Evaluation of Plastic Grain Engulfment Rescue Device

Douglas M. Kingman and Joe E. Muller
Agricultural Mechanization Department of Agriculture Sciences
Sam Houston State University, Huntsville, TX 77341-2088
Email: dougkingman@shsu.edu

Kara N. Nelson, Graduate Student and Research Assistant
Department of Agriculture, Illinois State University, Normal, Illinois

Abstract: Full and partial engulfment incidents in free-flowing grain and other loose materials continue to occur and are documented each year in newspapers, university and federal safety literature, and by other surveillance activities. Although a grain rescue tube design made from stainless steel has existed since the 1980s, it was determined that it was not suitable for use in all or most partial engulfment situations. Specifically, the major components of the tube were not able to be passed through small openings typically associated with on-farm grain bins and even some commercial storage facilities. During rescue demonstration activities at such facilities, it was learned that the tube weighed in excess of 180 pounds and was difficult to insert into a grain mass. In order to address the rescue of a partially engulfed individual, a rescue tube made from PVC plastic pipe was constructed and evaluated in a bin of shelled corn. It was concluded that the plastic tube had some features that were beneficial. The sliding tube sections allowed easy insertion into the grain, lightweight components facilitated handling and lifting, and tube sections fit easily through small openings associated with on-farm storage structures. Recommendations suggested that further development and testing is warranted. Additional work should explore the use of tube sections made from ultra high molecular weight (UHMW) plastic and inserting the tube sections in other bulk materials such as sand, granular fertilizer, salt, and rock.

Intended Audience: This publication is intended for those individuals conducting research in the area of agricultural mechanization and for other working as agricultural safety specialists.
**Introduction**

Full and partial engulfment incidents in free-flowing grain and other loose materials continue to occur and are documented each year in newspapers, university and federal safety literature, and by other surveillance activities. The rescue of an individual that is engulfed in grain is difficult, and sometimes results in the death of the victim, rescue workers, and bystanders (Freeman et al., 1998). A review of the available rescue equipment for use during the extrication of a partially-engulfed individual resulted in identifying only two devices.

Although a grain rescue tube design has existed since the 1980s, it was determined that it was not suitable for use in all or most partial engulfment situations. Specifically, the major components of the tube were not able to be passed through small openings typically associated with on-farm grain bins and even some commercial storage facilities. During informal demonstration activities at such facilities, it was learned that the tube weighed in excess of 180 pounds and was difficult to insert into a grain mass.

In order to more adequately address the rescue of a partially engulfed individual, a rescue tube was constructed from plastic. Evaluation of the device was necessary in order to determine if the further testing and development was necessary. The evaluation measures were developed from a list of design criteria reported by Carpenter and Bean (1992) who constructed and tested a somewhat similar rescue tube.

**Review of Literature**

Since 1978, Purdue University has maintained a national database of agriculture-related engulfment cases that have occurred in loose agricultural materials in both commercial and on-farm facilities (Kingman, 2005). The database presently contains over 500 documented cases of fatal and non-fatal engulfments in the U.S. and Canada. A study of cases that occurred between 1966 and 1999 revealed that approximately five individuals per year in the U.S. and Canada suffocated in on-farm metal grain bins due to engulfment in grain (Kingman et al., 2001).

A follow-up study was conducted by collaborating researchers at Illinois State University and Purdue University that reviewed more recent cases that occurred from 1980 through 2001. Results from the study of the more recent cases indicated that the average number of deaths was approximately eight per year and that the engulfment problem was continuing (Kingman and Field, 2003). Although these summaries are the only known studies that focus solely on on-farm and commercial engulfments, other universities publish yearly summaries of agricultural related fatalities that include engulfments. State of Illinois and Iowa Cooperative Extension websites have noted deaths from asphyxiation as a result of engulfment for years 2005 and 2006 (Illinois Fact Sheet, 2006 and Iowa Farm Safety Publications, 2006). Engulfment reports can also be found in newspaper articles and industry websites. In November, 2006, two individuals died in separate incidents as a result of being engulfed in grain. (GEAPS, 2006 and Vardon, 2006). Both victims were fully or partially immersed in grain and suffocated.
Schwab et al., (1985) examined the vertical pull applied to a subject during the static and dynamic engulfment of a mannequin in shelled corn and wheat. The study determined that a partially engulfed individual can not be safely pulled from the grain, but must be removed only after grain around the victim is taken away. The National Institute of Occupational Safety and Health (NIOSH) has also collected data on engulfment incidents. NIOSH (1994) reported that from 1980 through 1989, 227 deaths occurred in confined spaces as the result of mechanical asphyxiation by engulfment in loose materials. The materials included several agricultural and non-agricultural products (Figure 1).

![Image of pie chart showing the distribution of engulfment fatalities]

**Figure 1: Loose materials involved in engulfment fatalities as reported by NIOSH from 1980 through 1989.**

NIOSH (1994) also reported findings from Fatality Assessment and Control Evaluation (FACE) investigations of fatal occupational injury incidents. FACE investigations were conducted in order to gather detailed information on contributing factors. One hundred and nine of the 423 incidents investigated by FACE in the years of 1983 through 1993 involved individuals who died in confined spaces. Seven of those incidents occurred in a bin or silo. Table 1 indicates the findings of the FACE investigations related to the reasons for entry into the confined space. Of the seven incidents that occurred in a bin or silo, it was found that five of the victims entered the bin in order to dislodge material.

Table 1: FACE Reported Confined Space Type and Reason for Entry

<table>
<thead>
<tr>
<th>Type</th>
<th>Const.</th>
<th>Insp.</th>
<th>Repair/ Maint.</th>
<th>Rescue</th>
<th>Retrieve Object</th>
<th>Dislodge Material</th>
<th>Unknown</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank</td>
<td>0</td>
<td>5</td>
<td>14</td>
<td>11</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>Pipeline/Tunnel</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Tanker Truck</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Utility Vault</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Vat/Pit Digester</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>14</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>Silo/Bin</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Sewer Manhole</td>
<td>4</td>
<td>3</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>27</td>
</tr>
<tr>
<td>Well</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>11</td>
<td>44</td>
<td>39</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>109</td>
</tr>
<tr>
<td>(% of Total)</td>
<td>4.6</td>
<td>10.1</td>
<td>40.4</td>
<td>35.8</td>
<td>3.6</td>
<td>4.6</td>
<td>0.9</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Freeman et al., (1998) completed a summary of 71 fatal and non-fatal engulfment cases that occurred in loose agricultural material at commercial grain storage, handling, and processing facilities. They reported that 92% of victims that became fully engulfed by loose agricultural material did not survive. The survival of a partially engulfed victim was not always guaranteed. It was found that incidents that involved a partially engulfed victim at the time the rescue began resulted in at least one fatality in 80% of the cases. The reported survival rate for employees working alone was 6% (1 out of 16) and that when two or more workers were present, the survival increased to 36% (11 out of 30). The work of Freeman et al., (1998) contributed to the development of the safety education material, “Don't Go with the Flow”, designed specifically for commercial grain handlers and emergency personnel (NGFA, 1998).

Kingman et al., (2001) conducted a study to summarize on-farm engulfment incidents and to develop strategies that would contribute to the prevention of fatalities and injuries that occurred in on-farm grain bins due to flowing grain engulfment cases. Summarizing the cases, Kingman et al., (2001) reported that 181 engulfment fatalities were documented in on-farm grain bins from 1964 through 1998 in the U.S. and Canada. They also reported that there was evidence to suggest that non-fatal engulfment incidents also regularly occurred and were not being reported or identified by existing surveillance efforts.

Kingman (1999) reported that a commercial grain handling company (Anderson’s Grain Company) and a high school agricultural class had constructed a total of six prototype rescue tubes made of stainless steel for use at commercial facilities. The Prototype Grain Rescue Tube
(Figure 2) was first described in literature by Carpenter and Bean (1992). The tube had three sides that when connected, formed a cylinder shape. Other features of the tube included:

1. Outside handles for carrying and providing an impact point during insertion
2. Air hose attachment for air mask inside of tube
3. Attachable lid to prevent re-entry of grain in case of avalanche
4. Inside handles to allow victim to climb out of the tube
5. Quick connect clips for assembling sides and lid

Figure 2. Prototype Stainless Steel Rescue Tube, Andersons Grain, Inc.

Carpenter and Bean (1992) reported a list of design criteria that was used to guide the development of the stainless steel rescue device. The criteria included:

1. Unit that can be easily and rapidly assembled and inserted into the grain mass while surrounding the victim
2. Strong and rigid unit which can withstand pressures exerted by the grain mass and from impact forces resulting from forced insertion (hammering)
3. Modular, lightweight and portable device that can pass through grain bin entryways
Although the stainless steel device was build, Kingman (1999) reported that there were no he could find no documented cases of this rescue tube being used during actual rescue attempts. A comprehensive study of the device, documenting its efficacy or its applicability with farm-sized grain bins was not available. Kingman (1999) reported that a farmer in Indiana was partially engulfed in a 40,000 bushel capacity bin of shelled corn with only his head and hands above the grain. A local volunteer fire department used a portion of a hog feeder to temporarily protect the victim from being completely covered in grain prior to extrication (Figure 3). The farmer was eventually extricated by the Indianapolis Fire Department who constructed a cofferdam around the victim. The materials included plywood, cut 15 inches by 30 inches and 6-foot T-posts. The T-posts were driven into the grain in order to support the plywood walls of the cofferdam.

Figure 3. Portion of Hog Feeder Used to Protect Victim

Several homemade devices have been utilized by farmers, rescue workers, and individuals involved in farm safety activities. One such device was made from a 55 gallon metal barrel that was in three parts, and held together by hinges. The hinges were welded to the barrel but allowed the device to be folded together for storage.

Case Study of Engulfment Incident
The observations reported in the following case study are the result of a previous effort to conduct investigations of actual engulfment incidents. Kingman (2002) visited eight farms in the Midwest where fatal and non-fatal engulfments had occurred. This case is a representative incident that demonstrates how an engulfment could occur. Like most incidents investigated, it

was determined that no specific cofferdam materials were utilized to assist in the recovery of the victim. In order to maintain victim and interviewee anonymity, personal information, incident location, and the date of incident has been omitted.

The victim, a 57-year-old grain farmer, was attempting to restore flow in his 15,000-bushel bin of shelled corn when he became fully engulfed and died. Three days prior to the incident, a bird nest of intertwined twigs and vines fell from inside the bin roof onto the surface of the grain during the initial unloading of the bin. The nest became lodged in the unloading auger inlet and prevented the flow of corn from the bin.

Over a three-day period, several attempts were made to remove or break up the nest. A farmhand, who had worked for the farm operator (victim) for over 14 years, assisted in the effort to unclog the bin. The victim stood inside the bin while the farmhand stood outside, adjacent to the ladder, operating the unloading auger controls (Figure 4). On occasion, the individual working inside the bin would become tired from running the pole up and down in the grain and would exchange places with the person outside the bin. The person inside the bin was using a long metal pipe with a hook on the end of it in an attempt to snatch the nest to remove it or pulverize it so it would flow out of the bin.

![Figure 4. Position and Activities of Victim and Farmhand Prior to Engulfment (Kingman, 2002)](image-url)
After several attempts to remove the nest, which involved moving the pole up and down in the grain, the inside man would shout to the auger operator to “bump the switch.” This meant that the auger was momentarily switched on and then off to see if flow had been re-established. The farm operator, who was in the bin at the time, instructed the farmhand to switch the unloading auger on and leave it on until instructed to switch it off. At that time, the victim’s wife appeared at the bin asking for the victim to see if he could take a telephone call. The farmhand indicated that the victim was in the bin and the wife immediately switched the unloading auger off. After yelling for the victim and receiving no reply, she and the farmhand ascended the ladder and entered the bin.

The wife found the victim’s glasses and baseball-style cap laying on the surface of the grain, near the center depression. She reached down into the grain and touched his head and hand, both of which were trembling. Rescue personnel were immediately summoned and within 45 minutes, after cutting holes into the sides of the bin and removing the main door so the corn could be removed, the victim’s body was recovered. The cause of death was asphyxiation.

The victim was reported to be well aware of the dangers of flowing grain. He had been a rural volunteer fire fighter and rescue worker for over 35 years. During his service, he had even responded to a fatal engulfment that had occurred 15 years prior to his own death. There was no evidence of out-of-condition grain on the day of the incident. The process used to unplug the bin placed both the farm operator and farmhand at risk of engulfment. Either one could have been the victim.

The dilemma of nests clogging the auger in the victim’s bin was a recurring problem. In fact, it is common for a pole to be fitted with a hook to assist in safely removing materials or items that occasionally block the flow of grain. On prior occasions, the victim and the farmhand had been able to grasp a nest with the hook and pull it from the auger opening. On the day of the engulfment, the farmhand recalled that the victim was significantly irritated with the situation and that he insisted on removing a nest before lunch.

**Evaluation of PVC Grain Rescue Tube Device**
A plastic PVC grain rescue device was constructed and tested using a mock victim that was partially engulfed in a farm grain bin. The development and testing of the device was initiated in order to determine if it could be used to facilitate a safe and rapid extrication of a victim. The plastic tube was somewhat modeled after the Prototype Grain Rescue Tube, introduced by Carpenter and Bean (1992). Using Carpenter and Bean’s (1992) design criteria as a guideline, a list of observable criteria were developed and used for the evaluation process. The list included:

1. Tube parts fit through 18 inch diameter passages and typical grain bin entryways
2. Rapid insertion into grain
3. Simple and easy to build
4. Large enough to surround entrapped individual
5. Withstand impact forces during handling and insertion
6. Light weight and portable
7. Relieve pressure on victim that is exerted by the grain mass
8. Rigid unit capable of withstanding pressure from grain mass

**Construction Materials for the Plastic Rescue Tube**
The plastic pipe tube was constructed out of a 15 inch diameter schedule 40 poly vinyl chloride (SCH 40 PVC) pipe. The 40 inch-long pipe was cut in half and a sliding coupling system was installed to allow the halves to be connected, but inserted into the grain mass independently. The coupling system consisted of attaching SCH 40 PVC tee fittings to the edge of a long end of the tube section while 0.5 inch diameter SCH 40 PVC pipe was connected to the other edge.

**Testing: Rescue of a Mock Engagement Victim**
The plastic rescue tube was tested in a bin of shelled corn with several observers and researchers present. The testing exercise was begun after a volunteer was partially engulfed (Figure 5). After the halves were easily passed through the roof entryway, the tube was assembled and placed over the volunteer (Figure 6). Using a small sledge hammer, the tube halves were easily driven down into the shelled corn (Figure 7).

![Figure 5. Partially engulfed mock victim](image)
Once the tube was fully inserted, a few handfuls of grain were removed from within the tube. This allowed the volunteer to begin to pull his legs and feet upward through the grain. The mock victim was free from the grain approximately ten minutes after the tube was lowered into the bin, assembled and then inserted (Figure 8). The plastic tube was inadvertently dropped from the roof of the bin, and crashed onto the hard ground surface. It is unknown if the damage was solely due to the fall and subsequent impact, or if the repeated blows from the sledge hammer reduced the integrity of the plastic fibers.
Onsite Feedback and Observations
Besides the research staff, additional individuals that attended the testing event included a farmer, volunteer rescue workers, and a grain storage manager that had previous experience observing rescue workers attempting mock rescues with the stainless steel tube reported by Carpenter and Bean (1992). Feedback from these individuals was summarized in Table 2. Based on their observations, it appears that there were notable advantages and disadvantages of the plastic pipe tube.

Table 2. Feedback from Individuals Present at Testing of Plastic Tube.

<table>
<thead>
<tr>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid sidewall</td>
</tr>
<tr>
<td>Multiple sections allowed easy insertion into grain mass</td>
</tr>
<tr>
<td>Constructed from common, readily available materials</td>
</tr>
<tr>
<td>Light weight, facilitating ease of transport and hoisting</td>
</tr>
<tr>
<td>Sections fit easily through small bin entryways</td>
</tr>
<tr>
<td>Simple to use concept</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube section shattered when dropped from bin roof to ground</td>
</tr>
<tr>
<td>Gap between coupling and tube section wall allowed some inflow of grain</td>
</tr>
<tr>
<td>Difficult to remove from grain mass after rescue</td>
</tr>
<tr>
<td>Tube diameter, when assembled, too small to accommodate larger-sized victims</td>
</tr>
</tbody>
</table>

Evaluation Using Design Criteria
After the completion of the testing activities and review of the onsite observations, research staff compared the observed results with the previously formulated design criteria. Table 3 lists each criterion with an indication of whether or not the plastic tube design and performance was adequate or inadequate. It was found that the tube met or exceeded the expectations of the criteria, except in two areas. Although the tube was found to be easily and quickly assembled and inserted into the grain mass, it was determined that the assembled tube diameter was probably too small to accommodate larger victims. An additional inadequacy of the tube was its ability to withstand the forces from the impact of the sledgehammer and the inadvertent fall from the top of the grain bin.

The lightweight tube sections were easily raised and lowered up and down the grain bin and passed without difficulty through the grain bin entryways. The rigid walls of the tube sections were able to withstand the pressures from the grain and relieved the pressure that had been previously exerted on the victim.
The stainless steel tube introduced by Carpenter and Bean (1992) exhibited several features that might be useful during the extrication of a victim. A comparison of the features of the stainless steel tube verses the plastic tube highlights some differences and similarities of the tubes. One key difference is that the plastic tube has a coupling system that interlocks each tube section, but allows the tube sections to be inserted independently. A second key difference is the lack of a strengthened impact point for the plastic tube. A third difference is the material that each tube section is constructed from. It appeared that the lightweight plastic tube would facilitate portability issues as lifting and lowering the tube up and down the sides of a tall (excess of 50 feet) grain storage structure and allow easy handling of the sections from one rescuer to another. A fourth difference is the small diameter of the assembled plastic tube that would limit the accommodation of a large victim or victims in a non-vertical orientation. Other differences seem less important at the time of testing, but an open mind should be maintained for future development.

Table 3. Plastic Tube Design Criteria and Functionality

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Meet or Exceed</th>
<th>Inadequate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube parts fit through 18 inch diameter passages and typical grain bin entryways</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Rapid insertion into grain</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Simple and easy to build</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Large enough to surround entrapped individual</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Withstand impact forces during handling and insertion</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Light weight and portable</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Relieve pressure on victim that is exerted by the grain mass</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Rigid unit capable of withstanding pressure from grain mass</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 4. Comparison of Features: Stainless Steel Tube vs. Plastic Tube

<table>
<thead>
<tr>
<th>Feature</th>
<th>Stainless Steel Tube</th>
<th>Plastic PVC Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside handles</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Specific impact location</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Lid</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Air hose connection</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Inside handles</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Quick connect clips</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Sliding tube sections</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Forms cylinder shape</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Material</td>
<td>Stainless Steel</td>
<td>Poly Vinyl Chloride Plastic</td>
</tr>
<tr>
<td>Weight</td>
<td>180 lbs. (82 kg.)</td>
<td>25 lbs. (11 kg.)</td>
</tr>
<tr>
<td>Diameter when assembled</td>
<td>48 in. (122 cm.)</td>
<td>20 in. (51 cm.)</td>
</tr>
</tbody>
</table>
Conclusions:
Occupational Safety and Health Administration (OSHA) inspectors are more closely scrutinizing
country elevators and farms employing an annual average of 11 or more employees. These types
of grain handling and storage operations, although formerly overlooked by OSHA
representatives, are required to develop confined space entry and rescue procedures as part of an
overall safety plan (U.S. DOL, 1979). Within the rescue procedures, adequate rescue equipment
for extricating partially engulfed victims must be identified. Although a major grain handling
company has developed a containment system or rescue tube for use in large grain tanks to
attempt to meet these requirements (Carpenter and Bean, 1992), the rescue tubes have not been
found to be compatible with farm-sized bins (Kingman, 1999).

The potential for a successful rescue of a victim that is partially entrapped in loose grain in a
confined space, such as a farm grain bin or hopper, is reduced by the fact that a proven functional
cofferdam or rescue tube, is not presently available to rescue responders. Rescue workers
attempting to extricate victims that are engulfed in grain in both on-farm and commercial
applications have utilized a variety of rescue techniques including the fabrication of temporary
cofferdams constructed from available materials like plywood, plastic trashcans, and steel drums
(NRAES, 1999). None of these techniques have been adequately tested and some have the
potential of putting rescuers at risk of injury or engulfment. A tested rescue device that could
serve as a temporary cofferdam is needed to improve the efficiency of the rescue process, reduce
the number of partially engulfed victims who end up suffocating due to the inability of rescuers
to carry out extrication in a timely manner, and help grain handling operations meet OSHA
requirements.

The plastic tube testing activities demonstrated the potential that a device such as this could be
used to facilitate the rescue of a partially engulfed individual. The test and evaluation showed
that rigid, independent, sliding tube sections could easily be inserted into the grain mass. It was
evident that the plastic tube sections resisted the force exerted by the grain, while relieving the
pressure on the victim. The lightweight construction materials allowed ease of handling, but
were not tough enough to withstand impacts from the insertion or handling. The plastic tube,
with only two sections, was too small to fully surround victims involved with previous incidents.
The simple design allowed the tube to be easily constructed. The lack of handles made gripping
the tube sections difficult. Finally, even though the mock victim was able to escape, the gap
where the half-tube sections joined allowed some inflow of grain.

Recommendations
As a result of testing the plastic tube, evaluating the observations, and reviewing the literature,
the authors make the following recommendations:

- Make onsite visits to facilities where successful rescues have occurred
- Interview survivors of partial engulfment cases
• Conduct further study of a design similar to plastic pipe tube. Specifically the following items should be investigated:
  o Explore/test other materials for tube sections such as ultra high molecular weight (UHMW) polyethylene to improve durability
  o Further develop coupling system to increase durability
  o Decrease gap associated with coupling system in order to prevent inflow of grain
  o Add tube sections to increase overall diameter, accommodating larger victims
  o Design impact point
  o Explore the use of a special tool or driver for inserting tube sections
  o Add handles to facilitate carrying, transport, and removal of tube sections from grain
  o Consider bright colors for easier observation in dusty or dark conditions

Acknowledgements:
The authors would like to thank the Purdue University Safety and Health Research staff for their commitment to maintain a database of engulfment incidents and the Purdue University Agronomy Research Farm for the use of Grain Bin #7 and its contents. Additionally, we are appreciative of the assistance from Stoller Farms in Michigan and Indiana.

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