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~~GRAIN ELEVATORS AND PROCESSING PLANTS~~
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EPA Project Officer
William Lamason

EMISSION FACTOR DEVELOPMENT FOR SHIP AND BARGE LOADING OF GRAIN

Revised

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October 1984

GCA CORPORATION
GCA/Technology Division
Chapel Hill, North Carolina

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INTRODUCTION

The Air Management Technology Branch has responsibility for maintaining the document Compilation of Air Pollutant Emission Factors, AP-42 which is a basic source of emission factors used in the preparation of State Implementation Plans, review of Prevention of Significant Deterioration applications and other Federal, State, and local agency assessments of air pollution sources. These factors are updated from time to time to reflect emergence of new data which may be useful for characterizing an industry or other source. This document presents new data and emission factors for controlled emissions from ship and barge loading of grain.

Process Description

Grain elevators are transfer and storage areas for grain and are usually classified as either country, terminal or export elevators. Country elevators generally receive grain or soybeans as they are harvested from fields within a 10- to 20-mile radius of the elevator. The country elevators unload, weigh and store grain as it is received from the farmer. In addition, the country elevator may dry or clean the grain before it is shipped to the terminal elevators or processors.

Terminal elevators receive most of their grain from country elevators and ship to processors, other terminals, and exporters. The primary function of a terminal elevator is to store grain in quantity without deterioration and bring it to commercial grade so as to conform to the needs of buyers. As with country elevators, terminals dry, clean and store grain. In addition, they can blend grain to meet buyer specifications. Export elevators are similar to terminal elevators with the exception that they mainly load grain on ships and barges for export.

Grain loaded into ships at a terminal grain elevator is conveyed from the elevators to a gallery above the dock, from which it is dropped down one of several long telescoping spouts, into a hold. Grain loading rates are usually on the order of 1,000 tons (1,000 metric tons) per hour. The spouts can be either vertical or slanted and are typically 50 feet (15 meters) long. These generally have the capacity to telescope in their length by 20 to 40 feet (6 to 12 meters). As grain falls down the spout, it pulls air along with it. This air becomes quite dusty and the entrained dust is emitted at the bottom of the spout. More dust is emitted as the grain falls from the bottom of the spout into the hold. The amount of dust generated depends on the length of the loading spout, the distance between the bottom of the spout and the grain, and the "dustiness" of the grain. There are three types of ships which are used to haul grain: bulk-carriers, tween-deckers, and tankers. Bulk carriers are used for about 90 percent of the grain shipped from U.S. ports.

The holds of a bulk-carrier are unobstructed by internal bulkheads, and have large openings which permit easy access. The loading operation for a bulk-carrier can be broken into two stages: bulk-loading, and topping-off. In bulk-loading the grain is simply poured into the hold. During topping-off the loading spout must be moved about over the hold opening so that when the hold is filled there will be no air spaces under the sides of the hold or under the hold cover (see Figure 1). This prevents listing of the ship. Bulk-carriers are also known as self trimmers because special trimming methods discussed later are not needed. It is generally more difficult to control dust emissions during topping-off because the grain spout must be moved frequently and emissions are more affected by the wind.

The holds of a tween-decker contain horizontal intermediate decks (see Figure 1). In the loading of a tween-decker, special care must be taken to fill beneath these decks to prevent listing of the ship at sea. Devices (commonly called conveyors, slingers, trimmers, slides and other terms) to throw the grain into the corners of the hold are necessary. In addition, men must get into the hold to operate the trimming device. More dust is reported to be generated in the loading of tween-deckers than in the loading of bulk-carriers, because of the use of conveyors and slides.

Tankers are designed to carry liquid, but are sometimes used for grain. The holds may contain vertical bulkheads, and generally have small hold openings. These often necessitate the use of funnels to load the holds.

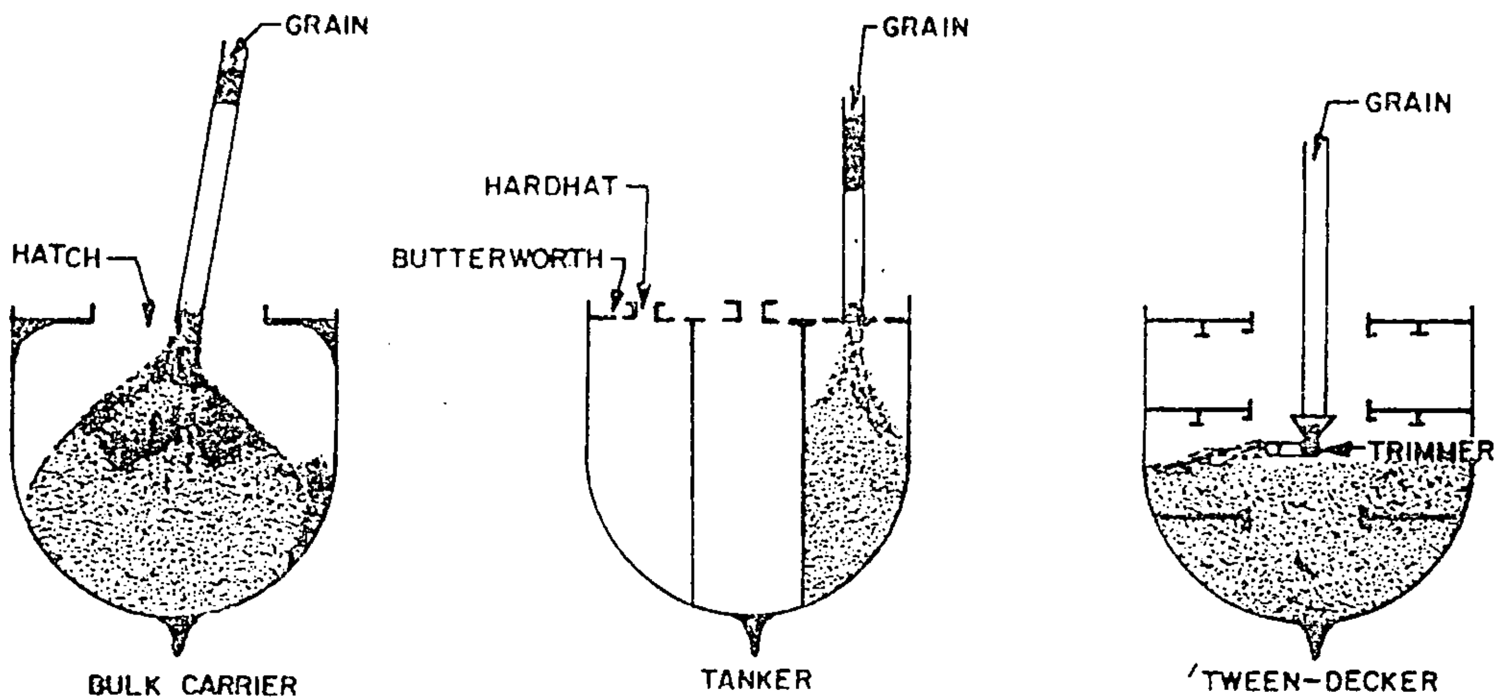

Figure 1. Schematic of bulk carrier, tanker and 'tween-decker grain loading.

Emission Control Techniques

Uncontrolled particulate emissions from shiploading at grain terminals generally have opacities averaging over 30 percent with short-term (6 minute averages) often exceeding 40 percent. Control of these emissions is complicated by the fact that the deck level of a ship will vary with the tide or river stage, the type of ship, and the trim of the ship. Three types of control systems are presently used to control shiploading emissions: aspirated tent systems, "dead-box" systems, and submerged loading systems.

Aspirated Tent Systems

In tent control, the emission of dust generated by grain falling into a hold is prevented by covering the top of the hold with one or several tarpaulin(s) or tent(s) (Figure 2). Grain is poured through a small hole in the tent at a rate of about 1,000 t/hr (1,000 metric ton/hr). Dust laden air is drawn from under the tent to a control device, usually a fabric filter, through one or more aspiration hoses. These can be attached to the side of the loading spout, or inserted under the side of the tent. Tent systems can be used with either vertical, or slanted loading spouts, but the spouts must be capable of telescoping by about 20 feet (6 meters) in length so that they can reach the hold opening level regardless of the tide stage, or the trim of the ship.

Tent control systems, when properly used, completely eliminate visible emissions during the bulk-loading phase, however, they are not used in all circumstances. During topping-off, the tents are removed so that the loading spouts can be moved, and so that the operators of the loading spouts can make sure that the grain is properly distributed and the hold is completely filled. Also, tents apparently cannot be used when tween-deckers are being loaded, as men must remain inside the hold.

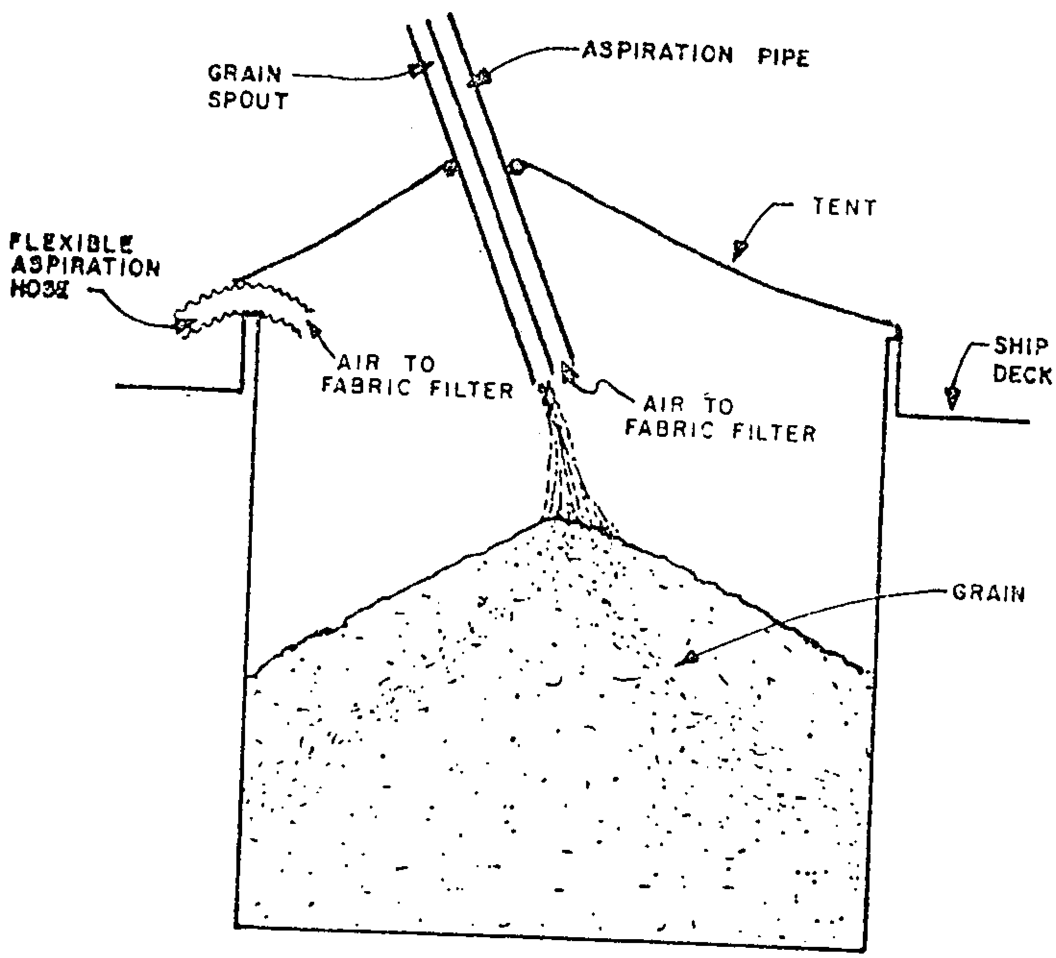

Figure 2. Tent and suction dust control system.

Dead-Box

A more versatile method of controlling shiploading emissions is the use of a "dead-box" (Figure 3). Grain is dropped through a vertical chute into a dead-box, from which it is allowed to fall a short distance into the hold. Typical grain flow rates for dead-box systems range from 1,000 to 2,000 t/hr. The dead-box greatly reduces the velocity of grain which falls into it, and thus reduces the amount of dust generated at the impact site of the grain in the hold. Dust generated as the grain drops through the chute, and upon impact of the grain with the baffles in the dead-box is drawn from the top of the box to a fabric filtration system.

A dead-box should be suspended 6 to 12 in. (15 to 30 cm) above the grain level in the hold, because dead-box performance deteriorates rapidly as height increases. The distance to the grain level varies with the depth of the ship, water level around the ship and the amount of grain in the hold. In order to hold the dead-box near the grain during all phases of loading, the telescoping range of the loading chute must be about 40 feet (12 meters). Dead-box control can be used to reduce emissions during topping-off as well as during bulk-loading. It is also expected to reduce emissions from tween-decker loading. Some dust emission would, however, be expected from the conveyors or slides used to throw grain to the sides of the holds.

Submerged Loading

In the submerged loading technique for controlling dust emissions from shiploading the bottom of the loading spout is actually buried below the grain level in the hold (Figure 4). Grain falling down the chute has sufficient kinetic energy to push its way out of the bottom of the chute. Dust generated as the grain falls down the spout and when it hits the grain in the hold is removed through a port about 10 feet (3 meters) from the bottom of the spout. Dust laden air is drawn through a pipe attached to the loading spout to a fabric filtration system.

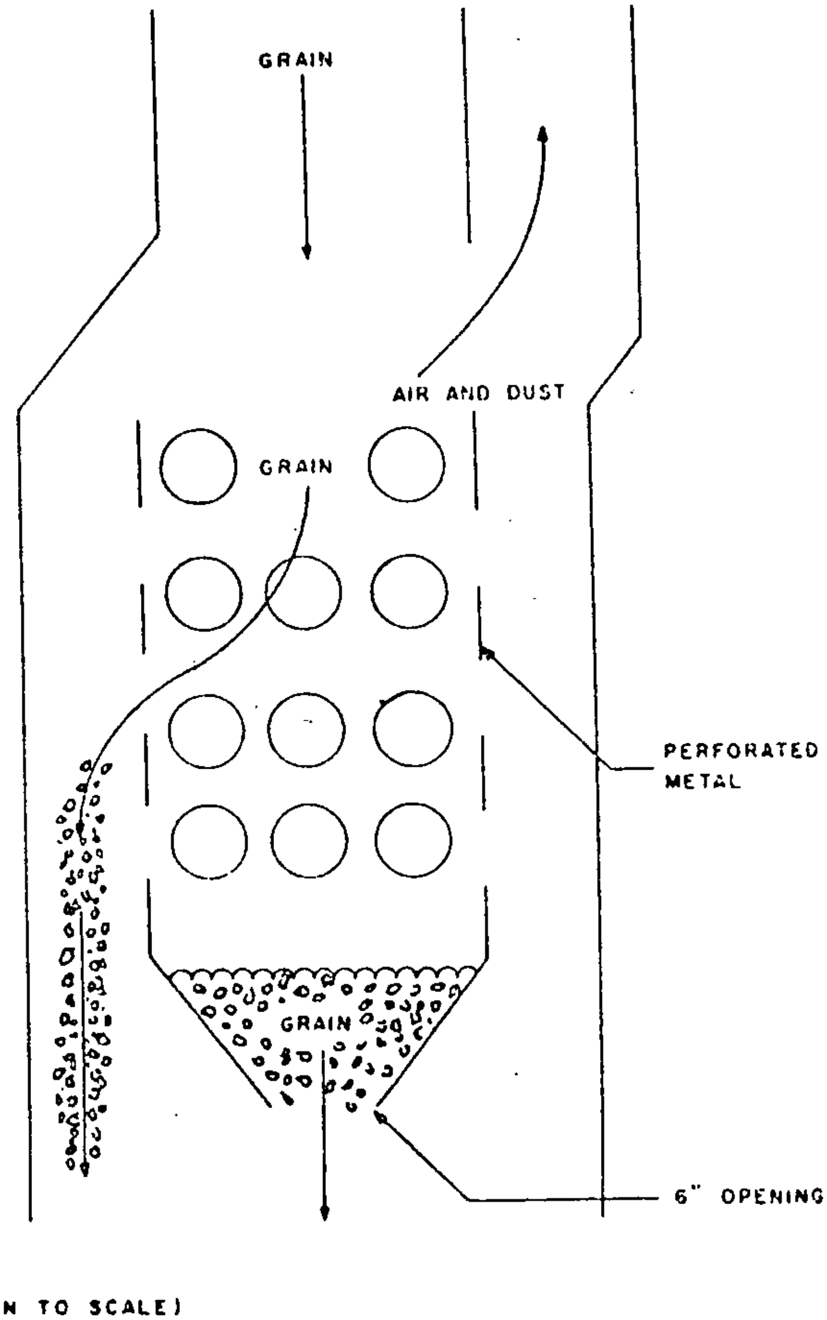

Figure 3. Dead-box in use at Cargill in Portland.

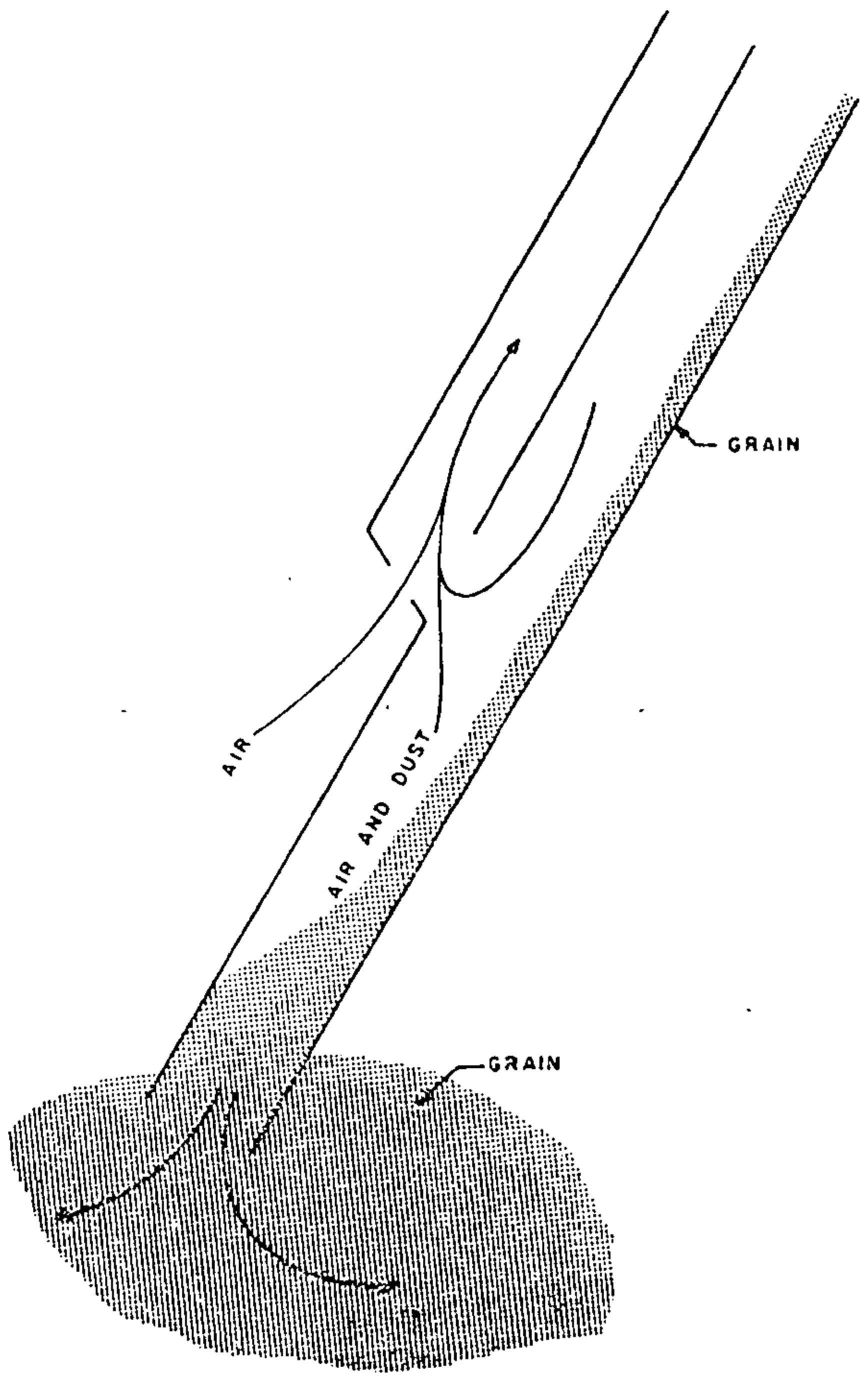

Figure 4. Submerged loader in use at Cargill in Seattle.

The grain loading rate used with this system is generally about 1,500 t/hr. The grain spouts are about 90 feet long, (30 meters) and can telescope by about 40 feet (12 meters) so that the top of the spout can almost always reach the grain level in the hold. The tip is generally kept buried 6 to 12 in. (15 to 30 cm) under the grain level. All of the movement of the grain spout is controlled by motors which can move the spout even when it is submerged. A sensor can be located near the bottom of the leg which shuts off the grain conveyors to the leg when the leg becomes clogged.

Emissions

This section presents emission factors for particulate emissions from ship and barge loading of grain at grain elevators. The information presented here is the results of fugitive particulate emssion tests and particle size distributions performed at several terminal grain elevators in the United States. Appendix A of this report contains the complete test report for the emissions data presented in this section.

Uncontrolled particulate emissions from ship and barge loading are fugitive emissions with emission factors averaging 0.11 lb/ton (0.055 kg/MT). Tent controlled loading produced an average emission factor 0.028 lb/ton (0.014 kg/Mg). It should be noted that when the tent is in place, essentially no fugitive emissions are visible; and the resultant emission factor is due to uncontrolled emissions during topping-off operations which prevent the use of the tent. Approximately the top 25 percent of the loading must be accomplished with the tent removed to allow the movement of the loading arm. Consequently, the average emission factor is the result of uncontrolled emissions for 25 percent of the time.

The emission factors for dead-box controlled loading range from 0.0006 to 0.0056 lb/ton (0.0003 to 0.0028 kg/Mg). This range is the result of how well the control device is operated. Emission factors are dependent on how high the box is held above the level of the grain in the hold of the ship. Higher distances produce more emissions.

Table 1 presents emission factors for uncontrolled, dead-box, and tent controlled emissions from ship and barge loading at grain elevators. No measurements were conducted on submerged loading at any facility. However, visibile emissions are similar to those using dead-boxes.

Particle size distribution data are presented in Figure 5. Particle size determinations were made primarily during topping off. It should be pointed out that all of the control techniques presented in this document are techniques to capture the fugitive emissions and require the use of fabric filters to actually remove the particulate matter. Emission rates and factors from the fabric filters have not been measured and consequently have not been included in the computation of emission factors for ship and barge loading at grain elevators. The fabric filters serving ship and barge loading regularly serve other operations at the grain elevator as well. Simply applying a removal efficiency of the fabric filter to the uncontrolled emissions from ship and barge loading may not be accurate because the particulate matter caught by the capture device (i.e. dead-box and submerged loading) is most likely higher than the uncontrolled emissions presented in this report. This is due to the configuration of the capture-device where more turbulence and suspended particulate is expected. However, for tent controlled emissions, the removal efficiency of the fabric filter can probably be applied to the uncontrolled emissions because the extra turbulence and corresponding suspended particulate do not exist.

TABLE 1. AVERAGE FUGITIVE PARTICULATE EMISSION FACTORS FOR SHIP AND BARGE LOADING AT GREAIN ELEVATORS

Process	Emission Factors lb/Ton	Emission Factors Kg/Mg
Uncontrolled loading	0.11	0.55
Tent controlled loading		
Bulk loading	0.00	0.00
Topping-off[a]	0.11	0.55
Average[a]	0.028	0.014
Dead-box controlled loading		
Well operated	0.0006	0.0003
Poorly operated	0.0056	0.0028

[a] About 25 percent of the total grain loaded is loaded during the topping-off phase. The tents cannot be used during topping-off.

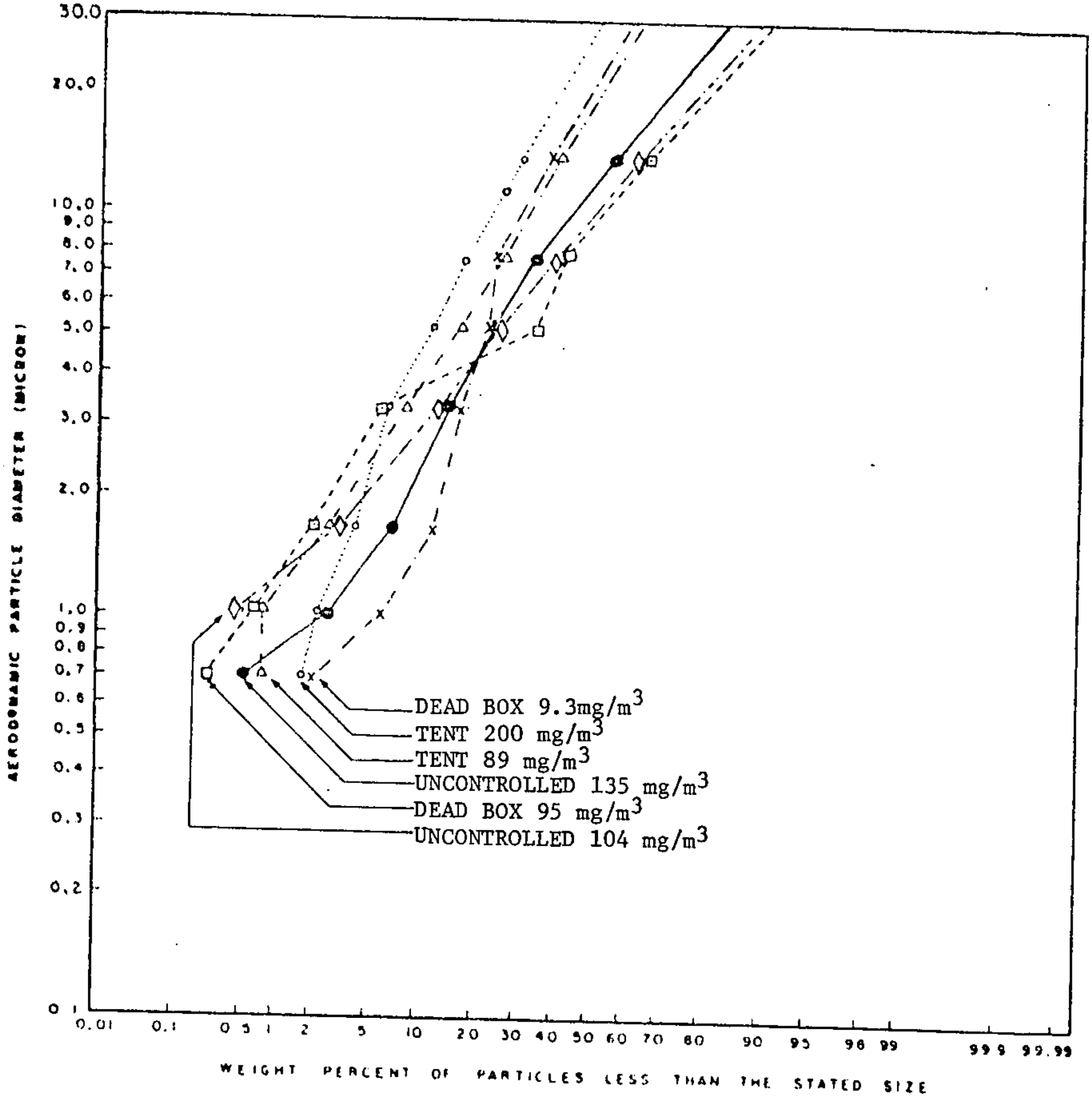

Figure 5. Size distribution of particulate emissions from shiploading, primarily topping-off.

APPENDIX A

PARTICULATE EMISSION FACTORS AND FEASIBILITY
OF EMISSION CONTROLS FOR SHIPLOADING OPERATIONS
AT PORTLAND, OREGON GRAIN TERMINALS, VOLUME 1

GCA-TR-79-06-G(1)

GRAIN TERMINAL CONTROL STUDY

Contract No. 68-01-4143
Technical Service Area 1
Task Order Nos. 24 and 47

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PARTICULATE EMISSION FACTORS AND FEASIBILITY OF EMISSION CONTROLS FOR SHIPLOADING OPERATIONS AT PORTLAND, OREGON GRAIN TERMINALS

VOLUME I

Final Report

by

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June 1979

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ABSTRACT

Observations of shiploading operations at nine grain terminals in Portland, Oregon; Seattle and Tacoma, Washington; and Duluth, Minnesota are discussed. Also, a preliminary evaluation of the compliance status and/or feasibility of compliance of shiploading operations at the Portland, Oregon elevators with State visible emissions regulations is presented. Estimates of particulate emission factors for shiploading operations at the Portland elevators have been developed through a measurement program.

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ACKNOWLEDGEMENT

The authors wish to sincerely acknowledge the assistance and advice of Mr. Norman Edmisten, EPA Task Officer for this project. Also the assistance received from Mr. Jim Close and Mr. Thomas Bispham of the Oregon Department of Environmental Quality was appreciated. The cooperation of the stevedores and the grain terminal operators was most important to this program and their efforts are acknowledged.

SECTION 1

SUMMARY AND CONCLUSIONS

SUMMARY

There are four terminal grain elevators in Portland, Oregon operated by the Bunge, Louis Dreyfus, Cargill and Columbia Grain companies.* Shiploading operations at these four terminals were observed in order to evaluate the compliance status and/or feasibility of compliance of the operations with Oregon state visible emission regulations. Dust concentration measurements were made at these facilities so that estimates of the particulate emission factors from shiploading operations could be made.

In addition to the four Portland terminals, shiploading operations were observed at the Cargill terminal in Seattle, Washington; the Continental Grain and United Grain terminals in Tacoma, Washington; and the International Multifoods and General Mills terminals in Duluth, Minnesota. The Cargill-Seattle and Continental Grain - Tacoma terminals were visited as examples of terminals with well-controlled shiploading operations. They use submerged loading and dead-box control systems, respectively. The United Grain Terminal in Tacoma uses a tent control system. Measurements of dust concentrations under the tents at United Grain, Bunge and Dreyfus were made in order to determine whether the use of aspirated tents to contain and collect dust would pose an explosion hazard (see reference 1 for a discussion of this work). Finally, the Duluth terminals were visited prior to the Portland observations in order to determine what type of measurements could be made to estimate particulate emission factors from shiploading.

The Cargill terminal in Portland uses a dead box system to control particulate emissions from bulk carrier loading. When the dead boxes were well-operated, emissions were limited to 10 percent opacity and estimated emission factors for total particulates and suspendable particulates (< 30 μm aerodynamic diameter) were 0.3 g/t (0.0006 lb/ton)† and 0.2 g/t (0.0004 lb/ton). When the dead boxes were not properly operated, that is when they were held too high above grain level or allowed to swing excessively, visible emissions with an

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*The Columbia Grain terminal was operated by Cook Industries during the sampling activities discussed in this report.

†Conversion factors for the metric and British units used in this report are presented in Appendix A.

average opacity of 40 percent were observed and the estimated emission factors were 2.8 g/t (0.0056 lb/ton) and 2.4 g/t (0.0048 lb/ton) for total and suspendable particulates respectively. The Oregon state visible emissions regulations for the Portland area state that there should be no visible emissions with opacities greater than 20 percent. It appears, that it is possible for the state opacity regulations to be met at the Cargill terminal during bulk-carrier loading if the control systems are properly operated. In the near future, Cargill may be modifying a trimming machine for use during tween-decker loading. This is expected to allow compliance with the standard during tween-decker loading as well as bulk-carrier loading.

The Columbia terminal in Portland, at the time of this study had no particulate emission control system for shiploading and was, therefore, not capable of complying with the Oregon state visible emissions standards. Columbia Grain is continuing installation of a dead-box system begun by Cook. This system should enable the Columbia terminal to comply with the regulations during bulk-carrier loading. Columbia is also considering altering a trimming machine so that emissions can be controlled during tween-decker loading. Whether this is done will depend on the number of tween-deckers loaded by Columbia in the near future.

Both the Bunge and Louis Dreyfus terminals at Portland have available tents with aspiration systems to control dust emissions from shiploading. These systems are not presently in use because stevedores, concerned about grain elevator explosions, have refused to use tent control systems. Measurements made at the United Grain, Bunge and Louis Dreyfus terminals, indicate that the concentrations of dust under tents during shiploading are well below minimum explosive limits for grain dust cited in literature.[1]

During shiploading observations at Bunge and Louis Dreyfus, the tent control systems were in use. Such systems are generally used during bulk-loading of bulk-carriers, but not during topping-off of bulk-carriers, or during loading of tween-deckers. During bulk-loading when the tents were in use, at Bunge and Louis Dreyfus, there were no visible emissions. During topping-off, emissions with opacities in excess of 50 percent were observed. Measurements made at the Bunge, Louis Dreyfus and Columbia terminals were used to estimate emission factors for uncontrolled shiploading or topping-off. The average estimated emission factors are 55 g/t (0.11 lb/ton) for total particulate and 40 g/t (0.08 lb/ton) for suspendable particulates.

Use of the existing tent control systems at the Bunge and Louis Dreyfus terminals during bulk-loading of bulk-carriers would reduce emission factors for total particulates from 55 g/t (0.11 lb/ton) to 14 g/t (0.026 lb/ton) if topping-off were started when the top of the pile of grain was within 4 feet of the top of the hold and to 8 g/t (0.016 lb/ton) if topping-off were delayed, as it should be, until the grain reached the top of the hold. Suspendable dust emissions comprise about 70 percent of the total particulate emissions. The terminals would still be in violation of the state visible emission standards during topping-off and tween-decker loading because tents cannot be used in these operations. Although emissions from topping-off could be reduced by holding the loading spouts closer to the grain level, opacity would probably still exceed 20 percent.

CONCLUSIONS

Properly operated dead-box control systems used to load bulk-carriers can achieve compliance with Oregon's 20 percent opacity regulation during all phases of bulk-carrier loading. Proper operation requires that the stevedores maintain a distance of less than 15 to 30 cm (6 to 12 in.) between the grain spout and the surface of the pile. The above specification can be achieved by reasonable attention to the loading generation. Cargill and Columbia can therefore comply with Oregons opacity regulation during bulk-loading.

Most ships used to handle grain are bulk-carriers. Discussions during this study indicated that Cargill did not load any tween-deckers or tankers during the past year (1977). Columbia does not normally load tankers but does ship 2 to 4 percent of its grain in tween-deckers. The loading of tween-deckers was not addressed in depth in this study. It appears that dead-box control systems can only be used to control emissions during loading of bulk-carriers. Discussions with Cargill indicated that it may be possible to modify trimming machines to reduce emissions during the loading of tween-deckers.

Tent control systems, as used at Bunge and Louis Dreyfus eliminate visible emissions during the bulk loading share of loading a bulk-carrier. Bunge and Louis Dreyfus can therefore comply with Oregon opacity regulation during the bulk-loading phase. During topping-off, the loading spout must be moved and the pattern of filling in the hold must be observed. Tent systems can not be used during this final phase of loading a bulk-carrier. The amount of grain loaded during the topping-off phase should be minimized in order to reduce emissions at minimal costs. A pile of grain in a hold typically assumes a cone shape as it is loaded. Topping-off is sometimes defined as the last 4 feet of loading. However, this definition is not precise as it ignores the shape of the grain pile. It is reasonable to maintain the tent control system until the top of the cone of grain reaches the top of the hold. Adoption of this procedure will reduce emissions with minimal, if any, cost impact. During topping-off emissions can be minimized by holding the spout as close to the grain as feasible.

Burge and Louis Dreyfus can not control emissions from loading tween-deckers with the current control systems. However, these facilities only ship about 2 to 3 percent of their grain in tween-deckers, tankers are not used to any significant extent.

The only methods which presently enable terminals to reduce visible emissions to less than 20 percent opacity during all phases of bulk-carrier shiploading are dead-box systems and submerged loading systems. Retrofitting of dead-box systems to the Bunge and Louis Dreyfus terminals would require major modifications to the shiploading galleries at the terminals at costs on the order of $5,000,000. Amortized over 15 years at 10 percent interest, these costs would amount to about $700,000 per year, which would be about $0.70 per metric ton of grain loaded, or 1.9 cents per bushel.* The cost of emission

*Assuming that 1 million tons of grain are loaded per year.

control appears high relative to the profit of terminal grain elevators which is only about 2.1 cents per bushel. It should also be noted that control costs of 1.9 cents a bushel are small compared to the selling price of grain which is $3 to $4 per bushel. However, the ability of terminal owners to raise prices to cover increased costs and maintain profit margins has not been evaluated in this study.

If a submerged loading system could be retrofitted to Bunge and Louis Dreyfus without major gallery modifications, the cost would be on the order of $100,000, which, amortized over 15 years amounts to about $14,000 per year. This is about 0.14 cents per ton loaded or 0.038 cents per bushel. If, on the other hand, major gallery modifications are necessary as they probably would be, the cost could be similar to retrofitting dead-box control systems.

SECTION 2

BACKGROUND

LOADING OPERATIONS

Grain loaded into ships at a terminal grain elevator is conveyed from the elevators to a gallery above the dock, from which it is dropped down one of several long telescoping spouts, into a hold. Grain loading rates are usually on the order of 1,000 metric tons (1,000 long tons) per hour. The spouts can be either vertical or slanted and are typically 15 meters (50 feet) long. These generally have the capacity to telescope in their length by 6 to 12 meters (20 to 40 feet). As grain falls down the spout, it pulls air along with it. This air becomes quite dusty and the entrained dust is emitted at the bottom of the spout. More dust is emitted as the grain falls from the bottom of the spout into the hold. State and/or local visible emission regulations are often exceeded during uncontrolled shiploading operations. The amount of dust generated depends on the length of the loading spout, the distance between the bottom of the spout and the grain, and the "dustiness" of the grain. Conversation with longshoremen and elevator operators, and observation of loading operations indicate that wheat is the least dusty grain, and that spring wheat tends to be the dustiest type of wheat. Corn and barley are dustier than spring wheat, and soybeans are dustier still. Finally, pellets are much dustier than any grain. Pellets are animal food consisting of bits of pulp which are compressed to form cylinders about 1 cm (0.5 in.) in diameter and 2 cm (1 in.) long.

There are three types of ships which are used to haul grain: bulk-carriers, tween-deckers, and tankers. Bulk-carriers are used for about 90 percent of the grain shipped from U.S. Ports.

The holds of a bulk-carrier are unobstructed by internal bulkheads, and have large openings which permit easy access. The loading operation for a bulk-carrier can be broken into two stages: bulk-loading, and topping-off. In bulk-loading the grain is simply poured into the hold. During topping-off the loading spout must be moved about over the hold opening so that when the hold is filled there will be no air spaces under the sides of the hold or under the hold cover (see Figure 1). This prevents listing of the ship. Bulk-carriers are also known as self trimmers because special trimming methods discussed later are not needed. It is generally more difficult to control dust emissions during topping-off because the grain spout must be moved frequently and emissions are more affected by the wind.

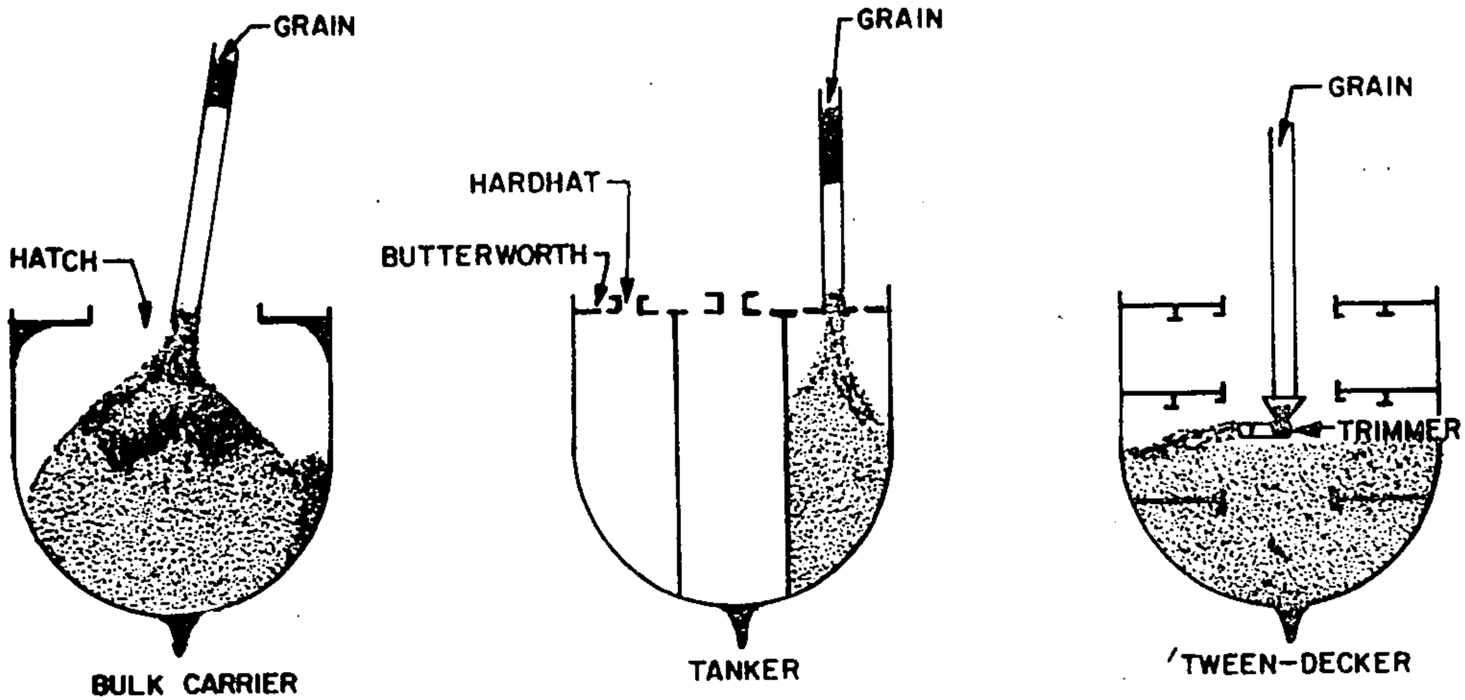

Figure 1. Schematic of bulk carrier, tanker and 'tween-decker grain loading.

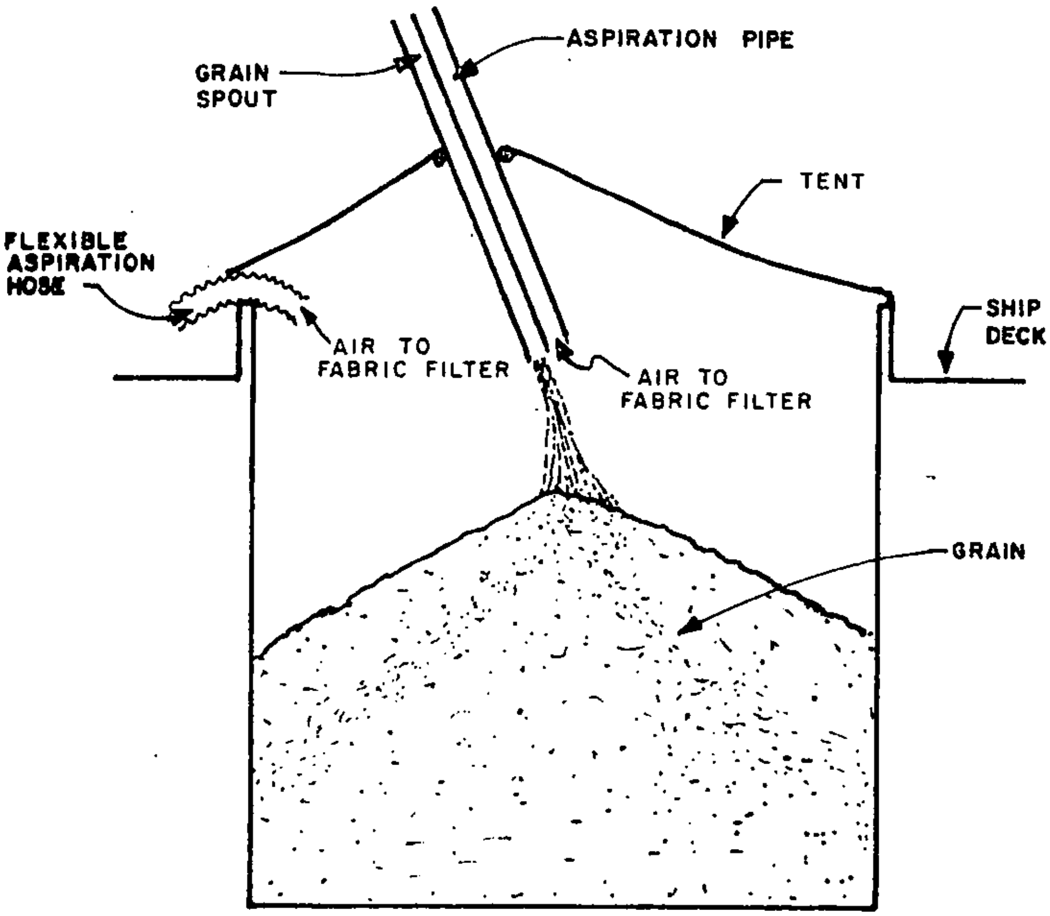

Figure 2. Tent and suction dust control system.

The holds of a tween-decker contain horizontal intermediate decks (see Figure 1). In the loading of a tween-decker, special care must be taken to fill beneath these decks to prevent listing of the ship at sea. Devices (commonly called conveyors, slingers, trimmers, slides and other terms) to throw the grain into the corners of the hold are necessary. In addition, men must get into the hold to operate the trimming device. More dust is reported to be generated in the loading of tween-deckers than in the loading of bulk-carriers, because of the use of conveyors and slides.

Tankers are designed to carry liquid, but are sometimes used for grain. The holds may contain vertical bulkheads, and generally have small hold openings. These often necessitate the use of funnels to load the holds.[2]

VISIBLE EMISSIONS REGULATIONS

Visible emissions regulations vary from state to state. The general Oregon state regulation for visible emissions states that the opacity of emissions must not exceed 40 percent for more than 3 minutes of any hour. A much more stringent state regulation applies to "special control areas" in the state, such as the City of Portland and the Northwest Regional Area of Oregon. This regulation states that the opacity of visible emissions must not exceed 20 percent for more than 30 seconds in any hour (Oregon Administrative Rule 340-28-070).[3] The four grain terminals in the Portland area are subject to this latter regulation.

EMISSION CONTROL TECHNOLOGY

Uncontrolled particulate emissions from shiploading at grain terminals generally have opacities average over 30 percent with short-term (6 minute averages) often exceeding 40 percent. Control of these emissions is complicated by the fact that the deck level of a ship will vary with the tide or river stage, the type of ship, and the trim of the ship. Three types of control systems are presently used to control shiploading emissions: aspirated tent systems, "dead-box" systems, and submerged loading systems.

Aspirated Tent Systems

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Tent control systems, when properly used, completely eliminate visible emissions during the bulk-loading phase, however, they are not used in all circumstances. During topping-off, the tents are removed so that the loading spouts can be moved, and so that the operators of the loading spouts can make sure that the grain is properly distributed and the hold is completely filled. Also, tents apparently cannot be used when tween-deckers are being loaded, as men must remain inside the hold.[4-6]

The major capital cost of retrofitting tent control to an existing facility would be the cost of the aspiration and fabric filtration systems. This cost would be about $30,000 dollars/loading leg.[7]

Dead-Box

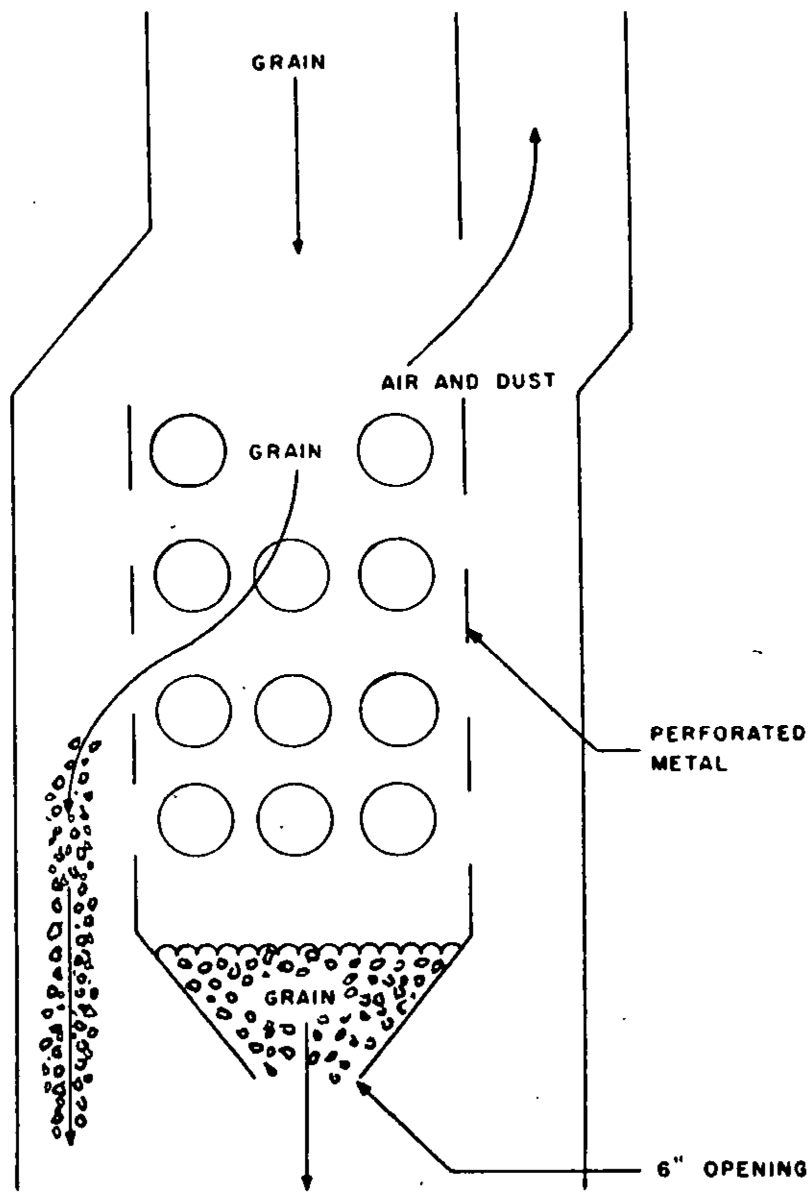
A more versatile method of controlling shiploading emissions is the use of a "dead-box" (Figure 3). Grain is dropped through a vertical chute into a dead-box, from which it is allowed to fall a short distance into the hold. Typical grain flow rates for dead-box systems range from 1,000 to 2,000 t/hr-The dead-box greatly reduces the velocity of grain which falls into it, and thus reduces the amount of dust generated at the impact site of the grain in the hold. Dust generated as the grain drops through the chute, and upon impact of the grain with the baffles in the dead-box is drawn from the top of the box to a fabric filtration system.

A dead-box should be suspended 15 to 30 cm (6 to 12 in.) above the grain level in the hold, because dead-box performance deteriorates rapidly as height increases. The distance to the grain level varies with the depth of the ship, water level around the ship and the amount of grain in the hold. In order to hold the dead-box near the grain during all phases of loading, the telescoping range of the loading chute must be about 12 meters (40 feet).[8,9] Dead-box control can be used to reduce emissions during topping-off as well as during bulk-loading. It is also expected to reduce emissions from tween-decker loading. Some dust emission would, however, be expected from the conveyors or slides used to throw grain to the sides of the holds.

The cost of retrofitting a dead-box control system to an existing facility would be much higher than that of retrofitting a tent system. A dead-box system would generally require major modifications to the loading equipment. A new gallery would almost certainly be needed to support the additional weight of the dead-boxes. Major modifications to the dock which supports the gallery might also be necessary. The total cost would vary from elevator to elevator, depending on the gallery and dock in use at the elevator in question. The consensus of opinion of grain elevator owners and operators and equipment suppliers is that a cost estimate of $1 million per loading leg would not be unreasonable.

Submerged Loading

A submerged loading technique for controlling dust emissions from shiploading was developed at the Cargill terminal in Seattle, Washington. The bottom of the loading spout is actually buried below the grain level in the hold (Figure 4). Grain falling down the chute has sufficient kinetic energy to push its way out of the bottom of the chute. Dust generated as the grain



(NOT DRAWN TO SCALE)

Figure 3. Dead-box in use at Cargill in Portland.

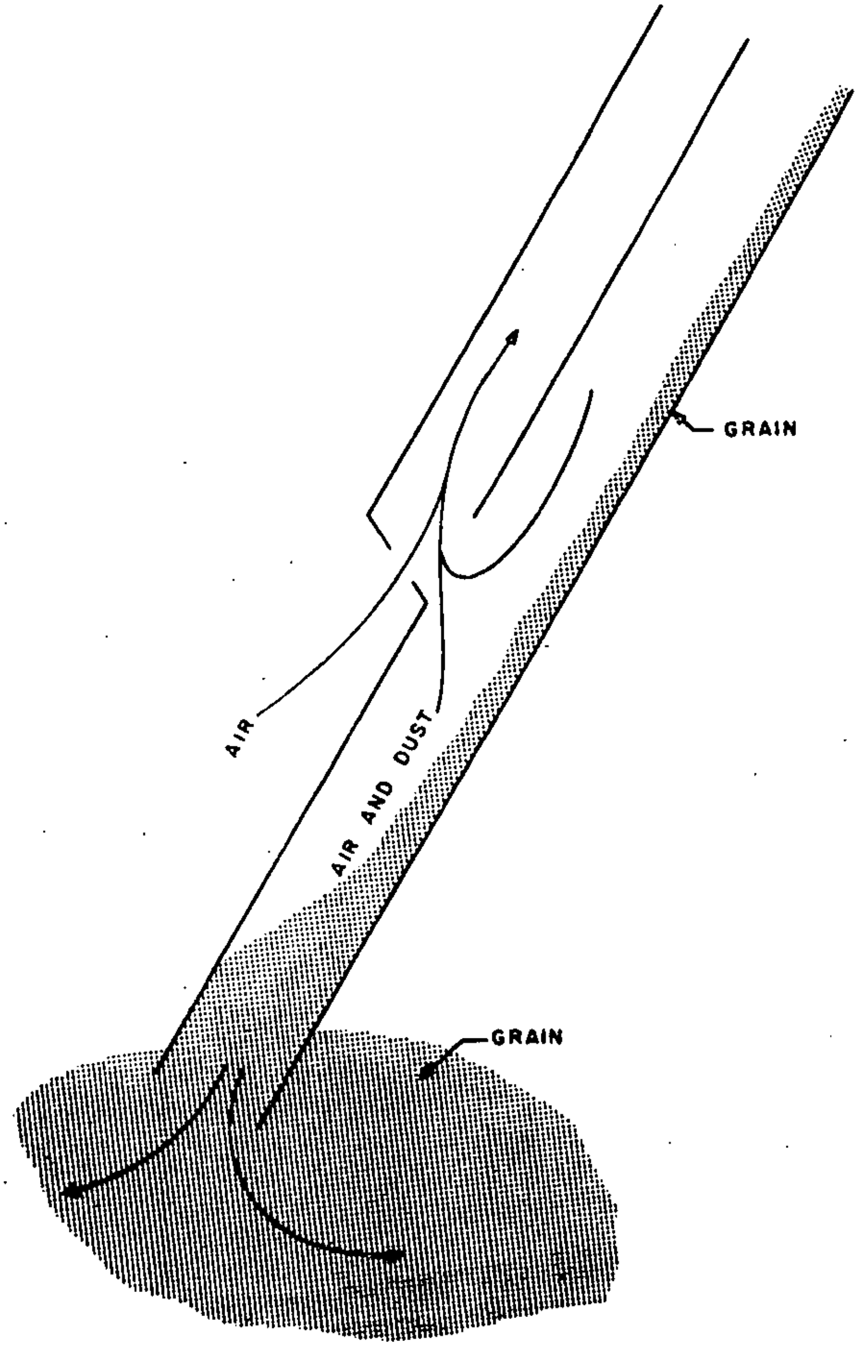


Figure 4. Submerged loader in use at Cargill in Seattle.

falls down the spout and when it hits the grain in the hold is removed through a port about 3 meters (10 feet) from the bottom of the spout. Dust laden air is drawn through a pipe attached to the loading spout to a fabric filtration system.

The grain loading rate used with this system is generally 1,500 t/hr, and the aspiration rate is about 325 m^3/min (12,000 cfm). The grain spouts are about 30 meters (90 feet) long, and can telescope by about 12 meters (40 feet), so that the top of the spout can almost always reach the grain level in the hold. The tip is generally kept buried 15 to 30 cm (6 to 12 in.) under the grain level. All of the movement of the grain spout is controlled by motors which can move the spout even when it is submerged. A Roto-Bin-Dicator®* sensor is located near the bottom of the leg, and shuts off the grain conveyors to the leg when the leg becomes clogged. This instrument is an electro-mechanical device consisting of a pressure sensitive diaphragm that actuates an electrical circuit when the pressure created by the grain exceeds a present level.

The Cargill-Seattle control system can be used either with the grain spout tip slightly submerged, or with the tip slightly above grain level. If the tip is kept within 15 to 30 cm (6 to 12 in.) above the grain level, the visible emissions should remain below the 20 percent opacity level. If the spout is kept buried by 15 to 30 cm, visible emissions are completely eliminated.[10] The grain spout should be kept buried, but should not be allowed to clog. When the spout clogs, it must be lifted out of the grain, causing visible emissions. During topping-off, the spout must be moved slowly, to prevent the tip from surfacing. The submerged loading system is effective both during bulk-loading and topping-off of bulk-carriers. For tween-decker loading, the Cargill-Seattle terminal has a trimmer which can be attached to the aspiration tube on the grain spout, so that trimmer dust emissions during tween-decker loading can also be reduced.

The capital cost of retrofitting a submerged loading system to an existing facility would depend on the loading spouts, gallery, dock and aspiration system in use at the facility in question. Such a retrofit would necessitate the attachment of telescoping aspiration tubes to the loading spouts, and would probably require additional telescoping capabilities for the spouts. Submerged loading would require a spout telescoping capability of 12 meters (40 feet), whereas spouts at most terminals can only be extended by about 6 meters (20 ft). From conversations with elevator operators and manufacturers of air pollution control equipment for grain elevators,[11] a rough estimate of the cost of such additions has been obtained. The cost would be on the order of $20,000 per leg. If there is no existing aspiration system at the facility in question, or if the existing system is not capable of handling the extra load of a submerged loading system, the cost would be much higher. Also, galleries at most terminals were not designed to handle the additional weight and torque of aspiration tubes and additional telescoping sections. Thus, installation of a control system similar to that at Cargill-Seattle may require refurbishing of the gallery, and perhaps even the loading dock. The cost of such work would probably approach the cost of retrofitting dead-box control, about $1 million loading spout.

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*Bindicator - 800-521-6361, P.O. Box 9, 1915 Dove St., Port Huron, Michigan 48060

Comparison of Tents, Dead-Boxes and Submerged Loading Systems

Tents with aspiration are inexpensive to retrofit relative to the other two control technologies. They are very effective during bulk-loading; completely eliminating visible emissions with practically no operator attention. However, tents do not control emissions during topping-off or tween-decker loadings. Also tents do require additional work and time to set up before loading can be started. Setup time can be expected to decrease significantly as stevedores gain experience in use of the tent. High winds can also cause problems with tent control systems but this is a very infrequent problem in the Portland area.

Dead-box control systems require special galleries with sufficient height and strength, to handle the loading spouts and provide adequate manueverability. These systems operate in a vertical loading mode and the heavy spouts must be moved over the ship. Telescoping capability to reach nearly to the bottom of the shiphold is required. Dead-boxes, as a retrofit control system, are much more expensive than tents with aspiration. From an environmental viewpoint the advantage is that dead-boxes can control emissions during all phases of bulk-carrier loading. They require careful operator attention to keep the spout near the grain level and thus reduce emissions to below 20 percent opacity. No special setup time or effort is required to initiate loading. Typically, during bulk-loading, some visible emissions may be present. Dead-box systems do not control emissions from tween-deckers.

The costs of retrofit submerged loading systems are similar to dead-box systems when major gallery modifications are required. These slanted spout systems do not impose as great a demand on the gallery as a dead-box. There may be cases where submerged loading retrofit costs could be much less than dead-box costs. In fact, the submerged loading system in Seattle was originally designed to operate close to the grain pile, not submerged. No modifications were required to use submerged loading at the Seattle terminal. Other advantages and disadvantages of submerged loading are similar to dead-box systems.

SECTION 3

SITE INSPECTIONS AND MEASUREMENTS

INTRODUCTION

The objectives of this project were to measure the particulate emission factors for shiploading operations at the four Portland, Oregon grain terminals and to determine the feasibility of controlling these emissions to meet the Oregon state visible emissions limit of 20 percent opacity. All four Portland terminals frequently have particulate emissions whose opacities exceed 20 percent. The Portland terminals are run by the Bunge, Louis Dreyfus, Cargill and Columbia Grain companies. Bunge and Louis Dreyfus have tents with aspiration systems to control shiploading emissions, while Cargill has a dead-box control system, and Columbia is in the process of installing a dead-box. The Bunge and Louis Dreyfus terminals are located on the Willamette River in downtown Portland, while the Cargill and Columbia terminals are located 9 to 12 miles north of the city center.

In November 1977 the General Mills and International Multifoods grain elevators in Duluth, Minnesota were visited in order to obtain background information on shiploading operations at grain elevators, and to determine what measurements could be made to estimate dust emission factors. The four Portland terminals were visited in January 1978. The opacities of visible dust emissions were observed, and measurements of dust levels downwind of shiploading equipment were made. Results of these measurements have been used to estimate emission factors for the elevators. Two elevators in the State of Washington - Cargill in Seattle, and Continental in Tacoma - were also visited in January 1978 as examples of well-controlled shiploading facilities.

Background information on shiploading and on particulate emission control equipment for shiploading was provided by representatives of each of the nine grain elevators visited by GCA personnel. This information is summarized in Table 1. The total amount of grain loaded at the four Portland sites is about 4 million tons (long tons or metric tons)/year. The average ship loaded has a grain capacity of about 18,000 metric tons. About 5 percent of the ships loaded are tween-deckers but, because of their small capacity, they only account for about 2 percent of the grain loaded. Few, if any, tankers are used to carry grain in Portland.

The Portland grain elevators load wheat almost exclusively. The grain is generally transported to the elevators by train from eastern Washington or Idaho. The wheat shipping business depends on export demand but the January to April period usually represents 50 percent of the annual shipments.

TABLE 1. BACKGROUND INFORMATION ON SHIPLOADING OPERATIONS

Company	Location	Average ship size (1000 t)	Percent of tween-deckers	Percent of tankers	Grain loading rate (t/hr)	Topping off rate (t/hr)	Tween-decker loading rate (t/hr)	Tween-decker topping off* (percent)	Emission control	Aspiration rate (m^3/min)
International Multifoods	Duluth	15	-	-	400	-	-	-	None	-
General Mills	Duluth	-	-	-	-	-	-	-	None	-
Bunge	Portland	16	5	-	1,200	600	120	30	Tent	240
Louis Dreyfus	Portland	22	5	0	1,000	400	-	10	Tent	80 - 240
Cargill	Portland	27	-	0	2,200	500	-	12	Dead-box	-
Columbia Grain (Cook)	Portland	7	7	0	1,000	200	-	30	Dead-box	340
Continental Grain	Tacoma	37	0	7	1,000	300	-	-	Dead-box	708
Cargill	Seattle	22	7	2	1,500	750	400	-	Submerged load	680
United Grain	Tacoma	-	-	-	750	-	-	-	Tent	283

*The time spent topping-off at each facilities varies because ships often obtain grain at more than one facility. Some facilities do more bulk-loading while other facilities do more topping-off.

SITE DESCRIPTIONS AND VISUAL OBSERVATIONS

Portland Facilities

Bunge--

The Bunge terminal was inspected 7 January 1978, in September 1978 and again in March 1979. During the first inspection, a 15,000 metric ton capacity bulk-carrier was being filled with wheat. Messrs. J. Faherty and R. Palmquist described shiploading operations and particulate emission control equipment. The Bunge facility handles wheat exclusively and loads about 98 percent of this wheat to bulk-carriers. The remainder is loaded to tween-deckers.

The loading chutes at Bunge are slanted and are about 15 m (50 ft) long with the capacity to telescope in length about 6 m (20 ft). They can generally reach below the hold cover level during bulk-loading but sometimes cannot reach the grain level during topping-off, because at this time the ship is low in the water. Although there are several chutes at the facility, only one is usually used at a time. The loading rate is about 1,200 t (long tons or metric tons)/hr during bulk-loading, 600 t/hr for topping-off, and 120 t/hr for tween-decker loading.

A tent made of light weight plastic is available to control particulate emissions from bulk-loading at the Bunge terminal, but it is presently not in use for reasons mentioned earlier. The tent has a collar in its center through which the loading spout can be inserted. It is generally tied down at the edges of the hold. The associated aspiration system draws air from under the tent through flexible hoses to a manifold system connected to a fan and a fabric filter. The fan-fabric filter system were designed to handle 880 m^3/min (31,000 acfm) but the flexible hoses apparently limit the amount of air that can be withdrawn from a single hold. Only two hoses are capable of reaching any single hold and reportedly about five hoses must be left open to prevent collapse of the hoses in use. The actual ventilation rate applied to a hold varies depending on the number of hours in the hold, the number of hoses left open and the position of the hoses relative to the fan. With one hose in the hold, the aspiration rate is typically 110 - 140 m^3/min (4,000 - 5,000 acfm).

During bulk-loading the tent aspiration system completely eliminated visible emissions. Without aspiration the tent tended to inflate and some visible emissions were evident at the sides of the tent. These visible emissions are minor and variable; they may or may not exceed the 20 percent opacity limit. The ventilation rate of 110 - 140 m^3/min (4,000 - 5,000 acfm) was adequate to eliminate visible emissions during bulk-loading.

During uncontrolled loading and topping-off opacities up to 60 percent were observed. A formal visible emissions evaluations (EPA Method 9) was conducted by GCA on September 18, 1978.[14] Nine sets of 6 minute readings at Bunge indicated an average opacity of 48 percent with individual 6 minute readings ranging from 30 to 60 percent. A tween-decker was being loaded during the above observations but informal observations of bulk-carrier loading indicated similarily high opacities.

Louis Dreyfus--

The Louis Dreyfus facility in Portland was visited 9 January 1978, in September 1978 and in March 1979, and Messrs. L. Harper and D. Guthrie described shiploading operations. Like the Bunge terminal, the Dreyfus elevator handles mostly wheat and loads mostly bulk-carriers. About 2 percent of the grain handled is loaded to tween-deckers, and an insignificant amount is loaded to tankers. During the January visit, a 35,000 metric ton bulk-carrier was being loaded with wheat.

The facility has several slanted loading spouts of which one is used at a time. The chutes are about 15 meters (50 feet) long and can telescope about 6 meters (20 feet). The loading rate is 1,000 t/hr during bulk loading, and 250 to 500 t/hr during topping-off or tween-decker loading.

At the time of the first inspection, construction of the aspiration system had not been completed at Dreyfus, however a tent was available to reduce dust emissions. The tent aspiration system has since been completed and was in operation during the March 1979 visit. There are three sets of two aspiration hoses, about 50 cm (18 in.) in diameter, connected by duct work to a fan and a fabric filter. The total capacity of the filter is 878 m^3/min (31,000 acfm), however some of the air is drawn from transfer points. In addition, the full capacity of the system is not applied to the hold in which grain is being loaded. At least two hoses are typically left open outside the hold while two are placed in the hold. GCA's measurements showed an aspiration rate of (160 m^3/min) 5,600 acfm when two hoses were in the hold and several hoses were open between the active hoses and the fan. In a second case one hose exhausted air from beneath a tent at 120 m^3/min (4,300 acfm). This latter hose was connected to the manifold near the fan and only two hoses, both farther away from the fan, were open. Some visible emissions seeping from the tent were evident when the aspiration rate was 80 m^3/min (2,800 acfm) but all visible emissions were eliminated at the higher aspiration rates.

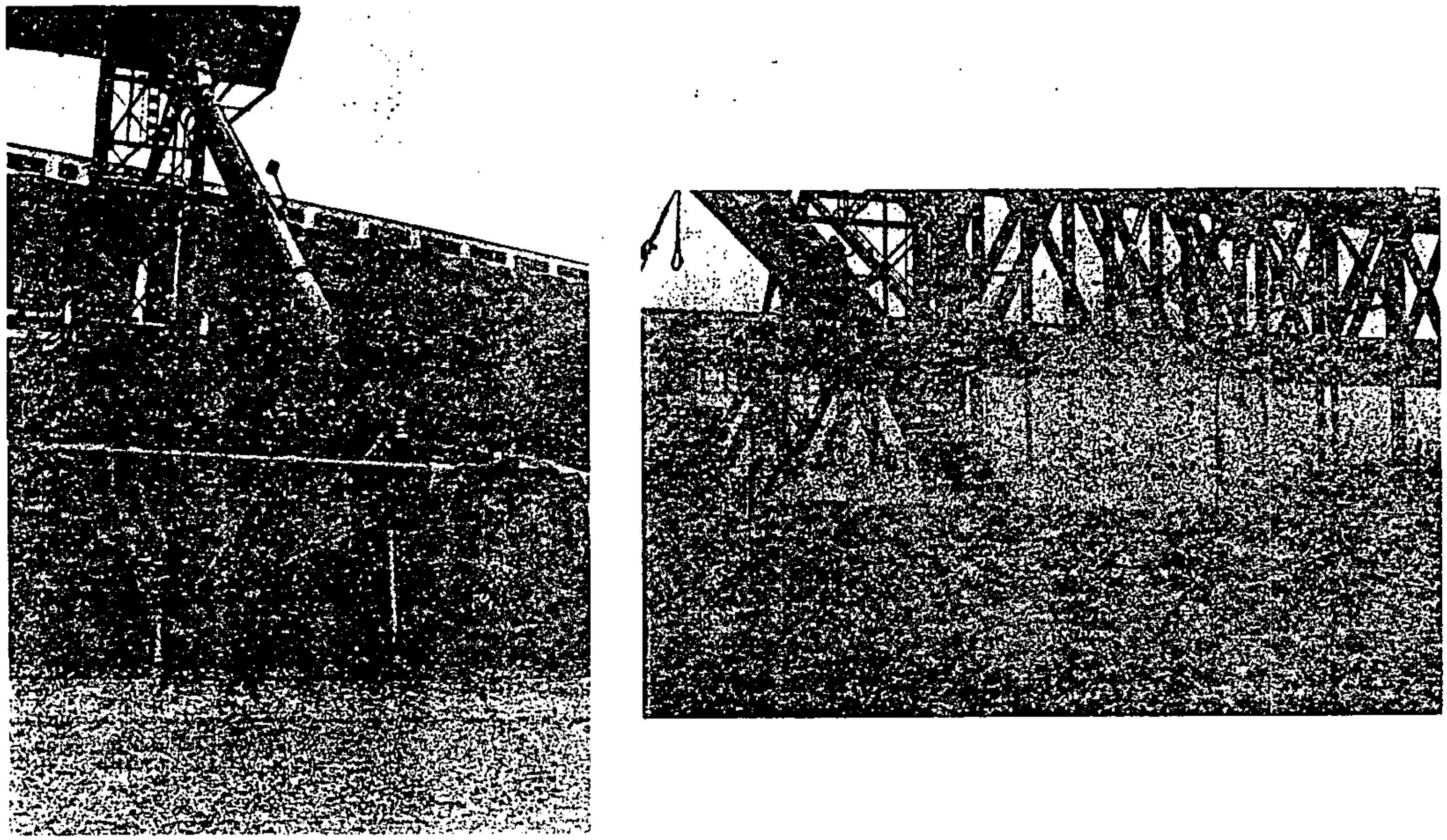
Seven sets of formal (EPA Method 9) observations of opacity, during uncontrolled loading, were conducted at Louis Dreyfus Corporation on September 18, 1979.[14] Average opacity was 38 percent with a maximum 6-minute reading of 52 percent and a minimum of 32 percent. Similar informal data were obtained during the January 1978 inspection.

Photographs of shiploading operations at the Louis Dreyfus terminal are presented in Figure 5.

Cargill--

The Cargill terminal in Portland was inspected 10 January 1978. The elevator superintendant, Mr. H. Johnson, provided background information on elevator operations. The Cargill elevator only handles wheat, and loads bulk-carriers almost exclusively. For example, during the latter half of 1977 no tankers were loaded and only one tween-decker was loaded. During the visit, a 35,000 metric ton bulk-carrier was being loaded with wheat.

Cargill uses dead-boxes to control particulate emissions from shiploading. There are several vertical spouts equipped with dead-boxes, but only one is used at a time. Grain flows through the dead-box at a rate of 2,000 to 2,500 t/hr during bulk-loading and 700 to 800 t/hr during topping-off. Air is drawn from the box to a fabric filter.



Tent control system — *Topping-off operation*

Figure 5. Grain loading operations at the Louis Dreyfus elevator.

The dead-boxes worked well when they were properly operated. During the morning of January 10, an entire hold was filled and topped-off with visible emissions limited to 10 percent opacity. During the afternoon, another hold was loaded by a different group of longshoremen, who did not operate the dead-box properly. The opacity above the hold averaged over 40 percent and was at times 100 percent.

Figure 6 shows grain loading operations at the Cargill elevator.

Columbia Grain--

On 11 January 1978, the Columbia Grain terminal, then the Cook terminal, was inspected. The plant superintenant, Mr. J. Beach, and the plant foreman Mr. Henning, described loading operations at the terminal. Like the other Portland elevators, this terminal handles mostly wheat and bulk-carriers, although about 2 to 4 percent of the grain handled is loaded to tween-deckers. During the visit, Cook was loading a bulk-carrier with wheat.

The terminal uses vertical loading chutes and loading rates of 1,000 t/hr for bulk-loading, and 150 to 200 t/hr for topping-off. Particulate emissions during shiploading are presently uncontrolled, however installation of a dead-box type control system is underway. The air aspiration rate from the top of the dead-box will be 340 m^3/min (12,000 acfm).

During the January 11 visit, the grain-loading spout was held 3 to 9 m (10 to 30 ft) above the grain level in the hold. Large visible clouds with opacities approaching 100 percent were produced. The clouds were visible 100 (330 ft) downwind of the dock. Figure 7 shows grain-loading operations at the Columbia elevator during the January visit.

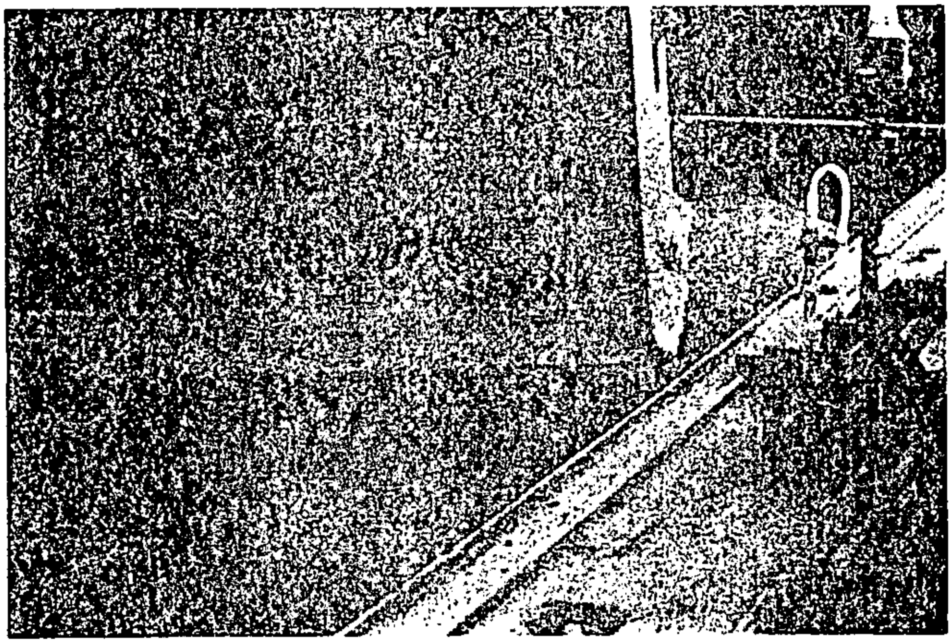
Other Facilities

Continental Grain - Tacoma, Washington--

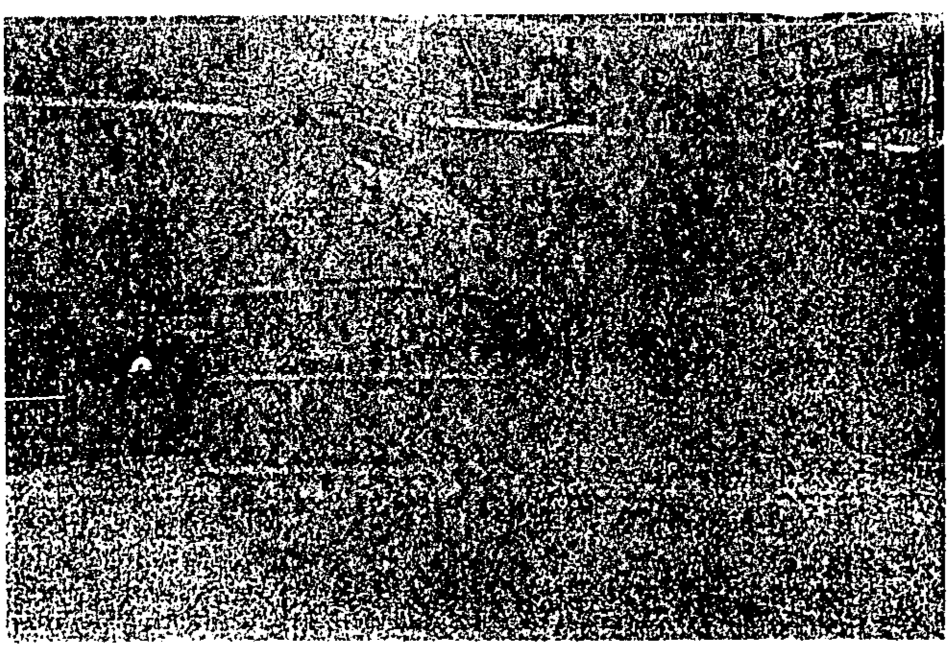
The Continental Grain terminal in Tacoma, Washington was visited 14 January 1978 as an example of a well-controlled facility. Mr. D. Davis described shiploading operations at the facility. Most of the ships loaded are bulk-carriers, with about four tankers being filled per year. Very few tween-deckers are filled. The terminal handles mostly wheat but also ships some feed barley, corn, sorghum and pellets. During the visit, a 14,000 metric ton bulk-carrier was being filled with beet pulp feed pellets.

The Continental Grain terminal uses dead-boxes to control particulate emissions from shiploading. Grain flows through the dead-box, which is called a "bullet" at Continental, at 1,000 t/hr during bulk-loading and 300 t/hr during topping-off. Air is drawn from the top of the box to a fabric filter at a rate of 710 m^3/min (25,000 acfm).

The performance of Continental's "bullet" system depended, as did the performance of the Cargill-Portland dead-box system, on how it was operated. During the January 14 visit, the bullets were held much too far above the pellet levels in the holds. Because of this, and because pellets are dustier than grain, the dust emissions were sometimes substantial. Opacities above the hold ranged from 0 percent to as much as 50 percent. Figure 8 shows the bullet control system in use.

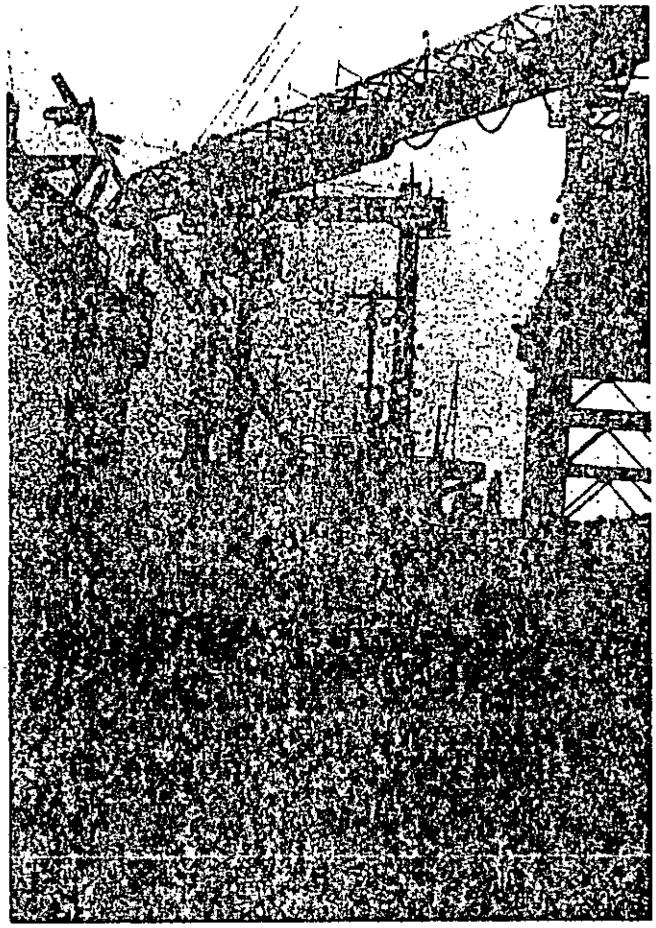


Dead-box control system operated correctly with GCA measuring equipment



Dead-box control system operated incorrectly

Figure 6. Grain-loading operations at the Cargill elevator.



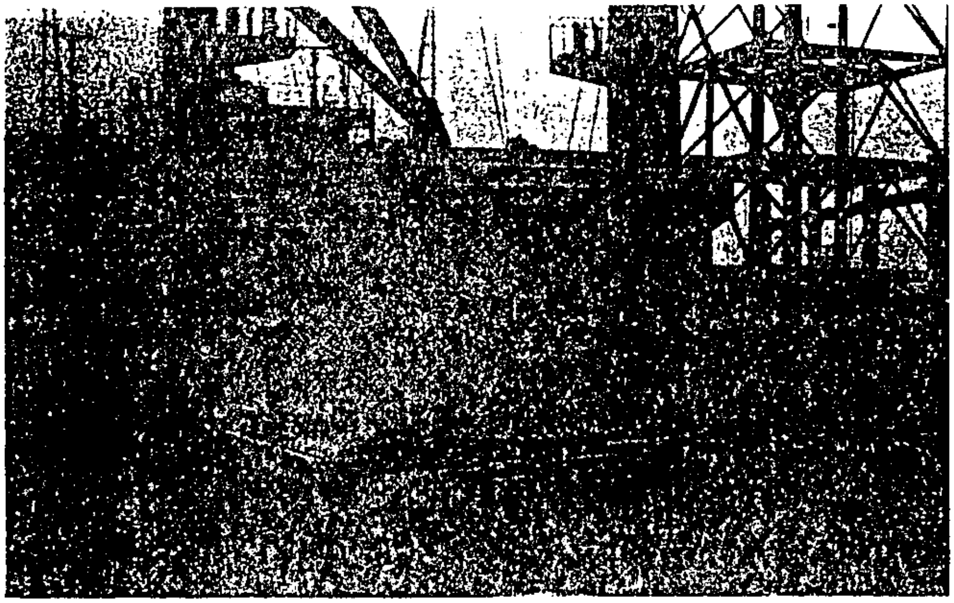


Figure 7. Uncontrolled shiploading operations at the Columbia elevator.

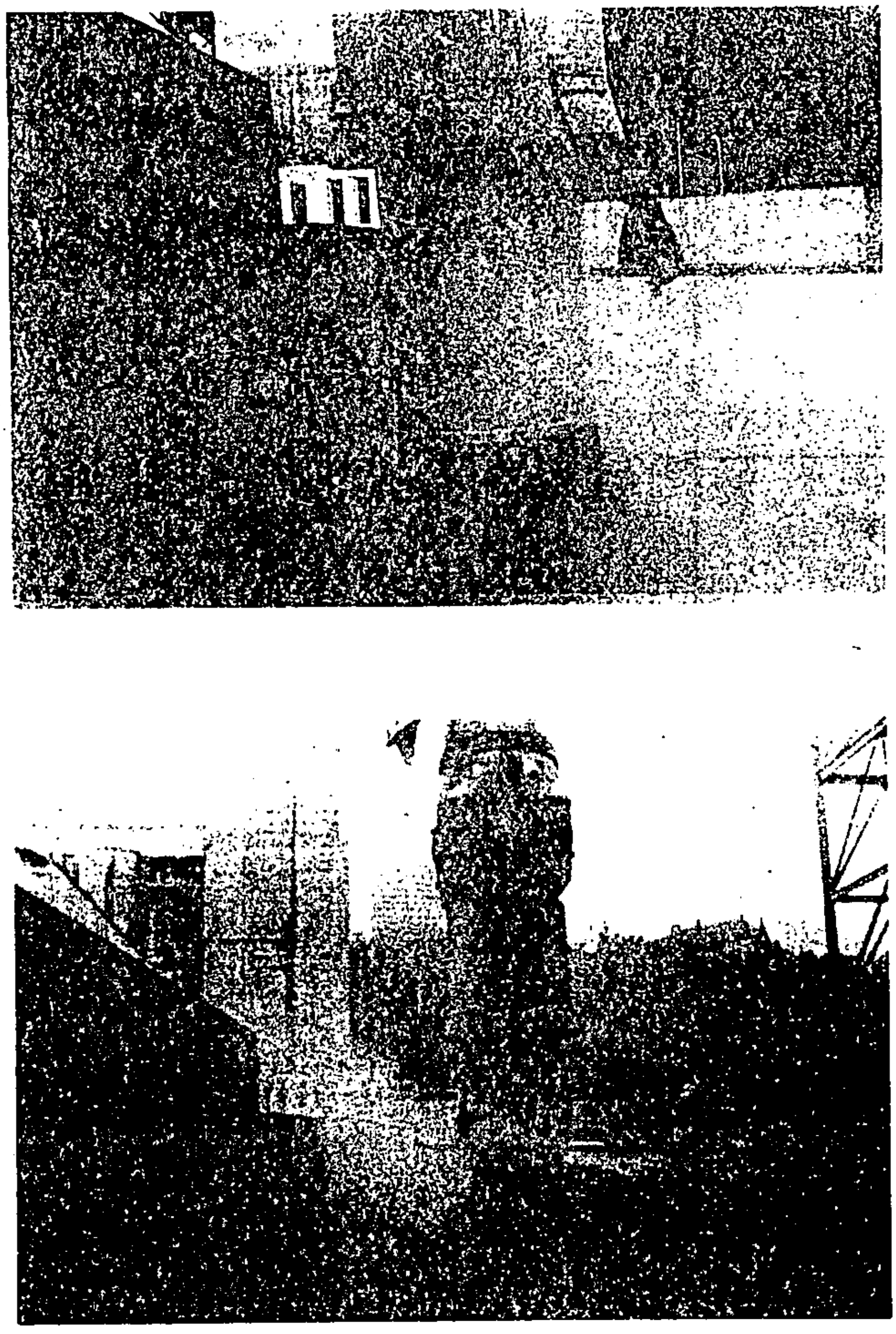


Figure 8. Bullet or dead-box control system at Continental grain in Tacoma.

Cargill-Seattle, Washington--

The Cargill terminal in Seattle, Washington was visited 16 January 1978, in order to observe an operating submerged loading system. Messrs. J. Downes and M. Rudolph described shiploading operations at this facility. Cargill handles mostly wheat and some corn and barley. About 90 percent of the ships loaded are bulk-carriers, while some 8 percent are tween-deckers, and 2 percent are tankers. During the inspection, a bulk-carrier was being filled with wheat.

The submerged loading system in use at Cargill in Seattle was described earlier (see the BACKGROUND section). The system eliminated visible emissions when the loader was kept buried. It was effective both during bulk-loading and during topping-off of the bulk-carrier. Occasionally, the loader would become buried too deep due to inattention on the part of the operator, and it would become clogged. When this occurred, the loader had to be lifted out of the grain and visible emissions in excess of 20 percent opacity were produced.

The submerged loading system worked well during loading and topping-off There were usually no visible emissions (see Figure 9). When loading of a hold was begun, some dust was formed in the hold because the spout did not reach the bottom of the ship, and because there was not enough grain for the spout to be buried. This dust generally settled back into the hold and no clouds were formed above the hold. Occasionally, during bulk-loading, the spout was moved to keep the grain level. If the spout was moved too quickly, some dust was formed. Also, the spout would sometimes become clogged and it was necessary to raise the spout above grain level to let the grain flow out. This created clouds with opacities of up to 10 to 30 percent for about 1 minute. Usually, however, the submerged loader was properly used and there was no visible emissions.

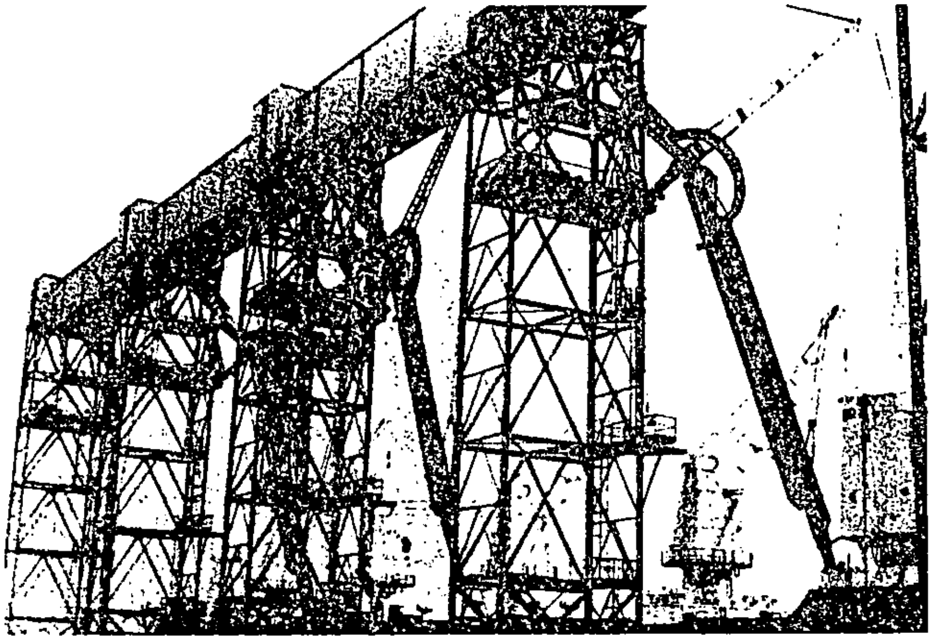
United Grain - Tacoma, Washington--

The United Grain terminal in Tacoma was visited 15 to 18 November 1978 in order to determine whether tent control of particulate emissions from shiploading could pose an explosion hazard at the Bunge and Louis Dreyfus terminals in Portland. During the visit, a bulk-carrier was being loaded with wheat. Dust concentrations and other parameters related to dust explosibility were measured at various locations inside the holds of the ship during both tent controlled loading and uncontrolled loading or topping-off. The tent eliminated visible emissions during bulk-loading of wheat.

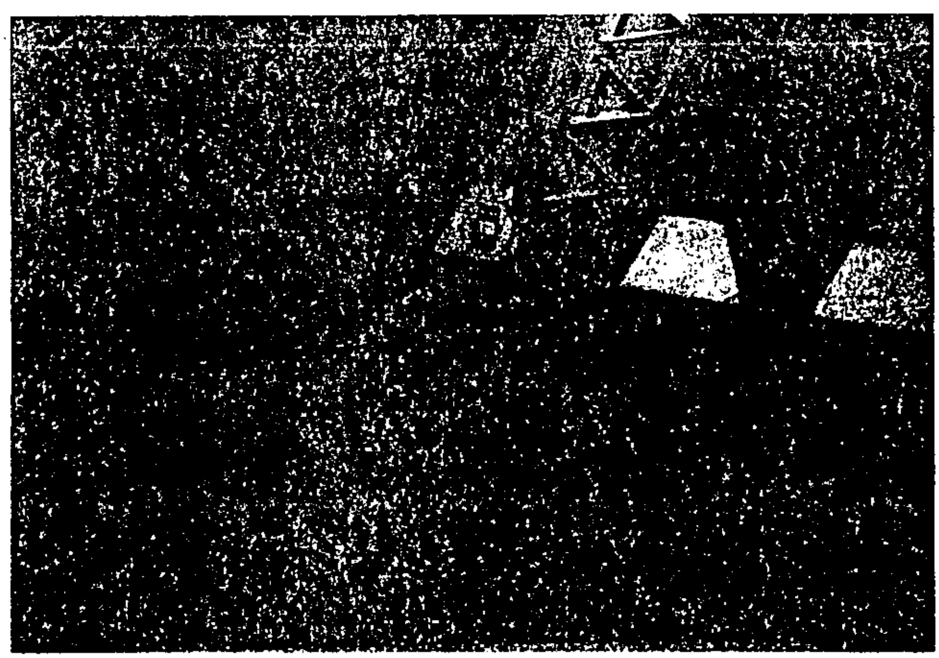
Duluth Facilities

The International Multifoods and General Mills terminal grain elevators in Duluth, Minnesota were visited 16 and 17 November 1977. Shiploading operations were observed in order to determine what type of measurements could be made to estimate particulate emissions from shiploading.

Mr. H. Graves of International Multifoods provided background information on loading operations at Duluth. The International Multifoods terminal handles about 85 percent wheat and 15 percent barley, and does most of its business in the spring and fall.



Submerged loading system in use



View of the loading system and conveyor gallery

Figure 9. Cargill submerged loading facility in Seattle.

Both of the terminals have several loading spouts which are attached to the elevators themselves, rather than galleries on the docks. The spouts must be moved by hand, and are capable of pouring grain at only 400 metric tons (long tons)/hr. Neither of the terminals use control systems to reduce particulate emissions from shiploading.

Summary of Visual Observations

Observations were made of the performance of all three types of particulate emission control systems presently in use: tents with aspiration, dead-box systems, and submerged loading systems. Uncontrolled loading operations were also observed; opacity during uncontrolled loading was usually 30 to 50 percent.

Tent systems with aspiration eliminated visible emissions during bulk-loading of bulk-carriers, however these cannot be used for topping-off of bulk-carriers or for tween-decker loading. Opacity during topping-off and tween-decker loadings is typically 30 to 50 percent with both higher and lower opacities possible. However, emissions from uncontrolled topping-off and tween-decker loading are clearly greater than 20 percent opacity.

Dead-box control systems were capable of greatly reducing visible emissions during both bulk-loading and topping-off of bulk-carriers under typical conditions. During observations made by GCA, when the boxes were held less than about 60 cm (2 ft) above the grain level, and moved about slowly, there were virtually no visible emissions. When, however, dead-boxes were held high above grain level or were allowed to swing visible emissions easily exceeded 20 percent opacity. Also, when pellets were loaded rather than wheat, as was the case during observations of loading operations at the Continental Grain terminal in Tacoma, Washington particulate emissions with opacities greater than 20 percent were generally visible.

The submerged loading system in use at the Cargill elevator in Seattle reduced particulate emissions to an even greater extent than did the dead-box control systems. The system was effective during both bulk-loading and topping-off of a bulk-carrier. As with dead-box systems though the performance of the system depended on how well it was operated. When the loader was kept submerged, visible emissions were eliminated. When it was allowed to clog, it was necessary to raise it above grain level, causing visible emissions in excess of 20 percent opacity.

Performance of dead-box and submerged loading systems is very dependent on the performance of the operator. Tents do not require operator attention after they are properly attached to the hold.

EMISSION MEASUREMENTS

At the four Portland grain elevators, total and respirable particulate concentrations were measured in the dust clouds generated during shiploading. Particle size distributions were also determined. The concentrations, along with estimates of cloud cross-sectional areas and wind velocities, were used to estimate particulate emission rates of shiploading operations. Size distributions were used to determine what fraction of the particles emitted will tend to remain suspended over long distances.

A probe consisting of an Andersen* cascade impactor, a cyclonic preseparator also made by Andersen, and a glass fiber back-up filter was used to measure total particulate concentrations and to determine particle size distributions. Air was drawn through the probe by a vacuum pump and the flow rate was maintained at about 9.1 liters/min (0.32 acfm) by critical orifices. Any particles entrained in the sample air were collected by inertial impaction or filtration either in the cyclonic precollector, on one of seven preweighed substrated in the Andersen impactor, or on the preweighed back-up filter. At the 9.1 liters/min flow rate, the impactor and associated collectors classified particles into the following size ranges:

- ≤ 0.71 μm (micrometers),
- 0.71 to 1.04 μm,
- 1.04 to 1.57 μm,
- 1.67 to 3.3 μm,
- 3.3 to 5.2 μm,
- 5.2 to 7.7 μm,
- 7.7 to 11.2 μm,
- 11.2 to 13.5 μm,
- ≥ 13.5 μm.

Average concentrations and size distributions of particulate matter in air sampled during a run were determined using the weight of particles collected in the cyclone, the weights of the back-up filter and impaction substrates before and after the run, the sample air flow rate, and the run duration. Durations of the Andersen impactor runs ranged from 25 to 62 minutes.

An RDM-101 respirable dust monitor produced by GCA Corporation's Precision Scientific Group† was also used occasionally to measure respirable dust concentratons. The RDM-101 collects particles smaller than 3 to 6 μm and larger than about 0.4 μm by impaction onto a greased substrate. Beta ray attenuation is used to determine the amount of particulate matter collected on the substrate, and the RDM automatically calculates the average respirable dust concentration in the sampled air and displays the concentration as a digital readout. The RDM was used to make short-term measurements (1 to 5 minutes).

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* Andersen 2000, Inc., P.O. Box 20679, Atlanta, Georgia 30320, see Reference 12 for a description of the Andersen impactor.

† GCA Corporation, Precision Scientific Group, Burlington Road, Bedford, Mass. 01730

Particulate Concentrations and Size Distributions

The results of Andersen impactor measurements are presented in Table 2 and in Figure 10. The measurements were made at the edges of the holds being loaded at the four terminals, generally downwind of the emission sources. One run was made at each of the Bunge and Louis Dreyfus terminals during topping-off operations. Two runs were made at each of the other two terminals, Columbia and Cargill. The two runs made at the Columbia terminal were both made downwind of the loading spout during uncontrolled bulk-loading and yielded similar results.

At Cargill, the first run was made while the dead-box was being operated properly, with no visible emissions. The second run was made while the dead-box was held far above grain level and was being moved much too quickly. The probe was located in the same place relative to the dead-box and loading spout during the two runs. It is interesting to note that the average concentration measured in the first run while the dead-box was operated properly, is a factor of 10 below that measured in the second run.

Particles smaller than 30 μm (suspendable dust particles) have been estimated using total concentrations and size distribution data extrapolated to 30 μm as shown in Figure 10. These estimates are presented in Table 3, with results for total particulates and the less than 3 μm fractions (respirable particulates). Particles longer than 30 μm will settle out of the atmosphere near the grain terminal facilities possibly causing complaints as a result of nuisance dust. Particles smaller than 30 μm will remain suspended in the atmosphere and contribute to ambient air quality degradation. Respirable particles if inhaled tend to deposit in lungs possibly contributing to health effect problems.

Respirable particles were also measured with the respirable dust monitor. Results were typically one-third to one-half the results for the similar size fraction measured by the Andersen impactor. These results were used primarily to define the plume and for short-term (1 to 5 minutes) indications of dust concentration. Differences in sampling configuration and sampling intervals may be responsible for the differences in results. The Andersen impactor measurements are used in this report because they represent longer sampling intervals (25 to 60 minutes).

Emission Rates

One method of estimating particulate emission rates from a source producing visible dust emissions involves studying a cross-section of the cloud in a plane perpendicular to the wind direction. The emission rate is equal to the product of the average dust concentration in the cross-section, the area of the cross-section, and the average windspeed.

In the test made at the Bunge terminal, the Andersen impactor was placed at the edge of the hold approximately 30 degrees removed from directly downwind of the emission source (see Figure 11). Because of the configuration of the ship, the equipment could not be placed directly downwind of the source. At the point where the measurements were made, the cross-section of the cloud

TABLE 2. RESULTS OF ANDERSEN IMPACTOR MEASUREMENTS IN PLUMES GENERATED BY GRAIN LOADING

Test	Test duration (min)	Total measured concentration (mg/m^3)	Size distribution (concentration in size range, mg/m^3)								
			> 13.5 μm	11.2-13.5 μm	7.7-11.2 μm	5.2-7.7 μm	3.3-5.2 μm	1.67-3.3 μm	1.04-1.67 μm	0.71-1.04 μm	< 0.71 μm
Bunge	37	89	54.8	4.8	7.4	7.7	7.1	5.0	1.5	0.0	0.6
Dreyfus	32	200	142	18.6	15.8	10.0	10.4	4.8	3.4	1.0	3.2
Cargill-1	62	9.3	5.9	0.18	1.1	0.19	0.53	0.35	0.53	0.36	0.18
Cargill-2	62	95	33.8	9.7	12.1	8.6	25.4	3.7	1.1	0.38	1.9
Columbia-1	25.4	104	39.3	14.4	10.4	15.6	11.8	9.6	2.6	0.42	0.0
Columbia-2	34	135	60.5	10.0	20.9	13.5	12.0	9.0	5.8	2.6	0.68

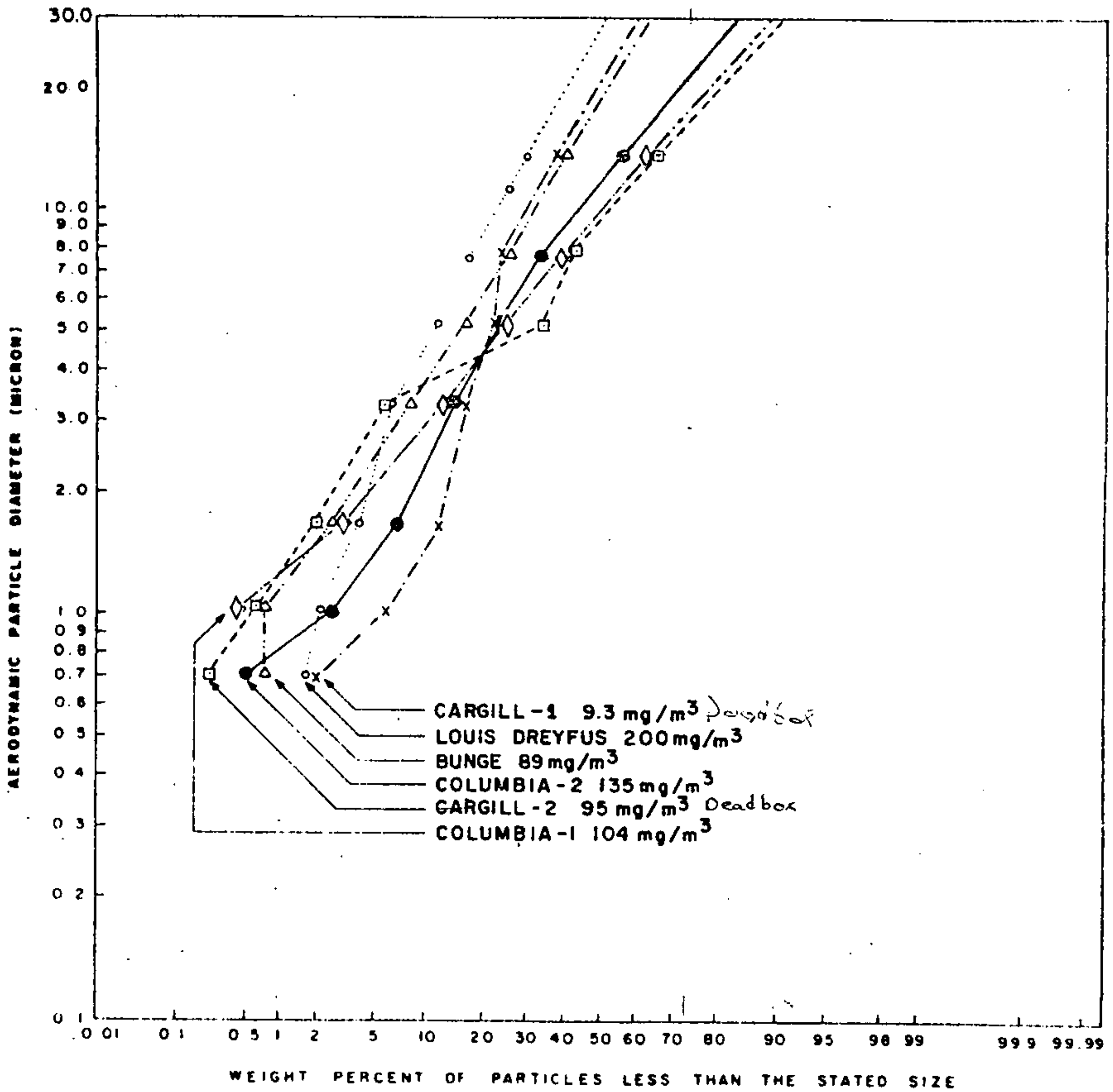

Figure 10. Size distribution of particulate emissions from shiploading, primarily topping-off.

TABLE 3. PARTICULATE CONCENTRATIONS IN SELECTED SIZE RANGES

Test	Total concentration mg/m^3	Suspendable particles (smaller than 30 μm) mg/m^3	Respirable particles (smaller than 3 μm) mg/m^3
Bunge	89	59	5
Dreyfus	200	100	10
Cargill-1	9.3	6.1	1.4
Cargill-2	95	81	4.6
Columbia-1	104	92	12
Columbia-2	135	110	13

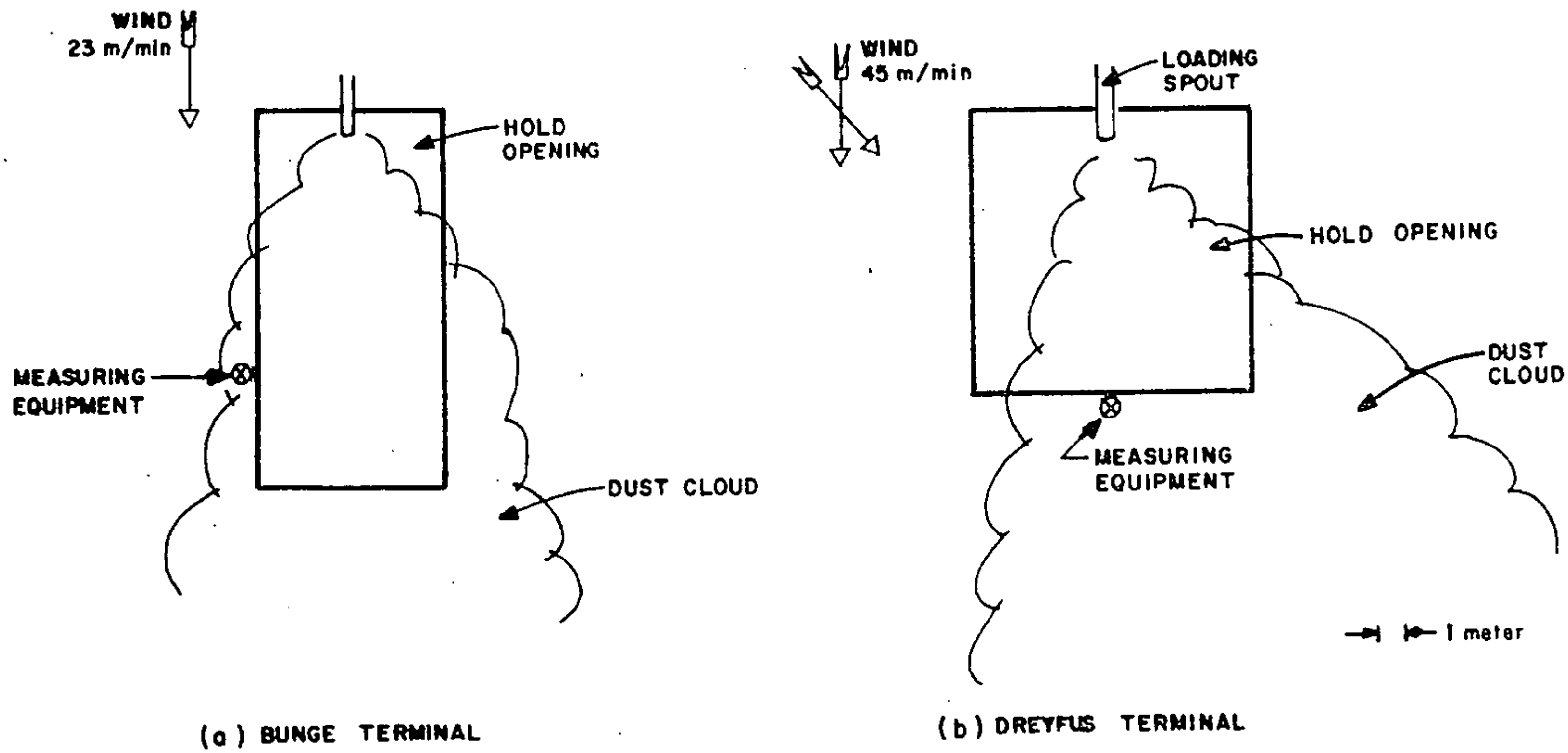

Figure 11. Placement of measuring equipment at the Bunge and Dreyfus grain loading terminals.

was roughly half elliptical, 12 meters (40 ft) high and 6 meters (20 ft) wide with an area of 56.5 m^2 (608 ft^2). The wind velocity was 23 m/min (75 ft/min) which indicates a volumetric flow rate of 1,300 m^3/min (46,000 acfm). Average particulate concentrations were 89 mg/m^3 total, 59 mg/m^3 suspendable and 5 mg/m^3 respirable indicating emission rates of 6.9 kg/hr (15 lb/hr) for total particulates, 4.6 kg/hr (10 lb/hr) for suspendable particulate and 0.39 kg/hr (0.86 lb/hr) for respirable particulates. Emission rates for Bunge and the other facilities are presented in Table 4.

At the Louis Dreyfus terminal, the Andersen impactor was placed directly downwind of the emission source (Figure 11). The average total, suspendable and respirable particulate concentrations were 200 mg/m^3, 100 mg/m^3 and 10 mg/m^3. At the point where these measurements were made, the cross-section of the cloud was roughly a half ellipse about 4.5 m (15 ft) high and 9 m (30 ft) wide, and the windspeed was 45 m/min (150 ft/min). The emission rates derived from the above data are 24 kg/hr (53 lb/hr), 12 kg/hr (26 lb/hr) suspendable dust, and 1.2 kg/hr (2.6 lb/hr) respirable dust.

During the first test at the Cargill terminal, the Andersen impactor and the RDM-101 were placed at the edge of the hold being loaded, about 45 degrees removed from the average downwind direction from the dead-box (see Figure 12). The windspeed was 30 meters/minute (100 ft/min) and the wind direction varied through at least 90 degrees. The average total suspendable, and respirable dust concentrations measured by the Andersen impactor were, respectively, 9.3 mg/m^3, 6.1 mg/m^3 and 1.4 mg/m^3. As was mentioned earlier there was no visible emission cloud during this test. It is therefore, impossible to estimate the dust emission rate by taking the product of the plume area, the windspeed, and the average concentration in the plume. However, based on the measured dust concentrations and observations at other facilities, emissions at Cargill appeared to be an order of magnitude lower than at Bunge and Louis Dreyfus.

During the second Cargill test, the dead-box system was not operated properly, and there were visible emissions. The Andersen impactor was located in the same spot as during the first test, but RDM-101 measurements were made in several different locations (see Figure 12). The wind was steady with a speed of 75 m/min (250 ft/min), but the top of the hold was sheltered from the wind on two sides by the hold covers which had been lifted to a vertical attitude. The average total, suspendable and respirable dust concentrations at the edge of the hold measured by Andersen impactor results were 95 mg/m^3, 81 mg/m^3 and 4.6 mg/m^3, respectively.

A slight upward airflow of 15 m/min (50 ft/min) could be detected at this site. This was presumably the result of turbulence caused by the raised hold covers. If one assumes that air was entering one side of the hold and leaving the other side at 15 m/min, emission rates were 6.1 kg/hr (13.5 lb/hr), 5.2 kg/hr (11.5) and 0.30 kg/hr (0.66) for total, suspendable and respirable particulates. RDM-101 readings were also taken some 12 m (40 ft) downwind of the dead-box, both behind the hold cover and on a small platform slightly higher than the hold cover level. At this point, the dust

TABLE 4. MEASURED EMISSION RATES FOR GRAIN LOADING

	Loading rate (t/hr)	Emission rate (kg/hr)*		
		Total particulates	Suspendable particulates	Respirable particulates
<u>GCA Observations and Tests</u>				
<u>Uncontrolled Loading</u>				
Bunge (topping-off)	600	6.9†	4.6†	0.39†
Louis Dreyfus (topping-off)	400	24	12	2.6
Columbia-1	1,000	47	42	5.5
Columbia-2	1,000	58	47	5.5
<u>Tent Controlled Loading</u>				
Bunge‡	1,200	0.0	0.0	0.0
Louis Dreyfus‡	1,000	0.0	0.0	0.0
<u>Dead-Box Controlled Loading</u>				
Cargill-1 (properly operated)	2,200	0.6	0.4	0.09
Cargill-2 (poorly operated)	2,200	6.1	5.2	0.30
<u>Monsanto Test§</u>				
Uncontrolled loading	630	-	-	0.42

*1 kg/hr = 2.205 lb/hr.

†These values may be low because of restrictions on the location of measuring equipment.

‡Estimates of 0 are based on the lack of visible emissions.

§Reference 13.

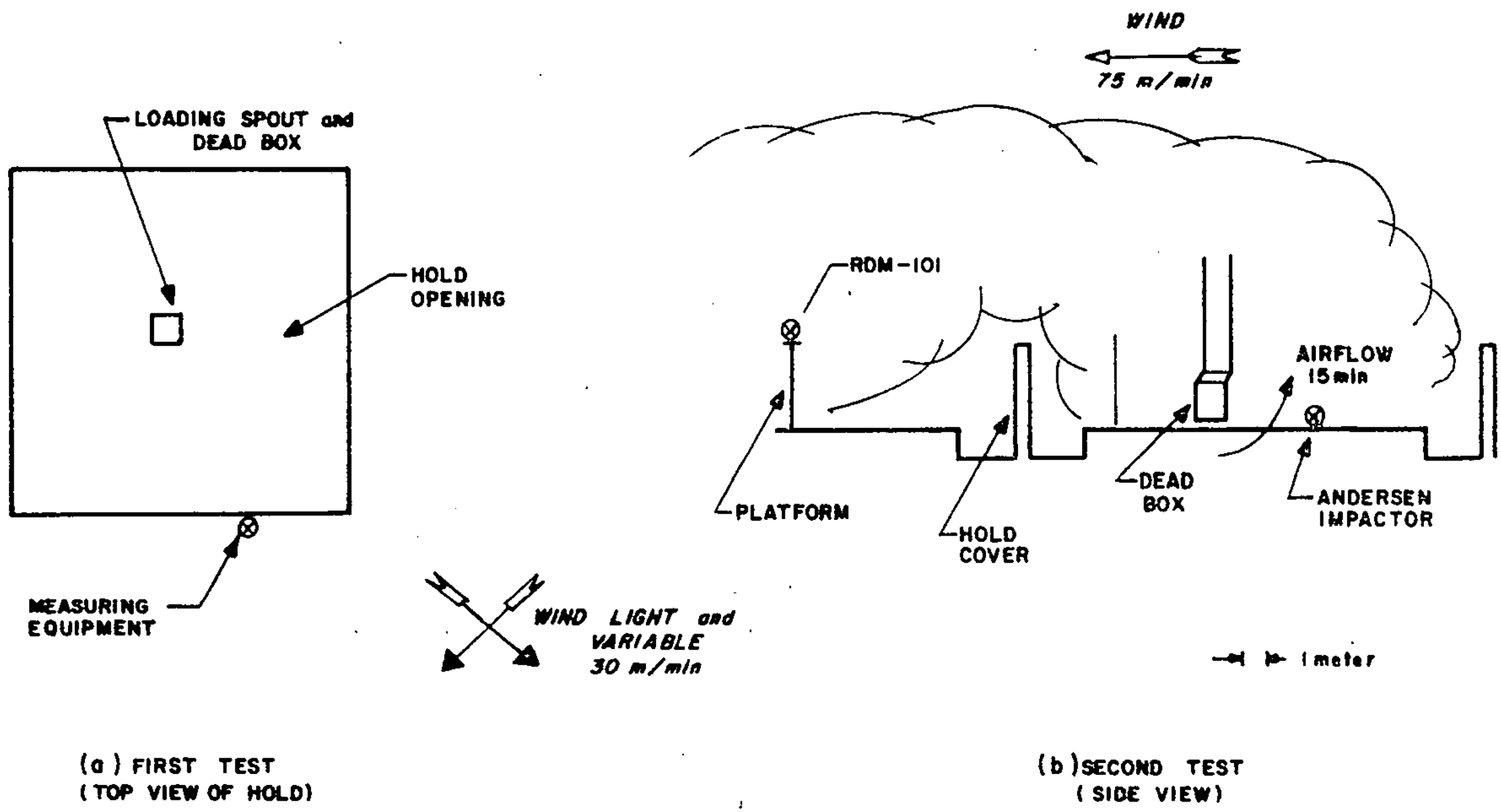

Figure 12. Placement of measuring equipment at the Cargill grain-loading terminal.

cloud cross-section was roughly circular, about 6 meters in diameter (see Figure 12). The average respirable dust levels at the deck level and on the platform were 0.23 mg/m^3 and 0.74 mg/m^3. The respirable dust emission rate given by the product of the average of these levels, the plume area, and the windspeed is 0.062 kg/hr (0.14 lb/hr), which is less than the 0.30 kg/hr (0.66 lb/hr) measured above the hold and the difference may be attributable to the different sampling locations and methods.

Very rough estimates of the emission rates during loading of the first hold at Cargill can be obtained by multiplying the emission rates for the second hold by the ratios of the concentrations detected at the edge of the hold opening during loading of the first hold to those detected during loading of the second hold. The emission rates 0.6 kg/hr (1.3 lb/hr), obtained by this method are 0.4 kg/hr (0.9 lb/hr) and 0.09 kg/hr (0.2 lb/hr) for total, suspendable and respirable dust, respectively. These represent estimates of emissions from well-run dead-box loading of wheat to bulk-carriers.

During emission testing at the Columbia terminal, the grain spout tips were kept at approximately the level of the hold covers, thus allowing grain to fall some 6 to 12 meters (20 to 40 ft) into the holds. Dust emissions were substantial. The Andersen impactor was placed at the edge of the hold, directly downwind of the loading spout, the emission source. RDM-101 readings were taken at approximately 1.5 meter intervals along the hold edge. The placement of measuring equipment is illustrated in Figure 13, and respirable dust concentrations measured during the two tests with the RDM-101 are presented in Table 5. During the first test the emission cloud being studied was half-elliptical in cross-section, and was 9 meters (30 ft) high and 10 meters (33 ft) wide in the plan where the measurements were made. The emission cloud studied in the second test was also half-elliptical 12 meters (40 ft) high and 14 meters (46 ft) wide. The windspeed during the tests was about 90 meters/min (300 ft/min).

Since dust concentrations were measured at several locations along the side of the holds during the two Cook tests, it is possible to calculate the average dust concentrations in the plumes at the hold edges, rather than merely calculating the time average concentrations for single spots as was done for the Bunge, Louis Dreyfus, and Cargill tests. The approximate average respirable dust concentrations for the plume passing through the instrument locations can be found by taking the averages of the sets of RDM-101 readings presented in Table 5 weighted by the squares of distances of the measuring equipment locations from the cloud center. This method assumes that variations of dust concentration with height were proportional to variations with horizontal distance perpendicular to the wind direction. The average concentrations of respirable dust given by this method are 2.6 mg/m^3 or 60 percent of the center point concentration for the first Cook test and 1.2 mg/m^3 on 31 percent of the center point concentration for the second test.

With the above data it is not necessary to assume that the Andersen impactor data at the plume center represents the full plume. Instead, one

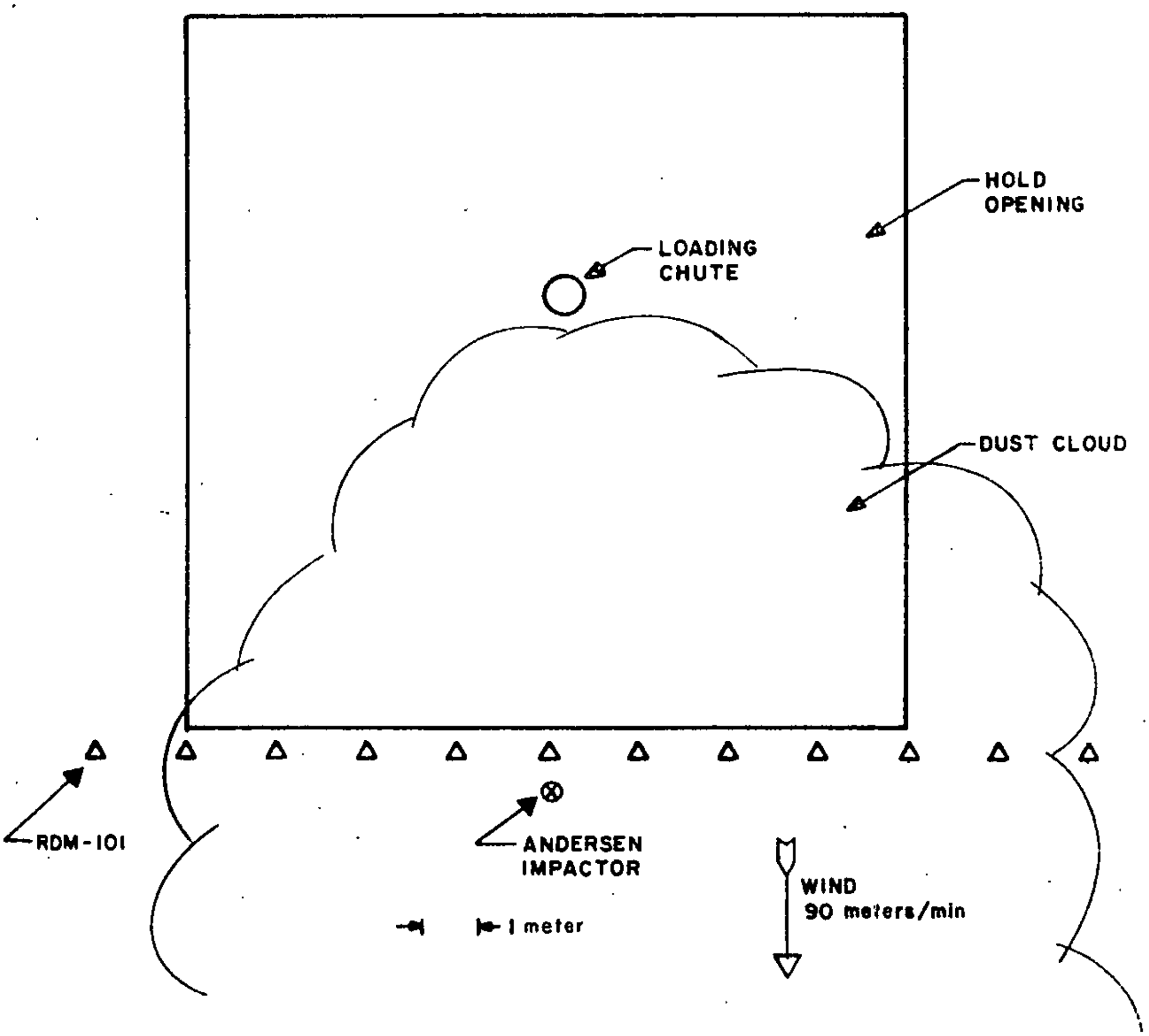

Figure 13. Measurements made at the Columbia elevator.

TABLE 5. RESPIRABLE DUST CONCENTRATIONS MEASURED AT THE COLUMBIA ELEVATOR

Distance and direction from impactor and plume center (meters)	Average concentration (mg/m^3)	
	Test 1	Test 2
-7.5	0.0	0.0
-6	2.2	0.4
-4.5	3.1	1.4
-3	5.5	1.2
-1.5	4.6	2.8
0	4.4	3.9
+1.5	3.6	3.1
+3	3.7	3.1
+4.5	2.3	3.1
+6	0.0	2.0
+7.5	0.0	1.2
+9	-	0.8

can assume that the plume average concentration is 60 percent and 30 percent of the Andersen impactor results represented in Table 3. The average suspendable dust concentrations by this method are 55 mg/m^3 for the first run and 33 mg/m^3 for the second test. Estimated emission rates are 42 kg/hr (93 lb/hr) and 47 kg/hr (104 lb/hr) suspendable dust for the first and second tests, respectively.

EMISSION FACTORS

Emission factors for various phases and types of shiploading at the four Portland grain terminals have been calculated using the emission rates estimated above and the loading rates used at the facilities. These are presented in Table 6. Estimates have been made in the past of emission factors for shiploading, however, these are not generally based on emission measurements, but on the amount of grain lost during shiploading, which is about 500 g/t (1 lb/ton).[15] This is a questionable method of estimating emissions, since some grain is spilled. Our measurement for total particulate emissions indicate an emission factor about one order of magnitude lower. Monsanto Research Corporation has also measured an emission factor for respirable dust from uncontrolled shiploading as shown in Table 6.

Visual observations indicate that emission factors for uncontrolled bulk-loading and topping-off operations should be similar. Emission factors estimated for uncontrolled bulk-loading at the Columbia terminal and for uncontrolled topping-off at the Louis Dreyfus facility are similar. The emission factors estimated for topping-off at the Bunge terminal should probably be disregarded because of the fact that measurement equipment was located at the fringe of the plume. The average estimated emission factors for uncontrolled loading (disregarding the Bunge tests) are 55 g/t (0.11 lb/ton) for total particulates, 40 g/t (0.08 lb/ton) for suspendable dust, and 5.8 g/t (0.012 lb/ton) for respirable dust. The Monsanto estimate of the respirable dust emission factor for uncontrolled loading, 0.67 g/t (0.0013 lb/ton) falls below the range of the GCA estimates of respirable dust emission factors for uncontrolled loading of wheat.

Estimated emission factors for dead-box controlled shiploading at the Cargill terminal are lower than those for uncontrolled loading, as would be expected. Also, the emission factor for the test where the dead-box was poorly operated (Cargill-2) are much higher than that for the test where the dead-box was well operated (Cargill-1).

The overall emission factors for shiploading with tent control can be estimated by taking the averages of the emission factors for uncontrolled loading and those for controlled loading, weighted by the percentage of time spent bulk-filling and topping-off for a typical hold. Grain elevator operators indicate that when tents are used to control dust emissions 10 to 30 percent of the hold must be filled without the tents (topping-off). Also, one can calculate the percentage of a hold which would normally be filled without the use of a tent. Normally in tent-controlled loading, the tent is used until the top of the pile of grain in the hold is within about 4 ft of the top of the hold. At this point the average distance between the top of the hold and the grain level in the hold will, of course, be greater than

TABLE 6. EMISSION FACTORS FOR SHIPLOADING

	Loading rate (t/hr)	Emission factor* (g/t)		
		Total particulates	Suspendable particulates	Respirable particulates
GCA Observations and Tests				
Uncontrolled Loading				
Bunge (topping-off)	600	.023 11.5†	7.7†	0.65†
Louis Dreyfus (topping-off)	400	60	30	6.5
Columbia-1	1,000	47	42	5.5
Columbia-2	1,000	58	47	5.5
Tent Controlled Loading				
Bunge‡	1,200	0	0	0
Louis Dreyfus‡	1,000	0	0	0
Dead-Box Controlled Loading				
Cargill-1 (properly operated)	2,200	0.3	0.2	0.04
Cargill-2 (poorly operated)	2,200	2.8	2.4	0.14
Monsanto Test§				
Uncontrolled loading	630	-	-	0.67

*1 gram/metric ton (1 g/t) = 0.002 pound/short ton (0.002 lb/ton).

†These values may be low because of restrictions on the location of measuring equipment.

‡Estimates of 0 are based on the lack of visible emissions.

§Reference 13.

4 ft, and will be determined by the shape of the hold, and the angle of repose of wheat, which is about 23 degrees. The volume of the unfilled portion of the hold would also be determined by these parameters. This unfilled portion is filled by topping-off. The percentage of a hold which would be filled by topping-off has been calculated for various loading conditions.

- For a hold 40 ft deep, 40 ft wide, and 40 ft long, which during bulk-loading, is filled so that the top of the grain pile is at the level of the top of the hold, the portion of the hold filled by topping-off would be about 15 percent.

- For a hold of the same dimensions which is filled so that the top of the grain pile is 4 ft below the top of the hold, the portion to be filled by topping-off would be about 25 percent.

- For a hold 60 ft deep, 60 ft wide, and 60 ft long filled so that the top of the grain pile is 4 ft below the top of the hold, about 22 percent would be filled by topping-off.

These volume percentages are in agreement with the estimates made by the elevator operators.

If, in tent-controlled loading, the portion of a hold filled by topping-off is assumed to be about 25 percent, the combined emission factors for the loading bulk-filling and topping-off will be roughly 25 percent of the emission factors for uncontrolled loading. Thus, the total emission factors for tent-controlled loading are about 14 g/t (0.028 lb/ton) for total particulates, 10 g/t (0.02 lb/ton) for suspendable dust, and 0.003 lb/ton for respirable dust.

Average emission factors for tent controlled loading are compared with emission factors for dead-box controlled loading and uncontrolled loading in Table 7. The table shows that average emission factors for tent controlled loading are 50 times higher than those for dead-box control when the dead-box is well operated; they are about 5 times higher than those for dead-box control when the dead-box is poorly operated.

TABLE 7. AVERAGE PARTICULATE EMISSION FACTORS

Process	Emission factors (g/t) [lb/ton]		
	Total	Suspended	Respirable
Uncontrolled loading	55 [0.11]	40 [0.08]	5.8 [0.01]
Tent controlled loading			
Bulk-loading	0	0	0
Topping-off*	55 [0.11]	40 [0.08]	5.8 [0.01]
Average*	14 [0.028]	10 [0.02]	1.5 [0.003]
Dead-box controlled loading			
Well operated	0.3 [0.001]	1.2 [0.002]	0.04
Poorly operated	2.8 [0.006]	2.4 [0.005]	0.14

*Note that only about 25 percent of the total grain loaded is loaded during the topping-off phase.

SECTION 4

TECHNICAL FEASIBILITY OF MEETING OPACITY REGULATIONS AT PORTLAND GRAIN TERMINALS

Observations of shiploading operations at the Portland grain terminals indicated that all four of the terminals were occasionally or frequently in violation of the State of Oregon visible emissions standard for the Portland area. This standard states that the opacity of visible emissions should not exceed 20 percent for more than 30 seconds of a given hour.

CARGILL

The dead-box control system now in use at the Cargill terminal at Portland is capable of satisfying the Oregon visible emissions standards during the loading of bulk carriers if it is properly used. If the box is kept within 6 to 18 inches of the grain level and is moved about slowly the opacity of visible emissions created by grain dropping from the box will be less than 20 percent. On the other hand, if the device is not used correctly, visible emissions with opacities in excess of 50 percent can result.

The Cargill terminal is also planning to modify a trimming machine so that emissions from the loading of tween-deckers can be controlled by ducting air from the machine to the fabric filter control system used for the dead-boxes. Such a system would be similar to the system for use during tween-decker loading at Cargill in Seattle, and is expected to reduce visible emissions to under 20 percent opacity.

Thus, in the near future, the Cargill terminal should be capable of meeting the present Oregon visible emissions standards except in severe weather or under other upset conditions.

COLUMBIA

The Columbia terminal in Portland is not presently capable of meeting the Oregon state visible emissions standard during any phase of shiploading. Columbia Grain is continuing the construction of a dead-box control system. When this control system is installed, the Columbia terminal will be able to meet the standard while loading bulk-carriers both during bulk-loading and during topping-off. The Columbia Company is also considering altering a trimming machine so that emissions can be controlled during the loading of tween-deckers. Whether an altered trimming machine is obtained will depend on how many tween-deckers are handled at the Columbia terminal in the near future.

BUNGE AND LOUIS DREYFUS

Both the Bunge and Louis Dreyfus terminals have tent control systems which are capable of eliminating visible emissions during most phases of shiploading. These systems are not presently used, because of concern generated by explosions at grain elevators in late 1977 and early 1978. Stevedores at Portland feel that containment of dust in the hold by tent control systems poses an explosion hazard. Measurements of dust concentrations under tents used to control emissions were made by GCA at the United Grain facility in Tacoma, Washington and at Bunge and at Louis Dreyfus. Results of these tests showed that dust concentrations found under the tents were well below minimum explosive limits for grain dust cited in literature.[1]

The tent control systems available at Bunge and Louis Dreyfus could be used for bulk-loading operations, but would not generally be used during topping-off or during the loading of tween-deckers. Emissions from these shiploading operations can technically be controlled by systems such as those in use at the Cargill terminal in Portland and the Cargill terminal in Seattle although the cost may be very high.

Problems associated with installing a submerged loading system such as that in use at the Cargill facility in Seattle are discussed in the BACKGROUND Section of this report (Section 2). Some changes would certainly be necessary in order for the Bunge and Louis Dreyfus terminals to use such a system. First, it would be necessary to increase the telescoping capabilities of the loading spouts from about 6 meters (20 ft) to about 12 meters (40 ft). Second, it would be necessary to attach telescoping aspiration pipes to the outside of the loading spouts, and to merge the pipes and the spouts in a manner similar to that illustrated in Figure 4. Third, a system would be needed whereby the conveyors feeding the loading spouts would be automatically shutdown when the spouts become clogged. Such a system is described in the BACKGROUND Section of this report (Section 2). The aspiration systems which were installed at the terminals for use with the tent systems are capable of meeting the aspiration needs of submerged loading systems; however, it would be necessary to install ductwork to connect the system to the loading spout aspiration pipes. The consensus of opionin of grain elevator operators in Portland and Seattle and manufacturers of pollution control equipment for grain elevators[11] is that the cost of these changes would be on the order of $100,000 to refit about five loading spouts. Some other changes may also be necessary. Both terminals use motors which are required to move loading spouts during submerged loading; however, it may be necessary to use more powerful motors. The cost of this change would be minor. The factor which will determine whether submerged loading would be feasible for the Bunge and Dreyfus terminal will be whether or not the shiploading galleries would have to be refurbished to handle the additional weight and torque which would result from attaching additional telescoping sections and aspiration tubes to the loading spouts. If such work is necessary (and it probably is needed), the cost of installing submerged loading would be as high as 5 million dollars for five loading spouts.

The designers of the shiploading galleries would be in the best position to determine whether the galleries would have to be altered to support the weight of attachments to the loading spout. Both the Bunge and Louis Dreyfus elevators have experimented with attaching an aspiration tube to a loading spout; however, they have not tried to add additional sections.

Because of the nature of the galleries and the loading chutes at the Bunge and Louis Dreyfus terminals in Portland it would not be possible to install a dead-box control system such as that in use at Cargill in Portland without making major modifications. The consensus of opinion of grain elevator operators in Portland and Seattle and manufacturers of pollution control systems for grain elevators is that the cost of such modifications would be on the order of $1,000,000 per loading spout (see Section 2). Thus, depending on the number of loading spouts to be converted, the cost of installing dead-boxes at Bunge or Louis Dreyfus could approach $5,000,000.

A cost of 5 million dollars for refurbishing a gallery to allow the use of dead-boxes or submerged loading, if amortized over a period of 15 years at 10 percent interest, would amount to about 700,000 dollars per year. The grain throughputs of Portland terminals vary from year to year, and from terminal to terminal, but are typically about 1,000,000 metric tons per year. Thus, the cost of major refurbishments amortized over 15 years would amount to about 0.70 dollars per metric ton of grain shipped, or 1.9 cents per bushel. The average profit for grain terminals is only 2.1 cents per bushel. The ability of grain elevator owners to increase grain prices, currently $3-4 per bushel, to maintain profit margins has not be assessed in this study.

If submerged loading could be retrofitted to the Bunge and Louis Dreyfus terminals without major modifications to the galleries and docks the cost would be substantially less. The estimated cost of 100,000 dollars for adapting five loading spouts, if amortized over a period of 15 years at 10 percent interest would amount to about 14,000 dollars per year, which is about 1.4 cents per metric ton, or about 0.038 cents per bushel. This cost is about 2 percent of the average profit per bushel.

Again, this latter cost would apply only if it is possible to make additions to the loading spouts without making major changes to the loading gallery. Major modification would probably be required, greatly increasing the costs.

The first step to reduce emissions should be full use of the tent control systems at the Bunge and Louis Dreyfus terminals. The estimated average uncontrolled emission factors were 40 g/t (0.08 lb/ton) of suspendable dust, while the estimated average emission factor for bulk-carrier loading with tent control would be 11 g/t (0.022 lb/ton). This value is arrived at assuming that topping-off begins when the top of the pile of grain in the hold is 1.3 meters (4 ft) below the tent. Emissions should be further reduced by minimizing the amount of grain loaded in the topping-off phase, by filling the hold until the grain in the center of the hold reaches the level of the tent. By this method the amount of grain loaded in the topping-off mode could be reduced from about 25 percent to 15 percent. Emissions would be reduced 40 percent from 10 g/t (0.02 lb/ton) to 6 g/t (0.12 lb/ton). If the grain spout is moved during bulk-loading so that some of the space near the edges of the hold is filled before the tent is removed, then the average emission factor for bulk-carrier loading with tent control will be even lower. Also, topping-off emissions could be reduced by holding the grain spout closer to the grain during topping-off.

Emissions from tween-decker loading amount to a small increase in the average emission factor, since only about 2 percent of the grain shipped from Portland is loaded to tween-deckers.

Emissions from a dead-box control system are 0.2 to 2.4 g/t (0.004 to 0.048 lb/ton) depending on whether the system is well operated or poorly operated. Emissions from a submerged loading would also vary with the mode of operation, but would be somewhat less than from dead-box control systems. Thus, the use of the existing tents would result in an 85 percent reduction of the average emission rate of suspendable, while the use of dead-boxes or submerged loading would result in an 87 to 99 percent reduction of the average emission rate. In the former case visible emissions in excess of the 20 percent limit would occur at least once every 2 days, while in the latter case, such emissions would be generated only as a result of improper operation of the control equipment, or in adverse weather conditions.

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10. Inspection of the Cargill Grain Elevator in Seattle, Washington. January 1978.

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APPENDIX A

CONVERSION FACTORS FOR SELECTED METRIC AND BRITISH UNITS

TABLE A-1. CONVERSION FACTORS FOR SELECTED METRIC AND BRITISH UNITS

To convert from	To	Multiply by
g (grams)	gr (grain)	15.432
g	lb (pound)	0.0022
μm (micrometer)	in. (inch)	0.000254
cm (centimeter)	in.	2.54
m (meter)	ft (foot)	3.281
m^2	ft^2	10.76
m^3	ft^3	35.32
g/m^3	gr/ft^3	0.437
g/m^3	lb/ft^3	0.000062
m/min	ft/min	3.281
m^3/min	ft^3/min	35.32
g/t (metric ton)	lb/ton (British)	0.002

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