

Summary of Prior Grain Entrapment Rescue Strategies

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ABSTRACT. *Entrapment in flowable agricultural material continues to be a relevant problem facing both farmers and employees of commercial grain storage and handling operations. While considerable work has been done previously on the causes of entrapment in grain and possible preventative measures, there is little research on the efficacy of current first response or extrication techniques. With the recent introduction of new grain rescue equipment and training programs, it was determined that the need exists to document and summarize prior grain rescue strategies with a view to develop evidence-based recommendations that would enhance the efficacy of the techniques used and reduce the risks to both victims and first responders. Utilizing the Purdue University Agricultural Entrapment Database, all data were queried for information related to extrication of victims from grain entrapments documented over the period 1964-2006. Also analyzed were data from other sources, including public records related to entrapments and information from onsite investigations. Significant findings of this study include the following: (1) between 1964 and 2006, the number of entrapments averaged 16 per year, with the frequency increasing over the last decade; (2) of all cases documented, about 45% resulted in fatality; (3) no less than 44% of entrapments occurred in shelled corn; (4) fatality was the result in 82% of cases where victims were submerged beneath the grain surface, while fatality occurred in 10% of cases where victims were only partially engulfed; (5) the majority of rescues were reported to have been conducted by untrained personnel who were at the scene at the time of entrapment; and (6) in those cases where the rescue strategies were known, 56% involved cutting or punching holes in the side walls of the storage structure, 19% involved utilizing onsite fabricated grain retaining walls to extricate partially entrapped victims, and the use of grain vacuum machines as a rescue strategy was on the increase. Among the recommendations growing out of the study are these: (1) conduct further tests on the efficacy of grain rescue strategies, including the use of recently introduced grain rescue tubes and grain vacuum machines; (2) incorporate the findings into future first responder training programs; and (3) enhance the first response skills of personnel working at grain storage facilities, both on-farm and at commercial operations.*

Keywords. *Entrapment, Flowable, Grain, Rescue, Suffocation.*

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Entrapment in flowable agricultural material continues to be a relevant problem facing both farmers and employees of commercial grain storage and handling operations. While considerable work has been done previously on the causes of entrapment in grain and possible preventative measures, there is little research on the efficacy of current first response or extrication techniques. With the recent introduction of new grain rescue strategies, equipment, and training programs, it was determined that the need exists to develop evidence-based recommendations that would enhance the efficacy of the techniques used and reduce the risks to both victims and first responders. Therefore, the specific objectives of this study were: (1) review prior published grain rescue strategies and their efficacy and summarize for incorporation into current training programs; (2) document and summarize from the Purdue University Agricultural Entrapment Database previously used rescue strategies employed during actual entrapments; and (3) develop evidenced-based recommendations for future first responder training.

Utilizing the Purdue University Agricultural Entrapment Database developed by Freeman et al. (1998) and Kingman et al. (2003), all data were queried for information related to extrication of victims from grain entrapments documented over the period 1964-2006. Also analyzed were data from other sources, including public records related to entrapments and information from onsite investigations.

Significant findings of this study include the following: (1) between 1964 and 2006, the number of entrapments averaged 16 per year, with the frequency increasing over the last decade; (2) of all cases documented, about 45% resulted in fatality; (3) no less than 44% of entrapments occurred in shelled corn; (4) fatality was the result in 82% of cases where victims were submerged beneath the grain surface, while fatality occurred in 10% of cases where victims were only partially engulfed; (5) in those cases where the rescue strategies were known, 56% involved cutting or punching holes in the side walls of the storage structure (this strategy was used for both partially entrapped and fully engulfed victims), 19% involved utilizing onsite fabricated grain retaining walls to extricate partially entrapped victims, and the use of grain vacuum machines as a rescue strategy was on the increase; and (6) injuries and secondary entrapments were documented occurring to 14 emergency first responders at the scene of grain entrapments, including six who died as the result of being involved in the rescue attempt. None of the six were members of professional or volunteer emergency response teams.

Statement of the Problem

In this article, the term “entrapment” is used in a broader sense to describe events in which an individual is trapped, possibly due to engulfment in flowable agricultural material, such as corn, small grains, and feed, inside a structure considered a confined space (e.g., silo, bin, grain transport vehicle, outdoor pile, or bunker silo) where self-extrication is not possible. The term “engulfment” is used to describe events in which an individual is submerged (i.e., fully buried) in flowable agricultural material, such as corn, small grains, and feed.

From the time Purdue University began documenting cases of flowable agricultural material (FAM) entrapment and engulfment in the mid-1960s, efforts have been made to better understand the contributing causes of these incidents in order to improve the design of grain storage and handling facilities, encourage compliance with safe work

practices, and increase the relevance of preventative educational material. Due to the growing frequency of such incidents during the 1960s and 1970s, the U.S. Occupational Safety and Health Administration, Cooperative Extension personnel, grain bin manufacturers, the media, and the grain industry began to educate farmers and commercial elevator operators about the dangers associated with FAM entrapments and engulfments and to explore possible intervention strategies. Even with those efforts, the current national average is no fewer than 23 documented entrapments annually, and that frequency appears to be increasing, with 33, 38, 42, and 51 cases documented in 2007, 2008, 2009, and 2010, respectively (Riedel and Field, 2011). Approximately half of these more recent entrapments resulted in fatality.

Because entrapment continues to be a relevant problem and has a high probability of fatality, there has been growing interest in both developing more effective preventative strategies and first response or extrication techniques. Historically, the primary first response approach was body recovery, due to the high frequency of death (Baker et al., 1986). In some cases, rescue procedures actually contributed to the death of victims and/or caused secondary entrapment of rescuers. The extrication method most widely used was cutting holes in the wall of the bin to release the grain from around the victim (Field et al., 1999). In the 1990s, researchers and emergency response professionals began developing and testing FAM rescue procedures based on confined space rescue techniques similar to those used in non-agricultural settings (Maier et al., 1999). Such techniques typically employed high-angle/rope rescue systems and specialized equipment, such as temporary grain retaining walls (GRWs) that were fabricated onsite.

While much was known about general industry confined-space and high-angle/rope rescue practices, a review of the literature revealed only scant information about the application of these approaches to FAM entrapments and engulfments. Even though a number of professionals and organizations were conducting FAM rescue training for emergency first responders, there was a lack of sound research upon which to design the training curriculum contents. In some cases, the information being disseminated was not well understood or eventually proven to be incorrect.

It was thus concluded that a need existed to develop evidence-based rescue strategies, especially with respect to the use of GRWs, including the grain entrapment rescue tube (GERT), which was introduced as a form of grain retaining system to protect the partially entrapped victim from further entrapment from in-flowing grain and to aid in extrication. There was also need to summarize prior rescue techniques and document the current strategies being used in real-world situations in order to develop recommendations for rescue protocols and preventative strategies that would reduce the likelihood of FAM-related incidents being fatal.

Literature Review and Prior Research

Grain Entrapment Research

Since the late 1960s, Purdue University has been gathering data on incidents involving flowable agricultural material (FAM) entrapments in agricultural confined spaces (Kingman et al., 2001). Previously documented incidents have been coded and catalogued in the Purdue University Agricultural Entrapment Database (PUAED). The overwhelming majority of cases in the database involve entrapment and engulfment in

stored grain. Analysis of the data has resulted in several publications related to grain entrapment, including Kelley and Field (1995), Freeman et al. (1998), Kingman et al. (2001), Kingman et al. (2003), and Kingman et al. (2004). Although prior work has provided valuable analysis of causal factors associated with entrapment situations, these earlier studies did not fully explore the rescue dimension involved with previous FAM entrapment incidents.

The only identified prior research that related directly to grain entrapment rescue were those conducted by Schwab (1982) at the University of Kentucky and by Schmechta and Matz (1971) in Germany. Schwab analyzed the speed at which a person can become entrapped in grain and the amount of vertical pull needed to extricate a person so entrapped. Schmechta and Matz evaluated the speed at which a person sank into a column of grain being unloaded from the bottom; they also studied the ability of entrapped persons to free themselves when buried to various depths. The findings of both Schwab (1982) and Schmechta and Matz (1971) indicated that: (1) self-extrication was possible when an individual was entrapped to the knees, (2) self-extrication was possible but with considerable difficulty when entrapped to the waist in non-flowing grain, and (3) self extrication was not possible when entrapped to the chest. Schmechta and Matz also found that, when entrapped to the chest, breathing was made more difficult due to the added pressure of the grain.

Grain Entrapment Rescue

Initial anecdotal findings concerning possible grain entrapment rescue strategies based upon Purdue's early investigations of FAM incidents were first outlined in an audiovisual presentation by McKenzie (1971) used for extension education programs. He reported that most FAM entrapments were fatal and that onsite fabricated grain retaining walls (GRWs), including barrels with both ends cut out, had been used to assist in victim extrication.

FAM rescue strategies based on the Purdue investigations were published in the 1980 edition of "Farm Rescue" (Baker et al., 1980), with additional findings incorporated in the 1986 and 1999 editions (Baker et al., 1986; Field et al., 1999). In the 1999 edition, with over 135,000 copies distributed nationwide (primarily to emergency response personnel), specific rescue strategies were recommended for extrication of victims from small (i.e., <20,000 bushels) on-farm grain storage structures. One such strategy involved rapidly removing the grain from around the entrapped victim by cutting V-shaped holes, spaced equal distance apart, around the perimeter of the bin. (However, rescuers were cautioned that too many openings and/or openings that were too large might jeopardize the structural integrity of the bin.) Another strategy described was an onsite fabricated GRW constructed around a partially entrapped victim to protect him from additional in-flow while the surrounding grain was being removed. These recommendations had application to both smaller commercial and on-farm structures; however, no information was provided regarding the problems associated with emergency evacuation of grain from larger commercial storage units, including concrete silos and steel tanks.

In 1987, Iowa State University published a series of pamphlets on grain elevator safety for distribution to commercial grain storage and handling operations (ISU, 1987). Funded by the USDA, the series covered 14 topics, one of which was "Suffocation Hazards Associated with Stored Grain." This pamphlet discussed ways in which individuals become entrapped, cautioned about toxic atmospheres, provided guidelines

for bin and tank entry, and addressed emergency procedures following entrapment. Rescue situations involving completely engulfed and partially entrapped victims were considered. In both instances, the authors suggested cutting evenly spaced holes around the base of the bin; however, again, no information was provided regarding the use of GRW devices, limitations on the size of structure that could be breached, or the potential of structural failure.

In 1993, the American Academy of Orthopedic Surgeons published “Rural Rescue and Emergency Care,” which provided a rather detailed account of grain facility rescue techniques (Worsing et al., 1993). Topics that needed to be addressed for safe confined-space rescue were identified, including pre-incident planning, hazardous atmospheres, physical hazards, psychological hazards, and rescue techniques associated with grain entrapment. Special consideration was given to the use of GRWs and to cutting openings in the side of grain storage structures. In the section about onsite implementation and use of fabricated GRWs, the authors recommended that “the shield (GRW) should be made of plywood forced vertically into the grain. Three sheets may be used to form an overlapping triangle, or four sheets in a square or rectangle with overlapping edges. A section of snow fence covered with canvas also makes a lightweight, portable shield.” No mention was made as to the source(s) of that information or whether the shield designs had been tested.

Several newsletters, general extension publications, and books also raised concerns about FAM entrapment and extrication (Field, 1980; Aherin and Schultz, 1981; Aherin, 1987; Allen and Noyes, 1994; Mulhern, 1997). There has also been extensive coverage of the hazards related to FAM in the general farm printed media.

In 1999, preliminary findings from Purdue University’s collection of entrapment case studies were incorporated into a National Feed and Grain Association sponsored training program titled, “Don’t Go with the Flow” (Maier et al., 1999), which was designed for commercial grain industry personnel involved with day-to-day grain handling operations. The material described rescue strategies based on confined space rescue techniques in general use at the time and identified by a formal process using a panel of experts. The following seven steps were recommended to be taken in event of a grain entrapment:

1. Stop! Never rush into an entrapment situation in an attempt to rescue the victim.
2. Shut down and lock out all unloading equipment.
3. Activate local emergency fire rescue services and plant first response personnel.
4. Turn on aeration and roof exhaust fans.
5. Assemble employees at a predetermined location.
6. Assess situation and resources, including: stability of grain mass, condition of victim, air quality inside structure, availability of necessary rescue equipment, and personnel best suited to carry out the rescue.
7. Implement a situation-specific action plan.

Efforts to develop portable grain rescue tubes were first reported by Carpenter and Bean (1992), who reported on a tube designed and built by the Andersons Grain Company and later used in an actual rescue. A patent search identified one grain rescue tube design (U.S. Patent No. 6,062,342) submitted by Dale Dobson (Dobson, 2000). Kingman et al. (2001, 2003, 2004) reported on efforts to develop prototype grain rescue tubes using a variety of materials. In 2006, two tube designs were introduced at the Grain Elevator and Processing Society Exchange in Nashville, Tennessee. One

was manufactured by Regulatory Consultants, Inc., and the other by Liberty Rescue Systems based upon the Kingman design.

No research was identified that actually assessed the efficacy of any specific grain entrapment response strategy or the equipment used, such as cutting open the structure or using GRWs or rescue tubes. This lack of research-based information has contributed to the uncertainty regarding the most appropriate first response measures, and thus places first responders at risk of injury or death, which was documented in this study.

Research Methodology

The Purdue University Agricultural Entrapment Database (PUAED) was established as a means of consistently coding and storing data on both fatal and non-fatal incidents involving flowable agricultural material (FAM) and agricultural confined spaces. The database contained data on 686 FAM-related cases documented from 1964 through 2006, which were analyzed for this study. Case reports were derived from newspaper clippings, case studies submitted by agricultural safety professionals, state and federal reports, internet searches, death certificates, onsite investigations, and proceedings from civil litigation. The clippings of incidents reported in the press were gathered through a long-term subscription service that yielded over 12,000 reports of farm-related incidents from throughout the U.S. These were screened for cases involving confined spaces in agriculture. In addition, media reports were received from a variety of sources, including voluntary reporting.

Being comprised of information from many sources, the database does not consistently nor comprehensively cover all details related to every FAM entrapment case, nor does Purdue imply such, since many incidents go unreported for a variety of reasons explained in other articles (see Kingman et al., 2004).

A search of the PUAED uncovered 323 cases (47%) that contained sufficient information for use in this study dealing with rescue strategies. Only limited follow-up investigations were conducted to gain further information on cases that had been entered into the database. However, significant effort was made to gather more complete information on additional cases that were documented during the course of the study, including conducting onsite investigations. It is important to note that, of the cases contained in the database, 52% provided no information regarding the rescue attempts or strategies used. In fact, in 74% of the cases, the rescue was reported simply as "body recovery," which reflects the high fatality rate associated with these incidents (Kingman et al., 2004). The cases identified and summarized provide the best understanding of the rescue strategies currently being utilized.

Although most of the cases contained in the PUAED involved grains and oilseeds, some had been documented that involved other agricultural materials, such as silage, hay, and fertilizer in confined spaces like silos and storage bins. These cases were not included in this study; but it should be noted that successful rescues from these other materials were rare and often presented a set of complex issues to first responders, such as removal of massive amounts of bulk material.

The PUAED also contained reports of incidents that occurred in grain transport vehicles (GTVs). Again, such cases were not included in this study. However, entrapments in or rescues from GTVs, with respect to causative factors, have been analyzed

elsewhere (see Freeman et al., 1998; Kelly and Field, 1995; Kingman et al., 2001; Kingman et al., 2003; and Kingman et al., 2004).

This present study was undertaken to analyze documented FAM cases in the PUAED and to summarize the data concerning rescue situations, rescuer characteristics, types of rescue equipment used, techniques attempted, and rescue success rates. The information presented is a summary of the findings and includes data from both fatal and non-fatal incidents involving FAM in both commercial and on-farm structures. It is felt that analysis of the PUAED rescue information, along with supplemental documentation gathered through follow-up investigations, yielded findings that should enhance the reliability of future recommended rescue practices, including what has been attempted, what works, what does not work, what equipment has proven most useful, and what precautions are needed to prevent secondary victims.

The importance of this research was confirmed during two FAM incidents that occurred near completion of this study. In both cases, a serious conflict took place at the scene among the different first responder groups present as to the most appropriate strategy to follow to extricate the entrapped victims. In one case, the efforts were successful despite the conflict; in the other case (discussed later), they were not.

Identifying the Cases

This research was conducted using the currently available data in the PUAED plus supplemental case study information. A description of how these data were originally gathered, stored, and queried has been presented elsewhere (see Kingman et al., 2001).

Since its development, the PUAED has been continually updated with new cases and information from cases identified during earlier periods. Approximately 30 to 50 new cases are added annually. The more recent cases have been discovered through internet searches of articles related to this topic, grain industry email alerts (e.g., Grain Elevator and Processing Society [GEAPS] industry alerts) and in-depth findings collected from civil litigations and onsite investigations. In the internet searches for FAM entrapment cases, Google alerts and Newslibrary.com search engines were used. Keywords for those searches included: "farm accident," "farm injury," "grain bin," and "silo."

It has been determined that not all incidents are reported in the public media, especially those not resulting in a fatality or those in which the victim was able to self-extricate and was unwilling to report the incident. This conclusion is based on anecdotal observations involving discussions with first responders, farmers, and commercial elevator personnel at various fire/rescue training events, agricultural trade shows, and grain industry expositions where the Purdue Agricultural Safety and Health Program staff was distributing grain entrapment and general farm safety information. At these events, the staff spoke to individuals who had been entrapped in grain storage structures and were either rescued by co-workers or had extricated themselves. Whenever mentioned, these accounts were noted by Purdue staff and later checked against the database. Usually such cases, especially non-fatal cases, had not been previously recorded. Typical reasons for past victims' reluctance to report their experiences included embarrassment, fear of punishment by supervisors, and fear of external regulatory involvement. No good estimate exists as to the frequency of or contributing factors associated with these undocumented cases. In addition, it was found that summaries of farm-related fatalities and injuries from state and U.S. Department of Labor sources (e.g., NIOSH) did not comprehensively document FAM incidents.

Table 1. Criteria fields for data entry into the PUAED.

Type of structure	# of workers nearby	Rescuer effects	Size of structure	# of all agencies involved	# of direct observers
# of emergency rescuers	# of all rescuers	# of emergency agencies	Equipment used in rescue	Rescue techniques used	Are rescuers trained in grain entrapment rescue?
Description of mistakes made	Total time of entrapment	Total time for rescue	Victim effects	Depth of entrapment	Was a grain retaining wall used?
Month	Day	Year	Weekday	Time	Age
Sex	County	State	Relationship	Work status	Residence farm
Farm type 1	Farm type 2	Accident type	Agent of injury	Location	Classification
Working	Used safety equipment	Fatality	Narrative	Medium	Grain movement
Last name	First name	Contact name	Contact title	Phone number	Case info. notes
Newspaper clipping	Death certificate	State extension report	Accident report (non-state)	Other	Unknown
None	Source notes	Non-farm case	Agent category	Rescue info. entered	

Entering the Data

All documented cases were coded using a standardized coding form and then entered into the PUAED, which utilizes Microsoft Access database software. Column headings for the 59 previously established criteria fields (Kingman, 2002) are listed in table 1. As already noted, not all cases entered into the PUAED have enough information available for data entry into each of the criteria fields. If information was not available for a particular field, then no entry was made in that field.

Running the Queries

Queries can be quickly and easily performed with the PUAED, allowing data to be sorted and analyzed and comparisons made. The ability to mine the information in the database permits users to find and analyze what had been documented concerning past FAM rescue attempts.

The general information fields that were queried for inclusion in this research study were: *Type of structure*, *Size of structure*, *Total time of entrapment*, *Victim effects*, *Depth of entrapment*, *Year*, *State*, *Farm type 1* (primary farm business, i.e., grain, beef, dairy, poultry), *Fatality*, and *Medium*. This information was queried in order to get a better overall picture of grain entrapment incidents, allowing for evaluation of frequency, locations, and types of entrapments.

Within the PUAED, there were 373 cases that included some information on entrapment rescue attempts. That information was queried from the following criteria fields: *Rescuer effects*, *# of emergency rescuers*, *Equipment used in rescue*, *Rescue techniques used*, *Were rescuers trained in grain entrapment rescue?*, *Description of mistakes made*, *Total time for rescue*, *Was a grain retaining wall used?*, and *Rescue information entered*.

The majority of queries were single-criterion queries. The fields were examined individually and tallied. In some cases, queries prompted investigation into other criteria fields when the generated data needed additional explanation. Deciding which fields to query was determined by evaluating those fields that included the most information thought to be useful from a grain entrapment rescue standpoint. An example of some of the criteria fields that were not explored included: *Name* of the entrapped person,

County in which the entrapment took place, and the *Time of day* the entrapment occurred.

Also available for review and analysis were hard copies of the reports of grain entrapments, including printed and online news articles, video clips, and documents generated from prior litigation, such as police reports.

Findings of the Study

General Observations Concerning Grain Entrapments

Beginning in the late 1950s, grain harvesting and handling technology changed substantially, with a rapid increase in on-farm storage as well as the construction of larger commercial and on-farm storage structures. In the Midwest, much of this change was driven by the switch from harvesting ear corn to harvesting shelled corn. The growth of on-farm storage and the conversion to shelled corn have been the primary factors leading to an increase in flowable agricultural material (FAM) entrapments. Of the 686 cases documented in the Purdue University Agricultural Entrapment Database (PUAED), 67% occurred on farms, with the remainder primarily at commercial sites. A review of the more recent cases, however, shows a growing number of incidents now happening at commercial grain storage sites (Roberts and Field, 2010). In entrapment cases where the grain type was known, 49% occurred in shelled corn. In all known cases, the number one identifiable factor that led to victims entering grain storage spaces was spoiled or out-of-condition grain.

Entrapments have been documented in the PUAED in all but nine states: Louisiana, Maine, Nevada, New Hampshire, New Mexico, Rhode Island, Vermont, Washington, and Wyoming. The bulk of incidents (over 55%) have occurred in the Midwest Corn Belt states of Iowa, Illinois, Indiana, Minnesota, Ohio, and Nebraska. This list closely parallels states with the greatest storage capacity: Iowa, Illinois, Kansas, Nebraska, Texas, and Minnesota (USDA, 2010).

Over the 1964-2006 period, an average of 16 FAM entrapments were documented per year, with an average of 12 of those 16 (75%) resulting in death. Between 1996 and 2006, however, the frequency of documented cases increased to an average of 22 per year, with an average of 17 of those 22 (77%) resulting in death. Figure 1 is a bar

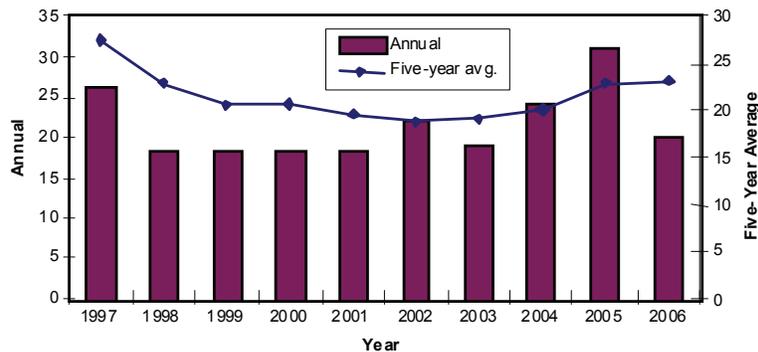


Figure 1. Documented U.S. grain entrapments with five-year running average.

graph that represents the five-year running average for entrapments. Lowest in 2002, the average has been steadily rising since then. The following factors are believed to have contributed to the increase in documented cases: (1) heightened interest by federal and state agencies in documenting work-related injuries and deaths; (2) better surveillance systems, including the ability to conduct nationwide online searches of many local newspapers; (3) a significant increase in the amount of grain being produced, stored, and handled; and (4) a significant increase in the size and capacity of grain storage facilities (USDA, 2009).

Survivability of Entrapment

In the 686 recorded FAM incidents in the PUAED, 75% of the entrapments proved to be fatal. This high percentage of fatalities is most likely a reflection of the small percentage of non-fatal cases being reported or documented in most states. In Indiana, where the data have been more comprehensively and consistently gathered over the past 30 years, the percentage of fatal cases was lower (66%). If this “2 fatality to 1 non-fatality” ratio were applied to all documented cases, then it could be estimated that over 750 cases of fatal and non-fatal entrapment occurred nationwide during the period reported.

Of the 239 cases where the depth to which the person was entrapped is known (e.g., to the shoulders, waist, etc.), 62% involved an engulfment, i.e., the person was drawn completely below the grain surface. In the 149 incidents where engulfment was reported to have taken place at any time during the event, the survival rate was less than 18%. In the 90 cases where partial entrapment was known to have taken place, the survival rate was 90%. In other words, rescue efforts were unsuccessful in 82% of cases where the victims were submerged in the grain, compared to rescue efforts being unsuccessful in only 10% of cases where victims were partially entrapped.

Reasons Behind Unsuccessful Rescues

The primary reason for unsuccessful rescues of victims in engulfment situations appeared to relate to the amount of time between engulfment and discovery, and then extrication from the grain. Victims most frequently suffocated, due to mechanical asphyxiation involving the ingestion of grain before rescuers arrived on the scene. In cases in which victims were partially entrapped, the reasons for unsuccessful rescue were two-fold: (1) victims being further buried when rescuers entered the structures and walked on the unstable surface of the grain in an attempt to make contact (eight documented cases), and (2) victims being buried deeper when rescuers opened unloading doors or activated unloading equipment in order to remove grain from the storage structures (14 documented cases). An unloading auger below an entrapped victim, when turned on, will only draw the victim further into the grain mass.

In addition, victims were sometimes unintentionally injured (e.g., separated spinal cords, dislocated arms, cracked ribs) as a result of rescuers trying to extricate them with inappropriate or makeshift harnesses or improvised ascending devices (eight documented cases).

In one case, an entrapped worker died when a co-worker tied a rope under the victim’s arms, ran it outside the bin, and tied it to a pickup truck, which was then driven away in an attempt to pull the victim out of the grain. Other problematic responses included: (1) an incident in which co-workers tried to free an entrapped victim for 3.5 hours before finally calling trained emergency personnel, and (2) several cases in

which rescuers made lengthy, and often futile, attempts to dig out entrapped persons without the aid of grain retaining walls or devices.

Rescue and Recovery Times

Rescues from FAM engulfments and entrapments are usually complicated, time-consuming endeavors requiring specialized rescue personnel and specialized equipment (Maier et al., 1999). Of the 124 documented cases for which the duration of entrapment and/or extrication was known, the average time of entrapment was 3.7 hours and the average time for rescue/recovery was 3.3 hours. This difference indicates the typical lag between when an individual is first discovered entrapped and when the rescuers first arrive on the scene. The longest reported entrapment was 60 hours (a body recovery), and the shortest just 4.8 minutes. In the shortest time case, the victim had slipped into ground meal, was buried approximately 3 feet under the surface of the meal, and was pulled free by co-workers in less than 5 minutes. In the longest time case, the victim was noticed missing 2 hours after having entered a 305,000 bushel capacity soybean bin. Rescuers had to remove approximately 267,000 bushels of beans before the body was uncovered.

Emergency Rescue Agencies and Related Personnel

The term “emergency rescue agency” refers to an emergency first responder group, such as an emergency medical service (EMS), a fire department, or a technical rescue team. Within the PUAED, police departments and coroners’ offices were not entered in the # of *emergency agencies* criteria field but rather in the # of *all agencies involved* field. For enumeration purposes, if any two or more emergency rescue agencies from different localities responded, they were counted as two or more agencies.

In most of the documented cases, multiple agencies were involved in grain entrapment rescue attempts. However, in over two-thirds of the cases, there were no data on the number of agencies present. Although unconfirmed, reasons for multiple agencies responding to an incident could include: (1) complexity of the rescue, (2) amount of manpower needed to move large quantities of grain, and (3) mutual aid agreements among various rescue agencies to respond to these types of incidents. Table 2 shows that, out of the 205 cases for which the number of rescue agencies responding was known, 140 (68%) involved two or more such agencies. In one case, seven agencies had responded. It appears, but has not been confirmed, that the first “official” first responders at the scene were often law enforcement personnel responding to the 911 call.

Table 3 lists the 35 documented cases for which the number of personnel from emergency rescue agencies responding to specific incidents of entrapment was known. In 22 of those 35 cases (63%), no rescue agency personnel were involved in extricating the victim; rather, the rescues were reported as being conducted by untrained family members, employees, or neighbors. In these instances, the untrained persons were already at the scene when the entrapment took place or arrived at the scene and performed the rescue before the trained first responders arrived. Only 11 of the 35 cases (31%) included information on the number of rescue agency personnel present during the actual rescue of the victims. One case is known to have had approximately 40 personnel from four different rescue agencies at the scene; and in two cases, total number of rescue agency personnel plus untrained volunteers present was in excess of 100.

Table 2. Emergency rescue agencies reported at the scene of a FAM entrapment (205 known cases out of 686 documented cases).

Emergency Rescue Agencies	Cases
7	1
6	1
5	6
4	22
3	43
2	67
1	50
0	15

Table 3. Number of rescue agency personnel at the scene of FAM entrapments (35 known cases out of 686 documented cases).

Rescue Agency Personnel	Cases
0	22
10	1
12	1
18	1
20	3
25	3
30	1
40	1
100+	2

From photographs accompanying many of the cases, it is apparent that numerous agencies were involved, but just how many different agencies could not be confirmed; thus, no information was entered in the respective fields.

Of all persons involved with a grain entrapment rescue (whether emergency response personnel, farmers, elevator employees, or family members), only 11 cases in the PUAED involved individuals identified in news coverage of the incidents as having had at least some training related specifically to grain entrapment rescue. While the data are too limited to draw conclusions about the level of training received, some of the techniques reported as being used (e.g., turning on the unload auger, attempting to forcefully extricate the victim from the grain mass) suggest that many first responders had not been exposed to current confined-space extrication methods.

Hazards to First Responders During and After Actual Rescues

In the documented FAM rescue cases, among all individuals participating in the rescues (e.g., neighbors, family members, emergency response personnel), 14 were reported to have become secondary entrapment victims, six (43%) of whom died. None of the deceased secondary victims were trained emergency response personnel.

Among the 373 documented cases, no fewer than 20 trained first responders and six untrained volunteers received medical treatment for strains, heat exhaustion, and dehydration experienced during FAM rescues. In addition, 25 individuals involved in 13 different rescues experienced respiratory distress resulting from the dust-filled, moldy conditions (as is common with out-of-condition grain). Because of the relatively few cases in which such data were available, it can be assumed that the number of incidents of first responder injuries and illnesses are substantially underreported.

**Table 4. Types of structures involved in FAM entrapment rescues
(124 known cases out of 686 documented cases).**

Type of Structure	Rescues in Structure
Unspecified metal bin	72
Corrugated metal bin	24
Concrete silo	10
Flat storage	7
Silo	6
Wood	3
Concrete bin	1
Unspecified bin	1

Entrapment Dangers During Grain Rescue Training Exercises

A few cases were documented in which unintentional entrapments and injuries happened during FAM training exercises for rescue personnel. In at least two incidents, trained first responders became entrapped and had to be extricated by others participating in the training. In one case, a high-angle rescue team member became entangled in ropes while suspended over the surface of the grain and had to be extricated by a second team. In another case, a first responder became wedged in the 56 cm (22 in.) diameter access door on the roof of a corrugated steel bin and had to be freed with the use of lubricants. In yet another case, a training participant who was partially buried as part of an exercise began having breathing difficulty and had to be treated. There were also reports of other incidents occurring during rescue training, including falls, heat exhaustion, strains, hypersensitivity responses to dust and airborne mold, and overexertion.

Structures Where Entrapments Occur

Table 4 shows the types of structure where FAM rescues were known to have taken place. Of the 124 cases where the structures were identified, by far the most common was unspecified metal or corrugated bins (96 of the 124 cases). This parallels earlier findings by Kingman et al. (2001) that over 77% of reported incidents involved metal bin structures. Little data were available as to size of the structures. In the 86 cases where size was known, 50% of the structures were 20,000 bushels or less in capacity; the other 50% were from >20,000 bushels up to 400,000 bushels. There were no data on the difference in rescue strategies used based upon size of the structure.

Rescue Techniques

The most common technique used by rescuers (trained and untrained) was to cut holes in the sides of the structures to allow the grain to flow away from around the victim. As noted by Field et al. (1999), cutting V-shaped openings can be an effective means of freeing an entrapped individual in a smaller metal bin (i.e., 20,000 bushels or less). Of the 118 cases where this rescue technique was documented, 109 (90%) included either cutting or punching holes into the structure. (Note: Despite verbal reports of a training video purportedly showing an explosion while holes were being cut in a grain bin, no such video could be located, nor have documented reports been found regarding either structural failure or fire/explosion associated with cutting or punching holes into structures using power saws or gas torches.)

Only four cases documented specially trained rescue personnel or high-angle rescue teams rappelling down to partially entrapped victims, an approach used to gain direct access to a victim without causing deeper entrapment. In three of the four cases, the victims survived. In addition, three of those cases involved concrete silos 100 feet tall

or taller of unknown bushel capacity, while the fourth involved a 26,000 bushel concrete silo of unknown height.

A rescuer entering a grain storage structure without rappelling would have to walk on the surface of the grain. When grain is being or has been drawn out of the base of the structure, the grain mass resembles an inverted cone, with the center of the cone over the outlet where the grain is drawn out. When victims become entrapped in grain flow, they are typically located at the center of the inflowing cone and thus are drawn down to the outlet. A rescuer walking on the surface of the inverted cone can cause the victim to be buried deeper in the mass as the surrounding grain flows down the cone to the center of the mass. There were reported instances in which rescuers placed sheets of plywood in front of them prior to taking steps forward. This allowed them to walk down the inclined surface of the grain without causing additional inflow of grain, thus preventing further burying of the partially entrapped victim.

In only three cases were the storage structures' aeration fans reported turned on during the rescue operation, a measure currently recommended in order to provide a fresh flow of air to an entrapped individual while rescuers work on extrication (Field et al., 1999; Maier et al., 1999). In two instances, the victims were first entrapped by the grain and then came in contact with the unloading augers beneath the grain surface, which further complicated the rescue attempts. When the victims became entangled in the unloading equipment, rescuers needed to not only remove the grain, but also disassemble or cut apart the augers to free them.

Rescue Equipment Used

Table 5 identifies the various types of equipment reported or documented as being used when conducting FAM rescues in the 131 cases where such information was available. Much of the equipment listed was used either for breaching the grain storage structure or for removing grain from around the victim and away from the structure that had been breached. In 37 of the 131 cases (28%), the apparatus was some form of grain retaining wall (GRW) or device. Such a device was usually constructed of wood or sheet metal (in one case, a hog feeder cylinder) as a means both to hold back flowing grain from further burying the victim and to allow the rescuers to remove a small quantity of grain from inside the device (where the victim was) and thereby free him. A GRW was only useful in situations where the victims were only partially entrapped, since they had to be located within the grain mass before the device could be deployed. (Note: No commercially manufactured GRW was identified as being used in any of the cases documented.) Since this study was completed, three cases were identified in which a commercial grain rescue tube was used to extricate a partially entrapped victim from a grain storage structure. A picture of the tube used is included as figure 2.

Use of portable grain vacuum systems during rescue attempts appears to be growing as these combination vacuum/blower units have become more widely available in commercial and on-farm operations. They are capable of moving several thousand bushels per hour and are very effective at removing grain from around a victim. However, they also create a potential for secondary entrapment of the operator who is working directly on the grain surface, and they pose a potential health risk because of the amount of dust dispersed into the air when they are operating.

**Table 5. Types of rescue equipment reported having been used at FAM entrapments
(131 known cases out of 686 documented cases).**

Rescue Equipment	Cases	Rescue Equipment	Cases
Grain retaining wall	37	Auger	2
Loader	28	Rappel	4
Vacuum	26	Rope	2
Torch	18	SCBA	2
Harness	16	Pneumatic cutter	1
Saw	13	Air chisel	1
Vacuum unit	6	Snow blower	1
Jaws of life	5	Backhoe	1
Ladder truck	4	Face shield	1
Fan	3	Pulley	1
Bulldozer	3	Block and tackle	1
Crane	3	Come-a-long	1
Chop saw	3	Grader blade	1
Shovels	3		



Figure 2. Commercially manufactured grain rescue tube used in an extrication exercise.

An Entrapment Case Study

Toward the end of this research, an opportunity arose to visit the site of an entrapment and unsuccessful extrication while rescue attempts were still in progress. The entrapped victim was a 70-year-old male who had farmed all his life. With family members, he was transferring shelled corn from an 18,000 bushel bin into a semi-truck trailer. Having seen him climbing up to the top of the bin and sitting on the roof near the entry by the eave to monitor the unloading process, the family members left the area to carry out other tasks around the farm.

After a short time (exact amount not known), one of the family members returned to the bin. Realizing that the father was no longer atop the bin or in the vicinity, the family member first looked around the farmstead, then drove to an adjacent farm, and finally called neighbors to see if the father had gone to visit any of them. After at least



Figure 3. First hole cut in the bin wall during the attempted rescue documented in the case study.

an hour of searching, one of the sons noticed that something was blocking the flow of grain out of the bin and correctly concluded that his father may have entered the bin and become entrapped.

The augers and unloading equipment were shut off and an attempt to establish visual contact with the victim was made by accessing the roof hatch. Using a cell phone, 911 was called and three local fire departments responded to the scene, as did various neighbors. The time for all three units to respond was approximately 30 minutes. When the firefighters arrived, the family members and a couple of neighbors had already begun cutting holes in the side of the bin with an oxy-acetylene torch and had turned on the bin's aeration system. The initial holes were approximately one foot square, allowing only a limited amount of grain to be removed (fig. 3). Family members indicated that they turned on the aeration fan both to supply their father with some air (if he was still alive) and to let him know that they were outside, thereby providing hope of rescue.

Concerned about both the threat of explosion as a result of cutting with a torch and the aeration system suspending dust in the air, the fire departments' incident commander ordered that all cutting and aeration equipment be stopped. (The incident commander is the director and chief authority during an emergency situation, and is usually the commander of the first emergency response unit to arrive at the scene.) The firefighters then began discussing alternative means of rescue. Frustrated by the delay, the family and some of the neighbors resumed cutting into the bin to remove more grain. Again, the incident commander, in the presence of a law enforcement officer, demanded that they stop, which they did.

Soon, an argument erupted between the family members, neighbors, and firefighters about the potential for explosion from the cutting operation and the best way to perform the rescue. The non-first responders felt that the firefighters were taking too



Figure 4. One of the additional holes cut during the case study rescue (left) and the triangle-shaped opening through which the victim's body was eventually removed (right).

long to develop a plan and that the best thing to do in this situation was to continue cutting holes in the bin walls to release more grain and to turn the aeration equipment back on. However, the firefighters were adamant about the danger of fire or explosion associated with the cutting because of the corn and dust within the bin. The argument increased in intensity until the incident commander requested that local law enforcement at the scene secure the site and reduce access by family members and other non-fire/rescue personnel.

Some of the responding neighboring farmers became impatient and proceeded to again cut around the base of the bin. Attempts by one fire department to breach the bin wall with a hydraulically powered “jaws of life” were unsuccessful. The jaws did not open wide enough to grasp the steel sheeting due to the corrugations, and its “bites” were too small to efficiently cut the needed openings. When the cutting continued despite the order to cease, one of the fire departments chose to leave the scene. The bin was eventually breached enough to allow much of its contents to be emptied out onto the ground. At this point, some neighbors and remaining firefighters entered the bin and began shoveling corn away from the center. A short time later, the victim's body was uncovered and removed through a large, triangular opening that had been cut (fig. 4).

The entire entrapment time was approximately 2.5 hours. The individual who first uncovered the victim said that he was face down against the bin floor and that in his hand was a long pole, the one that one of the family members had used earlier to break up clumps of out-of-condition corn when the flow was slowed due to plugging of the outlet.

After the victim's body was removed, most of the remaining firefighters left the scene, and clean-up efforts were initiated by local volunteers and family members.



Figure 5. Front end loader filling a semi-truck trailer during clean-up following the case study extrication.

Some neighbors brought food and drink for the workers and grieving family; another distributed dust masks to those involved with the clean-up operation. All volunteered their time and equipment to help remove the thousands of bushels of grain that surrounded the bin. At one point, two semi-trucks were being loaded by two front end loaders, a skid steer loader, and more than 25 individuals with shovels. A third truck that arrived later was loaded using a PTO-operated grain vacuum that had been brought to the scene by a local elevator. Even after 2 hours, the site was still not completely cleared of grain. Figures 5, 6, and 7 show the clean-up process following extrication of the victim from the grain bin.

The characteristics of this particular case are very similar to a number of other cases reviewed for this study. Comparable features included:

- The victim was male.
- The entrapment took place on a farm and in a relatively older and smaller corrugated steel bin.
- The reason the victim entered the bin was to clear a plug in the grain flow that resulted from out-of-condition grain.
- The medium in which the entrapment took place was corn.
- There was uncertainty among first responders concerning the best strategy to access the victim.
- Holes were cut in the bin wall (using a torch) to allow the grain to flow out of the structure so that the entrapped victim could eventually be recovered.
- Clean-up following the extrication required much manpower, tools, and equipment. Among the items used were front end loader, skid steer loader, grain vacuum, shovels, and semi-trucks and trailers.



Figure 6. Skid steer loader removing grain from around the grain bin.



Figure 7. Volunteers and family members using a grain vacuum to clear corn around the bin.

- There were multiple (in this case, four) emergency response agencies at the scene.
- In excess of 50 first responders were involved in the rescue attempt.
- A large number of volunteers were present to assist with the rescue and clean up.
- The victim was found on the floor over the opened outlet.

Several months after this incident, a grain entrapment rescue training event was held involving approximately 75 first responders, many of whom were at the scene; one of the victim's sons was also in attendance. A presentation was made on the technical aspects of FAM entrapment and state-of-the-art rescue strategies, including dem-

onstration of a grain entrapment rescue tube (GERT). Considerable discussion took place regarding the potential risks of cutting open a grain storage structure, the problems associated with threatening the structural integrity of larger storage units, the hazards of employing large-capacity grain vacuum units, and other hazards to first responders. None of the attendees identified any secondary injuries resulting from the rescue attempt, but a few mentioned subsequent respiratory distresses due to dust inhalation. (There was a substantial amount of moldy corn associated with this incident.) One issue raised was the role of the incident command system (ICS) and how conflicts in proposed strategies were managed. Even though the ICS is officially in place as part of the National Response Framework, it has not been fully implemented at the local level nationwide due to jurisdictional issues and personality differences between the leadership of the different agencies.

Summary

Review of the 686 cases of flowable agricultural material (FAM) entrapment documented in the Purdue University Agricultural Entrapment Database (PUAED) indicates that entrapments and engulfments in FAM continue to take place and, in fact, are increasing in number. It is clear that these incidents are complex and require specialized skills on the part of first responders, trained or untrained. Specifically, the study's findings can be summarized as follows:

- From 1964 to 2006, an average of 16 entrapments has been documented per year, with that average having increased to 22 between 1996 and 2006. Two-thirds (67%) of the documented entrapments in FAM occurred on farms, and 74% of the reported cases resulted in death of the entrapped victim.
- The majority of documented rescues from FAM are completed by untrained first responders who are employed at the site or are neighbors who are called to the scene. Of these rescuers, 14 sustained injuries or became secondary (entrapment) victims, including six who died at the scene.
- Based on frequency of techniques used during rescue attempts, the findings suggest that the method perceived to be most effective to extricate a victim from a grain mass was removing the grain from around the victim by cutting or punching holes in the side of the grain storage structure. This method was documented in 56% of the 196 cases where the rescue technique used was known. The second most frequently applied technique is constructing a grain retaining wall (GRW) around a partially entrapped victim and removing the grain from inside it, thereby freeing the victim. This method was used in 19% of those 196 cases.
- Availability and utilization of powerful portable grain vacuum machines in documented rescue attempts is on the increase and provides a previously unavailable resource for first responders. However, potential risks with this equipment were identified.
- The lack of more comprehensive rescue data continues to be a limiting factor in the development of more effective and safe rescue strategies. Specifically, the role of grain rescue tubes and their efficacy, the contribution provided by aeration fans to the potential of a successful rescue, and the potential structural threats associated with breaching large-capacity grain storage structures to

expedite removal of grain in order to access and extricate a victim entrapped in the grain need to be studied further.

- The role that high-angle rescue teams can play in successfully extricating partially entrapped victims is not well understood since their use has been limited. However, due to the height of some of the structures involved, the need for high-angle rescue skills is apparent.
- The risks to first responders have not been well defined and need to be addressed to reduce the potential of secondary entrapment and injury.
- Training conducted to enhance the efficiency of first responders to FAM entrapment can present a variety of hazards to participants, including partial, unintentional entrapment and exposure to toxic dust.

Conclusion

Much remains unknown concerning the approaches to successfully rescue victims of FAM entrapments. There are too many gaps within the current PUAED to clearly ascertain the most effective rescue strategy (or strategies) due to the diversity of the entrapment cases documented. In other words, it is unlikely that there is just one way to carry out an effective FAM-related rescue. It is believed that both preventative and rescue measures could be enhanced as a result of continued data collection and analysis, especially from the completion of onsite investigations at actual FAM entrapment locations.

This study's findings, including feedback from first responders, suggest that there is increasing polarization between those advocating preventative measures to reduce the frequency and severity of FAM entrapment and those focusing on disseminating information on possible rescue strategies. Based upon the fundamentals of injury and illness prevention, it is recommended that greater investment be made in developing engineering design standards and safer work practices that reduce the likelihood of worker exposure to FAM. This position does not intend to diminish the need to develop, test, and implement new FAM rescue strategies, but the priority for expending limited resources should be on prevention of such incidents.

The need exists for additional research on the design of grain storage and handling facilities that accommodates current confined-space rescue practices. This includes incorporating access points that allow entry by first responders equipped with self-contained breathing apparatus (SCBA) and appropriate anchor points that meet current confined-space entry standards.

Designers and manufacturers of grain storage structures should conduct studies to aid in predicting the consequences associated with rapid removal of grain that would occur if those structures are breeched during FAM rescue operations. The potential for multiple victims due to catastrophic failure of a grain storage structure should be considered. Warnings concerning potential structural failure if breeched should be posted on the structure itself and included in the operator's instructions. In addition, recommendations for extrication from FAM should be included in operator instructions along with safety and health information.

Current curricula being used to train first responders for FAM incidents need to be reviewed to ensure that participants are not placed in unnecessarily hazardous situations, especially where an entrapment could occur. Training exercises should involve

the appointment of a safety officer to monitor for unsafe conditions and ensure the use of appropriate personal protective equipment and accepted first response procedures.

Lastly, a consensus standard or practice regarding FAM rescue should be developed and incorporated into emergency first responder training curricula. Such a standard or practice should lead to fewer conflicts at the sites of FAM entrapments as to the most effective strategy to employ under specific situations. The standard should be flexible to reflect the diversity of FAM incidents that have been identified, address issues such as the nature and characteristics of FAM, rapid grain removal procedures, location of potential anchor points, risk of toxic atmospheres, use of portable grain vacuum units and their potential risks, role of grain entrapment rescue tubes (GERTs), and identify other response and recovery related hazards to first responders.

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