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Spoilage and heating of stored agricultural products

Prevention,
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Spoilage and heating of stored agricultural products

Prevention, detection, and control

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Recommendations for pesticide use in this publication are intended as guidelines only. Any application of a pesticide must be in accordance with directions printed on the product label of that pesticide as prescribed under the *Pest Control Products Act*. **Always read the label**. A pesticide should also be recommended by provincial authorities. Because recommendations for use may vary from province to province, your provincial agricultural representative should be consulted for specific advice.

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CONTENTS

PREFACE

Most agricultural products in Canada are stored safely with minimal loss of quality. However, each year a small proportion of these products becomes spoiled or self-heated (spontaneously heated), resulting in degrading or other quality loss. Situations involving fire are very serious and may cause major losses of a product, damage to the physical plant, and human injury.

Some commodities are more susceptible to spoilage and self-heating than others, and this can lead to severe problems for those responsible for, but unfamiliar with, the handling and storage of such commodities. When spoilage or self-heating problems do occur it is often difficult to obtain information on how to solve them.

The objective of this manual is to provide some basic information on the causal factors of spoilage, self-heating, and self-ignition in stored agricultural products, on methods used for the prevention, detection, and control of such problems, and on the behavior and management of selected commodities in storage.

The manual is intended as a guide for farmers, elevator, mill, and warehouse managers, agricultural extension workers, and exporters in solving their storage problems. It is also intended to assist fire fighters, police officers, insurance adjusters, and occupational health and safety officers who currently must rely on widely scattered and often inadequate information for their decision making.

The manual is divided into two parts. Part I deals with changes that occur during storage; self-heating; effects of molds; prevention, detection, and control of spoilage and heating; safety; problem investigation; and legal aspects. Part II is devoted to detailed accounts of the storage characteristics of specific commodities.

Because documented cases of spoilage and heating problems are not readily available, the same mistakes in management may occur in isolation in different parts of Canada. It is hoped that this manual will become the catalyst of later editions by encouraging readers to document their experiences of heating and spoilage problems for the benefit of others.

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C. Letain, L. Reece, B. Snell, Research Station, Agriculture Canada, Winnipeg, Man., entered numerous drafts on the word processor; R. Sims of the same station produced the line drawings and photographs; and S.V. Balchin, Research Program Service, Research Branch, Agriculture Canada, Ottawa edited the manual.

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Occupational Safety and Health (NIOSH); extracts from *Storage of cereal grains and their products*, American Association of Cereal Chemists Ltd.; text from *Spontaneous heating of stored cotton seeds*, S. Navarro; extract from *Grain storage: Physical and chemical consequences of advanced spontaneous heating in stored soybeans*, American Chemical Society; extracts from *Marine fire prevention, fire-fighting and fire safety*, Prentice-Hall Inc.; text from *Fire investigation*, Pergamon Books Ltd.; text from *Detection of grain silo fires using thermography*, AGEMA Infrared Systems; text from *Handling commodities in transit*, Sosland Publishing Company; extracts from *Heated-air grain dryers* and *Grain aeration and unheated air drying*, O.H. Friesen and Manitoba Agriculture; extract from *Fishmeal strikes again*, Hazardous Cargo Bulletin; extracts from *Grain storage*, University of Minnesota Press; and an extract from *Alleged mycotoxicosis in swine: Review of a court case*, Canadian Veterinary Journal.

This manual is dedicated to my wife, Carol, for her considerable encouragement and support during the project.

Part
I

Principles involved

Chapter 1. Changes that occur during storage

PRINCIPLES

Stored agricultural products are influenced by many factors that determine their keeping quality. These factors include product condition, storage container or structure, length of storage, and type of handling (Sinha 1973). Unlike inert materials such as sand, agricultural products in storage change physically and chemically and need to be managed carefully.

The original condition of a product is probably the most important factor affecting its storage. The product's moisture content (M.C.) and temperature will influence and even direct events that occur during storage and may sometimes lead to spoilage and self-heating.

MOISTURE

During storage, moisture within the product reaches an equilibrium with the air within and between the product particles and produces a relative humidity level that may be suitable for the growth and development of deteriorative organisms. In stored seed, the lower limit of moisture content for mold growth is near the upper limit of moisture content in dry, that is, straight grade, seed.

Table 1 shows the maximum moisture content levels at which cereal, pulse, and oilseed can be sold as straight grade, as permitted under the *Canada Grain Act*. The levels are subject to periodic revision. If seed is sold as straight grade and the moisture content levels exceed the values shown in Table 1, a penalty is charged. The amount of the penalty is determined by the amount of moisture content above the acceptable level. Because seed with the moisture content levels shown in Table 1 can be sold without penalty, such values are often assumed to represent safe levels (Moysey and Norum 1975). In practice, though, the safe moisture content levels are one or two percentage points below those given in Table 1. This is because some seed lots may have a higher moisture content or a higher level of damage than others, some may include green weed seed or other debris, and some may have suffered the effects of temperature variation or high temperature drying (see Part II).

Table 1 Maximum moisture content levels for straight grade seeds*

Barley	14.8
Canola/rapeseed	10.0
Corn/maize	15.5
Domestic buckwheat	16.0
Domestic mustard seed	10.5
Fababeans	16.0
Flax	10.0**
Lentils	14.0
Oats	14.0
Peas	16.0
Rye	14.0
Safflower	9.6
Soybean	14.0
Sunflower	9.6
Wheat	14.5

* Percentage wet weight basis (Canadian Grain Commission 1987)
** From 1 August 1988

RELATIVE HUMIDITY

Biological organisms that cause stored products to deteriorate require different levels of relative humidity for normal development. Generally, the level for bacteria is above 90%, for spoilage molds it is above 70%, and for storage mites it is above 60%. The levels required for insect development range from 30% to 50%. However, specifying only the relative humidity levels is oversimplifying the physical limits of deterioration. Both relative humidity and moisture content are dependent upon temperature. For example, if the temperature of an air sample having a relative humidity level of 50% is increased five degrees from 25°C to 30°C, its relative humidity level will decrease to 38%. If the temperature of the air sample is decreased five degrees from 25°C to 20°C, then the relative humidity level will increase to 69%. The effects and interactions of temperature, relative humidity, and moisture content on stored products and their associated organisms are complex. A concise explanation of the theory of moisture in stored produce is given by Mackay (1967).

TEMPERATURE

Important facts concerning temperature are as follows:

- The high temperatures of grain harvested and binned on a hot day are retained within unaerated grain bulks for many months due to the insulation properties of grain.
- Temperature and moisture influence enzymatic and biological activities and thus the rate of spoilage.
- Temperature differences within bulk commodities favor mold development through moisture migration resulting from sinking colder, denser air, followed by rising warmer air and subsequent moisture adsorption near the top surface.

SAFE STORAGE GUIDELINES

Moisture content and temperature determine the safe storage period for any grain or oilseed. The canola/rapeseed storage time chart (Fig. 1) predicts the keeping quality of canola/rapeseed over 5 months, under varying temperatures and moistures. If the temperature or moisture content of canola/rapeseed falls within the spoilage area of the chart, take steps to reduce one factor or both. To reduce the moisture content, either delay combining to allow further drying in the swath or artificially dry the seed. To reduce the seed temperature, aerate the bin

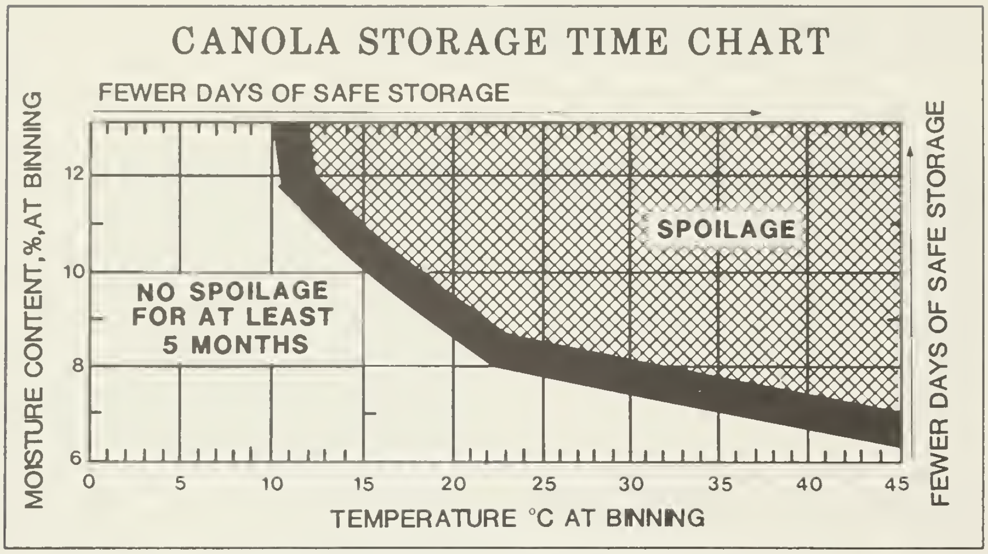

Figure 1 Canola/rapeseed storage time chart based on seed moisture and temperature at binning.

contents. Safe storage guidelines have been developed to predict the long-term keeping quality of other commodities (Wallace et al. 1983).

RESPIRATION AND HEAT PRODUCTION

Respiration occurs in all living cells. Aerobic respiration, occurring in the presence of oxygen, is essentially responsible for the breakdown of carbohydrates, fats, and proteins to carbon dioxide, water, and energy. The energy liberated during aerobic respiration is used by the cells to fuel metabolic processes and is then released as heat.

Dry mature seeds in storage are largely dormant and have a very low respiration. However, freshly harvested, immature seeds or seeds with a high moisture content have a much higher respiration. This is because the seeds are still metabolically active and molds that are present on the surface and within the seed coats are actively respiring. Heat, which is produced by both seed and mold respiration, is manifested as an increase in grain temperature.

Chapter 2. Self-heating

When a stored material increases in temperature by generating heat without drawing heat from its surroundings the action is called self-heating. The increase in temperature occurs in two phases. Phase one is known as *biological* heating, which normally occurs up to 55°C and exceptionally up to 75°C. Phase two is known as *chemical* heating, which occurs from above 75°C to at least 150°C. Biological heating is caused by the activity of plant cells, molds, bacteria, insects, and mites. Chemical heating is caused by oxidation. This chemical reaction may increase the temperature to the ignition point, depending on the commodity and storage conditions (Fig. 2). For information on the theory of thermal ignition see Beever and Thorne (1982). For information on evaluating and controlling the hazards of self-heated material see Bowes (1984).

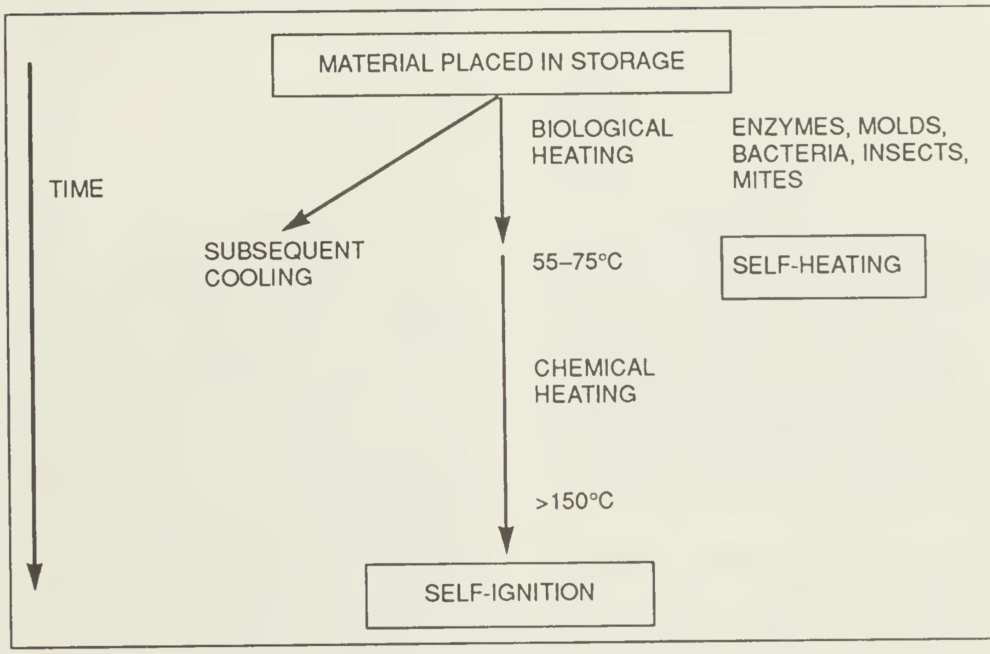

Figure 2 Schema showing progression of self-heating in stored products.

Stored materials vary widely in their tendency to self-heat (Table 2). Cornmeal feeds and fish meal have a high tendency to self-heat, whereas shelled peanuts and various grains have a relatively low tendency to do so (National Fire Protection Association 1949). Generally, processed products have a higher tendency to self-heat than do whole grains. Spoilage and heating problems are discussed in Part II of the manual.

CHEMICAL HEATING

When the biological heating exceeds 75°C, a purely chemical process may occur and raise the temperature of the material to ignition. This chemical process, known as oxidation, releases heat.

Table 2 Stored materials and their tendency to self-heat*

Tendency to self-heat				
High	Moderate	Low	Very slight	Possible
Alfalfa meal	Brewers' grains	Cottonseed	Grain (various)	Burlap bags
Cornmeal feeds	Cocoa bean shells		Hides	Sawdust
Fish meal	Feeds (various)		Jute	
Fish scrap	Hay		Linseed	
Tung nut meals	Manure		Peanuts (shelled)	
	Wool wastes		Powdered eggs	
			Powdered milk	
			Sisal	

* National Fire Protection Association 1949. See Table 14 for comprehensive list of commodities.

The oxygen required for oxidation can be available either as free oxygen in the air or as liberated oxygen in chemical reactions. Chemical oxidation proceeds at a more rapid rate if preceded by biological heating.

SELF-IGNITION

The self-heating of a stored commodity to its ignition temperature is called self-ignition. The terms spontaneous ignition and spontaneous combustion are also used but the term self-ignition is preferred. Self-ignition may be affected by a variety of chemical and physical factors (American Insurance Association 1983; Bowen 1982).

The following general conditions affect self-ignition:

- The rate at which heat is generated by the fuel material.
- The oxygen supply available.
- The rate of heat loss to surroundings.

A number of vegetable and animal oils and fats undergo sufficient oxidation at normal temperatures in air to self-ignite. Examples are linseed, soybean, and fish oils. The reaction is promoted by exposure of a relatively large surface area of the material to the oxygen in the air as occurs when a fibrous material such as a cloth or bag is impregnated with the oil or fat. Enough air must be available to permit oxidation but not to dissipate the heat.

Some vegetable products are susceptible to self-ignition due to their inherent oxidizable oil content (examples are corn meal and rice bran), whereas others such as hemp, jute, and sisal appear to self-ignite only if impregnated with an oxidizable oil, even though they may heat when wet with water.

Moisture content is a factor in self-ignition. Although small amounts of moisture may increase the rates of oxidation and heat generation in many materials, moisture may also reduce the likelihood of ignition by promoting dissipation of the generated heat. However, high moisture content may contribute to the biological heating (American Insurance Association 1983).

BIOLOGICAL SPOILAGE AND HEATING

Enzymes

Enzymes are specialized proteins of living matter that catalyze, or speed up, chemical reactions. During the processes of growth and maturation, plant material in the field goes through a number of chemical reactions that are catalyzed by enzymes. Freshly harvested seeds entering the bin are often immature and may have increased enzymatic activity, resulting in high respiration rates and in heat production. High seed moistures and green weed seeds and debris also favor increased enzymatic activity. During this early storage period, carefully monitor the stored commodity.

Molds

Products in storage provide food and an environment for many organisms and microorganisms, including molds (fungi). Of these, the spoilage molds, certain storage or post-harvest molds (Christensen and Kaufmann 1969), are the most important cause of deterioration of grain and its products.

Spoilage molds exist as spores in soil, on decaying debris, in harvesting equipment, and within storage structures and are gathered by the combine harvester and distributed among the grains. The various types of spoilage fungi each require a different relative humidity level and temperature for their growth and development. Some species, like *Aspergillus amstelodami* (a yellow-green mold sometimes found growing on the top of homemade jams), grow at low humidities, affect seed germination, and produce water during their growth, which enable more damaging molds to grow. Such molds include *Aspergillus candidus* (colonies are white) and *Penicillium* species (green or blue green), both of which impair seed germination and are frequently associated with hot spots in bins of grain. Hot spots are areas within a bulk commodity that have a higher temperature than the surrounding material.

The development of an artificially induced hot spot was studied in wheat bulks by Sinha and Wallace (1965). Heating was initiated by *Penicillium* species growing in a grain pocket at –5°C to +8°C and with 18.5 to 21.8% moisture. The hot spot reached a maximum of 64°C and cooled in 2 weeks.

Preharvest molds, originating from the growing plant, also occur on grains in storage. Some preharvest molds may produce harmful toxins on developing grains in the field. For information on preharvest and post-harvest molds see Christensen and Sauer (1982).

Bacteria

Although bacteria outnumber molds on grain surfaces and in flour, they are not usually important during storage of these commodities in Canada. This is because during most years crops are harvested and binned dry, and species of bacteria require a high relative humidity (90–95%) for their growth. Numbers of bacteria decrease during storage when the moisture content is too low for growth. Their numbers are also decreased during artificial drying of grain. When the moisture content is adequate, their growth contributes to self-heating and to production of sour and putrid odors (Semeniuk 1954). A general account of the bacteria associated with stored grain is given by Wallace (1973).

Insects

More than 60 species of insects can occur in stored grain and grain products in Canada (Sinha and Watters 1985). Insect metabolic activity within dry grain bulks containing 15% M.C. or less can result in heating up to 42°C (Cotton and Wilbur 1982). Insect-induced hot spots occur most frequently in southern Alberta, where grain is often binned at an ambient temperature of 30°C. Ambient temperature is the temperature of the surrounding medium, in this case, the atmosphere. A further consequence of this localized insect metabolic activity is an increase in product moisture content above 15% in the vicinity of the hot spot, permitting spoilage molds to grow and sometimes producing temperatures up to 62°C.

Several of the insects infesting farm-stored grain are destructive. These include rusty grain beetles, red flour beetles, squarenosed fungus beetles, sawtoothed grain beetles, granary weevils, hairy spider beetles, and meal moths (Loschiavo 1984).

Many of the insects that occur in stored products in the Prairie Provinces survive freezing temperatures (the rusty grain beetle survives –5 to –10°C), but they cannot reproduce below 17°C. Where grain temperatures remain above 17°C for long periods, as occurs in the centre of unaerated grain bulks, insects can do extensive damage. The effect of insect damage is worsened in high moisture grains.

Mites

Mites are fragile creatures and are difficult to see. Their presence gives a strong minty odor to grain, which, when heavily infested, becomes unpalatable as animal feed. About eight kinds of mites are common in stored grain in Canada, all of which can withstand low temperatures. Mites feed on broken grain, weed seeds, and molds present on the grain and thrive in moist grain. They spread mold spores on and in their bodies, and through their metabolic activity can, like insects, encourage development of spoilage molds (Sinha and Wallace 1973).

Advanced biological heating

Mold-induced heating of stored grains, pellets, feeds, and hay attains temperatures of 55°C and remains at this level for weeks. The heating then either gradually subsides or passes into the next stage where thermophilic molds take over. These sometimes carry the temperature to 60°C and may be succeeded by thermophilic bacteria and actinomycetes that carry it up to 75°C, the maximum temperature attained by microbiological activity (Christensen and Sauer 1982).

Chapter 3. Effects of molds

Growth and development of spoilage molds affect products in storage by causing adverse quality changes, aggregation of product, heat-damage, and production of toxins and allergens. Table 3 summarizes the effects and consequences of mold activities on stored products.

ADVERSE QUALITY CHANGES

Growth of spoilage molds on the surface of seeds often results in a dull rather than a bright appearance as in normal seeds. Dull appearance is sometimes considered a degrading factor. The presence of spoilage fungi on seeds is also often associated with musty odors, which are a degrading factor (Canadian Grain Commission 1985; United States Department of Agriculture 1972).

Other important effects of spoilage fungi on seeds include reduction in germinability and discoloration of whole seeds or portions of them, including the germ. Under the right moisture conditions, spoilage fungi invade the germs with no visible signs of molding, weaken the seeds, and eventually cause seed death. Some strains of the spoilage molds *Aspergillus restrictus*, *A. candidus*, and *A. flavus* can cause severe damage and kill the germs quickly. As fungal invasion of the germs of seeds continues, the tissues of the germ become brown and then black (Christensen and Sauer 1982). Discoloration caused by fungi results in lower grades both in the USA (United States Department of Agriculture 1972) and in Canada (Canadian Grain Commission 1985).

AGGREGATION OF GRAINS

Mold activity in binned seed products can result in clumping and aggregation of grains in localized areas, formation of bridges of material across the top or within the bin contents, or adherence of material to bin walls (hang-ups), as illustrated in Fig. 3.

Clumping

Clumps of grain within a bulk result from the mycelia, or hairlike filaments of spoilage molds on, in,

Table 3 Effects and consequences of mold activities on stored products

Effects		Consequences
1. Adverse quality changes	- dull appearance	
	- musty odors	- possible degrading
	- visible molds	
	- reduced germination	- rejection for seed purposes
	- germ damage, discoloration	- degrading
	- increased free fatty acids	- rejection for processing
2. Aggregation of product	- clogging of pipes, augers	- interruption of operations
	- sticking to bin walls	- uneven pressure effects, partial bin collapse
	- bridging of bin contents	- dangerous air space
	- aggregation and/or fusion of bin contents	- cleaning out costs, unusable facilities
3. Heating of product	- bin-burning	- damage to product and premises
		- possible degrading, rejection, extra costs
		- could lead to fire-burning, explosions
4. Contamination of product by harmful substances	- mycotoxins	- livestock poisoning, feed refusal
		- rejection of shipments
		- loss of markets
		- chronic human health problems
	- respiratory/allergenic effects	- breathing problems in animals and humans
		- employment of other grain handlers may be required

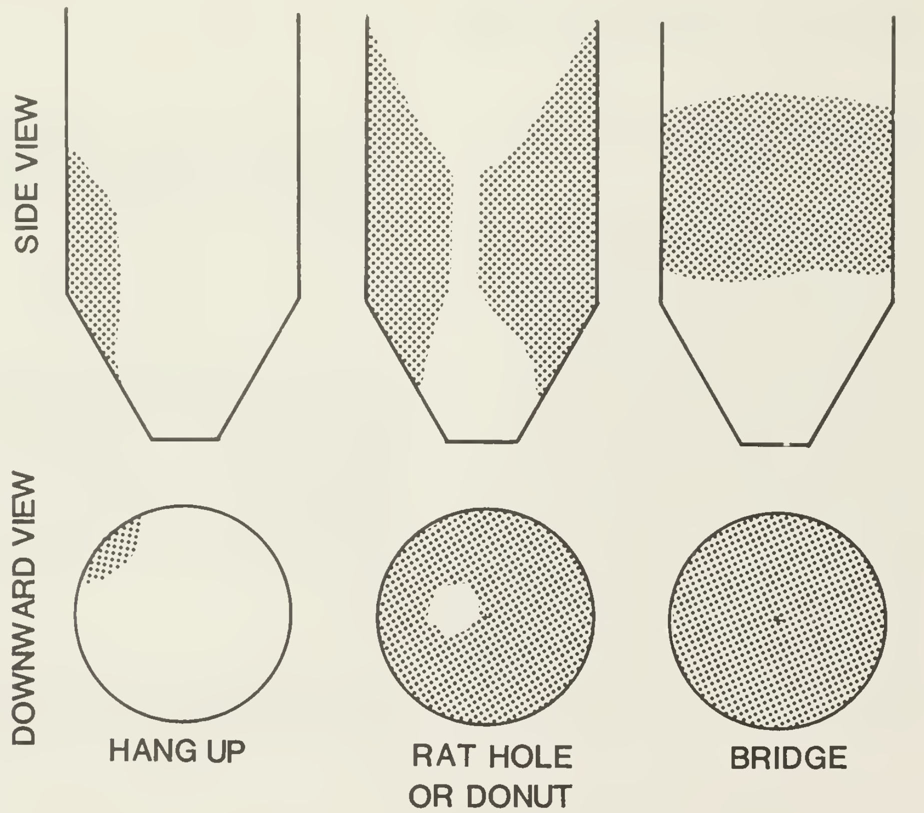

Figure 3 Types of hang-up and bridging problems caused by aggregation of materials in silos (after Northern Vibrator Manufacturing Co., Georgetown, Ont.).

and among the seeds, thus binding them together. Burrell et al. (1980), studying moist rapeseed, observed that each clump was formed by mycelia radiating from a nucleus consisting of a foreign body or a badly damaged seed. Clumps generally develop when some localized areas of the bin contents are of higher moisture content, permitting mold development. Large clumps may block the free passage of seeds through augers and pipes and can result in interruption of plant operations. Clumps are the basic cause of a nonfree-flowing condition that can lead to off-centre flow in the bin-emptying process. Off-centre flow places the bin structure at risk. Sometimes mold growth results in large columns of aggregated material that may be found, for instance, below pipe line openings (Meronuck 1984), or even in fusion of entire bin contents. Such problems result in temporarily unusable facilities or extra chipping-out costs.

Upper bridging

A crust, usually several centimetres thick, consisting of rotted kernels, mold tissue occupying the space between kernels, and sprouted grain, sometimes develops at the top of grain bulks when they are undisturbed for several months. This development is known as upper bridging and is caused by uneven bin temperatures and uneven moisture levels resulting from convection currents within the bin (University of Kentucky 1984).

Upper bridging at the top of grain bulks causes a severe hazard to persons handling stored grains, since air spaces are created beneath the crust in partially unloaded bins. Workers may accidentally break through the surface and become trapped during unloading operations. Even if the bin is not being unloaded, workers may fall into a large void left from previous unloading operations and either suffocate or be forced to breathe toxic gases and microbial spores until they are rescued (see Chapter 7 Safety).

Upper bridging may also occur in sealed silos when conditions are favorable for microbial growth (Nichols and Leaver 1966). The surface grain mats together and adheres to the silo sides, resulting in an empty cone over the extraction auger. Lumps of matted grain may break off, fall into the empty cone, and be extracted with the clean material. As matting increases, extraction may become jerky and eventually, if the grain bridges across the silo, the flow ceases and the silo has to be opened.

Middle bridging

Numerous examples of middle bridging within grain bulks, consisting of matted, germinated, and molded seeds and mold mycelia, were observed in 1979 when the flood waters of the Red River entered grain bins near Winnipeg, Man. After the waters had subsided the contents were examined. It was found that bridges had developed just above the uppermost water level. Most grains above the bridges were salvageable if the farmer could move them before the putrefactive odors from the wet grain beneath the bridges permeated into the grain above (Mills and Abramson 1981).

Hang-ups

Moist bin contents sometimes adhere to the walls and gradually a collar of material with a central hole (rat hole, or donut hang-up) is built up across the bin. When viewed from above, the hang-up appears to be ring-shaped with the stored material flowing downward through the central hole. Frequently, managers of grains and grain products are unaware of the existence of hang-ups within bins, which only become evident when self-heating or insect infestations occur, or when the bin is emptied.

Bridge formation, adherence of material to bin walls, and clogging of some entry points in augers can result in uneven pressure effects and sometimes severe damage to bins. Walls may buckle under the uneven pressures caused by the flow of stored material in bins. Most bins are designed for centre emptying. Off-centre emptying causes uneven and, it is believed, increased loads (at least close to the wall channel). Hang-ups can cause wall buckling or denting (Jenike 1967). The subject of bin collapse due to pressure effects is described by Ravenet (1978). Bridged or adherent material in place for many months can also provide a harborage and breeding ground for insects, which move out from the bridge to infest good grain or processed materials.

HEAT DAMAGE

Spoilage fungi including *Aspergillus* species such as *A. candidus* (white or cream) and *A. flavus* (yellow green) can, through their respiration, raise the temperature of stored products up to 55°C. Development of these molds frequently occurs in pockets of increased moisture within bulks. The pockets result from moisture migration, high-moisture weed seeds, plant debris, heavy rains, or melted snow.

The elevated temperatures result in internal browning or blackening of seeds, reduced seed quality, and lower or no germination. The effects of heat damage become progressively worse if the initial mold heating is succeeded by chemical heating. The presence of heated brown or black seeds and/or a burnt odor in a sample of grain lowers the grade in the USA and in Canada. The presence of only 2% heated, internally brown seeds in a sample of canola/rapeseed in Canada lowers the grade from No. 1 Canada to No. 3 Canada, with accompanying monetary loss. If more than 2% heated seeds are present in the sample, the seed is further degraded to Canola or Rapeseed Sample Account Heated (Canadian Grain Commission 1987). Similar fixed levels of permissible heated seeds exist for other crops. Seed lots with elevated levels of heated seeds cause problems for the processor, as oil from heat-damaged oilseeds requires extra decolorizing procedures during processing and thus extra costs.

Heat-damaged externally blackened kernels are classified as either bin-burnt or fire-burnt, depending on the severity of the heating. Fire-burnt beans are often shiny black on the outside, with large internal cavities, whereas bin-burnt beans, although often black on the outside, are brown to dark brown in cross sections, with no large, internal cavities. Furthermore, the fire-burnt beans are often fused together (Christensen and Kaufmann 1977). The same phenomena have been observed in our Winnipeg laboratory with bin-burnt and fire-burnt canola/rapeseed, wheat, and malting barley. Ultrastructure and mineral distribution in sound and heat-damaged canola/rapeseed have been studied by Mills and Chong (1977).

Heat-damage may also result from improper artificial drying. Seeds damaged by excessive heat in drying have reduced viability, are darker, and may have blistered pericarps, or seed coats. If heat-damage is extreme the seeds may explode or partially pop (Freeman 1980).

TOXINS

Under suitable conditions of moisture and temperature, spoilage molds produce poisonous substances, called mycotoxins, on stored grains and processed feeds. When mycotoxin-contaminated grains are eaten by susceptible animals, disease conditions called mycotoxicoses may result. The effects of mycotoxins on animals vary, depending on the species and age of the animal, and the type and amount of toxin present in the feed. Disease effects include lack of weight gain, formation of tumors, loss in productivity, fetal abnormalities, and sudden death. In western Canada, ochratoxin A, produced by the spoilage mold *Penicillium verrucosum* var. *cyclopium*, and sterigmatocystin, produced by *Aspergillus versicolor*, have been found in damp or accidentally wetted stored grains associated with livestock health problems (Abramson et al. 1983). In the USA, aflatoxins, produced by *Aspergillus flavus*, sometimes occur in poultry feeds (Hamilton 1985). Aflatoxins have also been reported in grain dust, posing health problems for workers handling aflatoxin-contaminated corn in Georgia, USA (Burg et al. 1982). Recently, aflatoxin was shown to occur in fragments of fungal mycelium and other mycotoxins in the fungal spores, in grain dust (Palmgren and Lee 1986). For an overview of the worldwide risks from mycotoxins see Mannon and Johnson (1985). For a summary of available information on mycotoxins as they affect human and farm animal populations in Canada see Scott et al. (1985).

It is possible that other toxic substances including carcinogens are produced when grain and grain products become heated and/or burnt. If they are produced, such toxic substances and their effects on animals when heat-damaged products are incorporated into animal feeds require investigation.

ALLERGENS

Spoilage fungi present in and on stored grains cause allergic health problems in both humans and animals. Two types of fungus-related health problems have been described in humans: bronchial asthma and farmer's lung. Such health problems are caused by allergic reactions in the respiratory tract stimulated by allergens, primarily from fungal spores. In 1968, over 70% of the grain in the province of Saskatchewan in western Canada was harvested or initially stored in a tough or damp condition because of unusual harvest conditions. Subsequently, 20 out of 3200 farmers and elevator managers who had worked with the damp, heated, or spoiled grain developed acute farmer's lung syndrome (Dennis 1973). For a review on the nature of grain dust, work exposure to the dust, and related health disorders see Manfreda and Warren (1984).

Chapter 4. Prevention of spoilage and heating

Spoilage and heating problems in stored commodities are prevented by a knowledge of commodity storage behavior, prior planning, and application of appropriate management practices. Ways to prevent spoilage and heating problems during storage are outlined in Table 4.

STORAGE STRUCTURES

Obtain advice from a registered professional engineer on the most suitable types of storage structures for the region and their intended use. Once selected, locate the structures on a well-drained site on properly designed foundations, thus avoiding ingress of drainage water and cracked floors. Locate vertical silos that are to be used for storing large amounts of combustible animal feeds in the open, well clear of buildings, and away from any other combustible material (Fig. 4) (Fire Protection Association 1968).

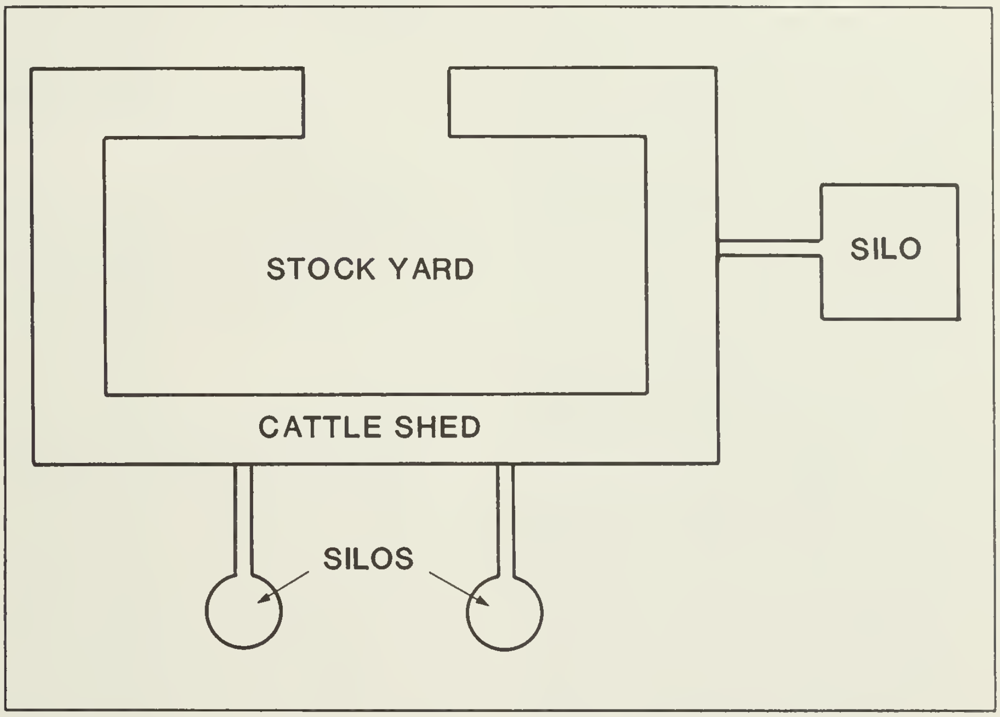

Figure 4 **Location of farm silos in relation to buildings and other combustible material (after Fire Protection Association 1968).**

Empty the bins completely at regular intervals and examine within to detect adherent material (hang-ups) sticking to the walls. Clean empty bins thoroughly, then spray floor and walls with an appropriate insecticide to kill any remaining insects which might infest the new grain. Remove old grain and debris near bin doors, under aeration floors, and under drier floors. Remove any vegetation growing near the bins as it could harbor grain pests.

Some silos are available (for example, Carter-Day All Flow®, Minn.) with inflatable membrane liners, designed to fit against the inner surface wall and floor, which prevent hang-ups, rat holes, and bridges from forming in the stored product. When a sensor senses demand for product discharge the membrane liner automatically inflates, changing the angle of repose of the product and pushing it to the discharge opening.

Keep structures in a good state of repair and weathertight to keep out wind-driven rain or snow which, on melting, provides moisture for mold development. Repair cracks in concrete walls and floors, and seal gaps at the metal wall/concrete base interface to keep out moisture and to reduce the number of hiding places for insects.

MANAGEMENT BEFORE STORAGE

Decisions made while the crop is still in the field can prevent potential storage problems. Such decisions might be to air-dry small grains sufficiently in the field to ensure safe moisture levels during binning; to determine the seed moisture content and temperature of samples obtained from the combine to predict, by means of charts, the keeping quality of the crop (Kreyger 1972; Mills and Sinha 1980; Wallace et al. 1983); and to separately combine wetter outer or lower areas of the field, with immature seeds of high respiratory activity, then bin the grain in smaller observation bins in the farmyard until it is aerated.

REJECTION AT ENTRY

Elevator managers receiving loads for storage in a facility have the right to refuse loads that have doubtful keeping quality or that are in poor condition, thus preventing later handling and storage problems.

If time permits, before elevator entry, managers should determine the degree of invasion by spoilage fungi of suspect seed lots by plating out representative samples and reject if found unsuitable. A railcar load of soybeans, for example, already lightly or moderately invaded by spoilage fungi, is a poorer risk for continued storage than a railcar load of sound beans. The molds may or may not be visually apparent. Such loads stored under conditions that are favorable to mold development progress toward advanced spoilage more rapidly than sound beans (Christensen and Kaufmann 1972). Plating of samples before elevator entry is likely impractical in most busy elevators but could be useful in particular situations.

Table 4 Prevention of spoilage and heating problems in stored products

Grain crop in fields	- Air-dry small grains in swaths to safe moisture content levels. - Provide special binning or artificial drying for moist or immature grains
Binning	- Obtain advice on suitability of bin system for required purpose. - Provide adequate site drainage. - Clean interior and surroundings to remove pest harborages. - Keep in good repair and inspect regularly for leaks. - Spray with insecticide, and fumigate if required. - Refuse loads of doubtful keeping quality on entry. - Know history of material. - Get pre-binning samples and test for spoilage mold invasion. - Remove debris before binning. - Use a properly adjusted grain spreader or stirring device in the bin to evenly distribute fines; some spreaders may worsen fines distribution. - Sample and determine range of moisture content of material throughout binning. - Turn over stocks periodically. This procedure, however, is expensive, labor intensive, and may create more broken material, e.g., in corn. It is better to aerate.
Aeration	- Know principles of aeration and likely problems. - Obtain advice on floor design and fan size. - Remove debris before aerating stocks. - Aerate to cool or warm the product (see Friesen and Huminicki 1986).
Drying	- Obtain advice on most suitable system. - Clean stocks except corn before drying; clean corn after drying because BCFM must be dried for storage and feed use. - Remove accumulations of dust and fuzz from walls and burner area. - Use wind deflectors to keep airborne material and moisture from entering burner. - Check for leaking propane tanks and lines. - Inspect electrical wiring and circuit breakers. - Check for uneven drying. - Use proper air-to-grain ratios on stirring devices to prevent stagnating drying fronts. - Be careful of excess drying temperatures. - Cool after drying. - Check electric moisture meters for accuracy.

(*continued*)

Table 4 Prevention of spoilage and heating problems in stored products (*concluded*)

High moisture grains	
Chemical preservatives	- Clean material before treatment. - Use correct dosage rate for a particular grain moisture content. - Use sufficient chemical on all or part of the bulk. - Aerate material to prevent moisture migration. - Protect concrete or steel surfaces with plastic or acid-resistant paint when using propionic acid preparations.
Ensiling green material	- Cut green material at correct stage of development and pay special attention to any stock that is wilting, the percentage of dry matter, and the length of the cuts. - Fill silos quickly to ensure good compression for air exclusion. - Use distributor to pack material along silo wall. - Ensure doors and walls are tight (top unloading). - Keep top and bottom hatches closed to prevent chimney effect (bottom unloading). - Know the minimum percentage of moisture content for safe storage of material. - Put a green plug of moist material at top of filled silo (unsealed silo). - Remove material quickly. - Partially unload immediately after filling to prevent bridging of auger (oxygen-limiting silos).
Processed products	- Remove metal fragments to prevent foci for hot spots. - Cool off ground material or artificially dried material in small quantities before binning. - Vibrate bin walls to prevent bridging. - Avoid contamination with liquids liable to self-heat. - Avoid storage in close proximity to heat sources, for example hot ducts, engines, or bin lights. - Avoid overdrying. - Ensure that bin conveyors do not become sources of frictional heat or electrical sparks.
Education	- Educate staff on storage characteristics of different commodities. - Ensure staff are aware of moisture content ranges and moisture migration. - Stress the importance of regular inspections and a proper reporting system

MANAGEMENT DURING STORAGE

General handling

Cleaning harvested material to remove high-risk debris, broken seeds, immature weed seeds, chaff, dust, and other fines can improve the efficiency of aerators and bin driers by increased airflow. With corn, remove fines from the screens after drying, because BCFM (broken corn foreign material) has to be dried for storage and feed use. Cleaning units incorporated into standard grain augers now permit grain cleaning during augering (Anonymous 1982). If it is not possible to clean the seed, then use a properly adjusted grain spreader or stirring device (Gebhardt 1983) inside the bin to prevent the accumulation of fines and other material in the bin core. Withdraw one or more loads, on completion of binning, through the bottom of the bin to remove fines and to make an inverted cone suitable for ambient air-cooling rather than a peaked surface. In Saskatchewan, bins are often filled as full as possible to provide less room for snow to accumulate, but in high-humidity areas such as Manitoba the overfilling of bins can reduce ventilation and increase the likelihood of spoilage.

Sample and determine the ***range*** of moisture content of the harvested material as it is placed in the bin. The highest moisture level is the one of greatest concern. Aerate the binned material. In non-aerated bins, after binning turn the material into another bin or truck to even-out any moisture pockets and temperature differences. Turning is costly and increases FM (foreign material), especially in corn, and is therefore done sparingly.

Inspect regularly the storage structure and its contents for leaks in bin roofs or in hatch covers on ships, for snow blown in through cracks, for open doors, and for spoilage. Install permanent metal ladders on the sides of storage structures to facilitate such inspections. Probe the material regularly for signs of spoilage and heating, particularly in the top bin centre, or install remote CO_2 (carbon dioxide), and temperature sensors. The detection of such problems is described in a later section.

The probable development of spoilage molds in a lot of seeds during storage is predicted by the amount of existing spoilage mold present and a knowledge of the history, condition, and type of seeds involved. Decisions are then made regarding how long to keep the particular lot, whether it should be disposed of, or which preventive measures need to be taken.

Aeration

Aeration is the practice of forcing unheated air, by means of a fan, through grain to maintain its condition and reduce the chances of spoilage and heating. This system lowers the temperature of the bulk if the grain is above the ambient air temperature, maintains a uniform temperature throughout the grain mass, which reduces or eliminates moisture migration, removes hot spots, reduces mold and insect growth, and removes storage odors. Aeration is commonly used on the Canadian prairies at airflow rates of 1–2(L/s)/m^3. There are many aeration systems available. Proper floor design and fan size are important and requirements need to be checked with a professional agricultural engineer. Aeration principles and the proper operation of aeration systems are described by Friesen and Huminicki (1986).

Localized spoilage may occur if the airflow is too low in some regions of the bin, if there is excessive debris, or if the fan is shut off before all the grain has been cooled in the fall or warmed in spring, as condensation may occur between cooler and warmer parts of the grain mass. In extreme situations, if heating is far advanced, aeration may result in self-ignition and loss of the crop.

Drying

Drying grain prevents spoilage and subsequent heating of grain in storage. Other advantages of drying grain include a longer harvest season and the option for earlier harvesting with reduced field losses (Friesen 1981). To obtain maximum benefits from a grain dryer it is necessary to set up a well-organized system for grain handling. The following methods, each involving the movement of air through grain, are available for drying grain:

- *High temperature or heated air drying* method involves blowing heated air through the grain in a separate dryer or in a bin.
- *Low temperature air drying* method uses the potential of atmospheric air for drying grain.
- *Combination air drying* method involves heated air drying, followed by in-storage cooling and atmospheric air drying.
- *Dryeration* method involves heated air drying, followed by a tempering period and cooling and drying in a separate bin.
- *In-storage cooling* method (an alternative to in-dryer cooling) transfers hot grain directly to the storage bin for cooling.

The subject of grain drying is too complex to describe here. The reader is referred to publications by Friesen (1981), Friesen and Huminicki (1986), and Moysey (1973) for detailed information. General recommendations for the design, installation, and utilization of driers are published by the American Society of Agricultural Engineers (1986), but these may differ from Canadian recommendations.

Fires in dryers

Fires can occur in both farm and commercial dryers, and are detected by a sudden rise in exhaust air temperature. Fires can occur in heated air dryers if dirt and residues accumulate in the burner area. Sunflower seeds often have fuzz attached to them which is released in the drying process and if drawn through the fan and burner may ignite. Corn kernel debris composed of red dog and other fines may ignite. Canola seeds may also ignite when passed through a burner.

Suggested ways to reduce the risk of fires in dryers (Broadhurst 1985; Friesen 1981) are as follows:

- Check propane gas tanks and lines for leaks.
- Inspect electrical wiring for soundness. Wire insulation can be cracked, dried out, or rubbed bare, especially on connections to equipment which is in constant movement. Circuit breakers can deteriorate through lack of use to the point where they do not break when overloaded.
- Repair and do not bypass controls such as air switches provided as safety measures by the manufacturer.
- Clean the seed to remove light or fine material before drying.
- Use wind deflectors to prevent drawing of airborne material through the burner.
- Remove accumulations of dust and fuzz from the walls and other areas of the drier.
- Avoid excess drying of seed.
- Keep temperature of drying air within recommended safe limits.
- Be alert at all times during the drying cycle.
- Put sunflower seed and canola through the dryer on warm dry days without starting the burner.
- If a fire occurs, shut off the heat and fan.
- Have water and/or fire extinguisher ready for use.

Commercial dryers are also vulnerable to fires. Detection and control of fires in commercial dryers are discussed in a later section.

High moisture grain storage

Mold growth on high moisture grains of above 22–25% M.C. is prevented by limiting the available oxygen supply, as in sealed silos. Another method is by the application of mold inhibitory chemicals to the grains.

Sealed storages When high moisture grain such as corn is placed in a sealed silo, the grain undergoes fermentation, oxygen is

Table 5 Amounts of propionic acid required for preventing mold growth in high moisture grain*

Moisture content (%)	Propionic acid required	
	Percentage ** ***	Kilograms/Tonnes ** ***
18	0.3–0.6	2.5–4.9
22	0.5–0.8	4.1–6.6
26	0.6–1.0	4.9–8.3
30	0.8–1.2	6.6–9.9

* Source: University of Kentucky (1984).

** Rate for short-term storage in cool weather over winter.

*** Rate for 1 year's storage, beginning late fall.

depleted, and carbon dioxide is increased by the respiration of the grains, yeasts, and bacteria. Aerobic mold growth is halted but germination is impaired, making the seed only suitable for animal feed. On removal from the silo, mold growth recommences; therefore exposed grains must be fed rapidly to keep ahead of mold growth. The high moisture grains may be stored in glass-lined, oxygen-limiting steel silos or in other kinds of airtight bins that have a breathing system to prevent structural failure because of differential pressures and to limit the exchange of in-storage gas with outdoor air. For details on the selection and use of oxygen-limiting silos see Bellman (1982) and Pos (1980). High moisture corn is also stored in sealed concrete silos and in bunkers covered with plastic. The corn is usually cracked and packed tightly to quickly develop anaerobic conditions (Tuite and Foster 1979).

The following problems may be encountered during storage of high moisture grains in sealed silos: spoilage of corn near walls of concrete silos caused by the failure to spread the material in uniform horizontal layers; and surface spoilage caused by removing the grains too slowly, allowing oxygen levels to increase. In oxygen-limiting silos, bridging may occur over stationary unloading augers. Where only one fixed auger position is available some unloading should be done immediately after filling is completed to set up a flow pattern, thus preventing bridging (Pos 1980).

Chemical preservatives When high moisture grain is treated with the recommended dosage of a registered preservative chemical the grain can be removed from storage without concern for spoilage. Propionic acid is the most common material used, applied either as 100% propionic acid or in mixtures with acetic acid, isobutyric acid, or formaldehyde, but the latter materials do not enhance the efficacy of propionic acid significantly. Other materials under investigation are sulfur dioxide(SO_2) and ammonia (NH_3) (Tuite and Foster 1979). The acid dosage rate depends on the moisture content of the grain (higher moisture contents requiring more acid (Table 5)), temperature, and length of storage period. Acid-treated grain does not need any particular type of storage structure, but when galvanized steel sheets are used severe corrosion can result. This problem can be corrected by prior coating with chlorinated rubber paint (Theakston 1972).

Grain that has been treated with a preservative can also be subject to mold spoilage and should be inspected regularly during storage (University of Kentucky 1984). Mold growth releases moisture, enabling the molds to spread to the treated grains. This occurs under the following conditions:

- When an incorrect dosage rate of preservative for the particular grain moisture content is used.
- When insufficient acid is used on all or part of the bulk.
- When wet spots develop through moisture migration. To prevent wet spots, aerate acid-treated grain to break up temperature gradients that cause moisture migration, clean the grain before storage, and use correct fan and aeration flow rates. If aeration is improperly done, readsorption could occur in the upper grain layers, and free moisture could drop back from the roof onto the grain, diluting the acid, thus permitting mold growth.
- When treated grains are in contact with unprotected concrete or steel. Such surfaces should be covered with plastic or acid-resistant paint (University of Kentucky 1984).

Ensiling green material

Chopped green plants and chopped green hay, stored as silage and haylage (medium moisture forages) in vertical and horizontal silos, are subject to both spoilage and heating problems. Spoilage commonly results in a loss of 10% dry matter in a properly managed, conventional concrete silo. New concrete designs now provide walls of greater density with lower porosity, allowing a more airtight container and ensuring less spoilage. Losses have been further reduced by proper filling techniques and the use of silage distributors to ensure uniform loading. Oxygen-limiting silos with an effective gas seal can control dry matter losses to 2–4%. Traditionally, losses in uncovered horizontal silos have been as high as 32%, but they can be reduced by as much as 50% by sealing the silage with an airtight polyethylene cover, properly weighted down and protected from puncturing (Pos 1980), and by utilizing the material at a sufficient rate to minimize exposed surfaces to the air.

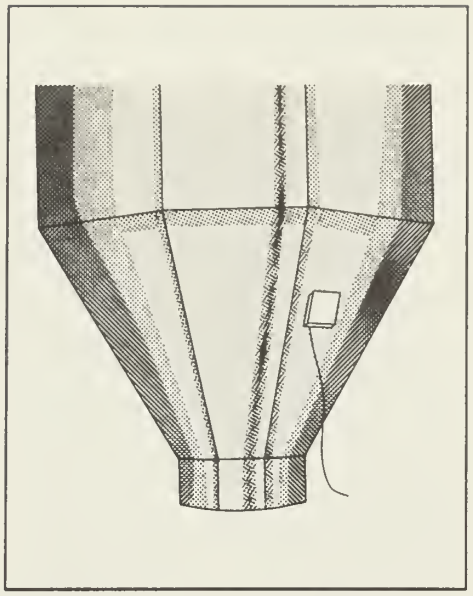

Figure 5 Magnetic vibration device installed at base of feed bin to prevent hang-ups and bridging (Seedburo Equipment Co., Chicago).

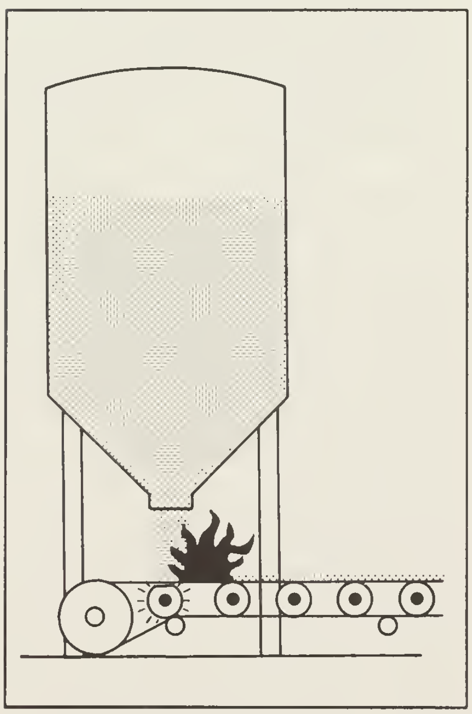

Figure 6 Fire on belt conveyor caused by frictional heat or electrical sparks as a result of poor maintenance (after Fire Protection Association 1968).

Heating problems and fires can occur in both top- and bottom-unloading vertical silos. With top-unloading types, ensure that the doors and walls are tight with no gaps. With bottom-unloading types, keep the top and bottom hatches closed to prevent the creation of a chimney effect by air being drawn through the silo. The moisture content of the ensiled material is critical in preventing heat-damage and fires. If haylage, for example, is stored below 40% M.C., fires may result. The advised moisture contents of haylage in bottom-unloading silos are 40–55% (R. Nelles, pers. com. 1986), and in top-unloading silos they are 50–65% (Campbell 1973). The key to preventing outbreaks of fires is good filling management. This includes cutting at the right stage, proper attention to wilting, short chop length, and fast filling rates with decreasing dry matter levels and, in the case of "unsealed" silos, a "plug" of unwilted material at the top (Institution of Fire Engineers 1970).

Processed products

Handle processed products more carefully than unprocessed ones because the natural defenses of the seeds have been mechanically destroyed, they are mixtures of finely divided materials and additives, and they are often subjected to heat during processing. Take the following precautions to prevent spoilage and heating problems:

- Replace damaged pellet dies every 4–5 months to prevent formation of burnt pellets and metal fragments.
- Remove metal fragments that could act as focal points for hot spots in the processed product and cause damage to the pellet die.
- Avoid excessive drying of meals. Tung nut meals, for example, are susceptible to overheating if dried too much (National Fire Protection Association 1949).
- Cool the product properly before storing it.
- Install appropriate vibrating devices to feed bin walls to prevent bridging and hang-ups (Fig. 5).
- Check loading and unloading conveyors to ensure that fires cannot be caused by frictional heat or electrical sparks (Fig. 6).
- Avoid contaminating the product with liquids liable to self-heat.
- Store the product away from heat sources (Fire Protection Association 1968, 1978).
- Clean feed distribution equipment (Hamilton 1985).

Note: Vibrating devices added to bin walls require proper installation and use, or structural problems may result.

EDUCATION

A well-informed staff is the first defense against spoilage and heating problems in storages. Ensure that staff are aware of the storage characteristics of different commodities; have a knowledge of the importance of moisture content ranges and moisture migration patterns in bins, silos, and ships; know the probable causes of spoilage and heating problems; and know the importance of regular inspections and a good reporting system. This knowledge can be obtained from training courses and on-the-job instruction.

Chapter 5. Detection of spoilage and heating

Spoilage and heating in stored commodities are detected by the presence of certain distinguishing features, by regular environmental monitoring, and by detailed examination of samples. Some distinguishing features, for example melted snow on roofs and putrefactive odors, permit recognition of very advanced stages of spoilage and heating, whereas others, such as carbon dioxide levels slightly above those present in ambient air, permit recognition of the early stages or even incipient spoilage. A list of distinguishing features useful for detecting early (E), intermediate (I), or advanced (A) stages of spoilage and heating is given in Table 6. The features are grouped according to the following detection viewpoints: (a) from the exterior of the storage structure; (b) from the interior of the storage structure above the stocks; (c) during the movement of stocks; (d) during monitoring of the stocks in storage; and (e) during detailed examination of samples in the laboratory.

EXTERIOR OF STORAGES

Odor

Spoilage and heating can occasionally be detected from outside the storage structure by a recognizable change in the normal odor of the stored product. The presence of putrefactive or burnt odors means that much of the product in store is likely in an advanced stage of spoilage or heating. Putrefactive odors were evident outside flood-damaged bins of cereals after the Manitoba Red River flood in the spring of 1979 (see Fig. 18*a*), and burnt odors were detected outside a severely heat-damaged bin of faba beans in the fall of 1979. The odors were associated with advanced spoilage or heating and detectable from a distance of several hundred metres.

Melted snow

The absence of snow from the roof of a bin when snow is present on other bin roofs indicates advanced heating, and the melting of snow around the bin for several centimetres indicates severe heating.

Free liquid

In some instances of advanced heating, particularly of moist seeds, the bin or silo contents are heated to such an extent that distillation occurs. A brown liquid is produced, which may flow through the seams of metal bins or the joints or cracks of silos, and may collect in pools on the ground outside the structure. This phenomenon occurs in stored soybeans and stored faba beans (Mills 1980).

Steam, smoke, and flames

Steam may emerge from roof hatch openings as part of the distillation process described in the previous section. Smoke and flames may be visible from outside the structure when severely heated contents are in contact with air at the point of attachment of aerators, under drying floors, or in the upper parts of the storage structure. Smoke and ionic products produced during early stages of fire hidden within structures, for example in a ship's hold, are detectable by smoke and other detectors.

Thermography

Thermography is the science of producing pictures from invisible thermal radiation (Wishna 1979). Temperature variations in stored products within storages are converted into images and viewed and recorded by photography (Boumans 1985; Rispin 1978; Wishna 1979). The technique is particularly useful for early detection and for determination of the extent of grain fires in large concrete silos. Devices are available with or without temperature measurement. The equipment is expensive but may be obtained on a fee-paying basis from local energy conservation companies, or services may be contracted.

INTERIOR OF STORAGES ABOVE STOCKS

Heat haze

When viewed horizontally the air space above the surface of the stocks appears to shimmer. This "heat haze" is caused by the release of heat into the air from a heat source in the product and indicates advanced heating within the bulk.

Steam

When the stored commodity contains high amounts of moisture or immature material, steam may be released from the surface, indicating advanced heating. During a 1982 Manitoba survey of bins containing frost-damaged canola, advanced heating was detected in one wooden bin by the presence of a column of steam rising from the centre surface. The canola was between 9.1 and 14.1% M.C. and reached 102°C after only 10 days storage (Mills et al. 1984).

Sprouting, bridging

The presence of sprouted grains, often with green vertical shoots, on the centre surface of bulks indicates that the seed moisture content levels in the uppermost layers, apart from being high enough for seed germination, are more than sufficient to support mold spoilage. Sprouted grains also indicate poor air circulation in the bin and leaking roofs, and are often associated with the development of an upper bridge across the bin. The presence of such a bridge can be detected by probing with a grain probe.

Probe resistance

The degree of resistance experienced when pushing downward with a grain probe can determine the vertical extent of the upper bridge and the degree of aggregation among the grains below. If it is difficult or impossible to push downward, it is likely that aggregation and compaction due to activities of spoilage molds are the causes.

Table 6 Detection of spoilage and heating in stored products

Detection viewpoint	Distinguishing features	Indicative of spoilage	Indicative of heating
Exterior	- Odor (putrefactive)	A	–
	- Odor (burnt)	–	A
Exterior: walls and roof of silo	- Snow melting on the roof; space existing between the structure and surrounding snow	–	A
	- Brown liquid flowing through wall seams onto the ground	A	A
	- Smoke, vapors, steam, or fire	–	A
	- Hot areas near bin wall visible by thermography	–	A
	- Change in the color of thermal paint or label	–	A
Interior: above stocks	- Heat haze above the surface	–	A
	- Steam column rising from the surface	A	A
	- Odor (musty)	I	–
	- Sprouting grains, bridging, visible mold (green, blue, yellow, or white)	A	–
	- Sampling probe difficult to push into contents	I,A	–
During movement of stocks	- Auger ceases to operate	A,I	–
	- Smoldering fire bursts into flame	–	A
	- Presence of black fused hot or cold materials in stocks	–	A,I
	- Presence of insects, middle bridge	I	I
During monitoring of stocks in storage	- Temperature higher (I,E) or much higher (A) than expected product temperature, as detected by rods, thermometers, thermocouples, or cables	A,I,E	A,I,E
	- Moisture content levels increase, particularly near surface	I,E	–
	- Elevating CO_2 levels	I,E	–
	- Sampling	A,I,E	A,I,E
Detailed examination of samples in laboratory	- Presence of brown or black material, sometimes fused	–	A,I
	- Tobacco-like odor when crushed	–	I
	- Presence of spoilage molds (green, blue, yellow, or white)	I,E	I,E
	- Presence of the fungi *Monascus* and *Paecilomyces* is indicative of failure of acid treatment to grain	I,E	–

Key:

E = early or incipient spoilage and/or heating.
I = intermediate spoilage and/or heating.
A = advanced stage of spoilage and/or heating.

Molds

The presence of blue, green, yellow, orange, or white spoilage molds on the surface of the bulk or within the upper bridge indicates that moisture and temperature conditions suitable for development of such molds exist. Musty odors are often associated with the development of spoilage molds on the grain.

MOVEMENT OF STOCKS

Adverse changes within bulk-stored products are frequently detected by removing 5–10 t of product through the bottom of the bin to see whether it flows freely or has any sour, musty (indicative of mold spoilage), or tobacco-like (heating) odors, or other abnormalities.

Auger blockage

During the process of bin unloading, augers sometimes stop operating. The cause is frequently due to blockage of the augers by loosely aggregated or densely packed material resulting from either localized or more extensive mold activity, indicating intermediate or advanced levels of spoilage. If the auger under the floor has multiple openings and they are all open (a common practice), then a blocked centre opening will result in off-centre emptying and potential structural problems.

Heat fusion

Sometimes black fused chunks of product are present in the unloaded stocks. The fused chunks are likely to be first noticed in clogged augers or on gratings, for example when railcars are unloaded. These fused chunks can be very hot and are the result of advanced biological and chemical heating. If they are very hot, the chunks may spontaneously ignite when exposed to air during unloading operations. For this reason, fused chunks are a serious potential cause of elevator fires and explosions and should be handled with extreme care.

Smoldering

When advanced heating occurs deep down in large concrete silos, affected stocks may smolder undetected for many months. The presence of such heating problems are frequently first detected during movement of stocks, when hot smoldering material from deep within a silo is exposed to air. The exposed smoldering material may be accompanied by considerable smoke, burnt odors, and even flames. Black fused chunks may also be present.

Insects

Movement of grains sometimes reveals unsuspected insect infestations. At a terminal elevator in British Columbia, a large silo was used for wheat and barley cleanings for several years, during which time it was not emptied. A severe insect infestation, later controlled by fumigation, was discovered during partial unloading of the silo but the problem reoccurred. On emptying the bin a well-developed middle bridge consisting of high-moisture material, some of which was at an intermediate stage of spoilage, was present. The bridge provided an ideal habitat for ongoing insect development.

MONITORING OF STOCKS

Most of the detection methods described previously have been concerned with ways of recognizing the intermediate or advanced stages of spoilage and/or heating in stored commodities. Monitoring of stocks *in situ*, however, provides the main means of recognizing the early stages of these problems. Four major monitoring methods are employed: temperature, moisture/relative humidity, and carbon dioxide measurements, and sample removal and examination.

Temperature

Temperatures within stocks much higher than ambient air temperatures usually indicate heating, but in some instances, they indicate retained field heat. In winter, temperatures at the centre of unaerated bins, especially those of large diameter, are higher than that of the surrounding grain or ambient air because the product will be at the temperature it entered storage. Temperatures of various parts of the stocks and of the ambient air need to be monitored from initial storage on a regular schedule to determine whether the stocks are actually heating. As an illustration, the temperature of ambient air and of stored grain 1 m and 2 m from the walls was determined in two 4-m-diameter bins. The temperatures were –5°C, 4°C, and 14°C and –5°C, 6°C, and 31°C, respectively. The grain temperature when the bins were filled was 18°C; therefore, the 14°C temperature was considered the result of residual field heat, and the 31°C temperature was considered the result of probable biological heating.

Monitoring of temperature changes and detection of heating within stocks is achieved by using equipment such as bin thermometers, thermocouples, thermistors, temperature-sensing cables, thermography, temperature sensitive paint and labels, and vertically inserted steel rods.

Bin thermometers are designed for grain but can be used for other products. They consist of a mercury-in-glass thermometer inserted within and near the tip of a pointed steel pipe into which other sections of pipe and a T-shaped handle are threaded to push the thermometer to the desired depth. The advantage of bin thermometers is that temperature checks can be conducted at a variety of locations. Disadvantages include short penetration distance (the probe probably does not reach the actual problem heating area), and excessive time and labor. A more desirable method is to attach thermometers to metal wire and to insert them into steel pipes installed in the grain, thus permitting increased depth of penetration and multiple-indicating points along the tube (Medders 1975). Note that mercury-in-glass thermometers and the steel pipes can take 10 to 30 min to reach the grain temperature because of the low thermal diffusivity of grain.

Thermocouples consist of a pair of metal wires, usually copper and constantan, joined at one end electrically. Thermocouples change in impedence when exposed to temperature differences and, when connected to a temperature monitor, detect increases in temperature. They are available for monitoring temperatures from –70°C to 400°C and for higher temperatures if ceramic cable is used. Grain bin monitoring devices based on thermocouples vary from simple thermocouple wires or probes periodically attached to portable monitors, to commercially available systems employing multistrand cables permanently attached to continuously recording monitors with alarm systems. Thermocouples are inserted into grain either before or after filling the bins (Lyster 1983).

Thermistors, small devices similar in appearance to resistors, are used to measure temperature changes with the advantage of using ordinary speaker wire rather than more expensive thermocouple wire (Anonymous 1985). They are particularly valuable in smaller bins. Because thermocouples and thermistors pick up temperature changes only at points relatively close to them, it is advisable to locate sensors where heating is most likely to occur. In western Canada, the preferred locations for sensors are at the top centre of bins at depths of 30 cm, 45 cm, 1 m, and 2 m.

Temperature-sensing cables are usually recommended for storages of 544 t capacity and above. For 544-t bins, suspend four cables from the roof (Fig. 7). Mount the centre cable to one side of the bin centre to reduce drag on the cable when unloading grain. Space sensing points at intervals of 1.2–1.5 m along each cable (McKenzie et al. 1980). Use more cables in bins of larger volume (Boumans 1985; Foster and Tuite 1982). Attach support brackets to roof and bin walls for cables longer than 6–9 m, as most bin roofs are not able to take the weight and the cables or the roof might be pulled down (G. Henry, pers. com. 1986).

Thermography is sometimes used in large silo complexes to detect heating of inaccessible stocks and electrical and mechanical equipment. Thermography is particularly useful for detecting and determining the extent of grain fires in large silos, which can smolder unnoticed for many months (Boumans 1985; Rispin 1978; Wishna 1979). Thermal-imaging cameras were recently used to determine the location of fires and heat levels in a stubborn shipboard fire involving wet animal feed, oil, and other substances generating intense smoke (Fire Protection Association 1986).

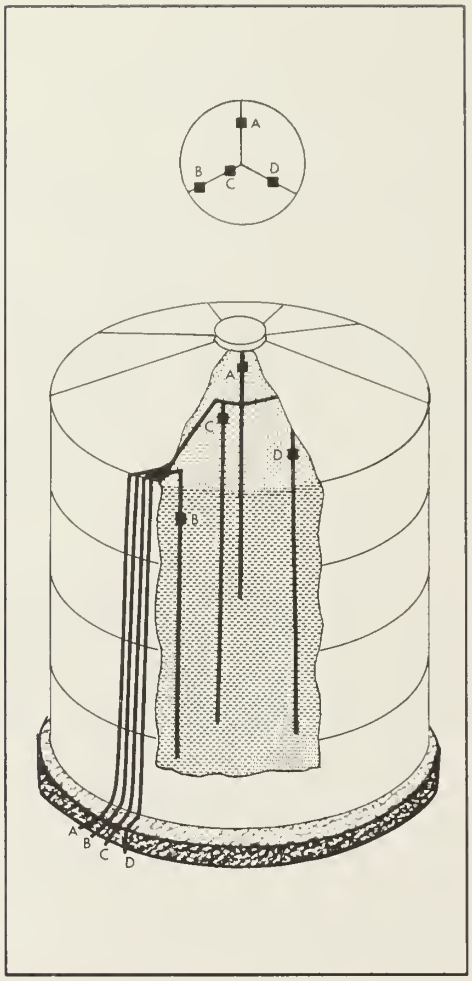

Figure 7 Bin temperature monitoring system of four sensing cables *A–D* suspended from the roof. Cables *A*, *B*, and *D* are located halfway from wall to bin centre and *C* is located close to the centre. Note: Cables longer than 8–12 m require support brackets (McKenzie et al. 1980).

Temperature-sensitive paint or labels are commercially available to provide quick visual monitoring. Temperature-sensitive paint is applied in small strips to the roof and walls of a bin, and thermally sensitive labels are attached to equipment. The disadvantage is that these monitoring aids are not reusable, and temperature rises have to be excessive before the roof or wall temperature rise is greater than that due to other causes, such as solar radiation.

Steel rods, 1 cm in diameter, that are vertically inserted 3–4 m into the grain mass for 15 min, and then withdrawn, provide a quick check for rising temperatures.

Limitations of temperature recording systems

Temperature recording systems are an important component of stored grain management, as significant temperature rises can be detected early if frequent measurements are made. However, they have their limitations and for maximum effectiveness need to be used in conjunction with other detection methods. Sometimes deterioration occurs before there is any detectable rise in temperature and it is not recognized by temperature sensors. Hot spots can remain undetected, because temperature sensors are only sensitive for distances of 30–60 cm and the heat from a pocket of heating grain moves very little (Lyster 1983). A slight rise in grain temperature at the thermocouples above and lateral to a hot spot may be the only indication of severe spoilage in a large silo. If this is disregarded or missed, a considerable volume of grain may be in the final stages of spoilage before trouble is recognized (Christensen and Kaufmann 1972). To detect any hot spots that may be occurring between sensor locations it is necessary to use a grain thermometer or portable temperature probe attached to a monitor and/or take samples with a grain probe.

Temperature sensors may also miss insect infestations, which develop in warm grain. Much grain was combined at 30°C and above in western Canada in the fall of 1981, with the grain at the centre of bins remaining at these high temperatures for several weeks. A farmer checking the bins would have found no change in temperature and assumed that the grain was in good condition. However, many of these bins contained rapidly multiplying populations of the rusty grain beetle. The presence of this insect is not detectable by temperature measurements alone but is easily detected with the use of a simple grain probe (Lyster 1983) or insect detection traps inserted into the grain (Loschiavo and Atkinson 1973).

Moisture

Changes in grain moisture are usually monitored by removing samples from bulks and conducting moisture determinations, using laboratory equipment such as electrical moisture meters or drying ovens. Remote sensors are now available for monitoring moisture changes that occur within grain bulks (Gough 1974, 1980; Waterer et al. 1985) (Fig. 8).

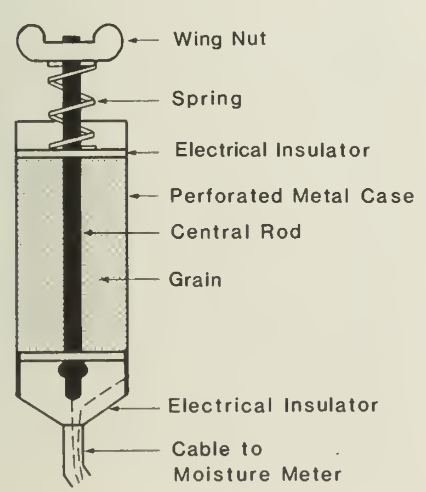

Figure 8 Diagrammatic view of sensor for monitoring moisture in stored grains (after Gough 1980).

Reethorpe moisture sensors have been described (Gough 1974), and modified forms are used in New South Wales, Australia to monitor moisture in 4-m deep horizontal bins of paddy rice. They were also used by storage engineers of the Tropical Development and Research Institute, London, England, to detect moisture content changes that occurred in bulk brown rice in 100 t steel silos in South Korea, which has a tropical summer and a continental winter. The unaerated rice was stored at 13.5% M.C. (wet basis) for 8 months and the top surface became moldy at the end of the storage period. Sensors inserted into the bin before and during bin filling indicated that moisture had migrated to the top of the bin and to the north bin wall, giving rise to local moisture content increases of 7 and 3%, respectively (Gough et al. 1987). Reethorpe moisture sensors placed mainly at surface locations can detect climatically induced moisture changes and they may be able to detect incipient spoilage. In the tropics, detection devices are often put in the wrong place in bins. This is because their correct placement is dependent upon solar orientation rather than on positions taken from moisture sensing in temperate climate installations, which are commonly in the middle of the grain bulk (J.A. Hallam, pers. com. 1986). Moisture sensing has the disadvantage of being expensive compared to temperature sensing, but the advantage of direct indication of moisture content justifies the additional cost.

Carbon dioxide (CO_2)

Low-level grain spoilage caused by molds, mites, and insects can be detected in bins by measuring CO_2 concentration in the intergranular air. These organisms produce CO_2 as they respire; therefore, by measuring the level of CO_2 concentration their presence can be detected before serious grain damage occurs. The following levels of CO_2 concentration apply: in atmospheric air 0.03%, in low-level spoilage 0.08–0.1%, in serious spoilage 2.0% or higher, in hot spots 5.0 to 7.0%.

To measure levels of CO_2 concentration in stored grains and other commodities, a simple device (Fig. 9) consisting of a 50-mL plastic syringe, a commercially available CO_2 analyzer tube, and polyethylene and rubber tubing has been developed at the Winnipeg Research Station. To determine CO_2 levels, the polyethylene tubing is inserted into the grain, the syringe and CO_2 analyzer tube are attached to one end, air is drawn through into the syringe, and the level of CO_2 present read from the color-coded scale. Analyzer tubes are commercially available for CO_2 measurement with scales of 0.01–0.3, 0.1–1.2, 0.5–6.0, 0.5–10.0, 1.0–20.0, and 5–60% CO_2. The device and its operation are described in detail in Wilkins (1985*a*).

The technique permits accurate detection of spoilage and insect infestations in grain bins much earlier than is possible with temperature and/or moisture measurement devices, and is particularly useful in large bins, as described in the following example. In the spring of 1985, a 544 t previously aerated bulk of wheat, binned at 10.1–14.7% M.C. (mean 14.2%) and 0.03% CO_2 (normal)

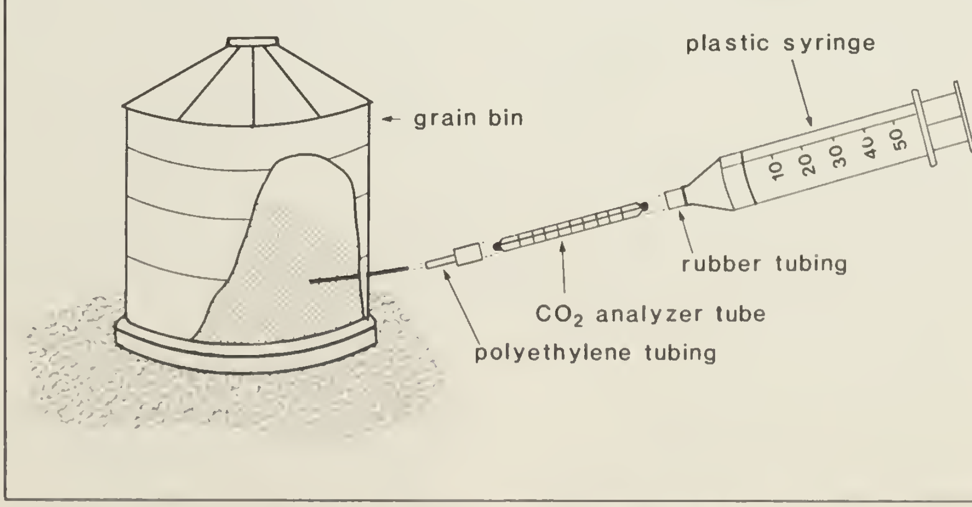

Figure 9 Device for detecting grain spoilage by CO_2 measurement.

levels the preceding fall, developed a sudden rise in CO_2 levels. Three gas sampling tubes were located near the wall, at the centre and midway between these locations, 30 cm above the floor. The ends of the tubes were covered with mesh to prevent them from being plugged with debris. During the winter and early spring, moisture increased near the floor and around the periphery of the bin walls. In early March, CO_2 values suddenly increased from 0.1 to 1.1% over 5 weeks in this region. The grain was aerated to remove moisture. Although less than a tonne was affected, without early detection the potential for damage was considerable in such a large bin. Furthermore, the grain was intended as feed for pigs and serious health problems could have resulted if mold had developed and been integrated in their rations.

Sampling

Regular sampling of grain stocks enables existing or potential spoilage and/or heating problems to be detected before considerable damage has occurred. Sampling procedures used to locate trouble areas include sampling on a systematic and spot basis. Sampling of stocks is needed at weekly or more frequent intervals at the outset to ensure that moisture and temperatures are acceptable. Sampling intervals may be lengthened to monthly or longer periods, provided the moisture and temperature levels have stabilized and the temperature inside the bin is below 0°C. Sampling should also be initiated when obvious signs of deterioration are apparent, for example musty or off-odors or water vapor coming from the grain mass.

Representative grain samples are obtained with specialized sampling equipment, using standardized methods. The *partitioned grain trier* (Fig. 10*a*) is the most widely used sampler. This device is used to obtain samples to determine insect infestation, grain damage, and moisture, and consists of a 1.5-m-long, brass double tube divided into compartments for sampling at specific depths. The trier is filled by inserting it full length into the grain at a 10° angle from vertical with compartments closed and facing up, twisting the handle to open the compartment doors, and moving it up and down quickly three times in the grain. The trier is then removed after the doors are closed and emptied by laying it across a piece of cloth to catch the grain as the doors are opened. To obtain surface samples, the trier is pushed horizontally about 7.5 cm below the grain surface. The *deep-cup, or bin, probe* (Fig. 10*b*) allows samples to be taken from greater depths than are possible with the grain trier. The brass sample cup is inserted into the grain and 90 cm extensions added to reach the desired depth. A short pull of the handle opens the top, allowing grain to flow into the cup. *Pneumatic grain samplers* (Fig. 10*c*) can obtain grain samples from deep silo bins. Preferred locations are the centre core and near walls warmed by the sun or other heat sources. Sections of sampling tube are attached to a cyclone air pump, which provides the suction force for pulling up the sample grain and for pushing the probe further into the mass. Using this equipment, two people can make six or seven 24-m probes during a working day, but this may vary with the type of grain and its moisture content.

Sampling plans may be utilized to locate hot spots or pest populations within storages. Details of such plans are given for full upright circular bins, flat storages, and overfilled bins by the University of Kentucky (1984). Detailed plans are given in Laewer et al. (1981) for representative sampling of 4.5–18-m diameter circular bins for moisture and temperature determinations, and in Kramer (1968) for representative sampling of covered hopper cars.

SAMPLE EXAMINATION

At the laboratory each sample is coded, and details of its origin, history, date obtained, crop, variety, and other details are recorded. Each sample is then thoroughly mixed and portions set aside for specific tests, many of which can be rapidly performed to give an assessment of sample condition.

Moisture content

It is vital to know the range of moisture content of grains within the bin or silo, as this largely determines the storage risk. If the moisture content of some grains in a bin is sufficient for mold development and spoilage, early detection of such material prevents spoilage and heating problems from occurring.

Many methods measure grain moisture, including the hot-air oven and the electronic (electrical capacitance, electrical resistance) methods. The hot-air oven is widely used as a check method and procedures have been established for many crops. For wheat of less than 25% M.C., for example, the American Society of Agricultural Engineers (ASAE) Standard is to heat 15 g in a hot-air oven at 130°C for 19 hours. After oven drying, samples must be cooled before weighing, otherwise the convective air currents caused by the hot sample dishes would affect the weighings. Electronic methods are in practical use in many grain storage facilities. They are relatively accurate and fast, but they also have faults. Most electronic meters for measuring moisture content are not suitable for high moisture content grain and their sensitivities decrease with increasing moisture. Further, the calibration of such devices needs to be checked periodically against results obtained with the hot-air oven method. For recent evaluations of grain moisture meters see Prairie Agricultural Machinery Institute (1981).

Color and odor

The external and internal color and odor of seeds in a sample provide much useful information on their storage condition. Dull seeds indicate the likelihood of spoilage molds and other spoilage problems. Brown or black seeds accompanied by a tobacco-like odor indicate bin-burn. This can be seen when the seeds are viewed in cross section. Black vacuolated seeds, usually fused together and accompanied by a fire odor, indicate fire-burn. A few bin-burnt or fire-burnt seeds in a sample results in significant crop degrading and monetary losses.

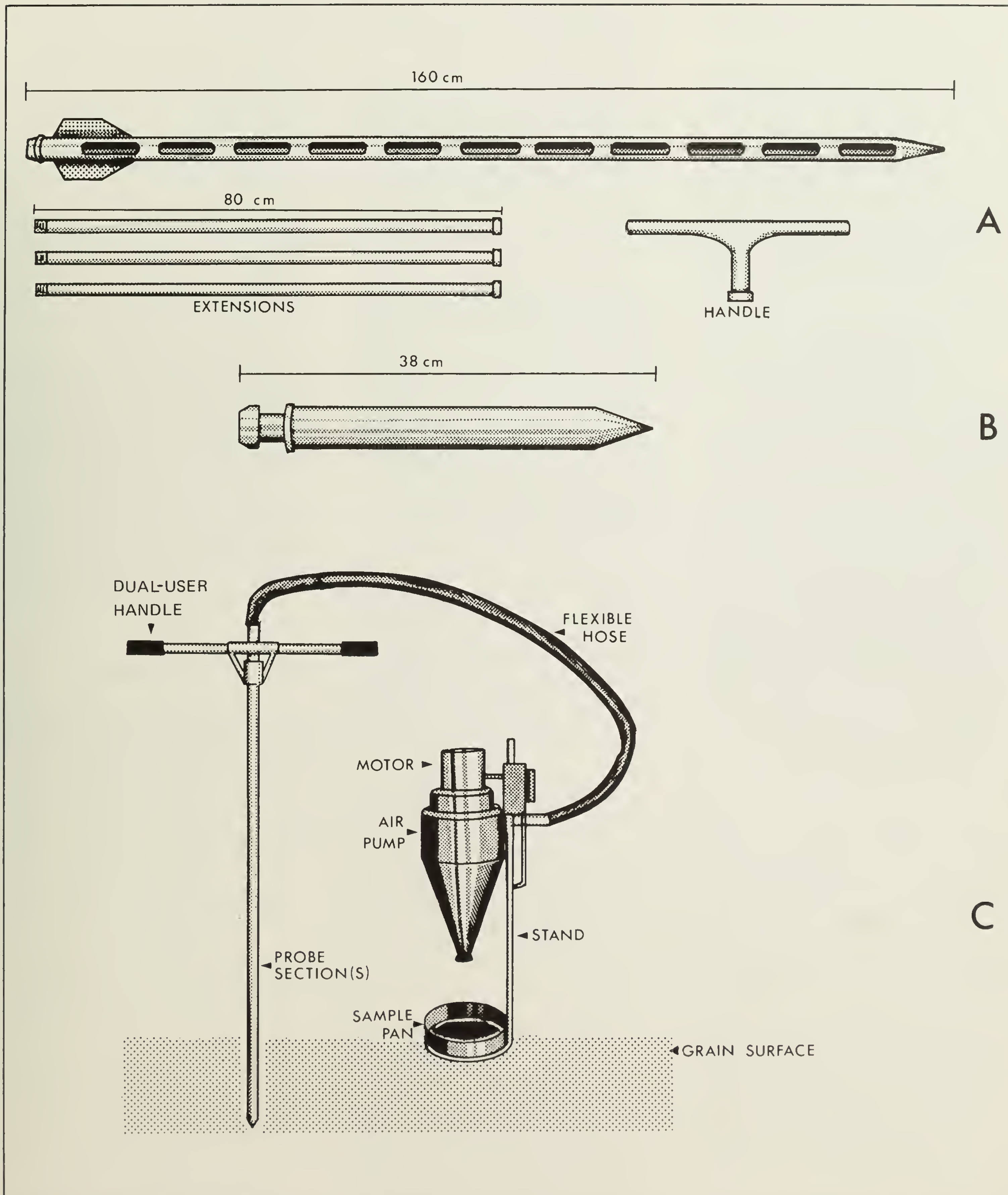

Figure 10 Equipment for deep grain sampling: *A*, deep bin fin trier; *B*, torpedo probe; *C*, pneumatic grain sampler (Seedburo Equipment Co., Chicago).

With canola/rapeseed the quickest way to detect prior heating is to crush the seeds. The crush test (Canola Council of Canada 1974) consists of attaching 100 seeds to masking tape, crushing once with a hard roller, then counting the number of dark brown seeds. It also quickly permits an assessment of the number of immature green or mature yellow seeds present. The number of green seeds in a sample is indicative of crop immaturity, the amount of seed moisture content, and potential heating problems in storage.

Molds, seed germination

Seeds plated on filter paper moistened with water for 7 days and exposed to light usually produce green shoots. Variously colored molds may be present on the seed surface. If shoots are absent, the sample is likely old and the germs possibly damaged by spoilage molds. Surface-sterilized seeds plated on moistened filter paper or agar (a jelly-like substance) containing salt (NaCl) may have white, yellow, orange, blue, or green post-harvest molds on the surface. The abundance of such molds indicates spoilage and heating problems. By plating seed samples from selected locations in a bin it is possible to detect the onset of spoilage before widespread damage occurs, and to learn the storage history and the keeping quality of the stocks. The presence of *Monascus* sp. and *Paecilomyces varioti* fungi on acid-treated grain indicates that certain chemical treatments are beginning to fail (Tuite and Foster 1979). For information on the detection of molds in foods see King et al. (1986).

Insects, mites

The presence of insects and mites in stored grain samples can be detected within 16 hours, using a Berlese funnel. This equipment, which consists of a metal funnel screened at the bottom, is filled with 150 g of grain. The heat from a 30-W bulb, placed just above the grain surface, drives any insects and mites from the grain into a jar, which contains a 70%-alcohol preservative. The method is not reliable for detecting stages of insects that live inside the grains.

A more rapid method for detecting mites and some insects is sieving. Grain samples are placed on a mesh sieve, then shaken. Insects can be detected visually. Mites, barely visible to the naked eye, fall through the mesh onto the collecting tray beneath and can then be examined microscopically.

Physiological changes

Deteriorating seeds change in physiology, some of which are readily detectable and indicative of changes occurring in storage. Fat acidity value (FAV), is a measure of the chemical changes occurring within deteriorating seeds. FAV measurement involves grinding a known weight of a sample of seeds, extraction in a solvent (petroleum ether) for 16 hours, followed by titration against a standardized potassium hydroxide solution. The higher the FAV the higher the level of deterioration. Electrical conductivity is a measure of the condition of the cell membranes of seeds. Its measurement involves soaking seeds in deionized water for 80 min, then reading the conductivity of the leachate water with a conductivity meter. Elevated conductivity levels, indicative of leaking cell membranes within seeds, are usually associated with seeds that are deteriorated (Mills and Chong 1977).

Chapter 6. Control of spoilage and heating

Control of spoilage and heating involves four main steps: preparatory planning, problem determination, problem handling and control, and salvage. Emphasis is placed first on determining the extent and type of the problem, then on applying appropriate measures.

PREPARATORY PLANNING

When designing or modifying facilities for fire protection and control, the local fire chief should be consulted on such matters as the location of water mains, emergency lighting, and exit provisions. It is necessary for the fire chief to be familiar with the facilities and to be asked to participate in practice fire drills. Staff of the facility need to be equipped with two-way radios, be trained to handle spoilage and heating problems, and be aware of potential safety hazards.

PROBLEM DETERMINATION

Once spoilage or heating is suspected, the tendency is to react immediately, which often results in incorrect action being taken. This tendency must be avoided. Before optimal control measures can be applied, certain key questions have to be answered including the nature and extent of the problem, commodity involved, temperature distribution, and facilities and staff available. At sea, additional important questions have to be answered including the availability of radio advice and fire-fighting facilities at nearby ports. Answers are needed for the following:

- What is the nature of the problem? If spoilage is the problem, only a localized portion of the stocks will likely be affected. If heating is the problem, the situation is potentially more serious, as fire could result and affect part or all of the stocks and other facilities.

- What is the extent of the problem? This is best determined by probing the stocks and using a thermometer or thermocouple to determine the temperature distribution pattern. ***On no account should the pile or bin contents be opened up suddenly to search for the source of the heating or spoilage, as the exposure of smoldering material to the air may cause almost instantaneous ignition of the entire mass of material*** (Bowen 1982). If the temperature within the pile is more than 10–15°C above the ambient, then potentially dangerous heating is occurring. If possible, obtain a thermographic profile of silo bins (Rispin 1978). If the temperature within the pile is less than 10–15°C from ambient, probe the bin contents with a deep bin cup and check by visual and odor examination for any spoilage.

- Which commodities are involved and in what form? It is important to know whether the products affected are cereals, oilseeds, or pellets and whether they are bagged or in bulk, because these factors can affect the type of control measures applied.

- What staff and facilities are available? After informing the local fire chief of the problem, staff on the premises should be identified and briefed and off-duty staff recalled. A quick inventory of available empty bins, metal-sided trucks, or paved areas into or onto which commodities can be transferred is useful.

PROBLEM HANDLING AND CONTROL

The following account summarizes methods used to handle and control spoilage and heating situations that occur in commodities stored in indoor or outdoor piles, in farm bins, in vertical silos, in ships, and in port installations, or that occur within equipment such as dryers or conveyers (Tables 7 and 8). ***The methods outlined can only be considered as general guidelines, not as specific instructions for handling problem situations. This is because each spoilage and heating situation is different with unknown modifying factors and the human and financial risks are consequently high.*** It is strongly recommended that the advice and services of a safety engineer be obtained whenever complex spoilage and heating problems occur, particularly with binned materials.

SPOILAGE PROBLEMS

Numerous fungal and other spores are present on spoiled grains and grain products. During handling wear a mask, take breaks every 15 min to breathe in fresh air, and provide cross ventilation by fans. Entering bins, silos, and ships' holds to handle problems requires safety equipment and other persons in attendance.

Outdoor piles

Grain is often stored unprotected on the ground in large piles for many weeks after harvest. A crust of sprouted and moldy grains may develop on the top surface and spoilage may occur within the bulk (Mills and Wallace 1979). First, separate the outer crust and any moldy clumps from non-moldy grains; later burn or bury this material. If necessary, dry the remainder of the bulk or cool it in a bin until a dryer becomes available.

Grain stored in open-topped or polyethylene-covered temporary bins is more prone to spoilage than when stored in metal bins. Most hot spots (and spoilage) occur in columns within 15 cm of the wall in both bin types, particularly in polyethylene-covered bins, during summer. Spoilage also occurs when water runs down the grain cone and enters depressions in the grain or small holes in the plastic. Separate the spoiled material from the good grain with a shovel (Muir et al. 1973).

Table 7 Handling and control of spoilage in stored commodities

Type of storage	Spoilage location and type	Handling or control method used
Outdoor piles	Top crust, centre of pile	Wear a mask.* Separate the material by shoveling, burning, or burying it.
Open-topped farm bins Polyethylene-covered farm bins	Within 15 cm of wall	As above.
Farm bins	Around doors, on floors of nearby empty bins, beneath roof vent or roof holes	As above.
Farm bins	Within lower bulk (flood damage)	Wear a mask*. Probe for crust, remove the good grain above it and discard the crust and spoiled grain below it.
Farm bins	At or near surface as full or partial bridge	Use proper safety practices for bin entry.** Loosen material and remove it through the top hatch or the uncovered side port.
Farm bins and vertical grain silos	Within bulk as full or partial bridge, as compacted mass, or within unload auger	Use proper safety practices for bin entry.** Remove unspoiled material from above, using a portable pneumatic grain elevator (Fig. 11), loosen spoiled material, and remove it through the upper hatch in same manner. A less effective method is to cut a hole in the wall to unload the material.
	Within bulk (early stages of spoilage)	Aerate and/or dry the material, then rebin.
Vertical grain silos	Within bulk (early stages of spoilage)	Mix by transferring to another bin, or aerate and/or dry the material, then rebin.
Vertical grain silos	On walls as adherent material (hang-ups)	Use proper safety procedures for bosun's chair.*** Dislodge adherent material ***working only above the obstruction*** (Fig. 12), or dislodge the material, using a whip device from above bin.
Railcars	Within cars as compacted mass	Wear a mask.* Dislodge and aspirate compacted material.

(*continued*)

Table 7 Handling and control of spoilage in stored commodities *(concluded)*

Type of storage	Spoilage location and type	Handling or control method used
Ships and barges (in bags)	On bag surfaces wetted by condensed water	Wear a mask.* Remove and air-dry bags, then assess quality of stock.
Ships and barges (in bulk)	Near surface under hatch joint as sprouted grains and in triangular area below	Wear mask.* Separate caked and moldy material, using a shovel and aspirate the material or elevate it out in a bucket.
	In mid-bulk as full bridge or crust from seam leak or hull puncture	Wear a mask.* Remove the bridge by aspiration, without mixing, then remove the grain beneath.
	In lower or mid-bulk from water entering through ventilators or bilge control valves, then moving upward	Wear a mask.* Use pneumatic or mechanical unloading equipment to move good grain. Probe for crust, remove the good grain above it and discard the crust and spoiled grain below it.

* Double dust mask, rest every 15 min.

** Gas canister respirator, safety belts and ropes, two attendants.

*** Gas canister respirator, safety belts, two attendants, bosun's chair located above the adherent wall material.

Farm bins

Handling spoilage problems within farm bins requires careful consideration. Determine the location and extent of the spoilage by visually examining the product and by probing it to ensure that the most suitable handling techniques are used. When discovered at the early stages, spoilage can be controlled by transferring the product to another bin, aerating continuously until the temperature front is through the grain, or drying and rebinning. When spoilage is at an advanced stage, select remedial actions that minimize admixture of spoiled and non-spoiled material and damage to the bin and associated structures. Remove spoiled grains around doors, separate spoiled material beneath roof vents or roof holes from unspoiled material, then discard. If spoiled grains occur as a bridge or larger area in a bin or within internal auger systems, gradually remove the non-spoiled material to uncover the spoiled area. Remove this by aspiration, using a portable pneumatic grain elevator (Fig. 11), digging out and winching through an upper hatch, cutting hole(s) in the sides, or removing a metal wall sheet. ***Extreme care must be taken when removing grains from around blocked auger systems, as uneven pressure effects may result in the collapse of one or more bins and associated conveyor systems.*** If spoilage is extensive and the grains are cemented together by mold mycelium, use pickaxes, jackhammers, or even rototillers to break up the material. Remove spoiled material from above. It is possible to remove spoiled bin contents from below by using a front-end loader to lift the bin wall, then augering.

Flooded bins

Determine the maximum water level attained, usually visible as debris marks on the outer bin wall or on nearby buildings, after flood waters have receded. Within the bin look for a layer of sprouted, moldy grains at or about this water level. Salvage grains above the sprouted layer before spoilage odors permeate the sprouted layer. Dry grains 5–30 cm above the sprouted layer. Bury or burn sprouted, moldy, and sodden grains (Mills and Abramson 1981).

Vertical grain silos

Early stages of grain spoilage can be controlled by transferring the product to another bin, aerating continuously until the temperature front is through the grain, or drying and rebinning. Advanced stages of spoilage are harder to handle and control. Grain tends to aggregate into a solid mass after storage in a moist condition as occurs, for example, when a moist carlot of grain is added to a silo of dry grain. When this occurs in the lower part of a silo or when unloading, augers become blocked by clumped grains. Remove the unspoiled product from above either by aspiration, winching material up and out, or via an exit made in the upper wall. Break up and remove the spoiled material in the same manner. Dislodge adherent material or hang-ups on the upper bin walls, using a bosun's chair from above (Fig. 12*a*). Alternatively, use a special whip device operated by compressed air from outside the bin (Fig. 12*b*).

Table 8 Handling and control of heating and fires in stored products

Type of storage	Type of heating	Handling or control method used
Outdoor piles	Heating or smoldering fire	Locate problem area, using a temperature probe, remove crust and heated material, cool.
Indoor piles	As above	As above. Keep dust levels low, remove by tractor bucket to outside of building, cool.
Farm bin or vertical grain silos	Heating	Locate problem area, using a temperature probe. If temperature is below 50°C, turn or aerate the stocks to cool off. ***If severe heating is occurring, do not aerate, as a flame fire may result.***
Vertical grain silo	Smoldering fire in ground animal feeds, pellets, or whole grains	Do not disturb with pressurized H_2O or foam because of danger of dust explosions. Wear a respirator.* Seal openings to reduce O_2 supply, carefully purge contents with N_2 or CO_2, measure atmosphere in silo and work rooms, and remove contents when the O_2 level is less than 10%. When contents are cool, make a hole in the bin or silo wall at its base to allow the material to flow out.
Wooden grain elevator	Flame fire	Since the building usually cannot be saved, add water from a safe distance to diminish flames, but not to the grain itself to avoid spoilage. Save moveables such as accounting records. Avoid disturbance with pressurized H_2O or foam. Use only a hand pump in the elevator.
Vertical silage silos (top and bottom unloading)	Smoldering fire	Do not add water or foam to fire through open-top hatches; place placards to warn fire fighters of explosion hazard; do not close roof hatches if steam or smoke is issuing forth or if silo is vibrating; close but do not secure hatches if silo is quiet and no steam or smoke has come out for several hours; inject CO_2 or liquid N_2 into silo, taking gas safety precautions to extinguish fire. See methods described by Murphy and Arble (1982), and NIOSH (1986).
Fires in dryers	Flame fire	Shut off heat and fan; if necessary, use water to extinguish the fire.
Shipping container	Smoldering fire	See methods described in R.J. Brady & Co. (1979), Nicholls (1984), and Chapter 6 of this manual.
Ship or barge	Smoldering and flame fires	For details of CO_2, water, and other control systems used, see R.J. Brady & Co. (1979), Reanney (1969), Rushbrook (1979), and Taylor and Pucill (1982).

* Gas canister respirator, safety belts and ropes, two attendants.

Take extreme care when using the bosun's chair. Dislodged material can bury anyone working at levels below the obstruction.

Railcars

Spoilage can occur in railcars as a result of rain entering through open lids before loading, and in cars containing high moisture seeds that are mislaid in a siding en route to commercial drying facilities. In winter, spoilage occurs in cars of freshly pelleted materials with too much residual heat. Such spoilage results in adsorption of moisture and mold growth and makes the unload system inoperable. In such instances, dislodge the spoiled material either by digging or by using compressed air jets, then remove through the top hatch. Check for noxious gases and oxygen deficiency, and work in pairs, taking adequate safety precautions (National Safety Council 1962).

Ships and barges

Spoilage occurs on the surface and also deep within the holds of cargo vessels, bulk carriers (Figs. 13*a*, 13*b*), and barges in transit (Christensen and Kaufmann 1978). Spoilage may occur because of incipient molded grain, inadequate blending, too high a moisture, condensation, also known as ships sweat or cargo sweat (Knight 1985), or other reasons. Before unloading, remove with a shovel any sprouted or caked grains that are on the surface, together with any deeper triangular-shaped areas of spoiled grains beneath the hatch joints. With bagged cargoes, especially those transported from cold climates to hot ones, condensation and mold development may occur on the bags. Unload, dry, and assess contents of affected bags for quality and end use.

Spoilage that occurs deep within the holds of oceangoing ships is caused by water entering either through a weld or hull puncture or through ventilators or other deck openings (see Fig. 13*a*). In either situation, the water moves up to a certain level above which dry grains are unloaded mechanically or by aspiration. The amount of water in the hold, its location, and the length of time the grain has been wet are factors that determine whether the grain beneath is spoiled or not (see Table 7). Spoilage that occurs deep within the holds of lake ships is mainly the result of leaking cargo hold bilge valves, not, as in ocean-going ships, the result of leaking seams or hull punctures, because the cargo hold is separated from the hull plating by a double bottom and side tanks (H. Uustalu, pers. com. 1986).

Figure 11 Portable pneumatic elevator for moving grain and grain products.

In vessel transit, if the product is shipped too moist or too warm, spoilage cannot be prevented whether shipboard ventilation is used or not on the voyage (Milton and Jarrett 1970). Ventilation onto the surface of the bulk via deck ventilators is ineffective in controlling spoilage deep within the hold, is of doubtful use in controlling spoilage on the surface, and may aggravate spoilage if the air relative humidity is above 80% and the air temperature is above 25°C (Christensen and Kaufmann 1978). The most effective control method is prevention. Ideally, dry the shipments to safe moisture limits to prevent spoilage in transit, especially for long voyages (Milton and Jarrett 1970). The amount of kernel breakage affects the rate of spoilage in corn and must be kept low by careful handling (Paulsen and Hill 1977). For information on the effects of condensation, and mold, insect, and mite damage in containerized and non-containerized ships cargoes see Knight (1985).

HEATING AND FIRE PROBLEMS

Extreme care must be taken when handling and controlling heating situations in stored commodities in order to avoid fires and explosions. Avoid disturbance of heating materials with pressurized water or foam, as a dust explosion may result. Each situation requires evaluation at the scene by a safety engineer and specialized fire fighters to determine the optimal handling method. Table 8 summarizes methods used for handling heating situations in various types of storages.

Outdoor piles

Cereal grain piles may heat if left unprotected from rain for 2–3 months. Heating is likely in freshly harvested grain in piles larger than 1000 t because of seed respiration. It is aggravated by development of a sprouted surface crust, which prevents air circulation and facilitates heat buildup. First,

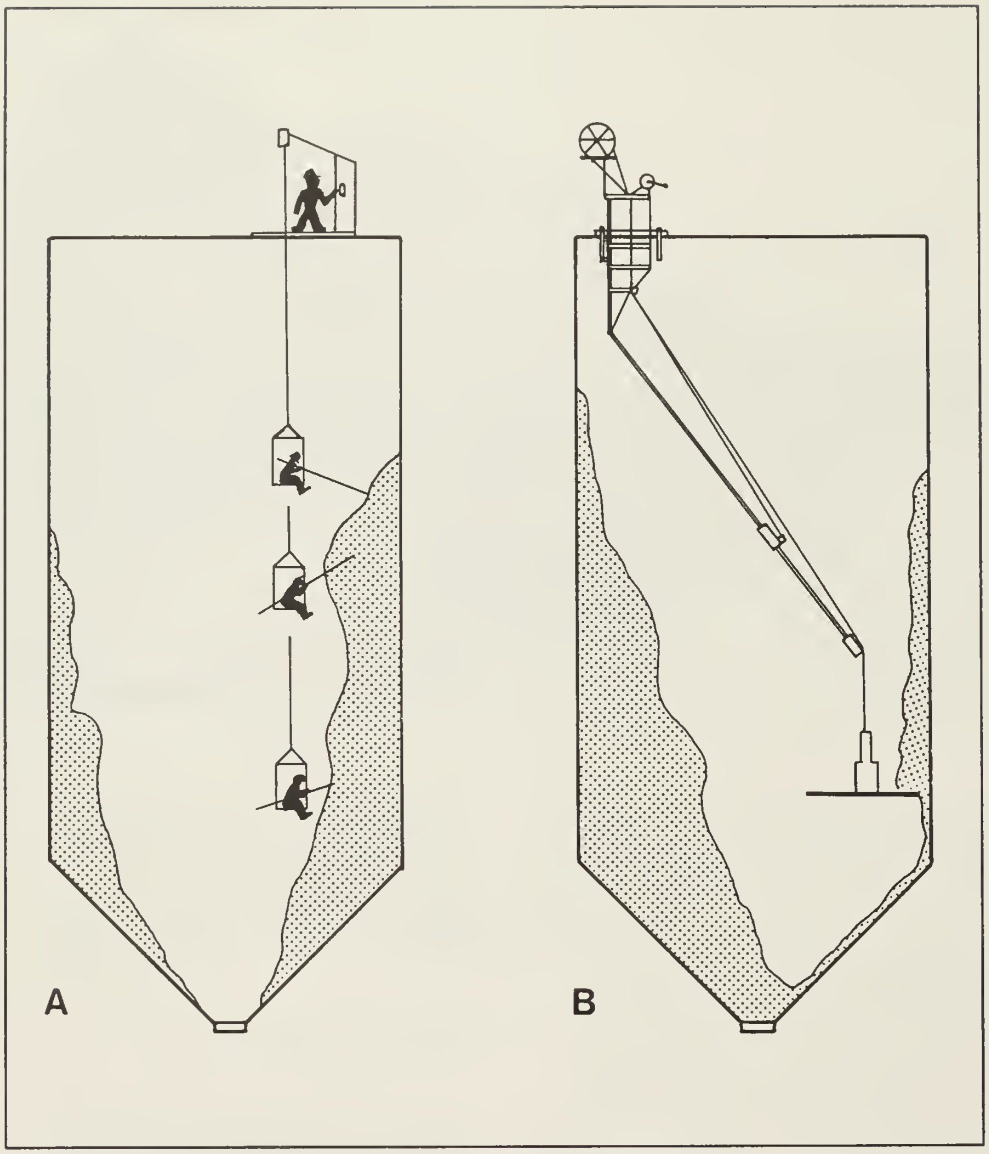

Figure 12 Removal of bin hang-ups: *A*, bosun's chair, showing upper safe working position and extremely hazardous positions beneath (after Boumans 1985); *B*, remote-controlled whip device (Northern Vibrator Manufacturing Co., Georgetown, Ont.).

determine the location of the heated area within the pile and temperatures involved, probably 30–60°C. Remove and discard the crust, then remove the heated material by tractor bucket and allow to cool in a 30-cm layer on a concrete floor. When cool, dry and bin or restack in a smaller pile until sold.

Indoor piles

Some conditions that cause pelleted feed materials piled in warehouses to heat and smolder are as follows: (1) accidental addition of water due to flooding or leaky roofs, (2) part of the stock being warmer than normal due to inadequate cooling, and (3) the presence of metal fragments heated during processing. Heating of pelleted feeds is aggravated by the presence of animal fats, oil seeds, or flammable contaminants in the pellets or on the floor, and on disturbance a heated pile may suddenly ignite. Grain piles are less likely to ignite but may do so, for example, when burning grain is conveyed accidentally from an earlier fire and incorporated into the pile (Boumans 1985). First, determine the location of the heated area in the pile and the temperatures involved. Avoid disturbing the piled material creating potentially explosive dust clouds. Remove the unaffected material, then the heated material, using a tractor bucket. Move the heated material from the building and spread it in a 30-cm layer to cool. Spraying heated grains with water is not advised (see next paragraph).

Silos

Handling of heating situations involving grain and silage stored in vertical silos is described in Campbell (1973), Fire Protection Association (FPA)(1968), and National Institute for Occupational Safety and Health (NIOSH) (1986), sometimes with conflicting advice.

NIOSH (1986) recommends that fires in silos be extinguished through injection of carbon dioxide or nitrogen. Water or foam should not be directed into the fire through the top hatches, since this may allow oxygen to enter the silo and cause the suspension of explosive dust (NIOSH 1985). For more information see the section on vertical silage silos and Murphy and Arble (1982). The NIOSH recommendations (1986) are for oxygen-limiting silos, but they could be applied to other types of vertical silo. If in doubt obtain professional advice.

Several years ago an explosion at a terminal in Thunder Bay, Ont., was blamed on the creation of "coal gas" when water was introduced into the silo.

Farm bins and vertical grain silos

Fires occur after the aeration of materials in an advanced state of biological and chemical heating; when pelleted materials are binned together with hot fused lumps of aggregated material or hot metal fragments; or when smoldering or very hot material, originating from a fire elsewhere in the complex, is added to bins of unheated material. The following methods have been used to control smoldering fires.

Nitrogen (N_2) Dinglinger (1981) describes (in German) a major fire that occurred in West Germany involving a silo of feed pellets, which was safely extinguished using 18 000-m^3 of N_2 gas over 10 days (Fig. 14). Dinglinger states that if a smoldering fire is discovered in a silo containing animal feed pellets or other coarse materials, the chimney effect

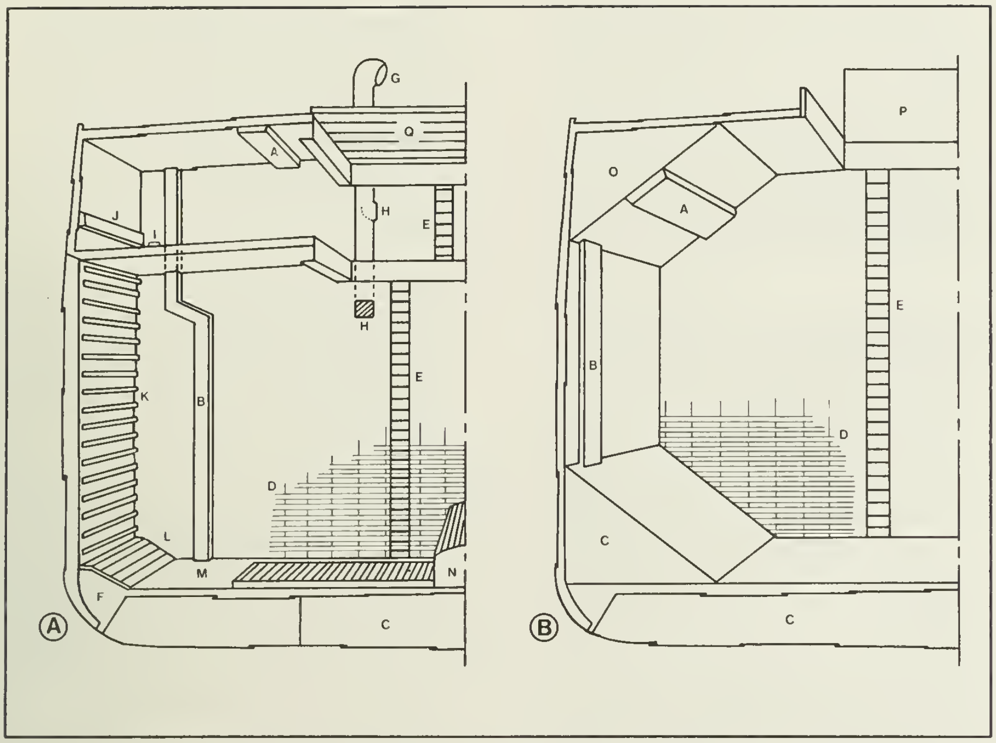

Figure 13 Midship sections of (A) cargo vessel, and (B) bulk carrier: *A*, electrical casing; *B*, pipe guard; *C*, fuel tank; *D*, wooden bulkhead; *E*, ladder; *F*, bilge area; *G*, ventilator; *H*, ventilator grill; *I*, trimming hatch; *J*, degaussing casing; *K*, cargo battens; *L*, limber boards; *M*, wooden ceiling (on bearers); *N*, propeller shaft tunnel; *O*, wing tank; *P*, McGregor hatch (open); and *Q*, hatch (closed) (after Monro 1969).

created by the heat of the fumes will keep supplying fresh air to the fire. Fume condensates eventually cause the product to stick together, creating the risk of bridge formation near the source of the fire. Quickly emptying the silo without first purging with N_2 or other suitable gas may cause the bridge to collapse and the dust raised to ignite. The following procedures are recommended for silo fires:

- Seal openings at the base and floor of the silo as quickly as possible, including cracks along flange mountings. This cuts off or at least slows down the supply of fresh oxygen. Bridges may even be prevented from forming in the first place.

- Purge cavities in the silo with inert gas. Install permanent nozzles for this purpose at the base and floor of the silo as a precautionary measure.

- Monitor the atmosphere in the silo and adjacent work rooms.

- Once the atmosphere in the silo is such that ignition is no longer possible (less than 10% oxygen gas (O_2)), clearing may begin.

Carbon dioxide (CO_2) Boumans (1985) describes the use of CO_2 for controlling smoldering fires in silos. After sealing the silo, CO_2 is applied as a gas at a rate of about 1 kg/m^3 silo volume. A valve is fitted to the silo hopper for entrance of the CO_2 under pressure. Special precautions are required during application to prevent suffocation. Additional CO_2 is applied every few hours to maintain the required level of gas at the top of the material. Smith (1982) gives complete instructions on how to use CO_2 to control fires in Harvestore® oxygen-limiting silos.

Other

For silo bins with outside walls, a hole is cut in the wall above the fire to remove undamaged material, which is allowed to run very slowly into trucks or onto the ground. The disadvantage with pouring the material onto the ground is interference with operations at ground level. Meeker (1979) extinguished a fire in a silo containing soybeans by cutting an upper hole to remove undamaged material and a lower one to extract burning material. Do not use the existing conveyor system when discharging. For interstitial silo bins, install a temporary closed screw conveyor from the hopper outlet directly to the outside and discharge the bin in an inert atmosphere by continuously introducing CO_2 into the conveyor, or better, into the bottom of the hopper near the outlet opening (Boumans 1985).

Never store discharged material that contains (or contained) heated fused chunks of material without a long period of cooling in a thin layer and close monitoring. This is particularly important when wooden structures are involved. Even when large chunks are removed by screening, small portions of heated material may remain, causing fires or explosions during handling and storage.

Vertical silage silos

Numerous fires and occasional explosions have occurred in the USA in vertical silos containing grass silage or haylage (Koegel and Bruhn 1971; Campbell 1973; NIOSH 1986). The sequence of events leading to an explosion in a bottom-unloading 6 x 18-m silo

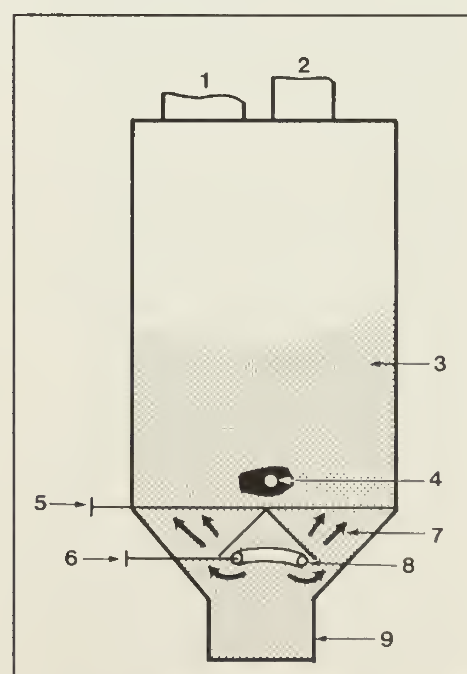

Figure 14 Nitrogen purging of a smoldering fire in an 80-t feed mill silo: (*1*) intake chute; (*2*) filter bags with beater; (*3*) feed meal; (*4*) smoldering fire pocket; (*5*) lever for moving safety hood; (*6*) pressure hose connector for N_2 intake; (*7*) N_2 gas; (*8*) circular channel with drill holes; (*9*) outflow (after Dinglinger 1981).

containing rye silage and first-cutting alfalfa hay of high moisture content are described by Singley (1968). Four days before the explosion, which lifted the structure's 15-t concrete roof, the roof hatches and discharge door at the base were left open to receive more hay but this action created a chimney effect within the silo. At least 2 days before the explosion, the hay delivered by the unloader was noticeably charred. This charring produced flammable gases until the open flame combustion point of the moist hay was reached. The fire was extinguished with 9000 L of water. Note: Use of water to extinguish silo fires is hazardous (see next paragraph).

On 27 August 1985 three fire fighters in the USA were killed when a burning oxygen-limiting silo exploded. The fire fighters were spraying water onto the fire from the top of the silo when an explosion lifted the concrete silo roof, throwing them to the ground. The explosion was due either to a buildup of combustible gases from incomplete combustion or a dust explosion, or to a combination of the two. Opening the top hatches to apply water to the fire could have increased the level of oxygen and created an explosive atmosphere. Air entrained in the water stream may also have contributed to the explosion. Additionally, the water spray could have suspended the dust and increased the risk of explosion. Because of the improper fire fighting methods used and the lack of proper operating and maintenance procedures in this case, the National Institute for Occupational Safety and Health (NIOSH) subsequently issued a safety warning and the following recommendations (NIOSH 1986).

Fire departments are warned that directing water or foam onto a fire through the top openings of an oxygen-limiting silo may result in the silo exploding.

Recommendations for preventing fires and explosions in oxygen-limiting silos include the following:

- Hatches should be ***kept closed*** when silos are not being filled or emptied. If the silo is properly sealed, the amount of oxygen trapped is usually insufficient to support a fire by self-heating.
- Proper maintenance of the silo should be performed in accordance with the manufacturer's instructions to ensure the integrity of the oxygen-limiting features.
- The moisture content of stored silage should be controlled, as should the type of cut of the silage. Filling rates recommended by the manufacturer should also be followed to reduce the possibility of self-heating. A description of the elements of good silage is given by Murphy and Arble (1982).

Recommendations for fire control in oxygen-limiting silos include the following:

- ***Water or foam should not be directed onto the fire through the top hatches***, since this may allow oxygen to enter the silo and cause the suspension of explosive dust.
- Placards should be placed on the silo warning fire fighters that it is an oxygen-limiting silo, and they should include information concerning the proper extinguishing techniques.
- Do not close open-roof hatches if steam or smoke is coming from the hatches or if the silo is vibrating.
- Roof hatches should be safe to close if the silo is quiet and there has been no smoke or steam coming from the hatches for several hours. ***Do not secure the hatch.*** This will permit the relief of any subsequent pressure that may build up.
- Large quantities of carbon dioxide (CO_2) or liquid nitrogen (N_2) should be injected into the silo to extinguish the fire. Some silos have valves specifically designed for this. If it is necessary to drill a small hole in the silo for insertion of the gas tube, care should be taken not to allow additional oxygen to be pulled into the silo. All handling precautions normally associated with CO_2 or N_2 should be taken. For a 6-m diameter by 18-m-high silo, 20 standard cylinders of CO_2 or 40 standard cylinders of liquid N_2 are required. For other silo sizes and amounts of gases required see Murphy and Arble (1982).
- Manufacturers, in conjuction with the local fire departments, should establish a program to provide valves designed for injection of gases for fire control on all new and existing oxygen-limiting silos.
- Certain manufacturers, for example Harvestore® Products (1982), have step-by-step instructions on how to extinguish fires in their silos. Farm owners should obtain these instructions from the silo manufacturer.

For further information on handling fires in vertical silage or other silos contact the National Institute for Occupational Safety and Health, 944 Chestnut Ridge Road, Morgantown, West Virginia 26505; Tel. (304) 291-4595.

Dryers

Shut off the heat and fan to extinguish fire in a dryer. The fire may snuff itself out in a recirculating dryer if the auger is left running, but it is often necessary to use some water to extinguish it (Friesen 1981).

Ships

Control of smoldering fires in ship cargoes requires careful consideration, technical knowledge, and a well-trained staff using modern equipment. Management of such fires is made difficult in that they occur in complex moving structures strongly influenced by sea and atmospheric conditions, often at a considerable distance from outside help. Factors that apply on board ship differ from those which apply in a warehouse situation. This difference must be considered, otherwise both cargo and ship may be lost. Each cargo fire situation is unique and must be treated on an individual basis. The approach used to manage the fire is determined by whether the ship is in port or at sea. For a recent account of fighting a stubborn fire, probably caused by self-ignition of wet animal feed, in a general cargo ship at sea and in port see Fire Protection Association (1986). The reader is referred to the excellent books on the science of fire fighting on ships by Reanney (1969), R.J. Brady & Co. (1979), and Rushbrook (1979). Details on how to fight container fires on the decks and in the holds of ships are given in R.J. Brady & Co. (1979) and Nicholls (1984).

Nicholls (1984) outlines problems encountered when fighting dockside shipboard fires in Port Elizabeth, South Africa, and the procedures developed to combat them.

- Communication problems, both in language and in nautical terms, often occur between fire fighters and ships' crews, complicating the efforts to extinguish the fires.
- Each ship is different and fire fighters are continually working in unfamiliar territory.
- There is a constant need to be aware of the ship's stability, a factor which determines the amount of water that can be used.
- On ship arrival, fire fighters need to know the following:
    - What is burning (or believed to be)?
    - Where is the seat of the fire (or thought to be)?
    - What is the risk of the fire spreading from one compartment to another?
    - What steps have already been taken to deal with the fire?
    - What fixed fire protection is available?
    - What cargo is being carried? (The ship's manifest or cargo plan should be produced.)

Open hold fires in early stages of development are tackled from within the hold, using high-pressure jets, or from the deck, using hose lines. Move the cargo onto the quayside by crane, then dampen down. If the fire increases, quickly batten down the hatches before they become heat distorted, and introduce carbon dioxide from the ship's installation. Inspect adjacent holds, remove cargo from nearby bulkheads, and discharge additional carbon dioxide.

Closed hold fires are recognizable from smoke issuing from ventilators and hatches. Use high-pressure water lines to extinguish flames before crews, wearing breathing apparatus, enter the hold via the booby hatch to determine the extent of the fire and to inspect the bulkheads. Keep the hold closed to prevent the fire from flaring and possibly causing severe damage to the cargo and ship. Close and cover the ventilators with wet tarpaulins and discharge the ship's carbon dioxide installation into the hold. Using dockside tankers, add more carbon dioxide to the affected hold via a small hole, enlarged in stages and drilled in the deck. Take a temperature reading by lowering a thermometer into the hold. Apply additional carbon dioxide every 2 hours, every hour if the temperature does not decrease. Apply cooling jets to the bulkheads and the ship's sides. When the fire is out and the fire fighters and crew have inspected the hold, wearing breathing apparatus, introduce four high-pressure hose lines into the hold via the booby hatch and dampen the affected area before opening the main hatch. Continue dampening until the hold is certified free of gas, then have the cargo removed by stevedores.

Container ship fires are difficult to tackle. The vessels have a high freeboard, which creates an access problem, and they are inherently unstable. Water cannot be used because of its adverse effect on cargo and because of the stability problem. To solve the access problem use a roofless container that has one side removed to transport equipment and personnel to the deck by crane. Hoist medium-expansion foam-making equipment and concentrate to the deck and add the foam through vertical side hatches. Off-load the deck-stowed containers at the same time to gain hatch access. Open hatches and apply foam from the top, keeping side hatches closed. The affected container is usually located by a more rapid breakdown of foam and possibly the presence of an updraft. When the affected container is located, remove the surrounding containers and spray the damaged one, using high-pressure jets, then remove it to the quay (Nicholls 1984).

SALVAGE

After a fire, the safe removal of a product is done by salvage operators, who sort and subsequently screen the material to maximize its salvage value. This operation requires considerable experience. The services of salvage companies are retained by insurance firms when they are dealing with pertinent insurance claims.

Guidelines for salvaging products from grain elevators are as follows:

- By the time a fire is discovered in a wooden grain elevator it is usually too late to save the elevator or product (see Fig. 18*b*). Devote efforts to moving railcars, protecting fertilizer sheds and adjoining elevators, and removing record books.
- Add water to the fire itself to reduce its intensity and to other buildings. Do not add water to the grain itself. Wet grain is difficult to salvage and must then be separated and dried. Remember elevators often hold in excess of 6000 t of grain, but grain driers only operate at a rate of about 6 t/hour.
- Do not apply water to the same spot for prolonged periods.

The most likely causes of fire in grain elevators in order of frequency are *mechanical* (moving parts, bearings, hot debris falling into dust, and so forth); *lightning* (look for melted copper rods as evidence); *arson* (look for pieces of a bottle that might have been filled with fuel and rags); *electrical* (motors, wiring, inspection boxes); and *self-ignition*. Self-ignition does not usually occur in small elevators and is more likely to occur with oilseeds or meals than with coarse grains. In large terminals, severe heating problems occur more frequently, as they are aggravated by large volumes of product, high pressures, closed-up spaces, and bin gases. A useful account of the salvage of grains and grain products is given by the Grain Dealers Mutual Insurance Company (1961).

Knight (1985) has compiled a generalreference book for the use of cargo surveyors, adjusters, insurers, and others concerned with packing, transporting, and stowing commodities worldwide. Of special interest is the section describing the general principles to be observed when doing a survey on damaged goods.

Chapter 7. Safety

EDUCATION AND TRAINING

Storage facilities operated by experienced managers and trained staff are generally safe places in which to work, but because of the existence of potential hazards, uninformed persons can put themselves and others at risk. It is of paramount importance that all persons working on either a full-time or a part-time basis or for contractors must be made aware of potential hazards existing on the plant or farm. Special attention must to be given to children working on or visiting farms.

Full-time staff require training as teams to handle routine but potentially hazardous situations, to apply first-aid procedures, to handle emergencies with ambulance and local fire brigades, and to guide part-time staff and contractors in safety practices. Managers need to be aware of the latest safety methods and any new management practices affecting safety and should bring them to the attention of staff. They must issue safety guidelines for staff and contractors, particularly welders, and strictly enforce a no admittance policy for casual visitors, for example bargers waiting to unload their vessels. It is most important that the manager or superintendent is given advance notice of persons intending to enter the bins to work and is again notified when the work is completed and everyone is safely out (National Safety Council 1962). For more information on occupational safety in grain elevators and feed mills see National Institute for Occupational Safety and Health (1983).

Table 9 Causes of fatalities in elevators, mills, and other grain-handling facilities in selected incidents (Cloe 1983)

Types of accidents	Number of incidents	Number of fatalities
Suffocation	32	33
Explosion/fire	18	37
Falls	19	19
Contact with electric current	12	13
Collapse of structures	7	7
Caught in augers/conveyors	6	6
Crushed between surfaces	4	4
Hazardous vapors	2	2
Caught in machinery	2	2
Drowning	2	2
Run over by grain truck	1	1
Totals	105*	126

* Selected cases reported to the Occupational Safety and Health Administration (OSHA), Washington, D.C., during the period 1977–1981.

PROTECTIVE WEAR

Wear tight-fitting clothing to avoid being entrapped by machinery belts and augers or by bin projections. Wear strong, flexible boots to protect the feet from being crushed or penetrated. Always have various different types of masks and respirators available, plus additional filters. Use this respiratory equipment routinely, as dust, always present in grain and feed-handling facilities, can pose a serious hazard to health. Wilkins (1984) describes the main types of respirators used by animal producers to reduce their exposure to dust, and health problems, in dusty barns. Never enter a bin containing out-of-condition grain unless you are wearing proper respiratory gear, because bad grain can produce toxic gases. Never shovel molded grain out of a bin without wearing a mask. Take frequent rests in fresh air. Exposure to spores in moldy grain can have lasting effects on one's health (Manfreda and Warren 1984). Keep up-to-date on the latest respiratory protection equipment available and use it. It will pay dividends in the long run.

HAZARDS

Suffocation

In recent years the number of suffocations that have occurred in grain bins has increased in the USA for many reasons, such as larger on-farm facilities, increased mechanization, and lack of knowledge of grain movement and safety precautions (University of Kentucky 1984). Fifty-one suffocation deaths occurred in farm bins in Nebraska and Indiana between 1970 and 1979, and 33 out of 126 deaths in 105 selected incidents in grain-handling facilities in the USA between 1979 and 1981 (Table 9) were due to this cause (Cloe 1983).

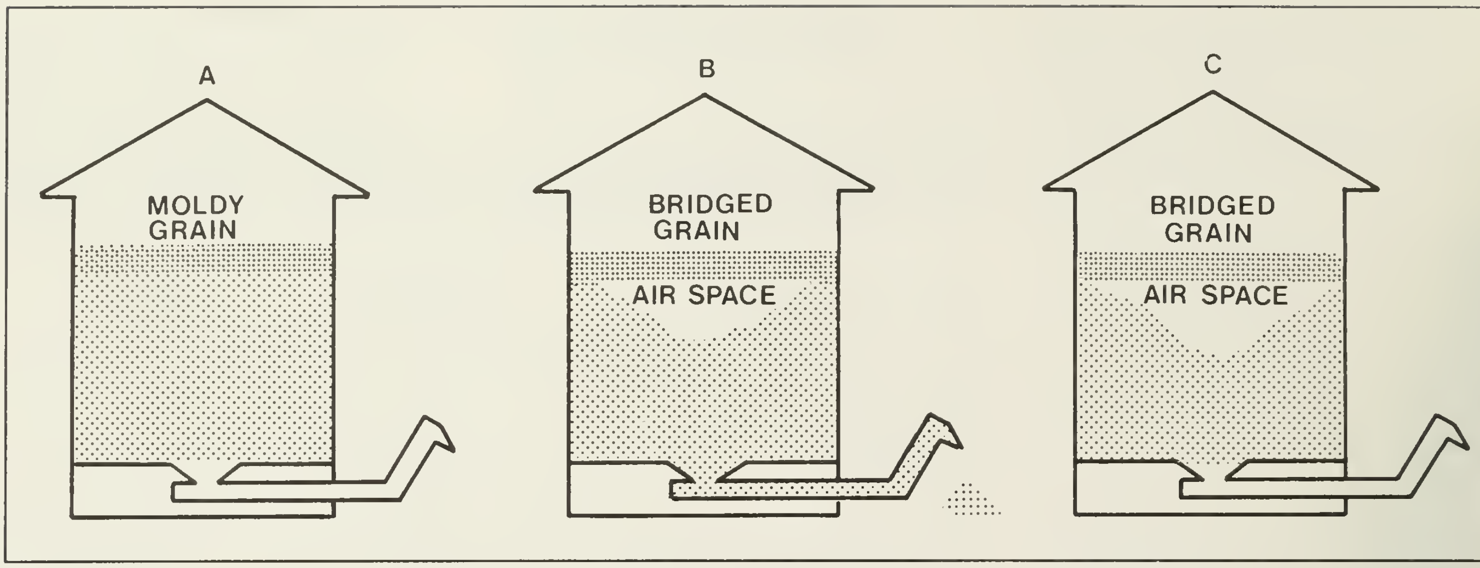

Figure 15 Potential hazards created by bridging: *A*, moldy grain causes bridge to form before unloading; *B*, air space is created as loading begins; *C*, air space remains after unloading stops (after University of Kentucky 1984).

Suffocations occur when persons within bins become engulfed by flowing grain during unloading operations by bottom auger or gravity feed methods. Some crops such as flaxseed or millet act like a quicksand and operators can quickly sink under their own weight; the situation is even worse with flowing stocks (National Safety Council 1962). Persons within wet holding bins emptying by gravity feed into automatic-batch grain dryers can easily be engulfed during reloading of the dryer with wet grain. Other instances of suffocation occur when operators fall into air spaces, which are often present beneath bridged grain (Fig. 15), are buried by falling steep piles of moist grain, or breathe noxious gases, for example carbon dioxide produced by out-of-condition grain (University of Kentucky 1984). Suffocation as a result of diaphragm collapse can occur from welding fumes within bins under repair (Broadhurst 1985).

Suffocations can be prevented by taking the following precautions:

- Installing ladders inside bins.
- Obtaining safety harnesses and ropes.
- Obtaining long poles and rakes to break crusts and bridges.
- Purchasing a self-contained breathing apparatus.
- Learning how to lock-out electrical bin systems.
- Setting up an action plan for supporting and rescuing persons from bins.
- Never entering a hermetically sealed silo without flushing first with fresh air.
- Never walking across binned flaxseed or millet.
- Never entering a bin containing out-of-condition grain without wearing a self-contained breathing apparatus.
- Never entering a bin without first shutting down the electrical power to bin systems.
- Breaking crusts and bridges with a pole or rake, working from the outside of bins.
- Breaking crusts and bridges with a remote-controlled whip device (see Fig. 12), working from the outside of bins.
- Entering a bin only if attached to safety harness and rope and anchored to a second person, and having a third person on standby to assist in pulling you up or going for help (Fig. 16).
- Moving to the wall ***immediately*** if grain starts to flow.
- Closing any bin access areas that are at the top of empty bins.
- Using the bosun's chair apparatus safely by working only above hang-ups (see Fig. 12).

The following account illustrates the difficulty involved in pulling out a trapped person from a grain bin. A salvage operator in western Canada cut a 30-cm diameter hole in the side of a bin of heated cereals prior to unloading by auger. Shortly after, an inexperienced worker was reported missing and later found buried up to his shoulders in grain in the bin. The auger was immediately switched off and five men with shovels tried to dig him out but were unsuccessful. As a last resort, a rope was put around the man's waist and tied securely to the roof. The auger was switched on again to lower the grain level and eventually the man was pulled out (E. Dorge, per. com. 1986).

Toxic gases

Exposure to toxic gases produced during the storage of agricultural products or by-products has resulted in many fatalities among farm families and their employees in recent years. Nitrogen dioxide (NO_2), carbon monoxide (CO), and carbon dioxide (CO_2) are the gases most likely to be encountered during handling of stored products, whereas hydrogen sulfide (H_2S), ammonia (NH_3), and

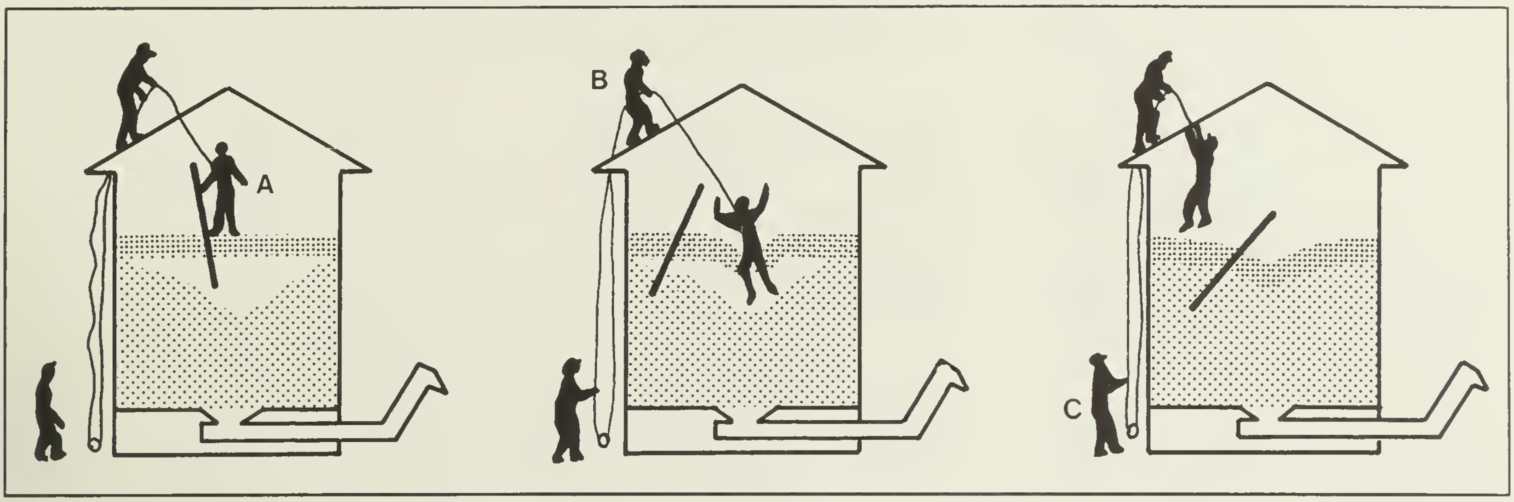

Figure 16 Investigation of a questionable bin, using three persons for maximum safety: *A*, the person inside the bin is secured to the outside; *B*, the person on the roof calls out instructions and assists in lifting; *C*, the person on the ground assists in pulling and, if necessary, goes for help (after University of Kentucky 1984).

CO_2 occur during storage of liquid manures (Table 10) (Agriculture Canada 1979). Methane (CH_4), which is highly flammable, is also produced (Broadhurst 1985). Hydrogen cyanide (HCN), generated during storage of moist flaxseed, is absorbed through the skin and can cause death (Western Producer 1977).

Nitrogen dioxide is produced in silos under certain conditions by green material such as chopped corn silage. This gas is extremely toxic, and when present in high concentration has a characteristic reddish or yellow brown color, sometimes visible above the surface of the material. In low concentration it is colorless and odorless but just as lethal. NO_2 can develop within 6 hours of placement of material in the silo, the most dangerous period being 12–60 hours after filling. Usually, the gas dissipates in 3–6 weeks, but without ventilation it can remain indefinitely (Jonas 1979). When inhaled it reacts with water in the respiratory tract to produce acids, which burn the mouth, nose, throat, and lungs. The first symptoms are often a burning sensation and coughing. Inhalation of NO_2 may cause silo filler's disease, or nitrogen dioxide pneumonia (Grayson 1957).

Carbon monoxide is almost as toxic as NO_2, is colorless, therefore visually undetectable, and is produced during ensilage and incomplete combustion of materials, as in fires. CO has also been detected in sample grade flaxseed and heating soybeans (Ramstad and Geddes 1942). The following example illustrates the sudden danger that can be caused by CO during fire-fighting operations (Reanney 1969). A fire fighter combating a fire in a ship's hold went into an adjacent empty hold to examine the bulkheads. Because the empty hold was entirely free from smoke and heat he did not wear a breathing apparatus. While traversing the empty hold, he suddenly became ill but was quickly rescued. The cause was attributed to a pocket of CO, resulting from leakage through cracks from the fire-affected hold next door. Breathing apparatus must be worn by fire fighters who are working in enclosed spaces close to fires because of the danger of CO and other toxic gases.

Carbon dioxide is colorless but is relatively less toxic than NO_2 and CO at low concentrations, although it can be fatal at high concentrations. It is often produced during respiration of grains, molds, and insects in grain and feed bins and oxygen-limiting silos, and during ensilage of green materials.

Toxic gas poisonings can be prevented by taking the following precautions:

- Monitoring the levels of NO_2, CO_2, and CO in storages by using a system of plastic tubing, hypodermic syringes, and Dräger tubes (see Fig. 9) (Wilkins 1985*a*).
- Remembering never to enter oxygen-limiting silos or grain and feed tanks containing out-of-condition grain unless you are wearing a self-contained breathing apparatus and a safety harness, and have two trained persons in attendance.
- Reminding family members and workers of the dangers of NO_2 in silos each year at harvesttime.
- Remembering that NO_2 sinks and that a door left open near the silage surface could allow the gas to move down the chute into the feed room. Livestock have died when a connecting door to the barn was left open, and workers have succumbed to silo gas as it sank down the chute when they climbed the chute ladder and opened a door above their heads. Therefore, always close the barn door to the feed room and open the doors and windows in the feed room to allow fresh air into the chute (Jonas 1979).
- Ventilating thoroughly silos containing freshly harvested forages before entering.
- Using a fan to flush the silo air free from toxic gases.

Table 10 Toxic gases encountered in stored farm commodities (Agriculture Canada 1979)

Toxic gas	Chemical symbol	Specific gravity	Toxicity	Flammability (Percentage by volume in air)	Description	Source
Nitrogen dioxide (silage gas)	NO_2	1.58 (sinks in air)	5 ppm (extremely toxic)	–	Reddish color in certain concentrations, bleach-like odor	By-product of early stages of silo fermentation of forages
Carbon monoxide	CO	0.96	50 ppm	12–74% (very flammable)	Clear, odorless	By-product of incomplete combustion of carbonaceous material; occurs in heating materials and during fires
Carbon dioxide	CO_2	1.53 (sinks in air)	5000 ppm	–	Colorless, odorless	Product of respiration; occurs in grain and feed storage tanks, oxygen-limiting silos, liquid manure systems
Hydrogen sulfide	H_2S	1.19	10 ppm	4–50%	Clear, colorless pungent odor	Formed in liquid manure systems; formed during uncontrolled anaerobic digestion of organic substances
Ammonia	NH_3	0.60	25 ppm	10–30%	Clear, colorless pungent odor	Formed in manure as a by-product of putrification

The following example illustrates the dangers of toxic gases on farms (Jonas 1979).

A 17-year-old youth on an Ontario farm entered a 12 x 3.6-m tower silo into which four loads of chopped corn silage containing high levels of nitrates had been placed 6 hours previously. After being in the silo for less than 5 min leveling the corn, he felt dizzy, went outside, began to feel weak and nauseated, and later became delirious, vomited, and complained of suffocation. Almost lethal levels of oxides of nitrogen were present in his blood, although he saw no gas and smelt nothing. One year after the accident, he was still suffering from after effects. He tired easily, and on damp days his lungs, nose, and throat burned. His sense of smell was beginning to return but he still could not taste anything. He had to avoid dusty areas, as he had no nasal hairs to filter dust particles, and he still choked easily when he ate. X-rays showed that his lungs were as black as those of a person who had smoked for 90 years. It was considered that because of his youth, the damage would probably repair itself in time.

Fumigants

In Canada, hydrogen phosphide (phosphine) evolved from aluminum and magnesium phosphides is used to control insect pests in storages. Methyl bromide is used as a fumigant of empty holds of ships and mills. Although fumigants are usually applied by licensed pest control operators, elevator managers and railcar, plant, and ship personnel should be aware of the toxic effects and behavior of fumigants used in their workplace, for example their reaction to water and penetration to adjacent spaces, and of appropriate first aid procedures in emergency situations. Poisonings have occurred in grain elevators after persons have entered pits or bins fumigated 1–2 weeks earlier. Poisonings have also occurred on ships after leakage of fumigants into passenger compartments from treated stocks. Davis and Barrett (1986) have summarized the development of the United States in-transit shipboard fumigation program and the safety procedures used. Normally, fumigated holds are aerated at port of discharge by opening all hatches. Fumigant gas concentrations are monitored 1 m above the grain surface every 30 min until the fumigant gas is at or below 0.3 ppm. The grain may then be safely removed, using pneumatic or grab-type equipment.

Fumigant poisonings can be prevented by taking the following precautions:

- Remembering nearby human habitations that could be affected by gases and vapors.
- Fumigating on a windless day.
- Identifying fumigated premises or stocks by prominently displaying warning signs.
- Working in pairs.
- Wearing a self-contained breathing apparatus when opening hatches, doors, and windows after an area has been fumigated.
- Changing the canister of a canister-type gas mask each time this type of breathing apparatus is used.
- Monitoring levels of phosphine and methyl bromide by using Dräger tubes or other devices.
- Avoiding the use of water on materials fumigated with phosphine, as more phosphine may be generated.

See Bond (1984) for a comprehensive description on control of insects by fumigation and recommended safe practices.

Fires and explosions

Fires and explosions can result not only in injury to plant personnel at the scene but also, through modification of the environment, to fire fighters and salvage operators. To minimize risks, fire fighters need to know the types of commodities they are dealing with in order to select the correct extinguishing medium, for example foam, water, sand, or carbon dioxide, and the correct breathing apparatus. They also need to know whether gas cylinders, chemicals, and other dangerous substances are on site. Salvage operators should be advised of any gas cylinders that may be in the ruins and of any weakened structures such as walls which, if disturbed, may suddenly release large volumes of hot material.

Fires and explosions are known to occur in vertical silos containing grass silage or haylage (Koegel and Bruhn 1971). Fire fighters fighting such fires are at risk from explosions. Campbell (1973) describes the events leading to an explosion in a partially filled, bottom-unloading type silo that contained smoldering haylage and produced a mixture of carbon dioxide and flammable carbon monoxide. Following previously recommended fire-fighting procedures, fire fighters went to the top of the affected silo, 18 m above ground level, opened the hatch, and directed water or foam onto the hot haylage, thereby injecting air into the silo. The ingredients for an explosion were then present — a flammable gas and oxygen — in a closed container, and a spark from a glowing ember touched off an explosion (Campbell 1973). ***Current recommended fire-fighting procedures are much safer (see section on vertical silage silos).*** Descriptions of the effects of explosions in silos containing silage are given by Campbell (1973) and Singley (1968). Boumans (1985) describes the effects of dust explosions in silos containing grains and grain products, and the methods of explosion prevention and protection. Aldis and Lai (1979) have reviewed the literature relating to engineering aspects of grain dust explosions. For information on the investigation of fires and explosions see next section.

An excellent summary of safety procedures to follow while working in grain and feed silos, tanks and bins, food product tank cars, and liquid storage tanks is given by the National Safety Council (1962).

Chapter 8. Problem investigation

This chapter provides guidelines for persons investigating the causes of spoilage problems that result in animal sickness and death, and the causes of heating problems that result in fires or explosions. The investigation of these types of problems requires a careful systematic approach, making the fullest possible use of available information. The collection and documentation of such information is of paramount importance if legal proceedings are later involved (see Chapter 9).

For an excellent account of the damage that can be caused to commodities during storage, stowage, and carriage, the reader is referred to Knight (1985).

SPOILAGE AND/OR ANIMAL SICKNESS

Suggested steps to take when investigating spoilage and/or animal sickness problems, as summarized in Table 11, are as follows:

Information collection

Visit the site promptly. Interview key persons involved, such as eye witnesses. Take photographs of premises and of sick or dead animals.

Extent of spoilage

Ascertain the source of the spoiled and sickness-associated materials. For instance, were the materials produced, stored, and used as feed on the premises or were they manufactured elsewhere and brought to the site to be stored and used as feed, for example feed pellets? Determine whether the spoiled or suspect materials formed a portion or all of one or more bins on site. If confined to one bin, determine the location of the affected material. This might be in the upper or lower part of the structure, in pockets, near the upper centre, near doors, near the aeration floor, under spout lines, on the surface, or close to or adherent to walls. Take samples of affected

Table 11 Suggested steps for investigation of spoilage and animal sickness problems in stored commodities

1)	Information collection	- Get to site as soon as possible - Interview key persons - Take photographs of premises, sick animals
2)	Extent of spoilage	- Ascertain whether source of spoiled and sickness-associated materials is on site or derived from outside - Determine whether affected materials form a portion or all of bin(s) on site - If affected materials form a portion of bin(s), determine its location within the bin(s) - Take samples of affected and unaffected materials, then label, bag, and later photograph them
3)	Cause of spoilage	- If spoilage occurred in the *upper part* of the bin, look for badly fitting hatches, missing bolts, water in bucket elevator, moisture migration, aeration problems, non-use of spreader - If spoilage occurred in *lower part*, look for leak between bin wall and concrete wall, poorly fitting doors; spoilage in dead spot above aeration floor - If general spoilage occurred, probably the product moisture content was too high for safe storage
4)	Animal sickness	- Check out infectious disease(s) as cause - Change to new feed - Check history of herd/flock - Check history of feed, determine whether new consignment was involved - Check history of supply, determine whether new supplier was involved - Consult a veterinarian, obtain post-mortem results - Look for source of moldy material - Take samples of affected and unaffected materials, then label, bag, and later photograph them

(*continued*)

Table 11 Suggested steps for investigation of spoilage and animal sickness problems in stored commodities (*concluded*)

5)	Analysis of samples	- Check for increased moisture content levels, increased FAV (fatty acid values) - Check for decreased seed germination - Examine for musty or off-odors - Check for preharvest and post-harvest molds - Check for mycotoxins - Check feed ingredients and dosages
6)	Advice on control and prevention	- Spoilage: remove and discard affected material, dry remainder and rebin, seal bins, aerate - Animal sickness: change feed, change supplier, order short-term supplies
7)	Summary	- Spoilage is most often caused by improper storage - Animal sickness is caused by mycotoxins in the feeds, by mistakes made during feed formulation, or by many other agents and factors - Consult a veterinarian who is familiar with sickness patterns in the animals affected regarding the probable cause of sickness

and unaffected stocks for comparison purposes, using a scoop, multi-chambered trier and/or deep bin probe, label them, seal them in double plastic bags, and place in a cooled container for transportation to the laboratory. Take photographs of the affected and unaffected sampled material.

Cause of spoilage

Spoiled material that occurs in the *upper part* of the bin is sometimes caused by extra moisture entering or becoming localized in the region. Spoilage is also caused by rain or snow entering through open or poorly sealed hatches, or via improperly sealed joints between sheeting or bolt holes. Other causes include the entrance of run-off water from elevator buckets or grain spouts, the development of moisture migration in non-aerated bins, the development of a moisture front in aerated bins through inadequate fan size or interruption of aeration, the presence of excessive green weed seeds, or the accumulation of fines under the spout lines as a result of a spreader either not being used or not being used properly. Spoiled material that occurs in the *lower part* of the bin is often caused by extra moisture entering via a leak between the concrete floor and bin wall or via a poorly sealed door. Higher moisture material may occur in spring in the dead spots near the walls above the partially perforated aeration floor. If spoilage in the bin is not confined to one area, then some or all of the seeds were binned at too high a seed moisture content, and possibly seed temperature, for safe storage.

Animal sickness

In situations involving animal sickness, change existing feed and use feed from a fresh source to alleviate symptoms and to either implicate or exonerate the original feed. The following actions may then be considered: ascertain the history of the flock or herd and its normal sickness rate; obtain history of current feed to determine whether sickness symptoms were associated with an old consignment or with a new one; obtain information on the reliability of the supplier and any problems that might have been encountered by other customers; discuss animal sickness and stress symptoms with a veterinarian; attend postmortem examinations, if possible, and take photographs; look for possible source of spoiled feed, for example water or rain leaking into feed troughs, presence of hard lumps of material in the feed, or use of moldy grains that could be associated with toxins; take samples of affected and unaffected materials as checks, identify them, and photograph them.

Analysis of samples

Examine all suspect and control samples for increased moisture content levels, decreased seed germination levels, increased fat acidity value levels, the presence of musty or off odors, and the presence of species of preharvest and/or post-harvest molds. Where animal sickness is involved, analyze samples for aflatoxins, ochratoxin A, sterigmatocystin, citrinin, patulin, penicillic acid, trichothecenes, zearalenone, and other mycotoxins, depending on the preharvest and/or post-harvest molds present in the sample and the symptoms of animal sickness. Analyze feed ingredients of manufactured feeds to determine whether duplicate or even triplicate dosages of particular items were accidentally added.

Advice on control and prevention

Once the cause of spoilage has been determined, take steps to control the situation and prevent its reoccurrence. Remove and discard spoiled material, wash down or spray walls with a solution containing two parts Clorox® and eight parts water to control spoilage molds (Charles 1985), then if necessary dry the unspoiled

Table 12 Suggested steps for investigation of heating, and fire- and explosion-related problems in stored commodities

Procedures		
1)	Information collection	- Get to site as soon as possible - Interview key persons and eyewitnesses on origin of the problem - Check local newspapers for photographs, and reports - Take own photographs
2)	Extent of problem	- Determine the type and volume of commodities involved - Determine the damage caused to facilities and stocks - Ascertain age of facilities and type of construction - Check structural condition of the facilities - Check for possible fire hazards - Determine what fire fighting and other procedures were used
3*a*)	Cause of heating	- Storage of high moisture content material - Improper or inadequate storage management procedures, including cleaning, aerating, turning, monitoring and insect control - Entrance of moisture through leaks or bucket elevator - Defective, poorly calibrated moisture meters - Proximity to steam pipes or other heat sources - Improper use of fumigants
3*b*)	Cause of fire and/or explosion	- Arson - Welding - Mechanical - Electrical - Lightning - Static electricity - Improper fumigant use - Self-ignition, lumps of very hot material within stocks or in railcars or ships - Explosion, addition of water or foam to fire in silo

(*continued*)

Table 12 Suggested steps for investigation of heating, and fire and explosion-related problems in stored commodities (*concluded*)

Procedures	
4) Examination of facilities	- Obtain floor plan of facility, showing location and contents of each storage bin - Examine structure and contents for evidence of causes listed in section 3*b* of this table - Determine location of initial heat source, path of fire, or explosion - Look for used fumigant containers - Obtain samples of unaffected and affected material, then label, bag, and photograph them
5) Analysis of samples	- Differentiate between spoiled, bin-burnt, and fire-burnt material - Relate these to sites of spoilage, heating, fire, or explosion - Examine lumps of black fused material and relate to either self-ignition or late fire damage
6) Summary	- Heating problems are usually caused by biological and chemical activity - Self-ignition is the least likely cause of fires and explosions; therefore check for other causes such as arson first - Self-ignition might be involved if heated material is aerated or exposed to air - Explosions may result if heated fused material is transported into a facility from a railcar, barge, or truck

remainder and rebin. As a preventive measure, seal bins and install proper aeration and monitoring devices.

With instances of animal sickness, change the feed or the supplier of feed and order quantities sufficient only for short-term use.

Summary

During the investigation remember that *spoilage* is most often caused by improper storage of the material. There are many reasons for improper storage: the moisture content and temperature of the material at binning might have been initially too high for safe storage and needed to be dried or aerated, the material might have been improperly aerated or improperly treated with propionic acid during the storage period, or perhaps moisture was allowed to locally increase during storage either due to moisture migration or through leaky roofs and walls. *Animal sickness* symptoms may be associated with the presence of mycotoxins or with mistakes in feed ingredient dosages. They may also be associated with numerous other agents or factors. The assistance of an experienced veterinarian familiar with sickness patterns in the type of animal is essential to determine the exact cause of the sickness.

HEATING, FIRES, AND EXPLOSIONS

These types of problems can vary from being of relatively minor importance, involving localized pockets of heated material within a bulk, to being of major importance, involving destruction of storage facilities and damage to stored commodities by fire and/or explosion. Suggested steps to take when investigating heating and fire- and explosion-related problems, as summarized in Table 12, constitute a checklist of the major points to be considered in most investigations. Due to the complex nature and uniqueness of problems, the list does not cover all eventualities.

Suggested steps to take when investigating heating, fire, and explosion problems, as summarized in Table 12, are as follows:

Information collection

Visit the site promptly. Interview on- and off-duty staff, insurance adjusters, fire fighters, police officers, newspaper reporters, and eye witnesses regarding the source of the heating, fire, or explosion. Obtain photographs and samples before excessive site disturbance occurs.

Extent of problem

Ascertain the nature, type, and volume of the commodity or commodities involved; the extent of the damage caused to the facilities and stocks; the structural condition of the facilities and existence of hazards; and the fire-fighting procedures used.

Cause of heating

Examine temperature, moisture content, and product condition records to determine whether pockets of high moisture material existed as a source of heating in the stocks. Such records and interviews with personnel permit an assessment of the frequency and adequacy of cleaning, aerating, turning, and insect monitoring and control procedures used in the facility. The undetected entrance of rain or snow via leaks or of water via bucket elevators, the use of defective or poorly calibrated moisture meters, proximity to steam pipes, engine spaces, or illuminated electrical lights, and improper use of fumigants are all potential causes of heating problems and should be checked.

Cause of fire and/or explosion

Fires may be caused deliberately for reasons such as financial gain, to conceal another crime, to destroy or protest, to become a hero or heroine, to fulfill a need (mental disorder), or because of boredom (Dennett 1980). Generally, because of prior involvement, the presence and activities of arsonists in a community are known to the police. Clues such as remnants of oily rags may provide evidence of arsonists activities.

Fires and, in particular, explosions, may result from the use of welding equipment in and around storage facilities. The sparks provide a primary ignition source for an initial dust explosion, which dislodges debris from ledges and provides the fuel for a subsequent major conflagration.

Overheated mechanical bearings and electrical motors, and faults in electrical fittings and wiring are also known to cause fires (see Fig. 6). Because lightning can set fire to structures it is worthwhile to check for damage to the lightning conductor and for the occurrence of electrical storms at the time of the fire.

Static electricity can cause explosions in dusty situations; therefore check the procedures used for minimizing risk from electrostatic charges in the facility. Overalls made of synthetic materials with a high capacity for retaining electrostatic charges can be instrumental in causing an explosion.

Fumigants containing either aluminum or magnesium phosphide are often used in pellet or strip form to control insects in flour mills and other bulk storage areas. When exposed to moisture or heat these substances produce the flammable toxic gas phosphine. For this reason, the investigator should check with plant personnel to determine whether fumigation with these substances had recently occurred. Fire may result from the accidental addition of water to fumigant pellets or strips or even from rain coming into contact with the contents of discarded fumigant containers dumped into the garbage. Localized high concentrations of pellets poorly distributed within a mass of grain can create enough heat to cause a fire or to damage the kernels of grain immediately above, resulting in downgrading and economic loss. Ventilation by fans in premises fumigated with phosphine may result in ignition due to changes in gas compression and sparks from the fans.

Fires and explosions may result from the self-ignition of strongly heating commodities exposed to air or oxygen. An indication of self-heating or self-ignition on site is the presence of very hot fused material within otherwise cool stocks, some of which may have ignited when exposed to air and provided an ignition source for dust explosions. The fused lumps may have originated from within a ship, barge, railcar, or silo and may have been carried via conveyor belts for some distance within the plant to the site of the fire or explosion. Another indication of self-heating is the presence of brown liquids coming out of bin seams, and sooty deposits beneath aeration floors, both the result of improper aeration of strongly heating stocks. Often, strongly heating stocks will continue to smolder for long periods but will not ignite unless additional air or oxygen is supplied.

Fires and explosions may result from complex causes; see an interesting account of the SS Green Hill Park disaster by Stanton (1987).

Examination of facilities

Obtain a floor plan of the facility that shows the location and contents of each storage bin, ship, barge, truck, or railcar. Determine whether any movement of stocks was occurring at the time of the fire or explosion, and if so, the type of commodity and the locations involved. Examine the facility and its contents for evidence of the causes (see Table 12, section 3*b*). If possible, do this while uncovering the stocks with an experienced salvage operator. Look, for example, for remnants of oil-soaked rags as evidence of arson, and for the presence of discarded fumigant containers as a possible cause of the fire or explosion. Determine the location of the initial heat source and probable path of fire and explosion from on-site examination and photographs. Obtain samples of unaffected, heat-damaged and fire-damaged material, then label and photograph the samples and put them into bags.

Analysis of samples

On laboratory receipt, examine the samples, divide them into spoiled, bin-burnt, and fire-burnt categories, and relate their occurrence to sites of spoilage, heating, fire, and/or explosions in the plant. The presence of fused heated material may indicate a source of self-heating or it may relate to damage caused much later when the stored material was consumed by fire.

Summary

Heating problems in stored commodities are most likely caused through biological and chemical activity. Fires and explosions are not usually caused by self-heating; therefore other causes, for example, arson, should first be examined. Self-ignition may be involved if heated fused material is exposed to air or is aerated. Fires and explosions may result if heated fused material is transported into a facility after unloading silos, railcars, ships, or trucks.

Chapter 9. Legal aspects

Anyone involved in the stored products business may someday be required to attend court as a plaintiff, a defendant, a witness, or an expert witness in a lawsuit concerning stored commodities. Attending court can be a frightening experience to the uninitiated. The purpose of this chapter is to provide some general background on the subject by describing procedures used before and during court and the types of cases involving stored products that might be encountered.

The following section is quoted largely from Sinkwich and Jamieson (1982) and to a lesser extent from Macdonald (1976), and relates to Canadian civil law. For a description of United States federal courts see Want Publishing Company (1984).

Law cases are referred to by the names of the plaintiff and the defendant, the date, and the law journal in which they appear. For example, in *Holian v. U.G.G.* (1980), 13 C.C.L.T. 269 Manitoba C.A., C.C.L.T. is the abbreviation for Canadian Cases on the Law of Torts, 13 and 269 refer to the volume number and the page number, and C.A. is the abbreviation for Court of Appeal. Other journal abbreviations used in this chapter are A.C. (Appeal Cases), A.C.W.S. (All Canada Weekly Summaries), O.L.R. (Ontario Law Reports), H.L. (House of Lords), Q.B. (Queen's Bench), and So. 2d (Southern Reporter, 2d series).

PROCEDURES

Many cases are negotiated and settled out of court by lawyers after either a pretrial hearing or an examination of discovery before a judge. During these proceedings the lawyers exchange relevant records and examinations of facts. If settlements are not reached at this stage, then the cases are normally heard in civil court.

During the trial the *plaintiff* first presents his or her case by presenting witnesses and evidence. *Witnesses* are only allowed to testify to matters of fact that they have witnessed. *Expert witnesses*, persons with special skill or knowledge of a particular science or trade, must first be qualified before the court as to their suitability. Once qualified, they are permitted to do one or more of the following: draw upon fact and express professional opinion, reach conclusions, respond to hypothetical questions, explain professional procedures to the judge and/or jury (Byrd and Stults 1976). For the roles and rights of expert witnesses see Cook (1964), and for guidelines for effective testimony by expert witnesses see Brickey and Vazquez (1977). The *defendant* cross-examines each of the plaintiff's witnesses immediately after the plaintiff has completed the direct examination. After the plaintiff has presented all his or her evidence, the defendant presents a case in the same way. Both parties then summarize their cases, beginning with the plaintiff. It is during this stage of the proceedings that legal argument, which involves looking at relevant precedent and distinguishing cases, occurs. The judge then makes a decision based on the applicable law and the facts as he or she finds them.

To succeed, the plaintiff must prove his or her version of the facts on the *balance of probabilities* (i.e., that it is more likely than not). As an aid in achieving this goal, the plaintiff may wish to make a careful cross-examination of witnesses and evidence presented by the defendant. Finally, the court must decide whether on the whole of the evidence on the balance of probabilities the plaintiff has satisfied the onus on him or her and has proven his or her case.

If the plaintiff is successful, judgment is made for the plaintiff, and the judge decides the appropriate award. Legal costs, including the cost of court time, may also be awarded to the successful party. The judgment can be appealed to the *Court of Appeal* and in certain instances to the *Supreme Court of Canada*. On appeal, arguments are usually based on questions of law, not of fact.

DIVERSITY OF LITIGATION

An examination of the literature shows that storage problems resulting in litigation usually involve either spoilage and/or heating, insect infestation, animal health, and fires and/or explosions (Table 13). Legal cases may be complex, involving several countersuits. For example, in the event of a storage problem the owner of a silo may sue his or her insurance company, which, in turn, may countersue the elevator construction company, dust equipment manufacturer, and others. In addition, if human deaths are involved, families of the deceased may initiate further legal actions.

Instances of spoilage and/or heating, insect infestation, animal health, and fires and/or explosions may result in a number of quite different kinds of litigation, as seen from the following list:

(a) *Prosecution for breach of statutory duties* under the *Canada Grain Act*, and regulations made under that Federal Statute. Particularly noteworthy is s.86(c), which says "No operator of a licensed elevator shall ... except under the regulation or an order of the Commission, receive into or discharge from the elevator any grain, grain product or screenings that is infested or contaminated or that may reasonably be regarded as infected or contaminated." Any person or corporation infringing this section is liable to a fine and/or imprisonment, as set out in s.89(2) of the Act. Note that the Act may be violated, and punishment earned, even though there has been no "fault" or "blame," or even negligence, on anyone's part. If infested grain is discharged, the hapless discharger is liable.

Table 13 Types of storage problems resulting in law suits

Problem	Location	Likely cause
Spoilage and/or heating	Silos	- failure to maintain quality through faulty management (poor warehouse-keeping)
		- delivery of low-quality product into storage
		- ineffective oxygen-limitation
		- inadequate equipment performance, e.g., aeration fans
	Ships	- improper care during voyage
		- product in poor condition at time of delivery to ship
Insect infestation	Ships	- failure to control pests
Animal sickness and/or death	Animal barns	- feeds containing mycotoxins
Fire	Silos	- delivery of low-quality product
		- inadequate N_2/CO_2 gas protection
	Bins	- aeration of heating product
	Elevators	- welding repairs, friction
Explosion	Silos	- hot fused product igniting dust on entry
Structural collapse	Silos	- flowing grain

The law calls this rather severe approach "strict liability." We shall encounter it again shortly.

(b) *Bailment.* Whenever one person stores grain belonging to another person, or takes possession of it for purposes of carriage or transportation, a *bailment* is said to have occurred. The person receiving the goods is called the *bailee*; the consignor is called the *bailor.* A bailee owes a duty of custodial care to the bailor, that is, a duty to take care of the goods and to handle them skillfully, especially perishable commodities, such as grain. If the duty is broken, the bailee (for example, the elevator operator) may be sued in contract, if the storage was a contractual one, for reward, or in tort (a non-contractual civil wrong, typically the tort of detinue or of negligence), if the bailment was a gratuitous undertaking. In either event, actions involving breach of duty of custodial care by a bailee have an important procedural peculiarity in both Canada and England (but not in the USA). Once the plaintiff (bailor) has proven that bailment occurred, and that the goods were in due course contaminated, damaged, destroyed, or lost, it is up to the defendant (bailee) to prove that the disaster did not occur as a result of negligence on the part of the bailee. If the bailee cannot prove that, then the case will be settled in favor of the bailor.

Examples of some bailment cases follow: Christensen and Kaufmann (1969) relate an American case — *careless storage under a contractual bailment.* During the 1950s in Cairo, Ill., 6600 t of winter wheat was locally harvested, transported by truck, and stored in a large bin. The weather during harvest was changeable, with intermittent showers. According to the warehouse manager, all the grain was at an average and uniform 13.2% M.C., although some truck loads received were at 14.0% M.C. Most of the grain was binned at 27–32°C. In December the grain began to heat and was transferred to prevent further spoilage and heating. When unloaded in early spring, the wheat was 40% germ-damaged and of *Sample* grade, resulting in a $242 000 (U.S.) loss to the warehouse manager.

In the resulting lawsuit, the warehouse manager maintained that he had exercised care and caution during storage of the grains and that the poor keeping quality was probably due to a late spring frost, affecting the crop before harvest. The spoilage and heating in the bulk, however, were due to growth of storage fungi on moist grains, that is, grains above 13.5% M.C., within the bulk. Because of poor management, the warehouse manager was deemed responsible for the loss, as he did not monitor the bulk for changes in moisture content or development of storage molds, nor did he check the accuracy of his moisture meter.

Another example, involving a *bailment of carriage*, is given by the same authors: in May 1962 a cargo of about 2500 t of bagged No. 2 white corn was loaded onto a ship in New Orleans. After a voyage of 18 days through the Gulf of Mexico, Panama Canal, and Pacific Ocean the ship arrived at El Salvador, its destination. On arrival, much of the corn was spoiled and the remainder spoiled during subsequent warehouse storage, with a total loss of $200 000 (U.S.). In the resulting lawsuit, the question at issue was whether the corn had been in bad condition and prone to spoil when loaded on the ship or whether improper care during the voyage had resulted in the loss.

On investigation it was shown that the corn had been in good condition when shipped. The shipper had kept a loading sample of the corn, which after 2 years still had 80% germination, less than 2% damaged kernels, and was free from visible storage fungi. Corn samples obtained from bags unloaded in El Salvador, by comparison, had 0% germination, 20–40% damaged kernels, and were heavily invaded by storage fungi. Moreover, the kinds of storage fungi invading the surface-sterilized corn kernels indicated that the corn must have been exposed to 85–90% R.H. and a moderately high temperature for at least 2 weeks. The ship's log showed that during the voyage the relative humidity of the air ranged from 85 to 90% and the temperature ranged from 27.0 to 29.5°C. As the ship had no forced ventilation system, ventilation was provided through the scoop ventilators, which were kept open except when it was raining. The bagged corn in the holds was thus exposed to a continual blast of warm moist air during the voyage. By exposing samples of corn of the same quality as the loading sample to 85–90% R.H. and 27–29.5°C for 18 days, it was possible to obtain corn in the same condition as that which arrived in El Salvador. Further, the same types of storage fungi were present. This was convincing evidence, and the case was settled in favor of the grain firm that had supplied the corn.

A Canadian case dealing with the alleged negligence of a bailee of grain is the Ontario case of *Quintal & Lynch Ltd.* v. *Goderich Elevator Co.* (1923), 54 O.L.R. 200: a decision of that province's Court of Appeal. A total of 2100 t of No. 1 feed-oats had been consigned to the defendant company for storage. Due to alleged careless storage, the oats became heated and tough. After an exhaustive review of the evidence, the Court concluded that the heating and deterioration had probably occurred after the defendant company had relinquished possession of the oats, and therefore it was not to blame for the spoilage. The defendant company's bailees had discharged the burden of proof incumbent upon them, and they were exonerated.

(c) *Tort of negligence.* In a host of different situations, the tort of negligence may be invoked against those who (i) carelessly store grain so that it ultimately causes damage to other persons or to their property; (ii) carelessly conduct their grain-storage activities so that other persons are harmed incidentally (for example, by fires, explosions, the spread of contaminants or disease, or the escape of fumigants), or need to take costly precautionary measures against any of these perils; or (iii) carelessly manufacture buildings, structures, or machines designed for the storage or preservation of grain, with resultant damage to that grain.

Usually, a *complainant* under item (iii) would have a contract with the alleged negligent company which supplied or manufactured the equipment, and would sue that company for breach of contract rather than for negligence. These kinds of cases are discussed under Breach of contract.

Items (i) and (ii) are typical cases in the tort of negligence. Reported cases are rare, but if a person stores grain in such a way that it deteriorates, develops toxins, and eventually kills livestock or causes animal sickness when the grain is fed to them, that person is liable in contract, under the *Sale of Goods Act*, if the contaminated feed is sold to the stock owner directly (Schiefer and O'Ferrall 1981); or liable in the tort of negligence if the contaminated feed is sold to a dealer, from whom it is passed to the ultimate consumer. The leading cases in this context are the English cases of *Kendall* v. *Lillico* [1969] 2 A.C. 1, and *Ashington Piggeries* v. *Christopher Hill* [1972] A.C. 441, both of which are treated as authoritative by Canadian Courts.

One can imagine all kinds of cases: overheated grain that might cause a fire; unskillful storage that might result in an explosion which destroys nearby property of a neighbor; carelessly used or stored fumigant chemicals (see *Holian* v. *U.G.G.* (1980), 13 C.C.L.T. 269, Manitoba C.A. — lax storage of phostoxin tablets gave rise to $90 000 award!) that might cause injuries to persons in the vicinity; failure to keep disease or biological contaminants under control in one's premises, causing catastrophic loss to neighbors (see *Weller* v. *Foot and Mouth Disease Research Inst.* [1969] 1 Q.B. 569).

These situations may give rise to the tort of negligence, and perhaps, in some cases, to the tort of nuisance, too. In every case, the essential question would be — did the defendant exercise reasonable care, skill, and expertise in the storing of grain and related activities? If not, then the defendant would be liable. Expert witnesses may be called upon to testify as to the *usual* practice of those experienced in the particular field of endeavor. It would be rare indeed for a Court to castigate as negligent what is considered the usual practice of people experienced in a given field. Compliance with usual practice is therefore a potent, although not impregnable, safeguard against negligence liability.

(d) *Torts of strict liability.* Under the heading Tort of negligence, it was noted that negligence liability may arise when fires or explosions result from careless storage, or when pests escape from bins and infest bins belonging to a neighbor. In the latter case, the plaintiff (neighbor) may not even have to prove negligence on the part of the defendant, since the situation might well constitute a *strict liability tort*, under the *Rylands* v. *Fletcher* principle (*Rylands* v. *Fletcher* (1868), L.R. 3, H.L. 330), and the defendant, even if personally blameless, would be required to pay for all damages resulting from the infestation.

(e) *Statutory duties and civil liability.* Legal scholars used to think that if one broke a *Statutory duty*, for example the *Statutory duty* under s.86(c) of the *Canada Grain Act*, considered earlier, one was automatically guilty of a punishable offence, and liable for damages to anyone whose interests suffered as a result. That disturbing thought was recently disposed of by the Supreme Court of Canada in *Her Majesty The Queen* v. *Saskatchewan Wheat Pool* (1983), 23 C.C.L.T. 121.

The Canadian Wheat Board, as agent for the Crown, directed that a cargo of wheat be shipped on board the *MV Frankcliffe Hall*. The wheat had been stored in the Saskatchewan Wheat Pool's terminal elevators at Thunder Bay, Ont. After the wheat had been loaded and the ship had sailed, it was discovered that part of the grain was infested with larvae of the rusty grain beetle. The Canadian Wheat Board had to unload and fumigate the ship's holds, at a cost of $98 261.55. The Board sought to recover the sum, founding its action upon the Canada Grain Act, s.86(c), which prohibits the delivery of infested grain out of a grain elevator. At trial before the Federal Court, it was held that the *Statutory duty* placed an absolute duty upon the defendants, the breach of which gave rise to a civil liability on their part, notwithstanding the absence of any allegation or clear evidence of negligence. Evidence of reasonable care on the defendants' part was simply no defence. The defendants appealed successfully to the Federal Court of Appeal, which held that the *Canada Grain Act* was a statute designed for the general regulation of the grain industry, and that it was not designed to provide any particular class of persons, like the plaintiff, with any civil cause of action. The Board brought this further appeal to the Supreme Court of Canada, urging once more that a civil right of action was given to it by virtue of the breach of the statute. Subsequently, the appeal was dismissed and the Board's action was rejected by the Supreme Court.

The Supreme Court ruled that the breach of a statute does not automatically, in and of itself, give rise to civil liability (that is, an obligation to pay compensatory damages for resultant harm or loss), if all the statute does is provide for a minor fine or some other punitive measure. If the statute itself ordains a civil remedy for breach of the duties it sets out, well and good; otherwise, breach of the statute's terms is simply evidence, admissible in court but not necessarily conclusive, that there has been civilly actionable negligence, that is, a departure from the standards of care or skill that a reasonable person in the defendants' position might have been expected to show.

(f) *Contractual actions and the Sale of Goods Act.* Whenever a person sells goods to another, whether the goods purchased are specific (for example, 15 t of oats in an elevator at Silver Plains), or generic (for example, 12 t of No. 1 feed oats), the liability of the seller for the quality of the goods delivered is governed by the law of contract, a complex body of rules long since codified, so far as such contracts of sale are concerned, by the *Sales of Goods Act*. This statute, with only minor local variations, exists in essentially the same form across Canada and throughout the Commonwealth. Its principal importance for present purposes is this. It is open to those who buy and sell stored agricultural commodities to agree upon any terms they choose, as to the quality of the merchandise. But to a large extent, the contracting parties may elect to leave the details to be filled in by the statute, the *Sale of Goods Act*, itself, providing as it does for a series of "implied warranties or conditions" on the part of a seller — that is, promises which a seller will be "deemed" to have made to the buyer, whether they were expressly spelled out or not. The implied promises are as follows:

- That the goods correspond to the description agreed upon;
- That the goods are of "merchantable quality" (that is, however defective or poor in quality, they are at least capable of finding a market somewhere, as goods of the same description as that used in the sale);
- The goods are fit for any specific purpose (for example, feeding dairy cattle) made known by the buyer to the seller at or before the time of the sale; and
- (where applicable) that the goods correspond in quality to any sample furnished by the seller to the prospective buyer.

It is obvious that all or any of these conditions, or implied promises, may be broken in situations where grain or produce has deteriorated or become contaminated due to unskillful storage. There have been many instances where expert witnesses have been called to testify to the propriety, or otherwise, of storage procedures, and the seriousness of the resultant degradation of the product. One common context for such litigation is that class of case where the defective feed-product bought by the plaintiff has caused animal sickness or injury to livestock, due to the presence of mycotoxins.

Actions involving mycotoxins

Some suits have been settled on the basis of the amount(s) of mycotoxin(s) present in the suspect feed sufficient to have caused the symptoms observed in the affected animals. Other claims, however, have been based on inadequate or misleading evidence, such as laboratory tests showing the presence of potentially toxigenic molds in the suspect feed. Such evidence has no scientific validity, but in the hands of a good attorney it may sway a jury (Mirocha and Christensen 1982). Many aspects of mycotoxin identification, occurrence, development on different substrates, and effects on animals at subclinical dosages are insufficiently known. Another area of concern is obtaining meaningful samples for mycotoxin analysis.

Because of these scientific technical difficulties, one or more expert witnesses, sometimes with opposing views, may be involved in lawsuits (Marshall 1983). The following example, which occurred in a Canadian prairie province (Schiefer and O'Ferrall 1981), illustrates the complicated nature of lawsuits involving animal sickness and mycotoxins.

The operator of a swine operation with 150 sows and 600 feeder pigs signed a contract with a feed company for repeated bulk delivery of several types of pellets consisting of 75% grain and the balance various protein supplements and mineral and vitamin mixes and premixes. Soon after delivery of pig grower pellets on 5 February 1976, vomiting and diarrhea were observed in all feeder pigs. To overcome the problem of enteritis, medication was added to the 10 February ration and the symptoms disappeared but reappeared after reintroduction of the non-medicated ration in March. Later, swollen vulvas and swollen mammary glands were observed in sows and pregnant gilts, and there was an increase in incidence of abortions and a decrease in litter size. The feed company halted further shipments and eventually sued the operator for nonpayment of feed received since February. The operator counterclaimed for losses incurred as a result of the defective feed. A number of analytical tests for mycotoxins were performed on the feed and animal tissues but were negative and the cause was never clearly established.

In the subsequent law suit the operator, supported by statements from two veterinarians, contended that the feed delivered in February and March was the initial cause of the problem. One veterinarian diagnosed hyperestrogenism in the breeding animals and suspected that "the cause was nutritional, possibly mycotoxins." His recommendation to change to other feed corrected the situation temporarily until the operator started to feed the suspicious feed again.

The feed company pointed out that none of the various samples taken had shown any evidence of presence of mycotoxins during the course of laboratory examination, that all its feed grains were purchased from areas known to have had very little rainfall before or during harvest, and that the grains originated from various sources within the area. It was argued that if a mycotoxin was involved at all, the production of mycotoxins may have started on the farm in improperly designed storage or transport facilities. Considerable clumping of wet and moldy feed due to rain entering the auger boot had been observed on visits to the farm.

The court was of the opinion that the problems on the farm started at the time of the feed deliveries of 5 and 10 February, and that all problems, both in feeder pigs and in sows, were most likely related to this feed. There appeared to be little doubt as to the diagnosis of hyperestrogenism, although no nutritional cause was found. The judge noted that it was not possible to say, with any certainty, how the mycotoxins, if any, had developed and ruled that the feed company would have to pay for the costs of the two unwholesome feed deliveries of 5 and 10 February.

Schiefer and O'Ferrall (1981) reviewed the veterinary, toxico-analytical, and legal aspects of the case. Regarding *veterinary aspects* they speculated that, in the absence of mycotoxins, a viral infection caused enteritis in the feeder barn and that the infection moved on to the sow barn to cause interuterine fetal death, reduced litter size, and infertility with a high number of sows recycling. Regarding *toxico-analytical aspects*, several shortcomings were apparent. The only samples collected by deep sampling at various sites were taken on 4 August, about 4 months after the initial problem arose. Also, the sensitivity of laboratory tests performed for the mycotoxin zearalerone left much to be desired. Regarding *legal aspects*, after the operator counterclaimed under the Sale of Goods legislation for the losses incurred as a result of the defective feed, the feed company was put in the position of having to defend its feed, that is, having to prove certain facts in order to succeed. However, the triers of fact in this case, judge or judge and jury, bound and determined to find a cause, found the feed was the most likely cause of the problem and that therefore, on balance of probabilities, the feed was defective. The swine operator succeeded. He was not required to pay for the defective feed and in addition he recovered losses for damages incurred.

The court's decision in favor of the operator, however, may have been a misapplication of the legal rule governing the standard of proof in civil cases. Since most cases of hyperestrogenism in sows are not satisfactorily explained, the moldy feed was equally likely to be the cause of the problem.

Schiefer and O'Ferrall (1981) make these important conclusions and recommendations:

- Feed companies are advised to perform tests for mycotoxins on unprocessed grain or on the final pelleted or crumbled product on a regular basis to ensure the quality of their product.
- Veterinarians, feed company representatives, and other people involved should ensure that feed samples are taken properly, identified unmistakably, and submitted to reliable analytical laboratories.
- Any disease outbreak needs to be thoroughly investigated from various viewpoints.
- Feed testing should be done by recognized laboratories, using methods with detection limits low enough to show that mycotoxins are not present at concentrations considered harmful, and confirmation of identity by chemical methods must be performed by competent analysts.
- Veterinarians advising feed companies ***should be aware of the disadvantage of not being in a position to contradict the evidence of livestock owners who will likely testify that they never had any problems until they started feeding the feed received from the company***.

They must also act quickly to gather available evidence and conduct necessary tests.

- Veterinarians advising the farmer should be aware of the dependency upon accurate descriptions by the producer and should gather all available evidence.

- Legal action should require quantitative demonstration of a known toxin at a concentration that is consistent with the disease condition observed (Pier et al. 1980).

(g) *Contractual liability.* A defendant, whether sued in the tort of negligence, previously discussed, or in the present contractual phenomenon of *Sale of Goods Act* liability, will often depend on the doctrine of *Privity of Contract.* This says that one can only sue or be sued in contract (including the Sale of Goods Act) if one is in a *direct* contractual relationship with one's opponent. Thus, if a buyer received, say, a defective storage tank from an independent regional distributor, contractor, or retailer, the buyer could sue *that* person or company in contract but not the manufacturer, since the buyer was not dealing directly with the manufacturer. The buyer could sue the manufacturer, if at all, only in the tort of negligence.

Several illustrations might be of interest at this point. A case of contractual liability – note the direct dealings between the parties – arose in a British Columbia case arising – as so many actions do, both in contract and in tort of negligence – out of fires or explosions allegedly due to careless storage practices. In this case, however, the plaintiff's contract action was unsuccessful. The case was *Cargill Grain Ltd.* v. *Neptune Bulk Terminals* (1984), 25 A.C.W.S. 244, a decision of the distinguished British Columbia Court of Appeal.

Wheat bran pellets owned by the grain company were stored under contract in a warehouse. The contract with the warehouse company was for storage only, making no provision for inspection or circulation. Some months after delivery, the pellets began to heat. The grain company was warned, in writing, that the pellets were damp and warm but no reply was received; subsequently, a fire occurred due to self-ignition of the damp pellets. During the process of moving the pellets they were found to be infested with insects. The warehouse company had the facilities fumigated twice, the second fumigation also involving partial dismantling of the building to get at crevices. The trial judge found that any loss suffered by the grain company was due to its delivery of defective goods, that the warehouse company was sufficiently diligent in the care of its goods, and that the grain company was negligent in delivering defective goods and thus liable to the warehouse company.

In the appeal, it was judged the trial judge had erred in stating that the *Warehouse Receipt Act* (British Columbia) did not apply if defective goods were delivered, but that he did not err in finding the *warehouse company had met the standard of care required by the Act, considering the contractual background.* Based on his finding that the pellets became infested while in the possession of the grain company, the trial judge was correct that the grain company breached duty to test grain cars for infestation. It was decided that the warehouse company was entitled to be compensated for the full loss by the grain company, and the appeal was dismissed.

In a Louisiana case, *Pellets Inc.* v. *Millers Mutual Fire Insurance Co.* (1971), 241 So. 2d 550 Louisiana C.A., contractual liability was likewise in issue, this time because of *inadequately controlled atmosphere protection.* In 1967 a Louisiana feed company that produces bermuda grass pellets signed a contract with a contractor to install equipment, including a generator to provide oxygen-free gas at its plant. The pellets were stored in four 15 x 21-m storage tanks labeled A–D into which the gas was piped to produce a controlled atmosphere necessary to preserve pellet vitamin content and to reduce the possibility of fire by self-ignition. In early December 1968, a fire occurred in tank C. The insurance company paid for the loss incurred, then canceled its insurance coverage. In late December 1968 a fire allegedly occurred in tank A but the insurance company refused to pay for any losses incurred on the grounds that no fire was visible on 2 January 1969, the date the policy was canceled. The feed company then sued the insurance company for losses incurred. Several parties were made third party defendants, including the contractor. At the trial the verdict was in favor of the feed company, but the third party demand against the contractor was rejected. This verdict was appealed by the feed company.

At the appeal hearing before a jury, it was determined that on 6 January 1969 the temperature at 3.7–4.6 m from the top of tank A was 107°C. It was also determined that on 27 January the first actual flame, or glow, was noted from pellets discharged from a valve near the bottom of the tank, which was then less than half full. To empty the tank faster, a hole was cut in the bottom and a large pile of glowing embers emerged. From this and other evidence it was determined that an undisputed fire occurred in tank A on 27 January 1969, that the policy had not been legally and effectively canceled on 2 January 1969, and that the insurance company was liable for the damage caused by the fire.

A second part of the appeal dealt with a third party demand by the insurance company against the contractor for negligence in the manner in which it constructed and designed tank A. It was claimed that the contractor had failed to properly vent the tank, apply pressure release valves, make the pellet conveyors gas tight, properly pipe oxygen-free gas into tanks at more than one point, and install flow meters and inspection cocks. The main thrust of the insurance company's argument was that because the gas system was improperly connected to the storage tanks, condensation occurred, resulting in oxygen and water getting into the gas system. The court rejected the demands against the contractor because equipment for use in conjunction with the storage tanks was to be installed by the contractor in accordance with drawings to be furnished and approved by the feed company. The contract did not require the contractor to do any design or engineering work.

Where damages sustained by a plaintiff have, in truth, been caused by the negligent design or manufacture of equipment or of a storage facility, and such equipment or facility, with its inherent defects, has been acquired not directly from the manufacturer but from some hapless dealer, the plaintiff can proceed against the manufacturer, ordinarily only in tort, typically the tort of negligence.

The foregoing discussion outlines and illustrates most of the types of litigation in which anyone handling stored agricultural products might anticipate becoming involved in, whether as a party or as an expert witness. It also illustrates, incidentally, most of the grain-storage calamities, mishaps, and types of mismanagement that may give rise to such litigation. But these illustrations are not exhaustive. One particularly hard-to-categorize case, decided by Lord Denning and his English Court of Appeal in 1974, is known to lawyers as *The Tres Flores* [1974], 1 Q.B. 264. A ship was chartered to load a cargo of maize (corn) at Varna, Bulgaria and take it to Famagusta, Cyprus. The ship arrived at Varna at 5:00 hours on Sunday, 22 November 1970. No berth was available, so it was anchored in the roads. At 10:00 hours the Master of the ship gave notice of readiness that the ship was ready to receive a complete cargo of corn in accordance with the charter. On Monday, 23 November 1970, the charterers had the cargo of 6500 t of corn ready for loading in the port of Varna. The ship was still in the roads and because of heavy weather the inspectors could not get out and inspect it until Friday, 27 November 1970, at which time they certified that there were pests in the cargo spaces and ordered a fumigation before loading. The fumigation took 4.5 hours on Monday, 30 November 1970, and on 1 December 1970, the charterers accepted the notice of readiness. No berth was available for the ship until 7 December 1970, when loading commenced; loading was completed on 13 December 1970.

The ship's owners subsequently claimed for demurrage (a charge for the detention of a vessel beyond the time agreed upon) incurred while the ship was in the roads. The owners claimed lay time began at 14:00 hours on Monday, 23 November, whereas the charterers said it began on Tuesday, 1 December 1970. At the trial, the verdict was in favor of the charterers. The subsequent appeal by the owners was dismissed for the following reasons:

- The charter had a precondition to the validity of notice of readiness to load, which was not fulfilled until fumigation had been completed on 30 November 1970.

- When the Master of the ship gave notice of readiness, the ship should have been ready for loading whenever the charterers' instructions were given. Since there were pests in the holds of the ship, which made it unready to receive cargo until fumigation had been completed, lay time commenced at 14:00 hours on 1 December 1970.

It is not known what the pests were in this instance, but although the case itself is not easy to categorize from a legal viewpoint, it is another situation where the failure to secure stored grain against infestation by pests gave rise to exceedingly expensive litigation. One can neither catalog nor predict exhaustively the range of situations where competency in grain-storage may be called into question by the law.

Part
II

Storage characteristics of specific commodities

Chapter 10. Commodity characteristics

In Part I, the principles involved in spoilage and heating of stored products were dealt with. In Part II, the storage behavior and problems associated with specific commodities are described. For convenience, the characteristics of each commodity are described in the following order: *relative storage risk*; *moisture content standards* for dry, tough, damp, moist, and wet categories, established by the regulations of the Canada Grain Act and subjected to periodic revision; *moisture content limits* by the United States Department of Agriculture (1978); *safe storage guidelines; drying guidelines*, mainly as described by Friesen (1981) and Hall (1980); *spoilage and heating degrading factors* such as heated, bin-burnt, fire-burnt, and rotted; *appearance of damaged kernels* as described by the Canadian Grain Commission (1987); and known *storage and/or drying problems*. Problem situations encountered during storage of the commodity are described, including details of case histories and management practices used.

For additional information on the characteristics of a wide range of commodities and associated problems encountered during storage, stowage, and carriage, the reader is referred to Lloyd's Survey Handbook (Knight 1985).

RELATIVE STORAGE RISK

Five risk levels of spoilage and/or self-heating in stored commodities are given in Table 14 for a range of commodities. The risk level for each commodity was determined according to an overall assessment of seed/particle size, the need for an inert storage atmosphere, the total oil content, the presence of residual oil, and the known history of storage problems. Table 14 is an expanded and updated version of Table 2 (National Fire Protection Association 1949), to include soybean, canola/rapeseed, and other products.

SAFE STORAGE GUIDELINES

Safe storage of a commodity depends largely on its moisture content (M.C.) (more strictly, the relative humidity of the intergranular atmosphere), its temperature, the period of storage, and other factors. Whenever possible, information on these key factors, together with the commodity moisture content in equilibrium with 70% relative humidity (R.H.), about which level molds begin to develop, are provided for each of the 35 commodities described in Part II. For convenience, the moisture content — relative humidity data are summarized in Table 15.

DRYING GUIDELINES

As the temperature of the drying air is raised the rate of grain drying is increased. However, grain damage occurs if the temperature is too high. To prevent grain damage it is important that the maximum air temperature does not exceed the maximum allowable temperature of the grain being handled. The maximum drying temperatures cited for each commodity are conditional on drying to not more than 1% below the moisture content standards for straight grade seeds (except canola/rapeseed) (Canadian Grain Commission 1987), and on the removal of not more than 6% moisture in one pass through a high-speed dryer. With dryers where the grain is exposed to heat for long periods (such as in non-recirculating bin dryers) it is advisable, particularly with canola/rapeseed, to use temperatures 5–10°C lower than those listed for commercial use (Friesen 1981). The consequences of dryer damage are more serious with some crops than with others. It may reduce the value of a given crop more for some uses than for others. Indirect effects of dryer damage may be more important than direct effects. Reduction in viability makes the grain more susceptible to invasion by molds and subsequent deterioration. Brittleness caused by the effects of high drying temperatures leads to more breakage in handling (Freeman 1980).

DEFINITIONS OF DEGRADING TERMS

According to the Canadian Grain Commission (1987) definitions of degrading terms are as follows:

Bin-burnt kernels closely resemble fire-burnt kernels in color. However, unlike fire-burnt kernels, a cross section of bin-burnt kernels appears smooth and glassy. The weight of a bin-burnt kernel is similar to a comparable-sized sound kernel.

Fire-burnt refers to kernels charred or scorched by fire. In cross section such kernels resemble charcoal with numerous air holes. Unlike a bin-burnt kernel, a fire-burnt kernel weighs much less than a normal kernel of comparable size.

Heated refers to kernels having the typical color, taste, or odor of grain that has heated in storage, including kernels discolored from artificial drying, but it does not include charred kernels.

Rotted refers to the decomposition or decay of kernels caused by bacteria or fungi indicated by a blackening, discoloring, and softening of all or part of the kernel.

Alfalfa pellets (*Medicago sativa* L.)

Relative storage risk: Very high

Moisture content standards: None in Canada but manufacturers are required to set down the maximum moisture content present.

Safe storage guidelines: Generally avoid moisture extremes. The safe moisture content is regarded as 9–10%; however, after processing, pellet moisture content may be as low as 6.6–8.5%. Pellets are sieved before binning, and the resultant fines are pelleted to improve ventilation, avoid waste, and reduce fire risk. After cooling, pellets are stored in large bins of up

Table 14 Relative risk of spoilage and heating in stored commodities

	Risk level				
	Very high (Class 1)	High (Class 2)	Moderate (Class 3)	Moderate-low (Class 4)	Low (Class 5)
Size of particles/seeds	very small	small	small to large	moderate	moderate
Type of product	oilseeds; grass products	meals with oil, small fibers	oilseeds	cereals with high oil content	cereals pulses
Problem frequency	very many	numerous	numerous	some	occasional
Inert gas requirement	essential to preferred	none	none	none	none
Examples	alfalfa	brewers' grains	canola/ rapeseed	cattle, swine, poultry feeds	barley
	poppyseed*	corn meal	cottonseed		domestic buckwheat
		cotton	domestic mustard seed	corn/ maize	fababeans
		fishmeal	flaxseed	canola/ rapeseed meal	field beans
		hay	safflower seed		lentils
		rice bran	soybean		millet
			sunflower seed		oats
					peanuts peas rice rye screenings sorghum triticale wheat
					wheat bran, shorts, middlings

* Essential

Table 15 Equilibrium moisture content and percentage wet basis of grains, and other materials (after Hall 1980; Henderson 1985; Kreyger 1972; Löwe and Friedrich 1982)

Material	Temperature (°C)	Relative humidity(%) 40	50	60	70	80	90	100
Grains								
Barley	25	9.7	10.8	12.1	13.5	15.8	19.5	26.8
Buckwheat	25	10.2	11.4	12.7	14.2	16.1	19.1	24.5
Cottonseed	25	6.9	7.8	9.1	10.1	12.9	19.6	
Field beans								
flat small white	25	9.6	11.0	12.6	15.0	18.1*		
dark red kidney	25	9.6	10.7	12.5	15.0	18.6*		
Flaxseed	25	6.1	6.8	7.9	9.3	11.4	15.2	21.4
Oats	25	9.1	10.3	11.8	13.0	14.9	18.5	24.1
Peas (green)	25–35	9.7	11.3	13.1	15.3	19.3	27.2	
Poppy (opium)	25–35	5.9	6.9	8.0	9.5	11.7	17.0	
Rice (whole grain)	25	10.9	12.2	13.3	14.1	15.2	19.1	
Rye	25	9.9	10.9	12.2	13.5	15.7	20.6	26.7
Shelled corn	25	9.8	11.2	12.9	14.0	15.6	19.6	23.8
Sorghum	25	9.8	11.0	12.0	13.8	15.8	18.8	21.9
Soybean	25	7.1	8.0	9.3	11.5	14.8	18.8	
Wheat								
soft red winter	25	9.7	10.9	11.9	13.6	15.7	19.7	25.6
hard red winter	25	9.7	10.9	12.5	13.9	15.8	19.7	25.0
hard red spring	25	9.8	11.1	12.5	13.9	15.9	19.7	25.0
durum	25	9.4	10.5	11.8	13.7	16.0	19.7	26.3
Other materials								
Alfalfa hay	26	6.6	8.3	10.0	13.0	14.5		
Bran	21–27				14.0	18.0	22.7	38.0
Linseed cake	21–27				13.5	17.5	23.5	40.5
Oat straw	29	7.6	8.5	10.9	11.5	14.5		
Pig feed pellets	25	9.4	10.6	12.2	14.0	17.0	22.7	
Broiler pellets	25				13.0			
Dairy cattle pellets	25				13.0			

* Unreliable because of mold growth

to 810 t. Commonly, a carlot is withdrawn from filled bins to remove any out-of-condition pellets near the surface. Later in the season the bin is topped up with more pellets for long-term (9 months) storage. Aeration is sometimes used to cool stored pellets. A pipe is installed at the top of sealed bins for the addition of nitrogen gas to maintain pellet quality and to extinguish fires. For transportation, it is essential to use tight railcars (National Fire Protection Association 1981).

Appearance: Pellets made from first-cut alfalfa are usually much greener and contain more weed seeds than those made from second-cut-alfalfa.

Storage problems: Dehydrated alfalfa pellets have a history of heating problems and are difficult to handle once severe heating or fire occurs. In several recent cases in Canada the following procedures were used after heating was discovered:

- The bin was opened up but oxygen gas present in the air stimulated the incipient fire, which produced smoke and heat and resulted in a severe loss of product.
- The bin was aerated but the pellets were in an advanced stage of heating and the plant burnt down.
- The bin was flushed with nitrogen gas but fire restarted when the product was moved.
- The bin could not be unloaded because the internal auger was clogged. A hole was cut at the base of the bin for placement of an external auger. The external

auger then clogged, and a workman who tried to clear it with a stick was thrown back and injured.

Anticipate problems with stored alfalfa pellets by constantly monitoring pellet condition, using sealed bins with inlet pipes for carbon dioxide or nitrogen gas addition, in case of fires or, ideally, storing the pellets under nitrogen gas or some other inert gas. Once the fire is out, removal of heated pellets from bins is achieved by using a front-end loader to lift the metal sheets at the base of the bin, then augering the product from the resulting pile.

Case history: In September 1987 smoke and steam was observed coming from the roof ventilator of an 810-t bin of alfalfa pellets at a plant in western Canada. The pellets had been in storage from 1 to 2 months, during which time bin temperatures were not monitored. A decision was made to remove any undamaged pellets by cutting two ground level apertures in the walls at opposite sides of the bin. After 100 t of pellets were removed an explosion occurred, displacing the ventilator and pellet inlet pipe and damaging the roof strakes (Fig. 19*a*, 19*b*). The accompanying fire blackened the walls and roof above the level of the pellets (Fig. 19*c*). The fire was controlled by adding water through the top opening and by removing hot material through the larger (225 x 130 cm) aperture. Later, another hole was made in the wall to allow access by front-end loader. All pellets were damaged by smoke or fire.

Management practices used

- Pellet moisture content determinations were taken after drying and were allegedly about 10%.
- Pellets were removed periodically through a vacuum pipe attached to the lower bin wall and added through the roof inlet pipe.
- Pellets were removed by cutting apertures in bin walls with an oxyacetylene torch.
- Fire was controlled by adding water under pressure through the top vent from an aerial ladder and by removing burnt and smoldering material through the wall apertures.

Correct procedure

- Pellets should have been screened before storage in order to remove fines and waste, to improve airflow, and to reduce fire risk.
- Moisture contents should have been determined on periodic loading samples to obtain information on maximum moisture content and likely hazards.
- Moisture content and temperature of the binned stocks should have been carefully monitored at intervals and data recorded for future reference.
- Thermocouples should have been installed in the bin.
- Stocks should have been aerated to even out temperature and moisture gradients.
- Inlet pipes for CO_2 or N_2 gas addition should have been installed on the bin for pellet storage or fire control.
- Professional advice should have been sought when smoke was first noticed.
- Fire should have been extinguished by blanketing with CO_2 from above through the 15-cm diameter inlet pipe and through other small holes drilled in the walls.
- The bin should have been sealed to keep out air and provision made for gas pressure release.
- Water should not have been added to the burning stocks, as oxygen may be introduced creating explosive conditions (National Institute for Occupational Safety and Health 1985).
- Bin contents should have been left to cool off before removal.
- Holes should not be cut in the wall when the material is smoldering because of oxygen introduction, favoring fires and explosions (Fig. 18*c*).
- Holes should be cut with a metal cutting saw, not a cutting torch unless the structure is empty (Harvestore® Products 1982).

Barley (*Hordeum vulgare* L.)

Relative storage risk: Low

Moisture content standards:

Dry: up to 14.8%

Tough: 14.9–17.0%

Damp: over 17.0%

Safe storage guidelines: The maximum moisture content for safe storage of barley is 13% for 1 year and 11% for 5 years (Hall 1980). Barley containing 10.3–12.1% initial moisture content and having a temperature of 22–35°C was kept in good condition with no increase in free fatty acids in Manitoba farm bins for 3 years (Sinha and Wallace 1977). Barley seeds stored for 18 months in a laboratory at and below 13.2% M.C. were not invaded by fungi, according to Tuite and Christensen (1955). Seeds just above and below 14% M.C., however, were invaded by *Aspergillus restrictus*, a slow-growing member of the *A. glaucus* group of spoilage molds, after several months. Burrell (1970) has delimited the moisture content-temperature combinations at which mold spoilage and mite problems may be expected in barley over a 32-week period under UK farm conditions. He showed that high-value malting barley needed to be dried down to 12% M.C. and cooled to avoid risk of mite infestation.

Drying guidelines: Maximum safe drying temperatures are 45°C for barley required for seeding or malting purposes, 55°C for commercial use, and 80–100°C for feed (Friesen 1981). However, the preference of maltsters in Canada is that barley intended for malting should not be dried by the producer.

Degrading factors: Barley seed is degraded when it contains fire-burnt, heated, or rotted kernels or has a heated or fire-burnt odor. Barley is graded *Sample* if it contains over 0.5% fire-burnt seed or has a fire-burnt odor, if it contains over 10% heated seed and has a distinctly heated odor, or if it contains more than 10% pure rotted kernels. When both heated and rotted kernels are present they are considered in combination.

Appearance of heated kernels: The hull over the germ is discolored often to a golden brown color. When the hull is removed by pearling (mechanical dehulling), the germ appears red or brown. As the degree of heat damage increases, a greater portion of the pearled kernels shows the mahogany-red to brown coloration.

Storage problems: Freshly harvested grain with a moisture content above 14% may heat and go out of condition. Only a moderate development of spoilage molds is needed to destroy the germination ability of barley and give it a musty odor. Barley that is to be used for seed or malting purposes requires close watching and special care in storage (Dickson 1959). Any detectable rise in temperature of malting barley is regarded as an indicator of trouble (Christensen and Kaufmann 1972). Table 16 indicates the estimated number of weeks for decreased germination to occur in 11–23% M.C. barley stored at 5–25°C (Kreyger 1972).

Spoilage of moist barley (23–40% M.C.) may occur in sealed and unsealed silos and in structures containing acid-treated grains. Air may enter airtight tower silos during top reloading as grain is removed from below, resulting in molding and heating (Nichols and Leaver 1966). In unsealed concrete-staved silos spoilage occurs in the uppermost grain when the top seal of wilted grass and plastic sheeting is inadequate or when less than 7.5 cm of feed is removed each day (Lacey 1971). Spoilage can also occur in high moisture barley treated with propionic and other acids when inadequate acid is used, and when condensation occurs, diluting the acid treatment.

Case histories: 1. In Greece, barley with an average of 13.5–14.5% M.C. was stored in silos at a brewery. The contents of one silo heated to 40°C and seed germination was reduced due to the activity of spoilage fungi in the *Aspergillus glaucus* group. The problem was how to prevent spoilage, heating, and loss of seed germination in barley received from farms at variable moisture contents and temperatures. The plant was equipped with aeration equipment, but when it was used condensation occurred in the bins, aggravating the situation. The problem was solved by turning the barley to evenly distribute seed moisture and temperature (De Vries, pers. com. 1985).

2. During the prolonged wet fall of 1977 in western Canada considerable amounts of grain were piled on the ground prior to artificial drying and binning. The ecological changes occurring within the piles were studied over a period of time. One 6-week-old sprouted barley pile was found to have ecological habitats favoring development of particular fungi. Samples from the south and west of the pile, warmed by the sun, had the most *Alternaria* (a field fungus), a very low *Penicillium* level, and low carbon dioxide levels; samples from the north and east of the pile had the highest levels of *Aspergillus glaucus* group species; and samples from the centre of the pile had a low level of *Alternaria*, a high level of *Penicillium*, a trace of *A. glaucus*, higher seed moisture, and lower germination (Mills and Wallace 1979).

3. A self-unloading lake ship filled with barley was moored overwinter in Montreal harbor. In the spring, the contents of one hold were severely spoiled and heated,

Table 16 Estimated number of weeks for decreased germination to occur in stored barley (after Kreyger 1972)

Moisture content (wet basis) (%)	11	12	13	14	15	16	17	19	23
Storage temperature (°C)	Maximum safe storage (weeks)								
25	54	39	25	16	9	5	2.5	1	–
20	110	80	50	32	19	10	5	2	0.5
15	240	170	100	65	40	20	10	4	1
10	600	400	260	160	90	50	21	8.5	2
5	>1000	1000	600	400	200	120	50	17	4

with strong off-odors and steam rising from the cargo. Red hot fused chunks and free water were present in the lower bulk. The problem was traced to a continuously lit lamp in the hold.

Barley malt (*Hordeum vulgare* L.)

Malt is germinated, kilned, and aged barley.

Relative storage risk: Low

Safe storage guidelines: Malt is kilned in a current of hot dry air and is stored with or without the removal of dry and brittle culms. Dry malt is stable in storage because it has a low moisture content varying, according to type, from 1.5 to 7%. Unlike barley, it is readily crushed (Briggs 1978). Considerable volumes of malt are shipped from Europe and North America to breweries abroad. Some of the strongly hygroscopic malt spoils in transit when exposed to moist conditions. Caking of malt by spoilage fungi on arrival at a brewery in Nigeria was investigated by Okagbue (1986). Problems associated with occurrence of the field fungus *Fusarium* and the storage fungus *Aspergillus versicolor* on malting barley are described by Christensen and Meronuck (1986).

Case history: In March 1983, prepared malt of 4.2% M.C. was binned in a concrete silo at a malting plant in western Canada. About 5 weeks later three carlots of the prepared malt were removed from the silo, sampled, and found to contain traces of burnt malt. The affected bin was partially unloaded and both heated and unheated malt was discharged. The heated malt varied in moisture content from 7.0 to 10.4%. Hot spots were also present. The problem was traced to a heavy rain about the time of loading when the bin was one-third full. Water had drained from a large open area into the basement and entered the bin via a bucket elevator and a conveyor belt. Subsequently, the bin was loaded with more malt until it was filled.

Brewers' and distillers' grains

Brewers' grains, or *spent brewing grains*, are the insoluble residues from brewed malt; *distillers' grains* are the residues from the manufacture of alcoholic beverages distilled from grains.

Relative storage risk: High risk of fire with overdried brewers' and distillers' grains.

Moisture content standards: In Canada no moisture content standards are delimited for dried or undried material, but the manufacturer is required by the *Feeds Act* to state the maximum moisture content present.

Safe storage guidelines: Brewers' grains normally contain about 11% water by weight and are either sold wet and used directly as feed for stock, or dried. The dried grains are either used directly as fodder or incorporated into feed mixes. When dried brewers' or distillers' grains are stored in large quantities, spontaneous fires sometimes occur. Dry brewers' grains react exothermally with dry oxygen or air. The generation of heat is caused by oxidation of the natural oil present in the grains (Walker 1961). The National Fire Protection Association (1981) states that dried brewers' and distillers' grains need to be maintained between 7 and 10% M.C. and require cooling below 38°C before storage. The Association also states that it is very dangerous to dry the grains below 5% M.C. According to Snow et al. (1944), the safe moisture content levels for distillers' grains are 11% (equivalent to 72% R.H.) for 3 months storage, and 9.8% (65% R.H.) for 2–3 years storage, at 15.5–21°C.

Canola/rapeseed (*Brassica campestris* L.; *B. napus* L.)

Canola is the term used in Canada for low erucic and low glucosinolate content *Brassica campestris* and *B. napus* cultivars. The term *rapeseed* is used outside Canada to describe all *B. campestris* and *B. napus* cultivars but refers in Canada only to high erucic acid types. The storage behavior of canola and rapeseed is similar.

Relative storage risk: Moderate

Moisture content standards:

Dry: up to 10%

Tough: 10.1–12.5%

Damp: over 12.5%

Safe storage guidelines: Extreme care is needed to safely store canola/rapeseed seed because the upper moisture content limit of so-called dry seed is currently 10.0%. This is too high for long-term safe storage, as growth of spoilage fungi in the *Aspergillus glaucus* group occurs at 70% R.H., which is equivalent to 8.3% M.C. at 25°C. If the seed is binned at above 25°C, or if pockets of immature seeds or green weed seeds are present, a seed moisture level of even 8.3% is too high for long-term safe storage. As a rule of thumb, bin canola at a maximum of 8.0% M.C. for storage longer than 5 months. The chart shown in Fig. 1 predicts the keeping quality of canola/rapeseed seeds for a 5-month period, given varying temperature-moisture relationships (Canola Council of Canada 1981; Mills and Sinha 1980). If the temperature or the moisture content of the harvested seed falls within the spoilage area of the chart, the grower must take steps to reduce one factor or both. To ensure safe storage, the following steps are recommended:

- Bin at least 1.5 percentage points below the 10.0% cut off.
- Use an efficient deflector under the auger to spread the heavier, moister, green material and fines away from the core.
- Clean the seeds as soon as possible.
- Use an aeration unit to quickly cool the seed to 5°C or 0°C for the winter-holding period.
- Monitor the seed temperature every few days during the fall and every 2 weeks during the winter.

Re-auger non-aerated seed after it has been stored for 3–5 days to break up any pockets of green weed seeds and dockage that might facilitate heating, and to create an inverted cone to allow air

Figure 17 *a*, discoloration due to visible molds on surface of red kidney bean; *b*, aggregation or clumping of canola seeds by mold mycelium with two seeds visible in cross section; *c*, badly bin-burnt (charcoal black) and undamaged (brown) canola seeds.

Figure 18 *a*, effects of flood water on a bin of wheat in Manitoba with the swelling grain causing shearing of panel bolts and bin collapse; *b*, fire in a wooden elevator in Alberta with unburnt grain (arrows), flowing through fire-weakened walls. About 85% of the grains were salvaged despite total elevator destruction; *c*, canola oil made from severely heat-damaged canola seeds (dark bottle), from the same seeds but later decolorized, and undamaged canola seeds (clear bottle), respectively.

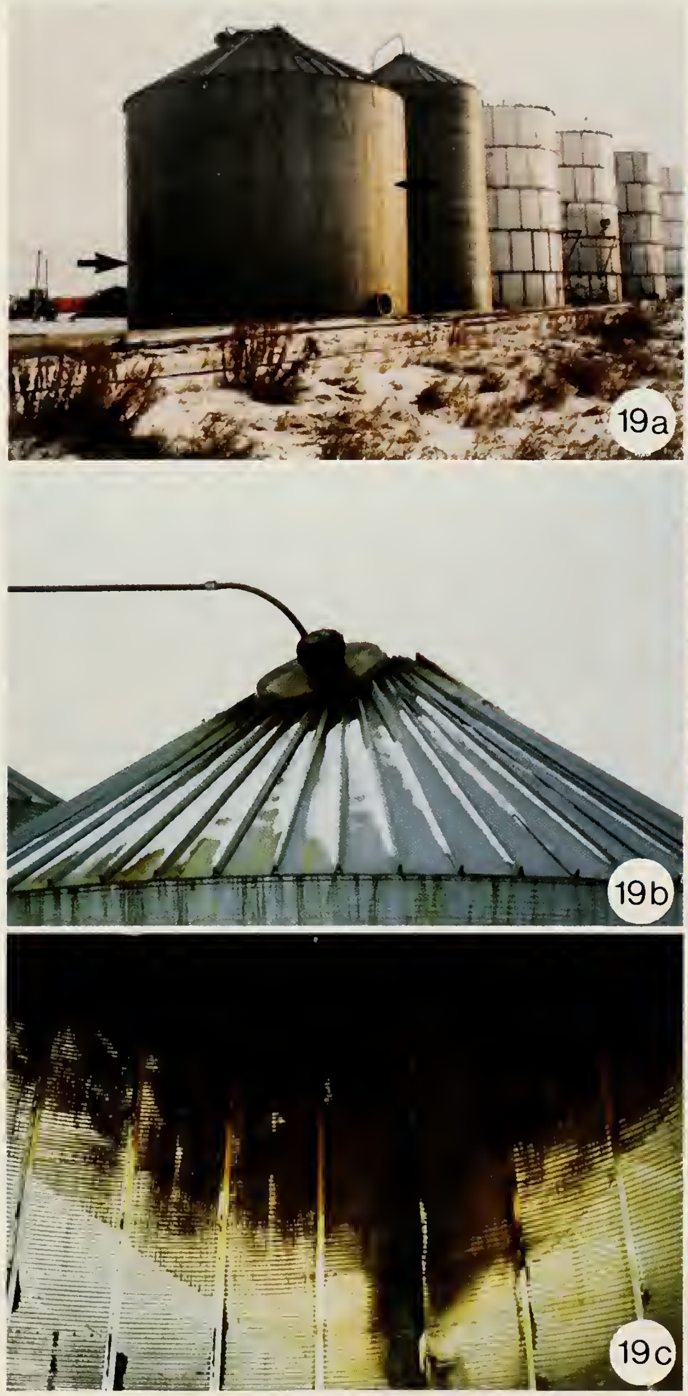

Figure 19 Effects of a fire in binned alfalfa pellets: *a*, explosion damage to roof apex, fire damage above wall opening (arrow), and brown distillate on walls (arrow); *b*, explosion damage with displacement of roof cap, ventilator, inlet pellet pipe, and distortion of roof strakes; *c*, fire damage to interior walls directly above removed wall panel.

Figure 20 Effects of a fire in binned fababeans: *a*, brown distillate leaking through seams onto ground; *b*, soot deposits within aeration duct; *c*, ash residues and undamaged beans as comparison.

Figure 21 Effects of spoilage and heating in binned flax: *A* and *B*, collapse of bin after partial removal of contents by auger; *C*, fused lumps of severely heated and moldy seeds with ashes of totally burnt seeds from inside bin.

to penetrate. Canola/rapeseed is more vulnerable than barley to pest infestation when stored in farm bins (Sinha and Wallace 1977).

Drying guidelines: The maximum drying temperatures are 45°C for canola/rapeseed intended for seeding purposes and 65°C for commercial use, providing the seed is not dried below 7.5% M.C. When canola/rapeseed is exposed to heat for a long period, as in non-recirculating bin dryers, it is advisable to use temperatures 5° to 10°C lower than those listed for commercial use. This is because the oil quality is affected by long exposure to high temperatures (Friesen 1981). Damaged seeds undergo a reduction in oil quality because of the marked rise in level of free fatty acids (Nash 1978).

Degrading factors: Canola/rapeseed is degraded when it contains heated, bin-burnt, or fire-burnt seed and/or has a heated or fire-burnt odor. Canola/rapeseed is graded *Sample* if it contains over 2.0% heated seed and/or has a distinctly heated odor, or if it has a fire-burnt odor.

Appearance of heated seeds: Seeds are crushed in strips of 100 seeds (Canola Council of Canada 1974) to determine the extent of heating. Heating is classified into three categories: *charcoal black* (badly bin-burnt), *dark chocolate brown* (distinctly heated), and *light tan* (slightly damaged from oxidation). Limits of heat-damaged seeds specified in statutory grades apply to charcoal black and/or dark chocolate brown seeds. Samples containing light tan seeds are carefully checked for odor, including both the bulk of the sample and the freshly crushed seed strips. If an odor is present, or if in combination with black or brown crushed seeds, the light tan seeds are considered as heated. In the absence of these symptoms, the light tan seeds are classed as damaged.

Charcoal black (Fig. 17*c*) and dark chocolate brown canola seeds when crushed produce a dark canola oil (Fig. 18*c*).

Storage problems: Canola/rapeseed goes through a period of active respiration after binning. If the heat and moisture of respiration is not quickly removed, mold growth and respiration soon occurs. To counteract the situation, aerate or turn the stocks as soon as possible.If some or all of the stocks are of higher seed moisture content, the seeds need to be dried, then aerated. ***Do not consider stored canola to be similar to stored wheat because, unlike wheat, adverse changes can occur very rapidly.***

Drying problems: A mass of stored canola/rapeseed is much denser than that of a stored cereal grain, and has a higher resistance to air movement. Two to three times more static pressure is required to force drying air through canola than through wheat. Since the designs of most dryer fans do not allow for changes in the air pressure produced, the result is lower airflow when drying canola. Less airflow means less energy required to heat the air to the selected drying temperature. Readjust the temperature when going from a cereal grain to canola during drying operations, because the lower airflow means longer drying times and the subsequent possibility of a temperature buildup (Canola Council of Canada 1981).

Molding and heating can occur exceedingly quickly in moist canola/rapeseed, and where this happens the seeds are likely to stick together (Fig. 17*b*). The result is that the value of the stored product for processing is greatly reduced because of a marked increase in the level of free fatty acids, probably associated with mold growth (Nash 1978). Burrell at al. (1980) determined the amount of time available for drying rapeseed before the appearance of surface molds at five temperatures and seven moisture levels. They found that seed clumping preceded the appearance of visible fungal colonies, but that germination was affected much later. For example, seeds at 25°C and 10.6% M.C. clumped after 11 days. Visible fungal colonies appeared after 21 days but germination was still unaffected after 40 days.

Case histories: 1. In August 1976 a farmer in the interlake area of Manitoba filled a 68-t bin with rapeseed. The rapeseed, combined on an extremely hot day, went into storage at 8.5–9.0% M.C. In late October, a hot spot was discovered at the centre of the bin, extending down about 120 cm from the top surface. The hot weather threshing produced a lot of fines, which had accumulated at the bin centre. The heating from the already warm rapeseed was compounded by the large amount of fines. On discovery, the heated material was immediately removed; the remainder of the contents was stored without incident. To prevent similar problems from reoccurring the farmer installed an aeration system, activated by a humidistat at relative humidities of 40% or less. Aeration took place from the moment the first seed entered the bin until winter, when it was switched off. A digital temperature probe was also purchased to check the bin contents every few days in the fall and 2 weeks in winter. No subsequent storage problems were encountered (Lyster 1978).

2. In the fall of 1985, a farmer near Winnipeg, Man., filled a 64-t bin with canola. During the winter of 1985 spoilage and heating occurred. The stocks could not be unloaded by the inbuilt auger at the base of the bin due to clogging by aggregated seeds. The problem was solved by removing the dry, free-flowing seed above the aggregated material by vacuum aspiration (Fig. 11) through the top vent, and then removing the aggregated material in the same manner. The farmer used a 12.5-cm diameter flexible hose and a portable 52 220-W 70-hp vacuum unit. It took 6 hours to totally unload the bin.

3. In 1975 a wooden boxcar filled with tough and damp rapeseed was sent to the drying plant at one of the terminal elevators. Unfortunately, the car was mislaid in a siding for 3 months and when it was opened the contents were a very light gray color and disintegrated when touched. The contents of the car had heated to the ashing point and had no salvage value, as nothing

could be saved. The wooden walls of the car were unharmed. (NB. The presence of blackened seeds would have indicated incomplete combustion of the car contents.)

Canola/rapeseed meal (see definitions and usage of terms under Canola/rapeseed)

Relative storage risk: Moderate to low

Moisture content standards: Pellets are guaranteed not to have more than 11% moisture content by the manufacturer.

Safe storage guidelines: The safe moisture content levels for meal storage are 7% at 30°C or 9.5% below 25°C, for 1 year (White and Jayas 1988). Discoloration of the meal from yellow-green to brown occurred at 50°C, 10% M.C., in 1 month. Meal stored at 10.4% and 11.5% M.C. at 40°C, and at various moisture contents from 6.3 to 11.5% at 50°C, discolored after 3 months.

Storage problems: Oil, hexane, and other solvents that remain in meals and pellets after oil extraction are fire and explosion hazards during ship transport. Permissible levels of oils and residual solvents are regulated by the Canadian Coast Guard (1984). Solvent-extracted canola/rapeseed meal and pellets that contain not more than 4% oil and 15% oil and moisture combined, and that are substantially free from flammable solvent are exempt from the regulations on provision of a certificate from a recognized authority.

Cattle, swine, and poultry feeds

Formulations for complete feeds and for custom feeds are used for meals, pellets, and crumbles. Formulations are complex with many ingredients, including corn and/or other cereals, oilseed meals such as soybean, fats such as tallow, mixed vitamins, minerals, and other additives.

Relative storage risk: Moderate to low

Moisture content standards: There is no labeled moisture content requirement in Canada for cattle, swine, or chicken feeds containing more than one ingredient.

Safe storage guidelines: Avoid extremely low or high moisture content (National Fire Protection Association 1981); keep moisture content levels between 10 and 14%. This range is considered safe for storage of animal feeds by industry. Moisture content is of concern to manufacturers because of its effects on the efficiency of the pelleting process and how it affects storage of pellets. Look for excessive heating occurring during grinding of cereals prior to pelleting and during pelleting of certain feed concentrates containing high levels of proteins and animal fats.

Precautionary practices for storing and utilizing meals and pellets include watching for uneven flowability of feed indicating moisture uptake and incipient spoilage; looking for moisture migration and mold development affecting feed at the top and sides of the bin; checking for leaks through missing bolt holes, and poorly welded joints, and so forth; purchasing feeds according to usage, that is, not letting feeds sit for long periods; never putting new feed on top of old feed; and always cleaning out bins thoroughly when empty, preferably followed by a wash down in dilute Chlorox® solution to kill mold spores. Henderson (1985) examined the moisture content-equilibrium relative humidity (M.C. – E.R.H.) relationships at 5, 15, and 25°C of three pig meals and pellets made mostly from barley meal and wheatings with various proportions of soybean meals, and found that they were similar. The moisture content in equilibrium with 70% R.H. at 25°C was about 14%, similar to that for cereal grains. For most practical purposes, the M.C. – E.R.H. relationships of barley, wheat, and animal feeds containing 80% or more of cereal products, such as the pig feeds, can be regarded as similar. However, if the animal meal contains more than 18% of an oilseed such as soymeal it may be expected that the E.R.H. would be higher and a lower safe storage moisture content would be required.

Clancy (1979*a*, 1979*b*) gives the storage characteristics (moisture content, flowability, compaction properties, bulk density, and hygroscopicity) of some feedstuffs under UK conditions. The products described include cottonseed and groundnut pellets, coconut flakes, soybean meal, beet pulp pellets, grass cubes, fats, and molasses. Feedstuffs containing high amounts of molasses have poor flowability. Hamilton (1985) describes the problem of molding, and factors influencing the activity of fungi and antifungal agents, in poultry feed.

Case history: As a result of self-heating, a smoldering fire developed within a large silo in West Germany that contained animal feed pellets (Dinglinger 1981). Initially, fire fighters attempted to fill the headspace above the feed with carbon dioxide (CO_2) foam, but CO_2 concentrations in the workrooms at the silo base reached levels far above maximum allowable levels for safety. When attempts were made to empty the silo only the lower part could be cleared. A bridge had formed at a height of 15 m in the vicinity of the fire pocket, leaving about 150 t of feed pellets suspended in the upper part of the silo. In order to collapse the bridge, a hole about 50 cm in diameter was drilled. Because the discharge chute at the base of the silo could not be closed off completely, a strong convection current developed inside the silo, sucking enough air from leaks to keep the fire burning. A nozzle was mounted on the discharge chute (see Fig. 14) through which nitrogen gas (N_2) was fed into the silo from a supply unit and a normal fire-fighting hose. After N_2 purging, the oxygen gas (O_2) content in the silo at the source of the fire was reduced to 7%, thus suffocating and slowly cooling down the fire and reducing risks to fire fighters. Because of the low O_2 content in the silo, there was never a danger of a dust explosion occurring if the bridge had collapsed while the silo was being emptied. A total of 18 000 M^3 of N_2 were used during the entire process, which lasted 10 days.

Corn/maize (*Zea mays L.*)

Relative storage risk: Moderate - low

Moisture content standards:

Dry: up to 15.5%

Tough: 15.6–17.5%

Damp: 17.6–21.0%

Moist: 21.1–25.0%

Wet: over 25.0%

The maximum moisture content limits for grades (US) 1, 2, 3, 4, and 5 yellow, white, or mixed corn are 14.0, 15.5, 17.5, 20.0, and 23.0%, respectively (United States Department of Agriculture 1978).

Safe storage guidelines: The effect of moisture and temperature on allowable storage time for corn is given by Friesen and Huminicki (1986). Corn stored at 22% M.C., for example, will keep at 27°C for about 5 days, at 19°C for 10 days, at 13°C for 20 days, at 7°C for 40 days, and at 4°C for 60 days. The maximum moisture content for safe storage of corn is 13% for 1 year and 11% for 5 years. In shelled corn an intergranular relative humidity of 70% equilibrates with 14.0% M.C. at 25°C (Table 15) (Hall 1980). In Ontario, because of low winter temperatures, corn can be safely stored at 15% M.C. over the winter and spring if aerated properly. A moisture content of 13–14% is required for storage to late summer, and 11–13% for storage over several years. High moisture corn for animal feed is stored at moisture contents between 22 and 32% M.C. (Morris et al. 1981).

Drying guidelines: The maximum drying temperatures are 45°C for seed, 60°C for commercial use, and 90–100°C for feed (Friesen 1981). According to Morris et al. (1981) the critical maximum temperatures for drying of grain corn harvested at 28% M.C. in Ontario are 45°C for seed, 70°C for starch milling, 90°C for other industrial uses and non-ruminant feed, and 120°C for cattle feed. Drying corn is essential when harvested above 18% M.C. unless it is placed in airtight storage, preserved in propionic or other acids, or frozen (Campbell et al. 1977). Dryer damage to protein (case hardening) in corn diminishes its value for wet milling by rendering the separation of starch and protein more difficult (Freeman 1980).

Degrading factors: Corn is degraded when it contains fire-burnt, heated, or rotted kernels or has a fire-burnt, smoke, or heated odor. Corn is graded *Sample* if it contains fire-burnt kernels and/or has a fire-burnt or smoke odor, if it contains over 3% heated kernels or has a heated odor, or if it contains over 3% rotted kernels.

Appearance of heated, rotted, and blue-eye-molded kernels: *Heated kernels* include whole kernels or partial kernels that are either discolored by natural fermentation or severely scorched by artificial drying, and display a color range of amber to dark brown over the entire kernel. The germs are brown and severely damaged kernels have a puffed appearance, especially in the germ area. *Rotted kernels* are whole kernels or pieces of kernels that show advanced stages of decomposition and feel spongy under pressure. Samples are degraded according to established grade tolerances for heat- and rot-damaged kernels. Blue-eye-molded kernels have dark germs and when peeled show mold development. Corn that contains over 15% of kernels affected by blue-eye mold is graded *Sample*.

Storage problems: Corn is prone to breakage during handling and after drying at too high a temperature and drying rate (Tuite and Foster 1979; Hohenadel 1984). As a result, broken corn foreign material (BCFM) is increased and constitutes a storage hazard. When corn is loaded into bins from above, the BCFM collects in the central core or spout line. Spoilage may begin in the spout line partly because the fines, which consist mainly of fragments of corn endosperm, are more susceptible than whole kernels to invasion by storage fungi, and partly because insects and mites thrive in the fines and promote the growth of such fungi (Christensen and Sauer 1982).

Corn is prone to spoilage during transport by river barge and by ocean freighter from North and South American ports (Christensen and Kaufmann 1978; Milton and Jarrett 1969). In the United States, substantial amounts of corn are shipped from the midwest during cold weather to warmer southern states either for local consumption as animal feed or for export. Spoilage occurs on board ship because of a combination of factors (Tuite and Foster 1979). On arrival at New Orleans and other Gulf ports the corn is usually already infected by storage fungi, mainly *Aspergillus glaucus*. It picks up at least 0.1–0.2% M.C. from the humid air, and has a substantially increased level of BCFM due to the numerous handlings en route. The likelihood of spoilage is further enhanced by shipment at 15.5 to 16.0% M.C. and a lack of effective aeration on board ship. Corn shipped to the tropics or subtropics is particularly vulnerable. The storage life of corn is rapidly decreased with increased temperatures and increased

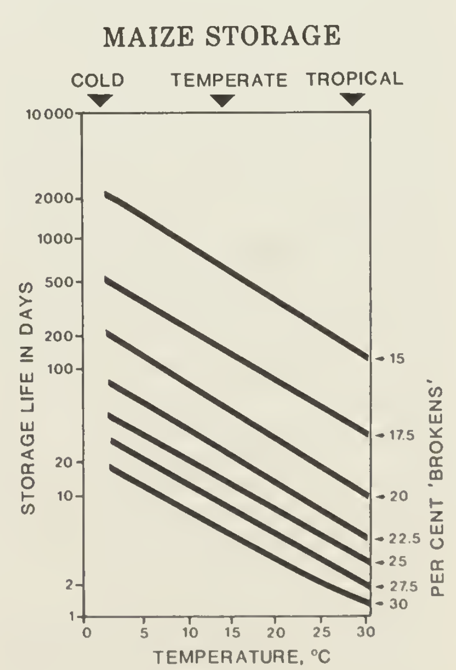

Figure 22 Storage life of maize in different environments (after Calverley and Hallam 1982).

breakage levels (Fig. 22) (Calverley and Hallam 1982). Spoilage and heating occur also in corn shipped from Argentina to Europe; the factors involved have been studied in detail by Milton and Jarrett (1969).

Aggregation of high moisture corn due to mold activity may cause blockage of augers and other components of grain handling systems. Uneven pressure effects can be created, resulting in total or partial bin or system collapse.

Drying problems: There is less trouble with drying corn than with small grains or oilseeds, because of its lower resistance, which reduces temperature variations in hot-air plenums. Stress cracks and "moisture rebound" may cause problems because of the large amount of water removed. These problems can be reduced by slowing down the drying rate after the corn reaches 18% M.C., using a slower cooling rate, or using dryeration (Campbell et al. 1977).

Case histories: 1. In March 1981, 10 000 t of yellow corn was shipped from North America via the St. Lawrence Seaway to Mali through the West African ports of Dakar and Abidjan. About 5000 t was unloaded at each port and transported inland by road and rail. Of the original consignment, only 5000 t was fit for human consumption by the time it reached its final destination. The changes that occurred in transit have been followed in detail by Calverley and Hallam (1982). According to the export certificate, the corn had 15.3% M.C. and 4.6% BCFM at loading. At Dakar the corn, now at E.R.H. 70% at 22°C (monthly daily mean temperature at Dakar), was shipped by rail in early June and was received inland without problems. At Abidjan the corn, now at E.R.H. 77% at 28°C, was mostly spoiled. Although some was transported inland, none was used for human consumption. The spoilage was aggravated by changes in temperature, breakage at loading, breakage at off-loading, and rough handling during inland transport. The situation was further compounded at Abidjan because natural ventilation in the bagged stacks was reduced by the high levels of BCFM, and a thick covering of dust on the bags.

2. In November 1982, a cargo of 9000 t of white dent maize was shipped by freighter from East London, South Africa to Liverpool, England. En route, fire was discovered in the cargo and the ventilators of the affected hold were sealed. On arrival in Britain the hatch was further sealed, gas extraction equipment temporarily employed, the unaffected cargo in the other holds removed, and 17 t of carbon dioxide (CO_2) added at intervals. The CO_2 contained the fire but the temperature continued to increase, indicating that the fire was spreading and increasing in intensity. Another 1.5 t of CO_2 was added and the cargo was unloaded by mechanical grabs. The fire only became visible later and was extinguished by 79.3 m^3 medium expansion foam and 140 t of water. The fire was attributed to heat from an unlagged section of main engine exhaust ducting, causing corn in the adjacent hold to overheat (Darby 1973).

For other case histories see Christensen and Meronuck (1986).

Corn meal

Relative storage risk: High

Safe storage guidelines: Corn meal usually contains an appreciable quantity of oil, which has a rather severe tendency to heat. Material should be processed carefully to maintain safe moisture content and to cure before storage (National Fire Protection Association 1949). The advised maximum moisture content for safe storage of corn meal is 11.5% at temperatures up to 27°C (Muckle and Stirling 1971).

Cotton bales (*Gossypium hirsutum* L.)

Relative storage risk: High

Safe storage guidelines: The myriad of small fibers that make up the cotton bale and cover its surface make it particularly vulnerable to sources of ignition as well as to rapid combustion. Fire in baled cotton has its own peculiarities, which demand respect and consideration if a large loss is to be avoided. Fires have been known to start in cotton that has been stored for months in inaccessible parts of warehouses. This cotton is often referred to as *cold cotton*. Fire has also been packed into a bale of cotton, at the gin, and the bale has been received, weighed, and placed into storage without the fire having been detected. This type of bale is known as a *fire-packed gin bale*. Bales involved in warehouse and yard fires have even flared up several days after it was thought the fires had been extinguished. Fire is considered to be extinguished in a bale 5 days after proper techniques have been used to put out the original fire. The best defense against fires is a well-maintained sprinkler system and good housekeeping, which includes setting up clean, wide aisles between the stacked bales.

Recommended procedures for fighting fires are as follows:

Fires in baled cotton in warehouses:

- Close all doors and cut off all drafts in the compartment concerned. This should be done whether the warehouse is sprinklered or not. Drafts not only provide fresh air to the fire, they also blow heat away from the fire, thus setting off more sprinkler heads where they can do no good.
- Give the sprinklers a chance to operate by not using the private hose system until the fire has been knocked down unless the system is not working or not controlling the fire.
- Let the sprinkler system do its job and vacate the premises if the fire cannot be controlled with inside equipment. This is because fire in baled cotton can flash over the storage with almost explosive violence.
- When the fire is under control by the sprinklers open the compartment door only enough to use the hose or to remove the cotton. The smoldering bales

should be moved outside as soon as possible, where they can be given individual attention.

- Use a spray or fog nozzle, not a solid hose stream. The force from a solid stream can scatter the burning wads of cotton over a wide area, thus spreading the fire.

Fire-packed gin bales:

- Understand how fires occur. During the ginning operation, any stones, pieces of metal, or other foreign objects in the seedcotton that strike the metal parts of the gin can cause sparks and ignite the fibers. Sometimes a fire immediately bursts forth, but often the smoldering cotton becomes incorporated into bales. Usually, the fire burns through to the outside of the bale within a few hours or days, and its presence is detected by smoke or smell.

- Store all suspicious bales in the open at least 1 m from other such bales and keep them under constant surveillance for a minimum of 5 days.

- Wet hot areas immediately they are detected, using water containing a wetting agent.

- Remove burned cotton by hand but do not remove bands from the bale, as this exposes more cotton fibers to ignition.

Fires in cotton yards:

- Apply water ahead and downwind of the fire, then work toward it.

- Look for fire under the bales.

- Be alert for flying sparks.

- Remove uninvolved cotton nearby and make a fire break with it.

- Remove burned cotton to segregated area.

The foregoing recommendations are abstracted from an excellent report by Baker (1963).

Cottonseed (*Gossypium hirsutum* L.)

Relative storage risk: Moderate

Moisture content standard: For the U.S. Quality Index, prime cottonseed is prescribed as containing no more than 12% moisture (Whitten 1981). Maximum moisture labeling is required.

Safe storage guidelines: In cottonseed, an intergranular R.H. of 70% at which molds could be expected to appear, equilibrates with 10.1% M.C. at 25°C (Table 15) (Hall 1980). For storage over several months, cottonseed should be below 10.0% M.C. and not above 10–15°C. Deterioration of cottonseed may begin in the field, particularly 10–15 days after the bolls have opened. Under ideal weather conditions the moisture content decreases at this time from 50% to 10% but if wet weather conditions prevail, delaying harvest, free fatty acid (FFA) levels increase. Cottonseed entering storage with a FFA content above 2.5% deteriorates much more rapidly than seed with 1% FFA. The rate of deterioration increases considerably at higher temperatures (Gustafson 1978).

In the United States, cottonseed is stored for 120 to 130 days (Whitten 1981), usually in flat metal-type warehouses equipped with aeration and temperature detection systems (Gustafson 1978). Cottonseed of questionable keeping quality is processed soon after arrival at the mill. Seed containing over 12% M.C. may heat unless steps are taken to cool the seed. With close control it is possible to store seed containing 10–11% M.C. and 2.5–5% FFA. Take extreme care when storing high fatty acid seed above 10% M.C. This seed heats in pockets and seed temperatures must be observed daily to ensure that the seed cools selectively; otherwise the entire mass may char (Whitten 1981).

High moisture content has a decisive effect on the respiration of cottonseed and mold development, which results in self-heating and charring. Self-heating may reach elevated levels, for instance, 95°C (Navarro and Paster 1978).

Case histories: 1. In Israel, cottonseed harvested during the 1978 season was stored in a Muskogee-type storage structure that contained 500 t of seed. The temperature of the cottonseed rose to 270°C due to self-heating. Tests were done on samples of cottonseed taken from different locations in the bulk. The moisture content of undamaged cottonseed was 7.2%, that of seed in the first stage of the heating process was 13.6%, and that of seed found in the hottest spot was 2.8%. The loss in weight of damaged cottonseed in the hot spot was 55.4% of that of undamaged seed. Free fatty acids of cottonseed in an advanced stage of self-heating reached 21.9%, whereas an increase in percentage of oil content was recorded. The observations indicated that the spontaneous heating was caused by movement of moisture within the bulk and failure of the aeration system in the storage structure (Navarro and Friedlander 1979).

2. Cargoes of cottonseed pellets on arrival in northwestern Europe from West Africa commonly have as much as 20 t of congealed and moldy pellets covering the surface due to condensation. This crust, sometimes 30 cm thick, has to be removed and discarded at considerable expense. The problem could be minimized if pellets were shipped in ventilated containers in which the air is changed five times per hour (Clancy 1979*a*). Similar problems occur with groundnut (peanut) pellets.

Domestic buckwheat seed (*Fagopyrum esculentum* Moench)

Relative storage risk: Low

Moisture content standards:

Dry: up to 16.0%

Tough: 16.1–18.0%

Damp: over 18.0%

Safe storage guidelines: A moisture content of 16% is considered safe for storage.

Buckwheat is usually swathed when 75% of the seeds have turned brown. However, since ripening is rarely uniform, some green seeds are usually present at harvest. The influence of storage regime and cultivar on lipid content, fatty acid composition, and sensory quality of buckwheat seed has been investigated by Mazza (1988).

Drying guidelines: The maximum drying temperature is 45°C for buckwheat intended for either seeding purposes or commercial use (Friesen 1981).

Degrading factors: Buckwheat is degraded to *Sample* if it contains distinctly heated or fire-burnt kernels and/or has a distinct fire-burnt or heated odor.

Domestic mustard seed

Yellow	(*Sinapsis alba* L.)
Brown	(*B. juncea* (L.) Cosson)
Oriental	(*B. juncea* (L.) Cosson)

Relative storage risk: Moderate

Moisture content standards:
Dry: up to 10.5%

Tough: 10.6–12.5%

Damp: over 12.5%

Safe storage guidelines: Mustard seed requires careful storage in a tightly sealed bin. Growers are advised to store seed at levels under 10% to minimize the risk of spoilage, and to use a deflector inside the bin to spread heavier, immature material, which is most prone to heating, away from the centre of the bin (Campbell et al. 1977).

Drying guidelines: The maximum safe drying temperature is 45°C for seed required for either seeding purposes or commercial use (Friesen 1981).

Degrading factors: Domestic mustard seed is degraded when it contains heated or bin-burnt seed and/or has a distinctly heated odor. Domestic mustard seed is graded *Sample* if it contains over 1.0% heated seed and/or has a distinctly heated odor.

Appearance of heated seeds: Seeds are crushed in strips of 100 seeds (Canola Council of Canada 1974) to determine the extent of heating. Heating is classified into three categories: *charcoal black* (badly bin-burnt), *dark chocolate brown* (distinctly heated), and *light tan* (slightly damaged from oxidation). Limits of heat-damaged seeds specified in statutory grades apply to charcoal black and/or dark chocolate brown seeds. Samples containing light tan seeds are carefully checked for odor, including both the bulk of the sample and the freshly crushed seed strips. If an odor is present, or if in combination with black or brown crushed seeds, the light tan seeds are considered as heated. In the absence of these symptoms, the light tan seeds are classed as damaged.

Fababeans (*Vicia faba* L. var. *minor*)

Relative storage risk: Low

Moisture content standards:
Dry: up to 16.0%

Tough: 16.1–18.0%

Damp: over 18.0%

Safe storage guidelines: The maximum recommended moisture content for storing sound fababeans is 16% in Canada (Evans and Rogalsky 1974) and 15% in Britain (United Kingdom Ministry of Agriculture, Fisheries and Food 1970). Fababeans of 14.2% M.C. that had not undergone frost damage were safely stored for 2 years in Manitoba by Wallace et al. (1979). Low-quality, frost-damaged beans that had been overwintered and had a moisture content above 15% often heated during the following summer.

Drying guidelines: Drying at a maximum of 32°C is recommended. Drying should be done in two stages if more than 5% M.C. is to be removed to attain a 16% storage M.C. Allow a few days between each stage to permit internal moisture to move to the surface. Do not dry beans rapidly at high temperatures because this cracks the seed and reduces viability (Campbell et al. 1977). The beans may also become overdried on the outside and underdried within. Underdried beans result in a pasty meal, which on prolonged storage becomes rancid and heated. At drying temperatures above 40°C, the skin wrinkles or splits, particularly with high moisture beans. Avoid cracking the testa, as microorganisms can then gain entrance and cause rotting (Nash 1978).

Degrading factors: Fababeans are degraded when they contain heated and/or rotted beans, or have a distinctly heated or musty odor. Entire beans and pieces of beans are considered in the grading. Fababeans are graded *Sample* if they contain over 1% heated and/or rotted beans, or have a distinctly heated or musty odor.

Appearance of heated and rotted beans: Heated and/or rotted fababeans are those which are materially discolored as a result of heating or rotting. Seed coats are dark brown to black, and the cotyledon tissue on dissected beans is either tan or brown.

Storage problems: Beans are normally combined when the pods are black and the haulms have shriveled. Because water loss is slow from the thick fleshy pods and large seeds, a prolonged period of ripening and drying may be required before combining, particularly in cool climates. If the crop is harvested too soon, the beans in the topmost pods will be immature. They will also be higher in moisture content than those in lower pods. Because of problems associated with prolonged ripening, late harvesting, frost damage (Wallace et al. 1979), and prolonged drying, fababeans are frequently binned in a nonuniform state and consequently need to be carefully monitored during storage.

Case history: In October 1979 a farmer in western Manitoba noticed steam coming from the top of one of his 270-t bins containing fababeans that had been harvested in 1978. The bin was fitted with a perforated floor and a detachable aeration unit. The beans had been initially stored at an average of 15.5% M.C. during cold weather the previous November. Heating in the bin was observed for the first time on 28 September 1979. After noticing the steam, the farmer switched on the aeration unit to suck cold night air through the beans to reduce their temperature. During the night, flames were seen coming from the housing that connected the aeration unit with the bin. The fan was then turned off. Five days after the fire the fababeans within the bin were partially cooked. Steam was coming out of the open roof hatch and a brown liquid was running out of the rivet holes at the join between the roof and bin wall. Two days later at least 90 L of the liquid had collected on the ground (Fig. 20*a*). The air temperature in the air space (Fig. 20*b*) under the perforated floor, determined by a thermocouple probe, was 260°C at a distance of 180 cm from the bin wall. The temperature within the bean mass above must have been higher but this could not be determined because of the difficulty of access. The outside bin wall was cool to the touch. Ominous bubbling and hissing sounds could be heard from within the bin and a strong, burnt, organic smell was noticeable at a distance of several hundred metres from the bin. Since no salvage was possible, the bin contents were left to smolder and eventually become converted to ash (Fig. 20*c*) (Mills 1980). Heating of the fababeans occurred in two stages: (1) a slow biological heating associated with deterioration, and (2) a rapid chemical heating, which was accelerated by aeration.

Management practices used

- Samples for moisture content determinations were taken from the trucks by probe.
- The Halross 919 moisture meter that was used was checked against a similar machine in a local elevator and found to register 0.04 higher.
- Beans were turned three or four times during the winter of 1978–1979 but not subsequently.
- Beans were aerated only on the night of the fire, 4 October 1979.
- Fire was extinguished by switching off the fan.
- Bin contents were left to smolder.

Correct procedure

- Beans should have been cleaned, aerated, or dried to several percentage points below 16.0% M.C. to provide a safety margin for moisture increases by translocation during winter months.
- Moisture content and temperature of the binned stocks should have been carefully monitored at intervals and data recorded for future reference.
- Moisture contents should have been determined on several samples from each load to obtain information on maximum moisture content and likely hazards.
- Thermocouples should have been installed in a bin this large (270 t) to indicate any abnormal rise in temperature caused by molds and bacteria.
- Stocks should have been aerated and/or turned at regular intervals to even out moisture and temperature gradients and reduce biological heating.
- Material known to be in an advanced stage of heating should not have been aerated.
- Farmer should have obtained professional advice on how to handle the heating problem, which was detected 7 days prior to the fire.

Field beans
(*Phaseolus vulgaris* L.)

This heading includes white pea beans, also known as white beans or navy beans (most important), light and dark red kidney beans, black beans, pinto beans, pink beans, small red beans, Great Northern white beans, yellow eye beans, and cranberry beans.

Relative storage risk: Low

Moisture content standards:
Dry: none
Tough: none
Damp: over 18.0%

Safe storage guidelines: A moisture content of 18% or less is recommended for safe storage of field beans (Campbell et al. 1977). For long-term storage, a moisture content of 18% is too high, even at 5°C for beans required for seeding purposes (Table 17) (Kreyger 1972). The maximum moisture content for safe storage of pea beans for up to 1 year is 17.0% (Hall 1980). Beans should be harvested when most of the pods are dry and the beans have hardened but before the seeds begin to shatter. The optimum moisture content for combining beans is 16–18%. At moisture content levels lower than this, damage can be severe and costly, as broken or cracked beans can only be used for livestock feed (Campbell et al. 1977).

Drying guidelines: Drying is necessary when beans are harvested damp because of poor weather or because of excessive harvesting losses due to shattering. Maximum drying temperatures for beans are 27–32°C. Dry beans slowly and, if necessary, remove excess moisture in two stages (see section on fababeans). Great care must be taken during drying; otherwise splits develop, even at relatively low temperatures, and hairline cracks, a degrading factor, increase at elevated temperatures. During drying keep the relative humidity of the heated air above 40% (Campbell et al. 1977; R. Stow, pers. com. 1986).

Degrading factors: Beans are degraded when they contain heated or moldy beans (Fig. 17*a*), or have a heated or distinctly musty odor. Beans are graded *Sample* if they contain over 1% heated beans or have a heated or distinctly musty odor, or if they contain over 1% moldy beans. Moldy beans are characterized by the presence of dark blue exterior molds that have

Table 17 Estimated number of weeks for decreased germination to occur in brown beans (after Kreyger 1972)

Moisture content (wet basis) (%)	11	12	13	14	16	18	20.5	23
Storage temperature (°C)	Maximum safe storage (weeks)							
25	31	22	16	11	7	4	2	0.5
20	55	40	28	19	13	7	3.5	1.5
15	100	75	50	30	20	12	6	3
10	200	140	95	60	38	20	11	4.5
5	370	270	170	110	70	39	20	9

developed in crevices on machine-damaged beans, and yellow to black interior molds that have developed in the concave centre area common to light and dark red kidney beans.

Appearance of heated kernels: Heated pea beans have a dull-colored seed coat varying from cream to mahogany. The color is more intense in the hilum area. Cotyledons vary in color from tan to dark brown when viewed in cross section. Very light cotyledons are classed as damaged rather than as heated. Heated light and dark red kidney beans have a dull, dark red to black seed coat. Beans must be split to determine the degree and intensity of heat damage.

Storage problems: Mechanical handling damage is a problem which becomes more severe at low temperature and moisture levels. To reduce damage, wherever possible use belt conveyors or front-end loaders rather than augers when handling beans. Avoid dropping beans from excessive heights, particularly onto concrete floors (Campbell et al. 1977).

Fishmeal

Relative storage risk: There is high risk with cargoes from Chile, Peru, and South Africa but less risk with cargoes from the Northern Hemisphere.

Moisture content standards: The moisture content standard is set between 6 and 12% in South Africa (Anonymous 1983*a*). In Canada, no levels are delimited but the manufacturer is required by the *Feeds Act* to state the maximum moisture content present in the product.

Safe storage guidelines: According to Snow et al. (1944), at 15.5–21°C, the safe moisture content levels for fishmeal are 11.5% (equivalent to 72% R.H.) for 3 months storage and 9.9% (65% R.H.) for 2–3 years storage. In 1983, South Africa produced a set of guidelines for carriage of fishmeal in ships' holds. The fat content should not exceed 11%, the product should be stored for at least 21 days before loading, and at loading the moisture content should be between 6% and 12%. Finally, the bags should have sufficient space around the rows in the hold to permit dispersal of heat generated within the stow. Fishmeal has recently been successfully carried in bulk in ships' holds under an inert gas blanket and as pellets treated with an antioxidant agent; however, there are problems with both methods and most of the fishmeal in international trade is still carried in bags (Anonymous 1983*a*).

Storage problems: Fishmeal carried in bags tends to heat when subjected to pressure stacked in ships' holds. Heating causes damage to the bags, a reduction in protein value, and self-ignition of cargo. It can also cause damage to the ship. In the early 1960s there were a number of incidents involving self-ignition of Peruvian and Chilean fishmeal cargoes. The high fat content of anchovies in the meal rendered the commodity particularly susceptible to self-ignition. Introduction of the new guidelines has reduced the number of such incidents in recent years.

Case history: Persistent fires occurred in a cargo of Chilean fishmeal held in the lower holds of the M.V. *Luise Bornhofen* in December 1982. The vessel, enroute to China, was diverted to Honolulu, and the crew spent 6 weeks discharging damaged and heated cargo. The self-heating of Chilean fishmeal cargoes occurred in three other vessels en route to China or Japan in January 1983. Tests on bagged fishmeal in the M.V. *Luise Bornhofen's* holds revealed that the fat content was below the accepted maximum for carriage in bags. To date, it is not known whether these latest incidents happened because of a relaxation in stowage standards or because of some other entirely new set of circumstances (Anonymous 1983*a*).

Flaxseed (*Linum usitatissimum* L.)

Relative storage risk: Moderate

Moisture content standards:

Dry: up to 10.0% (from 1 August 1988)

Tough: 10.6%–13.5%

Damp: over 13.5%

Safe storage guidelines: The maximum recommended moisture content for storage of flaxseed is 10.0%. However, for long-term storage, flaxseed for seed purposes at 10.5% M.C. requires cooling to 10°C or lower (Kreyger 1972). For more than 6 months storage at above 20–25°C the maximum moisture content must not exceed 10% anywhere in the bulk (Christensen and Kaufmann 1969). Harvested seed must be stored under dry conditions, because flaxseed is coated with a mucilaginous substance that becomes very sticky when wet. If flaxseed is stored in a tough or damp condition or is exposed to rain or snow, severe caking of the seed can occur, rendering it unfit for sale (Daun 1982). Flaxseed respires much more vigorously than cereals do in the 11–17% M.C. range (Bailey 1940), and when binned in a moist condition it will heat very quickly within a few days. For example, at 14% M.C. and 25°C, there was a marked production of carbon dioxide after 8 days and the presence of molds after 10 days (Larmour et al. 1944).

Drying guidelines: The maximum drying temperatures are 45°C for flaxseed required for seeding purposes, 80°C for commercial use, and 80–100°C for feed (Friesen 1981).

Degrading factors: Flaxseed is degraded when it contains fire-burnt or heated kernels, or has a fire-burnt or heated odor. Flaxseed is graded *Sample* if it contains over 10% heated seed or has a heated or fire-burnt odor.

Appearance of heated kernels: Heated kernels are usually shiny brown or black in appearance. When they are cut open, the color of the pulp is dark tan, orange, or dark brown, depending upon the severity of the damage. Severely heated kernels often have a heated odor.

Storage problems: Flaxseed harvested damp can produce deadly hydrogen cyanide (hydrocyanic acid, prussic acid) in the bin. Hydrogen cyanide is a very fast-acting poison, which can be absorbed through the skin (Bond 1984). Before entering a bin containing flax stored at high moisture levels or with a large proportion of sprouted or damaged seed make sure that the bin is thoroughly ventilated and that other persons are available if help is needed. In 1977, a Minnesota elevator worker died from hydrogen cyanide poisoning when he jumped into a bin of flaxseed. The hydrogen cyanide was generated by the seed, which had sprouted in the field before threshing and had been binned at a high moisture content (Western Producer 1977). In 1941, again in Minnesota, levels of up to 0.03% carbon monoxide (300 parts per million (ppm)) were found in the interseed air of *Sample* grade flaxseed in commercial storage (Ramstad and Geddes 1942). A useful account of spoilage problems occurring in stored flaxseed in Minnesota and North Dakota is given in Christensen and Kaufmann (1969).

Case history: Near Winnipeg, Man., in October 1985, an unaerated, wooden-floored 127 t metal bin on wooden skids was filled with flaxseed. Seeds from the same field were also put into an adjacent aerated 254 t metal bin built on a concrete base. The unaerated bin was 6 m from ground level to eave and strengthened by vertical angle irons; at binning, the seeds in the upper 1.8 m of the bin were at 11.3% M.C. Five months later, in March 1986, seed was removed by auger from the lower porthole of the unaerated bin. After 5 t of seed had been removed, the auger became clogged, and the lower part of the bin adjacent to the porthole collapsed (Figs. 21*a* and 21*b*). After flaxseed had been removed from the top 1.8 m of the bin, a solid crust, hot to the touch and with visible steam, was uncovered. Much adherent fines and pod debris was present on the bin walls. Beneath the crust was a large volume of fused, charcoal black, and aggregated moldy seeds. The producer was able to save 24% of the binned seeds in good condition; of the remainder, 40% was less than 25% heated, 6% was 50% heated, and 30% was totally unusable and discarded (Fig. 21*c*). All the aerated flaxseed was disposed of in good condition (Wilkins 1986). The structural problem here is denting, a condition caused by eccentric unloading (Jenike 1967); it is not a floor problem (G. Henry, pers. com. 1986).

Management practices used

- Probe samples for moisture content determinations at the elevator were obtained but only from the upper 1.8 m of the bin.
- Samples taken at similar locations during the winter failed to detect adverse smells or heating.
- After the bin had collapsed, the wall near the lower porthole was supported with a front-end loader bucket.
- A hole was cut in the upper bin wall to permit removal of good flaxseed at the top of the bin.
- Flaxseed was shoveled to the hole by the producer.
- Initially, no ventilation was provided, but later, roof sheets were removed and a 50-cm diameter fan was installed at the apex to provide cross ventilation.
- Crusted material was broken up with a rototiller and the bin was cut in half and lifted off to permit removal of fused material.

Mistakes made

- Moisture content determinations were not done on representative samples during loading of bin.
- Only the top 30% of the contents were monitored.
- The air space above the binned flaxseed was inadequate, yet unaccompanied entry was made without safety ropes and without adequate ventilation on entrance.

- The producer reacted immediately; he should have asked for professional advice before taking any action.

Correct procedures

- The bin should have been erected with provision for aeration.
- A spreader could have been used to disseminate plant debris and fines; however, spreaders are of low capacity and tend to densify the grain, thus they may be a disadvantage when aerating.
- Thermocouples should have been installed vertically through the bin centre.
- Several loads should have been augered into trucks, then re-added to the top of the bin; removed material should have been examined for heating.
- Deep probe samples should have been taken from the lower part of the bin.
- Persons entering the bin should have been wearing protective clothing and a safety harness, and should have been under strong cross ventilation.
- At least one other person should have been in attendance.

Hay

Relative storage risk: High

Safe storage guidelines: The maximum moisture content for safe storage of hay is 20–25% for 1 year and 15–20% for 5 years (Hall 1980). Wet or improperly cooled hay is almost certain to heat in hot weather. Baled hay seldom heats to a dangerous level, and it should be kept dry and cool for safe storage (National Fire Protection Association 1949). Quality changes that occur in hay during storage, including heating and non-enzymatic browning, are summarized by Moser (1980). Wet hay or dry silage (30–50% M.C.) may heat and result in considerable nutrient loss. In normal situations, a rise in temperature to about 50°C should not be alarming, since a temperature rise occurs in the sweating process. If the temperature reaches 60°C, the drop in feed value is of concern. The higher the temperature, the higher the oxidative losses and the most easily digested nutrients are oxidized first. Table 18 outlines the heating process in wet hay or dry silage (Moser 1980).

Lentils (*Lens esculenta* Moench)

Relative storage risk: Low

Moisture content standards:

Dry: up to 14.0%

Tough: 14.1–16.0%

Damp: over 16.0%

Safe storage guidelines: Once lentils are swathed they require 7–10 days to dry, depending on the weather, but they should not remain in swaths for a long period or they will become discolored. The acceptable moisture content for stored lentils is 13.5% or less. Efforts are under way to raise the upper limit of dry seeds to 16.0% M.C. similar to that of other pulses.

Drying guidelines: Natural air drying of lentils has several advantages over heated air drying, including the elimination of stress cracks, a reduction in augering resulting in less cracking and chipping, and less supervision. Proper design of a natural air drying system is critical; spoilage and heating may result if inadequate airflow is used (Manitoba Agriculture 1986). In heated air dryers, the maximum recommended drying temperatures for seed required for seeding and feeding purposes are 38–40°C. Corresponding maximum plenum temperatures are 60–65°C. Higher temperatures can harm germination and give off a roasted odor and taste (F. Beaudette, pers. com. 1986).

Degrading factors: Lentils are degraded when they contain heated seeds, or have a heated or musty odor. Lentils are graded *Sample* if they contain over 1% heated seeds, or have a heated or distinctly musty odor. *Samples* that contain distinctly heated seeds with brown to dark brown meats are degraded according to established tolerances. Samples that contain lightly damaged seeds with tan-colored meats are classified as heated if a distinct odor is present; otherwise they are classified as damaged.

Storage problems: If lentils are stored until the spring their thin seed coating may peel when handled. This results in the product being downgraded; consequently the crop is usually moved by Christmas.

Meals, pellets, and cakes

Relative storage risk: Very high to low, depending on the product.

Moisture content standards: In Canada, manufacturers are required to state the maximum moisture content on bags containing certain single-ingredient feeds, for example soybean meal. Labeling the maximum moisture content on bags containing mixed feeds and pellets is not a requirement. In Germany, the Feed Laws prescribe a moisture content of 14.0% for feed pellets (Löwe and Friedrich 1982).

Safe storage guidelines: The safe moisture content for processed feeds is usually taken as that in equilibrium with a maximum of 70% R.H., the level at which molds begin to grow. Safe moisture contents for selected feeds are shown in boldface in Table 15, assuming a storage period of up to 1 year and an absence of mites. If mites are present, then the safe moisture content is that in equilibrium with 60–65% R.H., as mite populations tend to die out or remain static in numbers at this relative humidity (Henderson 1985). Table 19 lists the major pellet, meal, and cake exports from Canada in 1985 (Statistics Canada 1985). In order of importance these are dehydrated alfalfa; canola/rapeseed oil cake and meal; dairy and cattle feeds; wheat bran, shorts, and middlings; pelleted screenings; brewers' and distillers' grains; and fishmeal. The storage behavior of these products is described under separate topic headings in the text.

Storage problems: Moisture and heat migration caused by extremes of temperature occur within pelleted

Table 18 Steps in the heating of stored wet hay or dry silage

Temperature (°C)	Processes	Nutrient changes
Ambient–40	Normal "sweating," possible cell respiration, limited microbial action. Some fermentation may take place.	Excess moisture driven off. Very little respiration loss.
40–50	Normal "sweating," microbial action, plant processes stop at 45°C. Some fermentation may take place.	Excess moisture continues to be driven off, very little respiration loss.
50–60	Thermophilic microorganism activity. Non-enzymatic browning begins.	Lowered digestibility and protein availability.
60–70	Thermophilic microorganism activity, increased oxidative reactions. Non-enzymatic browning continues.	Further lowering of digestibility and protein availability.
70–80	Biological activity ceases. Strictly chemical oxidative reactions. Above 80°C, temperatures may rise very rapidly. Severe non-enzymatic browning, caramelization of sugars.	Very high losses in digestibility and protein availability.
80–280	Oxidative reactions occur rapidly due to high temperature.	Charring of forage. Large dry matter loss.
280–300	Oxidative reactions continue.	Possible ignition if ample oxygen is present.

Source: Moser, L.E. 1980. Crop quality, storage, and utilization. Reproduced by permission of the American Society of Agronomy and the Crop Science Society of America.

and other granular materials, particularly when silos are not insulated. Temperature changes in a silo can occur because of fluctuating daytime and nighttime temperatures or because of the effect of the sun shining on one wall in conjunction with lower temperatures on the shaded side. They can also occur when inadequately cooled, recently made, pellets are stored or shipped under cold prairie conditions. Moisture migration leads to pockets of moisture accumulation, mold development, and eventually spoilage problems. Löwe and Friedrich (1983) in West Germany simulated the effect of the sun shining on one side of a large silo filled with pig pellets. Condensed water accumulated at the surface and at the outer walls, and spoilage occurred after 1 week. The molds clumped the pellets, impeding their flow and later their transportation. Even before any visible molds were evident, the flow characteristics declined because the pellets picked up moisture and became swollen and softened. A decline in flowability of pellets is indicative of moisture changes, and possibly also of mold and mycotoxin development.

Long-term hang-up, rat hole, and bridging problems frequently occur in silos that contain meals, screenings, pellets, and other finely divided materials. Examples of hang-ups recently removed from silos in the USA and Canada include corn screenings, corn gluten pellets, wheat middlings, bran, ground milo, soybean meal, cracked bean hulls, oat husks, and multiple screenings (B. Cartright, pers. com. 1986).

Heating problems in stored meals and pellets are caused by hot metal fragments and/or molasses being present in the meal (Fire Protection Association 1978), moisture migration, and the poor compressibility of hot (exceeding 150°C) outer layers of pellets (Friedrich 1980).

Oats (*Avena sativa* L.)

Relative storage risk: Low

Moisture content standards:

Dry: up to 14.0%

Tough: 14.1–17.0%

Damp: over 17.0%

Safe storage guidelines: The maximum moisture content for safe storage of oats is 13% for 1 year and 11% for 5 years (Hall 1980). A moisture content of 13% equilibrates with a relative humidity of 70% at 25°C (see Table 15). At

Table 19 Summary of pellet, meal, and cake exports from Canada in 1985 (Statistics Canada 1985)

	Main importing countries in order of their trading importance									
Commodity	Japan	USA	South Korea	Ireland	Taiwan	Indonesia	Norway	Britain	Dollar value per tonne	Total dollar value (all countries)
Alfalfa, dehydrated	1(5)	3(2)			2(2)				147.0	43 197 000
Canola/rapeseed, oil cake, and meal	3(3)	1(4)	4(3)		6(3)	2(3)	5(3)		128.7	39 620 000
Dairy and cattle feeds	2(3)	1(4)							217.4	24 204 000
Wheat bran, shorts, middlings	2(3)	1(4)	3(2)						118.1	16 044 000
Pelleted screenings	1(4)	2(2)	3(2)	4(2)					77.0	13 567 000
Brewers' & distillers' grains and other solubles		1(3)							116.1	11 447 000
Fish meal		2(2)			1(2)			3(1)	220.0	4 463 000
TOTAL										152 542 000

(1) very small (<5000 t)
(2) small (5000–25 000 t)
(3) moderate (25 000–100 000 t)
(4) large (100 000–200 000 t)
(5) very large (>200 000 t)

this relative humidity level, mold development slowly begins; therefore for long-term storage the moisture content should be below 13% M.C. to allow for anticipated moisture and temperature changes. If aeration is used, then 13% M.C. is safe for long-term storage. If oats contain more than 14% M.C. when binned they tend to become musty or heat-damaged due to mold activity. This markedly reduces their feed value and may make them unfit for use as food (Stanton 1959). At moisture contents between 15 and 17%, oats should be cooled to 15 and 5°C, respectively, to prevent mold development during medium-term (45 weeks) seed storage (Kreyger 1972).

Safe storage limits are similar for both hulled and hull-less oats at relative humidity levels below 90% (equivalent to 18.5% M.C. at 25°C), although the hull-less oats are more susceptible to mite infestation. At moisture contents in equilibrium with 90% R.H. or higher, hull-less oats are more vulnerable to infection by spoilage molds and decreased seed viability than hulled oats (Sinha et al. 1979). Levels of hydrolytic rancidity occurring in stored hulled and hull-less oats were investigated by Welch (1977). The level of hydrolytic rancidity was found to increase at higher moisture contents and with longer storage periods, but the level in hull-less oats only exceeded that in hulled oats if the grain was severely bruised.

Drying guidelines: The maximum drying temperatures are 50°C for oats required for seeding purposes, 60°C for commercial use, and 80–100°C for feed (Friesen 1981).

Degrading factors: Oats are degraded when they contain heated, fire-burnt, or rotted kernels, or have a heated, distinctly musty, or fire-burnt odor. Samples containing heated and rotted kernels are degraded numerically up to a combined maximum of 10%. Oats are graded *Sample* if they contain over 10% heated kernels, over 10% purely rotted kernels, over 0.5% fire-burnt kernels, or if they have a heated, distinctly musty, or fire-burnt odor.

Appearance of heated and rotted kernels: Heated oats that have been dehulled have a discolored germ or an orange or brown groat. Severely heated oats have a heated odor and/or a distinct brown or orange hull. Rotted oats are dark gray or black, and are spongy to the touch.

Storage problems: Instances of self-heating in oats are rarely reported. Self-ignition occurred in an elevator bin that contained oats (Grain Dealers Mutual Insurance Company 1961), and in a bin that contained wet oats (Bowes 1984). Levels of temperature, carbon dioxide, microflora, and so forth in stored oats harvested under wet fall conditions were monitored by Mills and Wallace (1979). Maximum levels attained in outdoor piles were 32°C (ambient 12°C) and 15.5% CO_2, and in bins 37°C (ambient –4°C) and 2.0% CO_2.

Peanut/groundnut (*Arachis hypogaea* L.)

Relative storage risk: Low

Safe storage guidelines: The advised maximum moisture content is 9% for unshelled peanuts and 7% for shelled peanuts at temperatures up to 27°C (Muckle and Stirling 1971). In shelled peanuts (groundnuts) an intergranular relative humidity of 70% equilibrates with a moisture content of 7% at 25°C (Pixton 1982). Peanuts differ from cereals, pulses, and oilseeds in that the flowers are fertilized above the ground and the developing fruit bend down and develop in the soil. Peanut kernels can thus be invaded by aerial molds, terrestrial molds, and intermediate molds, including *Aspergillus flavus*, both above and below ground (Martin 1976).

Drying guidelines: The maximum temperature for safe drying according to Hall (1980) is 32°C for peanuts intended for either seeding or commercial use, but Muckle and Stirling (1971) recommend a maximum temperature of 37°C for seed.

Storage problems: Careful harvesting and storage procedures are required to reduce fungal infection by *Aspergillus flavus* and the development of aflatoxins (Martin 1976). The degree of toxin production has been reduced by artificial drying (Jackson 1967).

Self-heating, promoted by the presence of damaged nuts and moisture, sometimes occurs when peanuts are stored in large stacks. It is often detected by an unpleasant smell given off by the decomposing stocks. To prevent heating, stacks should be limited to 2.4–3.0 m in height and 6.0 m in width. Lanes should be left between the stacks to allow for access in the event of fire. All wet nuts should be thoroughly dried before being stacked. The nuts should be kept dry and the maximum amount of ventilation provided to the storage. In the open, the stacks should be sited in a well-drained position and be protected against ingress of moisture. Where possible, damaged nuts should be kept separate in smaller stacks. Stack temperatures should be monitored at regular intervals. Once heating has reached 80°C, the temperature will likely continue to increase until ignition occurs. Because of this, affected stacks should be opened only after arrival of the fire brigade. Fires are extinguished with water, which should be applied to the seat of the fire and kept away from unaffected stacks (Fire Protection Association 1954).

Peanuts may be damaged by water that condenses on the roof of containers as a result of temperature gradients during shipment. The condensed water drips onto the upper layers, causing spoilage. To prevent such damage, calcium chloride was incorporated into the upper layers of 8.5% M.C. unshelled peanuts held in shipping containers in Israel (Navarro et al. 1982). The moisture content of peanuts in the upper layer of the control (untreated) container increased to 10.2% but dropped to 8.0% M.C. in the container treated with 60 kg calcium chloride. Considerable mold damage occurred in the control containers.

Drying problems: The drying of peanuts presents a special problem because the flavor of the dried product is of major importance (Freeman 1980). For reduction of aflatoxins, fast rather than slow drying has been recommended (Jackson 1967).

Case history: In April 1985, near Bombay, India, a 30–40 t stack of bagged unshelled peanuts was built on the ground and covered with a waterproof tarpaulin. The peanuts, harvested 6 months previously, contained an average moisture content of 8% and the 35-kg jute bags were piled 20–25 high. No spaces were left between the bags and no temperature monitoring of the bags was done. During May, 4 weeks after storage began, the pile was consumed by fire, which originated from within the stack. During storage, the average maximum daily temperature for the area was 38°C and the maximum temperature was 42°C (L.R. Sutar, pers. com. 1986).

Mistakes made

- The moisture content was too high for safe storage at a temperature of 38°C or more, particularly as the moisture content of some of the peanuts was above the average figure of 8%.
- No ventilation was provided to reduce effects of temperature and moisture migration.
- The stack was too large.
- The stack was not monitored for temperature and other changes.

Peas (*Pisum sativum* var. *arvense* (L.) Poir.)

Relative storage risk: Low

Moisture content standards:

Dry: up to 16.0%

Tough: 16.1–18.0%

Damp: over 18.0%

Safe storage guidelines: Peas are harvested when they are mature and hard in the pod. Yellow-seeded cultivars are harvested beginning at 16% M.C. Green-seeded cultivars are harvested at 18% M.C., or higher, to maintain good color, then dried down to 16%, or lower, for safe storage (Manitoba Agriculture 1986).

Drying guidelines: The maximum drying temperatures cited by Friesen (1981) are 45°C for seed required for seeding purposes, 70°C for commercial use, and 80–100°C for feed, whereas Campbell et al. (1977) cite 43°C and 71°C for seed and commercial peas. Temperatures higher than 45°C will harm germination of seed peas, especially green peas.

Degrading factors: Peas are graded *Sample* if they contain over 0.2% heated seeds, or have a heated, fire-burnt, or distinctly musty odor.

Appearance of heated seeds: Heated peas have dull seed coats and discolored cotyledons, ranging in color from light tan to dark brown.

Storage problems: Peas of about 15% M.C. may develop a surface crust during the winter as a result of moisture migration and snow seepage, particularly when they are stored warm without aeration. The seeds tend to clump and if left undisturbed become blackened as a result of mold activity. To prevent clumping, periodically walk across the top of the bin or move the top 30 cm of stocks with a shovel.

Before moving the first load in the spring, examine the top surface of the stocks. If there is any black crust remove it with a shovel; otherwise the first load will be ruined by admixture. Crusting is a particular problem in overfilled steel bins, and it also occurs in stocks stored in Quonset huts. It can be prevented by using a front-end loader to divide the stocks and disturb the surface layers (F. Beaudette, pers. com. 1986). Because of their size and shape peas exert a greater lateral pressure than wheat; therefore if grain bins are also used for storing peas they may require reinforcement (Winnipeg Free Press 1978).

Case history: In late October 1985 a seed plant operator in southern Manitoba unloaded split peas from a 4.3 x 8.2-m bin that contained 54 t of stock. The peas were warm to the touch and about 10% of them had turned brown. They had been harvested 2 months earlier and binned together with pod debris, volunteer material, and weed seeds. Management expressed concern that harmful toxins and molds might be present on the heated peas.

Management practices used

- Practically no management of the pea stocks occurred over the 2-month period.
- Samples were obtained through the bottom of the bin and sent for mold, toxin, and nutritional analyses.

Mistakes made

- The bin was filled to the top, making it difficult to monitor stocks.
- Debris was left with the peas for a prolonged period.
- Moisture content determinations were not made on incoming material and monitoring of pea stocks was not done.

Correct procedures

- Samples of each load should have been taken at binning to determine the range of moisture content present.
- Material should have been cleaned soon after binning, then aerated.
- Peas should have been monitored at regular intervals by probing, checking seed temperature, and running a quantity out and examining it for signs of deterioration.

Poppyseed (*Papaver somniferum* L.)

Relative storage risk: Very high

Safe storage guidelines: Poppyseed is extremely difficult to store, using regular equipment, because it has high levels of lipids and unsaturated oils. Autoxidation occurs very quickly. For example, 2–3 t of poppyseed placed in a truck can self-ignite within 2–3 hours of loading. Because of this problem, poppyseed must be stored under nitrogen in specially designed facilities. Poppyseed is grown in France for the pharmaceutical industry and is stored in a 4400-t facility at La Grande Paroisse, near Paris. On arrival at the storage plant, the seed is at a temperature of about 40°C. It is then cooled for 25 hours to 15°C by air at 0°C. If the seed is not cooled, the temperature can rise from 40° to 75°C within 24 hours. For long-term storage, 350 t sealed empty metal silos, 8 m high, are filled with 100% nitrogen before the poppy seed is added. The O_2 level in each silo when filled is about 2.8%. This level is reduced to a safe 0.8–0.4% 02 during storage, which is from about 20 August to 10 June each year (F. Benit, pers. com. 1985).

Rapeseed (see Canola/rapeseed)

Rice (*Oryza sativa* L.)

Relative storage risk: Low

Safe storage guidelines: Rice is usually combined at a moisture content above safe storage levels; therefore additional drying is required after harvest. In the United States, a moisture content of 12.5% or below is generally considered suitable for rice storage (Kunze and Calderwood 1980). The maximum moisture content for safe storage of rice for 1 year is 13% (Hall 1980). For rough paddy rice the maximum moisture content is 14.0% and for milled rice it is 12.0% at 27°C (Muckle and Stirling 1971). For whole grain rice an intergranular relative humidity of 70%, at which molds can be expected to appear, equilibrates with 14.1% M.C. at 25°C (Hall 1980). A commercial bulk storage system designed for long-term safe storage of rough rice must provide proper aeration to prevent self-heating and maintain the rice grain at a low moisture content (around 13.5% wet basis) to protect it from fungi and insects. Mold growth is inhibited below 21.1°C for rice at 13% M.C. wet basis, and insect activity is considerably reduced below 15.6°C. The operation of aeration systems for bulk storages in high humidity environments calls for the operator's constant attention (Steffe et al. 1980). For information on physical changes occurring in bulk stored rice see Gough et al. (1987).

Drying guidelines: The maximum drying temperature for rice intended for either seeding purposes or commercial use is 43°C (Hall 1980). The maximum drying temperature for paddy rice containing up to 20% M.C. is 44°C. If the moisture content is above 20%, the temperature should be reduced to 40°C (Muckle and Stirling 1971). Grain type affects the drying characteristics: long grain varieties dry the fastest, short grain varieties dry the slowest (Kunze and Calderwood 1980).

Rice bran

Relative storage risk: High

Safe storage guidelines: At 15°C, 12% M.C. equilibrates with 70% R.H. in adsorbing rice bran (Pixton 1982).

Storage problems: Rice bran is particularly susceptible to self-heating because it has a high content of oxidizable oils (National Fire Protection Association 1981). Fires resulting from rice bran self-heating have occurred in at least three ships. In one ship, fires occurred in two separate holds, one fire broke out while the vessel was at sea and the other when the ship was berthed at Avonmouth Docks, England. Steam injection was used to contain the fire at sea. Water was used to extinguish both fires soon after berthing (Anonymous 1966).

Twenty seven to 36 million tonnes of rice bran containing 5 to 7 million tonnes of bran oil are produced worldwide each year. Until recently, rice bran was only used for animal feed, but it is now made in extruded form for human consumption. In the past, millers did not know how to prevent bran enzymes from mixing with bran oil, and this mixing caused the oil to break down rapidly and render the bran inedible for humans. The extrusion process stabilizes the bran by using friction to create heat, destroys the bran enzymes that break down the oil, and allows the oil to be extracted economically. Removal of the oxidizable oils makes the rice bran safer to transport.

Rye (*Secale cereale* L.)

Relative storage risk: Low

Moisture content standards:
- Dry: up to 14.0%
- Tough: 14.1–17.0%
- Damp: over 17.0%

Safe storage guidelines: Because rye matures early in the summer, the moisture content more quickly reaches a safe storage level when compared to wheat or other grains (Shands 1959). To avoid spoilage, the moisture content of rye should not be over 13% (Rozsa 1976). Kreyger (1972) recommends 14% as the maximum moisture content for storage of rye seed. Long-term storage of rye seed at this moisture content requires cooling to 15°C, or less. Mold development occurs rapidly on seeds stored at above 14.0% M.C. For example, visible molds occurred on 15% M.C. seed stored at 25°C after only 4 weeks.

Drying guidelines: The maximum drying temperatures are 45°C for seed required for seeding purposes, 60°C for commercial use, and 80–100°C for feed (Friesen 1981).

Degrading factors: Rye seed is degraded when it contains fire-burnt or heated kernels and/or has a fire-burnt or heated odor. Rye is graded *Sample* if it contains fire-burnt kernels, if it contains over 5% heated seeds, or if it has a fire-burnt or heated odor.

Appearance of fire-burnt and heated kernels: Fire-burnt kernels are charred or scorched. Heated kernels are orange to dark brown, somewhat similar to heated barley, but they are difficult to detect because of color variations among rye samples. Heated rye often has a heated odor and/or other heated cereal grains in the sample.

Safflower seed (*Carthamus tinctorius* L.)

Relative storage risk: Moderate

Moisture content standards:
- Dry: up to 9.5%
- Tough: 9.6–13.5%
- Damp: 13.6–17.0%
- Moist: 17.1–22.0%
- Wet: over 22.0%

Safe storage guidelines: Safflower seed, grown in the drier areas of western Canada and USA, is either crushed and used for oil or used for bird feed. Direct combining is preferred over swathing, and shelling out is not a problem if the crop is harvested at or above 10% M.C. Safflower seed is stored at 9–10% M.C. (Wilkins 1985b). In California, Heaton et al. (1978) showed that increased free fatty acid (FFA) levels occurred in damaged and intact safflower seeds when stored at above 8% M.C. for 2 months. The increased FFA levels were largely due to field fungi. According to Christensen and Sauer (1982), an intergranular relative humidity of 65–70% equilibrates with 5–6% M.C., and a relative humidity of 70–75% equilibrates with 6–7% M.C. in safflower. Growth of *Aspergillus glaucus* spp. occurs at 6–7% seed M.C., and growth of *Penicillium* spp. and other fungi occurs at 10–12% M.C. (equivalent to 85-90% R.H.).

Degrading factors: Safflower seed is degraded when it contains heat-damaged kernels or has a heated odor, or rotted kernels, which are considered in combination with heat-damaged kernels. Safflower seed is graded *Sample* if it contains over 1% heat-damaged kernels or 1% rotted kernels, or if it has a heated odor.

Screenings

Pelleted screenings have a variable composition including, for example, No. 1 and No. 2 screenings from elevators (odd kernels, flax or barley screenings, weed seeds, chaff, and so forth) and/or refuse screenings including dust, molasses, steam, vitamins plus a binder, often ground barley, and sometimes fire-burnt salvaged grains.

Relative storage risk: Low

Moisture content standards: There is no labeled moisture content requirement for pelleted screenings.

Safe storage guidelines: Moisture content levels considered safe for pelleted screenings are 8–10%.

Sorghum (*Sorghum bicolor* (L.) Moench)

Relative storage risk: Low

Moisture content standards: The maximum moisture content limits for grades (US) 1, 2, 3, and 4 for all classes of sorghum are 13, 14, 15, and 18%, respectively (United States Department of Agriculture 1978).

Safe storage guidelines: Sorghum grain, also known as milo, is a cereal grain. Although the sorghum kernels are smaller and more rounded than corn, they have more protein and less fat than corn, and about the same amount of carbohydrates. Sorghum is grown mainly in semiarid regions and is used for human food and for animal feed. In the United States, it is grown for animal feed, mostly in Texas and Kansas. The maximum moisture content for safe storage of grain sorghum is 13% for 1 year and 10–11% for 5 years (Hall 1980). According to Muckle and Stirling (1971), the maximum moisture content for safe storage of sorghum at 27°C is 13.5%, but this figure varies considerably between varieties. In sorghum, an intergranular relative humidity of 70% equilibrates with 13.8% M.C. at 25°C (Table 15) (Hall 1980). In the United States, grain sorghum is harvested from standing stalks with a combine. The grain is physiologically mature when the greenest seeds drop to 35% M.C., but it should not be harvested until the grain has dried to 13% or less moisture unless the grain is to be dried artificially (Kramer 1959). Sorghum is readily stored if the usual management practices for cereals are employed. For more information on sorghum storage see Doggett (1970) and Sorensen and Person (1970).

Drying guidelines: The maximum safe drying temperatures are 43°C for grain sorghum intended for seeding purposes; 60°C for commercial use, and 82°C for feed (Hall 1980).

Soybeans (*Glycine max* (L.) Merrill)

Relative storage risk: Moderate

Moisture content standards:

Dry: up to 14.0%

Tough: 14.1–16.0%

Damp: 16.1–18.0%

Moist: 18.1–20.0%

Wet: over 20%

The maximum permissible moisture content limits for soybean grades (U.S.) 1, 2, 3, and 4 are 13, 14, 16, and 18%, respectively (United States Department of Agriculture 1978).

Safe storage guidelines: In dry fall weather, mature soybeans dry in the field from about 15% M.C. in the early morning to 10% at noon (Holman and Carter 1952). They absorb moisture again during the following night to repeat the cycle the next day. Soybeans can be harvested at a low moisture but only at the expense of added field losses and excessive mechanical damage. These effects can be minimized if beans are harvested at a higher moisture content before pods are completely mature, then dried to a safe moisture content for storage.

The safe moisture content for commercial seed is 13% for up to 1 year (Hall 1980), 10–11% for up to 4 years (Table 20) (Holman and Carter 1952), and 10% for up to 5 years (Hall 1980). These guidelines do not take into consideration such things as accumulation of fines under the spout lines. Soybeans are more difficult to store than shelled corn at the same moisture content and temperature. This is because the equilibrium moisture content of soybeans at a relative humidity of 65% and 25°C is almost 11%, or 2% less than for shelled corn (Barre 1976).

Storage fungi can slowly invade soybeans stored at 12–12.5% M.C., with the rate of invasion increasing above this moisture content level. Invasion of soybeans of 12.5–13.0% M.C. is unlikely to result in any loss of processing quality within a year even if the temperature is favorable for the growth of fungi, although it may cause some loss of germinability. The slow invasion of soybeans at moisture content levels of up to 13.0% by storage fungi can, however, be dangerous because it may result in a sudden, unexpected, and perhaps uncontrollable increase in fungus growth and heating (Christensen and Kaufmann 1972).

For continued silo storage, soybeans that are already lightly or

Table 20 Safe storage periods for soybean at several moisture levels (after Holman and Carter 1952)

Moisture content (%)	Market stock	Seed stock
10–11	4 years	1 year
10–12.5	1–3 years	6 months
13–14	6–9 months	Questionable, check germination
14–15	6 months	Questionable, check germination

moderately invaded by storage fungi are a poorer risk than sound beans, and progress toward advanced spoilage more rapidly. Once the seeds have been moderately invaded by storage fungi, the fungi may continue to grow and cause damage at slightly lower moisture contents and temperatures than they would in sound beans (Christensen and Kaufmann 1972).

Drying guidelines: The maximum safe drying temperatures, according to Hall (1980), are 43°C for soybeans intended for seeding purposes, and 49°C for commercial use, whereas Muckle and Stirling (1971) recommend maximum safe drying temperatures of 38 and 48°C, respectively.

Degrading factors: Soybeans are degraded when they contain heat-damaged, moldy, or rancid beans, or have a heated, distinctly musty or unpleasant odor. Heated beans are degraded numerically according to established grade specifications. Moldy and rancid beans are considered in combination with heated beans for grading purposes. Soybeans are graded *Sample* if they contain over 5% heated beans or have a distinctly heated or musty odor.

Appearance of heated, moldy, and rancid soybeans: Heated soybeans have an olive to dark brown seed coat and, when bisected, have tan to dark brown cotyledons. Moldy soybeans are wrinkled, misshapen, medium to dark brown, and often have a superficial covering of gray mold. They may also have a spongy texture and an unpleasant odor. Rancid soybeans have a deep pink discoloration.

Storage problems: Most cases of serious loss of quality in stored soybeans occur because those in charge of the beans do not know precisely the conditions prevailing in different portions of the bulk (Christensen 1976). The seed moisture contents and temperatures within the bulk must be known at all times and maintained at low levels to prevent mold development for safe storage. The condition of the stocks at the beginning of storage has an important bearing on their future keeping quality. Storage problems are aggravated by binning beans already lightly or moderately invaded by storage molds, the presence of significant amounts of cracked and split beans, and the presence of fines in the bin spout lines. The cracked and split beans and fines (mainly weed seeds), form focuses for heating and subsequent deterioration. Spoilage commonly begins in soybeans in the spout line because the high moisture weed seeds pack densely, preventing air penetration during aeration. Even if the beans at binning contain only 2–5% fines, the spout line may consist of 50–80% fines (Christensen and Kaufmann 1972).

Sweating, which occurs when cold grain is removed from storage and exposed to air that has a high relative humidity and is more than 8–10°C warmer, is also of concern. Under these conditions, moisture from the air actually condenses on the beans, and when rebinned the cumulative effect of this sweat, or moisture, can cause heating problems in storage (Gustafson 1978).

There is a genuine danger of self-ignition in soybeans because, unlike temperatures during heating of cereals, which do not usually exceed 55°C, temperatures during heating of soybeans can exceed 200°C (Christensen and Kaufmann 1972). The heat-damaged seeds lose at least 30% of their dry weight when the temperature reaches 200°C (Christensen and Kaufmann 1977). The differences between soybeans that have been subjected to microbiological heating (bin-burnt) and those that have been exposed to fire, or which have ignited (fire-burnt) are described by Christensen et al. (1973) and Christensen and Meronuck (1986). The distinction is important because insurance companies pay for loss due to fire, but they do not pay for loss due to microbiological heating.

Production of carbon monoxide (CO) was demonstrated during heating of soybeans by Ramstad and Geddes (1942). Several samples drawn 6–15 m below the surface of a heating soybean bulk gave lethal CO values between 0.005 and 0.02% (50–200 ppm).

Case histories: 1. In a Kentucky elevator in December 1950, vapor or smoke was observed coming from several bins containing soybeans. Columns of extremely hot, compressed grain in the centre of the bins, extending almost to 32 m, the full height of the bins, were uncovered as the sound grain at the periphery was withdrawn. The columns had to be broken up mechanically to permit removal through the unloading spouts. Maximum temperatures in the centre of one heating mass were 145–170°C. No free ash was observed on even the most deteriorated samples, indicating that combustion temperatures were not attained. Elevator records revealed that many of the soybean lots received 6–8 weeks previously had contained more than 15% M.C., a value higher than that considered safe (Milner and Thompson 1954).

2. A United States cargo of 6000 t soybeans was sent by freighter from New Orleans to a country in the Caribbean. The cargo was off-loaded by clamshell into trucks and then delivered to the processing plant. On arrival at the plant, discharge of the cargo was halted because the beans smelled bad and some had already sprouted. Since the general manager of the plant knew that conflicts would arise over who was responsible for the damaged beans, he immediately called his lawyer and insurance agent and later the shipper and importer of the beans. The Food and Drug Authority sent inspectors to examine the cargo and they declared that it was rotten and could not be off-loaded. Conversations with the captain and crew revealed that two hatches had leaked during the stormy voyage from New Orleans. Also, by the time the ship had reached its destination, some of the beans tested at 48% M.C. instead of the specified 12% (Anonymous 1983*b*).

3. In Israel, a bin of 2000 t (US) Grade 2 soybeans that contained

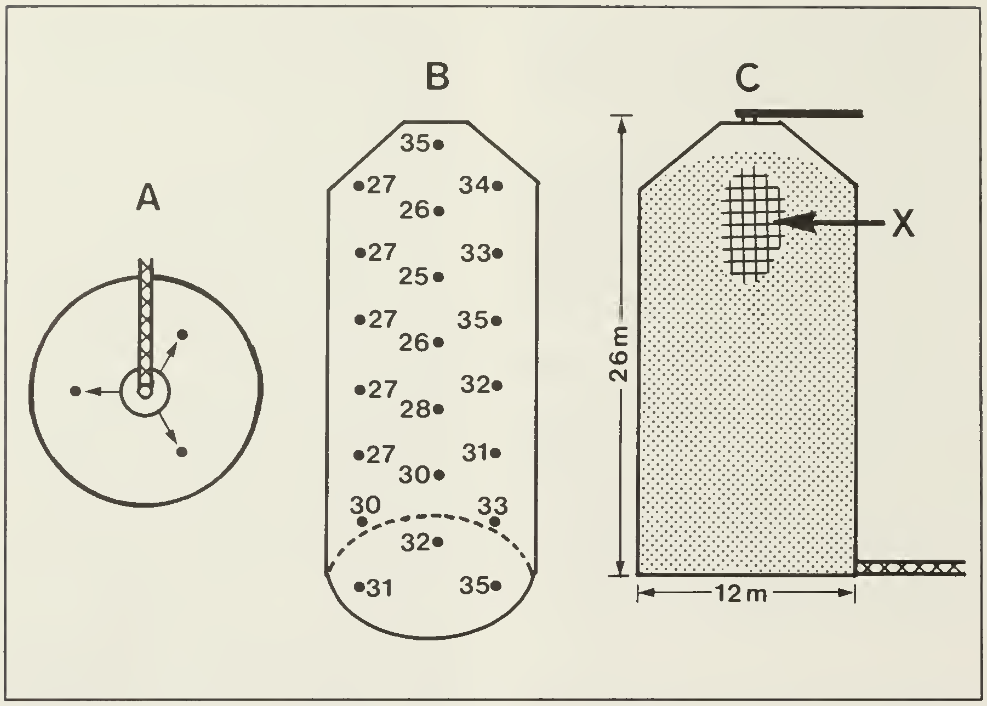

Figure 23 Diagram of bin containing soybeans, which shows location of heat-damage: *A*, cross-section, showing location of thermocouple cables; *B*, longitudinal section, showing temperatures in degrees Celsius before unloading; *C*, longitudinal section, showing the area (X) where heat-damaged beans were detected (after Ben-Efraim et al. 1985).

up to 20% cracked and split beans, up to 3% damaged beans, and up to 2% foreign material was stored safely for 5 months. Temperatures were recorded weekly by means of three thermocouple cables, each with seven junctions (Fig. 23*a*). Following a rise in temperature to 35°C in the upper part of the bin (Fig. 23*b*), it was decided to unload the bin contents. The presence of 30–50 t of heat-damaged beans in the upper central part of the bin (Fig. 23*c*), an area where no thermocouples were directly located, was only detected during unloading operations. Probably the low thermal conductivity of the soybeans prevented heat from dissipating rapidly enough for the thermocouples to detect the problem at an earlier stage. At the heated core, which consisted of a large amount of dockage and split beans, the moisture content was 22.4% and the free fatty acid (FFA) level was more than 35%. Corresponding figures for intact, undamaged beans around the heated core were 12.8% M.C. and 0.56% FFA. The maximum temperature recorded was 98°C at a depth of 1 m within the mass of heated beans (Ben-Efraim et al. 1985).

For other case histories see Christensen and Meronuck (1986) and Hesseltine (1982).

Sunflower seed (*Helianthus annuus* L.)

Relative storage risk: Moderate

Moisture content standards:

Dry:	up to 9.5%
Tough:	9.6–13.5%
Damp:	13.6–17.0%
Moist:	17.1–22.0%
Wet:	over 22.0%

Safe storage guidelines: Manitoba provincial recommendations state that sunflower seed can be stored at up to 10% M.C., but that a moisture level of 8.5% or lower is more desirable. Even at this moisture content level, spoilage can occur if the temperature is not reduced at the time the seed is put into storage (Manitoba Agriculture 1986). In North Dakota a maximum of 9% M.C. is suggested for safe storage (Cobia and Zimmer 1975). At or below 7.0% M.C. sunflower seed can be stored without aeration in the long term, but at 9.5% M.C., and above, only in the short term (Gustafson 1978). Robertson et al. (1984, 1985*a*) investigated the effect of seed moisture content on fungal growth and seed quality in seed stored at 10°C and 20°C for up to 60 weeks. No deterioration occurred in either the 7.5% M.C. seed stored at 10°C or the 6.7% M.C. seed stored at 20°C. Significant deterioration occurred in 9.8% and higher moisture content seed stored at 20°C, and this was likely caused by storage fungi in the *A. glaucus* group.

When sunflowers reach maturity, usually in mid-September, their heads turn yellow at the back and the bracts around each head turn brown. At this stage the seed moisture content is about 50%, but harvesting is usually delayed until the seed has dried to 12% M.C., or less (Daun 1982). In most areas of western Canada, there is no need to dry the seed (Durksen 1975). Since sunflowers can be threshed cleanly at 20% seed M.C., some growers prefer to harvest at this level and then dry the seed artificially to a safe moisture level for storage (Daun 1982).

Drying guidelines: Sunflower seed is easily dried and, because of its bulkiness, with relatively little cost (Durksen 1975). The maximum safe drying temperatures cited by Friesen (1981) are 45°C for sunflowers required for seeding and 50°C for commercial use. Durksen (1975) cites maximum safe drying temperatures of 43°C, 49°C, and 60°C, respectively, for sunflowers dried in batch-type non-recirculating, continuous flow, and batch-type recirculating dryers. Reduce temperatures of the batch type dryers during the last half hour of drying, and dry sunflower seed to 8.5% M.C. to allow for any recovery in moisture during storage.

Degrading factors: Sunflower seeds are degraded when they contain heated or fire-burnt kernels and/or have a heated, fire-burnt, or musty odor. When both heated and rotted kernels are present they are considered in combination. Sunflower seeds are graded *Sample* if they contain over 2% heated or rotted kernels, or have a distinctly heated, musty, or fire-burnt odor.

Appearance of heated seeds: When cut lengthwise, heated seeds have brown-colored meats.

Storage problems: Sunflower seed, as received from the field, normally contains from 3 to 20% trash, which should be removed, along with fine material and large blank seeds, before storage. Removing large, blank seeds allows for maximum utilization of storage space, and eliminating fines prevents hot spot development and allows for proper aeration.

Drying problems: The drying process should be carefully monitored to avoid two commonly encountered problems over-drying and dryer fires (Cobia and Zimmer 1975).

Over-drying occurs when operators forget or are unaware that sunflower seeds dry more rapidly than higher bushel weight seeds such as corn. Over-drying may result in heat-damaged kernels with dark-colored meats that are indistinguishable from those caused by post-harvest fungal invasion during storage. Robertson et al. (1985*b*) studied overheated *Sample* grade sunflower seed and found that heat-damage scores did not always accurately reflect sunflower seed and oil quality as determined by chemical analyses.

A dryer fire occurs when very fine hairs or fibers from the seed are rubbed loose during handling, float in the air, and ignite when drawn through the drying fan and open burner. The hazard is increased when seed is dried above 60°C and for this reason many farmers prefer to dry the seed at lower temperatures. The fire hazard is decreased when the fan can draw in clear air that does not contain fine hairs or fibers. This may be accomplished by using a portable dryer, by turning the fans into the wind, or by attaching long snorkel tubes to the drying fan (Cobia and Zimmer 1975).

Guidelines for drying sunflowers are as follows:

- Maintain good housekeeping practices. Clean around the dryer and in the plenum chamber.
- Do not over-dry.
- Ensure even flow for all sections of batch-type recirculating dryers and continuous flow dryers. Uneven flow causes over-dried spots and increases fire hazards.
- Do not leave drying equipment unattended.

Triticale (a hybrid of wheat and rye)

Relative storage risk: Low

Moisture content standards:
Dry: up to 14.0%

Tough: 14.1–17.0%

Damp: over 17.0%

Safe storage guidelines: In triticale an intergranular relative humidity of 70% equilibrates with 15.1% M.C. at 22°C. The moisture content–relative humidity equilibrium values for triticale at 22°C are higher than those for rye at 25°C or wheat at 20°C or 25°C. Triticale has a density about 20% less than that of wheat and 15% less than that of rye, and this may have some bearing on its higher moisture content–relative humidity values (Sinha and White 1982). Information on storage behavior of triticale is lacking, but from the foregoing it appears that triticale is less likely to spoil than wheat when stored at the same moisture content and temperature.

Wheat (*Triticum aestivum* L.)

Relative storage risk: Low

Moisture content standards:
Dry: up to 14.5%

Tough: 14.6–17.0%

Damp: over 17.0%

Safe storage guidelines: In soft red winter, hard red winter, hard red

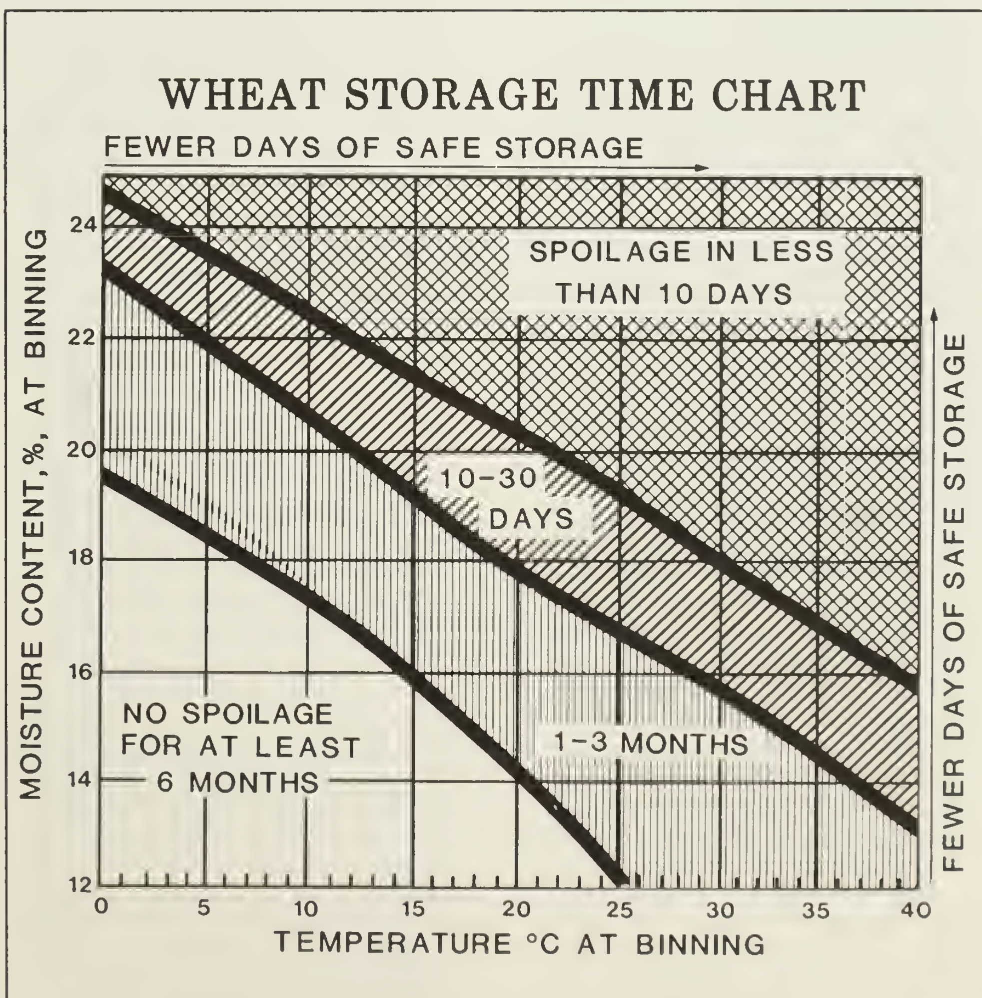

Figure 24 Wheat storage time chart showing zones in which spoilage occurs in less than 10 days, within 10–30 days, within 1–3 months, and no spoilage for at least 6 months (after Wilkins 1983).

spring, and durum wheats an intergranular relative humidity of 70% equilibrates with 13.5%, 13.9%, 13.9%, and 13.7% M.C., respectively, at 25°C (see Table 15). At 10°C, 70% R.H. equilibrates with a wheat moisture content of 15% (Friesen and Huminicki 1986). According to Hall (1980), the maximum moisture content for safe storage in a tight structure is 13% for commercial wheat and 12% for seed wheat. For long-term storage of commercial wheat the maximums are 13–14% M.C. for up to 1 year and 11–12% for up to 5 years. Safe storage guidelines for hard red spring wheat have been developed by Wallace et al. (1983) and summarized by Wilkins (1983). The periods of time during which wheat can be safety stored at various seed moisture content-temperature combinations are shown in Fig. 24. Compared to many other crops, wheat is readily stored but on occasion hot spots may develop.

Drying guidelines: The maximum safe drying temperatures are 60°C for seed required for seeding purposes, 65°C for commercial use, and 80–100°C for feed (Friesen 1981). Excessive heat during drying of wheat can damage the endosperm protein, impairing the suitability of the flour for bread-making (Freeman 1980). Maximum recommended *air temperatures* for drying milling wheats are 60°C for non-recirculating batch-type dryers and cross-flow continuous dryers, 60–70°C for recirculating batch-type dryers, and 70°C for parallel-flow continuous dryers. The *grain temperature* in any part of the dryer should never exceed 60°C.

Degrading factors: Wheat seeds are degraded when they contain heated, bin-burnt, fire-burnt, severely mildewed, or moldy kernels, or have a fire-burnt odor. Wheat seeds are graded *Sample* if they contain over 2% fire-burnt kernels, or over 10% heated, bin-burnt, rotted, severely mildewed, or rotted kernels, or if they have a distinctly fire-burnt odor.

Appearance of seeds: Fire-burnt kernels are charred or scorched. Distinctly heated kernels are pale brown to very dark brown but not black. Bin-burnt, rotted, severely mildewed, and moldy kernels are blackened and swollen, and have a puffed-up appearance as a result of severe heating or exposure to high moisture conditions. Such kernels may be discolored throughout and be spongy to the touch.

Storage problems: Hot spots, originating from either fungal or insect activity, may develop during the late fall, particularly in non-aerated grains. The ecology of an artificially induced hot spot was studied, using samples collected from two 13-t wheat bulks stored at Winnipeg, Man., during 1959–1961 (Sinha and Wallace 1965). Heating by fungi was initiated in winter primarily by the activity of low temperature *Penicillium* species growing in a 4-month-old grain pocket of –5°C to +8°C and 18.5% to 21.8% M.C. The hot spot reached a maximum of 64°C, and cooled in 2 weeks.

Case histories: 1. A large bin at Cairo, Ill., was filled with wheat, which had been harvested at 27–32°C. According to the records, the average moisture content was 13.2%; however, some grain was binned at or near 14.0%, and even at 16.0%, because of inaccurate readings taken from a faulty moisture meter. During the subsequent cool autumn, rapid moisture transfer likely occurred in the bulk. First slow, then rapid heating occurred, resulting in 40% germ damage, reduction to sampling grade, and considerable monetary loss. The spoilage was due to development of post-harvest fungi (storage fungi), and the warehouse manager was judged responsible (Christensen and Kaufmann 1969).

2. In a Middle Eastern country, a 30-m high concrete silo was filled with 5000 t of 13% M.C. wheat. The silo was instrumented with seven thermocouple cables, each with 10 equidistant sensors. The cables were located 1 m from the silo wall. After 3 months storage without aeration, the temperatures along six of the cables ranged from 24 to 36°C, but along the seventh cable they ranged from 89 to 96°C. The smoldering grains at 89–96°C were located on the sunny side of the silo. Probably the heating was caused by moisture transfer within the bulk, aggravated by diurnal changes occurring on the sunny side of the silo.

Wheat bran, shorts, middlings

Bran pellets contain about 50% large flake bran, 35% shorts (intermediate in size), and 15% wheat middlings (fine size). *Mill run pellets* contain 80–85% shorts from the milling process, 10% reground bran, and 5–10% ground screenings, consisting of buckwheat, barley, oats, broken wheat, weed seeds, and filter and flour dusts.

Relative storage risk: Low

Moisture content standards: There are no delimiting standards in Canada but ground wheat germ is required to have maximum moisture content labeling.

Safe storage guidelines: Moisture content levels considered safe by industry are below 10% M.C. for *bran pellets* and below 13.5% M.C. for *mill run pellets* for 0–3 weeks storage. According to Snow et al. (1944), the safe moisture content level below which mold growth does not normally take place for *bran* and *middlings* is 14.4% (equivalent to 72% R.H.) for 3 months storage at 15.5–21°C. For 2–3 years storage at 15.5–21°C, the safe moisture content level for bran is 12.8% (65% R.H.) and for *middlings* it is 13.1% (65% R.H.). In practice, freshly made *bran pellets* after cooling are at about 9.5% M.C. and *mill run pellets* are at about 13.2–13.6% M.C. To prevent condensation and subsequent mold problems from occurring in pellets in winter, bin the cooled pellets and examine them for residual heat, turn if necessary, then load into railcars. In summer, load the cooled pellets directly into the cars.

Appearance: *Bran pellets* have a pinkish tinge; *mill run pellets* are pink but less so than bran pellets.

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APPENDIXES

Appendix A

Temperature conversion table

°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
0	32	36	96.8	72	161.6	108	226.4	144	291.2
1	33.8	37	98.7	73	163.4	109	228.2	145	293
2	35.6	38	100.4	74	165.2	110	230	146	294.8
3	37.4	39	102.2	75	167	111	231.8	147	296.6
4	39.2	40	104	76	168.8	112	233.6	148	298.4
5	41	41	105.8	77	170.6	113	235.4	149	300.2
6	42.8	42	107.6	78	172.4	114	237.2	150	302
7	44.6	43	109.4	79	174.2	115	239	151	303.8
8	46.4	44	111.2	80	176	116	240.8	152	305.6
9	48.2	45	113	81	177.8	117	242.6	153	307.4
10	50	46	114.8	82	179.6	118	244.4	154	309.2
11	51.8	47	116.6	83	181.4	119	246.2	155	311
12	53.6	48	118.4	84	183.2	120	248	156	312.8
13	55.4	49	120.2	85	185	121	249.8	157	314.6
14	57.2	50	122	86	186.8	122	251.6	158	316.4
15	59	51	123.8	87	188.6	123	253.4	159	318.2
16	60.8	52	125.6	88	190.4	124	255.2	160	320
17	62.6	53	127.4	89	192.2	125	257	161	321.8
18	64.4	54	129.2	90	194	126	258.8	162	323.6
19	66.2	55	131	91	195.8	127	260.6	163	325.4
20	68	56	132.8	92	197.6	128	262.4	164	327.2
21	69.8	57	134.6	93	199.4	129	264.2	165	329
22	71.6	58	136.4	94	201.2	130	266	166	330.8
23	73.4	59	138.2	95	203	131	267.8	167	332.6
24	75.2	60	140	96	204.8	132	269.6	168	334.4
25	77	61	141.8	97	206.6	133	271.4	169	336.2
26	78.8	62	143.6	98	208.4	134	273.2	170	338
27	80.6	63	145.4	99	210.2	135	275	171	339.8
28	82.4	64	147.2	100	212	136	276.8	172	341.6
29	84.2	65	149	101	213.8	137	278.6	173	343.4
30	86	66	150.8	102	215.6	138	280.4	174	345.2
31	87.8	67	152.6	103	217.4	139	282.2	175	347
32	89.6	68	154.4	104	219.2	140	284	176	348.8
33	91.4	69	156.2	105	221	141	285.8	177	350.6
34	93.2	70	158	106	222.8	142	287.6	178	352.4
35	95	71	159.8	107	224.6	143	289.4	179	354.2

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