Special Report

Feasibility of depopulation of a large feedlot during a foot-and-mouth disease outbreak

Sara W. McReynolds, DVM, MPH, and Michael W. Sanderson, DVM, MS

Objective—To examine the feasibility of depopulation of a large feedlot during a foot-and-mouth disease (FMD) outbreak in the United States.

Design—Delphi survey followed by facilitated discussion.

Sample—27 experts, including veterinary toxicologists and pharmacologists, animal welfare experts, feedlot managers, and consulting veterinarians.

Procedures—4 veterinary pharmacologists, 5 veterinary toxicologists, 4 animal welfare experts, 26 consulting veterinarians, and 8 feedlot managers were invited to participate in a Delphi survey to identify methods for depopulation of a large feedlot during an FMD outbreak. A facilitated discussion that included 1 pharmacologist, 1 toxicologist, 1 animal welfare expert, 2 consulting veterinarians, and 2 feedlot managers was held to review the survey results.

Results—27 of 47 invited experts participated in the Delphi survey. Survey consensus was that, although several toxic agents would effectively cause acute death in a large number of animals, all of them had substantial animal welfare concerns. Pentobarbital sodium administered IV was considered the most effective pharmacological agent for euthanasia, and xylazine was considered the most effective sedative. Animal welfare concerns following administration of a euthanasia solution IV or a penetrating captive bolt were minimal; however, both veterinarians and feedlot managers felt that use of a captive bolt would be inefficient for depopulation. Veterinarians were extremely concerned about public perception, human safety, and timely depopulation of a large feedlot during an FMD outbreak.

Conclusions and Clinical Relevance—Depopulation of a large feedlot during an FMD outbreak would be difficult to complete in a humane and timely fashion. (*J Am Vet Med Assoc* 2014;244:291–298)

During the FMD outbreak in the United Kingdom, > 6 million animals were culled for disease control or because of welfare issues resulting from restriction of animal movement.[1] The United States has a large, highly productive and efficient livestock industry that is increasingly concentrated, compared with livestock production in the United Kingdom. The last FMD outbreak in the United States was in 1929. Thus, given the frequent movement of livestock and livestock products and the lack of vaccination against FMD, cloven-hoofed domestic and wild animals in the United States are fully susceptible to FMD.

The central United States has many large feedlot operations and an economy that relies heavily on the agriculture industry. Results of a simulation model[2] of an FMD outbreak that began on a feedlot in southwestern Kansas with > 40,000 cattle suggest that > 1.2 million of the 2 million (60%) cloven-hoofed animals in the surrounding area would be culled. Investigators of another simulation study[3] of an FMD outbreak in an 8-county area in the Panhandle region of Texas with approximately 1.8 million cattle reported that an FMD outbreak initiated in a feedlot with > 50,000 cattle would result in the culling of up to 230 surrounding livestock operations. According to the USDA National Agricultural Statistics Service, as of spring 2013, there were 330 US cattle operations with ≥ 8,000 cattle.[4] Introduction of FMD in the United States would be devastating to producers as well as the local, state, and national economies.

Control of highly infectious diseases such as FMD generally requires quarantine, depopulation (purposeful destruction [death] of a large number of animals), and disposal of entire herds to prevent the continued spread

Abbreviation

FMD	Foot-and-mouth disease

From the Department of Diagnostic Medicine and Pathobiology, College of Veterinary Medicine, Kansas State University, Manhattan, KS 66502.

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Address correspondence to Dr. Sanderson (sandersn@vet.k-state.edu).

of the disease. In extenuating circumstances, such as during a rapidly spreading zoonotic or foreign animal disease outbreak or when animals are isolated by a natural disaster, depopulation of affected or potentially affected animals must be performed efficiently and quickly.[5] In regard to FMD, the immediate depopulation of all cloven-hoofed animals on affected farms is considered a mainstay for eradication of the disease.[6] To effectively control the spread of an FMD outbreak and minimize its economic impact, an emergency response would require extensive understanding of the scientific, technical, and social aspects of livestock depopulation, and consideration of human and animal health and welfare concerns. During the early stages of the FMD outbreak in the United Kingdom in 2001, it became evident that the logistics of killing large numbers of animals had received little consideration,[7] and the Royal Society for the Prevention of Cruelty to Animals received numerous complaints from the public.[8] Substances used for depopulation should minimize environmental contamination or exposure of humans or other animals to those substances. Results of Operation Palo Duro, an FMD exercise conducted in 2007 by the Texas Animal Health Commission and the USDA APHIS in the Texas Panhandle region, suggest that timely depopulation and disposal of livestock carcasses is not feasible.[9] It is critical to determine whether cattle in a large commercial feedlot can be humanely depopulated in the event of a catastrophic zoonotic or foreign animal disease outbreak. Livestock depopulation can have a traumatic effect on veterinarians and the farming community.[10,11] The lesson learned from the 2001 FMD outbreak in the United Kingdom was that "a balance must be struck between disease control and welfare, but welfare must not be set aside, even in an emergency."[12] The *AVMA Guidelines for the Euthanasia of Animals*[13] state that under unusual situations such as the need for exigent disease eradication, euthanasia options may be limited, so the most appropriate technique that minimizes human and animal health concerns must be used. The objective of the study reported here was to evaluate possible methods for depopulation of a large feedlot in a timely and efficient manner that minimized human and animal health concerns and provided, to all extents practical, a humane death for the cattle. Depopulation was in response to an animal health emergency (ie, FMD outbreak), with the circumstances surrounding the event understood to be exigent and extenuating.

Materials and Methods

Study design—An online Delphi survey of experts within the cattle feedlot industry was conducted to explore potential methods for depopulation of a large commercial feedlot. Experts in food animal pharmacology, toxicology, and welfare as well as consulting feedlot veterinarians and feedlot managers were asked questions to identify possible methods and time requirements for depopulation of large feedlots. During the exploratory phase, experts identified and defined the depopulation methods and issues for discussion during an online iterative Delphi method, which was used to generate expert consensus. The Delphi method involved repeated polling of the experts by means of anonymous questionnaires to structure group communication.[14] The primary assumption of the Delphi method is that group judgments are more valid than individual judgments, and the anonymous nature of the communication aids in avoiding potential bias generated by face-to-face discussion. The responses obtained during each round (iteration) of polling were used as the referents for the subsequent round, and the polling continued until the median response of the participants did not change from one iteration to another (ie, a consensus was achieved). Briefly, participants answered the same survey questions during each iteration of the survey. After each iteration, the median response for each question was calculated and provided for participant consideration during the next round of the survey. This allowed participants to reconsider their responses in light of their peers' responses to the same questions. The responses of the final iteration were considered the group's judgment. Following the online Delphi survey, a facilitated roundtable discussion was held with experts from each area (pharmacology, toxicology, animal welfare, veterinary medicine, and feedlot management) to allow group learning of the technical and practical aspects of the issues identified during the survey.[15] Approval for this survey was obtained from the Kansas State University Institutional Review Board Committee for Research Involving Human Subjects.

Study participants—Food animal pharmacologists, toxicologists, and welfare experts; consulting feedlot veterinarians; and feedlot managers were invited to participate by e-mail. Invited pharmacology, toxicology, and animal welfare experts were identified on the basis of a literature review for authors of publications in each discipline and expert opinion. Consulting feedlot veterinarians were recruited from the membership of the Academy of Veterinary Consultants. Feedlot managers were recommended for the survey on the basis of their experience and knowledge of the industry by the participating veterinarians.

Survey development—The initial exploratory phase of the survey was designed to allow experts to identify the important issues associated with the depopulation of a large feedlot. Veterinary pharmacologists and toxicologists were asked to identify potential agents and methods for killing large numbers of cattle in a short period of time. Pharmacologists were also asked to list agents that could be used for sedation of a large number of cattle during a short period of time. Additionally, both pharmacologists and toxicologists were asked to provide a list of animal welfare considerations, human safety concerns, and carcass disposal considerations for each of the agents recommended. Consulting veterinarians and feedlot managers were asked to list possible methods for killing large numbers of cattle in a short period of time and potential human and animal concerns associated with mass depopulation.

The depopulation methods and issues identified during the exploratory phase were used as the foundation for the online iterative Delphi survey. During the iterative phase of the survey, a depopulation method was considered effective if cattle could be quickly and efficiently killed. Pharmacologists and toxicologists were asked to rate the effectiveness of each agent they identified during the exploratory phase. Consulting veterinarians and feedlot managers were asked to rate the effectiveness of

all depopulation methods identified during the exploratory phase. All participants were asked to rate the effectiveness of and their level of concern for each depopulation method on a Likert scale of 1 to 5 (1, highly effective or high concerns; 2, moderately effective or moderate concerns; 3, minimally effective or minimal concerns; 4, not effective or no concerns; 5, do not know).

For each depopulation method identified during the exploratory phase of the survey, a list of clinical signs commonly associated with that method was created on the basis of information obtained from toxicology textbooks[16–19] for consideration by the animal welfare experts. The animal welfare experts were then asked to rate each clinical sign in regard to animal welfare and public perception by means of the same Likert scale used by the other experts to rate the effectiveness of each depopulation method.

For each group of experts, the number of rounds for the iterative portion of the Delphi survey varied depending on how quickly a consensus was reached. Animal welfare experts completed 2 rounds, pharmacologists and consulting veterinarians and feedlot managers completed 3 rounds, and toxicologists completed 4 rounds.

Roundtable discussion—After completion of the Delphi survey, 1 pharmacologist, 1 toxicologist, 1 animal welfare expert, 2 consulting veterinarians, and 2 feedlot managers who participated in the survey were invited to participate in a face-to-face roundtable discussion on the various methods of depopulation and the time and labor required for each method. The discussion participants were selected on the basis of their expressed interest and willingness. Prior to the discussion, each participant was e-mailed an outline of the topics to be discussed during the facilitated discussion and the results from the Delphi survey. The goal of the discussion was to reach a consensus regarding the optimal and most timely method for depopulation of a large feedlot. The discussion was facilitated by one of the investigators (MWS) and began with a brief overview of the Delphi survey results. It was structured to sequentially address pharmacological, toxicological, and physical methods of depopulation. For each depopulation category, the Delphi results were summarized and key points were discussed and clarified to identify acceptable and unacceptable depopulation methods and the limitations of each method. For each depopulation method that was identified as potentially acceptable, the estimated time and labor requirements were discussed and compared. The roundtable discussion was recorded and lasted approximately 2 hours. A transcript of the discussion was created to summarize the participants' comments, which were then assessed to identify areas of consensus and disagreement among the group.

Results

Delphi survey—Of the 47 experts (4 pharmacologists, 5 toxicologists, 4 food animal welfare experts, 26 consulting feedlot veterinarians, and 8 feedlot managers) invited to participate in the Delphi survey, 27 (3 pharmacologists, 5 toxicologists, 3 food animal welfare experts, 12 consulting veterinarians, and 4 feedlot managers) completed the survey. Initially, all 4 pharmacologists who were invited agreed to participate in the survey, but 1 chose to drop out after the exploratory phase.

During the exploratory phase of the survey, pharmacologists identified 4 pharmacological agents and toxicologists identified 13 toxic agents that could be used to cause acute death in cattle. Additionally, the pharmacologists identified 6 pharmacological agents that could be used for sedation of cattle prior to induction of death. The consensus of the experts regarding each pharmacological (**Table 1**) and

Table 1—Pharmacological agents for sedation and induction of death in cattle that were identified by veterinary pharmacologists during the exploratory phase of a Delphi survey and the consensus of survey participants (veterinary pharmacologists, n = 3; veterinary toxicologists, 5; food animal welfare experts, 3; consulting feedlot veterinarians, 12; feedlot managers, 4) regarding the level of effectiveness and concern for human health, animal welfare, carcass disposal, and agent availability when used for the depopulation of a large US feedlot during an FMD outbreak.

Agent	Effectiveness	Human health risk	Animal welfare concern	Carcass disposal concern	Concern about availability of sufficient supply
For sedation					
Pentobarbital sodium (IM)	Minimal	Moderate	Moderate	High	High
Xylazine	High	Moderate	Minimal	Moderate	Moderate
Xylazine and ketamine	Moderate	Moderate	Minimal	Moderate	Moderate
Acepromazine injection	Moderate	Moderate	Minimal	Minimal	Moderate
Acepromazine granules (PO)	Moderate	Minimal	Minimal	Minimal	Moderate
Potent opiates (parenteral)	Moderate	High	Moderate	Moderate	Moderate
For induction of death					
Pentobarbital sodium (IV)	High	Minimal	Minimal	High	High
T-61 euthanasia solution	Minimal	Moderate	High	High	High
Potassium chloride	Minimal	Moderate	High	None	Minimal
Magnesium chloride	Minimal	Moderate	High	None	Moderate

A questionnaire was created on the basis of the results of the exploratory phase of the Delphi survey, and participants were asked to rate the effectiveness and their level of concern for various aspects of each agent on a Likert scale of 1 to 5 (1, highly effective or high concerns; 2, moderately effective or moderate concerns; 3, minimally effective or minimal concerns; 4, not effective or no concerns; 5, do not know). The same questionnaire was repeatedly administered to the participants until the median response for each variable did not substantially change from that of the preceding iteration.

toxic agent (**Table 2**) considered for induction of death or sedation was summarized. The only pharmacological agent considered highly effective for sedation purposes prior to induction of death was xylazine, and pentobarbital sodium administered IV was the only pharmacological agent considered highly effective for causing acute death. Although several toxic agents were considered highly effective for causing acute death, all of them were associated with substantial or high animal welfare concerns.

Consensus of the food animal welfare experts regarding the impact of a given depopulation method on public perception and the welfare of the cattle being killed as well as other cattle in the vicinity was summarized (**Table 3**). Feeding a toxic agent to cattle was associated with high animal welfare concerns, whereas exposing cattle that are grouped in a lane or pen to gunshots or carbon monoxide was associated with moderate animal welfare concerns. The use of a penetrating captive bolt with or without sedation and IV administration of a pharmacological agent were associated with minimal animal health concerns.

The only depopulation method considered highly effective by consulting veterinarians and feedlot managers was feeding a toxic agent to cattle (**Table 4**). Both veterinarians and feedlot managers considered penetrating captive bolt as a minimally effective method for depopulation. Sharpshooters shooting cattle with guns was considered a moderately effective depopulation method by veterinarians; however, feedlot managers did not consider it an effective method. Veterinarians had high concerns about completing depopulation of a large feedlot in a timely manner and the public perception and human safety associated with that depopulation and moderate concerns regarding mental trauma to the workforce, animal welfare, and carcass disposal during the depopulation process.

Roundtable discussion—Of the pharmacological agents discussed for depopulation purposes by the roundtable participants, pentobarbital sodium administered IV was considered an ineffective method because of concerns regarding its high cost and questionable availability of a sufficient supply and difficulty of disposing of pentobarbital-contaminated carcasses. Furthermore, any depopulation method that required IV administration of any kind of agent was considered impractical because each animal would have to be run through a chute, injected, and then manually removed from the chute after death before the next animal could be processed. Although the participants agreed that a large feedlot could vaccinate approximately 1,000 cattle/d through a chute, the need to manually remove dead cattle from the chute would slow throughput dramatically.

Table 2—Toxic agents for induction of death in cattle that were identified by veterinary toxicologists during the exploratory phase of a Delphi survey and the consensus of survey participants regarding the level of effectiveness and concern for human health, animal welfare, carcass disposal, and agent availability when used for the depopulation of a large US feedlot during an FMD outbreak.

Agent	Effectiveness	Human health risk	Animal welfare concerns	Carcass disposal concerns	Concern about availability of sufficient supply
Arsenic	Not effective	Minimal	High	High	Minimal
Cyanide	High	High	High	None	Moderate
Nitrates	Moderate	None	High	None	Minimal
Nitrite	Moderate	None	High	None	Minimal
Urea	Moderate	None	High	None	Minimal
Aluminum phosphide	High	High	High	Moderate	Moderate
Strychnine-coated milo	High	Moderate	High	Moderate	Moderate
Organophosphates	High	High	High	Moderate	None
Taxus sp	Moderate	Minimal	High	Minimal	Moderate
Bluegreen algae	Moderate	None	High	Minimal	High
Oleander	Moderate	None	High	Minimal	High
Carbon monoxide	Minimal	High	Moderate	None	Minimal
Carbamates	High	Moderate	High	Moderate	None

See Table 1 for key.

Table 3—Consensus of food animal welfare experts (n = 3) regarding level of concern for animal welfare and public perception associated with specific methods proposed for depopulation of a large US feedlot during an FMD outbreak as determined by a Delphi survey.

Method of depopulation	Animal welfare	Public perception
Application of a penetrating captive bolt to cattle restrained in a chute	Minimal	None
Application of a penetrating captive bolt to sedated cattle in a lane or pen	Minimal	Minimal
IV injection of a pharmacological or toxic agent to cattle restrained in a chute	Minimal	Minimal
Feeding a toxic agent to cattle in the ration	High	High
Sharpshooters shooting cattle grouped in a lane or pen	Moderate	Moderate
Carbon monoxide gas administered to cattle in an enclosed area (ie, silage pit covered with a tarp)	Moderate	Moderate

See Table 1 for key.

Table 4—Consensus opinion of consulting feedlot veterinarians (n = 12) and feedlot managers (4) regarding effectiveness of specific methods proposed for depopulation of a large US feedlot during an FMD outbreak as determined by a Delphi survey.

Method of depopulation	Veterinarians	Managers
Application of a penetrating captive bolt to cattle restrained in a chute	Minimal	Minimal
Application of a penetrating captive bolt to sedated cattle in a lane or pen	Moderate	Minimal
IV injection of a pharmacological or toxic agent to cattle restrained in a chute	Minimal	Minimal
Feeding a toxic agent to cattle in the ration	High	High
Sharpshooters shooting cattle grouped in a lane or pen	Moderate	Not effective
Carbon monoxide gas administered to cattle in an enclosed area (ie, silage pit covered with a tarp)	Moderate	Minimal

See Table 1 for key.

The roundtable participants considered a combination of xylazine and ketamine effective for sedation, even in fractious cattle. The participants were concerned that a sufficient supply of xylazine might not be available; however, when xylazine was used in conjunction with ketamine, a much smaller dose of xylazine was necessary to achieve the desired level of sedation, compared with that when xylazine was used alone. Nonetheless, participants did not believe that xylazine, even when used in conjunction with ketamine, would provide sufficient sedation if potassium chloride was to be injected to induce death. Another sedative discussed was acepromazine, which could be administered orally to cattle via the feed; however, the participants were concerned that a sufficient amount of the drug would not be available for mass sedation of all cattle in a large feedlot. Regardless of the sedative used, some method such as a captive bolt or firearm would be required to kill the sedated cattle after they are released into a lane or pen, become recumbent, and are restrained with a halter. Sedation followed by induction of death by captive bolt or gunshot would be a quicker method of depopulation, compared with individually restraining and killing cattle in a chute, but the participants were concerned about the human safety aspect associated with the use of a captive bolt or firearm on recumbent cattle in a pen.

During the Delphi survey, organophosphates were identified as highly effective for causing acute death in a large number of cattle in a short period of time. Moreover, depending on the organophosphate used, only a small amount would be required to cause death; therefore, there was no concern regarding the availability of a sufficient supply of a given organophosphate for depopulation of a large feedlot. The roundtable participants agreed that use of the most potent organophosphates would cause acute death in cattle and be preceded by few clinical signs. Although calculation of an adequate fatal dose and acquiring a sufficient supply of organophosphates were not concerns, ensuring that all cattle consumed an adequate dose of the organophosphate to cause death when it was being fed via the ration in a bunk was a concern. Not all cattle in a pen will eat immediately, and some cattle are more aggressive than others. To encourage all cattle to eat immediately, the participants recommended feeding the cattle 3 hours later than regularly scheduled. The participating toxicologist indicated that power washing the equipment used to deliver the organophosphate-laced feed with detergent would be sufficient to remove any organophosphate residues. Additional issues associated with depopulation by organophosphate poisoning that were discussed included manpower to dispose of the carcasses, environmental residues, and the potential for secondary poisoning of scavengers. The participants agreed that carcass removal and disposal would be major problems. They also agreed that up to 5% of cattle would not consume a sufficient amount of the organophosphate to cause death and a secondary method would be necessary to humanely kill those cattle. Finally, the consensus of the participants was that induction of death in cattle by consumption of a toxic agent would not be consistent with the definition of euthanasia (ie, ending the life of an individual by a method that minimizes or eliminates pain and distress[13]).

Although respondents of the Delphi survey did not consider carbon monoxide gas an effective method for depopulation, the roundtable participants did discuss its use. The participants did not agree on whether carbon monoxide gas was a timely or practical method for depopulation of a large feedlot.

Results of the Delphi survey identified the use of captive bolt or gunshot as an effective method to euthanize individual cattle, but neither was considered an effective means to depopulate a large feedlot in a timely manner. Similar to IV administration of pentobarbital, euthanasia of cattle by use of a captive bolt would require that each animal be run through a chute, killed, and manually removed from the chute before the next animal could be processed, thus slowing the depopulation process. The process could be sped up if the cattle were sedated in a chute and then released into a lane or pen for euthanasia by captive bolt or gunshot once they became recumbent. For unrestrained sedated cattle in a lane or pen, induction of death by gunshot administered by personnel with sharpshooting experience or training was considered by the roundtable participants to be a safer method for euthanasia than was the use of a captive bolt. The participants agreed that of the methods identified and discussed, the most convenient, lowest cost option for depopulation of a large feedlot was IM administration of a combination of xylazine and ketamine to cattle in a working alley followed by euthanasia with a captive bolt or gunshot after they were released from the alley and became immobilized. Depopulation of a feedlot by means of trained sharpshooters shooting unrestrained and unsedated cattle in an alleyway was considered unacceptable because of concerns about animal welfare, human safety, and public perception.

Discussion

The Delphi process is a method that combines the opinions of experts in an unbiased manner.[20] Compared with traditional discussions and meetings, a properly conducted Delphi survey greatly improves the likelihood of obtaining unbiased estimates that accurately account for the knowledge and judgment of the experts polled.[21] For the present study, the exploratory phase of the Delphi survey was used to allow participants to identify the depopulation methods that would be evaluated, thereby avoiding investigator bias. The anonymous nature of the iterative phase of the Delphi survey allowed participants to answer and reassess questions without bias associated with group pressure or pressure exerted by a dominant individual within the group.[14]

The roundtable discussion following the Delphi survey allowed experts from each relevant area (pharmacology, toxicology, animal welfare, veterinary medicine, and feedlot management) of the feedlot industry to review and discuss the survey results. This resulted in a better understanding of the technical and practical aspects for depopulation of a large feedlot across disciplines and, ultimately, a consensus on how best to approach the problem. During the roundtable discussion, bias was controlled by the presence of a facilitator who moderated the discussion and made sure that an expert in the topic being discussed was allowed to have the floor at the start of that particular discussion. The facilitator also ensured that the discussion proceeded and all experts participated so that the discussion was not dominated by 1 or 2 people. Finally, the facilitator ensured that all depopulation methods identified as effective during the Delphi survey were deliberated.

Despite the number of possible agents and methods for depopulation identified during the Delphi survey, the participating experts could not agree on any 1 agent or method that provided a safe and humane way to quickly kill a large number of cattle. Consulting veterinarians and feedlot managers felt that the most effective method for depopulation of a large feedlot would be to feed a toxic agent. The toxicologists agreed that several toxic agents could cause acute death in cattle but were concerned about compromised animal welfare and the safe disposal of the carcasses following the use of such agents. It should be noted that the issue of safe carcass disposal would be best addressed by environmental toxicologists; however, this group of experts was not included in the present discussion. Veterinary toxicologists are sufficiently trained and have experience to identify toxic agents of concern, but they lack training that environmental toxicologists have in terms of the environmental impact associated with the disposal of a large number of toxicant-contaminated carcasses. Of the pharmacological agents discussed, pentobarbital sodium, although effective for the euthanasia of individual cattle, was considered impractical for depopulation purposes because of the length of time and amount of labor required for implementation, the risk for secondary poisoning of scavengers, and concerns about the availability of a sufficient supply of the drug. The experts agreed that xylazine was an effective sedative for cattle, and could be useful in a depopulation protocol when used in conjunction with a method for induction of death such as application of a captive bolt or gunshot; however, similar to pentobarbital sodium, there were concerns about the time required for xylazine sedation and the availability of a sufficient supply of the drug.

The *AVMA Guidelines for the Euthanasia of Animals*[13] distinguishes depopulation (purposeful destruction [death] of a large number of animals) from euthanasia (induction of animal death with minimal pain and distress) and recognizes that the exigent need for depopulation of a large number of animals during a zoonotic or foreign animal disease outbreak may preclude the killing of all animals in a manner that meets the definition for euthanasia in the interest of preventing the spread of disease in a timely manner. During the roundtable discussion, oral administration of organophosphates in the feed was considered an effective method for induction of acute death with minimal clinical signs in most but not all cattle. However, the experts did not believe that organophosphate poisoning fulfilled the requirements for euthanasia and had concerns about animal welfare and public perception as well as the disposal of organophosphate-contaminated carcasses. Although organophosphate compounds are generally considered highly toxic, most available data are from reports of accidental exposures, in which the amount of the organophosphate to which an animal was exposed was unknown. Thus, it would be difficult to accurately calculate the amount of an organophosphate that would have to be incorporated into the feed to depopulate a feedlot. Also, regardless of the toxic agent used, it would be imperative to have a secondary method for induction of death readily available to humanely kill any cattle that did not die from toxicosis. Captive bolt and gunshot were regarded as humane options for killing cattle, but discussion participants were concerned about the physical safety and mental well-being of personnel operating the devices.

Participants of the Delphi survey did not consider carbon monoxide an effective depopulation agent. Conversely, the participants of the roundtable discussion thought it might be a timely method for depopulation, although they did have concerns about achieving and maintaining the concentration of carbon monoxide necessary to induce death while ensuring the welfare of personnel and other animals in the area. Guinea pigs collapse between 40 seconds and 2 minutes after being exposed to carbon monoxide at a concentration of 8%.[22] Carbon monoxide does induce loss of consciousness with minimal discomfort and often acute death, but simultaneously administering it to a large number of cattle would be technically difficult and care must be taken to avoid exposure of personnel. Participants felt that it would be logistically difficult to provide an adequate source of carbon monoxide that could quickly achieve and maintain administration of a uniform fatal concentration of the gas to a large number of cattle with minimal stress. In accordance with AVMA guidelines,[13] when carbon monoxide is used for euthanasia, the flow rate of the gas must be sufficient to rapidly achieve a uniform concentration of at least 6%. It is unknown whether a 6% concentration of carbon monoxide could be achieved with an ad hoc system on a large feedlot, and a consensus regarding its effectiveness as a depopu-

lation method could not be reached because of human health and animal welfare concerns.

In regard to pharmacological methods for depopulation, the consensus of the roundtable participants was consistent with that for the participants of the Delphi survey. Sedation of cattle with xylazine or xylazine in combination with ketamine followed by induction of death by the use of a captive bolt or gunshot was considered an acceptable and humane method for depopulation. This would require processing all cattle through an alley and chute to administer the sedative, releasing the cattle into a pen or lane, and then application of the captive bolt or gunshot once the cattle became recumbent. It is likely that a portion of the cattle would not become recumbent and would have to be killed by an alternate method such as gunshot by trained sharpshooters. In a study[23] that involved 90 healthy cows, only 52 (58%) became recumbent within 20.7 ± 8.4 minutes after administration of xylazine (0.5 mg/kg [0.23 mg/lb], IM). Because of concerns regarding the consistency with which xylazine induces recumbency in cattle and its availability, participants questioned the practicality of including sedation with xylazine in a depopulation protocol. Also, any method that required moving cattle through an alley and chute would necessitate proper handling of the cattle to minimize their pain and distress, ensure the safety of personnel, and protect other people and animals in the area.[13] Sedation of cattle prior to induction of death would require that the cattle be handled twice (once to administer the sedative and once when the cattle were recumbent in a pen or lane for application of the captive bolt or gunshot), although the dead cattle would not need to be manually removed from the chute, thus throughput would not be as adversely affected as it would be if cattle were euthanized while restrained within the chute. Regardless, if the feedlot had 50,000 to 100,000 cattle, it would be very difficult to kill the animals in a timely manner and properly dispose of the carcasses.

Physical methods for depopulation discussed were captive bolt and gunshot. Welfare concerns associated with both of these methods included the correct placement of the captive bolt or gunshot and the availability of a sufficient number of personnel with experience in animal handling. During the 2001 FMD outbreak in the United Kingdom, the lack of personnel trained in animal handling was reported as a problem. Results of a study[24] conducted at a slaughter facility indicate that it is rare for cattle to return to sensibility after correct application of a captive bolt. Nevertheless, acceptable secondary methods for inducing death in cattle following application of currently available captive bolt technology include pithing, exsanguination, and IV administration of potassium chloride.[13] A captive bolt with an attached air-injection system is being developed and researched that would make euthanasia by this method a 1-step process. The consensus of the roundtable participants was that application of a captive bolt to cattle restrained in a chute was an acceptable and preferred method for euthanasia, but it might not be practical for depopulation purposes because of the time and labor required to manually remove the carcass of each animal from the chute. The participants also agreed that appropriate application of a gunshot was an acceptable method for euthanasia of cattle, but the use of sharpshooters to shoot unrestrained cattle, although potentially quick, was deemed unacceptable because of concerns about the welfare for cattle that were not instantly killed by the first gunshot, the physical safety of personnel and other animals in the area, a lack of availability of qualified sharpshooters, and the public's response to that method of depopulation.

Although removal and disposal of carcasses was not a focus of the Delphi survey, it was a frequent topic of concern during the roundtable discussion. Regardless of the depopulation method used, the participants agreed that disposal of the carcasses would require a tremendous amount of labor, including that of veterinarians and equipment operators. Almost all of the experts that participated in the roundtable discussion had experience dealing with small numbers of animal carcasses resulting from disasters and were cognizant that the difficulties encountered with carcass removal and disposal in those instances would be multiplied many fold during depopulation of a large feedlot. Because carcasses cannot be left in the environment for extended periods of time, the rate of depopulation should not exceed the rate of disposal. The logistics of coordinating the use of equipment to remove cattle carcasses was considered a major issue, especially if the depopulation method used resulted in cattle being killed in or near a chute. Even with trained and experienced personnel, moving a large number of carcasses in a feedlot is a difficult task. Participants agreed that during an FMD outbreak, having a sufficient number of trained and experienced personnel available and the ability to properly dispose of carcasses in a timely manner would be critical for the successful implementation of a depopulation protocol.

Burial of carcasses is considered the most cost-effective method of disposal for occasional animals that die; however, the need to quickly dispose of thousands of tons of cattle carcasses during depopulation of a large feedlot could create a serious risk for pollution of local surface and groundwater resources.[25] Additionally, burial of a carcass contaminated with a pharmacological or toxic agent could result in that agent leaching into the soil or groundwater and inadvertent secondary poisoning of other animals such as eagles, hawks, coyotes, foxes, and domestic dogs and cats. Dependent on the dose administered, the use of a pharmacological or toxic agent to depopulate a large feedlot would likely require that the carcasses be buried in landfills designated for hazardous waste.[26] This would require additional time, manpower, and equipment to transport the carcasses to those landfills, and the volume of carcasses would likely strain or exceed the capacity of local hazardous-waste landfills.

The roundtable participants also discussed alternatives to mass depopulation of a feedlot during an FMD outbreak. One of those alternatives was to destroy cattle as necessary on the basis of the presence of clinical signs and letting the disease run its course. The size and duration of FMD epidemics are associated with factors such as efficiency of FMD detection, livestock density and movement, and effectiveness of control methods.[27–29] Allowing FMD to run its course in a feedlot would not be without substantial risk. Of primary concern would be the maintenance of adequate biosecurity to prevent the direct or indirect spread of FMD to other livestock operations yet still provide the quarantined cattle with adequate feed and care. Foot and mouth disease is not zoonotic; therefore, cattle from an FMD-

infected feedlot could be salvaged for slaughter once new cases of the disease were no longer developing so that the cattle could be transported to slaughter facilities without risk of spreading the disease to other livestock operations.

Vaccinating cattle against FMD virus might effectively decrease transmission of the virus within and between feedlots, thereby decreasing the need for depopulation. During the 2001 FMD outbreak in Argentina, vaccination of cattle against FMD and restriction of livestock movement significantly decreased transmission of the virus, compared with virus transmission in the absence of vaccination.[30] Vaccination is frequently used in conjunction with depopulation to control the spread of FMD virus.[31] During the 2001 FMD outbreaks in the Netherlands and Uruguay, depopulation of affected herds was initially implemented and then cattle in the remaining herds were vaccinated, and in both instances, the outbreaks were successfully stopped.[12] In the United States, a vaccine against FMD virus has been developed that enables vaccinated cattle to be distinguished from those naturally infected with the virus.[32] Thus, in the event of an FMD outbreak, vaccinated cattle would not need to be slaughtered to reestablish livestock trade with foreign markets.

In the event of an FMD outbreak, the goal of every response effort will be to stop the spread of the virus, and the strategy implemented will depend on many factors. In the United States, the response to an FMD outbreak will be coordinated by the USDA. The USDA's FMD Response Plan[33] includes emergency vaccination of all susceptible cattle against the virus, but the actual control plan implemented will be influenced by multiple factors including the location of the outbreak and the availability of the FMD vaccine and resources necessary to implement the response strategy.

Unfortunately, the Delphi survey and roundtable discussion failed to identify a completely acceptable method for the rapid depopulation of a large feedlot. All the depopulation methods identified had serious drawbacks. All participants agreed that, regardless of the method used for depopulation of cattle in a large feedlot, it would be very difficult to complete the task quickly and humanely and to dispose of the carcasses in a safe and timely manner. These results suggested that control of FMD in large feedlots will require methods other than depopulation, and research on available alternatives is necessary.

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