Chapter 8. Exposure Limits Related to Air Quality and Risk Assessment

Kelley J. Donham, MS, DVM
Professor, Department of Occupational and Environmental Health, College of Public Health
The University of Iowa

Peter S. Thorne, MS, PhD
Professor, Department of Occupational and Environmental Health, College of Public Health
The University of Iowa

George M. Breuer, PhD, CIH
Adjunct Professor
The University of Iowa

Wendy Powers, MS, PhD
Assistant Professor, Department of Animal Science, College of Agriculture
Iowa State University

Shannon Marquez, M Eng, PhD
Assistant Professor, Department of Occupational and Environmental Health
College of Public Health, The University of Iowa

Stephen J. Reynolds, PhD, CIH,
Professor, Department of Environmental Health
Colorado State University

Abstract

This chapter reviews the literature with regards to health hazard substances emitted from CAFOs. Furthermore, we reviewed the risk assessment process of pertinent federal agencies in regards to hazardous emissions from CAFOs. Occupational health hazards, for those working in CAFOs, have been long recognized. Research documents that current recommended or legal occupational exposure levels are not sufficient to protect workers. Although the research on occupational exposures of CAFO workers documents the hazardous nature of CAFO emissions at concentrations found inside buildings, the concentration of these hazardous substances are much lower in the ambient air of the community surrounding CAFOs. As occupational exposure limit recommendations are not highly relevant to the community, specific exposure standards are needed to help protect community residents as well as workers.

Regarding community standards, the risk assessment processes of the Environmental Protection Agency (EPA), and the Agency for Toxic Substances and Disease Registry (ATSDR) are the most relevant agencies in making recommendations for limits to community exposures. The EPA estimates levels safe for a lifetime exposure and ATSDR list levels for acute, intermediate or chronic levels. For ammonia, the EPA list 144 ppb for lifetime exposures and the ATSDR list 500 ppb for acute and 300 ppb for chronic exposure. For hydrogen sulfide, the EPA lists 0.7 ppb for lifetime exposure, and ATSDR lists 70 ppb for acute and 30 ppb for intermediate exposures. Considering these recommendations made by EPA and ATSDR, concentration recommendations, recommendations made in surrounding states, and consideration of the possible additive or synergistic effect of mixed exposures, hydrogen sulfide, ammonia, and odors should be regulated. The levels that should be considered are as follows: hydrogen sulfide, one hour time-weighted average of no more than 15 ppb at the residence or 70 ppb at the property line; ammonia, one hour time-weighted average of no more than 150 ppb at the residence and no more than 70 ppb at the property line; odors should be no more than a 1:7 dilution at the residence and no more than 1:15 at the property line.

8.1 Introduction

This chapter will review the scientific literature on exposure limits for occupational and ambient conditions, relative to CAFOs. Also, the relevance of existing standards for the health protection of workers and community residents will be discussed. Furthermore, the circumstances of mixed exposures will be reviewed. Finally, a risk assessment and recommendations for appropriate standards will be discussed.

8.2 Existing Occupational Health Exposure Limits or Recommendations

In the US, there are four sources of recommendations in regards to occupational exposure limits. These include the American Conference of Governmental Industrial Hygienists (ACGIH, 2001 TLV's for Chemical Substances and Physical Agents & Biological Exposures Indices), the American Industrial Hygiene Association (AIHA, AIHA Press, Fairfax VA, 2001), The National Institute for Occupational Safety and Health (NIOSH, Pocket Guide to Chemical Hazards, 1997) and the Occupational Safety and Health Administration (OSHA, Code of Federal Regulations, Chapter 29). The first two organizations (AIHC and ACGIH) are private professional organizations. The third, (NIOSH) is a governmental educational and research organization. OSHA is the only regulatory and

enforcement agency of these four. AIHC, ACGIH, and NIOSH, only recommend worker-exposure standards, but develop science-based recommendations, and not subject to the stakeholder pressures from the administration, industry, and labor, and other constituents groups, as is OSHA. The terminology for exposure limits is different for each of these organizations. AIHC, ACGIH, and NIOSH issue, respectively, Emergency Response Planning Guidelines/Workplace Environmental Exposure Level Guides (ERPPGs/WEELs), Threshold Limit Values (TLV) and Time Weighted Average Exposure Limits (TWA). OSHA issues Permissible Exposure Limits (PEL's).

The primary exposures of occupational concern in CAFOs include ammonia (NH_3), hydrogen sulfide (H_2S), carbon monoxide (CO), carbon dioxide (CO_2), particulate matter (PM), bioaerosols, and endotoxin. However, none of the bodies mentioned above have specified limits for bioaerosols or endotoxin. Table 1 lists the indoor concentration levels for each of these bodies for the agents specified.

Table 1. Maximum Concentration Levels Listed for Occupational Health

	NH3	H2S	CO	CO2	Total Particulate Matter	Respirable Dust	Bioaerosols	Endotoxin
AIHA	25 ppm	0.1 ppm	200 ppm	Not listed	Not listed	Not Listed	Not listed	Not listed
ACGIH	25 ppm	10 ppm	25 ppm	5000 ppm	$4\ mg/m^3$ (Grain dust) $10\ mg/m^3$ (Nuisance dust)	$3\ mg/m^3$ (Grain dust)	Not listed	Not listed
NIOSH	25 ppm	10 ppm	35 ppm	5000 ppm	$4\ mg/m^3$ (Grain dust)	Not Listed	Not Listed	Not Listed
OSHA	50 ppm	20 ppm	50 ppm	5000 ppm	$10\ mg/m^3$ (Grain dust) $15\ mg/m^3$ (Nuisance dust)	$5\ mg/m^3$	Not Listed	Not Listed

8.2.1 Occupational Dose Response Data For Humans

Exposure-response studies in workers have included an assessment of the response to the amount of time exposed, for particulate matter (PM), endotoxin, NH_3, and H_2S. Endotoxin and PM concentrations have had the strongest and most consistent relationships to respiratory symptoms and decrements in pulmonary function tests (PFT) (Donham et al., 1989; Donham et al., 1995;

Reynolds et al., 1996). A significant relationship was seen between microbial concentration and bronchitic symptoms (cough and phlegm) (Donham et al., 1989). A weaker relationship of bioaerosol concentrations to tightness of chest and febrile syndromes (flu-like illness with fever) was found (Donham et al., 1989). There was no relationship of bioaerosol to pulmonary function changes. Ammonia did show some relationship to decreased baseline pulmonary function in four different studies (Donham et al., 1989; Donham et al., 1995; Reynolds et al., 1996; Cumro et al., 2001, in press). In one of the studies, the levels of microbes showed a significant dose response relationship to symptoms of hyper-reactive airways (Donham et al., 1989).

A study in The Netherlands (Heederik et al., 1991) suggested that both endotoxin and Gram-negative bacteria were related to reductions in pulmonary function, as measured by forced expiratory volume in one second, (FEV_1) and forced vital capacity (FVC). Also, significant relationships were shown between symptoms of bronchitis, or Organic Dust Toxic Syndrome (ODTS) to endotoxin or Gram-negative bacteria exposure.

8.2.2 Occupational Exposure Limit Studies

There is little scientific doubt that disease symptoms and work-shift declines in pulmonary function are related to several components of the mixture of particulate matter, bioaerosols and gases found inside CAFOs. These components include dust, endotoxin, hydrogen sulfide, and ammonia. However, the most important question in this regard is how much exposure creates a health hazard? Knowledge of the appropriate exposure limits is extremely important for controlling the work environment.

Data, which suggest the exposure limits in relation to adverse pulmonary function and symptoms, are found in four dose-response studies (Donham et al., 1989; Donham et al., 1995; Reynolds et al., 1996; and Cumro et al., 2001, in press). The first is a study of workers on 54 pig farms in Sweden (Donham et al., 1989). Several significant correlations were found between respiratory symptoms and PFT and PM, endotoxin, ammonia, and carbon dioxide. Significant relationships were seen between health measures and environmental measures taken at stationary locations in the buildings. More recent data analyses from US studies have corroborated the previous exposure limit study (Donham et al., 1995; Reynolds et al., 1996). A longitudinal study of 208 swine farmers (randomly selected from a stratified sample of all pig producers in Iowa) resulted in consistent evidence of a dose-response relationship of exposure to the dust and gases found in pig buildings and respiratory symptoms, and decreased pulmonary function. Furthermore, multiple regression analyses of the data, provided results consistent with the exposure limits previously mentioned in the Swedish study.

The fourth dose-response study mentioned previously was conducted in the poultry industry with 149 poultry production workers (Donham, Leistikow et al., 1989). This study analyzed respiratory symptoms and PFT associated with exposures to PM, endotoxin, and ammonia. Regression analysis was used to determine maximum exposure levels that predicted more than 5% pulmonary function decline with adverse health responses (Donham et al., 2000).

These four studies reviewed above are in close agreement in regard to concentration levels of contaminants that represent hazardous exposures to workers in either swine or poultry CAFOs. Table 2, lists the recommended maximum levels from the scientific literature of environmental exposures based on the four studies reviewed above. Recommended maximum exposures for swine

health are also listed for comparisons sake. The worker health and swine health levels are reasonably close, indicating that protecting the health of workers also can provide benefits for health and production of swine.

Table 2. Human and pig exposure thresholds for various bioaerosol components found in swine buildings.
Exposure to concentrations of contaminants in excess of values given are associated with a higher proportion of ill-health in workers, and with disease, or lower production parameters in pigs. Taken from' Donham et al., (1989);[1] Donham et al., (1995);[1] Donham (1991);[2] Reynolds et al., (1996);[2] Donham et al., (2000).[1]

Bioaerosol component	Human health[1]	Swine health[2]
Total dust mg/m^3	2.4	3.7
Respirable dust mg/m^3	0.23	0.23
Endotoxin EU/m^3	100	150
Carbon dioxide (ppm)	1,540	1,540
Ammonia (ppm)	7.0	11.0
Total microbes cfu/m^3	4.3×10^5	4.3×10^5

8.3 Ambient Exposure Limits

The EPA currently has national ambient standards for particulate matter (PM), sulfur dioxide, oxides of nitrogen, ozone, lead, and carbon monoxide. Generally, speaking, these emissions are not relevant to CAFOs, except PM. However, tracing the source of PM is difficult at this time, (although there are at least two possible methods for use, LIDAR and chemical analysis of signature molecules attached to particulates.) The U.S. EPA has promulgated standards in response to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA: 40 C.F.R. Part 302). Under this act, regulated hazardous substances (CERCLA 40 CFR Parts 355 and 370) emitted from a point source may not exceed 100 lb/day for ammonia, hydrogen sulfide and a number of other pollutants. Ammonia emissions from four CAFOs studied swine production systems in Iowa (Zahn et al., 2001a; Zahn et al., 2001b) were recently reported to violate release, reporting requirements for NH_3 under the U.S. EPA Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, U.S. EPA, 2002). The range for ammonia emissions from these swine production sites ranged from 224 lbs NH3/day to 813.9 lbs. NH_3 day^{-1} (nder warm weather conditions). The observed aggregate emission rates for swine production facilities evaluated in this latter study were reported to exceed CERCLA reporting requirements for NH_3 by 55% to 88%. There is an additional federal act that may be relevant to CAFOs. The Emergency Planning and Community Right-to-Know Act (EPCRA) section 329(4), defines a facility to include stationary structures on a single site, or on contiguous or adjacent sites owned or operated by the same person. Under this definition, the aggregated emission rate of registered hazardous substances from all swine production facility point sources is subject to release reporting requirements. As part of the release reporting requirements, the polluting facility must develop an EPA-approved emission abatement plan to curb emissions from the emitting point sources.

Generally, there has been little published information available indicating that CAFO emissions exceed present federal Clean Air Act regulations. The EPA's 1998-draft strategy for addressing CAFO issues has not included health or air quality provisions. However, the pending revision of the

Clean Air Act will likely address these issues. There has been a USDA Air Quality Task Force working on the issues. This Task Force issued a report dated July 19, 2000, titled, "Air Quality Research and Technology Transfer White Paper and Recommendations for Concentrated Animal Feeding Operations" (http://www.nhq.nrcs.usda.gov/faca/Archives/2000/Policy/CAFO.htm) Currently, EPA has commissioned the National Academy of Science to conduct a study evaluating the human health impacts of emissions from CAFOs. This 14-month study has just begun. Generally, this issue has been left up to the individual states. The states of Colorado, and Missouri have odor regulations, based on the sentometry at 7:1, and 5.4:1 dilutions respectively at the property boundary (Colorado Department of Public Health and Environment Air Pollution Control Divisions Odor Concentration Measurement, Scentometry Test Policy for Housed Commercial Swine Feeding Operations, Colorado Department of Public Health and Environment, Denver, Colorado, January 25, 2001, www.Cdphe.state.co.us/ap/hog_policies:html, and Missouri. Pollution Control Agency, Feedlot Air Quality Summary: Data Collection, Enforcement, and Program Development, March 1999). Minnesota and California have state H2S regulations, which are 50 ppb, for not more than one-half hour, and not more than two occurrences per year, and 30 ppb for not more than one-half hour for not more than two occurrences in a 5-day period (property line of the emitter). There is also a provisional 60 ppb human risk value (HRV) limit for not more than one hour (at the receptor) (MN Pollution Control Agency). Current regulations and recommendations in regards to federal and state agencies are reviewed in more detail in chapter 9.0.

8.3.1 EPA Risk Assessments

Risk assessment has been defined as "the characterization of the potential adverse health effects of human exposures to environmental hazards" (NRC, 1983). In a risk assessment, the extent to which a group of people has been or may be exposed to a certain chemical is determined, and the extent of exposure is then considered in relation to the kind and degree of hazard posed by the chemical, thereby permitting an estimate to be made of the present or potential health risk to the population exposed. Regarding the primary inhalation exposures in CAFOs, the U.S. EPA has completed risk assessment evaluations for ammonia and hydrogen sulfide. Both are limited to chronic (24 hour/day lifetime exposure) health hazard assessments for noncarcinogenic effects. The completed risk assessments represent a consensus opinion of EPA health scientists representing various Program Offices and the Office of Research and Development.

The consensus process includes interpreting the available scientific literature applicable to health effects of a risk agent, and using established methodologies to develop values for inhalation reference concentration. With regard to multiple exposure routes, the U.S. EPA's position is that the potential for health effects manifested via one route of exposure (i.e. dermal or respiratory) is relevant to considerations of any other route of exposure, unless convincing evidence exists to the contrary. In other words, if there is convincing data of a health hazard to a specific substance from respiratory exposure, then the EPA assumes dermal exposures are also hazardous, unless there is convincing evidence to the contrary. As more epidemiological, animal studies, and new scientific information becomes available for CAFO-related exposures, EPA intends to review it, as appropriate, and develop more complete risk assessments.

Chronic Health Hazard Assessments for Noncarcinogenic Effects
The inhalation reference concentrations (RfC) and chronic health hazard summaries for NH_3 and $H2_S$ are listed in Tables 3 and 4, respectively. The No-Observed-Adverse-Effect Level (NOAEL) is

the highest exposure level at which there are no statistically or biologically significant increases in the frequency or severity of adverse effect between the exposed population and its appropriate control. Although some effects may be produced at this level, they are not considered adverse, nor precursors to adverse effects. The Lowest-Observed-Adverse-Effect Level (LOAEL) is the lowest exposure level at which there are statistically or biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control group. The Reference Concentration (RfC) is an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. The RfC is derived from a NOAEL, LOAEL, or benchmark concentration, with uncertainty factors (UF) generally applied to reflect limitations of the data used. The RfC is generally used in EPA's noncancer health risk assessments.

For ammonia, an uncertainty factor of 10 is used to allow for the protection of sensitive individuals. Additionally, a factor of 3 is used to account for several database deficiencies including the lack of chronic data and the lack of reproductive and developmental toxicology studies. Based on these factors, EPA sets the limit for lifetime exposures to ammonia at 144 ppb. For hydrogen sulfide, the uncertainty factor of 1000 reflects a factor of 10 to protect sensitive individuals, a factor of 10 to adjust from sub-chronic studies to a chronic study, and a factor of 10 for both interspecies conversion and data base deficiencies. Based on these factors, EPA sets the limit for lifetime exposures to ammonia hydrogen sulfide at 0.7 ppb.

Table 3. Environmental Protection Agency Reference Concentrations for Chronic Inhalation Exposure to Ammonia

Critical Effect	Exposures*	UF	RfC
Lack of evidence of deceased pulmonary function or changes in subjective syptomatology {Occupational Study}	NOAEL (HEC): 2.3 mg/cu.m	30	0.1 mg/cu.m (144 ppb)

*The NOAEL is based on an 8-hour TWA occupational exposure.
(HEC) is the adjusted human equivalent dose.
[1]USEPA, last revised 1991.

Table 4. Environmental Protection Agency Reference Concentrations for Chronic Inhalation Exposure to

Hydrogen Sulfide[1]

Critical Effect	Exposures	UF	RfC
Inflammation of the nasal mucosa {Mouse Sub-chronic Inhalation Study}	NOAEL (HEC)[2]: 1.01 mg/cu.m (0.73 ppm)	1000	0.001 mg/cu.m (0.7 ppb)

[1]USEPA, last revised 1995.
[2] NOEL (HEC) = No Effect Exposure Level, Human equivalent dose.
*See appendix A for references for these hazard assessment recommendations.

8.3.2 ATSDR Recommended Limits

Ambient exposure guidelines are also provided in the reviews produced by the Agency for Toxic Substances and Disease Registry, the federal agency charged with evaluating possible health risks from chemicals released at waste sites where the general public may be exposed. In their Toxicological Profiles, this Agency has reviewed the extensive literature concerning health effects of ammonia (ATSDR, 1990, reviewing more than 350 articles to assess possible human health effects of this compound) and hydrogen sulfide (ATSDR, 1999, reviewing about 470 articles), probably the two major contaminants of concern from animal operations as far as is currently known. While the ATSDR guidelines are not generally applicable and enforceable ambient standards, their focus is on protection of the public, including sensitive individuals, and thus they are relevant to the situation under consideration here.

The product of ATSDR reviews are generally information and guidelines related to public exposures near waste sites. They state:

> During the development of toxicological profiles, Minimal Risk Levels (MRLs) are derived when reliable and sufficient data exist to identify the target organ(s) of effect or the most sensitive health effect(s) for a specific duration for a given route of exposure. An MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure. MRLs are based on noncancer health effects only and are not based on a consideration of cancer effects. These substance-specific estimates, which are intended to serve as screening levels, are used by ATSDR health assessors to identify contaminants and potential health effects that may be of concern at hazardous waste sites. It is important to note that MRLs are not intended to define clean up or action levels. MRLs are derived for hazardous substances using the no-observed-adverse-effect level/uncertainty factor approach. They are below levels that might cause adverse health effects in the people most sensitive to such chemical-induced effects. MRLs are derived for acute (1-14 days), intermediate (15-364 days), and chronic (365 days and longer) duration and for the oral and inhalation routes of exposure (ATSDR, 1999, page A-1).

Thus the MRLs are designed to protect sensitive populations. However, as the MRLs are derived for individual contaminants; mixtures of chemicals such as CAFO emissions are potentially more hazardous, but difficult to assess from a health effect standpoint. The situation of mixed exposures is discussed in section 8.3.2.

The ATSDR report on ammonia (ATSDR, 1990) establishes a short-term (less than or equal to 14 days) MRL of 500 ppb for inhalation. A long-term (defined as greater than 365 days in this earlier Toxicological Profile) MRL of 300 ppb at the receptor is established. It appears that the 300ppb MRL would be the appropriate comparison value for public exposures beyond the property limits of a CAFO (table 6). Using the occupational 8-hour time-weighted-average recommendation for workplace exposure (nearly 100 times this value), while appropriate for the healthy adult working population, would be inappropriate for underline continuous exposure of the general public which includes sensitive populations, including infants, the elderly, and those with pre-existing conditions. Observed or estimated CAFO concentrations of 250 ppb are at times uncomfortably close to the long-term ammonia MRL (Subramanian, et al., 1996; Reynolds et al., 1997).

Hydrogen sulfide is another major contaminant of concern near confinements. The July 1999 ATSDR "Toxicological Profile for Hydrogen Sulfide" (ATSDR, 1999) derives "an acute inhalation MRL of 70 ppb" and "an intermediate MRL of 30 ppb" (p. 139); these would correspond to the 1-14 day and 15-364 day durations of exposure, respectively, and would be appropriate for those living adjacent to CAFOs (table 6). These MRLs are public health exposure guidelines, much lower than the occupational limit of 10,000 ppb.

Generally, there is limited peer-reviewed published literature on community assessments of hydrogen sulfide in the vicinity of CAFOs. There is a non-peer reviewed article by Jacobsen, (1997), for both ammonia and hydrogen sulfide. There have been several studies by the USEPA of continuous monitoring around CAFOs. One of these is a 1999 study in Northern Missouri is available from the EPA (Secrest, C.D., "Field Measurements of Air Pollutants Near Swine Confinement Animal Feeding Operations Using UV DOAS and FTIR," Office of Regulatory Enforcement, Air Enforcement Division USEPA, MS 2242A, 1200 Pennsylvania Avenue, NW, Washington, DC, 20460). Furthermore, the Minnesota Pollution Control Agency has conducted monitoring of numerous CAFOs. Their report on "Feedlot Air Quality Summary Data Collection, Enforcement, and Program Development (March 1999)," can be seen at http://www.pca.state.mn.us/hot/feedlots.html. These reports indicate that observed off-site concentrations near CAFOs at times may approach or exceed these ATSDR recommended limits.

There is a very important point to note, that there is variation in concentrations that can be measured, depending on atmospheric conditions. Stable atmospheres, particularly in the evening are condusive to build up of contaminants in the vicinity of CAFOs. Therefore, it is important that measurement periods take these predicable variations into account. In other words, just measuring during the evening as well as the day is important to obtaining an accurate assessment of actual exposure at the receptor.

Table 6. Agency for Toxic Substances and Disease Registry Minimum Risk Levels (MRL) for Ammonia and Hydrogen Sulfide[1]

Substance	Acute Exposure (1-14 days)	Intermediate Exposure (15-364 days)	Chronic Exposure (365 days and longer)
Ammonia	500 ppb	(None listed)	300 ppb
Hydrogen Sulfide	70 ppb	30 ppb	(None listed)

8.4 Relevance of legal or other recommended limits to occupational and ambient air quality associated with CAFOs.

Regarding OSHA occupational health exposure regulations, the PEL's listed for the hazardous substances found in CAFOs is not highly relevant. The reasons are as follows:

1. The scientific literature document s that endotoxin is one of the most hazardous substances to CAFO workers (Rylander, Jacobs, Organic Dusts, Exposure, Effects, and Prevention. CRC Press, 1994). However OSHA has no PEL standard for endotoxin
2. The OSHA PEL for PM is based on a non-biologically active (nuisance) dust. However, the PM inside CAFOs is highly biologically active, (high concentrations of microbes, endotoxins, and glucan) and is hazardous at much lower levels than in the 10 mg/m^3 published PEL (Donham and Scallon, 1986, and Donham and Reynolds 1996).
3. The PEL's are written assuming exposures to one toxic substance. CAFOs result in complex mixed exposures, which lowers the allowable exposure to each individual component of the mixture (Donham and Scallon, 1986, and Donham and Reynolds, 1996). Therefore, the OSHA or other recommended limits are not highly relevant. Although NIOSH, ACGIH, and AIHA are more stringent than OSHA, they are still much higher than research findings indicate they should be to offer, adequate worker protection in mixed exposure situations like CAFOs.

8.4.1 Mixed Exposures – Occupational
OSHA has established a Permissible Exposure Limit (PEL) for nuisance dust of 15 mg/m^3. The OSHA TWA's for respirable particles and ammonia are, respectively, 5 mg/m^3 and 50 ppm. Threshold limit values (TLV's) established by the American Conference of Governmental Industrial Hygienists (ACGIH) include 10 mg/m^3 for nuisance dusts, 4 mg/m^3 for grain dusts, 3 mg/m^3 for respirable dusts, and 25 ppm for ammonia (Table 1, NIOSH, 1994; ACGIH, 1994). However, several published research manuscripts (Donham KJ, et al., 1995, Reynolds S, 1996, Donham KJ et al., 2000) document that these limits are too high for CAFOs where a mixture of biologically active agents can combine to produce respiratory and systemic effects at much lower levels (Cumro et al., in press).

Multiple agents, multiple etiologies, and the potential for multiple interactions make thorough evaluation of health effects from CAFO emitants a very difficult task. The assignment of unquestionable causality to a single agent for a single adverse health effect or dysfunction in

confinement workers is unlikely at best. The 2001ACGIH publication for threshold limit values for chemical substances and physical agents states that when mixed exposures are present, and unless other data indicate differently, the effects should be considered additive. For example where C1, C2, and Cn are measured concentrations of hazardous substances, and T1, T2, and Tn, are their respective TLV's, then the relationship to determine if the level is under legal TLV's, the relationship is defined mathematically as follows:C1/T1 + C2 /T2 + Cn/Tn = < 1.

There may be instances when the effects of two substances are greater than additive, defined as a synergistic interaction. If synergy is present then mixed exposures are even more hazardous than if the effects were merely additive. Such a relationship between NH3 and PM in CAFOs, has been defined by Cumro and Donham, (in press). Data were analyzed from an exposure- response study of 149 poultry CAFO worker. Analysis of this data-set revealed prominent dose-response relationships between increasing PM, NH3, and endotoxin concentrations with corresponding cross-shift declines in worker lung function. Specific threshold concentrations were defined including total dust, 2.4 mg/m^3; respirable dust, 0.16 mg/m^3; total endotoxin, 100 EU/m^3; respirable endotoxin, 0.35 EU/m^3; and NH3, 12 ppm (Donham and Cumro, et al., 2000). As health effects to poultry workers from exposure to both dust and ammonia were less than half the published ACGIH TLV's, investigations were undertaken to study possible interactions between these substances. The results demonstrated that when workers are exposed to both PM and NH3, the adverse effect on pulmonary function is up to 156% greater than the individual effects of these gases (Cumro, et al., in press). Assuming a typical swine CAFO winter concentration of 10 ppm of NH3 and PM of 3.5 mg/m^3, and the TLV for grain dust of 4 mg/m^3, the correct relationship to determine if exposure limits are exceeded in this situation would be as follows: ([NH3]/TLV of NH3 + [PM]/TLV of PM) x 1.56. An example for a typical swine building would be as follows: (10 ppm / 25 ppm + 3.5 mg/m^3 / 4 mg/m^3) x 1.56 = 2.0. In other words, a typical building might exceed our recommended limit by two times. Synergy of simultaneous dust and ammonia exposures in a working environment raises the question of redefining exposure limits for organic dust and ammonia when workers are exposed simultaneously to these substances.

8.4.2 Mixed Exposures – The Community Setting

The EPA, in fact, treats mixed exposures in the community as additive (as ACGIH treats occupational exposures) unless there is information to indicate otherwise (USEPA 600890066F Methods for Derivation Inhalation Reference Concentrations and Application of Inhalation Dosimetry http://www.epa.gov/cgi-bin/claritgw). Existing data are clear that the community exposure concentrations are much less than in the occupational setting. The logical public health question is do mixed exposures in the community setting also have additive or synergistic health effects? Fundamental toxicologic principles would predict there would be additive or synergistic health effects of mixed exposures in the community, (as there would be in the occupational setting) if the hazardous substances effect the same body tissues or organ(s).

In the case of CAFOs, ammonia and hydrogen sulfide both have direct effects on the respiratory system, although ATSDR also warns that hydrogen sulfide is also a broad-spectrum poison. Whether exposure indices for these two respiratory irritants with similar short or intermediate term MRLs can or should be added is not immediately clear but certainly possible. A potential method to establish limits in mixed exposures would be to ratio the concentrations to the appropriate MRLs, with a sum below 1 suggesting no respiratory threat (similar to ACGIH for occupational exposures

ACGIH TLV's for Chemical Substances and physical agents and biological exposures indices). Note that a sum above 1 would not necessarily imply overexposure unless known toxic limits were reached, but would be an "indeterminate human health hazard" under the ATSDR classification scheme.

ATSDR notes hydrogen sulfide is considered a broad-spectrum poison. This means that it can poison several different systems in the body. Thus, in addition to possibly additive or synergistic effects on the respiratory system in the presence of ammonia, there may also be additive effects with other components of CAFO emissions. These materials occur together, not only with each other, but also potentially with a variety of other contaminants in hog manure. For example, there are endotoxins and other bioaerosols along with various other substances that contribute to the observed effect. Unfortunately, available research does not allow quantitive assessment of the health effects of all the mixtures of all substances in CAFO emissions.

8.5 Summary of Occupational Exposure Limits as Recommended from the Scientific Literature
There can be no questions that exposure to emissions while working in CAFOs can be a health hazard. There are over 50 publications documenting the risks. There are now 4 dose – response studies that agree quite closely, regarding the lowest observed health effect levels are. As the concentration of the livestock industry continues, and becomes more specialized, we have greater worker exposure because more are working full-time inside the buildings, rather than spending time in other farming activities as in previous diversified farms. OSHA has left the industry alone for the most part, but with many more large operations (with more than 10 employees), this segment of the industry clearly falls under OSHA's mandate. However, as previously discussed, the current OSHA limits are not highly relevant to protection of CAFO workers. The following concentration, listed in table 7, are scientifically supportable guidelines for occupational exposures, and are listed adjacent to current OSHA standards. (Donham et al., 1989; Donham et al., 1995; Reynolds et al., 1996; and Donham et al., 2000.

Table 7. Summary of Scientific Recommendations of Maximum Exposure Concentrations for Occupational Health Considerations of Swine and Poultry CAFO Workers.

	Human Health[1]	Current OSHA
Total dust mg/m^3	2.5	15
Respirable dust mg/m^3	0.23	5
Endotoxin EU/m^3	100	NA
Carbon dioxide (ppm)	1,540	5000
Ammonia (ppm)	7.0	50

8.6 Summary of Ambiant Exposure Limits as Recommended from Federal Agencies and Regional State Regulations

There has been no published literature on dose – response relationships of CAFO emissions and life quality or chronic health effects among community residents. However, several states have adopted emission standards based on the weight of evidence regarding individual chemical exposures (see chapter 9.0) Furthermore, ATSDR and the EPA have made recommendations based on hazard assessment evaluations. Also, consideration for mixed exposures should lower levels set for individual exposures. The following concentrations could be supported for CAFOs, based on the relevant information reviewed above.

H2S:
15 ppb at the residence for a one-hour average measure and 70 ppb at the property line. No more that seven exceedences would be allowed, per calendar year (with notice to the residents and DNR).
NH3:
150 ppb at the residence and 500 ppb at the property line for a one-hour average measure. There should be no more than 7 exceedences (with notice to residence and DNR), per calendar year.
Odor:
Odor would not exceed 1:7 dilutions at the receptor, or public use area, No more than 14 exceedences (with notice), per calendar year. An additional consideration could be given to a 1:15 dilution at the property line. Monitoring would be conducted via scentometry.

8.7 Justification for Recommendations of Exposure Limits

The concentrations listed in section 8.6 above, are based on a combination of data gained from relevant regulations in other states, and recommendations from made by several public health related agencies, including the World Health Organization, the US Environmental Protection Agency (EPA), and the US Agency for Toxic Substances and Disease Registry (ATSDR). The basis for the regulations promulgated in other states are reported in Chapter 9. The justification for levels recommenced by the EPA and ATSDR are described below.

The ATSDR minimal risk levels (MRL's) were developed in response to the mandate for the agency to list hazardous substances commonly found at listed facilities, the toxicologic profiles of these substances and to ascertain significant human exposures. That mandate is specified in The Comprehensive Environmental Response, Compensations and Liability Act (CERCLA) [42 U.S.C. 9604 et seq.], as amended by the Superfund Amendments and Reauthorization Act (SARA) [Pub. L.99-499]. The ATSDR has adopted a method similar to the EPA to determine the MRL's for respiratory exposures, or Reference concentrations RfC's. These levels are estimates of the daily human exposure to a hazardous substance that is not likely to cause adverse (non-cancerous) health effects, over a specified exposure period (acute – 1-14 days, intermediate – 15-364 days, and chronic, greater than 365 days). MRL's are derived when the ATSDR determines there is sufficient data to determine specific and sensitive health effects for a specific duration. Consistent with principles of public health, the MRL's are set to protect sensitive individuals, and that there is a safety factor built in as they are set below levels that might cause adverse health effects. The public health protection principle is also used by utilizing uncertainty factors (UF) when less than complete data are available. The MRL's undergo a rigorous review process, both internal, and external to the agency, are peer

reviewed, and are submitted for public comment. As of June 1, 2001, 286 MRLs had been determined, including hydrogen sulfide, and ammonia. The MRL's can be found on the ATSDR website at www.atsdr.cdc.gov/mrls.html. The ATSDR also publishes, "Toxicologic Profiles," which reviews the literature on the toxicology and public health significance, and justifications for MRL's determined for each of the substances for which an MRL is determined (www.atsdr.cdc.gov/toxpro2.html).

As mentioned previously, the more detailed methods ATSDR uses for determination of MRL's are very similar to the EPA methods for setting their risk levels, which are called reference dose concentration guidelines, (RfD's, for oral exposures, or RfC's for respiratory exposures). The EPA method is described in detail here to help explain how EPA and the ATSDR develop their exposure guidelines. The EPA Risk Assessment Method, are described in detail in the 416 page document 600890066F, entitled "Methods for Derivation Inhalation Reference Concentrations and Application Dosimetry" (www.epa.gov/cgi-bin/claritgw). The EPA has a long history of evaluating scientific information and in developing benchmark values for regulatory action to protect the public from adverse health effects. The National Academy of Sciences (NAS) has been charged with the evaluation of risk assessment processes performed by federal agencies to assure that regulations are based on best judgment and analysis of available scientific knowledge (Risk Assessment in the Federal Government: Managing the Process, NAS, 1983, and NAS Report on Sciences and Judgment in Risk Assessment, National Research Council, 1994). The NAS recommends that risk assessment should be separate from policy aspects of risk management to help assure recommendations for protection on the publics' health are not compromised by the political process. Furthermore, NAS defines risk assessment as "characterization of the potential adverse human health effects of exposures to environmental hazards and consists of the following steps:

1. Hazard identification: to determine the cause-health effect linkages of suspected hazardous substances;
2. Dose-response assessment: the estimation of the relation between the magnitude of exposures and the occurrence of the health effects in question;
3. Exposure assessment: determination of the extent of human exposure;
4. Risk characterization: determination of the nature and magnitude of human exposure, along with attendant uncertainty.

The EPA adopted its reference dose concentration guidelines (RfD's) and analogous guidelines for respiratory exposures (RfC's) based on the NAS guidelines, but the method is more rigorously defined and includes guidance for uncertainty factors (UF's) to help guide extrapolation in instances such as applying animal data to human exposures, and incomplete data (Barnes and Dourson, 1988). The process is a quantitative approach to interpretation of toxicology and epidemiologic data to determine a dose-response estimate, followed by a comparison to exposure estimate to analyze risk characterization. The RfC is defined as: An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without appreciable health risks during a lifetime (24 hours per day for 70 years).

The steps to calculating an RfC are as follows:

1. Determination of a no-observed-adverse-effect-level (NOAEL), which is the highest dose where no health effects are seen, or threshold level (Klaassen, 1986).
2. Determination of a human equivalent concentration (HEC) of the NOAEL, if the latter is based on animal data.
3. Determination of uncertainty factors (UF) that may include necessary extrapolations from:
    a. average healthy to sensitive humans
    b. animal to human data
    c. sub-chronic to chronic data
    d. lowest effect level to NOAEL
    e. incomplete to complete data base
4. Determination of any necessary modifying factors (MF) not addressed by the UF's, such as adjustments for low sample sizes, or poor exposure characterization.

The RfC determination could be defined by the following notation:

$$RfC = NOAEL[HEC] / (UF \times MF)$$

Usually a subjective confidence level is assigned to the RfC, based on the quality and completeness of the data and the extent of UF's used. These are issued not to disregard those with medium or low confidence levels, but to indicate that the values may change as more information becomes available. RfC's with a high confidence level may not expect to change in the future, relative to those with a low confidence level. The EPA's Integrated Risk Information System (IRIS), lists all the RfC's established, and discusses the UF's used in their determination.

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APPENDIX A
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APPENDIX B
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