U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF PESTICIDES PROGRAMS
REGISTRATION DIVISION (TS-767)
WASHINGTON, DC 20460

EPA REGISTRATION NO. 38719-5

DATE OF ISSUANCE NOV 21 1994

TERM OF ISSUANCE

NOTICE OF PESTICIDE: ☐ REGISTRATION ☒ REREGISTRATION

(Under the Federal Insecticide, Fungicide, and Rodenticide Act, as amended)

NAME OF PESTICIDE PRODUCT

Carbon Dioxide

NAME AND ADDRESS OF REGISTRANT (*Include ZIP code*)

BOC Gases
575 Mountain Ave.
Murray Hill, NJ 07974

5477245 675/22

NOTE: Changes in labeling formula differing in substance from that accepted in connection with this registration must be submitted to and accepted by the Registration Division prior to use of the label in commerce. In any correspondence on this product always refer to the above U.S. EPA registration number.

On the basis of information furnished by the registrant, the above named pesticide is hereby Registered/Reregistered under the Federal Insecticide, Fungicide, and Rodenticide Act.

A copy of the labeling accepted in connection with this Registration/Reregistration is returned herewith.

Registration is in no way to be construed as an indorsement or approval of this product by this Agency. In order to protect health and the environment, the Administrator, on his motion, may at any time suspend or cancel the registration of a pesticide in accordance with the Act. The acceptance of any name in connection with the registration of a product under this Act is not to be construed as giving the registrant a right to exclusive use of the name or to its use if it has been covered by others.

Based on your response to the Reregistration Eligibility Document, EPA has reregistered the product listed above Enclosed is a copy of your label stamped "Accepted". This action is taken under the authority of section 4(g)(2)(C) of the Federal Insecticide, Fungicide, and Rodenticide Act, as amended. Reregistration under this section does not eliminate the need for continual reassessment of pesticides. EPA may require submission of data at any time to maintain the registration of your product.

Make the revisions specified below you print the final labeling for this product.

1. On the Front Panel, rewrite the WARNING statement to read:

   WARNING: May be fatal if inhaled. Do not breath vapor. For handling activities in enclosed areas during and after fumigation, use either a supplied-air respirator with MSHA/NIOSH approval number TC-19C or a self-contained breathing apparatus (SCBA) with MSHA/NIOSH approval number TC-13F.

☐ ATTACHMENT IS APPLICABLE

SIGNATURE OF APPROVING OFFICIAL

DATE NOV 21 1994

EPA Form 8570-6 (Rev. 5-76)

2. Under AERATION you need to identify one or more direct-reading detection devices suitable for use with the product and provide or reference instructions on its use.

3. Change the heading on the next to last paragraph of the Front Panel to read:

   RE-ENTRY (5,000-30,000 ppm CO-2):

4. Change the heading on the next to last paragraph of the Front Panel to read:

   RE-ENTRY (over 30,000 ppm CO-2):

Submit one copy of your final printed labeling before you release the product for shipment. Refer to the A-79 Enclosure for a further description of final printed labeling.

Registrants may sell or distribute products bearing old labeling for **one year** after the date of this Notice. **Non-registrants** may sell or distribute products bearing old labeling for **three years** after the date of this Notice.

If these conditions are not complied with, the registration will be subject to cancellation in accordance with FIFRA section 6(e). Your release for shipment of the product bearing the amended labeling constitutes acceptance of these conditions.

A stamped copy of the labeling is enclosed for your records.

RAF

Robert A. Forrest
Producc Manager (14)
Insecticide-Rodenticide Branch
Registration Division (H7504C)

Enclosures: 1. Stamped label
2. A-79 Enclosure

Peacock WP#5:A:38719-5.CO2:305-5407,-6600:11/21/94

CARBON DIOXIDE

ACTIVE INGREDIENT: CARBON DIOXIDE 99.95%
INERT INGREDIENTS: (N_2, H_2O) 0.05%
100.00%

KEEP OUT OF REACH OF CHILDREN

WARNING

ACCEPTED
with COMMENTS
in EPA Letter Dated

NOV 21 1994

Under the Federal Insecticide, Fungicide, and Rodenticide Act as amended, for the pesticide registered under EPA Reg. No. 38719-5

<u>EXPOSURE MAY CAUSE SUFFOCATION & DEATH</u>
<u>VENTILATE USE AREAS BEFORE ENTERING</u>

STATEMENT OF PRACTICAL TREATMENT

If inhaled: Remove to fresh air immediately; keep victim lying down and warm. If breathing is difficult, give oxygen. Call physician immediately.

WARNING: May be fatal if inhaled. Do not breath vapor. For handling activities in enclosed areas during and after fumigation, use either a self-containing breathing apparatus (SCBA) with MSHA/NIOSH approval number TC-13F by itself, or in combination with, an supplied-air respirator with MSHA/NIOSH approval number TC-19C.

AERATION

After fumigation, aerate treated areas until the level of CO_2 as measured by BOC recommended direct-reading detection devices suitable for use with the CO_2, is <u>below 5,000 ppm.</u>

<u>RE-ENTRY (below 5,000 ppm CO_2)</u>
If CO_2 levels as below 5,000, persons may re-enter the treated area without respiratory protection.

<u>RE-ENTRY (10,000-15,000 ppm CO_2)</u>
If CO_2 levels are between 5,000 and 30,000, persons may re-enter the treated area without respiratory protection for 15 minutes or less. For periods longer than 15 minutes, persons must wear the respiratory protection device specified above under WARNING.

<u>RE-ENTRY (greater than 15,000 ppm CO_2)</u>
If CO_2 levels are over 30,000 ppm, persons must always wear the respiratory protection device specified above under WARNING.

DIRECTIONS FOR USE

It is a violation of Federal law to use this product in a manner inconsistent with its labeling.

GENERAL USE RESTRICTIONS

This product is used to fumigate silos, trucks, trailers, sealed railroad cars, and ships. The following raw agricultural commodities may be treated: wheat, oats, rice, barley, corn and processed foods. Dosage rates vary from 60% to 88%. Treatment times vary from 24 hours to 4 days. See U.S. Department of Agriculture manual AAT-S-13 titled "Methods of Applying Carbon Dioxide for Insect Control in Stored Grains" for details on treatment specifics. Call BOC Gases, Food Marketing Department, at (908) 771-1117 for additional help.

Do not fumigate if grain temperature is low (less than 40°F). Area should be as gas tight as possible before treatment. Maintain as near to 60% CO_2 as possible.

TRAINING

All persons working with this product should be knowledgeable of the hazards of this chemical, and trained in the use of required respirator equipment and detector devices, emergency procedures and use of the product. When used for fumigation of enclosed spaces, [boxcars, silos, ship containers, and other transport vehicles], two persons familiar with the use of this product must be present during introduction of the fumigant, initiation of aeration, and after aeration when testing for reentry. Two persons do not need to be present if monitoring is conducted remotely (outside of area being fumigated).

PLACARDING STATEMENT

The applicator must placard or post all entrances to the fumigated area with signs conforming to the following requirements:

a) The sign shall be at least 14 inches by 16 inches in size and the letters shall be at least 1 inch in height unless a smaller size sign is necessary because the treated area is too small to accommodate a sign of this size. Letters shall be clearly legible.

b) The signal word, "DANGER/PELIGRO" and the skull and crossbones symbol must be on the placard.

c) The statement, "Area under fumigation, DO NOT ENTER/NO ENTRE."

d) The date of fumigation.

e) The name of the fumigant (carbon dioxide).

f) Name, address and telephone number of the applicator or pesticide handler.

These signs must be posted at eye level and must be visible from all visible points of entry to the treated area. They must remain posted during application and throughout the restricted-entry interval until the concentration of carbon dioxide is below 5,000 ppm. Each separate placarded with this sign.

The applicator or person responsible for monitoring levels of carbon dioxide may remove the placard when the concentration of carbon dioxide is at or below 5,000 ppm.

FUMIGATION DIRECTIONS

Storage Vessel

Purge storage vessel (bin, silo, or sealed railcar) to a minimum concentration of 60% CO_2. We recommend two day treatment for adult kill, four days for all life stages. Follow guidelines set forth in USDA AAT-S-13 manual. For specific flows, contact qualified BOC Gases or fumigation engineer.

Trucks & Trailers

Treat as above. Do not move Truck or Trailer during treatment. They must be aerated before movement is allowed.

Shipboard, Intransit Ship or Shiphold Fumigation

IMPORTANT

Shipboard, intransit ship or shiphold fumigation is also governed by U.S. Coast Guard Regulations. Refer to and comply with these regulations prior to fumigation.

PROCEDURES

Prefumigation Procedures

1. Prior to fumigating a vessel for intransit cargo fumigation, the master of the vessel or his/her representative and the fumigator must determine whether the vessel is suitably designed and configured so as to allow for safe occupancy by the ship's crew throughout the duration of the fumigation. If it is determined that the design and configuration of the vessel does not allow for safe occupancy by the ship's crew throughout the duration of the fumigation, then the vessel will not be fumigated unless all crew members are removed from the vessel. The crew members will not be allowed to reoccupy the vessel until the vessel has been properly aerated and a determination has been made by the master of the vessel and the fumigator that the vessel is safe for occupancy.

2. The person responsible for the fumigation must notify the master of the vessel, or his representative, of the requirements relating to personal protection equipment, detection equipment and that a person qualified in the use of this equipment must accompany the vessel with cargo under fumigation. Emergency procedures, cargo ventilation, periodic monitoring and inspections, and first aid measures must be discussed with and understood by the master of the vessel or his representative.

3. During the fumigation or until a manned vessel leaves port or the cargo is aerated, the person in charge of the fumigation shall insure that a qualified person using gas or vapor detection equipment tests spaces adjacent to spaces containing fumigated cargo and all regularly

occupied spaces for fumigation leakage. If leakage of the fumigant is detected, the person in charge of the fumigation shall take action to correct the leakage, or shall inform the master of the vessel, or his representative, of the leakage so that corrective action can be taken.

4. If the fumigation is not completed and the vessel aerated before the manned vessel leaves port, the person in charge of the vessel shall insure that at least two units of personal protection equipment and one gas or vapor detection device, and a person qualified in the operation be on board the vessel during the voyage.

Precautions and Procedures During Voyage

Using appropriate gas detection equipment, monitor spaces adjacent to areas containing fumigated cargo and all regularly occupied areas for fumigant leakage. If leakage is detected, the area should be evacuated of all personnel, ventilated, and action taken to correct the leakage, before allowing the area to be occupied. Do not enter fumigated areas except under emergency conditions. If necessary to enter a fumigated area, appropriate personnel protection equipment must be used. Never enter fumigated areas alone. At least one other person, wearing personal protection equipment, should be available to assist in case of an emergency.

Precautions and Procedures During Discharge

If necessary to enter hold prior to discharge, test spaces directly above grain surface for fumigant concentration, using appropriate gas detection and personal protection equipment. Do not allow entry to fumigated areas without personal safety equipment unless fumigant concentrations are at safe levels, as indicated by a suitable detector.

"Personal protection equipment means an air supplied gas mask or respirator or a self-contained breathing apparatus (SCBA) for the fumigant, jointly approved by the Mining Enforcement and Safety Administration and the National Institute of Occupational Safety and Health."

STORAGE AND DISPOSAL

Do not contaminate water, food, or feed by storage or disposal.

Storage

Store in dry, cool, well-ventilated area under lock and key. Post as a pesticide storage area.

Store cylinders upright, secured to a rack or wall to prevent tipping. Cylinders should not be subjected to rough handling or mechanical shock such as dropping, bumping, dragging or sliding. Do not use rope slings, hooks, tongs or similar devices to unload cylinders. Transport cylinders using hand truck or fork truck to which the cylinder can be firmly secured.

Do not remove valve protection bonnet and safety cap until immediately before use. Replace safety cap and valve protection bonnet when cylinder is not in use.

Spill and Leak Procedure Statement
Evacuate immediate area of leak. Use respiratory device (see Precautionary Statement) for entry into affected area to correct problem. Move leaking or damaged cylinders outdoors or to an isolated location, observing strict safety precautions. When completely empty, return to manufacturer or, if instructed, recycle/dispose of leaking or damaged cylinders or containers in accordance with State and Local waste disposal regulations.

Do not permit entry into spill area by unprotected persons until concentration of carbon dioxide is determined to be less than 5,000 ppm.

Pesticide Disposal
Vent unusable carbon dioxide to open air.

Container Disposal: When cylinder is empty, close valve, screw safety cap onto valve outlet and replace protection bonnet before returning to shipper. Only the registrant is authorized to refill cylinders. Do not use cylinders for any other purpose. Follow registrant's instruction for return of empty or partially empty cylinders.

BOC GASES
575 MOUNTAIN AVE.
MURRAY HILL, NJ 07974

EPA REGISTRATION NO. 38719-5

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Methods of Applying Carbon Dioxide for Insect Control in Stored Grain

U.S. Department of Agriculture
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The success of these tests is partially due to the efforts of G. C. Pearman, Jr., of the Stored-Product Insects Research and Development Laboratory. The Farm Bureau Marketing Association's terminal elevator, North Charleston, S.C., furnished the facility and grain. Liquid Carbonic Corp., Chicago, Ill., provided a portion of the CO_2, and Art Riechert of this company furnished engineering expertise.

This publication is available from the Stored-Product Insects Research and Development Laboratory, P.O. Box 22909, Savannah, Ga. 31403.

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Methods of Applying Carbon Dioxide for Insect Control in Stored Grain

By Edward Jay[1]

ABSTRACT

Three methods of applying carbon dioxide to grain stored in silos are described. One method involves purging a full silo from the top, another involves purging a full silo from the bottom, and the third involves introducing carbon dioxide in the grain stream as a silo is being filled. Comparative purge times, carbon dioxide requirements, and costs are given. Modification of storage-facility atmospheres is a promising method to achieve residue-free insect control, and the merits of using carbon dioxide and nitrogen for this purpose are compared. Index terms: carbon dioxide, insect control, modified atmospheres, nitrogen, stored-product insects.

INTRODUCTION

Since the publication by Jay (1971) on using carbon dioxide (CO_2) to control stored-grain insects, considerable interest has developed worldwide on the use of this technique and on the use of nitrogen (N_2) and on combinations of atmospheric gases to achieve control. This interest has been generated because of the increasing worldwide problem of insect resistance to conventional insecticides and fumigants and also because of the residues associated with the use of these materials. Jay and Pearman (1973) showed that a 4-day CO_2 treatment of shelled corn having a natural infestation of stored-grain insects gave almost 100% control. Shejbal et al. (1973) showed that similar control could be obtained by using N_2, but the time needed to obtain control was 10 days. Banks and Annis (1977) conducted trials with N_2 in commercial, upright, welded-steel silos. Lethal atmospheres were attained and maintained in these silos for periods up to 30 days.

Both CO_2 and N_2 have merit in a residue-free insect-control program. Nitrogen has the advantage of filling 78% of the interstitial spaces initially. However, atmospheric oxygen (O_2) in these interstitial spaces must be reduced to less than 1% to obtain effective insect control, a situation difficult to achieve and maintain in storage facilities that are not gastight. Therefore, CO_2 is considered by the author to be more efficient than N_2 in situations where tight sealing is physically impossible or where it is not economically feasible to seal the storage structure to rigid gastight specifications. A CO_2 concentration of about 60% will give over 95% control of most stored-grain insects after a 4-day exposure at temperatures of 27° C or higher (Jay 1971), and the CO_2 concentration can fluctuate ±10% and still provide effective control. The low oxygen N_2 atmosphere, on the other hand, must be held for 10 or more days at 27° C or above to be effective against life stages of stored-grain pests. Even so, Shejbal et al. (1973) reported that control of insect eggs was not obtained in a 10-day exposure to 0.5% O_2 and 99.5% N_2. Unpublished laboratory

[1] Research entomologist, Stored-Product Insects Research and Development Laboratory, Science and Education Administration, U.S. Department of Agriculture, P.O. Box 22909, Savannah, Ga. 31403.

studies by the author have shown that eggs of the red flour beetle, *Tribolium castaneum* (Herbst), do not hatch in atmospheres above 20% CO_2 when the O_2 level is as high as about 19%. Similarly, AliNiazee and Lindgren (1970) reported that the percentage of egg hatch of *T. castaneum* and *T. confusum* Jacquelin duVal was inhibited partially or completely delayed in CO_2 atmospheres, while in similar N_2 atmospheres there was about the same percentage of egg hatch as there was in those eggs exposed to air. The author (unpublished laboratory studies) found that a concentration of about 62% CO_2 and 9% O_2 gave over 90% control of 0- to 25-hour-old eggs of the cowpea weevil, *Callosobruchus maculatus* (F.), in 2 days' exposure, while concentrations of 99.2% N_2 (balance O_2) took 3 days to produce the same results. One-week-old insects of the same species were controlled (90% or more mortality) in 2 days in the atmosphere containing 62% CO_2, while concentrations of 99.7% N_2 (balance O_2) took more than 3 days to give the same control.

In summary, CO_2 generally kills insects faster than N_2. It can be used in situations where leakiness may be a problem, and the concentration of 60% CO_2 can be allowed to fluctuate ±10% (or more, down to a low of 35%) leading to good control. (However, lower overall concentrations will necessitate longer exposure times.) In addition, sorption of CO_2 by grain or oilseeds may make it more effective against species whose immature stages feed inside the kernel. On the other hand, CO_2 is 1½ times as heavy as air and will sink from the top to the bottom of the treated storage facility unless it is tightly sealed. This sinking necessitates either adding CO_2 into the headspace periodically or recirculating the CO_2. (See Jay et al., 1970, for a description of this method. The method should be modified so that the recirculation fan is placed outside the storage facility to eliminate explosion hazard.)

If the above advantages and disadvantages of using CO_2 have been taken into consideration and there still remains a question of whether to use CO_2 or N_2, then economic factors enter into the decision. The comparative cost of the two treatments will depend on the availability of the gases, their unit cost (a unit is a ton, pound, cubic foot, cubic meter, etc.), the number of units required for effective insect control, the amount of grain to be treated per year (as the volume of gas used increases, unit costs will be reduced), transportation costs, and rental or purchase costs of vaporization equipment and storage containers (if equipment is purchased, can it be depreciated annually?).

The above advantages, disadvantages, and economic considerations obviously involve a decisionmaking process for which a flow chart is presented in figure 1.

This paper presents three methods of applying CO_2 to stored grain. The information presented by Jay (1971) on suggested conditions for using CO_2 should be consulted in conjunction with the material presented here. If a decision is made to use N_2 instead, Banks and Annis (1977) should be studied. However, some techniques described for CO_2 could be used for N_2 with slight modifications. Another method of creating modified atmospheres, the burning of air to reduce its oxygen content, is not considered.

METHODS OF APPLYING CO_2

Since the publication by Jay (1971) became available, the author has conducted several additional field tests. One of these was described by Jay and Pearman (1973) and is summarized here (method 1) for comparative purposes with other application methods. The three methods described attain and maintain a concentration of about 60% CO_2. The tests were conducted in 1,038-m³ (36,644-ft³) upright concrete silos measuring 24.7 m (81 ft), excluding depth of discharge chute, by 7.3 m (24 ft). The silos each contained about 711 metric tons (28,000 bu) of shelled corn (maize) having an 11% to 16% moisture content. (In some tests the corn was moved into a silo as the CO_2 was being applied.) The equipment used in all tests for applying the CO_2, including supply tank, vaporizers, and regulators for monitoring and controlling the concentration after the desired concentration was reached, was similar to that described by Jay and Pearman (1973). Deviations will be described in the individual tests.

Method 1: Purge a Full Silo From the Top

This is essentially the method described by Jay and Pearman (1973) and will not be dealt with at length. It involves introduction of gaseous CO_2 into the headspace above the surface of the grain.

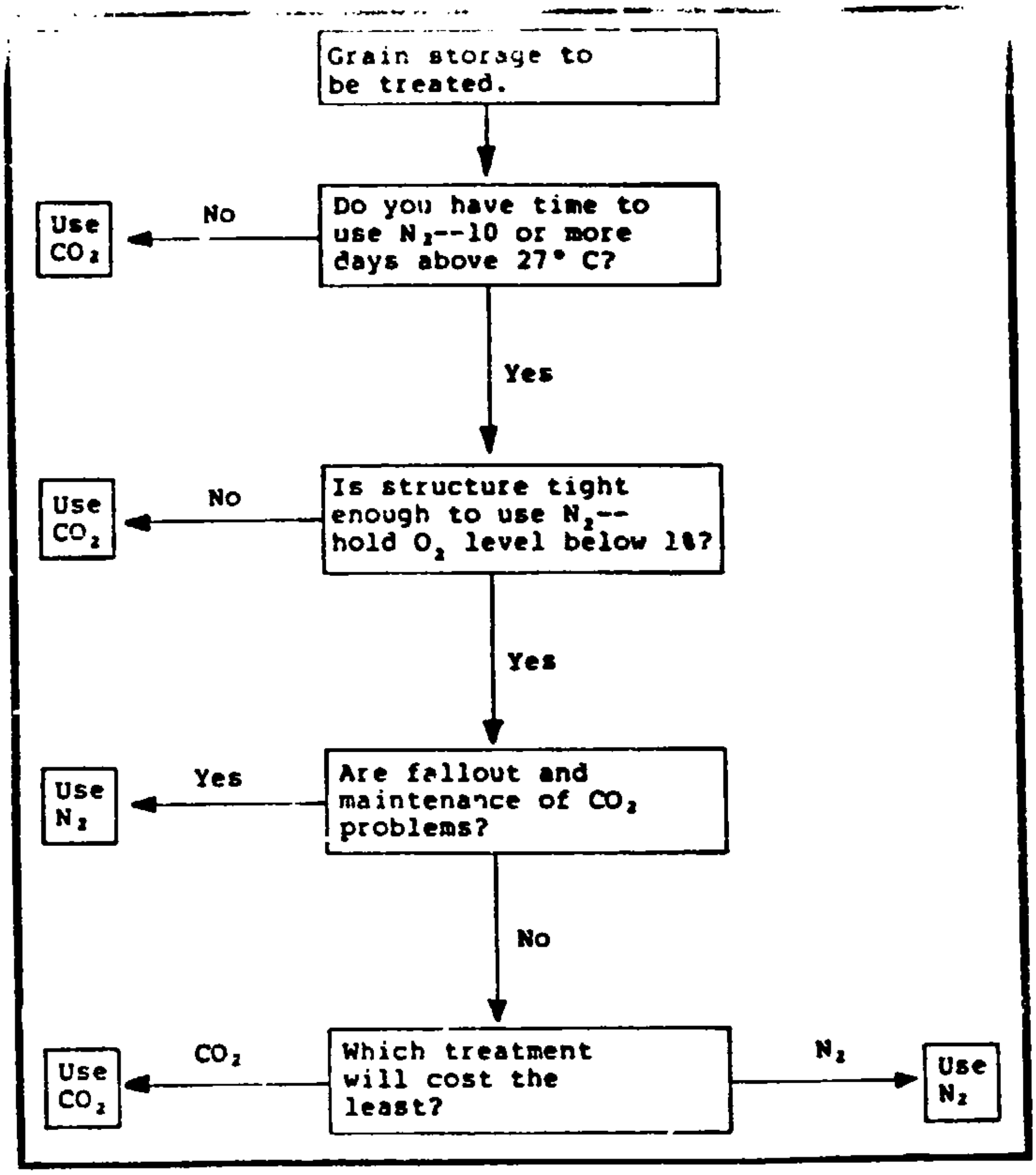

FIGURE 1.—Determining which modified atmosphere to use, CO_2 or N_2.

The CO_2 is forced down into the grain by positive pressure on the headspace of the storage facility. The CO_2 mixes with and displaces a portion of the existing atmosphere and creates a modified atmosphere lethal to any insects present. Its advantages are that it can be used where no other method is available, it requires only one application line, labor requirements are minimal, and costs may be lower than with the other methods. Its disadvantages are that CO_2 is lost in mixing and "blowback," purging time is longer than in method 3, and vaporization requirements are high.

METHOD 2: LIFT THE ATMOSPHERE OUT

In this test and in method 3, a set of air-sampling lines was placed into a silo through each of the two access openings in the flat top prior to filling. These lines differed from those which were probed into the corn in method 1. One of the two openings was about 1.2 m (4 ft) in from the wall, where the corn was discharged into the silo, and the other opening was about 1.2 m (4 ft) from the center of the top. Each set of sampling lines was made up of six 0.6-cm-i.d. (¼-inch) polyethylene tubes taped together so that six samples could be taken at intervals of about 3 or 6 m (10 or 20 ft) below the surface of the grain. Metal tips having slits to allow air entry were placed on the end of each line. The 12 lines were run to an air-sampling valve mounted outside on the top of the silo. One line was run from this valve to a gas partitioner in a mobile laboratory. This apparatus sampled 12 sites in the silo during each test, and it was similar to that used in method 1.

Prior to filling this silo, a 0.6-m-wide (2-ft) T-shaped pipe made of 2.5-cm-i.d. (1-inch) copper tubing coupled to 1.9-cm (¾-inch) heavy-duty rubber application hose was lowered into the metal discharge cone at the bottom of the silo. The pipe had a 2.5-cm (1-inch) copper ell on each end. The ells were turned up toward the top of the silo. Fine-mesh screen was soldered over the openings to prevent entry of corn and foreign material. The silo was filled, and the depths of the sampling lines in the corn nearest the wall were determined to be about 1.2, 4.3, 7.3, 13.4, 19.5, and 25.6 m (4, 14, 24, 44, 64, and 84 ft), and near the center, about 0.6, 3.7, 6.7, 12.8, 18.9, and 25.0 m (2, 12, 22, 42, 62, and 82 ft). The difference in depth between the two sets of lines was due to the slope of the grain from the discharge area to the opposite wall. The longest side line and the center lines were in the cone-shaped discharge chute near the T-shaped application pipe.

Gas flow was started into this silo from a full 8,940-lb tank of liquid CO_2, using the built-in vaporizer. The access openings in the silo were opened after 0.6 h of application to relieve pressure. After a 1-h application, 100% CO_2 was found at the lowest (25-m) sampling points, while only small amounts were found at other sampling points. After 4 h, the CO_2 concentration at about 19 m in the center site had reached 100%, and in the side samples, from 52% to 73%.

Approximately 84 m^3 (340 lb) of CO_2 was introduced during the first 4 h of application. At this time the flow rate was increased from about 21 m^3/h (85 lb/h) to about 46 m^3/h (185 lb/h). After 6.75 h, CO_2 concentrations at the 13-m center and side sites were 95% and 20%, respectively. Samples at depths of 19 and 25 m still contained 100% CO_2 at this time. After 8.25 h of treatment, the CO_2 concentration at the 13-m side site was 89%, while samples at 7- and 4-m depths and samples just below the surface contained 2% to 4% CO_2. After 11 h, the CO_2 concentration was 95% at the 7-m center site but was only 2% at the side sampling point at this depth. Carbon dioxide used in the first 12 h was 454.4 m^3 (1,840 lb). Application was continued at an average rate of 46.0 m^3/h (185 lb/h). After 12 h, the concentration in the 7-m side site had risen to 73%.

After 13.25 h, there was 98% CO_2 at the 4-m center site, while the side sample at the same depth contained 26% CO_2. All samples below these depths contained from 97% to 100% CO_2. After 14.5 h, the sample at the 0.6-m center site had a concentration of 93% CO_2, and the sample at the 1.2-m side site contained 12% CO_2. This low concentration was probably caused by a heavy concentration of foreign material in the area. Approximately 592.7 m^3 (2,400 lb) of CO_2 had been used at this time. Flow was terminated, and it is calculated that 2 additional hours at 46.0 m^3/h (185 lb/h) would have been required to penetrate the heavy concentration of foreign material under the discharge chute at the side.

Ten hours after shutdown all samples at and below 13 m had 80% or more CO_2, while samples above this point contained from a trace to 22%. Thirty-two hours after shutdown samples at or below 19 m had 52% to 80% CO_2, and samples above this point contained from a trace to 26%.

This silo was not equipped with an aeration fan, a fan shaft, or any other facility for introducing CO_2 directly from the bottom of the silo. In silos so equipped, there would be no need for the hose and the T-shaped pipe used.

The advantages of this method are low labor requirements, CO_2 costs comparable to other application techniques, and no loss of CO_2 in mixing and blowback. On the other hand, this is the slowest of all the methods tested, and there are problems in penetrating areas having a lot of foreign material. Also, the method produces a 100% CO_2 concentration, and concentrations above 60% seem to result in reduced insect control. (Apparently, a low oxygen, O_2, concentration anesthetizes the insects and prevents the venting of CO_2 and water, which is believed to be partially responsible for death.) However, this could be averted by blending air with the CO_2, producing a concentration of about 60% CO_2 and reducing total CO_2 used. Finally, two application lines are required, one to purge and one to supplement fallout of the heavier-than-air CO_2 from the headspace, and vaporization requirements are high.

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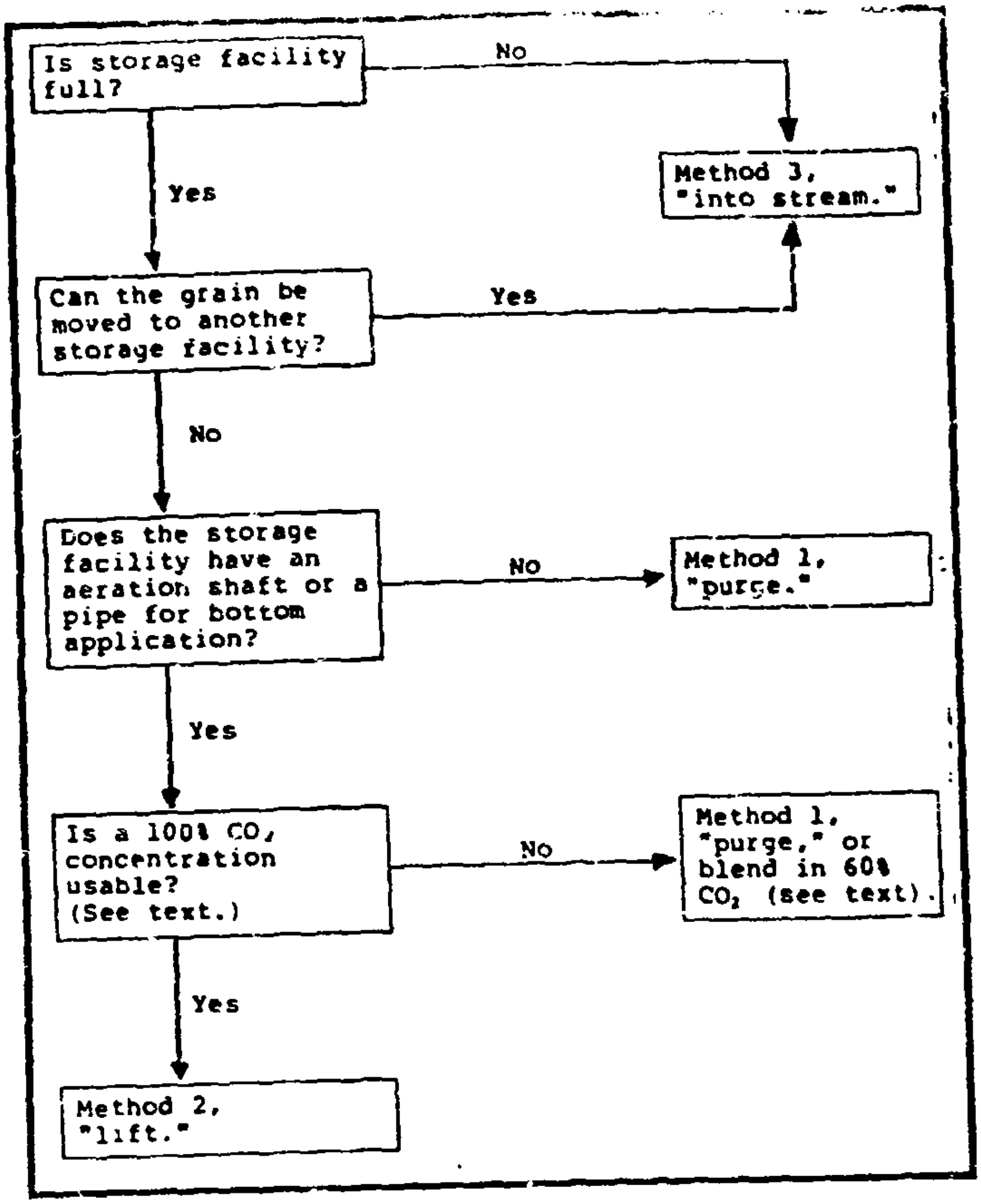

FIGURE 2.—Selecting a method for applying CO_2.

METHOD 3: APPLY CO_2 IN THE GRAIN STREAM

This test was conducted with liquid CO_2 from the same tank previously described. The CO_2 emerged from the equipment in a semisolid form called "snow" by the CO_2 industry. However, the snow soon sublimated and produced CO_2 gas. A CO_2 "horn" was attached to copper tubing (1.9-cm i.d., or ¾-inch), which was run from the liquid line on the CO_2 tank to the top of the silo. The tubing and horn were thoroughly grounded to prevent any sparks around the discharge area. Liquid CO_2 flow was started into an empty silo at the outer access opening, and in 10 min about 49.4 m³ (200 lb) had been introduced. Corn flow was then started into the silo and continued, with two brief interruptions of 3 min each, until the silo was filled with about 711 metric tons (28,000 bu) of corn in 2.33 h. At this point about 642 m³ (2,600 lb) of CO_2 had been introduced into the silo at a rate of 4.6 m³/min (18.6 lb/min). Carbon dioxide application was continued an additional 0.6 h, except for a 10-min interruption. At this time an

Table 1.—Characteristics of three CO_2 ap[illegible]

[CO_2 applied to 711 metric tons (28,000 bu) of corn]

Characteristic	Application method		
	Method 1, "purge"	Method 2, "lift"	Method 3, "into stream"
Time to attain lethal concentration (h)	8	16.5	3
Quantity to reach lethal concentration:			
Cubic meters [1]	625	716	827
Pounds	2,530	2,900	3,350
Quantity to maintain lethal concentration for 96 h (including purge time):			
Cubic meters per hour	17.8	[2]19.3	19.3
Pounds per hour	72	[2]78	78
Total CO_2 to treat:			
Cubic meters	2,332	2,568	2,679
Pounds	9,445	10,400	10,850
Cost per bushel ($):			
CO_2 at \$0.062/lb [3]	0.0176	0.0193	0.0202
CO_2 at \$0.078/lb [4]	0.0263	0.0290	0.0290
CO_2 at \$0.090/lb [5]	0.0304	0.034	0.0349
Cost per metric ton ($), CO_2 at \$0.062/lb [3]	0.691	0.761	0.794

[1] Calculated from 8.72 ft^3 CO_2 gas produced from 1 lb CO_2 liquid at -17.8° C and 306.5 lb/in^2 absolute.
[2] Calculated from "into stream" application, method 3.
[3] U.S. price, 1978, yearly usage of 100-500 tons CO_2.
[4] U.S. price, 1978, yearly usage of 50-100 tons CO_2.
[5] U.S. price, 1978, yearly usage of 0-50 tons CO_2.

additional 98.8 m^3 (400 lb) of CO_2 had been applied, and a small mound of snow had accumulated directly under the horn on the surface of the corn.

During filling, gas samples were taken adjacent to the access door where the CO_2 was being introduced. These samples were taken when excessive CO_2 blowback from the silo was noticed. Carbon dioxide concentrations were 5.4% to 16.2%, indicating a large loss of gas from the silo.

Three and one-half hours after the start of application (30 min after the snow had accumulated on the top of the corn), a complete series of air samples was taken from this silo. These 12 samples averaged 71% CO_2 and 6% O_2. The concentration of CO_2 ranged from 82% to 24%, and the O_2 concentration ranged from 2.1% to 11.4%.

Two and one-half hours after the application was stopped, an additional 86.4 m^3 (350 lb) of snow was applied through the top of the silo in 20 min. Twenty minutes later, the CO_2 average was 60%, and the O_2 average was 8% in all 12 samples. In this series of samples, the 1-m side sample contained 37% CO_2, and the 25-m center sample contained 44% CO_2; the range of CO_2 was 84% to 37%, and the O_2 range was 4% to 11%.

To maintain the CO_2 concentration, gas was reintroduced 6 h after the initial introduction. This was accomplished by running a 1.9-cm-i.d. (¾-inch) rubber hose from the gasline on the tank into the headspace of this silo. Gas flow was controlled by a CO_2 analyzer equipped with relays that controlled a solenoid valve in the application line. The controller was calibrated to maintain 55% to 60% CO_2 in the silo. This equipment is described in more detail by Jay and Pearman (1973).

Sixteen hours later, a complete series of gas samples was taken from the silo. The CO_2 concentration ranged from 59% to 52%, and the O_2 concentration ranged from 8% to 10%. The test was terminated at this point since experience has shown that once the desired concentration has been attained, the CO_2 analyzer and associated equipment will maintain the concentration within the silo at the concentration lethal to most stored-grain and oilseed insects.

This method is fast, and vaporization equipment requirements are low. The disadvantages include danger of explosion caused by improperly grounded application equipment, a potential need for two application lines, excessive loss of CO_2 from blowback, and high labor requirements (constant attention during application is required).

DISCUSSION

The decision on which application technique to use will have to be based on several factors (fig. 2). Table 1 presents a breakdown of the CO_2 costs for each method. The costs are based on the quantities of liquid CO_2 used in each test at the most recent prices the author could obtain and do not include the expense of renting storage tanks and vaporization equipment. At the lowest quoted price for CO_2, the costs ranged from $0.0175/bu ($490 for 28,000 bu) for method 1 to $0.0202/bu ($565 for 28,000 bu) for method 3. Since each method has its advantages and disadvantages and, in some cases, only one or two of the three methods could be used, the difference in cost between the three methods may be considered minimal.

These studies were conducted at only one storage facility, in upright concrete silos containing corn. Little effort was made to correct the obviously high leakage. Anyone using this information to conduct further field tests should consider all potential leaks. In upright concrete silos any cracks in walls are potential areas for gas leaks. The largest losses will occur around the discharge spouts at the bottom of the silos.

Each facility to be treated with modified atmospheres will have varying factors of volume, type and amount of grain, leak rate, temperature, vaporization equipment (if required), and other factors. Therefore, this information should be used as a guide and not as a representative indicator as to how a treatment will work in a given situation. Additional field studies are needed.

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