SMALL SCALE SIMULATED COMMERCIAL CA STORAGE ROOMS

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We have been working with controlled atmosphere (CA) research on fruits and vegetables for over 25 years. During that period we have used different chambers beginning with "plastic" film laminated to aluminium foil over a wooden frame (5) through 180-liter steel drums to modified 2000- and 4000-liter steel oil tanks. Much useful work can be done with such chambers but their small volume limits sample size, proper replication, and in some cases the results are quite different from those obtained in commercially sized rooms (3).

CA storage research can be done on a large commercial scale only if the conditions in the commercial room match those required for the particular research. What is required then is a small sized storage chamber which duplicates conditions in a commercial room, but of a cost which permits construction of several to allow valid replication, and at the same time which minimizes the risk of experimentation with large volumes of produce. Such chambers have been constructed (1,8), but in the former the equipment does not simulate present systems, and in the latter no detail is given. (Dr. Gary W. Apel, personal communication has kindly provided some detail.)

There is one major problem which makes construction difficult. This is making the chamber sufficiently "air-tight" that the oxygen level can be maintained with minimum purging. The use of very low oxygen levels makes the demand for "air-tightness" even more acute. The general construction procedures and materials of pilot-sized chambers are most economical if similar to commercial rooms but the need for eliminating leaks (gas exchange) is much greater. Leaks which could be tolerated in a commercial room cannot be accepted on a pilot-sized room because the size of the leak compared to the room volume and fruit volume is much greater in the latter. Other factors which must be considered are relative humidity and its control, temperature variability and its control, and rate and effectiveness of air movement.

A total of 8 chambers were constructed with the supplier of the last 4 being different from the first 4. The description which follows is of the last 4 because some changes were made as the work progressed. All were prefabricated standard "walk-in coolers" with some special construction and installation characteristics.

Description of chambers and modifications

Chambers

Size - nominal outside - 2.13 m (7 ft) x 2.13 m (7 ft) x 2.59 m (8.5 ft).

Metal - walls and ceiling - white painted steel, floor 16-gauge galvanized steel.

Door - 0.86 m (34 in) x 1.98 m (78 in), positive latch.

Insulation - 7.5 cm (3 in) thick sprayed in sandwich between inner and outer metal panels.

Special order - 5.1-cm (2-in) wood framework in panels around door to allow lag bolt attachment of steel door frame.

Refrigeration

Condensing unit - 746W (1 horsepower), accessible hermetic, air cooled, remote installation.

Refrigerant - R 12 (dichlorodiflurormethane)

Evaporator- low velocity blower coil, electric defrost, water drain inside cooler.

Controls - main thermostatic temperature control.
- safety thermostat with available low temperature alarm in series with main control.
- defrost timer.
- adjustable suction pressure regulator
- special switch to allow fans to operate without refrigeration.

Evaporators (A) These were ceiling-mounted blower coils with low velocity fans (Fig. 1, Aa). The evaporator is made up of 2 coils (Ab) and the fans draw the warmer "air" up betwen the 2 coils and the "air" is forced out laterally parallel to the ceiling. The evaporators were mounted centrally in the first 4 chambers, and off-center in the last 4 to avoid mounting the evaporator over a seam between 2 ceiling panels.

Scrubbers (B). These were constructed from plywood apple boxes [53 cm (21 in) x 38 cm (25 in) x 29 cm (11.5 in)] of approximately 36.4 liter (1 bushel) capacity. The boxes were remodelled to be almost airtight but with an opening in the plywood lid of 2.5 cm (1 in) x 15 cm (6 in). Control of access to the scrubber from the chamber atmosphere through this opening was provided by a plastic slide (Ba) held in place by grooves and operated manually by a wire (Bb) accessible to the outside through the porthole. Each scrubber contined approximately 13.6 kg (30 lb) of lime (Bc). If this lime [($Ca(OH)_2$)] became "used up" paper bags containing up to 4 kg of lime each were placed inside the chambers through the porthole. The scrubber was placed on an apple box to locate the wire slide control at the correct height.

<u>The atmosphere seal</u> (C). Two attempts were made to seal chambers with silicone caulking at all seams. Although these rooms could have been used for CA storage, because of a high leakage rate the cost of nitrogen to continually purge the system to keep the oxygen level down would have been excessive and it would have been necessary to add carbon dioxide continually if required. The walls and ceiling of the rooms were therefore sprayed inside with 1.3 cm (0.5 in) of polyurethane foam "fire proofed" with sprayed-on cementitious material. A heavier layer of polyurethane was applied at the floor-wall, and ceiling-wall joints. Polyurethane was sprayed only over the seam(s) on the floor. Wooden 2 x 4's supporting the false plywood floor were laid in the unsprayed areas. Polyurethane was applied after all installations (door etc.) had been made so that these joints or openings were also covered. The object was to have an integral polyurethane coating at least over the walls, ceiling and floor-wall junction. During erection of the chamber silicone caulking was spread on the seams and this caulking was used around the metal door frames, around the bolts supporting the evaporators, in all the holes allowing access to the cam latches before sealing with the metal caps, and under all pipe flanges used on the collars (D). After this caulking had dried all material on the surfaces of the metal was scraped off and the area was cleaned thoroughly with steel wool because polyurethane does not adhere to silicone. Particular attention was given to cleaning the galvanized floor because of the initial oily coating as well as the zinc oxides on the galvanized surface.

All lines and tubing passed through collars (D) made from appropriate lengths [20.5 cm (12 in) to 45.7 cm (18 in)] and diameters [1.3 cm (0.5 in), or 1.9 cm (0.75)] of black pipe with full-length threads. These were clamped to the inside and outside walls by pipe floor flanges [continuous internal thread] with the external flange spot welded to the pipe and fastened to the external surface with self-tapping metal screws. The internal collar was sealed to the wall with silicone caulking compound, cleaned well and oversprayed with polyurethane foam. Only single refrigeration lines were passed through a single collar because of the problem of sealing between two lines passing through the same opening.

The 4 thermocouple wires, the 0.6 cm (0.25 in) diameter copper sampling line, the electrical wires for a thermistor type temperature sensor, and the 2 Bourdon tubes of the refrigeration thermostats were passed through a single collar. Collars were filled with caulking compound and sealed inside and outside with Apiezon sealing compound (Apiezon Products, London, England). The inside seal was polyurethane sprayed over and around the thoroughly cleaned line(s) and the pipe projecting inside the room.

Heat buildup could occur in the junction box on which the internal vapor-proof light was mounted if the box were partially covered with the internal sprayed-on polyurethane. To reduce this possibility the box was mounted on a pipe projecting from the wall.

The "gas-tight" door (Fig. 2) A steel frame 15 cm (6 in) wide of 0.75-cm (0.31-in) material was lag bolted to the inner door frame at the sides and the top. A 5.1-cm (2-in) flange extended into the room at the bottom and was sealed to the floor with silicone caulking. (It was felt that it was unwise to bolt the flange to the floor because if the floor settled complete rupture of the seal could occur). The door, made of 2 cm (0.75 in) plywood, was bolted to the frame. A tight seal was assured by using caulking compound between the door and the frame. The larger opening [(57 cm (22.5 in) x 57 cm. (22.5 in)] was designed for personnel access as well as loading or emptying the chamber without removal of the large door. The opening in the door was framed with a 0.6-cm (0.25-in) steel frame to which the clear plastic viewing panel of polycarbonate or "plexiglass" [0.6 cm (0.25 in)] thick was attached and sealed with caulking compound. There was also a small [19-cm (7.5-in) diameter] opening (porthole) covered with a plastic cover to furnish a relief vent for rapid purging with nitrogen to allow manipulation of the scrubber control. The porthole was off center in the door to coincide with the placement of the internal scrubber.

The porthole cover was bolted directly to the door and sealed with caulking compound. The carriage bolts used were extended from the inside of the door with the square shank under the head driven into the plywood and a retaining nut on each of the 8 bolts countersunk into the exterior surface of the door and cemented into place with silicone caulking compound. A 0.6-cm (0.25-in) bulkhead tube fitting (Fig. 2) was placed in the bottom section of each door to allow direct sampling of the atmospheres for analyses with an Orsat analyzer as a check on both the atmosphere of the room and the analytical system.

Breather bag (E) Each chamber was fitted with a bag to assist in compensation for pressure changes (7, 9). These bags were waterbed mattresses resting on top of the chambers and connected to the chambers through a section of 1.27-cm (0.5-in) ID thick-walled flexible polyvinyl tubing to a 1.27-cm (0.5-in) pipe fitted with a "T" connection so tht nitrogen could be added to keep the bag partially inflated yet at the same time allowing nitrogen to pass into the chamber. A gate valve (Ea) was placed in the line to allow operation without the bag or permit leak testing of the chamber separate from the bag. The single-bed-size [190.5 cm (75 in) x 96.5 cm (38 in) x 20.3 (8 in)] mattress was the size finally chosen because they fitted in the space available on top of the chambers, although other larger sizes were used on some of the first chambers.

According to the directions of Pflug and Southwick (7) and Southwick and Zahradnik (9) these bags should not operate very well because the connecting piping to the chamber was too small and the bags were not suspended to reduce the pressure necessary to inflate the bags. However the bags appeared to reduce the nitrogen necessary for maintaining the atmospheres in the "leaky chambers", assisted in the initial oxygen pulldown when the bags were inflated at the end of the purging cycle, and also acted as a safety system to reduce the need for opening the relief valve when adding air or carbon dioxide.

Pressure relief "valve(s)" (F). These valves were patterned after the concept of Pflug *et al.* (8). The large water volume in the 10-liter glass bottles allowed the use of these valves for a complete season without the need of adding water. As well the enclosed space above the water surface restricted evaporation although the water bubbled vigorously with changes of pressure. The valves were set up to operate at presures of 1.25 cm (0.5 in) of water instead of the usual 2.5 cm (1 in) for a commercially sized room. They were connected to the chambers through 1.27-cm (0.5-in) ID copper and flexible polyvinyl or rubber vacuum tubing. A 1.27-cm (0.5-in) valve was connected to the copper tubing through a "T" to act as a manually operated relief valve (G).

Differential pressure gauge (H) A Magnehelic Differential Pressure Gauge, [± 2.5 cm (1.0 in)] of water (Dwyer Instruments, Michigan City, Indiana) was installed on a front panel of each chamber and was connected to the chamber through flexible tubing. The gauges were useful in indicating periods of negative or positive pressure in the chambers due to barometric or temperature fluctuations but also indicated the pressure during purging with nitrogen or when adding air or carbon dioxide.

Stacking of containers A false floor (K) was constructed of [0.6 cm (0.25-in)] plywood laid over wooden 2 x 4's" (Ka) laid flat on the galvanized steel between the sections of polyurethane foam on the seams. This floor was made of separate sections for easy installation and removal and perforated with numerous holes (5 cm in diameter) to increase evaporation of water placed directly on the metal floor. The false floor protected the polyurethane seal (Kb) on the floor and also kept the bottom boxes above the water added on the floor to maintain high relative humidity. Wooden dunnage (Kc) [1.9 cm (0.75 in) square] was placed between each layer of boxes and (4.4 cm square) between the false floor and the first layer of boxes to allow air movement among the boxes. The boxes were loosely stacked with spaces between the rows for the same reason.

Operation

Nitrogen purging system (I). For initial pulldown of oxygen, cylinders of nitrogen were connected to the "T" between the chamber an the expansion bag with the valve in the "off" position to isolate the bag. The porthole cover was loosened and held open to 0.6 cm (0.25 in) at the top to allow gases to escape and the nitrogen flow was set so that there was rapid movement of atmosphere from the chamber but no build up of pressure. Under these conditions it took approximately 19.7 m^3 (660 ft^3) of nitrogen to bring the oxygen level down from ambient (21%) to approximately 3%. It took from 1/2 to 3/4 hr to empty a cylinder (6.6 m^3). During the last few minutes of purging the valve allowing access to the expansion bag was opened to allow the bag to expand until it was at least half of full size. Further pulldown of oxygen was by using short-term purging as described above, a longer purging using the system described below, or by allowing the fruit to use up the oxygen in respiration.

In the 1984-1985 season, to conserve nitrogen use during oxygen pulldown, 2 rooms were connected in series so that the gas mixture of nitrogen plus the room air from the room into which nitrogen was being fed passed through a second room. Connection was made through plywood covers over the "portholes" connected by flexible plastic covered dryer tubing. To be effective the pressure was allowed to build up to approximately 1 cm in the first room into which the nitrogen was being passed. The purging of the second room was not very effective until the oxygen level in the first room decreased to less than 10%. However if the pairs of rooms to be purged in series were chosen so that the oxygen level desired in the first room was lower than the second, e.g. 1 vs 3% respectively, the system worked reasonably well with a saving of aproximately 1/3 of the nitrogen used in individual purging of rooms.

For those chambers requiring maintenance of the atmosphere by purging with nitrogen a system was designed to supply from 0.003 to 0.280 m^3 (0.1 to 10 ft^3) per hour to each chamber. Usually 3 cylinders (Ia) were manifolded to a common regulator. The flow from the regulator was controlled by a fine metering valve (Ib) and measured through an acrylic purge meter (Ic). A glass "U" tube (Id) 1.25 cm (0.5 in) in diameter, stoppered on the one arm was attached to the delivery line through a "T" junction. Approximately 2.5 cm (1 in) of water was kept in the arms of the tube. This "U" tube acted as a primary safety relief valve in case of failure of the regulator. The pressure relief valves on the chambers served as a secondary safety system.

Adding air. In several of the chambers it was necessary to add air almost daily to raise the oxygen level to that desired using a small vacuum-pressure pump with the duration of operation set on an electric timer. The practice of using a measured leak to air such as can be used in commercial CA rooms has not been attempted as a means of maintaining the oxygen level. Occasional inadvertent leaving of the small 0.60 cm (0.25-in) ID fitting in the door open resulted in reasonably rapid increases in oxygen level so the opening would have to be less than 0.60 cm in diameter which could pose a problem in calibrating the size of the hole. It is also likely that with a change in barometric pressure large changes would take place in the oxygen level if a hole were left open, particularly because the breather bag would not operate properly if the room were vented to air.

Adding carbon dioxide The system differs only from a commercial one in this one aspect - it was possible to add carbon dioxide to establish the desired atmospheres quickly. This would be difficult and expensive with a large commercial room. As well as initial addition to establish the atmosphere the addition of carbon dioxide was required sometimes during the season. Initially carbon dioxide was added in a rather haphazard fashion by turning on the regulator of a cylinder and of "pure" carbon dioxide and manipulating the flow by adjusting the secondary pressure until the flow was "felt" to be correct. This "feel" obviously varied among people and times so the method gave variable performance. To overcome this problem a purge meter was installed so that the operator adjusted the flow in the purge meter to approximately 0.057 m^3 (20 ft^3) per hour and measured only the time of adding carbon dioxide.

Analyses of oxygen and carbon dioxide Sampling lines [0.6 cm (0.25 in ID)] (J) were used to carry samples from inside the chambers (within the pile of boxes) to a central monitoring location. Initially analyses were performed using the system described by Kapotis (4); but for the past 2 1/2 years a microprocessor controlled automatic system (2,6) has been used.

Measurement of temperature. Four copper constantan thermocouples connected to a multipoint temperature recorder, one alcohol-in-glass thermometer, and a dial-type thermometer inserted into an apple were used in each chamber to monitor air and fruit temperatures. As well, in the last 4 chambers an electronic digital display of temperature using a thermistor was installed.

Measurement of relative humidity. Relative humidity (RH) was measured by a hair-type dial hygrometer with a synthetic fiber detecting element. However at the high RH humidity encountered these devices usually read 100% or more. Measurements with an aspirated psychometer indicated a RH in the 90-95% range. The lack of wrinkling or other signs of desiccation on the apple, even in the most exposed areas, also indicated a functional RH of 95^{+}%.

Performance

Gas-tightness Although extensive leak tests have not been performed, an example of a test on a tight chamber was a time of 40 minutes for the pressure of 2 cm (0.8 in) of water to decrease to 0.2 cm (0.1 in). A better indication of the tightness is that an atmosphere containing 0.5% oxygen was easy to obtain and that it was necessary to add air to maintain that oxygen level. It was also possible to operate the rooms without excessive use of nitrogen even if they contained only approximately half their total capacity of fruit. Even 3 chambers which leaked water during the first season could be used for an atmosphere of 0.5% oxygen as long as there was water on the floor to a depth sufficient to cover the wall-floor seams. The leakage was due to the failure of the polyurethane to adhere to the floor and the floor-wall junctures. The chambers were located in a sub-room of a larger refrigerated room and the air temperature was maintained during spraying at approximately 15.5°C (60°F) and the temperature of the chambers rose dramatically during the spraying process. However the temperature of the concrete floor upon which the floor of the chambers rested was considerably cooler than the air temperature because of cooling of the common floor from the larger room. It is expected that moisture condensed on the floor before, and during, spraying so that the polyurethane did not adhere.

During the following summer season all refrigeration was turned off and the temperature allowed to equilibrate with external temperatures. The polyurethane was removed from the floor and in a section about 15 cm up the walls around the periphery of the room, and the floor and bared wall sections were cleaned, scraped and dried. This area was then resprayed with polyurethane and the rooms became so tight that air usually had to be added each day to maintain levels of 0.5 or 1% oxygen.

One chamber of the first 4 purchased is not as leak-tight as desirable but functions reasonably well at a high cost for nitrogen. However, if all chambers were equally "leaky" the cost of nitrogen would be unreasonably high. Because of this high cost this chamber was not used in the 1984-1985 season for CA work although it has performed well as a refrigerated chamber. This chamber was "leaky" from original installation and its performance was not improved by patching with polyurethane. Probably the best, and possibly the only, way to make its performance acceptable from a cost standpoint would be to dismantle it completely and begin again. The other 3 chambers of the first four perform quite well but at an estimated cost of $3.00 to

$5.00 (Cdn) per week per chamber for nitrogen.

Relative humidity As indicated previously the RH appeared to be in the 95-100% range as judged by hair-type hygrometers and an aspirated psychrometer, and by lack of desiccation of fruit exposed most directly to air movement from the evaporator. We believe we can lower the RH by omitting putting water on the floor and by decreasing the evaporator temperature with drainage of the defrost water to the exterior of the chamber.

Temperature control Fruit temperature usually did not vary more than $\pm$ 0.5°C (1°F), and this variation seemed to be consistent throughout the chambers. Air temperature with the room full of fruit usually varied by not more than $\pm$ 1°C (2°F) but was minimized by placing the temperature control sensor in the air delivery stream from the evaporator.

Refrigeration capacity The system was not originally designed for heat removal from products placed in the rooms warm form the field. However the system(s) seemed to have adequate capacity as judged by the lack of need of defrosting at 3°C and the need for only one period of 15 minutes per day for defrosting when the system was run at 0.5 $\pm$ 0.5°C. As well, before the safety thermostats were installed the fruit temperature in one room dropped from 3°C to -3.3°C (26°F) in a few hours when a control malfuntioned.

Atmosphere variation Within the limits of the accuracy and precision of the analytical devices no variation of oxygen and carbon dioxide levels was found between the 2 sampling locations within one chamber. However differences even as small as 0.2% oxygen could be important and this possible variation deserves further research. The oxygen level in the chambers was usually controlled at the desired concentration $\pm$ 0.2% with the carbon dioxide in the "tight chambers" usually the desired $\pm$ 0.3%, but in the "leaky chambers $\pm$ 0.5%. Corrective procedures were usually taken after the daily analyses indicated a variation of $\pm$ 0.2% or more. With more frequent analysis or taking corrective procedures when there was a small deviation from that desired the variation could have been reduced. With the "leaky" chambers the least variation of oxygen level was achieved by using a constant low flow of nitrogen and adding air as needed to bring the oxygen level up to that required. This constant flow of nitrogen reduced both oxygen and carbon dioxide levels making the carbon dioxide levels more variable as addition of carbon dioxide was required frequently.

Durability One group of chambers has been in operation for 4 seasons with few problems. One thermostatic control malfunctioned and was replaced, and the refrigeration condensing unit purchased first was replaced twice while still under warranty. Although the relief valves were set at 1.25 cm of water and normally pressures were never higher than 2.54 cm, 2 rooms were inadvertently subjected to a pressure of 10 cm of water or more without structural failure. Failure of the gas seal will probably depend on the durability of some of the wooden structural components in the presence of the high relative humidities, and even free water at the floor-wall junctures.

Conclusions

Prefabricated "walk-in" coolers can be modified for use as pilot-sized CA chambers using standard techniques for both sealing and operation. However, it is necessary to use the utmost care in assembly and application of the gas seal (sprayed-on polyurethane) to minimize air leakage and thereby the costs of atmosphere maintenance.

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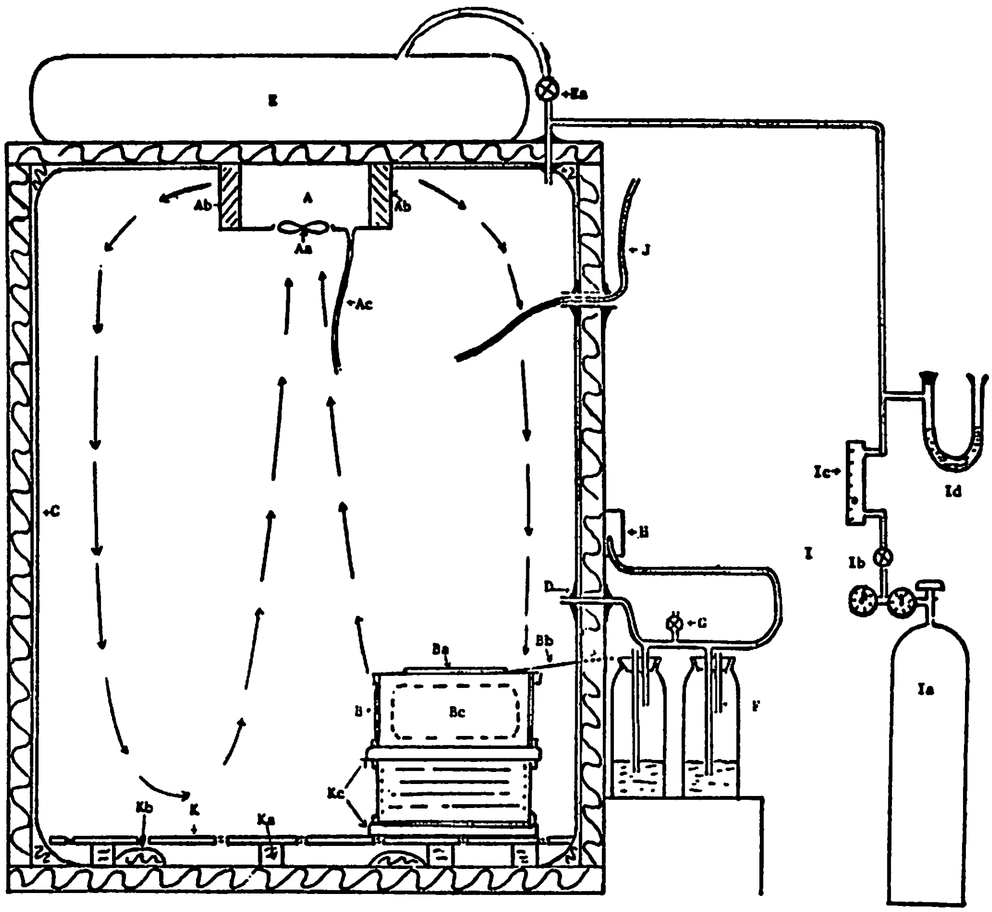

A - evaporator
Aa - fan
Ab - coil
Ac - defrost drain

B - scrubber
Ba - slide
Bb - wire control for scrubber
Bc - lime

C - sprayed-on polyurethane
D - collar with internal pipe flange

E - breather bag
Ea - gate valve

F - "automatic" relief valves
G - manual relief valve
H - differential pressure gauge

I - nitrogen purging system
Ia - nitrogen cylinder
Ib - metering valve
Ic - purge meter
Id - safety valve

J - sampling line

K - false floor
Ka - "2 x 4"
Kb - polyurethane floor seal
Kc - dunnage

Fig. 1. Schematic diagram of one chamber (not to scale).

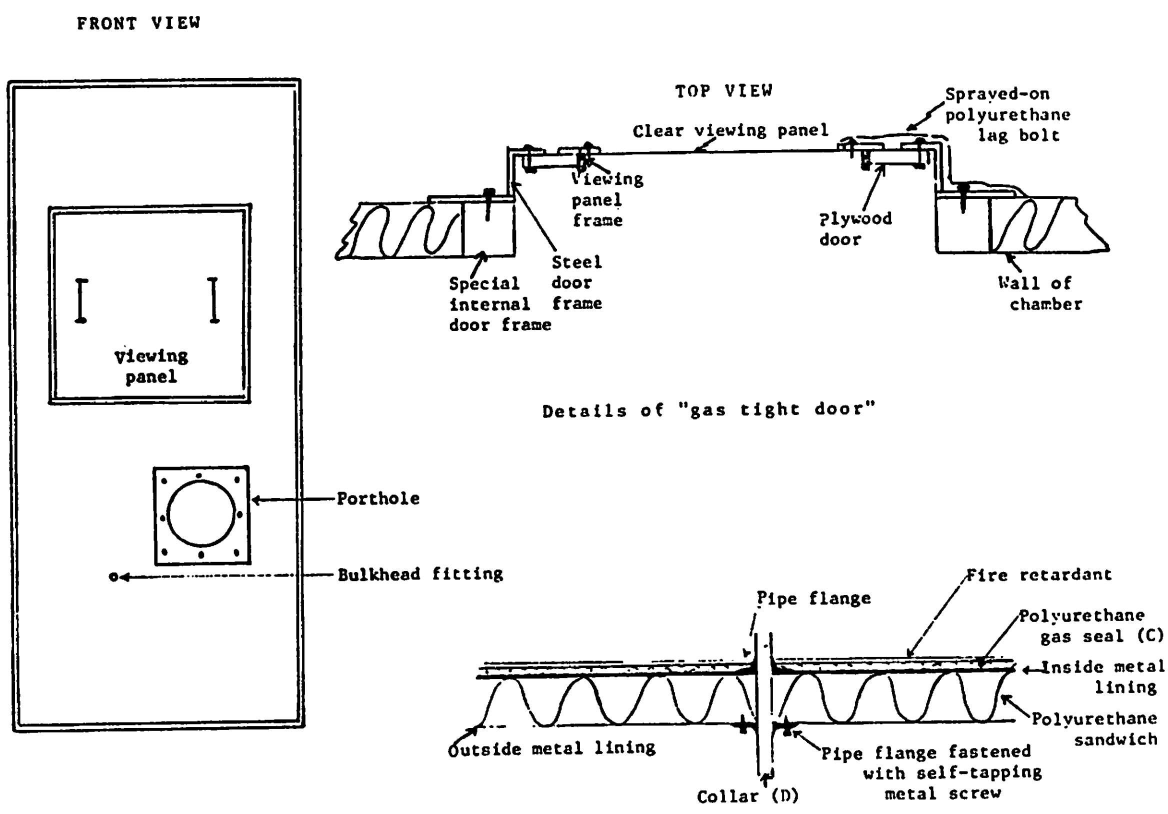

Fig. 2. Details of the gas-tight door, wall and wall penetration.