Humane Killing of Nonhuman Animals for Disease Control Purposes

Mohan Raj

Department of Clinical Veterinary Science, University of Bristol, United Kingdom

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Department of Clinical Veterinary Science
University of Bristol, United Kingdom

Reports and guidelines produced by international institutions such as the World Organization for Animal Health (OIE, 2005) describe various methods of killing nonhuman animals. Selection and implementation of a killing method may involve several factors. Preventing or minimizing risk to human health and safety may override animal welfare concerns if the disease has the potential to cause high mortality, for example, highly pathogenic avian influenza. Owing to the public health significance of this disease, the scope of this article presents only an overview of the welfare and practical aspects of large-scale killing of poultry on farms. Killing poultry in houses using a gas mixture eliminates the need for human contact with infective materials and birds. Several protocols for administering gas mixtures into poultry houses have been evaluated, mainly in Europe and North America. Overdose of anesthetics in feed and water has sedated birds kept under free-range or semi-intensive rearing systems. Containerized gas killing systems have proved successful on small-to-medium-size poultry farms. However, using nitrogen, a nonaversive gas, could greatly improve bird welfare.

Nonhuman animals on the farm, including poultry, are routinely killed in large numbers throughout the world for the purpose of disease control. The decision to kill millions of animals may be justified on the basis of (a) protecting humans if the disease is zoonotic, (b) eliminating suffering in diseased animals if there is no cure, (c) preventing suffering in susceptible animals due to the spread of disease, (d) maintaining a healthy national herd or flock—and thus a sustainable farming industry, and (e) gaining or sustaining disease-free status of a country and hence economic advantage over competitors in the global market.

Correspondence should be sent to Mohan Raj, Department of Clinical Veterinary Science, University of Bristol, Langford BS40 5DU, UK. Email: M.Raj@bristol.ac.uk
Various methods of stunning or killing animals, including those used for the purpose of disease control, have been described in several scientific reports, guidelines, and directives published by international institutions, for example, European Community (EC, 1993), American Veterinary Medical Association (AVMA, 2000), European Food Safety Authority (EFSA, 2004, 2005), and the World Organization for Animal Health (OIE, 2005).

Stunning methods render animals unconscious; they rely on slaughter (bleeding out), destruction of the brain (pithing), induction of cardiac arrest (cardiac ventricular fibrillation), or other means to cause death (maceration) in unconscious animals. The duration of unconsciousness induced by a stunning method should be longer than the sum of time interval between the end of stunning and implementation of a killing method and the time it takes for actual death to occur. Death should always be confirmed in animals using appropriate clinical signs before carcasses are disposed of.

Killing methods that induce immediate (within a few seconds) death are preferred for controlling disease outbreaks. The established or known stunning and killing methods for farm animals include the following:

1. Free bullets fired, using rifles, handguns, and shotguns for animals, including wild birds, for disease-surveillance purposes;
2. Penetrating and nonpenetrating captive bolts fired, using blank cartridges or compressed air for animals, including poultry;
3. Manual blow delivered to the head of a neonatal animal, using blunt objects or swinging the animal’s head against a hard surface (wall or pillar);
4. Cervical (neck) dislocation or decapitation for poultry;
5. Electrical methods, involving application of currents as head-only or head-to-body for animals, and water baths for poultry;
6. Gas mixtures, consisting of carbon dioxide, carbon monoxide, argon, or nitrogen, and mixtures of carbon dioxide and nitrogen or argon for pigs and poultry;
7. Lethal injection of an anesthetic drug for all animals, including poultry;
8. Maceration of newly hatched chicks, unhatched eggs, or unconscious poultry;
9. Various types of foam, created using air, carbon dioxide, or inert gases—these have been tested to kill poultry in houses, but only gas-filled foam is considered humane, a method not approved by the AVMA (2000); and
10. Overdose of anesthetics such as alpha-chloralose administered via food or water to sedate prior to killing them by other means—especially free-range poultry and birds in the wild or semidomesticated birds (such as pheasants and partridges whose carcasses are not fit for human or other animal food).
Several factors may be involved in the selection and implementation of a killing method, including the following: (a) nature of the disease (virulence and pathogenesis); (b) location of the infected farm (accessibility and area of spread species; (c) size, age, and number of animals to be killed; (d) operator and environmental health and safety; (e) availability of expertise; (f) resources required to deal with the disease; (g) biosecurity issues; and (h) the efficacy of killing methods. Animal welfare is a major factor to be considered, independent of others; all the killing methods have advantages and disadvantages.

Preventing compromise of human (including operators) health and safety may override animal welfare concerns if the disease is zoonotic and has the potential to cause high mortality. According to the World Health Organization (WHO, 2004), if highly pathogenic avian influenza (HPAI) H5N1 virus evolves to a form as contagious as normal influenza (human flu virus), a pandemic could begin. In view of the fact that previous influenza pandemics killed millions of humans (estimated 40–50 million during 1918, “Spanish influenza”; 2 million during 1957, “Asian influenza”; and 1 million during 1968, “Hong Kong influenza”): The seriousness of the situation cannot be overestimated. For this reason, the incidence of AI, especially HPAI H5N1, and virus genetics are closely monitored. Both H7 and H5 strains have been known to infect humans and global community participation is vital to containing AI (Monto, 2005). It is worth emphasizing that the persistence of HPAI in any part of the world is a potential pandemic threat to humans as well as poultry. The scope of this article is to present an overview of the practical aspects of large-scale killing of poultry on farms during disease outbreaks.

Because of human safety concerns, human contact with infected poultry should be minimized. Respiratory and lachrymal secretions and feces of infected birds are the major sources of HPAI H5N1 infection in poultry (OIE, 2005). Exposure to infected poultry and their feces or dust/soil contaminated with feces is a major source of infection in humans (WHO, 2004). Because of this, many of the conventional killing methods may not be satisfactory for health and safety or biosecurity grounds. It is perhaps not surprising to note that ventilation shut-down, which will eliminate the need for human contact with infective materials and handling of live or dead birds, has been legislated in England as a killing method for poultry kept under intensive housing systems (Statutory Instrument, 2006). This is highly controversial on animal welfare grounds but a practical solution to dealing with disease outbreaks in remote farms. Ventilation shut-down is defined in this legislation as “the cessation of natural or mechanical ventilation of air in a building in which birds are housed with or without any action taken to raise the air temperature in the building.” However, we do not know how bird welfare would be compromised with this technique; animal welfare advocates argue that birds would be killed through suffocation or heat stress. The Humane Slaughter Association (HSA) in the United Kingdom has stated that “this method raises considerable welfare concerns and the HSA looks to all concerned to take every step to avoid this situation
ever arising.” It remains to be seen whether ventilation shut-down will ever be implemented in the United Kingdom. Nevertheless, poultry physiologists and pathologists are urged to report a sound scientific analysis on the risk of compromising bird welfare during ventilation shut-down.

This drastic theoretical approach in the United Kingdom highlights the realization that killing of poultry in houses with minimum human contact is probably the best way of dealing with HPAI H5N1. The sheer number of poultry that might have to be killed during HPAI outbreaks also demands high killing rates (throughput) to minimize any delay between confirmation of disease and killing of infected poultry. For example, an outbreak of AI in the Netherlands during Spring 2003 involved 30 million birds on 1242 farms and in more than 8000 hobby flocks (backyard poultry units) within a radius of 3 km (Gerritzen, Lambooij, Reimert, Stegeman, & Spruijt, 2006). Under these circumstances, it is very likely that national resources (humans as well as materials) will be stretched beyond limits and, as a result, the likelihood of compromising poultry welfare will be increased.

KILLING OF POULTRY IN HOUSES

It is known that poultry consider humans predators; therefore, manual catching and handling induce avoidable fear and distress (Duncan, Slee, Kettlewell, Berry, & Carlisle, 1986). It is also known that rough handling of poultry during catching and crating may result in avoidable bruising and fractures, especially if these procedures are carried out by poorly trained personnel. For this reason, overdose via intravenous anesthesia—which is considered the most humane killing method—could not be achieved without the potential risk of compromising bird welfare. In addition to the stress associated with catching and shackling, it has been reported that electrocution of poultry involving water baths, supplied with 220 to 400 V (2–4 A total current intended to deliver 400–800 mA per bird in the bath), and closed-loop shackles lines failed to induce death in all the birds because a considerable proportion of birds hung on shackles lines flapped their wings, leading them to completely miss the electrified water bath (Gerritzen et al., 2006; Raj, 1997). Because of this, mobile, electrical water-bath killing systems would have limited use during disease outbreaks. Similarly, killing with a captive bolt requires the head of a bird to be restrained by hand to facilitate accurate positioning and shooting of the bolt into the brain (Raj & O’Callaghan, 2001). This method may be applicable only to backyard poultry or small flocks. Spillage of blood from the bolt wound could be a potential biosecurity hazard.

The cumulative suffering caused to live poultry during handling and restraining procedures under electrical and captive bolt methods may exceed distress caused by a gradual induction of unconsciousness with gas mixtures, including high concentrations of carbon dioxide (McKeegan, Demmers, Wathers, & Jones, 2003;
Raj, 1996; Raj & Gregory, 1994; Raj, Gregory, & Wilkins, 1992; Raj, Wotton, & Gregory, 1992; Raj, Wotton, McKinstry, Hillebrand, & Pieterse, 1998; Raj, Wotton, & Whittington, 1992). Several countries in Europe have dedicated their resources to research and development for establishing generic operating procedures or protocols for killing by administering gas into poultry houses—referred to as whole house gassing (WHG). For example, 23 end-of-lay hen houses involving 292,000 birds during 2005 and 32 end-of-lay hen houses involving 535,000 birds during 2006 were used to evaluate whole house gassing protocols in Sweden alone (L. Berg, Swedish Animal Welfare Agency, personal communication, April 13, 2007). The Scottish Executive, Environment and Rural Affairs and Department for Environment, Food and Rural Affairs in the United Kingdom are also continuing to develop new methods or refine existing ones.

Carbon Dioxide (CO₂)

Exposure to gas mixtures has been evaluated to some extent for large-scale killing of poultry, especially within houses. The advantages and disadvantages of using gas mixtures have been reviewed recently (Raj, Sandilands, & Sparks, 2006), and CO₂ has been widely tested or used to kill poultry in houses (Gerritzen et al., 2006). The main advantage of WHG is that the method is relatively fast, as gas injection can be completed within minutes without entering the house. Another advantage of this technique includes availability of CO₂ in large quantities at relatively low cost. With WHG in the United Kingdom, gas is delivered directly from a tanker into a poultry house via single or multiple lances (metal gas injection pipe with 32 mm internal diameter), which are inserted through holes drilled in the walls. The ventilation hatches in the houses are first sealed, which can be carried out from outside the building. Adjacent poultry houses that are linked indirectly via holes through which feed and/or egg conveyors pass need to be sealed, for example, using insulating foam to avoid gas leaks or inadvertent exposure of birds in adjacent houses to CO₂. It is worth mentioning that the house need not be sealed gas tight as the atmospheric air has to escape (otherwise, the house will become pressurized).

The WHG protocol can be varied according to the housing system and species of poultry. Based on the existing laboratory data, exposure to a minimum of 45% by volume of CO₂ in air for 2 min should be adequate to kill chickens and turkeys (Raj & Gregory, 1994; Raj et al., 1998), but it may take 10 min or more of filling to achieve concentration throughout the house. WHG trials involving CO₂ have used 1 hr postadministration “soak-up” time to allow for vaporization of solid CO₂, if any, and to achieve even distribution throughout the house. Anecdotal reports suggest that about 2 kg of liquid CO₂ is required for every 1m³ of poultry house to achieve a concentration of 45% by volume in air at head level of birds kept on deep
litter. This should be maintained for at least 5 min to ensure death occurs in all the birds. Liquid CO\textsubscript{2} is normally injected at the rate of about 0.5 tons per minute and the duration of injection depends upon volume of the house to be filled. Liquid CO\textsubscript{2} delivery pressures of up to 20 bar have been used in the Netherlands (Gerritzen et al., 2006) and it is very likely that lower delivery pressures (less than 5 bar) may create problems of freezing of pipes and eventually the tanker or silo. The amount of CO\textsubscript{2} gas required to achieve lethal concentrations in houses is estimated to be 1.5 x volume of the house. It is worth noting that these figures may vary according to number of variables, including the delivery pressure, atmospheric pressure, and temperature.

The use of CO\textsubscript{2} for killing ducks and geese remains controversial. Some reports suggest that CO\textsubscript{2} is effective in eventually killing these birds (Gerritzen, Lambooij, Reimert, Stegeman, & Spruijt, 2004). Personal experience with killing of Aylesbury ducks indicated that they survived for 5 min during exposure to 70% by volume of CO\textsubscript{2} in air, and a minimum of 80% by volume of CO\textsubscript{2} would be necessary to kill them within 2 min. Electrocution in a water bath has been suggested to be appropriate for ducks and geese; however, this method has its own bird welfare, human health and safety, and biosecurity problems. Captive bolts have also been used to kill ducks and geese.

Technical data sheets indicate that the boiling point of liquid CO\textsubscript{2} is –78.5 °C, which may vary according to the environmental temperature and pressure. Therefore, it is logical to assume that output from a liquid source such as tanker lorry could have this extremely low temperature, which is a bird welfare concern (Raj et al., 2006). However, it is possible to suggest on the basis of the existing knowledge that the ultimate low temperature reached in poultry houses—albeit for a few minutes—may depend upon several factors. These include the following:

1. The temperature of the poultry houses would increase as the result of sealing and ventilation shut-down just prior to gassing; and
2. Each bird is likely to produce “a quantity” of kilowatts heat until death occurs, especially due to convulsions (wing flapping) occurring prior to death.

The cumulative effects of these are unknown and may contribute to warming of CO\textsubscript{2} at the time of, or immediately after the delivery of, liquid CO\textsubscript{2}. In addition, heat production and loss in poultry houses may vary according to the construction materials, housing system, stocking density, number, age, and size of birds—and it may not be possible to predict these variables.

Gas engineers have tried to reduce this potential welfare concern by making use of the heat within the poultry house by varying the design of lance and position of its installation. By doing so, they also try to avoid birds being hit directly by the very cold gas delivered at high pressures. For example, while administering liquid CO\textsubscript{2} into deep-litter houses, the lance is cut at the tip at an angle of about 30° to the
ground and is positioned about 1.5 m from the floor level. Such an arrangement helps to make the jet stream of cold gas flow toward the roof and vaporize, making use of the available warmth in the airspace. A proportion of liquid CO₂ may still fall on birds as solid dry ice, depending upon the rate of delivery and environmental temperature and pressure.

In the event of having to fit the lance closer to the ground level, birds should be excluded from the front of the lance for a distance of about 20 m by partitioning the house with nets, wire mesh, or similarly perforated materials. In houses full of battery cages, liquid CO₂ is administered, using a lance cut at right angle to the floor and positioned to administer gas into the manure pit located beneath the battery cages. This facilitates the use of available heat in the manure pit. These arrangements may not be possible under all field conditions as the design, layout, and structure of houses vary widely to suit climatic, husbandry, and housing conditions.

Ideally, gas engineers should be made aware of the design, layout, and structure of poultry houses while planning to execute WHG and certainly prior to deciding on the position of the lance(s). Although the amount of heat available in this setup may not be sufficient to raise the temperature of CO₂ to the level closer to the body temperature, it certainly reduces the chances of compromising bird welfare by causing cold burn or frostbite. It could also be argued that the magnitude of drop in temperature during CO₂ administration may be less than that encountered by the birds under some conditions of transport to slaughterhouses. Our understanding, knowledge, and skill of WHG methods with CO₂ have improved a great deal since the 2003 Dutch experience, and continuous refinement will lead to better bird welfare.

In some countries, killing poultry in houses has also been tried by manually sprinkling or spreading crushed dry ice over the floor or laying cylinders of CO₂ gas on the floor and opening the valves. These methods of administration of CO₂ require personnel to wear gas masks and special protective equipment when entering infected premises involving potential health and safety hazards. No serious bird welfare concern associated with this method of administration of CO₂ has been identified or reported.

CO₂ may also be used to kill poultry following natural disasters, such as destruction of houses due to a hurricane or tornado.

**Nitrogen (N₂)**

Nitrogen gas is inexpensive, readily available, and nonaversive to poultry. Personal experience indicates that liquid nitrogen delivered from a bulk storage silo through air-to-air vaporizer (Cryoquip, 2007) produces gaseous N₂ at ambient
temperature without any of the difficulty normally associated with the use of liq-
uid CO₂—frosting or freezing of pipes and vaporizer due to the triple-point sub-
limation. N₂ has been evaluated in Denmark for killing layer hens in battery

cages (C. Andersen, Denmark, personal communication, April 26, 2007). It was
delivered from a tanker via copper pipes laid outside the house. The cold N₂ gas,
which is denser than air, was then infused into the house using hoses inserted
through ventilation holes on the roof such that the gas cascaded through the
cages. Under this situation, hypoxia (less than 2% residual oxygen) was success-
fully created, and all the birds were killed within 20 min of administering the
gas. Liquid N₂ has a higher boiling point and can be vaporized more easily than
liquid CO₂ using heat from atmospheric air. It is worth mentioning that the tem-
perature of liquid N₂ is –196 °C; therefore, only the gaseous form of N₂ should be
infused into poultry houses. The use of N₂ for killing poultry needs to be devel-
oped further.

Carbon Monoxide (CO)

Carbon monoxide delivered from a pure source has been used to kill poultry
in houses; however, some argue that convulsions may occur prior to loss of
consciousness (Gerritzen et al., 2006). The concentration required to kill
poultry has been reported to be 1.5 to 2.0% in air (Gerritzen et al., 2006). Be-
cause CO is lighter than air, it may diffuse rapidly throughout the house. It is
also lethal at low concentrations, highly explosive at concentrations above
12.5% by volume, and is not readily available (Raj et al., 2006). An exclu-
sion zone of several meters around the vicinity of the house is required to en-
sure human safety and the explosive nature of the gas requires the presence
of a fire brigade.

Cyanide

Hydrogen cyanide (HCN) gas was also tested in Europe for killing poultry in
houses and is known to kill rapidly; all the birds died in less than 10 min. The
method may not be satisfactory on welfare grounds as convulsions may occur in
conscious poultry. The risk of compromising human health and safety is also a
major concern. It is very likely that cyanide might become scarce in Europe be-
cause of adverse public opinion about the method. In addition, killing poultry
with this gas leads to a rapid rigor development and therefore imposes a practi-
cal problem of removing carcasses from battery cages.
Firefighting Foam

In the pursuit of developing methods of killing poultry in houses, the use of firefighting foam has been evaluated in the United States (Avi-Foam Depopulation Center, 2005). The manufacturer states,

Researchers and commercial poultry companies recently established that non-toxic, water-based foam with a certain bubble size presents a practical, effective, and humane method for mass depopulation. Foam of the right bubble size creates an occlusion in the trachea of birds, causing a rapid onset of hypoxia. The foam that blankets the broiler house induces physical hypoxia—the same cause of death as the approved method using carbon dioxide gas (CO₂).

A physiological definition of suffocation is the physical separation of the upper respiratory tract from the atmospheric air; therefore, occlusion of the upper respiratory tract with foam or water (drowning), food (choking), smothering (clamping nostrils), or strangulation (constriction of trachea) would amount to death due to suffocation or asphyxiation. In addition, a serious misinterpretation of science is that exposure of poultry to CO₂ does not rely on the induction of hypoxia to cause unconsciousness and death. In other words, exposure of poultry to 40% CO₂ in air (with 15% residual oxygen [O₂] and 45% residual nitrogen [N₂] from air) or mixture of 50% CO₂, 20% O₂, and 30% N₂ would lead to unconsciousness and death. The humanitarian advantages of using firefighting foam for killing poultry in houses remain to be evaluated.

Other Types of Foam

In view of the fact that the killing of poultry in houses has several benefits and none of the foam methods tested or developed so far are ideal, a preliminary study was carried out in our laboratory involving foam made using baby shampoo as surfactant and nitrogen gas (Raj, Smith, & Hickman, 2007). In this trial, chickens exposed to foam made with shampoo and air remained alive and well for up to 5 min by breathing air created by bursting bubbles around the head. In contrast, chickens exposed to foam made with shampoo and nitrogen died due to inhalation of pure nitrogen (anoxia leading to death). This result is very promising; however, further research and development are required before it can be considered for field application. In this regard, we need tests to ensure the foam is robust enough to hold gas and fill the entire poultry house to required height but fragile enough so that bird movement breaks bubbles and releases nitrogen. We do not yet know how birds might respond to the movement of foam around them.
Overdose of Anesthetic in Feed or Water

Alpha-chloralose has been used to deeply sedate poultry in houses or field conditions prior to killing them by using cervical dislocation, decapitation, or exposure to gas mixtures. Because alpha-chloralose at 3% or more is bitter to taste, birds may not consume lethal quantities in one feeding or drinking bout and may have to be fasted for a considerable period of time (24 hr) prior to administration. This substance can be used to sedate birds kept under free-range or semi-intensive husbandry systems (including birds in the wild and undomesticated birds such as guinea fowl, pheasants, and partridges) such that the stress of handling during the application of a killing procedure could be minimized or eliminated. This method is also ideally suited for controlling the movement by sedation of wild ducks and geese suspected of carrying a disease agent or suffering from a disease.

CONTAINERIZED GAS KILLING UNITS

Killing poultry in houses may not be feasible under all the field conditions (poultry kept in free-range or small holdings) or because some avian species are more resistant to the effects of CO₂ (ducks require higher CO₂ concentrations than chickens to die). Consequently, there is still an essential role for containerized gas killing systems. Various types of bins, bags, skips, and purpose-built containers have been developed and used for killing poultry on farms.

When using containerized gas killing systems, birds are manually caught and carried by their legs out of the house in small batches (typically three birds per hand) and dropped into the container supplied continuously with a minimum of 50% by volume of CO₂ usually from liquid delivery cylinders. A novel method developed in the United Kingdom involves catching and crating poultry into transport modules and then exposing them to a gas mixture in a container. The main purpose was to eliminate or reduce some of the risks of compromising bird welfare and operator health and safety. Bird welfare could be improved by implementing a gas mixture that is known to be nonaversive or less aversive to poultry than a high concentration of CO₂. Throwing batches of live birds into containers filled with a gas mixture could also seriously compromise their welfare due to the small size of the hole through which batches (handful) of birds will have to be introduced. Some birds dropped into the container may die as a result of compression and suffocation caused by more birds being dropped into the container without adequate interval between two consequent batches of birds. The stress on birds associated with live bird handling could be eliminated or minimized by crating them immediately after catching and then exposing the
crate full of birds to a nonaversive gas mixture. This would also minimize the risk of operators having to come in close proximity to the container and thus improve human health and safety. More effective control of gas delivery and continuous monitoring of gas concentrations inside the container and in the vicinity would minimize extremes of temperature and ensure gas concentrations. Overall system flexibility to be able to perform in a variety of situations—farm size, poultry species, and adverse weather conditions—is also essential.

A recent study reiterated that chickens find a mixture of 80% argon [Ar] and 20% CO₂ less aversive when compared with 50% by volume of CO₂ in air (Sandilands, Raj, Baker, & Sparks, 2006). The CO₂-Ar mixture is universally available as welding gas mixtures at affordable prices. In the United Kingdom, a cylinder full of 80:20 Ar:CO₂ mixture costs about £25.00; this should be adequate to kill two batches of poultry contained in transport modules at the stocking density of 480 birds per module. This equates to a cost of £12.50 per module or 0.02 pence per bird, which is a negligible or meager cost to achieve good welfare during killing. A containerized gas killing system involving this gas mixture has also been legislated for killing end-of-lay hens and broiler breeders that have no economic value to the farmers, processors, or retailers. The capital cost could be kept low if the poultry industry is encouraged to make and store wooden (or locally available material) containers on the farms and burn them on farm after use in order to improve biosecurity.

The following is a simplified procedure involved in this UK containerized gas killing:

1. Position the container on a level solid open ground;
2. Connect gas cylinder to the container;
3. Load crates or a module full of birds into the container, using a forklift;
4. Shut and secure the door;
5. Deliver the gas mixture until less than 5% by volume of residual O₂ is achieved at the top of the container;
6. Allow time for the birds to become unconscious and die;
7. Open the door, allow gas to be dispersed in air;
8. Remove the crates or module using a forklift;
9. Check each drawer for survivors;
10. Humanely kill survivors, if any; and
11. Dispose of carcasses appropriately.

Practical experience indicated that a residual O₂ of 5% by volume or less created using the CO₂-Ar mixture will cause death in pheasants, quails, chickens, and turkeys within 2 min. Ducks and geese require residual O₂ of 2% by volume or less to cause death within 2 min of exposure to this gas mixture. Allowing an interval of 5 min between each kill cycle to unload and reload containers with crates or mod-
ules would, in theory, enable the killing of up to 4,000 broilers or hens per hour. Based on extensive field trials involving various poultry species, detailed operating procedures have been drafted and a training DVD produced by the Department for Environment, Food, and Rural Affairs in the United Kingdom.

Potential disadvantages of using any containerized gas killing systems include prolonged human contact with infective materials, extensive bird handling (live and dead), the possibility of spreading infective materials outside poultry houses, and exposure to gases. In addition, rapid delivery of welding gas mixture from compressed cylinders may cause freezing of regulators and plumbing, which is likely to be worse during winter temperatures.

The feasibility of using nitrogen instead of the welding gas mixture should be explored under field conditions as bird welfare could be greatly improved by implementing this nonaversive gas. In addition, nitrogen gas is abundantly available in all the continents and can be vaporized without difficulty. The use of dry foam containing nitrogen also needs to be developed further.

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