Acknowledgments

Extinguishing Fires in Silos and Hay Mows is a complete revision of *Extinguishing Silo Fires*, NRAES–18. First published and distributed by NRAES in 1982, *Extinguishing Silo Fires* has undergone several minor revisions over the years. Since 1982, NRAES has sold over 45,000 copies of this publication. It has been used as a training manual for agricultural safety programs throughout the United States and Canada and, in this revised form, should continue to be a valuable resource for years to come.

This publication has been peer-reviewed by the persons listed below. It was judged to be technically accurate and useful for cooperative extension programs and for the intended audience. The authors are grateful for the many comments provided by reviewers, as they helped to add clarity and depth to the information in this publication.

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Cooperative Extension

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Extinguishing Fires in Silos and Hay Mows

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Introduction

Extinguishing Fires in Silos and Hay Mows will help firefighters understand how to approach and extinguish fires in silos and in hay and straw mows. Such fires can be controlled and extinguished before a disastrous loss occurs if the fire is discovered in time and appropriate actions are taken. This publication explains the different techniques used to control and extinguish fires in conventional vertical silos, oxygen-limiting vertical silos, modified oxygen-limiting silos, and stacks of baled hay and straw. It also outlines good silage-, hay-, and straw-making practices that can help minimize the risk of fire (see appendixes B and C on pages 29 and 30).

The information presented in this publication will also be useful to farm operators, emergency medical personnel, extension educators, and silo manufacturers and dealers, because they may become involved in making decisions or offering advice about extinguishing techniques or fire prevention.

CAUTION: A silo is a confined-space structure, and firefighters are obligated to follow the U.S. Department of Labor Occupational Safety and Health Act (OSHA) Confined Space Standard* for entry into a silo. Firefighters should be familiar with OSHA Standard 29 CFR Part 1910.146 before attempting to enter a confined space. The essential components of this standard are:

- Training and standard operating procedures must be established and adhered to when dealing with silo emergencies.
- All power to the structure involved must be locked out/tagged out.
- The air must be monitored in atmospheres that are Immediately Dangerous to Life and Health (IDLH).
- Any person entering a confined space must use personal protective equipment, including a breathing apparatus and a harness and lifeline.
- A designated person must be stationed outside the confined space to monitor the safety of the person entering the space.
- Adequate rescue resources must be present on-site.

* For more information and a complete copy of OSHA Standard 29 CFR Part 1910.146, visit OSHA's web site at <www.osha.gov>.

• CHAPTER 1 •

Silo Types

Two types of vertical or upright silos are common on farms: conventional silos (either with or without roofs) and oxygen-limiting silos. The approach to fighting a silo fire depends on the silo type. **Before attempting to extinguish a silo fire, it is essential to determine whether the silo is conventional or oxygen-limiting.**

A third type of upright silo is the modified oxygen-limiting silo, which is an oxygen-limiting silo that has been converted to a conventional silo. **In most cases of fire, a modified oxygen-limiting silo should be approached as if it were an oxygen-limiting silo** (see more discussion on this in chapter 5). Note that the material of which a silo is constructed (metal or concrete) does not determine whether it is a conventional, oxygen-limiting, or modified silo. Further investigation is required to make that determination.

More fires occur in conventional silos than in oxygen-limiting silos, because more oxygen is available in conventional silos to support combustion. Cavities or hollow tunnels that are created inside a silo by fire or by certain loading mechanisms may serve as chimneys that increase the draft and availability of oxygen for combustion of adjacent material. Although they are not as common as fires in conventional silos, fires in oxygen-limiting silos can be more hazardous because of the potential for an explosion.

Conventional Silos

Although they are typically constructed of concrete staves held together with pretensioned steel hoops, conventional silos may also be built with reinforced concrete, steel, wood, glazed tile, or brick. Some conventional silos are open at the top; others have a prefabricated metal hemisphere or domed roof for weather protection with openings for filling and inspection (figure 1-1). The silage unloader is suspended by a steel cable attached to a tripod of steel bars positioned at the top of the silo (figure 1-2). The electrically powered silo unloader rests on top of the silage and typically conveys or blows the silage into the external unloading chute (see next paragraph for an exception). Small unloading doors, built vertically up the side of the conventional silo wall, are successively opened inward as the silage level lowers. These unloading doors have steel hinge and lock mechanisms that serve as ladder rungs for climbing up the silo chute. Most unloading doors are wooden, but they can also be plastic, fiberglass, or metal. Metal or concrete silo chutes are only 30–36 inches deep, so it is difficult for firefighters to move up them when wearing a self-contained breathing apparatus (SCBA) and other protective gear and when more than one person is present.

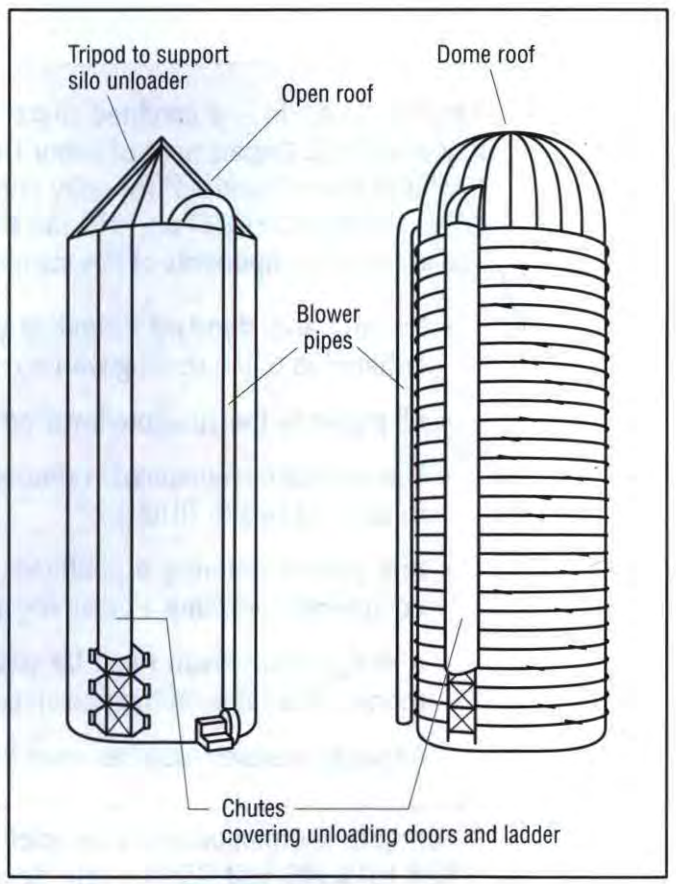

Figure 1-1. Conventional silos

Some 24- to 30-foot-diameter conventional silos have a hollow unloading chute in the center. During filling, the silo unloader distributes and levels silage, and the unloader and chute former are raised by cable and winch (figure 1-3). During unloading, the inside chute former is removed, and the top silo unloader brings silage to the central chute. There, silage drops to the bottom conveyor chute for delivery outside the silo.

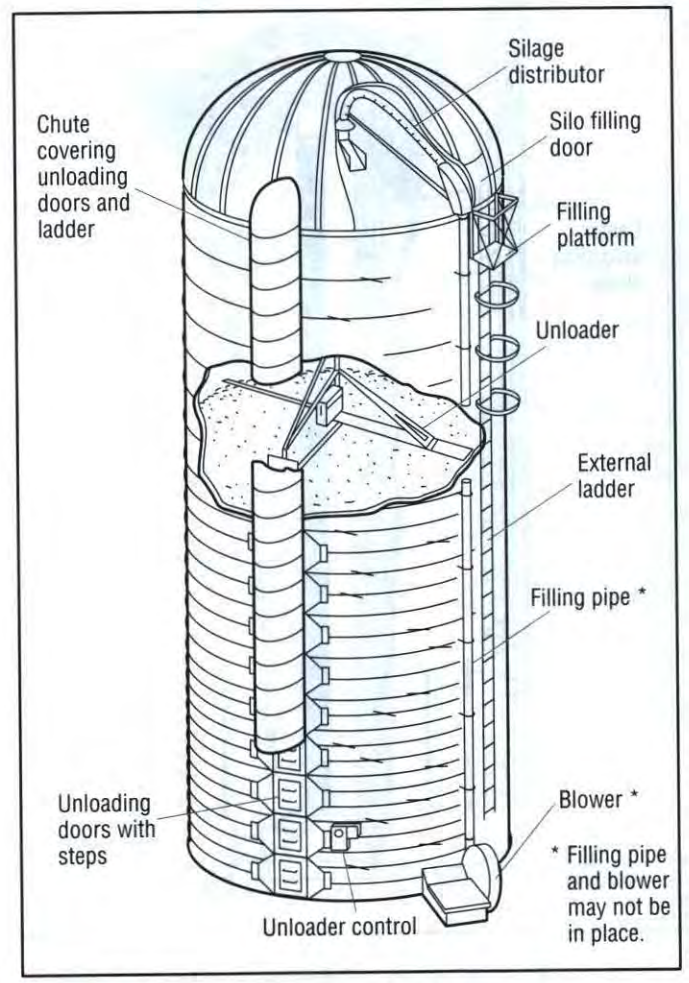

Figure 1-2. Top-unloading conventional silo

Oxygen-Limiting Silos

Oxygen-limiting silos (figure 1-4 on page 4) are often constructed of dark blue or green vitreous enamel-coated steel, poured reinforced concrete, or concrete staves. Both steel and concrete units incorporate design features that limit the exposure of the silage to outside air, thereby reducing spoilage and potentially improving the quality of the feed.

Oxygen-limiting silos do not have vertical hatch doors or external unloading chutes. Fill and unloading hatches are sealed with gaskets and clamps to limit airflow, and breather bags are utilized in some cases

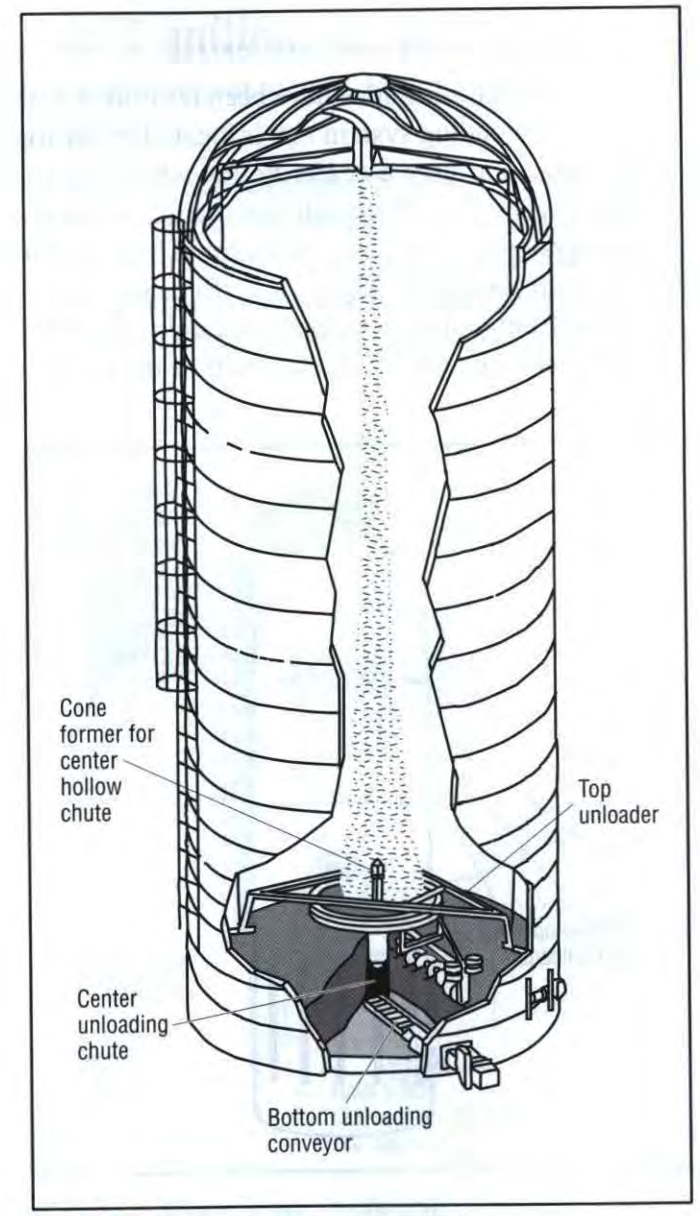

Figure 1-3. Conventional silo being filled

to compensate for air exchanges due to temperature and pressure changes. A typical oxygen-limiting silo has a bottom unloader that removes silage from the bottom of the silage mass using chains, augers, and conveyors.

Fires are relatively rare in these structures, but they can occur when hatches are left open, allowing air to enter during the ensiling process, or when excessively dry material is put in the silo. Because the units are sealed by design, the pressure buildup of gases during a fire can increase the potential for an explosion. **Special precautions are needed when fighting fires in oxygen-limiting silos**.

Modified Oxygen-Limiting Silos

Some oxygen-limiting silos have been retrofitted with the type of unloading system that is located on the top of the silage and uses a center hollow chute for unloading (figure 1-5). To install and maintain this unloading system, several silo doors must be added to the silo wall for access (figure 1-6). Because there is no tripod from which to suspend the unloader at the top of the silo, the roof of the silo will be the same as that of the oxygen-limiting silo. This type of system adds some complexities that need to be addressed when deciding on a firefighting strategy:

- Technically, when a top unloader and access doors are added, the structure loses its oxygen-limiting status. However, experience has shown that a dangerous buildup of gases can still occur during a fire, and therefore potential for an explosion does exist. Even though the top has been modified, the structure is still sealed very well.
- The chute that runs through the center of the silage can result in a tremendous chimney effect if a fire travels to the center of the silage. It is not yet clearly understood whether this results in a greater or lesser buildup of explosive gases.

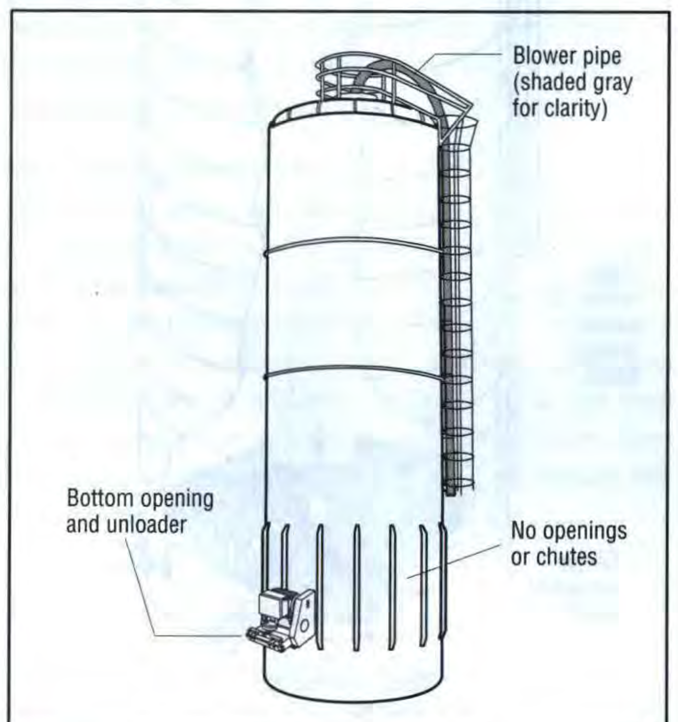

Figure 1-4. Oxygen-limiting silo

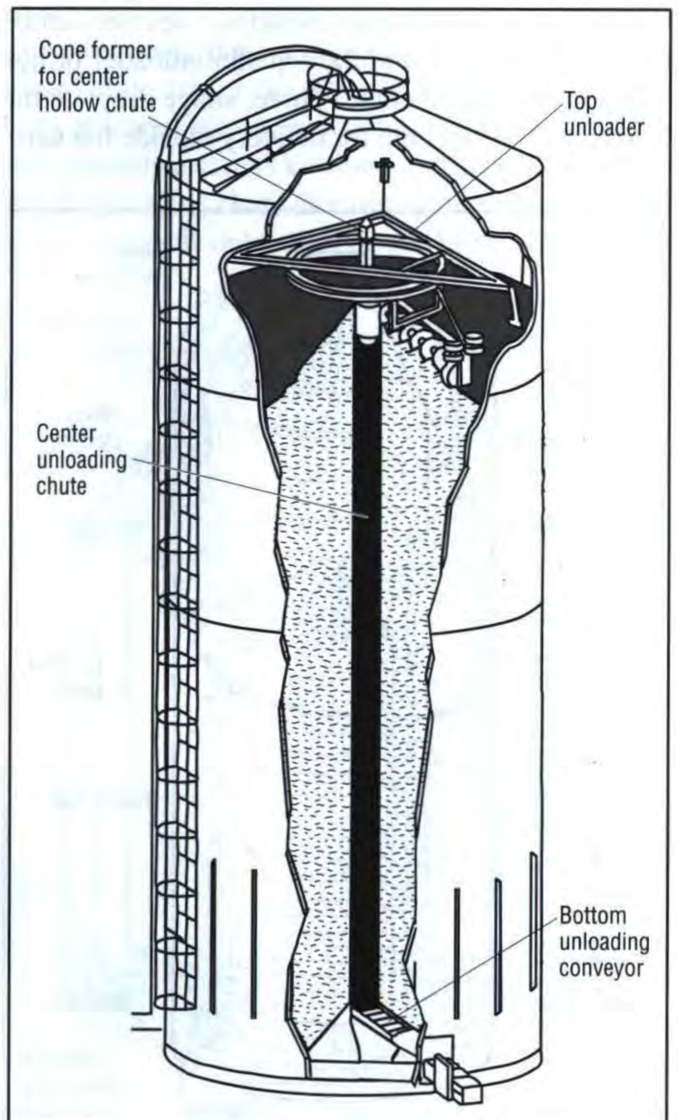

Figure 1-5. Modified oxygen-limiting silo with top unloader and center unloading chute

Another type of modification to an oxygen-limiting silo is the addition of a conventional top-unloading system and unloading doors and a chute along the entire height of the silo. To install such an unloader, it is necessary to put a domed roof on the top of the silo to allow space for the tripod that suspends the unloader. Generally, this type of modification results in a less tight silo structure.

Recognizing Silo Types

Whether a silo is conventional, oxygen-limiting, or modified oxygen-limiting can be determined by looking for a few identifying features. The characteristics or features of the three types include the following:

- Roof construction is a good indicator of silo type. Conventional silos either have no roof or a domed roof that is usually constructed of fiberglass or light metal (some older conventional silos may have a wood or shingled roof). Furthermore, conventional silos will have an opening in the roof where the silo wall and roof meet for the silo blower tube and for looking inside the silo. By comparison, the roof of an oxygen-limiting silo will be flatter and have an airtight hatch cover and one or more venting valves (figure 1-7). The silo blower tube will enter the roof in the center of the structure.
- Most silos that have a chute permanently attached to the outside of the silo for unloading purposes are conventional silos. The exception is a conventional silo that uses the center chute and bottom unloading system. Most oxygen-limiting silos do not have an attached outside unloading chute. The exception is an oxygen-limiting silo that has been modified.
- Most conventional silos have the unloader resting on top of the silage and moving down with the silage as it is unloaded. Most oxygen-limiting silos have the unloader at the bottom of the silo beneath the silage, and it always stays in that location. The

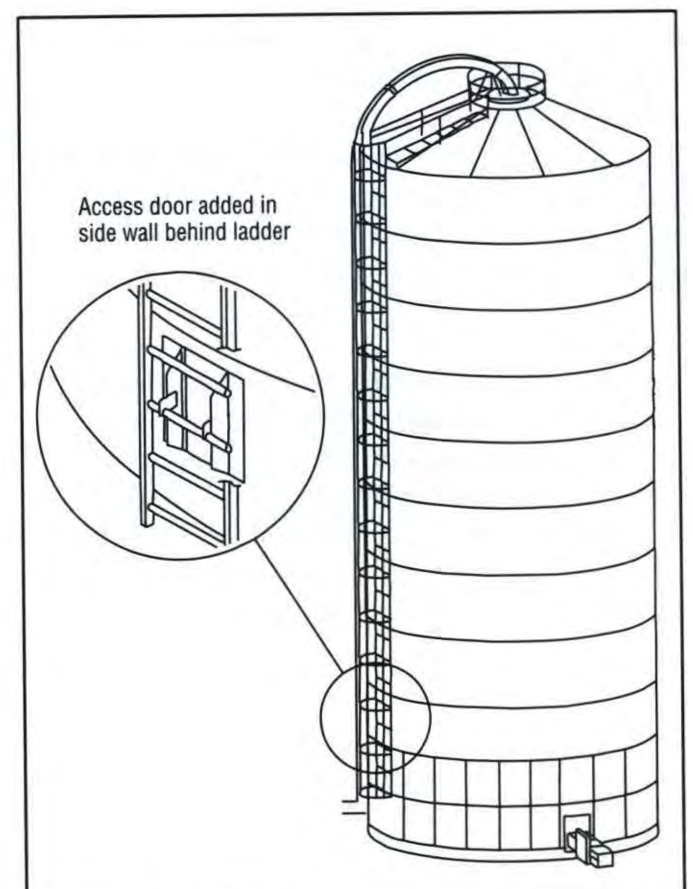

Figure 1-6. Modified oxygen-limiting silo with an access door added in the side wall

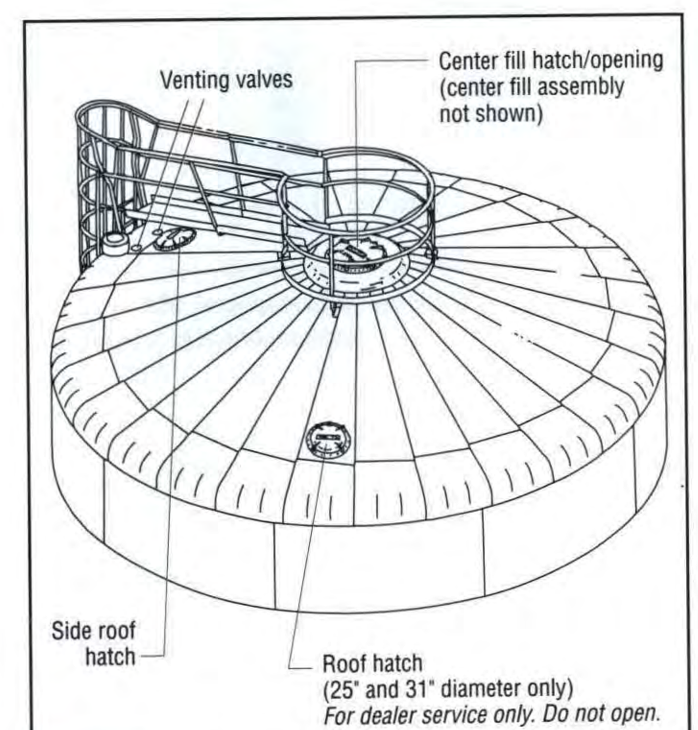

Figure 1-7. Roof of oxygen-limiting silo

exception is when the oxygen-limiting silo has been modified.

- It may be difficult to easily identify a modified oxygen-limiting silo because of the different ways that it may have been modified. **Never proceed with fire extinguishing procedures until you are certain of the type of silo.** Asking the farm operator is the best way to determine silo type.

• CHAPTER 2 •

What Causes Silo Fires?

Plant material continues to respire, or "breathe," for a short time after it is cut. After a silo is filled, aerobic respiration produces heat until the oxygen in the pile is consumed, then anaerobic fermentation produces heat and preservative acids until the chopped forage becomes stable.

If forage is stored at the recommended moisture content (see figure 2-1), the water in the forage helps absorb heat generated in the silage mass, and overheating will not occur. If forage is too dry, heat cannot dissipate quickly enough, and the internal temperature will rise until spontaneous combustion occurs. As the temperature rises above 130˚F, a chemical reaction occurs that may sustain itself. Heat kills microorganisms at 250–400˚F and begins to break down the forage by an oxidation process known as pyrolysis.

As pyrolysis continues, oxygen within the silage supports a smoldering fire. If the surrounding silage cannot support combustion, the fire may extinguish, leaving a charred cavity in the silage. In most silo fires, the fire will slowly spread (think days, weeks, or months) until it reaches the face of the silage or burns through a wooden silo door. Once the fire has access to unlimited oxygen, it can develop into a full-blown fire.

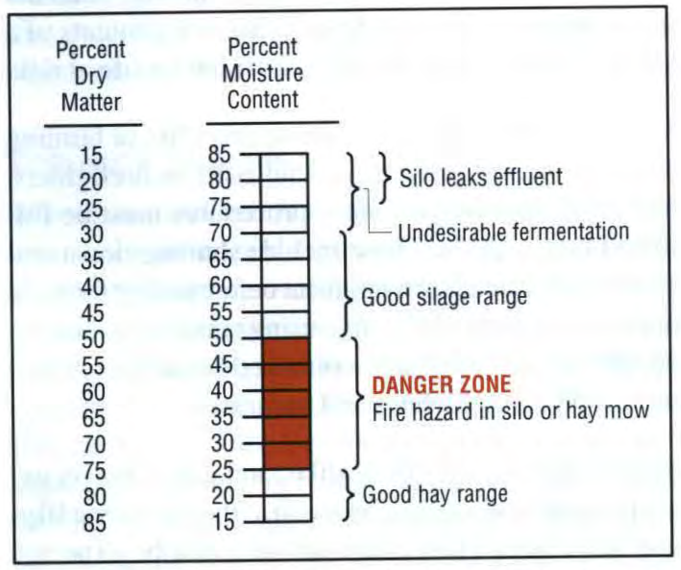

Figure 2-1. Characteristics of stored silage or hay by percentages of dry matter and moisture

• CHAPTER 3 •

Fires in Conventional Silos

If they are identified early enough, most fires in conventional silos can be extinguished by only a few firefighters with little risk and a relatively light use of an extinguishing agent. If the fire has progressed to the point where there are widely scattered open flames and large areas of engulfed silage, the silo contents may not be salvageable. In any case, the contents of a silo are never worth putting a firefighter's life at risk.

CAUTION: Entrance into a silo where a fire or burning silage is present presents special risks to firefighters, and all confined-space entry procedures must be followed (see page 1). These include shutting down and locking out unloading equipment before testing for toxic and explosive environments; using personal protective equipment, including self-contained breathing apparatuses; and using lifelines and harnesses.

Seldom are two silo fires alike, and decisions on exact procedures can only be made at the fire scene (figure 3-1). But certain characteristics can be expected in most conventional silo fires when the following factors are considered.

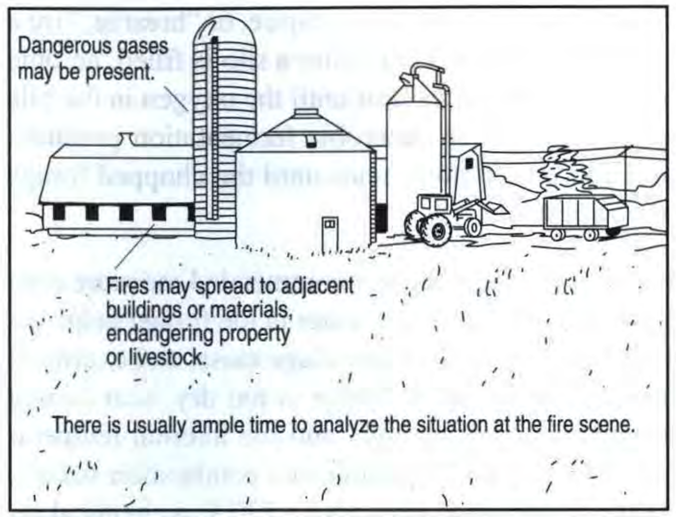

Figure 3-1. Common scene of a typical farm

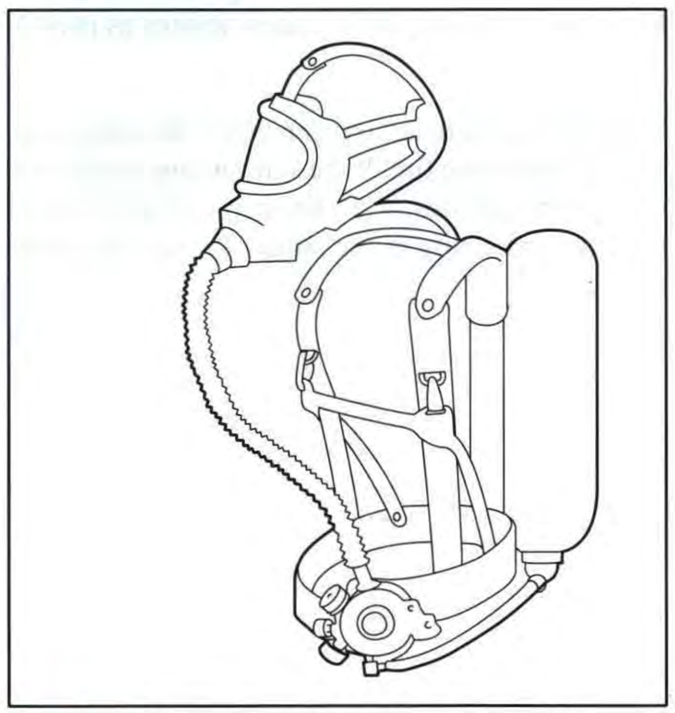

Figure 3-2. Self-contained breathing apparatus (SCBA)

Factors to Consider at the Scene of Conventional Silo Fires

Safety

- Always remember the prime importance of safety for firefighters and others at the scene of the fire, and strictly adhere to standard safety procedures. Use full turnout gear, a full body harness, a supplied-air respirator (SAR) or self-contained breathing apparatus (SCBA, figure 3-2), planking (see figure 3-5, page 14), and lifelines.
- Firefighters should always ask the farmer to confirm the silo type, and then verify the silo type visually.
- All silo-unloading machinery and electrical systems (such as wiring for electrical lighting) must be turned off and the power locked out when a silo fire is suspected. No one should examine or enter a silo until all machinery has been locked out.
- Confined-space entry procedures must be used when fighting fires (see page 1). A self-contained breathing apparatus (SCBA) is required for all personnel working inside the silo or attached chutes. A lifeline, harness, and appropriate support team are also required. By using overhead support and pulleys, the support team can remain on the ground. Minimal slack should be maintained in lifelines to minimize any potential falls or entrapment if the surface of the silage should give way.
- Firefighters should be aware that regular 30- and 45-minute SCBAs may run out of air while a firefighter climbs the silo chute or works inside the silo. Also, firefighters may not be able to climb the chute ladder with a full-size SCBA strapped on their backs. For these reasons, a supplied-air respirator (SAR) may be preferable. The supplied-air breathing apparatus includes a mask attached by means of a long air line to one or more large air cylinders located outside the confined space. Each mask has an emergency 5- or 10-minute backup tank attached for escape from a confined space. For more information about supplied-air breathing apparatuses, contact one of the companies listed in appendix D.
- Firefighters should be cautious on silo ladders and use a life belt and hook. The rungs of the enclosed chute ladder double as door handles and do not provide secure footing. Some may be broken, loose, or missing. External ladders may also be missing or weakened because of weather or mechanical damage.

Time

Silo fires burn slowly, so there is usually ample time at the scene to analyze the fire and seek expert advice. In many cases, there are no large flames and no immediate threats to other buildings. Often the silage will be glowing red with an occasional flame, similar to a charcoal fire. In some silos, there will be no visible flame or glowing embers, only smoke rising from beneath the top silage layer. The outside of the silo may be cool or warm and will have hot spots close to any combustion. Under these conditions, there is time to carefully examine relevant factors and plan step-by-step procedures for extinguishing the fire. The fire may burn for days, weeks, or even months.

Firespread

Fire may spread to other structures, equipment, or livestock if it burns through an unloading door. A burning piece of a door or hot silage may break out into flames as it falls down the chute and may then ignite surrounding materials. In some cases, burning silage has been augered or conveyed to adjoining buildings, where it ignited faster-burning materials. Remember that unloading doors become damaged as they burn, which makes them very hazardous to climb.

Exposure Hazards

The degree and nature of silo fire hazards vary. For instance, a life hazard may exist from the presence of considerable amounts of dangerous gases. A property exposure hazard may exist if a $300,000 barn is adjacent to the burning silo. In some fires, flames may be seen through burned-out unloading doors, while other fires slowly smolder. Be observant within and around adjacent buildings for livestock, power cables, loose roofing, conveyors, and power equipment, all of which can create life-threatening hazards for firefighters and others near the scene. Firefighters must approach and treat each hazard appropriately.

Toxic Gases

Several potentially hazardous gases are formed as a result of normal fermentation of crop material or as a result of a fire (see table 3-1 on page 10).

Carbon Monoxide

Carbon monoxide is formed in small quantities during fermentation. Once a fire starts, however, incomplete combustion of cellulosic materials (such as silage) forms larger quantities of carbon monoxide that

Table 3-1. Characteristics of dangerous gases that may be present in silos

Gas	Health Effects		Maximum Exposure Limits IDLH, Immediately Dangerous to Life or Health; REL, Recommended Exposure Limit; STEL, Short-Term Exposure Limit *(note 1)*			Physical Properties			Flammable Properties
	Acute	Long-Term	IDLH (ppm)	REL (ppm)	STEL (ppm)	Relative Density (air = 1) *(note 2)*	Color	Odor	
Carbon dioxide (CO_2)	Asphyxiant; headache, dizziness, sweating; increased heart rate	None	40,000	5,000	30,000	1.53 (heavier than air)	None (colorless)	None (odorless)	Nonflammable gas
Carbon monoxide (CO)	Asphyxiant; headache, nausea, weakness, dizziness	–	1,200	No standard; 200 "ceiling" *(note 3)*	No standard	0.97 (lighter than air)	None (colorless)	None (odorless)	Flammable gas; explosive between 12.5% and 74% by volume of air mixture; auto ignites at 1,128°F (609°C)
Methane (CH_4)	Asphyxiant	–	No standard	No standard	No standard	0.72 (lighter than air)	None (colorless)	None (odorless)	Explosive between 5% and 15% by volume of air mixture; auto ignites at 999°F (537°C)
Nitric oxide (NO)	Respiratory irritant; irritates eyes, wet skin, nose, throat; drowsiness	–	100	25	No standard	1.04 (heavier than air)	None (colorless)	Strong, pungent	Nonflammable gas, but will accelerate the burning of combustible materials
Nitrogen dioxide (NO_2)	Respiratory irritant; irritates eyes, nose, throat; coughing; chest pain	Permanent lung damage	20	No standard	1	2.62 (heavier than air)	Reddish-brown gas	Strong, pungent	Noncombustible liquid/gas, but will accelerate the burning of combustible materials
Nitrogen tetroxide (N_2O_4)	Respiratory irritant	Permanent lung damage	50	No standard	No standard	1.58 (heavier than air)	Yellow	Strong, pungent	Nonflammable gas, but will support combustion

Adapted from *NIOSH Pocket Guide to Chemical Hazards* (June 1997 edition). Supplemented with information from *Rural Rescue and Emergency Care,* which was published in 1993 by the American Academy of Orthopaedic Surgeons (and may now be out of print).

Note 1: Maximum Exposure Limits are established by NIOSH (National Institute for Occupational Safety and Health) and are expressed as three distinct values. (a) **IDLH** concentrations are Immediately Dangerous to Life or Health and are expressed in parts per million (ppm). (b) **RELs,** or Recommended Exposure Limits, are time-weighted average (TWA) concentrations for up to a 10-hour workday during a 40-hour workweek. RELs are also expressed in parts per million. (c) An **STEL,** or Short-Term Exposure Limit, is a 15-minute time-weighted average (TWA) exposure that should not be exceeded at any time during a workday. STELs are also expressed in parts per million.

Note 2: Relative densities of gases indicate how many times a gas is heavier than air at the same temperature. Air is assigned a density of 1. Gases with densities less than 1 are lighter than air; gases with densities greater than 1 are heavier than air.

Note 3: A "ceiling" REL should not be exceeded at any time.

mix with air. When the amount of carbon monoxide in the air is between 12.5% and 74% by volume, the mixture becomes highly flammable or combustible.

Carbon Dioxide

Carbon dioxide is present in small quantities in a flaming fire or after complete combustion. Carbon dioxide is nonflammable and heavier than air. At low concentrations it is nontoxic. But at higher concentrations, it displaces oxygen and is a life-threatening asphyxiant.

Nitric Oxide, Nitrogen Dioxide, and Nitrogen Tetroxide

Nitric oxide, nitrogen dioxide, and nitrogen tetroxide are poisonous gases that form when nitrogen-containing organic compounds such as silage burn. These gases also occur as byproducts of silage fermentation. The highest levels are present during the first 48 hours after silage is put into a silo, but dangerous levels may exist for up to 3 weeks. Nitrogen dioxide and nitrogen tetroxide are the most dangerous and are most likely to be present in the silo.

Methane

Small amounts of flammable methane may be produced when drought-damaged crops are ensiled. Farmers have reported seeing small, blue-flamed flash fires originating at the base of a silo chute and then traveling up the chute. Such fires are characteristic of burning methane gas. In some cases, the flash fire was set off by equipment and light switches being flipped on. These fires generally burn any silage chaff in the chute and may char or burn the outside of silo doors. Ignited silage chaff may be transported to other areas of barns by feed-handling equipment, or it may ignite other combustibles lying at the base of the silo chute. The authors are not aware of any instance where this type of fire ignited silage inside the silo.

Other Gases

Additional gas production from the burning of polymers is becoming quite common during silo fires. The gases produced when plastic silo liners and epoxy coatings inside vertical silos burn constitute a safety risk for firefighters. Wearing full turnout gear with a supplied-air respirator (SAR) or self-contained breathing apparatus (SCBA) helps protect against such toxic gases. (The same hazard exists from burning silage bags that lie horizontally.)

Chemical Additives

Occasionally, chemicals are added to corn silage to increase its nutritional value or protein content. The most commonly used chemicals are urea (which breaks down into ammonia and carbon dioxide) and anhydrous ammonia. Organic acid preservatives, such as propionic and acetic acids, are sometimes used in silage, but these are easily volatilized. The chemical additives pose no additional fire hazard, but they are acidic (approximately 4.5–5.0 pH) and can cause burning or other irritation of the eyes and respiratory tract.

Structural Damage

Always be observant for evidence of structural damage to the silo, the silo foundation, and silo attachments. Look around the silo for cracks in the structure. Also look for damage that may have occurred to cable stays, unloader cables, roof material, and the external ladder.

Controlling Fires in Conventional Silos

The procedures for extinguishing fires vary with each situation. Consider the following steps, even though the sequence may vary and some steps may not always be necessary.

Step 1a: Size Up the Situation (The Farmer)

In most cases, both the farm operator and the firefighters will size up the situation. The farmer will size up the scene as a part of discovering that a fire exists. If a fire is discovered, or even if it is only suspected, a farmer should immediately notify the fire department. Farmers should not climb the silo chute for a closer inspection, because there are too many unknown factors. For example, there is the possibility of fire gases, burning embers falling down the chute, and hot metal from the silo chute door frames. **Only a firefighter wearing full turnout gear and a supplied-air respirator (SAR) or self-contained breathing apparatus (SCBA) should enter the chute.**

After notifying the fire department, the farmer should attempt as many of the following actions as are warranted by the situation:

1. Close the bottom of the chute. Air moving through the chute will fan the fire. Sheet metal or other noncombustible materials should be used to close the chute.
2. Remove all livestock from any exposed or adjacent buildings.
3. Wet down the area around the silo chute to prevent firespread.
4. Place noncombustible shields (metal siding, etc.) over any openings to prevent sparks and embers from flying into barns and sheds.

Step 1b: Size Up the Situation (The Firefighter)

1. Ask the farmer to confirm that the silo involved is a conventional silo, and then verify the silo type visually (see "Conventional Silos," page 2, and "Recognizing Silo Types," page 5).
2. Lock out all power to avoid accidental startup of unloading equipment or an electrical shock from a burned or shorted-out power cord.
3. Determine the location of the silo unloading mechanism. Ask the farmer for the location of the unloader, and verify the location by visual inspection from the external filling platform.

   NOTE: Before any other entry or extinguishing procedures begin, the unloader must be secured with a chain to the upper support members or lowered completely to rest on top of the silage. Lowering the silo unloader is not recommended until any surface burning has been controlled.
4. Remove any material that the farmer may have used to close off the bottom of the silo chute.
5. There have been several instances where fire occurred in the chute only. After extinguishing any visible fire in the silo chute, make a close inspection of the doors to determine whether the fire has extended out from inside the silo or is in the chute only.

   Chute fires occur when dried silage and silage chaff that accumulates between the door frames and doors ignites. The ignition source of chute fires is not well understood, but possible sources include a combination of flammable gases from poor fermentation, sparks from static electricity or unloading equipment, and heat.

   Always wash down chute areas immediately and check to see if doors are burned from the outside in.
6. If the fire is not a chute fire, determine the location of the fire within the silo. It has been the authors' experience that the majority of fires occur in the top 10 feet of silage, and within that range, most fires occur in the top 4–6 feet (figure 3-3). Although a fire can start wherever the ensiled material is not at the appropriate moisture content, fires in conventional silos often originate near the unloading doors, where air leaks dry the silage. The first indication of a fire is often a burning or burned unloading door.

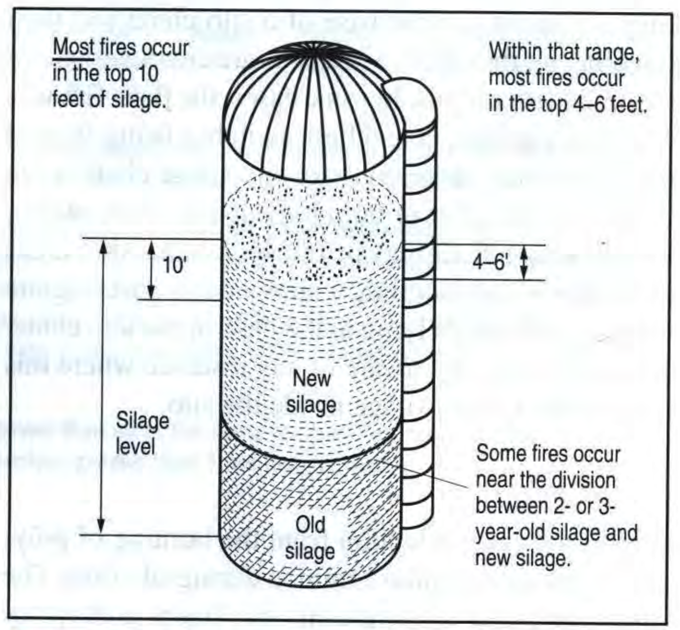

Figure 3-3. Location of most fires in conventional silos

The fire location can be determined by looking through the silo filling door (see figure 1-2, page 3) from an aerial ladder or the external filling platform or by climbing the silo chute. Sometimes it is necessary to check from both ends (that is, top and bottom). Remember, if it is necessary to climb the silo chute, the firefighter should wear full turnout gear, wear an SCBA or SAR, and use a safety harness with a ladder hook. Auxiliary lighting inside the silo is often needed; flood lights can be positioned from the filling platform or aerial ladder.

Many fire departments are now purchasing thermal imaging cameras and have used them to help identify where hot spots are from outside of the silo. Initial reports have been rather promising. Although the exact fire location may not be identified, the units do a good job of locating the approximate depth and side of the hot spot(s). Some departments have used a piercing nozzle from outside the silo with fairly good success. The nozzle is pierced directly into the suspected hot spot through the silo wall. This can only be effective if the hot spot is within reach of the end of the nozzle. This particular strategy may be a good alternative to steps 3 and 4 below, especially if the fire has progressed to the point where is it unwise to have personnel inside the structure.

Step 2: Knockdown Surface Burning

By the time the fire department arrives, the silo fire may have well-established flames on the surface of the silage. Unloading doors may have burned through, allowing flames to extend up the silo chute. Water will cool the fire and keep flames from spreading. Similar to determining the fire location (step 1b), knocking down surface fire may be done from an aerial ladder or the silo filling platform or from the silo chute. Sometimes dousing from both locations (the top and the bottom) is needed.

If the dousing is done from an aerial ladder or from the silo filling platform, only one firefighter in full turnout gear, complete with a lifeline and SCBA, is needed. If dousing is needed from the silo chute and the firefighter must climb more than 4–5 feet up into the chute, a second firefighter may be necessary to help handle hose. Both firefighters should have full turnout gear with an SAR or SCBA.

When knocking down a surface fire that is burning freely from the silo chute, use a straight-tip nozzle. The smooth bore water stream from the straight-tip nozzle penetrates the pile and better extinguishes fire that has become deep-seated. A 3/8-inch tip is recommended. After the surface fire is extinguished, follow steps 3 and 4 below for injecting water through probes for a subsurface fire.

As with any fire in an enclosed area, considerable amounts of gases, smoke, and steam will pour out when the fire in a conventional silo is hit with water. After dousing, remove as many unloading doors as possible above the top surface of the silage and open or remove all silage coverings or roof openings to allow hot gases to escape.

Step 3: Take Temperature Readings

A firefighter can only get a temperature reading by entering the silo. An unseen fire may create one or more small or large cavities in the silage. **A large cavity is a life-threatening hazard.** Any person entering the silo should be fully protected with turnout gear, a body harness, and a lifeline attached as high as possible to a beam or silo hoop. Minimal slack should be maintained in the line to minimize a fall if the surface of the silage should give way. An additional firefighter equipped with an SAR or SCBA and full turnout gear should be stationed on the silo filling platform or in the silo chute to observe, assist, and maintain radio communication with the ground.

One of the keys to extinguishing a conventional silo fire is to find the exact location or locations of the fire. This can be done with an easily constructed probe and a thermometer. It is recommended that every fire department have a probe and thermometers to locate hot spots in silage or hay. The most common design for the probe uses lengths of 3/8-inch or 1/2-inch galvanized pipe with a drive point ventilated with at least four holes (figure 3-4 on page 14). The other end of the probe has a 1/4-turn ball valve and sufficient adapters to connect the probe to a 1 1/2-inch fire line. Before taking temperature readings, be sure to follow the instructions below.

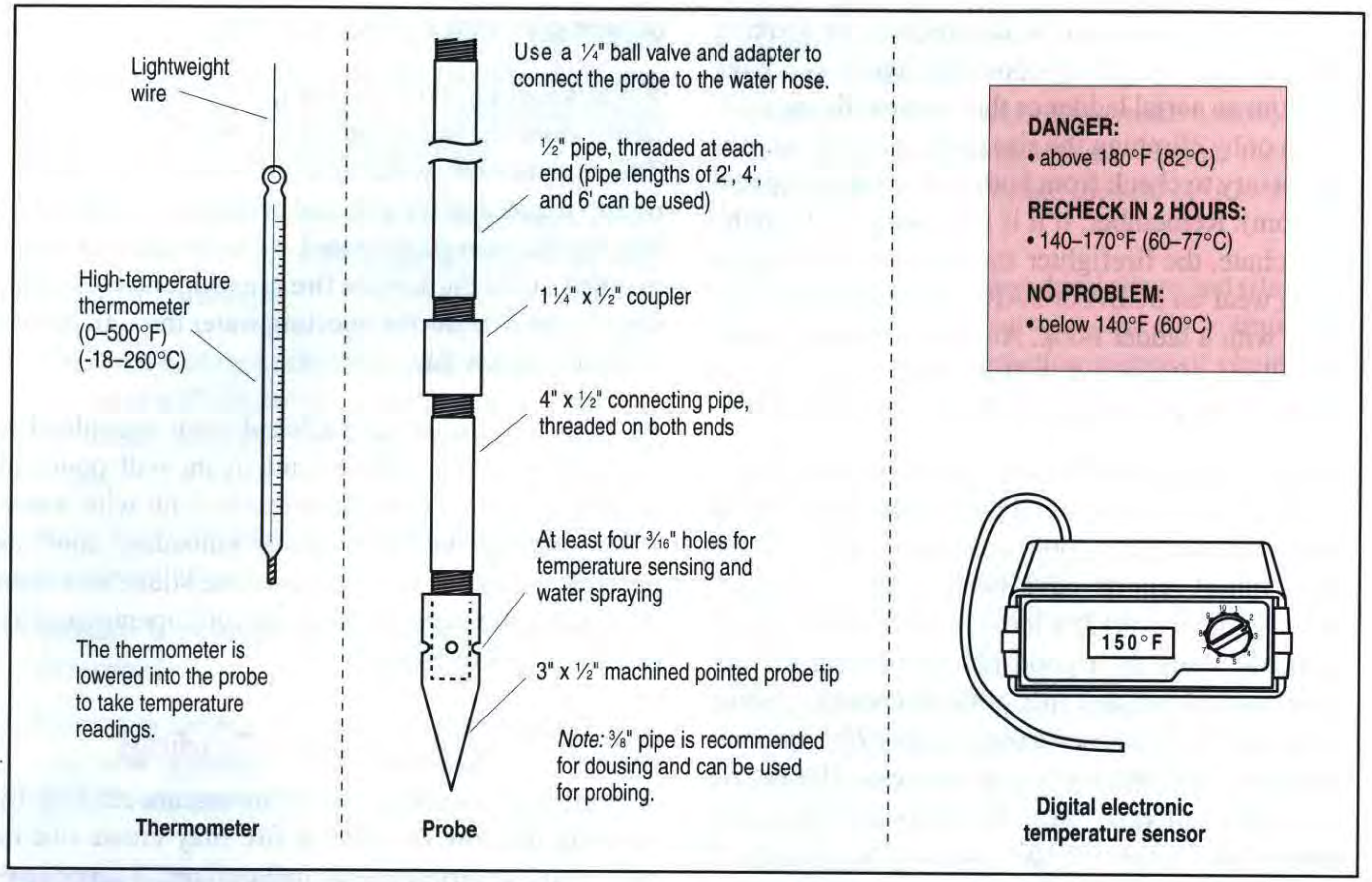

Figure 3-4. Thermometer, probe, and digital electronic temperature sensor

Do not step directly onto the silage, whether a fire has been confirmed or is only suspected. Lay wooden planks on the silage from the door frame to distribute weight over a larger area and minimize the risk of collapse into a fire cavity (figure 3-5). Planks may be hauled up the chute on some silos, or they may have to be lowered from the silo filling door. If all surface burning has been controlled, the frame of the unloader can also offer a platform from which to work.

Lower a high-temperature (0–500°F) thermometer or other temperature-sensing device on a lightweight wire into a probe to obtain temperature readings. A variety of remote reading devices (such as digital electronic temperature sensors) and temperature probes are available from various companies; they may be used separately or in conjunction with homemade probes. Dairy thermometers or other devices on the farm can also be adapted for use in an emergency.

Make several temperature readings, starting near any obvious hot spots, and gradually move toward the silo wall at 3-foot intervals. To help track progress in

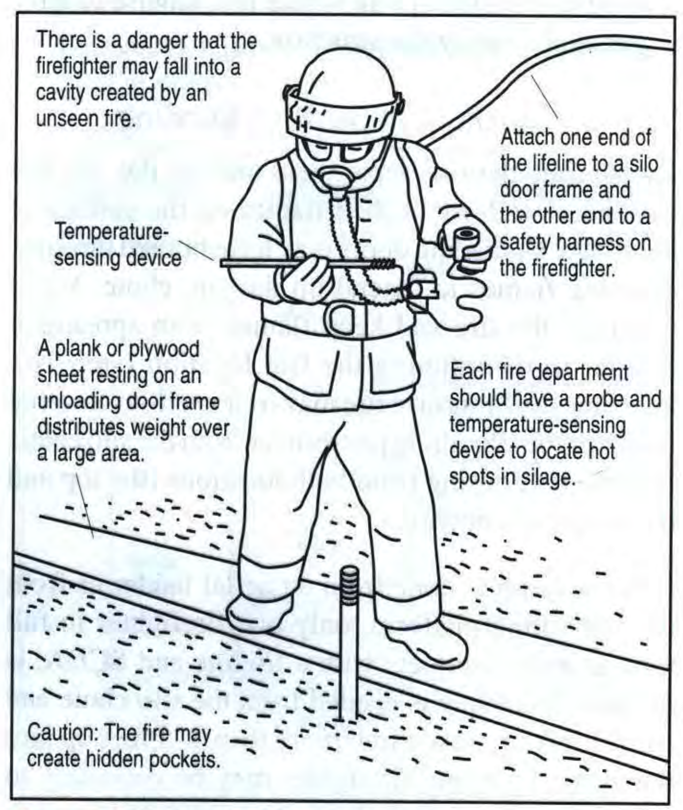

Figure 3-5. Probing for hot spots in silage

checking for hot spots and a firefighter's movements inside the silo, think of the silo as the face of a clock, with the chute at 6 o'clock (figure 3-6). Clock positions can be used in communications. If a fire is caught in its earliest stages, there may be only one hot area. If the fire is not caught early, several hot spots may exist, because the fire will follow air pockets to support itself. Therefore, it is important to take several readings across the silage. Make a diagram such as the one shown in figure 3-6 to keep track of hot spots.

How far a probe can be inserted into the silage depends on the condition of the silage. A probe will penetrate easily into a spot that has been charred or burned, but it may be difficult to push the probe more than 4–6 feet into packed, finely cut silage. Make every effort to insert the probe to a depth of at least 6 feet.

Temperature readings near 180°F or higher indicate that the material will eventually burn, and it has lost its value as feed. Temperature readings of 140–170°F may indicate that silage is heating, or they may indicate that residual heat from a hot spot is moving through the silage. Monitor temperatures every 2 or 3 hours at this stage. Temperatures below 140°F indicate no serious heating problems.

Step 4: Inject Water

Action must be taken to cool the silage if the temperature reaches 180°F or higher. Experience has shown that simply flooding the silo with water will not extinguish the fire (figure 3-7). Water always follows the path of least resistance; in this case, it will run down the inside silo wall and out the bottom, bypassing most of the hot silage. Water must be injected directly into hot areas of silage. Remove the thermometer from the probe, and connect the probe to a hose to inject water directly into the hot areas (figure 3-8). In most cases, the probe operator will have to go inside the silo and inject water from the top down; however, this action must be decided on at the fire scene.

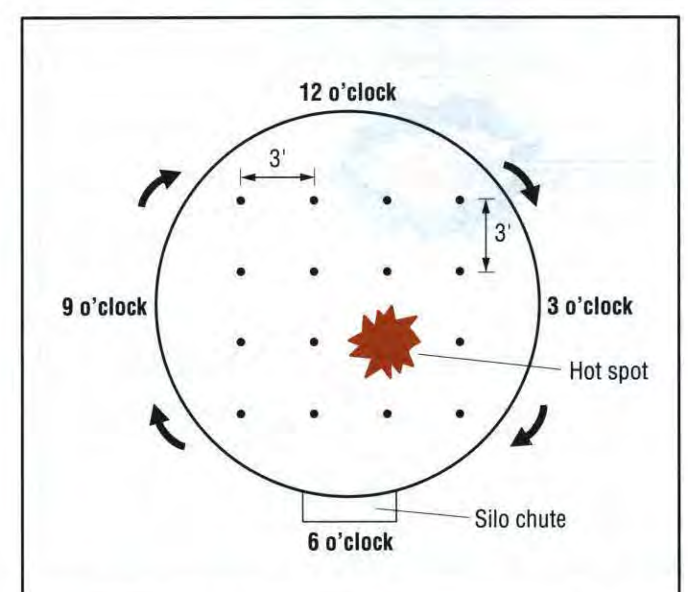

Figure 3-6. Locating hot spots using the clock method

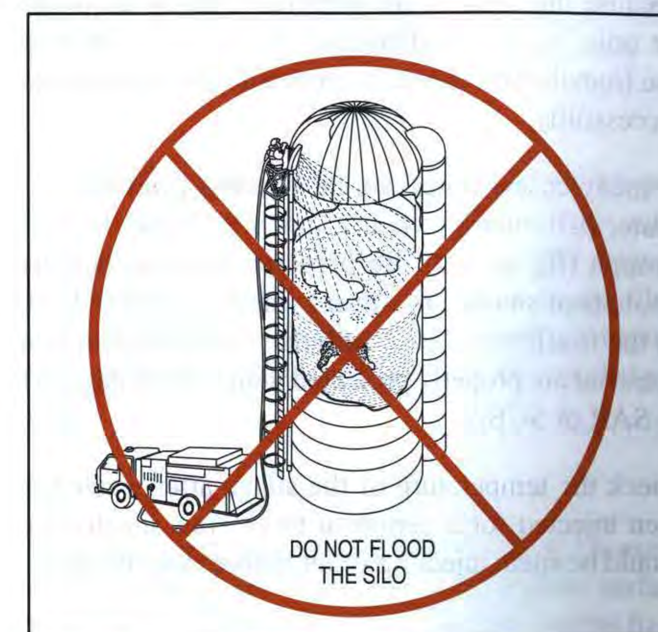

Figure 3-7. Do not flood a silo with water

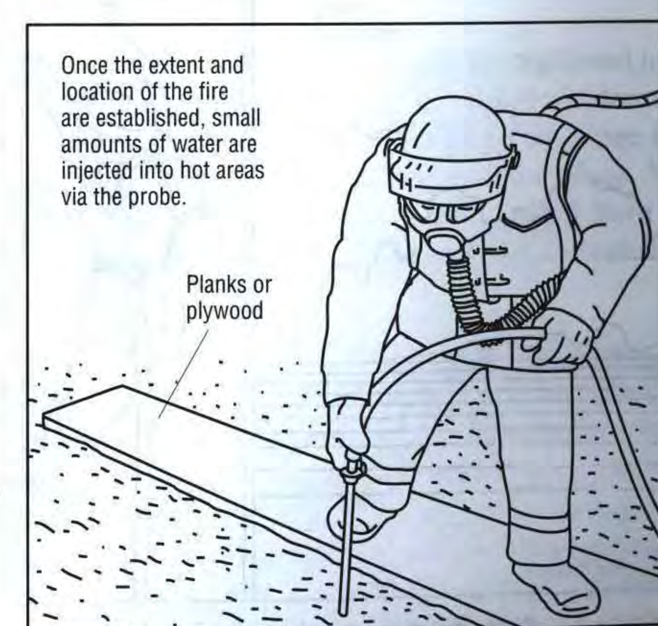

Figure 3-8. Inject water directly into the silage

When injecting water into silage, work slowly and methodically. Start with any known hot spot and move the probe in a circular pattern around the hot spot, 1–2 feet at a time. Leave the injection probe in a single spot for no more than 20–25 seconds before moving it.

CAUTION: Injecting too much water too quickly can cause steam to develop rapidly, which may in some cases cause an explosion (see "Water-Gas Reaction" at right).

Because the holes in the perforated tip of the probe are only 3/16 inch in diameter, use the smallest hose line from the fire engine. A garden hose has been used successfully.

In many cases, water can be injected from the silo chute, particularly when a hatch door has burned through (figure 3-9). Be prepared for considerable amounts of smoke and steam, which may blow back on the firefighter. Make sure that the firefighter and attendant are properly protected with turnout gear and an SAR or SCBA.

Check the temperature of the silage after water has been injected for a period of time. How much time should be spent injecting water before more temperature readings are taken can only be determined at the scene, but 30–45 minutes is a practical guide.

Water-Gas Reaction

There may be concern about creating a "water-gas reaction" and causing the silo to explode by injecting water into burning silage. In conventional silo fires, this is **not** a realistic expectation. The few violent explosions that have been reported from silo fires have all been in oxygen-limiting silos, where the explosive gases were trapped and could not escape. Even in these cases, it is not certain that the explosions were caused by water-gas reactions.

The water-gas reaction is the reaction of water molecules with burning carbon, which produces hydrogen (H_2) and carbon monoxide (CO) gases. This can happen when water is injected into very hot carbon fires. However, the chemical reaction is highly endothermic (heat-absorbing) and causes the temperature of the hot material to drop rapidly. This lowers the rate of the reaction and then stops the reaction totally. Thus, there would be only very small quantities of gases produced by a water-gas reaction.

Another important point that practically precludes violent explosions from occurring in conventional silos is that there is no containment of gases or air. Thus, there can be no explosion. For an explosion to occur in a silo, there must be containment and consequent buildup of pressure beyond the capacity of the structure. This does not happen in conventional silos. However, a few occurrences of minor explosions have been reported. These minor explosions have been caused by rapidly developing steam that was generated when too much water was injected too quickly.

Rapid steam production can be a risk when water is injected at very high flow rates and for long durations into areas of heavy combustion. Under such extreme conditions, steam is produced faster than its ability to escape from the cavity. Furthermore, the water has no opportunity to perform its extinguishing function. When injecting water, use minimum flow rates, and do not allow water to flow for more than 20–25 seconds in a single spot.

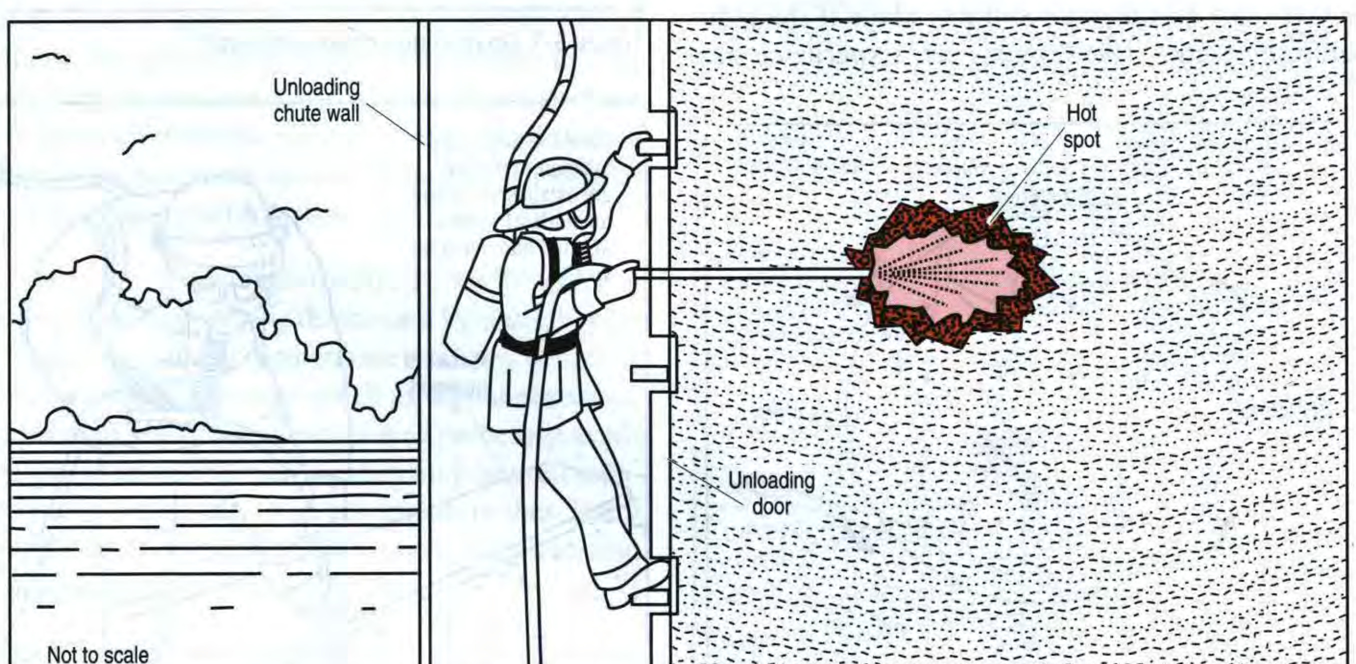

Figure 3-9. Water injection from the unloading chute

Water Additives

Chemicals that help water absorb heat will work if used on a silo fire. If chemicals are mixed according to their labels, no adverse effects will occur to the silage. Chemicals that reduce water friction are of no benefit, because large quantities of water are generally not used in fighting silo fires.

Step 5: Remove Damaged Silage after Fire

After a silo fire has been extinguished, unload damaged silage and deposit it at a safe distance from any buildings. This is important for three reasons:

- Overheated silage loses its nutritional value.
- The top layers of wet silage may spoil or mold.
- Any hot spots missed may reignite.

Heat Damage

Silage that has been heated to over 150°F will lose much of its nutritional value. Also, charred silage has little feed value, since cattle may not eat it depending on its taste or aroma. In some instances, however, cattle will actually eat more heat-damaged silage to try to compensate for the lost nutritional value. The only conclusive way to determine the quality of overheated silage is to have it tested for heat-damaged protein at a forage laboratory. Silage below the fire level will not be damaged and will not lose any nutritional value if it has not been saturated with water.

Water Damage

Silage saturated with water may mold and spoil, because much of the preserving acid produced during fermentation has leached out or been diluted. The nutritional value of the saturated silage is reduced, and the cattle may refuse to eat it. Water also increases the gross storage weight of the silage and can result in saturated silage that exceeds the silo capacity.

Reignition

When extinguishing conventional silo fires, it is possible to miss some hot spots. If spots are missed or only partially cooled, they can dry out and reignite. The injection of water tends to loosen silage fibers and create air spaces within the silage. If a hot spot is only partially extinguished, the extra air may help reignite the fire.

Unloading Precautions

In some cases, the top unloader may not be usable due to wetness of the silage or an uneven surface. Some of the silage may have to be removed by hand. Full turnout gear including an SCBA should be worn when removing silage.

As layers of silage are removed, take additional temperature readings and examine the silage to determine its condition. It is important to unload the silage to a level just below any burned or charred silage. Unloading below this level is necessary only if there are hot spots, fire-damaged silage, or water-saturated silage.

Most silo unloader motors are designed for intermittent operation and will overheat if run continuously. Another danger is that hot silage may flame up and burn the motor as layers are exposed to the air. To prevent these problems, allow the unloader motor to cool off every half hour, and use the cooling time to probe for hot spots. Lockout the unloader any time a firefighter is inside the silo or silo chute.

Advanced Fires in Conventional Silos

Some silo fires are not discovered until several weeks after ignition. A silo fire in its advanced stages rarely remains below the surface of the silage. Instead, the fire travels horizontally toward the walls of the silo or vertically to the upper surface of the silage.

Silage shrinks as it dries. As a result, there may be an air space several inches wide between the silage and the silo wall. When silage is exposed to the air, it dries further and becomes an excellent fuel for fire. Quite often, the unloading doors in a conventional silo leak air and permit the silage to dry and shrink for some distance down the silo. This drying produces a column of dry fuel along the doors. When fire reaches any of these areas of dry silage and abundant air supply, it spreads very quickly and burns freely instead of smoldering. Extinguish any surface fire before attacking the subsurface fire.

Types of Advanced Fires

The most common example of advanced burning is a fire along a column of dry silage behind the unloading doors (see left side of figure 3-10). Attack these fires in the following manner:

- Follow recommended safety practices, including adhering to confined-space procedures (see page 1) and using full turnout gear.
- From the silo chute, extinguish all surface burning by aiming a straight-tip nozzle through burned-out openings in the unloading doors. Usually, these doors will allow access to the fire. Chopping through a door that is not burned will be difficult and probably unnecessary.
- After extinguishing surface burning, extinguish all subsurface fire using short (2-foot or 4-foot) water probes. Insert them in the silage in all directions by passing them through the burned-out door openings (see "Step 4: Inject Water," page 15).
- After all fire is extinguished, replace burned doors with new or rebuilt ones. Backfill dampened silage into the burned-out cavities and level the top surface of the pile so the farmer can immediately begin the unloading process (see "Step 5: Remove Damaged Silage after Fire," page 17).

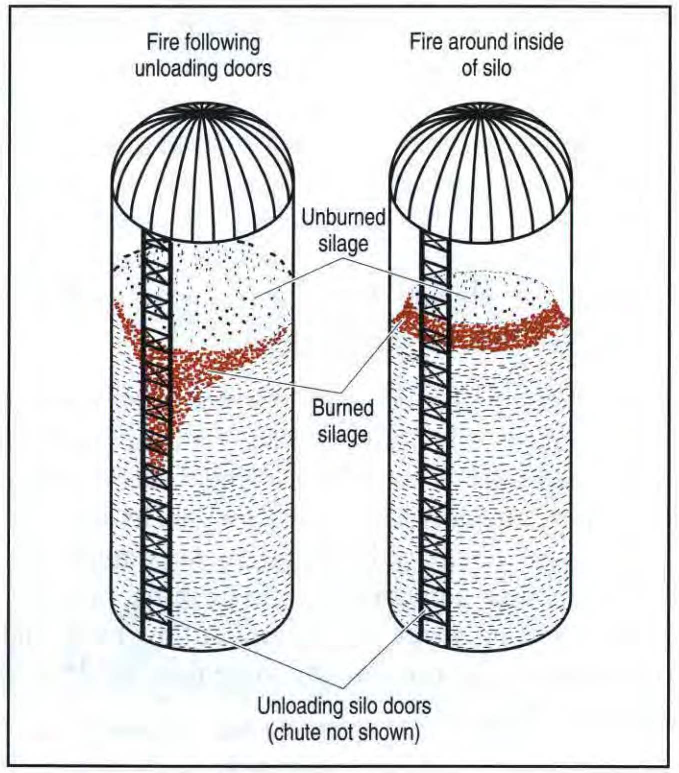

Figure 3-10. Typical advanced silo fires

The next most common type of advanced fire in a conventional silo is a fire burning in a circular pattern horizontally around the inside of the silo wall. The burn pattern is usually a trench-like area only 3–4 feet deep around the circumference of the silage at the top of the silo (see right side of figure 3-10). Attack these fires in the following manner:

- While employing confined-space procedures (see page 1), lay planks to walk on.
- Extinguish all surface burning using a straight-tip nozzle. Start the knockdown just inside the nearest unloading door, and advance halfway around the ring. Retrace the path and work around the other half of the ring to the far side of the silo.
- Extinguish all subsurface fire using water probes (see "Step 4: Inject Water," page 15).

Occasionally, a silo fire will be too far advanced to be extinguished. In such cases, prop up a piece of metal at the bottom of the silo chute to block off any falling embers, remove any conveyor or feed equipment, and wet down the unloading area.

Other Concerns

Structural Damage

In most silo fires there is little, if any, structural damage. If fires are allowed to rage out of control, concrete will crack, but this does not usually happen. Slow-burning fires seldom damage concrete, but they may damage or weaken a concrete plaster interior coating or plastic silo liner, especially near unloading doors where the temperature is very high.

Silo manufacturers do not recommend applying water to the outside of a silo. **Applying cool water to heated concrete may cause more damage to the silo wall than the heat alone.** Less stress is placed on the heated silo wall by allowing it to cool down naturally than by artificially cooling it with water. There is minimal danger of structural collapse, even if small areas of a silo wall become so overheated that they glow.

After a silo fire, the farmer should inspect and repair the silo as needed. A commonly needed repair is to a silo hoop that was damaged by thermal expansion or heat. The silo dealer or manufacturer and insurance carrier should be able to assist in this.

Fires outside the Silo

There is some question as to whether an external fire in a nearby barn can ignite silage inside a silo. This can happen with a large fire, but silos and the silage inside can be saved in many instances, even when the entire barn is lost. Outside heat is not readily transferred to the silage inside a silo.

Relatively thin layers of silage such as that on unloading doors may smolder or burn as a result of heat concentration from a fire outside the silo. These occurrences should be investigated and addressed appropriately, as outlined earlier in this publication (see "Controlling Fires in Conventional Silos," page 11).

The Use of Gas in Conventional Silo Fires

Carbon dioxide (CO_2) or nitrogen (N_2) may help to extinguish some conventional silo fires. Both gases displace oxygen that supports the fire, so the fire suffocates. However, the expense of the materials and problems involved in using them during cold weather make the water injection method followed by unloading overheated silage a more practical extinguishing strategy.

If gas is used to extinguish a fire, carbon dioxide is the usual choice because it is more readily available than nitrogen. Gases may be injected into the silage with a probe pushed through burned-out hatch doors, holes cut into hatch doors, or holes in the side wall.

After carbon dioxide or nitrogen has been used to extinguish a silage fire, certain procedures must be followed to prevent reignition. Most likely, the initial fire was caused when the silo was filled with silage that had a moisture content between 25% and 45% (see chapter 2, "What Causes Silo Fires?," page 7). The heat of the fire further dried the silage around it, creating additional fuel. After the fire is extinguished, the silage temperature must be checked twice daily to ensure that it doesn't reignite, especially near the fire area. This monitoring should continue for 2–3 weeks or until the temperature of the silage stays well within the "safe" range of 100–140°F for several days.

If the temperature rises and sufficient oxygen and dry material are present to support additional burning, the silo should be reinjected with carbon dioxide or nitrogen. The best fire control will occur when the silo is frequently charged with carbon dioxide or nitrogen. These gases reduce oxygen concentration in the silage so that it is below the amount required for combustion. Temperature monitoring must continue until the silage no longer heats to above 140°F.

If the fire continues to burn and the temperature continues to rise after the 3-week period, the silage will have to be removed from the silo. A fire watch should be stationed at the unloading chute to extinguish any burning material and wet down any charred or extremely dry material being unloaded. The unloaded silage should be taken to a remote spot in case it reignites at a later time.

• CHAPTER 4 •

Fires in Oxygen-Limiting Silos

Spontaneous combustion in an oxygen-limiting or sealed silo is rare but does occur. A fire in an oxygen-limiting silo can be extremely hazardous. With sufficient heat or flame to ignite the confined gases, the only thing preventing an explosion is insufficient oxygen. Proper methods or techniques for extinguishing these fires can prevent explosions.

Manufacturers are constantly warning farmers and firefighters to stay out of filled or partially filled oxygen-limiting silos. **There is not enough air inside an oxygen-limiting silo to support life.** Respiration and fermentation of the material in an oxygen-limiting silo convert oxygen in the air into carbon dioxide. Within 30 minutes of putting forage or high-moisture grain into a silo, the oxygen level may be too low for a person to breathe. If tools or other objects are accidentally dropped into the structure, no one should attempt to retrieve them without following proper confined-space entry procedures (see page 1).

The basic rule for proper maintenance of oxygen-limiting silos is to keep all openings closed, except when filling the silo or operating the unloader. Excluding air preserves the silage and prevents combustion. Even with silage at 55% dry matter, there is usually insufficient oxygen to support a fire after an oxygen-limiting silo has been filled and tightly closed. Sometimes a slow-charring fire will self-extinguish due to insufficient oxygen.

Despite these factors, there have been a few disastrous explosions in oxygen-limiting silo fires. Firefighters have been killed and seriously injured in silo explosions in Indiana, Louisiana, New York, Ohio, and Pennsylvania.

An oxygen-limiting silo always has some oxygen inside. Air and oxygen will be found in the dome above the bottom unloader and between the top of the silage and the silo roof. There may be other air leaks through the silo wall because of weather stress, defective materials, or poor workmanship. Many oxygen-limiting silo fires start or are sustained because the farmer neglected to close the top-hatch cover after filling or the unloader door after unloading.

Fires in oxygen-limiting silos are discovered when burned or burning silage comes out through the bottom unloader or when smoke escapes from the top of the silo.

Essential Safety Precautions

A fire in an oxygen-limiting silo can be extremely hazardous. If firefighters use improper extinguishing techniques, a devastating explosion could result. Contact the dealer immediately for assistance in identifying people who are trained in controlling fires in these structures.

On some silos, warning signs are placed at the base of the silo adjacent to the ladder and at the top of the silo near the closest roof hatch door opening. These signs warn firefighters and other emergency personnel to never use water or foam to extinguish an oxygen-limiting (sealed) silo fire (figure 4-1).

Do nothing that might increase the level of oxygen or air inside the silo. Do not open the top-hatch cover to pump in water or foam. Opening the hatch might allow enough oxygen to be pulled in to put gases into their explosive range. Even air trapped in water droplets and foam particles can increase the danger. **Do not use water or foam on fires in oxygen-limiting silos.**

Figure 4-1. Warning sign for oxygen-limiting (sealed) silos

Note: These signs are available from D. W. Miller Industries, Inc.; RD #1, Box 7B; Huntingdon, PA 16652.

Check the unloading conveyor door to see if it is properly closed and sealed. If it is not, seal it so that oxygen cannot enter through it to feed the fire. Openings such as manhole covers and drain caps used for silo maintenance should also be checked and sealed.

Leave an open roof hatch alone if smoke or steam is coming from the top, or if the silo shakes or rumbles. If the silo is quiet and you haven't seen smoke for several hours, it should be safe to close the top-hatch cover. However, **do not tie down or latch the cover.** If gas pressure increases above the relief capacity of the breather valve, the hatch should be free to open to relieve the pressure.

Controlling Fires in Oxygen-Limiting Silos

Closing all hatches for 1–3 weeks may be all that is needed to extinguish a fire in an oxygen-limiting structure. Decisions should be made in consultation with the farmer and the silo manufacturer's service representative. Periodic inspections should be made during this time to observe any progression of the fire, such as smoke or heating up of the silo wall.

One method of extinguishing fires that has been used in oxygen-limiting silos is for trained firefighters, silo service representatives, or suppliers of industrial gases to inject liquid nitrogen (which turns into a gas upon injection) or carbon dioxide to displace oxygen and cool the fire. However, injecting liquid nitrogen or carbon dioxide requires special training to avoid increasing the risk of explosion. The silo dealer can assist in contacting experienced individuals.

Injecting Gas into a Sealed Silo

If sealing the silo for up to 3 weeks does not extinguish the fire, inject liquid nitrogen or carbon dioxide into the structure to displace oxygen and cool the fire. Be careful not to introduce additional oxygen. Most silos have a pipe nipple that is used to inject gases for fire control. Oxygen-limiting silos should be inspected each year to determine whether the nipple is open and functional. If a nipple is not present, have the farmer install one or have one installed by the manufacturer or dealer. A pipe nipple could be installed even after fire has been discovered as long as there is no rumbling or shaking of the silo (figure 4-2).

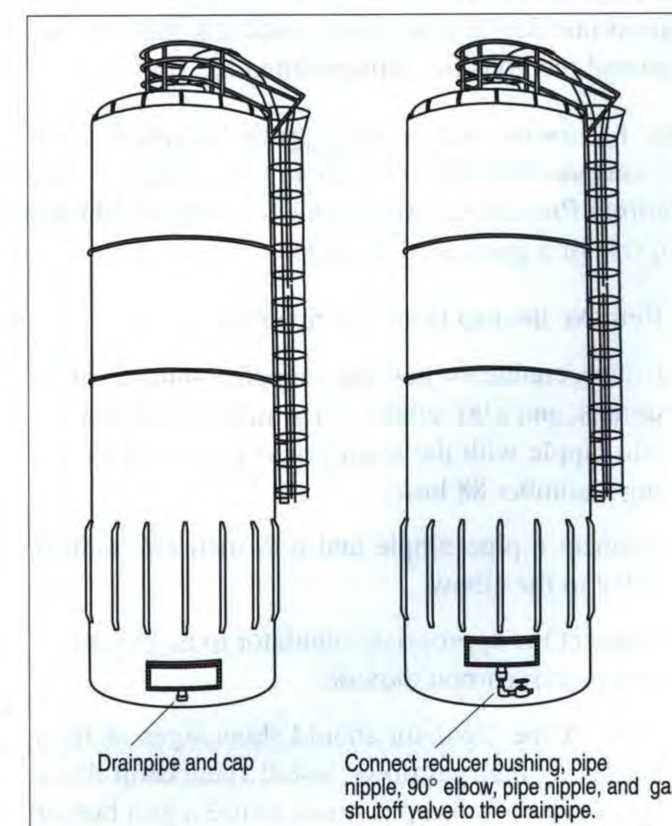

Figure 4-2. Connections for gas injection

The nipples for injecting gas into the silo can be found in several different places. Silos using chain and paddles to remove the silage usually have nipples directly below the conveyor in the silo wall. Those silos using a screw-type auger to remove the silage from the silo usually have nipples in the side of the auger housing near the discharge end. Some concrete oxygen-limiting silos have nipples in the inspection plate on the outside wall of the silo. Some silos have no nipples at all. Fire personnel should visit farms with silos prior to an incident to do incident preplanning and to locate important features of the silos.

Harvestore Structure Emergency Procedures: Fire Fighting Procedures, a four-page bulletin developed by A.O. Smith Harvestore Products, Inc. (March 1993), gives step-by-step instructions for extinguishing fires in their silos. The procedures outlined in the Harvestore bulletin are applicable, with slight variation, to other makes of oxygen-limiting silos. Differences or variations between this publication and the Harvestore bulletin are based on personal experiences of the authors. For additional information, always consult the operator's manual for a particular silo. If a fire should occur in an oxygen-limiting silo, call the appropriate dealer immediately and ask them to recommend methods for extinguishing the fire.

The following steps have been adapted from *Harvestore Structure Emergency Procedures: Fire Fighting Procedures.* See figure 4-3 on page 23 for a diagram of a gas injection setup.

1. Remove the cap from the pipe nipple.
2. Connect reducers, bushings, nipples, shutoff valve, unions, and a 90° elbow as required to connect the silo nipple with the appropriate gas regulator using a number 88 hose.
3. Connect a pipe nipple and a ¾-inch gas shutoff valve to the elbow.
4. Connect the appropriate regulator to a cylinder of nitrogen or carbon dioxide.

   Note: If the regulator should show signs of frost because of high gas flows, install a heat lamp above the regulator to keep it warm or use a gun burner heater.

5. Set the pressure regulator to approximately 40 pounds per square inch (276 kiloPascal) gas pressure. Open the gas shutoff valve and inject gas into the structure. The amount of nitrogen or carbon dioxide needed will depend upon the size of the structure and fill level. Monitor the gas injection equipment to ensure a uniform flow of gas.

   CAUTION: All gas cylinders must be grounded to the silo or an appropriate ground rod to ground any static electricity. Automotive battery "jumper cables" work well for this requirement.

6. Wait at least 48 hours after the structure has been injected. If visible signs of the fire are still present, inject the structure again.
7. If the structure itself is calm (no vibrations or rumbling) and no smoke or steam is visible, climb the structure and inspect and close the roof hatches if they were open. The hatch (or hatches) should **not** be secured down. If gas pressure subsequently builds beyond the capacity of the relief valve(s), these covers can lift to relieve the pressure.

Nitrogen and carbon dioxide cylinders are available in many industrial areas. The estimated amounts of carbon dioxide and nitrogen needed to control silage fires are listed in table 4-1.

Depending on the quantity and quality of the silage that remains, the silo may need to be emptied after the fire has cooled. If a small amount of poor-quality silage remains, the fire may reignite when the control gases escape. The fire is not likely to restart if a large amount of good-quality silage remains.

Table 4-1. Estimated amounts of carbon dioxide or liquid nitrogen needed to control silo fires

Silo Size	Carbon Dioxide (CO_2)	Liquid Nitrogen (N_2)
20 x 60	20 cylinders	40 cylinders
20 x 70	22 cylinders	44 cylinders
20 x 80	30 cylinders	60 cylinders
24 x 60	30 cylinders	60 cylinders
24 x 70	35 cylinders	70 cylinders
24 x 80	40 cylinders	80 cylinders
30 x 60	45 cylinders	90 cylinders
30 x 70	50 cylinders	100 cylinders
30 x 80	60 cylinders	120 cylinders

Note: Cylinders are 50-pound cylinders.

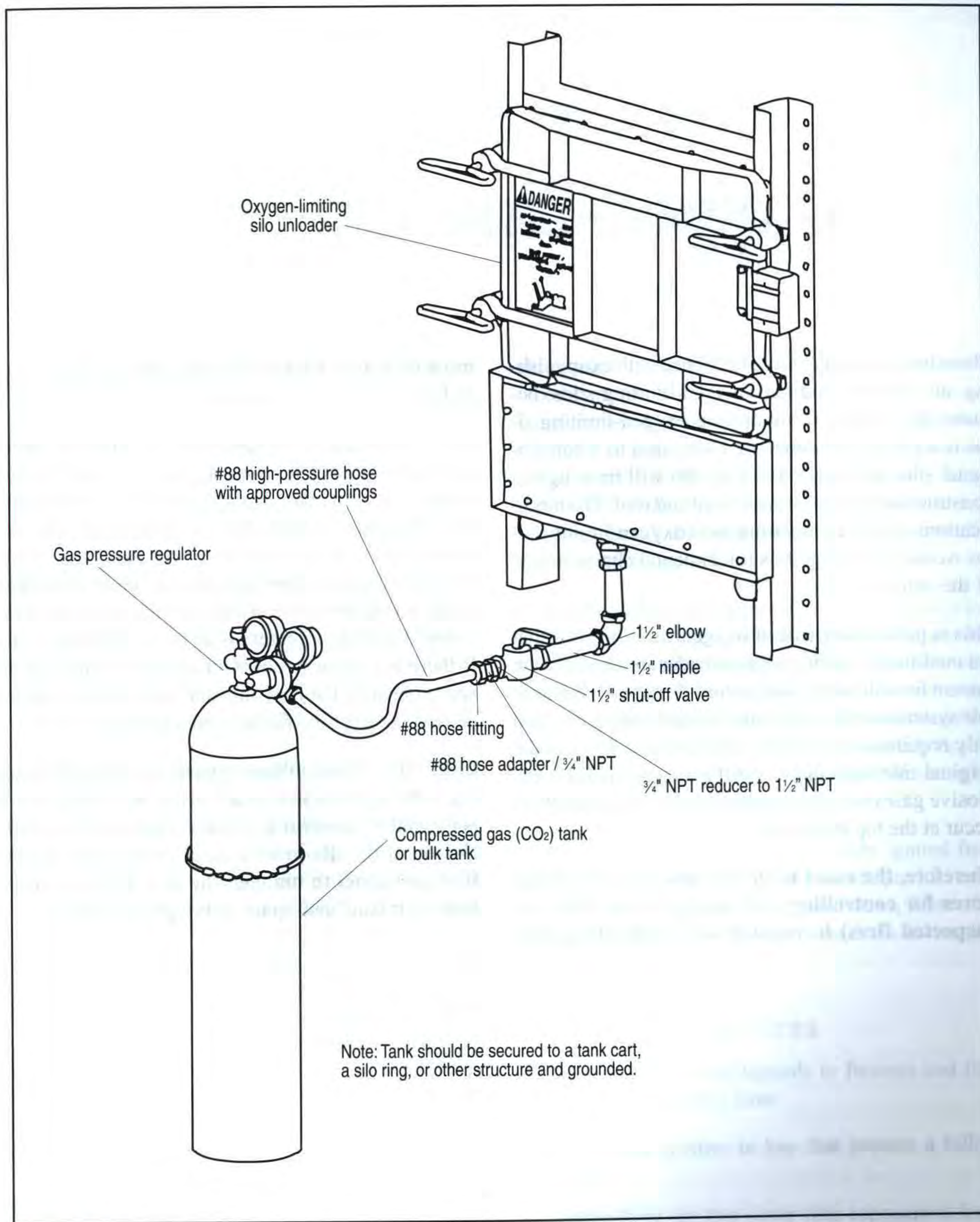

Figure 4-3. Gas injection setup

• CHAPTER 5 •

Fires in Modified Oxygen-Limiting Silos

There has been much less experience with extinguishing silo fires in modified oxygen-limiting silos, because the practice of modifying oxygen-limiting silos is a recent phenomenon. Compared to a conventional silo, an oxygen-limiting silo will have tighter construction between the silo wall and roof. The modifications made in converting most oxygen-limiting silos would not change this fundamental characteristic of the structure.

This is particularly true of oxygen-limiting silos that are modified by adding a top unloader and center chute system for unloading (see figure 1-5, page 4). Because this system uses the original oxygen-limiting roof and only requires installation of a few access doors in the original side wall, there is still great potential for explosive gases to collect and minimal oxygen levels to occur at the top of the silo.

Therefore, **the exact same precautions and procedures for controlling and extinguishing fires (or suspected fires) in regular oxygen-limiting silos must be used with modified oxygen-limiting silos.** Refer to chapter 4 for details.

In a few instances, oxygen-limiting silos are modified by replacing the original airtight roof with a domed roof that is not airtight. In this case, the modified silo becomes more like a conventional silo. Because there is little experience with this type of silo fire, special precautions are still warranted. If no open space is evident between the roof and side wall, then proceed as if the structure is an oxygen-limiting silo. If there is a domed roof with an easily observed air space between the roof and side wall, then it may be possible to treat the fire as a conventional silo fire.

CAUTION: If a modified oxygen-limiting silo is going to be approached as a conventional silo fire, it is crucial to monitor explosive gases and ventilate the top of the silo prior to using water or committing personnel to manage the fire. This is consistent with confined-space entry procedures.

• CHAPTER 6 •

Fires in Hay and Straw Mows

Causes of Hay and Straw Fires

Hay and straw can spontaneously combust under certain conditions. The most important factor is the moisture content of the hay or straw when it is baled. Hay and straw are usually stored inside barns to preserve their quality over an extended period of time.

Although hay and straw are both subject to conditions that can result in spontaneous combustion, it has been the authors' experience that there are many more instances of hay fires than straw fires. As a general rule, more heat is generated by hay going through its curing process than by straw going through its curing process. For this reason, only hay fires are discussed below, but the information also applies to straw fires.

After hay is baled, it goes through a respiration process similar to the process that silage undergoes. One goal of hay-making is to reduce the moisture content of the hay rapidly and to the proper level to inhibit biological and chemical reactions that produce heat. Forage specialists recommend that hay be field-dried to 20% or less moisture content before baling (see figure 2-1, page 7). A variety of chemical and biological additives are available to increase the rate of field-drying or to increase the moisture range for safely storing the hay. Some in-barn drying systems allow baling at up to 30% moisture. The hay is then dried in the barn using mechanical ventilation.

Baled hay continues to cure for several weeks after it is placed in storage and goes through several cycles of heating and cooling. If the hay moisture content is higher than 25%, more heat may be generated than can safely be dissipated through the hay and into the atmosphere. Additional factors that often determine whether or not baled hay overheats to a point of self-ignition include the physical size of the mow or haystack, the density of the bales, and ventilation around the perimeter of the stacked hay. Generally, larger haystacks with dense bales and poor ventilation around the perimeter of the haystack have a greater possibility of overheating.

Fires in freshly cut hay generally occur within the first 2–6 weeks after baling. Even when freshly cut hay has been dried to the proper moisture content or when cured hay has been in storage for a few years, it is still possible for it to catch fire by spontaneous combustion. Humid air, a leaky roof, or storing hay on the ground can increase the moisture content, creating the conditions for spontaneous combustion.

In at least one case, baled corn fodder ignited from spontaneous combustion. The corn fodder had been baled in late winter under wet conditions, froze after baling, and then thawed inside the barn in warmer weather.

Hazards of Hay Fires

At least three potential hazards to farmers and firefighters exist from hay fires:

- Burned-out cavities in hay that present a falling hazard
- Sudden flare-ups that occur with exposure to fresh air
- Toxic gas exposure

Falling into a burned-out cavity deep in the haystack is one potential hazard. Another hazard is hay bursting into flame from sudden exposure to fresh air. This may happen as bales are moved away from a stack of hay, or as bales are moved to a location away from barns or other buildings. A third potential risk is exposure to toxic gas (such as carbon monoxide) from severely charring or burning hay. Some farmers treat hay with a chemical preservative such as propionic acid or ammonia/urea. These preservatives are not known to produce any toxic gases under fire conditions. However, new products come on the market frequently, so toxic gases are always a possibility.

Safety Precautions when Approaching Hay Fires

1. Never investigate a hay mow fire alone. The hay may contain burned-out cavities. Moving bales to locate hot spots may result in a burst of flame as the hot bales come in contact with fresh air.
2. Wear full turnout gear with a self-contained breathing apparatus (SCBA) when approaching a fire. Severely charred or burning hay will emit carbon monoxide. Also, the hay could have been treated with a chemical preservative. Even though the most common forms of preservatives (propionic acid and ammonia/urea) are not known to produce toxic gases during fires, preservatives may emit toxic gases at elevated temperatures. Additionally, the preservatives are acidic (approximately 4.5–5.0 pH) and can cause burning or other irritation of the eyes and respiratory tract. Check with the farmer to determine whether preservatives have been used.
3. Heat, smoke, and the physical demands of moving hay bales have resulted in injuries, exhaustion, and heart attacks. Firefighters should be monitored, and those exhibiting signs of exhaustion should be rotated out of the team.
4. If checking for hot hay or extinguishing burning hay requires walking or standing on the hay, the firefighter must use a body harness and lifeline attached to a strong overhead beam. If this is not possible, stay off the hay.

Checking Hot Hay

Whether you are a farmer or a firefighter, decisions about how to go about checking for hot hay will depend on circumstances surrounding each case. These circumstances include whether hot hay is merely suspected or known to be overheating, the physical size of the haystack, the number of bales, and the type of structure in which the hay is stored.

Smoldering hay gives off a strong, pungent odor. This odor is an indication that a fire is occurring. Often, a farmer who suspects hot hay will attempt to pull some bales away to check on bales stored near the middle of the pile. Other times, hot hay may not be discovered until there is visible smoke or flames. Once a strong, pungent odor is detected, farmers should stay off the hay.

If hay has overheated, the role of ventilation changes drastically based upon the temperature of the hay. At lower temperatures, ventilation or air movement around the perimeter of the stored hay is important as a way of helping to dissipate normal temperature increases developed during the curing process. But once hay reaches 175°F or above, increased ventilation feeds the fire and should be avoided.

The best way to tell if a stack of hay is getting dangerously hot is to take a temperature reading. The same temperature probes and sensors used for checking the temperature of silage can be used for checking for hot hay (see "Step 3: Take Temperature Readings," page 13). Remember that some heat in new hay is normal. Research and experience suggest that farmers and firefighters should be aware of several critical temperatures and action steps involving heated hay. These temperatures and action steps are listed in table 6-1.

To check hay without temperature-testing equipment, drive an 8- to 10-foot ⅜-inch pipe into the mow. Leave it in for 20 minutes and then pull it out. If the pipe is too hot to hold in your hand, remove the hot hay.

Table 6-1. Critical temperatures and action steps for hot hay

Temperature	Action Steps
125°F	No action needed.
150°F	Entering the danger zone. Temperature should be checked twice daily. If possible, stacked hay should be disassembled to allow more air to move around heated bales for cooling.
160°F	Reaching the danger zone. Temperature should be checked every couple of hours. If possible, stacked hay should be disassembled to allow more air to move around heated bales for cooling.
175°F	Hot spots or fire pockets are likely. If possible, stop all air movement around hay. Alert fire service of a possible hay fire incident.
190°F	Remove hot hay. This should be done with the assistance of the fire service. The fire service should be prepared for hay to burst into flame as it contacts fresh air.
200°F or higher	Remove hot hay. A fire is almost certain to develop. This should be done with the assistance of the fire service. The fire service should be prepared for hay to burst into flame as it contacts fresh air.

Extinguishing a Hay Fire (Firefighters Only)

The specific procedures for extinguishing a hay fire will depend upon a number of factors. Questions that can help guide extinguishing procedures include the following: To what extent has the fire progressed within the stack? What are the dimensions of the haystack? Where is the hay located (for example, in a combustible building, in a pole barn or an enclosed barn, in a hay mow, at ground level)? Is the hay packaged in small or large bales? Can portions of a storage structure be opened up or removed to increase access to hot areas?

Only two extinguishing actions will always be appropriate: (1) douse any visible flames with water and (2) move all heated hay to a remote location, away from other exposures. Two additional actions may or may not be appropriate: (1) injecting bales with water using the same probe used for silo fires (see figure 3-4, page 14) and (2) opening up hot bales and dousing them with water to ensure they do not reignite.

Key Actions for Handling Hot Hay and Hay Fires

1. Douse any visible flames with water.
2. Check the temperature of suspected hot hay by using the same probe described in the section on checking silage for hot spots (see "Step 3: Take Temperature Readings," page 13). Hot spots with temperatures above 175°F indicate that fire pockets are likely.
3. Minimize air movement around hay if hay is 175°F or hotter to prevent feeding the fire with fresh air.
4. Inject hot spots with water using the same probe and method described in the chapter on fighting conventional silo fires (see "Step 4: Inject Water," page 15).
5. Move all heated or burned hay to a remote location, away from any buildings or combustible material. Heated bales can burst into flames while they are being moved, so use caution. Wetting down bales before moving them can help control this hazard.
6. Open up hot bales and douse them with water to prevent reignition.

• APPENDIX A •

Estimating the Value of Silage

On many farms, silage is the major food product for dairy cows and beef cattle. The destruction or loss of silage can have a severe economic impact on the farm operation. To help firefighters understand the potential value of silage, information and formulas for estimating the value of silage are given below. Being able to estimate the value of silage is one important variable in deciding how much effort should be expended in trying to save silage. The figures given represent typical ranges and approximations that are applicable to most areas of the United States. More specific values for a given locality can be substituted.

To estimate the value of silage in a tower silo, the volume and density of the silage in the silo and the dollar value of silage per ton of dry matter must be known. Silage density in tower silos will vary depending on moisture content, type of silage, length of cut, and type and size of silo. Density typically varies from 12 pounds dry matter (DM) per cubic foot at the top of silos to 20 pounds DM per cubic foot in the bottoms of large silos. Silage varies in economic value, depending upon market conditions and nutritive value. Typically, hay crop silages are worth $120–$150 per ton of dry matter. Corn silage is typically worth $95–$110 per ton of dry matter.

Example

Assume that 50 feet of haycrop silage is left in a 20-by-70-foot silo. If the silage is assumed to have an average density of 15 pounds DM per cubic foot and a value of $130 per ton DM, the value can be estimated as follows:

$$\text{Volume (cu ft)} = 0.785 \times \text{Diameter}^2 \text{ (ft)} \times \text{Height (ft)}$$
$$= 0.785 \times 20^2 \times 50 = 15{,}700 \text{ cu ft}$$

$$\text{Amount (tons DM)} = \frac{\text{Volume (cu ft)} \times \text{Density (lbs DM/cu ft)}}{2{,}000 \text{ lbs/ton}}$$

$$= \frac{15{,}700 \times 15}{2{,}000} = 117 \text{ tons DM}$$

$$\text{Value (\$)} = \text{Amount (tons DM)} \times \text{Price (\$/ton)}$$

$$= 117 \times \$130 = \$15{,}210$$

• APPENDIX B •

Prevention — Good Silage-Making Practices

To make top-quality, low-moisture silage and minimize the possibility of a fire, observe the following silage-making practices.

Table B-1. Summary of good silage-making practices

Practice	Reason	Benefit
Minimize drying time.	Reduce respiration.	Reduced nutrient and energy losses. More sugar for fermentation. Lower silage pH.
Chop at correct TLC. *(note 1)* Fill silo quickly. Enhance compaction. Seal silo carefully.	Minimize exposure to oxygen.	Reduced nutrient and energy losses. More sugar for fermentation. Reduced silo temperatures. Less heat damage (browning). Faster pH decline. More extensive pH decline. Better aerobic stability. Less chance of *Listeria*. Less protein solubilization.
Ensile at 30–50% dry matter content.	Optimize fermentation.	Reduced nutrient and energy losses. Proper silo temperatures. Less heat damage (browning). Control *Clostridia*. Prevent effluent flow.
Leave silo sealed for at least 14 days.	Allow complete fermentation.	Lower silage pH. More fermentation acids. Better aerobic stability. Less chance of *Listeria*.
Unload 2–6 inches per day. Keep smooth surface.	Stay ahead of spoilage.	Limit aerobic deterioration.
Discard deteriorated silage.	Avoid animal health problems.	Prevent toxic poisoning, mycotic infections. Prevent listeriosis, clostridial toxins.

Source: Silage and Hay Preservation, NRAES–5.

Note 1: "TLC" is theoretical length of cut. Chop haycrop silage at 3/8 inch TLC, corn silage at 1/4 inch TLC. With kernel or crop processor, TLC in corn silage should be 3/8 – 1 1/2 inches.

• APPENDIX C •

Prevention – Good Hay-Making Practices

To make higher-quality hay and minimize the possibility of a fire, observe the following practices.

Table C-1. Summary of good hay-making practices

Practice	Reason	Benefit
Mow forage early in the day.	Allow a full day of drying.	Faster drop in moisture. Less respiration loss. Less likelihood of rain damage. High quantity, quality.
Form into spread swath.	Increase drying rate.	Faster drop in moisture. Less respiration loss. Less likelihood of rain damage. High quantity, quality.
Rake or ted at 40–50% moisture content.	Increase drying rate.	Faster drop in moisture. Less respiration loss. Less likelihood of rain damage. Less leaf shatter. High quantity, quality.
Bale hay at 18–20% moisture.	Optimize preservation.	Less leaf shatter. Inhibition of molds, browning. Low chance of fire. High quantity, quality.
Store hay under cover.	Protect from rain, sun.	Inhibition of molds, browning. Less loss from rain damage. High quantity, quality.

Source: Silage and Hay Preservation, NRAES–5.

• APPENDIX D •

Vendors of Supplied-Air Breathing Apparatuses

CairnsAIR
11 Parkway Circle, Churchman's Center
New Castle, DE 19720
Phone: (888) 276-7247 or (302) 325-1190
Fax: (302) 325-1198
Web site: WWW.SPIDERGRAPHICS.COM/CAI

Interspiro, Inc.
31 Business Park Drive
Branford, CT 06405
Phone: (800) 468-7788 or (203) 481-3899
Fax: (203) 483-1879
Web site: WWW.INTERSPIRO.COM

MSA (Mine Safety Appliances Company)
P.O. Box 426
Pittsburgh, PA 15230
Phone: (800) MSA-2222
Fax: (412) 967-3451
Web site: WWW.MSANET.COM

Scott Health and Safety
309 West Crowell Street
Monroe, NC 28112
Phone: (800) 633-3915 or (704) 282-8400
Fax: (704) 282-8423
Web site: WWW.SCOTTAVIATION.COM

Other Publications from NRAES

The NRAES publications listed below address safety, emergencies, fires, and silage and hay. They may be of interest to firefighters, farmers, and educators.

Before ordering, contact NRAES for current prices and shipping and handling charges. Books can be ordered on the NRAES web site (see address below).

NRAES (Natural Resource, Agriculture, and Engineering Service)
Cooperative Extension • 152 Riley-Robb Hall
Ithaca, New York 14853-5701
Phone: (607) 255-7654
Fax: (607) 254-8770
E-mail: NRAES@CORNELL.EDU
Web site: WWW.NRAES.ORG

Currently, NRAES has published more than 95 publications and distributes a total of more than 170 publications; contact NRAES for a free catalog. Read more about NRAES on page 34.

Farm Safety

Farm Rescue: Responding to Incidents and Emergencies in Agricultural Settings (NRAES–10)

This publication will help familiarize emergency medical and rescue personnel with basic principles and procedures for responding to agricultural emergencies and will enable rescuers to approach a rescue with more confidence and a greater awareness of the risks involved. The most common types of incidents are described, and potential hazards to victim and responder are clearly identified. Five chapters are included: overview of farm rescue; agricultural equipment injuries and rescue; farm structure emergencies; farm chemical exposures, fires, and spills; and farm animal incidents. Among the agricultural emergencies discussed are tractor overturns, machinery entanglements, grain bin entrapments, electrocution, silo entrapments and fires, exposure to toxic gases, and agricultural chemical fires. Supplementing the text are 87 figures, one table, and three appendixes. This publication is a complete revision of *Farm Accident Rescue*, an NRAES best-seller since 1980 (over 136,000 copies have been sold since the first edition in 1980). (1999 • 78 pages)

Fire Control in Livestock Buildings (NRAES–39)

Every year, millions of dollars in livestock, farming equipment, and agricultural buildings are lost in fires. This publication helps farmers ensure that livestock buildings are constructed and equipped to minimize fire hazards. Topics discussed in the publication include the use of fire-retardant materials in construction, building management to limit the spread of fire, vent spacing, and cost estimates of installation and maintenance of early warning and automatic sprinkler systems. (1989 • 18 pages)

First on the Scene (NRAES–12)

Learn to make the right decisions in the crucial time between discovery of an accident and arrival of emergency medical personnel. This popular publication (over 26,000 copies have sold since 1989) provides detailed discussions and decision-and-action diagrams for specific farm accident scenarios involving machinery, storage facilities, chemicals, and electrocution. Such accidents often occur in isolated areas where help is not immediately available, so those first on the scene must understand the hazards and necessary reactions to enable a victim's survival. (1989 • 46 pages)

Silage and Hay

Dairy Feeding Systems: Management, Components, and Nutrients (NRAES–116)

This is the proceedings from the Dairy Feeding Systems: Management, Components, and Nutrients Conference, which was held December 1998 in Camp Hill, Pennsylvania. Included are 31 papers divided into nine categories: feeding systems, feed storage facilities, feed inventory management, feed delivery management, feed consumption area, monitoring and managing feed costs by monitoring and managing intake, feed quality control, feeding system economics, and herd nutrition and cropping management. The book will be a valuable resource for producers and farm managers; producer advisors and consultants; extension and university educators; nutritionists; crop specialists; feed, seed, and equipment sales representatives; nutrient managers and agronomists; veterinarians; agricultural engineers; facility designers; policy makers; lenders; and the agricultural media. (1998 • 402 pages)

Silage: Field to Feedbunk (NRAES–99)

This is the proceedings from the Silage: Field to Feedbunk Conference, held February 1997 in Hershey, Pennsylvania. Included are 36 papers divided into eight categories: plant and field issues to meet the challenge, harvesting a high-quality silage, storage methods, additives management, mycotoxins and spoilage, quality evaluation, feeding, and silage system management. The proceedings will be of interest to a diverse group of industry and agricultural professionals, including silage producers and users; extension and university educators; crop consultants; producer advisors and consultants; feed, seed, and equipment sales representatives; agronomists; plant breeders; animal scientists; agricultural engineers; soil and water conservation district personnel; nutritionists; veterinarians; IPM professionals; and analytical laboratory staff. (1997 • 464 pages)

Silage and Hay Preservation (NRAES–5)

Legumes, grasses, and corn silage form the basis of many farm nutritional programs. From the moment the crop is cut, processes take place that decrease the quantity and nutritional quality of the feed. This publication helps farmers conserve the digestible fiber, protein, and energy of forage and maintain it in a form that animals can use efficiently. Topics covered are the biology of silage preservation, preservation of hay, and additives for silage and hay preservation. (1990 • 53 pages)

Other Publications of Interest

On-Farm Agrichemical Handling Facilities (NRAES–78)

This publication discusses considerations a farmer should make regarding agrichemical storage, principal parts of the facility, storage environmental requirements, safety requirements, and storage alternatives. Included are two appendixes: one is a plan for a post-frame chemical storage building, and another is a list of companies that distribute equipment for storage or containment of chemicals. Also included are one table, 17 figures, and conversion factors. (1995 • 22 pages)

Used Farm Equipment: Assessing Quality, Safety, and Economics (NRAES–25)

This handbook shows the buyer how to inspect machinery for the reliability of its components and the quality of its safety features. The economics of owning and operating used machinery are covered, and methods of acquiring equipment are discussed. Several farm safety tips are highlighted in the publication, which also features 90 detailed illustrations. (1987 • 34 pages)

About NRAES

NRAES, the Natural Resource, Agriculture, and Engineering Service (formerly the Northeast Regional Agricultural Engineering Service), is an interdisciplinary, issues-oriented program focused on delivering educational materials and training opportunities in support of cooperative extension. The mission of NRAES is to assist faculty and staff at member land grant universities in increasing the availability of research- and experience-based knowledge to improve the competitiveness and sustainability of agriculture and natural resources enterprises, increase understanding of processes that safeguard the food supply, and promote environmental protection and enhancement. All NRAES activities are guided by faculty from member land grant universities (see the map below for a list of cooperating members).

NRAES began in 1974 through an agreement among the cooperative extension programs in the Northeast. In 1998, Virginia Polytechnic Institute and State University became an NRAES member university. The program is guided by the NRAES Committee, which consists of a representative from each member university, the NRAES director, and an administrative liaison appointed by the Northeast Cooperative Extension Directors Committee. NRAES is housed in the Department of Agricultural and Biological Engineering at Cornell University. Office hours are Monday through Thursday, 8:30 A.M. to 5:00 P.M., and Friday, 8:30 A.M. to 2:30 P.M., eastern time.

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