cannot infiltrate or move through the storage pile. Without oxygen, the oxidation process cannot take place, so it is important that the total coal surface exposure to air be as low as possible. Where coal is properly stored, spontaneous combustion is unlikely.[17]

Fire fighting operations must be taken into consideration during the design process of the silo. The process should include provisions to safely allow the material in a silo, bunker or stockpile to be evacuated in the event of self-ignition. To provide access to the interior of closed storage containers such as silos, they should be fitted with ports to accommodate the injection of fire fighting agents.[2,5,18] Silos that are greater than 50 feet tall should be provided with access points at different levels or have a fixed mitigation system at various zones for applying extinguishing agents.[2]

The silo involved in this incident, had a metal funnel placed inside the bottom to eliminate the possibility of stagnant coal. The corner areas were filled with metal plates to fill the void created by placing the round funnel inside a square silo. There was a seam created between these plates, the sides of the silo, and the funnel. The seam was filled with an expandable caulking compound to prevent oxygen from entering the storage silo. The seam degraded over time from the weight and abrasiveness of the coal and due to the normal expansion and contraction associated with climatic temperature change. This allowed oxygen to enter the silo and begin the oxidation process which likely led to the spontaneous combustion. Visual lines of demarcation could be seen around the seam where the funnel met the corner plates and the silo from above after the fatal event. This shows that the fire was burning hot enough in the specific location of the seam to visually change the appearance of the metal.

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Investigator Information

This incident was investigated by Jay L. Tarley, Safety and Occupational Health Specialist, 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. An expert technical review was provided by Paul Gilleod, ProBoard Fire Officer III, Fire Instructor II, Staff Instructor Southern WV Community and Technical College Academy for Mine Training and Energy Technologies, and Bob Taylor, Chairman, Board of Directors, PBR Coal Users Group. A technical review was also provided by the National Fire Protection Association, Public Fire Protection Division.

Additional Information

The PRB Coal Users' Group is formed to promote the safe, efficient and economic use of Powder River Basin coals by generating companies who currently use, or are considering the use of PRB coals. The objective is not to lobby for increased usage, but to: encourage the safe, economical use of PRB coals by those who elect to utilize the resource; to establish **best practices** for the **safe** operation and maintenance of PRB coal handling and storage systems based on "best available technologies"; to develop and maintain a data base of PRB coal users, both in North America and overseas; and to work with EEI, the American Coal Council and other involved industry groups. http://prbcoals.com/

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