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Development of methodology to document and code farm-related injuries and fatalities involving manure storage, handling and transport - with summary of 2017 incidents

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ABSTRACT

As part of ongoing surveillance of fatalities and injuries involving agricultural confined spaces by Purdue University's Agricultural Safety and Health Program, nearly 300 cases involving manure storage, handling, and transport equipment and facilities have been documented over the past 30 years. With the exception of a summary of 77 fatalities published by Beaver and Field[1], these cases have not been previously analysed or published due to a lack of resources and the limitations of the Purdue Agricultural Confined Spaces Incident Database (PACSID) which was designed primarily for analysis of grain-related cases. These limitations included differences in terminology used to code case information in the PACSID and dissimilar causative and contributing factors.

To develop a consistent and more useful approach to process and analyze data, 28 U.S. manure-related incidents involving 39 victims documented as having occurred in 2017 were examined for type of incident, victim characteristics, primary contributing factors, and nature of injuries. A review of literature was conducted to identify previously reported contributing factors, and a coding rubric was developed and reviewed by a panel of experts. It was determined that the rubric provided a consistent way to code and analyze descriptive information available on each case. A pilot analysis was completed of the 39 cases using the new tool, and results were summarized. The final methodology will be used to analyze all historically documented incidents, as well as future incidents. Findings presented include a review of relevant literature, discussion of the methods used in case documentation, classifications developed from sample data, and a summary of incidents in 2017. Anticipated outcomes include: 1) consistent strategy to document, code, and summarize manure-related incidents; 2) means of classification of key contributing factors; 3) identification of new or emerging trends; and 4) completion of previously documented incidents.

KEYWORDS

Asphyxiation; confined space; hydrogen sulphide; manure gases; manure pit

Introduction

Over the past four decades, Purdue University's Agricultural Safety and Health Program (PUASHP) has documented incidents involving grain storage, handling and transport equipment, and facilities. Data gathered from these incidents, often involving multiple victims (cases), were entered in an electronic database developed by Kingman and Field (2005).[1] The Purdue Agricultural Confined Spaces Incident Database (PACSID) now contains nearly 2000 individual cases representing persons injured or killed while exposed to agricultural confined spaces, primarily involving grain storage, handling or transport facilities, and equipment. Summaries of this data have been published by Field and Bailey (2)[2]; Kelley and Field (3)[3]; Kingman and Field. (2001)[4]; Kingman and Field (1)[1]; Roberts et al. (5)[5]; Riedel and Field (6)[6]; Cheng et al. (2016)[7]; and Cheng et al. (2018).[8] During the surveillance process, cases involving other non-grain related types of agricultural confined spaces were also documented but not added to the database, due to its design limitations or the lack of relevant selection categories. These cases included injuries and fatalities involving tower silos, bunker silos, wells, storage tanks and manure storage, handling and transport equipment, and facilities. Cases involving manure comprised the second largest

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Supplementary data for this article can be accessed here.

category of incidents following grain-related cases. These data could not be fully quarried or summarized due, as noted, to the differences in agents involved, such as the type of structure, and causative factors identified in the various types of confined spaces-related incidents. The development of a more relevant classification system was undertaken utilizing cases documented during 2017 as a convenience sample. From these cases, individual coding fields were identified that could be used to classify and summarize previously identified and documented cases of injuries and fatalities in which manure storage, handling, or transport were involved. Findings from the eventual analysis of all related cases documented to date and future cases will be used to develop more effective, evidence-based injury prevention and mitigation strategies and to develop a representative baseline for future assessment of these efforts. This article focuses on the development of the data classification and coding tools and processes and provides a summary of 2017 incidents using the methods developed.

Review of literature

A review of the published literature identified no attempt to consistently monitor over time injuries or fatalities associated with livestock manure storage, handling, or transport. In addition, no published work was identified that attempted to design an agricultural-based surveillance method or consistent data classification/coding system that could be used to assess the frequency or severity of these events.

Considerable research has been conducted and published on the chronic and acute health effects of exposure to the toxic environments often found in contained livestock production facilities including confined feeding operations and their associated manure storage facilities.[9–15] The most significant hazards identified in these studies related to the chronic respiratory hazards for workers exposed to gases and aerosols that are released from decomposing or agitated liquid anaerobic digested livestock manure, especially liquid manure slurry. However, none of the studies reviewed attempted to monitor on a continuing basis individual cases of injuries or fatalities, estimate the frequency or severity of these incidents, identify geographic distribution or primary farm type, or identify causative factors including those related to both respiratory and machinery hazards associated with manure storage handling or transport.

The National Institute for Occupational Safety and Health (NIOSH) published two reports on two incidents in 1989 involving seven workers who died due to exposure to oxygen deficient manure storage facilities on dairy farms. Five of the victims died attempting to rescue the initial victims.[16,17] There was, however, no evidence that NIOSH attempted to determine the frequency of these incidents.

In 1990, a NIOSH alert entitled "Request for Assistance in Preventing Deaths of Farm Workers in Manure Pits" was published to promote awareness of the risks of manure storage and the potential for multiple fatalities to occur.[18] The NIOSH alert described seven deaths from asphyxiation (suffocation) that occurred during two incidents involving entry into manure pits. This alert was developed to target injury-prevention efforts among farm workers who were at risk or may be unaware of the danger of entering manure pits.

Hallman reported on a NIOSH case study that illustrated the hazards of power take off operated manure pumps.[19] Though typically not identified as manure storage-related incidents, fatalities and injuries identified through the PACSID surveillance effort involving the transfer, pumping, agitation, and transport of liquid manure appeared to be more common than reported in the literature.

Based upon a convenience sample of cases documented by PUASHP prior to 2005, Beaver and Field analyzed 77 fatal U.S. cases that were documented between 1975 and 2004.[20] In addition, 21 severe injuries and 14 international cases were documented during the same period. The findings showed a greater proportion of events occurring at dairy operations (54.5%) versus at swine operations (44%). All the fatal cases documented were male, and 27% of the cases involved workers 21-years-old or younger, and 21% involved youth under the age of 16. The largest portion of fatalities (34%) occurred to persons conducting repairs or maintenance activities on manure handling equipment such as liquid

manure pumps and agitators. It was also found that 22% of those fatally injured had entered a manure storage or handling facility in an attempt to rescue another person. One of the recommendations from the study was to develop a centralized reporting system for these incidents and to conduct more in-depth investigations of incidents involving multiple victims. This summary represented one of the first attempts to obtain a more detailed understanding of the magnitude of the problem of manure related injuries and fatalities rather than a response to specific incidents. However, the authors recognized that the study was severely limited due to the small population size, the fact the cases analyzed were all fatal, and they were limited in geographic scope.

Four European incidents with 10 deceased victims involving manure pits, an outdoor open space beside a manure pit, and inside a biogas plant were reported.[21] Three of the four cases had multiple victims that all involved rescue attempts of unconscious co-workers or family members. The authors warned that in high concentrations, hydrogen sulphide, a gas identified in the reports cited, led to a loss of consciousness.

Hallam et al. summarized research on fatalities and injuries related to exposure to livestock manure with an emphasis on prevention strategies for decreasing mortality and improving facility design to reduce exposure to toxic gases.[9] The authors recommended that workers have access to self-contained breathing apparatus (SCBA), life lines, external observers, and other confined space access precautions. No longitudinal study of these incidents or attempts to determine frequency were mentioned.

Park summarized 17 incidents related to manure storage and transport in which 30 workers died and 8 were injured between 1998 and 2013 on Korean farms.[22] Cases were identified through newspapers and online searches, with the fatalities being primarily caused by asphyxiation. The authors recommended that additional surveillance efforts were needed, since there was no formal process in place to document and summarize these events.

Numerous extension/education publications and on-line sources were reviewed; however, none addressed attempts to assess the frequency of manure-related injuries and fatalities or conduct a risk assessment of all types of manure storage, handling, and transport practices to which workers are exposed. In numerous publications, the same high-profile incidents involving multiple victims were referenced. The primary focus of these educational resources was on exposure to toxic environments within manure storage structures.

Methods

The desired outcome of this research was to first develop a consistent method for documenting, coding, entering, and summarizing injuries and fatalities related to the storage, handling, and transport of livestock waste. A pool of nearly 300 unanalyzed cases already existed, but a method for organizing the data had not been developed as it had for cases involving grain storage and handling. The existing structure for the PACSID was used to develop a draft coding tool. This tool was then aligned with the work done by Murphy and Manbeck[23] to develop a safety assessment strategy for manure storage; the recommended safe practices found in the American Society of Agricultural and Biological Engineers (ASABE) Best Practice Standard ASAE EP[24]; and the relevant recommendations of the U.S. Department of Agriculture's National Institute of Food and Agriculture (USDA-NIFA) Committee on Agricultural Safety and Health.[25] The tool was reviewed by a panel of experts and then applied to the 28 incidents involving 39 individuals (cases) documented in 2017. Revisions were made to the tool to reflect feedback and to accommodate the scope of the data gathered from the 2017 cases. The resulting coding tool is attached as Appendix 1.

Documentation of cases

As noted, the currently used database was designed primarily to document, consistently store, and analyze data related to grain-related injuries and fatalities. During the search and ongoing surveillance efforts for these cases, unrelated cases involving manure storage, handling, and transport were documented. These overlaps occurred due to the similarities in the terminology found in the reports of both types of cases and

used as key terms in on-line searches. These terms included: "asphyxiation", "suffocations", "confined space", "fell into", and "rescued from". All documented "non-grain" cases were preserved but had not been entered in to the database for reasons noted above. Also, as noted in the review of literature, a convenience set of 77 of these cases, all fatal, was analyzed and reported on separately by Beaver and Field,[20] but was not included in the PACSID. Between 2013 and 2016, additional more aggressive on-line searches for manure-related cases were conducted as part of a U.S. Department of Labor OSHA Susan Harwood grant to develop safety training resources on agricultural confined spaces. Again, due to the lack of adequate or relevant coding fields, the cases were not entered in to the database or fully analyzed. However, findings did reaffirm the problem of secondary victims during rescue attempts and incidents involving manure handling equipment, which were addressed in the educational materials being developed. Findings led to a decision to expand surveillance efforts to include not only incidents related to drowning and toxic atmospheres related to manure storage, but also those involving auxiliary equipment, such as agitation equipment, liquid manure pumps, mechanical barn cleaners, and incidents occurring on public roadways during transport of solid or liquid manure. Associated with some of the data gathered was also information on manure spills that sometimes accompanied personal injury incidents.

Newspaper clippings were a primary source, but literature reviews, online searches, personal interviews, obituaries, documents from prior civil litigation, and earlier catalogued death certificates were also used to capture incidents. Over 12,000 archived newspaper clippings, not available online, of farm-related injuries and fatalities were manually reviewed to identify relevant cases. Sources also included case studies published by the National Institute for Occupational Safety and Health and state reports summarized in the Census of Fatal Occupational Injuries. Ongoing daily Google alerts were incorporated into the search process using a variety of relevant key words and phrases and have been monitored for over 5 years. These aggressive surveillance efforts resulted in nearly 300 cases being identified, with 39 fatal and non-fatal cases being documented in 2017.

Classification of cases

Upon completion of the pilot coding tool, the authors applied it to the cases identified in 2017 and collectively completed the coding as a means to test the applicability of the coding tool and develop a pilot summary of the data. This team approach led to additional revisions to the coding tool, especially in relationship to contributing factors and agents involved. Existing coding fields used to code grain-related cases were used as a basis for developing the new classification rubric. Comparable coding fields that were applicable to the revised coding tool, included:

- Date of incident (month, day, and year)
- Time of day
- State
- Address or county
- Type of farm (dairy, swine, beef, poultry, other)
- Fatal vs. non-fatal
- Number of victims
- Cause of injury or death
- Suffocation
- Drowning
- Asphyxiation
- Trauma from fire/explosion
- Trauma from fall
- Electrocution
- Entangled or caught in machine
- Trauma from roadway collision
- Trauma from equipment failure
- Access to uncovered manure pit
- Machine/vehicle related drowning
  - Victim
  - Name
  - Sex
  - Age
  - Relationship to farm

In addition, new categories for causative agents and contributing factors had to be developed to reflect the differences between grain storage, handling, and transport operations and those associated with manure storage, handling, and transport

facilities. The new descriptions of the agents involved are as follows:

- Underground or underfloor manure storage structures
- Above ground manure storage tank
- In ground manure storage (lagoon pit)
- Manure handling equipment (barn cleaner, skid steer, frontend loader)
- Manure transport vehicle (solid manure spreader, liquid transport vehicle)
- Manure agitation or pumping equipment
- Manure pumping pit or enclosure
- Electrical components
- Fire or explosion

A narrative section was also included to capture information such as the tasks being done by the victim at the time of the incident or extra ordinary circumstances. This section was, however, not searchable.

The final version of the coding tool was found to be applicable in most, but not all cases due primarily to insufficient data or unique circumstances in some cases requiring the use of "other" as a category.

Summary of 2017 cases

The following pilot summary represents what the larger summary will look like if resources become available to enter the case information from the previously identified, approximately 300 cases, into the modified PACSID using the new coding tool. It is further hoped that publication of this preliminary summary will lead to the identification of additional cases and feedback on the need for other information that would be helpful in designing injury prevention efforts.

A total of 28 incidents involving 39 individual cases were documented in 2017. Of these 39 individuals, 21 cases (54%) were fatal. Out of the 28 incidents, there were 8 incidents involving multiple fatalities/injuries. Two victims were reported in six incidents, three victims in one incident, and four in another. As with confined spaces in general, the risk of multiple victims involved in manure-related incidents is higher than other types of workplace-related incidents.

The cases were primarily work related, but also included 10 cases that were classified as non-work-related, including the death of a 3-year-old male who drowned after falling into an open manure pit and a 5-year-old male who fell off a manure spreader and was run over. All of the victims in 2017 were male, with an average age of 36, which is substantially younger than the average for grain-related injury victims, which is approximately 53.[26]

The distribution of incidents by month is shown in Figure 1. November and December were peak months, with the majority of these cases involving

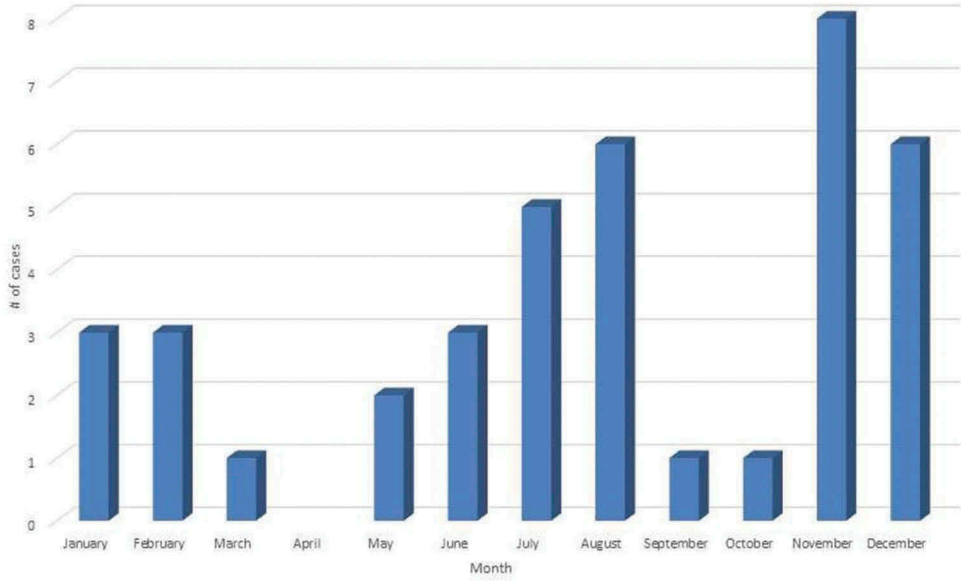

Figure 1. The distribution of cases by month (N = 39) for the 2017 summary.

handling, transporting, or field application of solid and liquid manure, especially on dairy farms. The second peak period of July-August reflected earlier findings that suggested there is greater risk of exposure to toxic manure gases, such as hydrogen sulphide, during hot weather when liquid manure is agitated and transferred by pumps for field application. (Figure 1)

Table 1 provides the distribution by state in which the incident was reported. Michigan, New York, Pennsylvania, and Wisconsin, all strong dairy states, ranked at the top of the list. Figure 2 shows the distribution of agents involved in 2017. The agent was reported in 21 cases, with manure handling equipment the most frequently identified agent (8 cases), and followed by manure transport equipment (5 cases). The actual cause of death other than drowning or asphyxiation was rarely mentioned, even when official police and fire/rescue reports were available.

Table 1. Distribution of cases by state (N = 39).

State	# Cases
PA	6
NY	6
MI	5
WI	5
MN	4
FL	3
ID	2
VA	2
CA	1
CO	1
IA	1
KY	1
TX	1

The type of toxic gas or level of oxygen that fatality victims were exposed to was rarely confirmed, but in prior research it appears that oxygen deficiency and the presence of high concentration of hydrogen sulfide were significant contributors to these deaths (Figure 2).

Regarding the type of farm, for 15 cases the specific type could not be determined due to insufficient data at the time of analysis. In cases where farm type could be identified, dairy was the most common with six. Swine and poultry operations each reported 1 case. Eleven of the cases took place on public roadways during transport of liquid or solid manure and two were reported to have occurred in a manure pumping station, or pump pit or enclosure.

Figure 3 illustrates the distribution of cases by general category. In 2017, 15 agricultural confined-space cases occurred at unspecified farms, eleven involved roadway manure transport vehicle and motor vehicle collisions, and six cases occurred on dairy farms.

Limitations

As with many types of agricultural-related injuries and fatalities, the high ratio of fatal to non-fatal

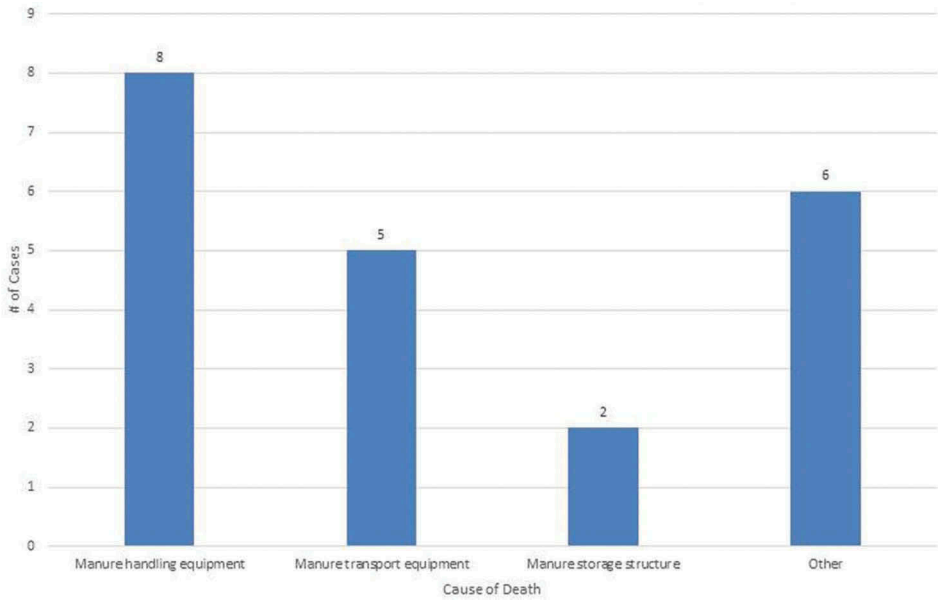

Figure 2. The distribution of agent involved in 2017 fatalities (N = 21) .

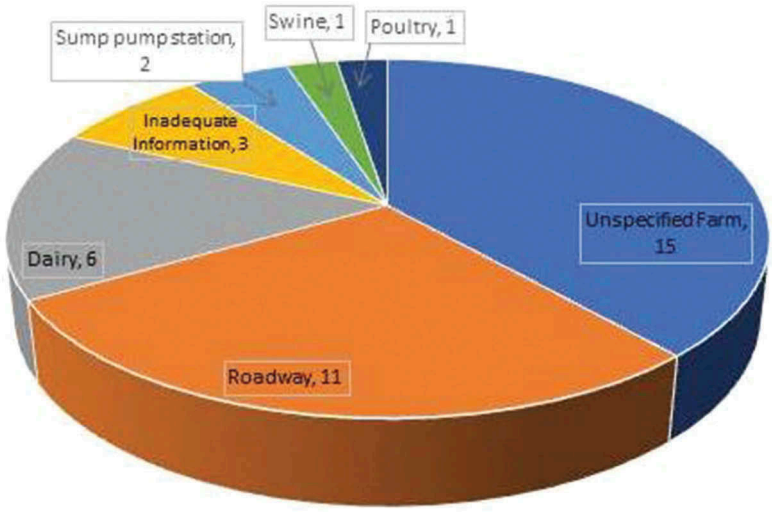

Figure 3. The distribution of cases by category for 2017.

incidents reported in this article suggests that a significant number of non-fatal or near-miss incidents go unreported preventing adequate documentation. The lack of any type of central required reporting process will continue to ensure under reporting of manure-related incidents.

There were multiple accounts unveiled during the discovery process in which workers were reported to have become overcome by a toxic environment during exposure to manure handling activities but were able to be removed from the site to recover without medical attention. In one case, a farmer shared about lowering his son on a rope sling into a manure storage structure and having the son pass out while suspended over liquid manure. The father was able to lift his son out, who recovered once reaching fresh air. None of these cases were included due to the wishes of the source and lack of adequate documentation. These types of "near misses", however, could provide valuable information.

There were also issues with identifying the actual cause of death, especially in cases involving drowning, asphyxiation, and exposure to toxic gases, including hydrogen sulphide. Where there was access to autopsy reports, exposure to hydrogen sulphide was mentioned in some cases, but more frequently the official cause of death was identified as asphyxiation due to oxygen deficiency. As with most farm-related fatalities, few autopsies are conducted. This lack of medical information also prevents a determination of the role of alcohol, drugs, or prior health conditions of the victim.

The data were also limited due to the inability to conduct additional on-site investigations involving interviews with victims and witnesses. It was found that few of these incidents are even investigated by the Occupational Safety and Health Administration (OSHA) due to the agricultural workplace exemption. For example, it was believed that incidents at large swine production operations are under reported considering the large number of these facilities with on-site manure storage structures and the large number of employees.

In general, a multisource surveillance system is needed to provide sufficient documentation for each case. These sources should not only include news media and on-line sources but also death certificates, workers' compensation reports, medical or hospital reports, coroner reports, police reports, and motor-vehicle incident reports. Such a system does not currently exist but is unlikely to be established in the foreseeable future.

Discussion

Because of the surveillance efforts, the scope of cases now being documented is believed to be more representative of typical injuries and

fatalities involving manure storage, handling, and transport operations. To date, nearly 300 cases have been documented between 1975 and 2017, but are yet to be fully summarized using the new coding process. This does not include a large number of cases documented outside the United States, including 11 in 2017.It is anticipated that the total number of cases will increase as the surveillance efforts continue.

It remains premature to draw firm conclusions regarding what will be found when the balance of the 300 documented cases are summarized. There are, however, indications that the frequency of incidents involving manure storage and handling not related to toxic environments will be higher than originally believed or suggested by the current published research and educational resources. Past failure to document incidents involving manure handling equipment such as barn cleaners, scrapers, and liquid pumps due to the focus on high profit, multi-victim incidents has caused a possible miss direction of prevention resources.

There is a need to continue the surveillance effort in order to provide an evidence-based response. This work, however, is not supported by any currently federally funded agricultural safety initiative.

Conclusion

The purpose of this preliminary effort was to develop a more consistent way to code injuries and fatalities that involve storage, handling, and transport of manure. This goal was achieved through the development of a standard documentation process and coding tool, and it is anticipated that the coding process will be used on the pool of cases that have been currently documented, along with future cases.

Regarding the frequency of these incidents, it appears they are relatively rare compared with other types of farm-related injuries and fatalities. However, this research clearly identified that there is a gap in the understanding of the problem, its scope and frequency, and the most effective strategies to prevent future incidents. It recommended that incidents involving all forms of agricultural confined spaces continue to be monitored and the findings used to promote regulatory, engineering, and educational efforts to reduce the frequency and severity of these incidents.

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Appendix

Agricultural Confined Space Incident Report Classification Form for Manure Storage, Handling and Transport Related Injuries & Fatalities

PACSID ID: _____

Source of Date for Incident Identification (Check all that apply):

- ☐ Published research article
- ☐ Phone/personal interview
- ☐ Electronic media (TV, Radio)
- ☐ News clippings
- ☐ Google alerts/on-line sources
- ☐ Other_____

1. General Incident Information

Date (Month/Day/Year) _____/_____/_____

Time of Injury _____ AM / PM **Weekday of Injury (circle)**: S M T W T F S

Address _____

County _____ **State** _____

2. Number of Victims _____

3. Incident Classification

☐ Non-fatal ☐ Fatal ☐ Unknown

4. Type of Farm

- ☐ Dairy
- ☐ Swine
- ☐ Beef
- ☐ Poultry
- ☐ Other, specify_____
- ☐ Unknown

5. Victim Information

Name (Last, First): _____ ☐ Unknown

Age: _____ ☐ Unknown

Name (Last, First): _____ ☐ Unknown

Age: _____ ☐ Unknown

Name (Last, First): _____ ☐ Unknown

Age: _____ ☐ Unknown

Name (Last, First): _____ ☐ Unknown

Age: _____ ☐ Unknown

Sex:

☐ Male ☐ Female ☐ Unknown

6. Cause of Injury

- ☐ Suffocation
- ☐ Drowning
- ☐ Asphyxiation
- ☐ Trauma from fire/explosion
- ☐ Trauma from fall
- ☐ Electrocution
- ☐ Entangled/caught in machinery
- ☐ Trauma a from roadway collision
- ☐ Trauma from equipment failure
- ☐ Machine/vehicle related drowning
- ☐ Other, specify _____

7. Relationship to Farm

- ☐ Farm/ranch owner or farm operator
- ☐ Farm/ranch hired worker
- ☐ Farm/ranch family member
- ☐ Children at play
- ☐ Rescuers/first responders
- ☐ Visitor
- ☐ Contractor
- ☐ Other, specify _____
- ☐ Unknown

8. Agent / Facility / Equipment / Involved

- ☐ Underground or underfloor manure storage structure
- ☐ Above ground manure storage tank
- ☐ In-ground manure storage (lagoon/pit)
- ☐ Manure handling equipment (barn cleaner, skid steer, frontend loader)
- ☐ Manure transport vehicle (solid manure spreader, liquid manure tank)
- ☐ Manure agitation or pumping equipment
- ☐ Manure pumping pit or enclosure
- ☐ Electrical component
- ☐ Fire/explosion
- ☐ Other, specify _____
- ☐ Unknown

9. Contributing Toxic Gases Identified (Exposure to toxic substances/gases)

- ☐ Hydrogen Sulfied
- ☐ Carbon Monoxide
- ☐ Methane
- ☐ Carbon Dioxide
- ☐ Ammonia
- ☐ Non

10. Location of Incident

- ☐ Livestock building
- ☐ Farm yard
- ☐ Field
- ☐ Roadway/highway
- ☐ Farm unspecified
- ☐ Manure shed
- ☐ Farm road
- ☐ Manure pit/lagoon
- ☐ Pump septic systems
- ☐ Other, specify_____

11. Additional Narration (including task at time of incident):

_____
_____
_____
_____
_____
_____
_____

Completed By:_____ **Date:**_____

***Incidence references attached to this report**