GASES, CHEMICALS AND POISONS
Gas Chambers

Many factors have to be considered in the design of a chamber to be used for killing dogs with gas. Details may vary from one gas to another and certainly the number of animals to be killed at a time will influence shape and design. Certain factors, however, can be considered to be common requirements for all gas chambers.

In the first instance, chambers need to be strong and durable. They should be airtight. One or more sides or ends should be arranged as doors which open fully so as to allow easy access and avoid leaving any fixed edges which will be difficult to clean. Corners within the chamber should be rounded for ease of cleaning and there should be a slope to allow drainage toward the door.

For safety, it is necessary to have in a chamber a means of exhausting gases harmful to attendants by use of a duct or chimney and an extractor fan.

For the welfare of the animals it is important that an unobstructed view should be ensured for the attendant by providing the chamber with large windows and an adequate electric light. Gas inlet valves should be muffled since cats especially may be alarmed by the hissing sound of gas entering the chamber.[5]

With most gases the concentration within the chamber is a critical factor in humaneness of the killing. It is then important to have a means of monitoring the concentration. Where this is not practicable, resort will have to be made to a timing device which under certain specified conditions of gas flow will permit an estimation of concentration in the chamber.

When several dogs are to be killed in one operation, it can help to have a mobile cage in which the animals can be wheeled towards and into the chamber.[6] Where this procedure can be avoided and the animals persuaded to enter the chamber voluntarily, considerably less anxiety will be caused to them.

The gases considered below will be:

1. Carbon monoxide
2. Carbon monoxide and chloroform
3. Carbon dioxide
4. Carbon dioxide and chloroform
5. Carbon dioxide with carbon monoxide
6. Nitrogen
7. Nitrous oxide
8. Cyanide
9. Chloroform

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[5]The possibility of using a low volatile and pleasant-natural or synthetic food odor or pheromone (in a container through which the incoming gas is passed) to make the animal less anxious and more relaxed during the induction phase of gaseous euthanasia is worth investigation.

[6]Over-crowding must be avoided.

Reported times to unconsciousness and death in dogs caused by gases are shown in Table I.

TABLE I.

REPORTED TIMES TO UNCONSIOUSNESS AND DEATH IN DOGS WITH VARIOUS GASES

Gas	Time to Unconsciousness Seconds	Time to Death Minutes	Authority
CO			
3%	330	14.5	Carding
4%	140	9.0	Moreland
4-6%	120	7.5	Moreland
4%	120	2.5	Blood et al.
5%	30	1.0	Blood et al.
CO & Chloroform	120-180	4-6	Richardson
CO_2			
70%	24	5	Carding
CO_2 & Chloroform			
0-80%	20	2	Despres et al.
40% CO_2 & 3.0% CO	30	4.5	Carding
Nitrogen with O_2 content reduced to 1.5% within 60 seconds	40	1.3	Fitch et al.

Carbon Monoxide

Carbon monoxide (CO) from a variety of sources has probably been the most used method of killing dogs and cats throughout the world during this century. It is still widely used in North America but its use in Europe has decreased in recent years. It has also been extensively used in Australia.

Carbon monoxide in concentrations as low as 2% will rapidly cause death through anaemic anoxia leading to paralysis of the respiratory and cardiac centers. Unconsciousness and death from this gas can occur without pain or appreciable discomfort.

The gas is non-flammable and non-explosive except under certain unusual conditions of temperatures and pressure and with concentrations about 10%. It has no odor below 80% concentration. The principal disadvantage is the danger to human health and life although no illness or deaths in attendants are known to have occurred through poisoning with this gas. Repeated, prolonged exposure to low concentration can have toxic effects similar to those experienced in cities with heavy traffic.

The following sources of carbon monoxide have been used:

1. Burning Charcoal
2. Coal gas
3. Exhaust fumes from petrol engines
4. Liquid gas from cylinders
5. Action of sodium formate on sulphuric acid
6. Reduction of carbon dioxide in a heated charcoal reactor

The average time of death in seven dogs inspiring 1% CO was recorded by Von Oettingen (1944) as 36 minutes. At 2% CO with an unstated number of dogs, Blood et al. (1968) recorded collapse at 4 minutes with death at 5.5 minutes while at 4% CO these times were reduced respectively to 2 minutes and 2.5 minutes. The times at 6% CO of .05 minutes for collapse and 1.0 minutes for death were not reduced by further increases in the concentration of gas. Thus higher concentrations of CO are not necessary.

The same investigators made the following observations on dogs killed in their tests: slight staggering for several seconds followed by complete collapse; a period of involuntary whimpering or crying for about 5 seconds succeeded by a period of supposed unconsciousness when there was no reaction to noise. Immediately before death there was a violent respiratory effort and a stiffening of all parts before relaxation and cessation of breathing.

The next report of trails on dogs recorded in the literature is Carding (1968), who used the action of sulphuric acid on sodium formate to generate pure CO to give chamber concentrations between 2% and 3%. Acid fumes were removed by passing the gas through sodium hydroxide. Fourteen adult dogs and eleven pups between three and six months were killed in a series of four tests. With the exception of several pups which moaned before collapse, all dogs collapsed without prior distress. Carbon monoxide is not recommended for puppies and kittens.

Moreland (1974) reported on trials involving more than 100 dogs killed either by exhuast fumes or cylinder gas. Some data from this work has been approximated where relevant and included in Table I. Finding no significant difference in killing efficacy between the two sources of carbon monoxide, the investigator made a useful comparison of their respective costs. He found that whereas costs of purchase were about twice as high as comparable costs for employing cylinder gas, the per animal cost of the engine exhaust method was less than one cent in terms of maintenance, fuel and labor charges. Per animal cost with pure gas varied from 8 cents at 4% to 12 at 6%.

Work on effects of carbon monoxide on other species includes:

Cats — Rohrie (1940), Gebauer and Pohlmey (1955), Gjesdal (1965) and Blood et al. (1968)

Guinea pigs — Ramsey and Eilmann (1932)

Various Species — Bancroft et al. (1966) reported that the dog is five times more sensitive to CO than the rabbit while humans are midway between the two.

Carbon monoxide is considered to be satisfactory as a means of killing cats with as little distress as in dogs (Blood et al., 1968).

The different sources of carbon monoxide present various advantages and disadvantages. The burning of charcoal either in blocks or small pieces in a furnace is simple and practicable for less industrialized regions. In certain conditions there may be a significant rise in the temperature of the chamber so that the flue gases need to be cooled before entering the chamber. It may be that overheating was the cause of unpublished complaints which led to the abandonment of chambers using this source of CO in Italian cities in recent years. Coal gas is no longer widely available for killing animals and in any case the dangers of explosion do not recommend this source.

Exhaust fumes from petrol engines are the most usual source of carbon monoxide. Special precautions have to be taken to reduce the temperature of the fumes and to remove impurities. Passage of the gases through a large water chamber will cool them and remove some carbon particles, oxides of nitrogen, hydrocarbons and oxygenates of hydrocarbons. Subsequent passage through a filter box containing hot air furnace filters, or a metal gauge filter with cloth screen, will remove carbon particles. Any motor vehicle engine in good operating condition is suitable if it is run at idling speed and on choke but adjusted to give minimum smoke. Killing by using exhaust fumes from a traveling vehicle produces a low concentration of carbon monoxide with a consequent long exposure to some irritating impurities before unconsciousness can occur and therefore should not be used. Pure carbon monoxide in cylinders is available in industrial areas but it is the most expensive source. It is also the most convenient.

Generation of the gas from sodium formate and sulphuric acid requires some simplification to make it more practical. The ideal would be an apparatus similar to a fire extinguisher in which the two chemicals are brought into contact by pressing a plunger or inverting the container. The carbon monoxide would then have to be passed through 10% sodium hydroxide to remove the acid fumes.

Reduction of carbon dioxide passed over a bed of charcoal heated electrically to about 800° C was used by Blood et al (1968). Ninety per cent pure carbon monoxide could be produced at very low cost. The charcoal bed had to be heated for an hour beforehand in order to reach the required temperature. To obtain a 6% CO concentration in their $50m^3$ chamber took about 15 minutes and the cost was less than a tenth of cylinder gas. The generator was not recommended because of danger from poisoning by 90% CO and the danger of explosion at this concentration with high temperatures (Blood, 1968).

If pure carbon monoxide were always to be employed, it is less likely that there would be criticisms of this method on humane grounds. After very many years of experience with carbon monoxide killing of dogs and cats (mostly under motor exhaust fumes) many agencies running pounds and shelters have been eager to abandon their use. Systems using such exhaust fumes require some maintenance and care and this may often have been overlooked. The most likely causes of poor results are probably low concentration of CO, high concentration of impurities, and overheating. These would be contributed to in the case of exhaust fumes by lack of proper tuning of the engine and poor function of the water tank and filters.

Sensitivity to carbon monoxide pollution is discouraging wider use of this gas for killing animals in industrial countries. In less industrial countries, where sophisticated apparatus and materials are less readily available for alternative methods of killing, the development of a reliable procedure for producing carbon monoxide by burning charcoal in a furnace would have considerable potential. A practical apparatus for generating

pure gas from chemicals might also help to make the systems more attractive and efficient.

Unless excellent ventilation is available in a room, a chamber used with carbon monoxide should always be outdoors. There may be a roof for protection of the apparatus and the attendant but the structure should remain open at the sides.

References

Bancroft, R. (1966) Transcript of 89th Convention of the American Humane Association, P.O. Box 1266, Denver, Colorado 80201, U.S.A.

Blood, D.C., Johnston, D.C. and Blackwood, J.D. (1968) Carbon monoxide euthanasia. A report to the Committee of the Victorian Division of the Royal Society for the Prevention of Cruelty to Animals. Unpublished.

Carding, A.H. (1968) Mass euthanasia of dogs with carbon monoxide and/or carbon dioxide: preliminary trials. *J. Small Anim. Prac.*, *9*, 245-259.

Fohrie, J.M. (1940) *J. S. Afr. Vet. Med. Assoc. II*, 151.

Gebauer, H. and Pohlmey, A. (1955) *Mh. Vet. Med.*, *10*, 582.

Gjesdal, F. (1965) *Medlemsbl. norske Vet. Foren.*, *17*, 239.

Haldane, J. (1895) The action of carbonic oxide on man. *J. Physiol.*, *18*, 430-462.

Moreland, A.F. (1974) CO euthanasia of dogs: Chamber concentrations and comparative effects of automobile engine exhaust and carbon monoxide from a cylinder. *J. Am. Vet. Med. Assoc.*, *1*, 853-855.

Ramsey, T.L. and Eilmann, J.H. (1932) Carbon monoxide acute and chronic poisoning and experimental studies. *J. Lab. Clin. Med.*, *17*, 415-427.

Vinter, F.J. (1957) The humane killing of mink. *Brit. Fur Farmers' Gazette*, August.

Vinter, F.J. (1965) Report on the Humane Killing of Chinchillas. Unpublished data.

Von Oettingen, W.F. (1944) *Publ. Hlth. Bull.*, *No. 290*, Washington, D.C.

Carbon Monoxide with Chloroform/Carbon Disulphide

In order to end the killing of dogs by forced oral dosing with prussic acid, Dr. Sir Benjamin Ward Richardson (1884) designed and constructed a new apparatus capable of killing without distress 100 dogs at a time. This was to deal with the maximum daily kill of dogs at the then Temporary Home for Lost and Starving Dogs, Battersea, London, where the apparatus was installed.

Following the death of the designer, his son in 1910 enlarged the unit to accommodate 150 dogs in two chambers in line with the increased surplus of dogs. Richardson's system was used for fifty years at this one site and it was only in 1934 that it was replaced. Sweeny (1975) reports that the Committee of the Home learned from the operators that with the large numbers of animals killed at a time there was often some howling and the dogs struggled with one another. The unit was replaced with an electrocution apparatus in which dogs were killed one at a time.

The chamber was constructed of double wooden walls separated by a filling of sawdust. Extensions protruded on either side to facilitate diffusion of the vapors when the body of the chamber was occupied by a two-tier cage. This has six wheels of 20 cm diameter and ran on rails from the kennels. When the sliding door at the front end of the chamber was raised, the cage was pushed up against a hinged safety door and traveled on rails to the interior. The door was then closed. Opening of a 3 meter chimney was controlled by a damper at its base.

The chamber was charged with gases before the dogs entered. Carbon monoxide was generated from two gas-fired condensing stoves, each capable of burning 1 kg charcoal/hour, arranged on one side of the chamber. The condensers removed water vapor together with the water-soluble impurities and the temperature of the fumes was reduced by this means.

To hasten the effect of the CO the gas was passed through a mixture of chloroform and carbon disulphide in a box filled with a highly porous material. There were two such boxes and into each was poured 300 ml of a solution containing equal proportions of the two fluids. At this point the dogs were placed in the chamber and a further 300 ml of the solution was added to the boxes.

Richardson reported that in the last 6,000 animals killed there were none which took a long time to die. They were gradually all unconscious in 2-3 minutes and dead after a further 2-3 minutes. If, after 4 minutes, animals could still be heard breathing by means of a stethoscope permanently fixed in the chamber wall, an additional 140-300 ml of the chloroform/carbon disulphide solution was added to the box. The chamber door was not opened until one hour after starting the operation.

It was noted that cats took longer to die than dogs but collapsed as quickly.

The 1903 annual report of the Home stated that Richardson had altered the procedure to good effect. The chamber now closed automatically as the cage was removed and so remained permanently charged with lethal gases. This greatly shortened the preparatory stages.

There are no other records known of this method in the scientific records and no indication that it has been used elsewhere. The same chamber is referred to in a popular journal of the times (Newnes, 1891). This method is probably of historical interest only.

References:

Newnes, G. (1891) Home for the Lost Dogs, Edite. *Strand Magazine, 1,* 652-653

Richardson, B. W. (1884) J. *Royal Soc. Arts.* December 26, pp. 138-151

Sweeny, H.J. (1975) Personal communication

Carbon Dioxide

Carbon dioxide (CO_2) has not been used for killing dogs routinely except in one small government shelter in Brazil (Dunin, 1969). Following work in Britain (Glen and Scott, 1973) the gas has been introduced by animal welfare agencies in that country and abroad for use on cats and kittens. In Canada, CO_2 cabinets are also used for killing dogs and newborn pups if they have first been made unconscious with chloroform.

Low concentrations of CO_2 up to about 10% are used in anesthesia to stimulate respiration. Higher concentrations depress the central nervous system which leads to unconsciousness, followed by respiratory arrest and death.

Carbon dioxide is a non-flammable, non-explosive gas, heavier than air of which it is a normal constituent to a very small extent. The gas is readily obtained from "dry ice" or, in compressed form, in cylinders available as a byproduct from breweries and other fermentation industries. Cylinder gas is generally used by preference but its cost is a significant item of expenditure.

Experimental use of 30% to 40% CO_2 was found to produce anaesthesia in dogs in 1 to 2 minutes, but with occasional struggling (Leake and Waters, 1929). Brown and Miller (1952) found in dogs that blood pressure fell precipitously as CO_2 concentrations exceeded 70% but that at 90% cardiac arrest was delayed until 4-9 minutes.

Trials in a chamber which involved 11 dogs in six tests reported by Carding (1968) indicated that 70% CO_2 was an approximate optimum. At this concentration collapse occurred after 20 seconds and presumed death at 5 minutes with practically no hyperpnoea before collapse and little paddling afterwards. At concentrations between 50% to 60% and at 80% hyperpnoea and paddling were pronounced. Average times of collapse at these concentrations were 30 seconds with presumed death occuring after an average of 10-18 minutes. At a concentration of 45% to 50% CO_2 collapse also occurred after 30 seconds but the dogs were still breathing after one hour.

The process of collapse in these trials varied. In the best result at 70% CO_2, the animal fell suddenly with no sign of previous anxiety and with transient paddling afterwards for 10 seconds. In other cases there was a similar rapid collapse but sudden collapse was replaced by a gradual sinking with mounting hyperpnoea followed by rapid paddling and unsuccessful attempts to regain the standing position. There was one disagreeable test in which the gas was introduced into the relatively large chamber after the dogs were placed inside. Collapse did not occur until 4 minutes after removal from the chamber. There was no marked excitement but some vocalization and scratching to get out. Salivation was marked.

Glen and Scott (1973) describe a simple cabinet and procedure by which they killed 10 cats and 20 kittens. Results were variable but, with one exception at 90 seconds, all animals had collapsed within a range of 25-60 seconds, at which moment they were presumed unconscious. In half the tests with initial CO_2 at more than 60% death occurred within the range of 1.5 to 6 minutes while in the remainder, with the initial CO_2 at 60% or less, the cats were still alive after 10 minutes when additional CO_2 was added to cause cardiac arrest. In each of these cases the cabinet was already charged with gas before the cats were introduced. When the gas was introduced after the cats were put in the cabinet, the time before collapse increased to a range between 80 and 140 seconds but there was no greater degree of excitement.

Some excitement was noted in most of the tests and was described as slight or moderate. Slight excitement consisted of obvious resentment against the gas as by licking and sneezing, and movements about the cabinet to seek the highest point. These signs never lasted more than 30 seconds. Moderate excitement involved more erratic movements and "yowling" but these signs also were of short duration.

The authors of the above work concluded that CO_2 represents a marked advance on the use of chloroform for killing cats and kittens from the humane viewpoint.

The use of 32% oxygen when anaesthetizing sheep with CO_2 was observed by Mullenax and Dougherty (1963) to cause less struggling. Klemm (1964) noted that the danger of respiratory and cardiac arrest in CO_2 anaesthesia in cats was reduced with supplementary oxygen. Mac

Arthur (1975) has subsequently described a double chamber in which a cat may first be made unconscious in a mixture of 70% CO_2 and 30% O_2 and then placed in the second chamber to die in pure CO_2. Unconsciousness is produced within 20 seconds mostly without struggling and death occurs within three minutes. The chambers are open-topped and glass fronted and they are charged with gas before the cats are placed inside. Trials have shown that cats can be killed at the rate of one every four or five minutes. Equally satisfactory results have been achieved with puppies and laboratory animals.

Extensive work has been reported on the effects of CO_2 on small animals extending from basic research to routine killing by this method. The list includes:

Cats — Klemm (1964), Glen et al. (1973) and MacArthur (1976)

Dogs — Leake and Waters (1929), Brown and Miller (1952) and Carding (1968)

Laboratory Animals — Woodbury, et al. (1958), Stone et al. (1961), Hyde (1962), Rudolph (1963), Kline et al. (1963), Lampman (1964), Breazile and Kitchell (1969), MacArthur (1976).

Low concentrations of CO_2 up to about 10% are used in anaesthesia to stimulate respiration. Higher concentrations depress the central nervous system which leads to unconsciousness, followed by respiratory arrest and death.

Work on domestic animals with CO_2 has centered on attempts to produce anaesthesia prior to slaughter. The list includes:

Pig — Blomquist (1957), Mullenax (1963)
Sheep — Mullenax (1961)
Chicken — Kotula et al (1957 & 1961)
Turkey — Drewniak et al (1955)

Comparatively little work has been reported on attempts to develop CO_2 as a practical and humane method of killing dogs. The expense of the cylinder gas is insignificant but not excessive in industrial countries, especially if the gas can be conserved for several cycles of operation. Conservation of the gas which is heavier than air suggests the necessity for loading through the top of the chamber. This in turn suggests that the chamber should be below floor level in which case a hoist is required for a large cage. When further work has been undertaken to determine optimum concentrations using a significant number of dogs a satisfactory range of chambers could be designed. A dip-lift apparatus would be necessary for animals larger than cats.

In the case of cats, CO_2 with oxygen appears to be reliable, rapid, safe, and simple as well as humane. Details of cost are awaited. At present CO_2 has not been adapted for satisfactory use on dogs, and until further developments show it to be humane, it should not be used on dogs. It is a valid alternative to intravenous barbiturate, which may be difficult to give to cats, and may be more humane than forcibly restraining wild or fearful cats for injection.

Addendum

Professor C. Health, Department of Pharmacology, University of Alberta, Edmonton, Alberta, comments:

"I worked with Brown, to whom you refer, from 1951 to 1955, giving 30% and 40% CO_2 mixed with oxygen, and have found it very distressing indeed. When, together with Brown, we used CO_2 alone to anesthetize dogs (administered via a mask) the dog fought and showed every sign of distress, and had to be very strongly restrained. It required at least 40% CO_2 on these occassions to produce unconsciousness.

"Because of these experiences, and on theoretical ground (CO_2 is a very strong respiratory stimulant known to cause dyspnoea) I fail to see any advantages of CO_2 over either decompression or nitrogen, and feel that the potential and real disadvantages of this gas should lead to its rejection as a practical method of euthanasia."

References

Blomquist, S.M. (1957) *Food Manufacture*, May.

Breazile, J.E. and Kitchell, R.L. (1969) Euthanasia for laboratory animals. *Fed. Proc., 28*, 1577-1579.

Brown, E.B. and Miller, F.A. (1952) *Fed. Proc. 11*, 18.

Carding, A.H. (1968) Mass euthanasia of dogs with carbon monoxide and/or carbon dioxide: preliminary trials. *J. Small Anim. Prac., 9*, 245-259.

Drewniak, E.E., Bausch, E.R. and Davis, L.L. (1955) USDA Circular No. 958, Washington, D.C.

Dunin, D. (1969) Personal communication.

Glen, J.C. and Scott, W.N. (1973) Carbon dioxide euthanasia of cats. *Br. Vet. J., 129*, 471-479.

Hyde, J.L. (1962) The use of solid carbon dioxide for producing short periods of anesthesia in guinea pigs. *Am. J. Vet. Res., 23*, 684-685.

Jukhnovski, S. (1960) Thesis, Alfort.

Klemm, W.R. (1964) Carbon dioxide anesthesia in cats. *Am. J. Vet Res., 25*, 1201-1205.

Kline, B.E., Peckham, V. and Heist, H.E. (1963) Some aids in handling large numbers of mice. *Lab. Anim. Care., 13*, 84-90.

Kotula, A.W., Drewniak, E.E. and Davies, L.L. (1957) *Poult. Sci., 36*, 585.

Kotula, A.W., Drewniak, E.E. and Davies, L.L. (1961) *Poult. Sci., 40*, 213.

Lampman, E.D. (1964) Useful equipment for the animal colony: bedding, bin loader, euthanasia chamber, feed sifter. *Lab. Anim. Care, 14*, 514-518.

Leak, C.D. and Waters, R.M. (1929) The anesthetic properties of carbon dioxide. *Anesth. Analg., 8*, 17-19.

MacArthur, J. (1976) Carbon dioxide euthanasia of small animals. In *Humane Destruction of Unwanted Animals.* Universities Federation for Animal Welfare, Potters Bar, Herts, England, pp. 9-17.

Mullenax, C.H. (1961) Thesis, Cornell University.

Mullenax, C.H. and Dougherty, R.W. (1963) Physiologic response of swine to high concentrations of inhaled carbon dioxide. *Am. J. Vet. Res., 24*, 329-332.

Rudolph, H.S. (1963) A small animal euthanasia chamber. *Lab. Anim. Care, 13*, 9-95.

Stokes, J. III, Chapman, W.P. and Smith, L.H. (1948) Effects of hypoxia and hypercapnia on perception of thermal cutaneous pain. *J. Clin. Invest., 24*, 299-304.

Stone, W.S., Amiraian, K., Duell, C. and Schadeer, C. (1961) Carbon dioxide anesthetization of guinea pigs to increase yields of blood and serum. *Proc. Anim. Care Panel, 11*, 299-303.

Woodbury, D.M., Rollins, L.T., Gardner, M.D., Hirschi, W.L., Hogan, J.R., Rallison, M.L., Tanner, G.D. and Brodic, D. (1958) Effects of carbon dioxide on brain excitability and electrolytes. *Am. J. Physiol.*, *192*, 79-90.

Carbon Dioxide with Chloroform

The combination of these agents for killing dogs was first reported by Desprès and Arlattaz (1967) who introduced the system at the municipal pound in Geneva where owners often stayed with their animals to witness its death. In 1969 a similar apparatus was installed in a private dog shelter just across the border in France. In Spain, de Bruyn (1969) modified the design of the apparatus for local manufacture and demonstrations were given at Gerona before public health and veterinary officials. Subsequently, a unit was installed at the new municipal dog center at Canto Blanco, Madrid, where it has given satisfactory service when properly used.

The reason for combining these agents was to utilize the rapid unconsciousness produced by relatively high concentrations of CO_2 with the more rapid lethal effect of chloroform.[7] The procedure of Desprès and Arletta (1967) was to place usually one dog in the chamber and then introduce CO_2 rapidly up to approximately 80%. The animal collapsed in about 20 seconds after which further CO_2 was passed through a vaporizer containing chloroform. Within 2 minutes the dogs were dead. Observations in France and Spain suggest that such rapid times are not invariably achieved with the modified apparatus under local conditions. The method was said by the originators to be equally satisfactory for cats.

Addendum

Professor H.C. Rowsell adds the following observations:

> In our laboratory we have used both uncharged chambers mixing carbon dioxide and chloroform as well as charged chambers with chloroform-carbon dioxide mixtures. The chloroform was vaporized. Death of rats had occurred in as short a period of time as 5 seconds with little evidence of muscular activity. Additionally, we have observed it with cats and dogs. We have demonstrated no signs of hyperventillation and collapse occurring within 3 to 10 seconds of exposure to the combined gases in cats and within 20 to 30 seconds in dogs. Carbon dioxide does have an interesting action. It not only produces a narcosis but it also stimulates the respiratory center, therefore, hyperventilation may be commonly observed. An additional action which probably relates to the success of the chloroform-carbon dioxide mixture is that carbon dioxide produces a dilation of the blood vessels in the brain, therefore, the chloroform is more rapidly taken up, producing the state of anaesthesia rapidly. It is in this area that I believe additional work should be done. Unfortunately at the present time, chloroform has been listed as a carcinogen. Additionally, we have known for years that it has an effect upon the liver and renal function as well as spermatogenesis. It is important, therefore, that before carbon dioxide and chloroform mixtures can be recommended, adequate methods must be developed to exhaust fumes to the outside. Again, if the chloroform is a carcinogen, then we must ensure that air dilution is sufficient so that it does not pose a human hazard.

[7]See *Addendum*, following.

References

de Bruyn, L.F. (1969) Personal communication.

Desprès, P. and Arlattaz, G. (1967) Installation pour l'euthanasie des animaux de fourriere. *Rev. Tech. Vet. Hyg. Aliment.*, February, page 26.

Desprès, P. and Arlattaz, G. (1969) Personal communication.

Carbon Dioxide with Carbon Monoxide

Von Oettingen (1944) reported that the toxicity of CO is increased by an increase in CO_2. In order to utilize this effect and to check if an economy in the quantity of CO_2 could be achieved by employing a small concentration of CO, Carding (1968) made a single trial with two dogs. The dogs were introduced to a chamber with about 40% CO_2 and collapsed after an average of 30 seconds. At this point CO generated from chemicals was introduced up to about 3% and death occurred at 4-5 minutes. The time of collapse was 10 seconds slower and death occurred 30 seconds sooner than with CO_2 alone at 70%.

Addendum

Professor Heath adds, "I see no value in considering adding CO_2 to other lethal gases such as chloroform or CO, both of which are individually excellent means of producing first unconsciousness, then death without recovery of consciousness. While technically it may be correct to say that CO_2 increases the toxicity of CO, i.e. lowers the LD_{50}, CO is very potent without the CO_2, and, in fact, the side effects of the added CO_2 are undesirable.

References

Carding, A.H. (1968) Mass euthanasia of dogs with carbon monoxide and/or carbon dioxide. *J. Small Anim. Pract. 9*, 245-259.

Von Oettingen, W.F. (1944) *Publ. Hlth. Bull., No: 290, Washington, D.C.*

Nitrogen

The first record of using nitrogen to kill animals was from Vinter (1957) who worked on ways for the humane killing of mink. She reported that although mink became restless while the gas was being introduced, they became unconscious after about 90 seconds. Death invariably occurred before 5 minutes. Vinter (1965) tested the use of nitrogen on chinchillas and found it satisfactory from a humane viewpoint. The AVMA Panels on Euthanasia (1963 and 1972) recommend that trials with nitrogen should be undertaken on other animals to check its feasibility for euthanasia. This work was carried out by Fitch, et al. (1974).

Nitrogen is an inert gas which is a major constituent of air. In high concentrations it can, by displaying oxygen, produce unconsciousness through hypoxia. Death occurs as a result of paralysis of the respiratory center. The gas, obtainable in liquid or gaseous form in pressurized cylinders, is readily available in industrial countries although it tends to be relatively expensive in some areas.

In their investigations, Fitch et al. (1974) who used the term "nitrogen flushing," killed 313 dogs, 36 cats, 1 pig, 2 rabbits and 8 ducks. Electroencephalograms (EEG) were recorded from 34 dogs as well as electrocardiograms (EKG) and arterial blood pressure. The animals were placed in a chamber for 5 minutes. EEG patterns showed the characteristic for sleep and unconsciousness in an average of about 40 seconds and became isoelectric at 80 seconds. When there had been an isoelectric EEG, zero arterial blood pressure and no spontaneous respiration for 30 seconds, attempts at revival were unsuccessful.

Behavior of the animals was summarized as follows:

All became unconscious and collapsed within one minute; there were no signs of pain in any animal before unconsciousness including cases in dogs of upper respiratory disease. After unconsciousness, there were instances of muscle twitching, gasping, convulsions and yelping. The authors suggested that these were a result of acute hypoxia occurring in the unconscious animal (Fitch et al., 1974).

The same authors noted that the technique was successful in all species tested except for neonate puppies and kittens, while reptiles and amphibians were not effectively killed. They add that unborn young were killed in a pregnant female euthanized.

They recommend that the nitrogen should be exhausted to the exterior of the building where no environmental harm could be caused. In their view, nitrogen would be economically competitive with other approved euthanasia methods in use.

Since the end of 1974 three companies[8] in the U.S.A. have marketed a cabinet lined inside and out with formica and having plexiglas doors complete with all the ancillary apparatus for nitrogen killing of dogs and cats.

Addendum

As yet, nitrogen for euthanasia has not been approved by UFAW. Hypoxia and paralysis of the respiratory center may be distressing and unavoidable prior to unconsciousness. Professor H.C. Rowsell adds the following pertinent observations:

> "In our hands, the nitrogen flushing method for euthanasia has been frustrating. As an agent to kill rats, there is much more muscular activity with nitrogen flushing as compared to CO_2. The experience which we have had with dogs and cats using the nitrogen flushing method has left some serious doubt in our minds as to its suitability as a method to produce a humane death. We used a chamber produced by Clark & Cote in Calgary, Alberta. The chamber is designed on that distributed by Snyder Manufacturing of Denver, Colorado, the group that I believe made the prototype for Dr. Fitch and his associates for their studies. We compared in these studies simultaneously the use of nitrogen and CO_2 as a method for producing a humane death in cats. We found in cats that very quickly these animals responded to the CO_2 level and would do some sniffing and in many cases, attempting to escape from the container (which was of the UFAW design). When the oxygen level in the container was down to 8%, they would collapse. On the other hand, with nitrogen, when the oxygen level fell to 3% or less, the animals would drop with rigidity in their limbs, throwing their heads back, and emit vocalizations (that one normally associates with extreme pain or distress) for 5-15 seconds. For the operators this was far more distasteful than the appearance of the animals with the carbon dioxide.
>
> "With the study of nitrogen flushing method in dogs, we found again that the dogs showed very little evidence of distress when the oxygen was around the 8% level, but once it fell to 3% and then onto the 1.5% when the machine was turned off, the dogs would fall, stiffen their legs and throw their heads backwards and vocalize very loudly. It was at the terminal end of this vocalization that the chambers were opened; on almost every occasion we found that the blinking reflex was present. This is an indication to us that the animal does not have a depressed central nervous system and is not unconscious when this stage is reached. It may be disorientated; however, animals at this stage can feel pain. We cannot categorically state that they are feeling pain during the induction of death at the 1.5% oxygen level. In many of the dogs that were tested, the chamber would only be opened 5 to 10 seconds; the oxygen level would rise to 8%. Before the nitrogen gas would come on again, approximately 20 seconds would have elapsed and the dog would be on his feet without staggering or falling about. One would expect that an animal in a state of depression of the central nervous system would not show such rapid recovery at this low oxygen level.
>
> "The fact that dogs in the nitrogen flushing method show a blinking reflex when the chamber is opened during the vocalization and the rapid return to a standing position without signs of central nervous depression suggests that the nitrogen flushing method may not be acceptable as a humane killing technique.
>
> "Using the carbon dioxide method and the nitrogen flushing method, the administration of a tranquilizer prior to putting the animals in the euthanasia chambers, changes the behavioral attitudes of the animal significantly: in both the nitrogen and the CO_2 chambers, struggling, escape reaction and vocalization will not then occur. It is, therefore, suggested that the only one way the nitrogen chamber might be acceptable is when it is used in animals that have been previously tranquilized."

[8]Snyder Manufacturing Co., 5500 East Pacific Place, Denver, Colorado 80222, Schroer Manufacturing Co., 2217 Campbell Street, Kansas City, Missouri 64108, Kirschner Scientific Products, Seattle, Washington.

References

American Veterinary Medical Association (1963) Report on Animal Euthanasia. *J. Am. Vet. Med. Assoc., 142,* 162-170.

American Veterinary Medical Association (1972) Panel on Euthanasia. *J. Am. Vet. Med. Assoc., 160,* 761-772.

Fitch, J., Hall, P. and Herin, R. (1974) Report to the American Humane Association on the Evaluation of the High Altitude (Low Pressure) Method of Euthanasia.

Vinter, F.J. (1957) Humane Killing of Mink. *Brit. Fur Farms' Gazette,* August

Vinter, F.J. (1965) Report on Humane Killing of Chinchillas. Unpublished data.

Nitrous Oxide

There has been little application of this gas in animal euthanasia. Ms. Gretchen Wiler (personal communication) has used this on a small scale for euthanizing kittens, puppies and adult cats. Monitoring two pound pressure release from a gas cylinder into a small, glass fronted chamber (with air vents on the lid), the animal falls within 25-30 seconds. The gas is turned off after 3 minutes and the animal removed after a further 5-7 minutes. Nitrous oxide appears to be less irritating than CO_2, is safer to personnel than CO, and on humane grounds, it is attractive since it is both an analgesic and an anesthetic. Adequate ventilation to prevent personnel from becoming intoxicated, is essential. The use of this gas, especially for euthanizing small numbers of animals, deserves further evaluation.

Cyanide Gas

Hydrocyanic acid (HCN) gas has a long history as a lethal agent for animals and humans. Polson and Tattersall (1959) mention its use to control scale on California citrus trees in 1886, to destroy vermin in carriages by the Cape Government Railway in 1898, to kill rats in ships in New Orleans in 1929 and by the Nazis in concentration camps from 1939. One Robert B. White had been executed in 1930 in a cyanide chamber in the U.S.A. The use of HCN to kill laboratory animals was referred to by Smith in 1965, and HCN has also been widely used in the last twenty years to kill wild animals such as rabbits. Unwanted dogs have been killed by HCN in outdoor pits, notably in Spain in former years.

A cyanide-cytochrome link is formed and this is reversible only if respiration can be continued (Polson and Tattersall, 1959). Cyanide gas is very irritating to the respiratory mucosa and the hypoxia acting on the brain leads to violent clonic convulsions and opistothonous prior to death.

The inhalation by humans of HCN in doses of 2 ml/liter or more will cause immediate giddiness, unconsciousness and collapse while death may follow quickly or following some delay (Polson and Tattersall, 1959). With smaller doses, collapse may be preceded by watering of the eyes, headache, irritation of the throat, palpitation of the heart, difficulty in breathing and weakness of the limbs.

The usual way of generating HCN for a gas chamber is to allow pellets of sodium cyanide (NaCN) or potassium cyanide (KCN) to react with sulphuric acid. Smith (1965) describes a common procedure for killing laboratory animals whereby pellets of KCN in a cheese cloth bag are suspended over a vessel in the chamber containing sulphuric acid. The bag of pellets can be dropped into the acid by means of a pulley or by cutting the attached cord and immediately the two chemicals come into contact the HCN arises as fumes.

Calcium cyanide (CaCN) is used in the fumigation of greenhouses at a rate of about 100 gm/1,000m^3. The CaCN is simply exposed to damp air at a temperature of 18°C or more. This procedure was used by the Nazis for mass murder at Strathof in Alsace (Polson and Tattersall, 1959).

Magnesium cyanide (MgCN) similarly reacts with moist air or water to generate HCN and in granule form is used to kill rabbits in their burrows, as well as occasionally for poaching river salmon.

There do not appear to be any cases recorded of death from accidental inhalation of HCN while poisoning rabbits, although Hume (1961) reported a case of accidental inhalation in which the victim became unconscious without distress and recovered spontaneously in the fresh air sufficiently to return home and eat lunch.

It is clear that HCN is too toxic to be recommended for routine use indoors because of danger to operators but the wide safety margin which exists when it is employed outdoors under stringent conditions is evidenced elsewhere. In World War I, the British used HCN in shells for a time, but they were found to be not very effective (Polson and Tattersall, 1959).

The present situation with regard to HCN and the killing of dogs and cats is that it is not now known to be in regular use anywhere. The reasons seem to be the violent convulsions which result and which are most disagreeable to witness either by operators or casual observers, and also the hazard to operators. While HCN cannot be considered an ideal method of killing, it may have a useful application in outdoor situations in less developed areas where better alternatives are not available. It could replace more painful methods and has the advantage of being cheap, irreversible (in the absence of treatment) and very quick-acting and, by virtue of its speed of action, it may be considered quite humane.

References

Hume, C.W. (1961) Letter to the editor, *Vet. Rec., 73,* 812

Polson, C.J. and Tattersall, R.N. (1959) *Cyanide Poisoning in Clinical Pathology,* English Universities Press.

Smith, D.C. (1965) In Gay, W.I. *Methods of Animal Experimentation.* London, Academic Press pp. 181 and 189.

Chloroform

This volatile substance was once commonly used as an anesthetic. Exposure to the fumes (either inhaled via a mask or when the animal is placed in properly constructed box containing chloroform) leads to unconsciousness with ten to twelve minutes: prolonged exposure leads to brainstem inhibition, respiratory then cardiac arrest and death. There are many effective designs of chloroform boxes for euthanizing small animals — cage birds, kittens, puppies, and cage pets such as mice and hamsters. The animals should not come into direct contact with the chloroform nor with a strong concentration of the vapor since it is extremely irritating to the eyes. To induce gradual anesthesia and death, the animal should not, therefore, be placed directly into a box already saturated with chloroform. In order to insure a smooth induction, it should be put in the box before the chloroform is poured onto a gauze/cotton-wool dispenser. A concentration of only 1.5 to 2% chloroform vapor in the air is sufficient to produce anesthesia and death. A stethoscope should be used when possible to make sure the animals are dead since short exposure (under ten minutes) may result in deep anesthesia and not death, especially if the chloroform vapor concentration is low. A ventilation fan and extractor hood should be used to evacuate the chamber after use since chronic exposure to chloroform fumes is an occupational hazard, being linked with sterility, liver and kidney damage and cancer in man.

Chemical Capture/Restraint

One critical area of animal control that also requires further research is in chemical capture and restraint of free roaming/feral animals. The following observations on the situation in America are relevant:

The use of nicotine sulphate and nicotine alkaloids is gaining widespread use as a means of capture and restraint, especially of free roaming dogs. It is administered by injection: a syringe loaded dart gun is one of the more popular methods used today by municipal animal control officers and police in various parts of the country. Correlated with the increasing use of this drug is an increase in owner complaints of their free roaming or accidentally escaped pets having been killed by such injections.

Nicotine sulphate or nicotine alkaloids are very potent, causing voluntary muscular paralysis, convulsions and ultimately respiratory arrest. Death is due to respiratory failure. Such problems could be avoided if,

(1) Accurate doseage could be assured. This is difficult without first weighing the dog. A dog with a thick coat, at a distance, may seem heavier than it actually is. It is, therefore, easy to miscalculate.

(2) A wide safety margin could be assured. Nicotine has a very narrow safety margin. A mere five pound body weight overdose could kill a dog.

(3) High species susceptibility could be avoided. The dog is one species that is particularly susceptible to the central nervous system effects of nicotine sulphate and nicotine alkaloids.

Nicotine preparations for capture/restraint of animals does not fulfill any of the above three criteria — it is easy to kill a dog with an overdose, there is virtually no safety margin and the dog is particularly prone to nicotine poisoning.

There are safer drugs which are already in use in several municipalities and which satisfy the above criteria and also satisfy two other criteria namely: (1) effects are easily reversible with in injectible antidote or the effects are transient and the animal recovers rapidly, and (2) from a humane viewpoint the drugs induce muscular relaxation, tranquilization and/or light anesthesia in contrast to the extremely distressing physiological and psychological effects of nicotine sulphate.

The following statement from a veterinary colleague, Dr. William J. Boever, Senior Veterinarian, St. Louis Zoological Park, St. Louis, Missouri, who has had considerable field experience on immobilization and capture techniques in wild and domestic animals, gives further warnings and guidelines:

> "The feat of capturing free roaming dogs is an extremely difficult one. First of all one is dealing with an animal in which (1) its exact weight and physical condition are not known, (2) the animal is already excited, making immobilization and anesthesia a poor risk, and (3) you are not sure when he last ate or his nutritional state. On top of all this, you have to load a dart and hit the animal in the muscle, making sure not to dart him in the head, thorax, abdomen, or lower leg. Then hopefully, if you are an expert marksman, the dart will fire and not misfire as sometimes happens and that the complete dose and not a partial dose is administered into the muscle and not into the fat or skin. This is a monumental task for someone educated and trained in anesthesiology, etc. much less the caliber of most individuals working for most of the municipalities. No wonter the success rate with nicotine and capture gun is usually less than 30%. (I have heard that in some municipalities of no dogs ever recovering from nicotine)."

It is, therefore, strongly recommended that alternatives[9] to nicotine sulphate be utilized where this drug is currently in use by police or animal control officers.

[9]eg. Rompun (xylazine) a sedative analgesic from Haver Lockhart.

Other chemicals with a wider safety margin have been used in the field, notably Ketamine (a phencyclodine derivative) and Rompun (a tranquilizer), the two being mixed in the dart syringe to give a single dose estimated at 10 mg/kg Ketamine plus 1 mg/kg Rompun. For small and delicate animals, a blow gun may be safer and more effective than a dart gun. Other effective tranquilizer/analgesic mixtures include Hypnorm (containing fentanyl, an analgesic and haloanisone, a butyrophenone tranquilizer) and Immobilon (which contains etorphine, analgesic, and a phenothiazine tranquilizer).

Animal Control and Poison Baits

This report would be incomplete without considering the use of poisons in animal control. Under certain circumstances, the use of poisons to destroy dangerous (eg. rabid) or otherwise harmful free-roaming and feral cats and dogs, becomes a necessity.[10]

The search for a quick acting poison that causes either no or minimal suffering and is palatable (or easily masked by the bait), continues. Scott (1976) has reviewed the various poisons available that have been used in animal control. (See Table II)

More research in this area is needed to develop a quick acting poison with minimal distressing side effects. It is unlikely that a dog/cat species-specific poison could be developed, but this would be advantageous considering the risk to human beings and other "non-target" species. Also secondary effects, as with sodium fluoracetate, should be considered; other animals eating the carcass of the poisoned animal may also be poisoned.

References

Scott, W.N. (1976) The use of poisons in animal destruction. In *Humane Destruction of unwanted Animals.* UFAW, Potters Bar, Herts, England, pp. 33-42.

Recommendations for Research

In the preceding pages consideration has been given to several different agents or combinations of agents which are often considered capable of causing unconsciousness and death in dogs or cats with limited or no distress. In only one of these cases, nitrogen, is there good scientific evidence and this has yet to be substantiated by further corroborative studies. In the case of carbon monoxide and carbon dioxide it remains important to establish more scientifically if they are equally able to produce unconsciousness without prior distress. This will require the collection of data from EEG[11] and arterial blood pressure recordings. Pure gas should be used.

[10]Where trapping is possible, a padded offset "steel jaw" trap is one of the more humane traps; cats and dogs may be live trapped in a humane trap-door type box trap.

[11]The electroencephalogram can provide useful information, particularly with respect to the length of time it is normal, abnormal and the period it takes in order to become flat. We should not delude ourselves into believing that it will tell us precisely what the animal is experiencing. Again, it must be re-emphasized that we can never put ourselves within the brain of that animal to really understand precisely the feeling of the animal. — H.C. Rowsell

TABLE II

A SELECTION OF FREQUENTLY USED POISONS (from Scott 1975)

Substance	Advantages	Disadvantages	Major Symptoms	Time to Death
Alphachloralose	Narcotic	Temperature-dependent		
Cyanide	Immediate death	Operator hazard	Excitement, convulsions, coma	seconds
Norbormide	Toxic only to *Rattus norvegicus*	Bitter taste in baits	Convulsions, coma	1-24 hours
Fluoracetates	Relatively quick death	Operator hazard	Excitement, convulsions, coma	hours
Anti-coagulants (e.g. Warfarin)	Operator safety	Ingestion over a period required. Days to death.	Diarrhea, vomiting, coma	days
Zinc Phosphide	The most humane of metallic compounds	Abdominal pain	Abdominal pain, coma	2-3 days
Antu*	Non-toxic to adult chickens	Bitter taste Death from "drowning"	Pulmonary oedema	hours/2 days

*use discontinued in the U.K. because it contains carcinogens.

The most valuable way of achieving this information would be for each gas to be tested on dogs, and where applicable on cats, in a similar chamber or cabinet. This would permit a study of the most effective concentration for each gas and a comparison of the costs involved at optimum concentrations of each gas (Project 3).

Investigations along these lines should quickly reveal the respective merits of the three principal gases. In order to obtain nearly simultaneous comparisons with the hope of mutual corroboration and international acceptance it would be extremely helpful to have such tests carried out in both North America and Europe.

It might already be surmised that in the industrial countries the preferred gas will be either nitrogen or carbon dioxide, perhaps both. In such areas these gases are readily obtained in cylinders although their costs may vary from country to country. In less industralized countries, these gases will not be so readily available. Provided carbon monoxide is satisfactorily vindicated, attention should be given to methods of production of CO suitable for less developed areas.

In a project for a chemical engineering laboratory, it will be important to determine the optimum specifications of a furnace for the burning of charcoal to produce CO and the practical procedure for ensuring that satisfactorily cool and pure fumes are delivered to the chamber (Project 4).

Another important project for a similar laboratory would be to design a suitable low-cost apparatus for the safe evolution of pure CO from chemicals such as sodium formate and sulphuric acid (Project 5).

There are cases in which HCN could prove practicable when other alternatives are not available.

Definitive directions for the design of chambers or pits, specifications for the type, quality and quantities of reagents, procedure for handling the reagents and the operational procedures for the whole process need to be drawn up. Safety precautions and emergency treatment measures should be included (Project 6).

Behavioral Tests

An additional project to cover "unknowns" in the area of overt behavioral reactions as indices of pain, distress and consciousness, is indicated. This would not only complement physiological data, but would also help overcome the serious limitations of relying upon basic physiological parameters as indices of emotional distress and pain. The following suggested studies are most applicable to evaluating decompression and gas chamber euthanasia methods.

(1) Control (sham) studies: observe behavioral reactions in confines of chamber with the system not operating. Blood samples may be taken before and after to measure plasma cortisol[12] levels as a biochemical index of stress.

[12] An additional measure of stress might be applied to the objective evaluation of euthanasia methods. Carney and Walker (1973) for example, measured plasma *corticosterone levels* in the rat and showed, on the basis of such biochemical evidence, that chloroform euthanasia is more stressful than either pentobarbital injection or decapitation. Carney, J.A. and Walker, B.L. (1973) Mode of Killing and Plasma-cortiscosterone Concentrations in the Rat. *Laboratory Animal Science 23, No. 5*

(2) As above, but with system in operation.

(3) If the method is non-traumatic to the animal, the animal should presumably show no increase in fear/anxiety, or escape reactions, or higher plasma cortisol levels when the procedure is repeated. In this test, (1) above would be repeated to evaluate habituation, and (2) above, with the animal being resuscitated with minimal trauma. With this design, we may be able to "ask" the animal to tell how it felt during (2) above. Great care would have to be taken with recompression — in fact, this test may only be applicable to evaluating gas chamber euthanasia. The possibility that the animal is rendered amnesic should also be considered.

(4) Conditioned Reflex Test. A sophisticated procedure which will tell if the animal is still conscious, may have application in future studies. A cat or dog may be quickly conditioned via an auditory signal (a bell or tone) to anticipate receiving a mild electric shock. It may be trained to escape or raise one leg in order to avoid the shock (EKG-associated tachycardia may also be monitored). Since an unconscious animal would have no overt reaction to the bell or tone, a clear behavioral index of consciousness is available. This technique will not, however, be reliable when an animal is (a) attempting to escape from the chamber (prior "shaping"/habituation may be needed), (b) semiconscious, (c) conscious but in a state of muscular rigidity. EKG or auditory evoked potential changes (necessitating the implantation of electrodes in the auditory cortex) following the conditional signal (bell or tone) may help overcome such variables.