



Online Ethics Center
FOR ENGINEERING AND SCIENCE

Anhydrous Ammonia Hose Failure

XYZ Hose Company And The Case Of The Bursting Hose

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Description

An overview of the Anhydrous Ammonia Hose Failure case study maintained by the Texas A&M University.

Abstract

Since 1940, anhydrous ammonia has been used by farmers in the spring and early fall as a nitrogen fertilizer. Farmers typically rent the equipment necessary from the area farmer's cooperative.

The nationally-respected hose maker, XYZ Hose Company, supplied many of the hoses that were purchased by the cooperatives and used for the nitrogen fertilizer application. In 1977, the company decided to switch from their rayon-reinforced hoses to a newly introduced material AAH #1 allowing them to undercut their competitors who were using stainless steel. Unfortunately, even though the hose was tested and met all the current industry standards, something went wrong with the XYZ AAH #1-reinforced anhydrous ammonia hose. The consequences for several of the product's end users proved to be quite devastating. In one case, the hose burst leaving a Kansas farmer legally blind and incapable of earning a living. He was forced to give up farming, the only occupation and life he had ever known.

The case examines two important issues that engineering students will undoubtedly face as they enter their chosen profession; (1) Engineering and corporate

responsibility to the public for failed innovation; and (2) the challenging of responsible risk assessment, product testing, and follow-up for innovative designs that do not fall within present industry standards.

Body

Instructor's Guide

XYZ Hose Company And The Case Of The Bursting Hose
Risk Assessment And Engineering/Corporate Responsibility To The Public

Introduction To The Case

In light of increasing public pressure for engineering accountability, the following case examines two important issues students will undoubtedly face as they enter the engineering profession: engineering and corporate responsibility to the public for failed innovation. An associated issue is the challenges of responsible risk assessment and product testing and follow-up for innovative designs that do not fall within present industry standards. As such, this is a suitable case study for incorporation in design, materials and systems curricula. It is particularly effective in an agricultural engineering seminar.

The XYZ Hose Company case is based on real-world experience; however, due to pending litigation on several claims, the company name is fictitious, as are the names of the key players and the product names.

Since the 1940's, anhydrous ammonia has been used by farmers in the spring and early fall as a nitrogen fertilizer. Due to the toxicity of the ammonia vapors expelled to the atmosphere when the material is "knifed" into the soil with steel knives, those working with anhydrous ammonia must use extreme caution.

Farmers do not typically own equipment used for this crop fertilizing process; instead, they rent a tractor and tank (a "nurse tank" filled with anhydrous ammonia) from their area's farmers' cooperative. Farmers' cooperatives throughout the country stock hoses and equip the anhydrous ammonia nurse tanks for use by the farmers. These cooperatives typically buy the anhydrous ammonia hoses directly from the manufacturer, in this case the XYZ Hose Company.

There are three elements associated with the manufacture of a hose: the tube, braid and cover. The tube is the innermost part of a hose, where liquids or gases are contained. Over the inner tube, two or possibly three braids of yarn or wire are wound to give strength to the hose. The outer-most element is then used as the bonding material. It is typically made of rubber; however, it may also be made from other materials. These three elements of the hose are processed so that they act as one unit.

Although most manufacturers of anhydrous ammonia hose used nylon or polyester as the reinforcing material in the 1960's, rubber manufacturing industry guidelines as set out by the Rubber Manufacturers Association (RMA) and The Fertilizer Institute's (TFI) recommended using stainless steel wire mesh for the braids. Stainless steel is the most dependable and robust braiding material; however, it is also the most expensive. Because nylon and polyester were less expensive and were approved earlier as safe in use by both RMA and TFI, most manufacturers continued using reinforcing materials other than stainless steel. By the end of the 1960's, however, nylon and polyester hose products appeared to be less and less effective. Anhydrous ammonia causes deterioration of any material(including stainless steel) over time, and the nylon and polyester products were starting to lose strength, often leading to minor accidents in the field. As a result, by the end of the 1960's, many manufacturers switched to stainless steel wire mesh as the reinforcing material, despite the added expense.

At the same time, the plastics division of a leading chemical company introduced a product called "AAH #1," an experimental yarn for use as a reinforcing material. In addition to favorable application with fenders, bumpers, tires and bullet-proof vests, AAH #1 yarn appeared particularly well-suited for use with hose products.

In 1974, a professor of agricultural engineering at a prominent state university presented results of a study¹ that attempted to determine the effects ammonia had

on the strength of various reinforcing yarns, including the experimental yarn AAH #1. The professor found that the experimental yarn "... is not materially affected by the low concentration NH₄OH vapor, but strength of the yarn is reduced over time to 46 percent of its original strength by the vapor from anhydrous ammonia."² In other words, rapid hose deterioration was deemed probable using AAH #1 as the reinforcing material. While the professor noted that his study findings were inconclusive, and thus he could not absolutely recommend eliminating AAH #1 as a reinforcing yarn, he did say that those using AAH #1 should over-design their hoses to compensate for diminished strength, and further that they should carefully monitor their hoses in use.

In 1977, a nationally-respected, family-owned firm, the XYZ Hose Company, decided to switch from their rayon-reinforced hoses to AAH #1. XYZ company representatives ran tests and decided that AAH #1 would prove more robust in the field than the less expensive nylon and polyester products. Switching to AAH #1 made sound business sense, because although more expensive than products previously used, AAH #1 allowed them to undercut their competitors who used stainless steel.

Until the introduction of XYZ's inexpensive AAH #1 hose in 1977, farmers' cooperatives characteristically used hoses reinforced with stainless steel. Thus, purchasing a cheaper hose, made of less expensive material, would obviously mean considerable cost savings for all involved: manufacturer, farmers' cooperative, and farmers.

Unfortunately, even though XYZ's AAH #1 hose was tested (at both XYZ and an independent testing laboratory) and met all the current industry standards, something went wrong with the XYZ AAH #1-reinforced anhydrous ammonia hose in use, resulting in devastating consequences for several of the product's end users. In one reported case, the AAH #1 hose burst while a Kansas farmer, Bob Smith, was setting up the equipment for knifing the anhydrous ammonia product into his fields. When the XYZ AAH #1 hose burst, releasing the toxic ammonia into the air, the force of the discharge blew Smith's protective goggles off his face. Smith is now legally blind, and has sustained lifetime disfigurement as a consequence of severe burns received. His physical disabilities have made him dependent on others, and he is now incapable of making a living as a farmer the only occupation he has ever known.

As a result of this and other calamitous incidents involving AAH #1 ruptures, XYZ as a corporation reacted in several important ways.

1) In 1983 XYZ discontinued manufacturing the anhydrous ammonia hose, as well as all other high-pressure ammonia hoses, because they believed there was no way the product could be designed to be completely fail safe against abuse of the hose in the field.

2) From 1987 to the present, XYZ and the responsible farmers' cooperatives, have made out-of-court settlements with those end users adversely affected by the AAH #1 hose. In depositional testimony, XYZ representatives contend that their hoses were not so much dangerous as misused/abused; yet, they settled out of court because they believed they had a corporate responsibility to the end user despite possible misuse of the AAH #1 product.

3) In 1988 XYZ placed advertisements in a Farmers' Cooperative Magazine, warning that their product was outdated (note, outdated versus dangerous) and should be returned for an immediate buy-back offer (and note, buy-back versus recall). In his depositional testimony, however, Smith asserted that XYZ manufactured and marketed a dangerous product, that neither XYZ nor the farmers' cooperatives adequately warned the end users of the dangers associated with the AAH #1 hose, and that XYZ did not monitor the product in use. These claims, contrary to XYZ's, raise important ethical issues that surround innovation. These include questions about how engineers and corporations should assess risk and, what the professional engineering and corporate responsibilities to the public are.

Guidelines For Presentation

1) Read student handout for a detailed description of the case.

2) At the class preceding the case discussion, distribute student handouts: XYZ Hose Company and the Case of the Bursting Hose, which includes a brief literature review on risk and the engineering decision-making process and an annotated bibliography. Let students know that, of legal necessity, XYZ is a hypothetical case, but that it is based on a real-world experience.

Have students come to the follow-up discussion class prepared to address the XYZ case in the light of the ethical issues raised in the student handout.

3) Discuss overheads depicting the XYZ Cast of Characters, Chronology of the AAH #1 Anhydrous Ammonia Hose, and XYZ Buy-Back Offer. Ask students some of the following questions:

- What are the ethical dilemmas engineers face when innovative design goes beyond current industry standards and specifications?
- What are the engineering/corporate responsibilities to the public when innovation fails?
- Did XYZ do the right things, at the right times? Did those involved in the case ask the right questions during the innovation process, and did they ask the right people at the right time? Why or why not? What entities should have been responsible for the various aspects of market penetration and product safety: XYZ design engineers, managers, and production and marketing personnel? Engineers at the independent test labs? Professional Engineering Societies? Those involved in writing the Rubber Manufacturers Association codes? Farmers' Cooperatives? Farmers?
- Should XYZ have labeled their hoses with more explicit warnings? Would it have made any difference? × After withdrawing the product from the market, did XYZ's advertisement in the Farmers' Cooperative Magazine suffice? Could the company have done more? If so, what? When does their responsibility end and the farmers' cooperative's and farmers' begin?
- Did XYZ act responsibly (or ethically) when arguing against the plaintiffs or other defendants (i.e., the farmers' cooperatives) involved in legal proceedings against them? Should XYZ have been sued at all?
- Who is culpable for the damages the XYZ product inflicted on the end users (i.e., the farmers)? The chemical company that introduced AAH #1? XYZ and/or its engineers? The independent testing laboratories? The owners of the cooperatives supplying farmers with anhydrous ammonia hoses? The farmers? Why?

4) End the discussion with XYZ Hose Company: Ethical Issues of the Case. Discuss the ethical questions raised by the case: What happens when professional codes and regulations lag behind technological innovations? What precautions must engineers take when trying to balance the benefits new technologies bring with

risks to public safety often associated with engineering social experimentation?
What are engineering and corporate responsibilities to the public for failed innovation?

Essays #1 through #4 appended at the end of the case listings in this report will have relevant background information for the instructor preparing to lead classroom discussion. Their titles are, respectively: "Ethics and Professionalism in Engineering; Why the Interest in Engineering Ethics;" "Basic Concepts and Methods in Ethics;" "Moral Concepts and Theories;" and "Engineering Design: Literature on Social Responsibility Versus Legal Liability."

Notes

1. Mayeux, Mansel M. "The Effect of Ammonia On the Tensile Strength of Selected Yarns," in Transactions of the American Society of Agricultural Engineers (ASAE), Vol. 17, No. 6, 1974, pp. 1088-90, 1093.

2. Mayeux, p. 1090. XYZ Hose Company Overheads 1) XYZ Cast Of Characters 2) Chronology of the AAH #1 Anhydrous Ammonia Hose (2 pages)

Chronology Of The XYZ AAH #1 Anhydrous Ammonia Hose

1940's - Ten leading rubber hose manufacturers market anhydrous

1960's: Ammonia hoses, using reinforcing materials such as nylon, polyester and stainless steel, as set out by the Rubber Manufacturers Association (RMA) and The Fertilizer Institute (TFI) industry standards manuals.

1960's: A major chemical company introduces AAH #1, an experimental yarn for use as a reinforcing material (used as a reinforcing material for automobile tires, fenders and bumpers, bullet-proof vests, and other consumer products with great success).

1974: Professor of agricultural engineering at a major state university conducts a study on the effect of ammonia on the tensile strength of selected yarns, including AAH #1. The study shows that AAH #1 has a high probability of deterioration over time when it interacts with the vapor from anhydrous ammonia.

1977: XYZ Hose Company designs, manufactures and markets their new product: anhydrous ammonia hose AAH #1. Per Rubber Manufacturers Association (RMA)

and The Fertilizer Institute (TFI) specifications. XYZ has hose tested and approved at independent testing laboratory. Only pressure tests performed; neither time versus-strength nor long-term tests performed. In 1977, RMA Specifications did not include any tests specifically designed for AAH #1-reinforced hose.

1978 - XYZ and farmers' cooperatives sued by several end users present:for field accidents apparently caused by rupture of anhydrous ammonia hose AAH #1 in the field under normal use.

1982: XYZ Hose Company commences stamping hoses with warning labels that hose should not be used beyond 30 months. This warning commonly disregarded by end users.

1983: XYZ discontinues manufacture of anhydrous ammonia hose AAH #1.

1987: XYZ negotiates an out-of-court settlement with farmer Bob Smith in the amount of \$1,400,000.

1988: XYZ places buy-back offer in Farmers' Cooperative Magazine, noting that all XYZ AAH #1 anhydrous ammonia hose should be returned at once because the product is outdated. XYZ receives over 500,000 feet of hose, some dating back as far as the 1950's, when XYZ produced hoses using nylon and polyester as the reinforcing material.

1991: XYZ negotiates one-half of an out-of-court settlement with farmer Tom Jones in the amount of \$125,000. The remaining one-half of the settlement paid to Jones by the DEF Farmers' Cooperative.

Ethical Issues Of The Case

- 1) What happens when professional codes and regulations lag behind technological innovations?
- 2) What precautions must engineers take when trying to balance the benefits new technologies bring with risks to public safety often associated with engineering social experimentation?
- 3) What are engineering and corporate responsibilities to the public for failed innovation?

Student Handout Synopsis

In 1977, a nationally-respected, family-owned firm, the XYZ Hose Company, decided to switch from their rayon-reinforced hoses to AAH #1. XYZ company representatives ran tests, and decided that AAH #1 would prove more robust in the field than the less expensive nylon and polyester products. Switching to AAH #1 made sound business sense, because although more expensive than products previously used, AAH #1 allowed them to undercut their competitors who used stainless steel.

Until the 1977 introduction of XYZ's inexpensive AAH #1 hose, farmers' cooperatives characteristically used hoses reinforced with stainless steel. Thus, purchasing a cheaper hose, made of less expensive material, would obviously mean considerable cost savings for all involved, from the manufacturers, to the farmers' cooperatives, to the farmers.

Unfortunately, even though XYZ's AAH #1 hose was tested at both XYZ and an independent testing laboratory, and even though it met all the current industry standards, something went wrong with the XYZ AAH #1- reinforced anhydrous ammonia hose in use, resulting in devastating consequences for several of the product's end users. In one reported case, the AAH #1 hose burst while a Kansas farmer, Bob Smith, was setting up the equipment for knifing the anhydrous ammonia product into his fields. When the XYZ AAH #1 hose burst, releasing the toxic ammonia into the air, the force of the discharge blew Smith's protective goggles off his face. Smith is now legally blind, and has sustained lifetime disfigurement as a consequence of severe burns received. His physical disabilities have made him dependent on others, and he is now incapable of making a living as a farmer the only occupation he has ever known.

As a result of this and other calamitous incidents involving AAH #1 hose ruptures, XYZ and the various farmers' cooperatives selling the product were sued by farmers. Bob Smith, and other farmers like him, claimed that XYZ did not properly design, test and monitor their product in use, and as such put the end user at inordinate risk. XYZ, on the other hand, argued that their product was misused or abused in the field; yet, because they are a responsible corporation, XYZ decided to pay out-of-court settlements to the various claimants for injuries they suffered while using the AAH #1 hose, no matter who was ultimately at fault. The jury is still out

on who is liable for the hose ruptures.

The case of the XYZ AAH #1 bursting hose raises important issues for engineers. What are the engineering and corporate responsibilities to the public? In addition, because XYZ's AAH #1 hose was innovative, and the specifications (written by the Rubber Manufacturers Association and The Fertilizer Institute) did not give guidelines for testing the experimental yarn as a reinforcing material, there is a question about the XYZ design engineers' responsibilities. When professional codes and regulations lag behind technological innovation, can engineers use existing specifications as bench marks in risk assessment?

Individuals Involved In The XYZ Hose Company Case

Several sets of actors played key roles in the XYZ Hose Company case. The following chart serves to illustrate their interaction:

XYZ Cast Of Characters

Major Chemical Company sells experimental AAH #1 yarn to various manufacturers, including XYZ Rubber Company which, in turn designs/manufactures/markets anhydrous ammonia hose (using experimental yarn AAH #1) and sells AAH #1 hose to between 8000 and 9000 Farmers' Cooperatives throughout the nation.

Farmers' Cooperatives, in turn either sell replacement hose (for those with equipment) or stock hoses, outfit anhydrous ammonia tanks and rent (for those without equipment) to Farmers associated with the particular Farmers' Cooperative in their area who are the end users of the AAH #1 product.

Following catastrophic results in the field, farmers (or end users) have initiated legal proceedings against both the Farmers' Cooperative involved and the XYZ Hose Company.

An Experimental Yarn and the XYZ AAH #1-Reinforced Hose

In the 1960's, the plastics division of a leading chemical company introduced AAH #1, an experimental yarn for use as a reinforcing material. In addition to favorable application with fenders, bumpers, tires and bullet-proof vests, AAH #1 yarn appeared particularly well-suited for use with hose products.

There are three elements associated with the manufacture of a hose: the tube,

braid and cover. The tube is the innermost part of the hose, where liquids or gases are contained. Over the inner tube, two or possibly three braids of yarn or wire are wound to give strength to the hose. The outer-most element is then used as the bonding material and it is typically made of rubber; however, it may also be made from other materials. These three elements of the hose are processed so that they act as one unit.

Since the 1940's, the industry standard for the braids was typically made of stainless steel wire mesh, although most manufacturers of anhydrous ammonia hose used nylon or polyester as the reinforcing material. Stainless steel is the most dependable and robust braiding material. Stainless steel is, however, also a relatively expensive material. Thus, when the less expensive AAH #1 yarn was introduced, it seemed stainless steel had finally met a forceful competitor. Throughout the late 1960's and into the 1970's, AAH #1 was tested for use in various applications, one of which was for anhydrous ammonia hoses.

Anhydrous ammonia is used by farmers in the spring and early fall as a nitrogen fertilizer. Due to the toxicity of the ammonia vapors expelled to the atmosphere when the material is "knifed" into the soil with steel knives, those working with anhydrous ammonia must use extreme caution. At the very least they must wear protective gloves and goggles.

Farmers do not typically own equipment used for spraying the fertilizer. Instead, they rent a tractor and tank (called a "nurse tank") filled with anhydrous ammonia from their local farmers cooperative. Farmers' cooperatives throughout the country stock hoses and equip the anhydrous ammonia nurse tanks for use by the farmers. These cooperatives typically buy the anhydrous ammonia hoses directly from the supplier, in this case the XYZ Hose Company. Until the introduction of XYZ's AAH #1 hose, farmers' cooperatives characteristically used hoses reinforced with either stainless steel or nylon and polyester, materials which are relatively unaffected by ammonia. While nylon and polyester were less expensive than AAH #1, they would become increasingly unreliable over time, because of the inevitable deterioration due to contact with anhydrous ammonia. The alternative was stainless steel; however, stainless steel is expensive. Thus, a hose more durable than one made of nylon or polyester, and of less expense than one made of stainless steel, provided a distinct advantage.

In 1974, three years prior to XYZ's market entry with their relatively inexpensive

AAH #1 hose, a professor of agricultural engineering at a major state university presented a study¹ that attempted to determine the effects of ammonia on the strength of various reinforcing yarns, including AAH #1. The three units of the hose are processed so that they act as one unit, and the inner tube of the hose is not completely impervious to ammonia fumes, so the outer cover of the hose must be pricked to allow small amounts of the ammonia fume to escape to the atmosphere when necessary. Although the concentration of escaping ammonia is quite low, the study found that even though AAH #1 "... is not materially affected by the low concentration NH_4OH vapor ... strength of the yarn is reduced over time to 46 percent of its original strength by the vapor from anhydrous ammonia."² In other words, it is highly probable that anhydrous ammonia hoses reinforced with AAH #1 deteriorate at a fairly rapid rate. While it was noted that the study's findings were inconclusive, and thus could not absolutely justify eliminating AAH #1 as a reinforcing yarn, the study did advise that those using AAH #1 should over-design their hoses to compensate for diminished strength, and that they should carefully monitor their hoses in use. In addition, the study noted that stainless steel was the most resilient yarn. While more expensive and cumbersome, the study found that stainless steel, on average, lasted longer than all other yarns, given the destructive affects of anhydrous ammonia.

It should be noted that the agricultural engineering professor was also a state authority on hoses, and he tested all hoses for the eight to ten different manufacturers who produced anhydrous ammonia hoses in the 1970's. Based on his findings, he either passed or failed each manufacturer's hose, using the Rubber Manufacturers Association and The Fertilizer Institute's specifications. Thus, as an authority on anhydrous ammonia, the professor's final recommendations were that:

Yarn material should be tested for resistance to ammonia by immersing it in a 5 percent solution of aqua ammonia and in the vapor from a 28 percent aqua ammonia solution for a period of 10 weeks. This test medium should be held at 70 [degrees Fahrenheit] during the period of immersion. Any yarn that loses more than 15 percent of its tensile strength in either of these two test mediums in a 10-week period should not be used to reinforce ammonia hose.

In 1977, three years after the above study was conducted, XYZ designed their new hose, using AAH #1 as the reinforcing material. The AAH #1 design was based on a previous hose that used rayon as a reinforcing material. AlCarlton, an XYZ design engineer, was acquainted with the 1974 study. According to Carlton, XYZ switched

to AAH #1 because it was a stronger reinforcing material than the rayon material the company had previously used. In addition, Carlton noted that while AAH #1 was more expensive than rayon, nylon or polyester, it was still less expensive than the recommended stainless steel product.

Between 1977 and 1983 there were no major design changes to the AAH #1 hose. There were, however, minor dimension adjustments made to aid in processing the hose.

In 1982, the cover of the hose was changed to accommodate a new label. According to XYZ's design engineer, even though adjustments were made, the AAH #1 hose met all the minimum physical properties of tube material necessary for industry standard specifications as detailed by the Rubber Manufacturing Association (RMA) and The Fertilizer Institute (TFI).

Both the RMA and TFI standards specify that any changes made to the hose must be approved by an independent testing laboratory. Thus, if the hose passed XYZ's internal quality control, it was then given to an independent research laboratory for inspection, as specified by RMA-TFI standards. The laboratory approved the modifications to the hose, and XYZ began manufacturing and production.

Each production run sample of the AAH #1 hose was sent to XYZ's quality assurance laboratory to determine if the hose met the required RMA-TFI specifications. The hose was then inspected throughout the manufacturing process by various personnel actually producing the hose. They pulled the hose and checked dimensions, ensuring that the hose met the required specifications. No one particular person was responsible for the overall manufacturing process for the AAH #1; rather, manufacturing was a segmented process. There were, however, standard operational procedures used, and findings were documented for all quality assurance and manufacturing operations.

For each hose sample, quality assurance inspectors tested the physical properties of the tube and cover, the adhesion between layers, the inner and outer dimensions, and the cold flex at minus 40 degrees fahrenheit. (A cold flex test involves subjecting the hose to minus 40 degrees fahrenheit for a given length of time, then bending the hose around a mandrel of a certain diameter to see if the hose will crack or break.)

Following cold flex tests, quality assurance inspectors checked for cover

perforations that allowed ammonia to escape through the cover of the hose. Quality assurance and manufacturing inspectors then proof-pressure tested the hose at 700 psi for 3-5 minutes. A burst test was then performed, where the pressure in the hose was increased until it burst.

XYZ representatives reported that the hose passed all specifications mandated by industry standards as they were written in 1977. One must remember, however, that industry standards in 1977 did not include specifications for the use of AAH #1 as a reinforcing material. As such, XYZ had to adapt the existing standards to meet the challenges of an innovative design.

Once the AAH #1 hose met the specifications of the Rubber Manufacturing Association and The Fertilizer Institute, and was approved by the independent research laboratory, XYZ was ready to market AAH #1 to its customers. These were the farmers' cooperatives located throughout the nation.

The farmers' cooperatives stocked XYZ's new hose and outfitted many of their anhydrous ammonia nurse tanks with XYZ's less expensive product. As anhydrous ammonia hoses have been in use in farming operations since the 1940's, the cooperatives' took no extra precautions with the new XYZ hose, connecting it to the nurse tanks as they had always done for other hoses.

Even though the AAH #1 hose was tested and met all the current industry standards, something went wrong with XYZ's innovative AAH #1-reinforced anhydrous ammonia hose just two years after marketing began. By 1979, accidents related to hose ruptures were reported, ruptures that resulted in devastating consequences for several of the product's end users. The first claim against XYZ came in 1978, and unsettled claims are still pending. (Note: at the same time, similar ruptures also occurred with other manufacturer's hoses, although the XYZ AAH #1 ruptures occurred more frequently.)

In one case reported in 1979, the XYZ AAH #1 hose burst while a Kansas farmer, Bob Smith, was setting up the equipment to knife the anhydrous ammonia product into his fields. When the XYZ AAH #1 hose burst, releasing the toxic ammonia into the air, the force of the discharge blew Smith's protective goggles off his face. Smith is now legally blind, and has sustained lifetime disfigurement as a consequence of severe burns received.

As a result of Smith's accident and others, XYZ reacted in several important ways.

First, XYZ instituted a warning label campaign. Despite the 1974 study warning that hoses should be over designed and monitored in use, XYZ had never visited the farmers' cooperatives to inspect deterioration levels of the AAH #1 hose between 1977 and 1983. XYZ representatives noted that because they serviced so many cooperatives (between 8000 and 9000), individual hose inspection was not a realistic option. As a manufacturer, XYZ felt their job was to deliver an industry-approved product, and they did. Monitoring how the hose was treated in use was simply too onerous a task. As a result, hose inspection became the domain of the farmers' cooperative.

By 1979, Clifford Williams, XYZ's manager of industrial hose development, was alarmed by the growing number of accidents. He reviewed the quality control and product failure historical files, and determined that well over 50% of the failures were caused by some type of misuse or abuse in the field. This misuse was of two types. First, repetitive flexing or bending of the hose near the coupling caused failure by over-stressing the hose materials. Second, many hoses were left out during winter months, causing the anhydrous ammonia residue to freeze and expand the hose.

Representatives of the farmers' cooperatives and the farmers themselves, however, claimed that they used the XYZ hose in precisely the same way they used all other manufacturer's hoses, and that the XYZ hose was the only brand causing such frequent and devastating ruptures.

Thus, by the late 1970's, XYZ and other industry leaders associated with the Rubber Manufacturing Association suggested that something be put on the hoses to better ensure farmer safety. XYZ took the lead. After completing his analysis of hose failures, Williams did not recommend a recall of the AAH #1 hose. Instead, he recommended that XYZ adopt a warning-label system. XYZ notified farmers' cooperatives of the hazards associated with AAH #1 product misuse, and told them to use the AAH #1 hose in accordance with the RMA IP112 Care and Use Manual that Williams had helped the Rubber Manufacturing Association produce.

Thus, in 1982 XYZ designed a warning label, and indicated that the hose would have a 30-month service life if it was not severely bent, kinked, or flexed below a recommended radius. XYZ representatives put in place this conservative, self-

protection mechanism to ensure farmers' cooperatives would finally avoid overusing and abusing the AAH #1 product. XYZ insisted the problem was not with the AAH #1 product; rather, the blame was to be placed on an "irresponsible minority" of farmers' cooperatives who failed to keep maintenance records, and take hoses out of service after the recommended service life.

Problems continued, however, and XYZ was so concerned about the end users and the liability issues the company faced, that in 1983 XYZ discontinued manufacturing the anhydrous ammonia hose, as well as all other anhydrous hoses. Convinced that the real problem was traceable to misuse, XYZ feared that there was no way the product could be designed to be completely fail-safe against misuse or abuse in the field. In 1984, the majority of other anhydrous ammonia hose manufacturers followed XYZ's lead and left the industry. Those few manufacturers that remain have switched exclusively to stainless steel, now officially recognized as "the" industry standard.

Despite their initial warnings, and contacts with farmers' cooperatives, accidents in the field continued.

Thus, in 1988, five years after their market retreat, XYZ placed an advertisement (see the following page) in a farmers' cooperative magazine, warning that their product was outdated (note, outdated versus dangerous) and should be returned for an immediate buy-back offer (and note, buy-back versus recall). Again, as with the warning label system, XYZ's buy-back offer was unprecedented.

WARNING:

All XYZ AAH #1 anhydrous ammonia hose should be returned at once! Product Is Outdated

The XYZ Hose Company discontinued manufacturing AAH #1 anhydrous ammonia hose in 1983. Prior to that time, hose labeling and instructions warned that the product should not be used beyond 30 months.

Since anhydrous ammonia is a critical application, outdated hose should never be sold or used for this purpose. So in the interest of continued user safety, XYZ now considers all remaining AAH #1 hose new or used outdated.

Immediate Buy-Back Offer

Through June 30, 1988, anyone who still has this XYZ hose will be reimbursed at a price above the current cost of replacement hose and couplings. AAH #1 of any age, regardless of condition, can and should be returned. We're requesting the help of agricultural industry trade associations, cooperatives, distributors, implement dealers, and fertilizer users in passing along this important message.

Notify XYZ At Once

Simply call XYZ's toll-free number for instructions on how to be reimbursed, quickly and easily. For the safety of all concerned, we want to take any remaining AAH #1 hose out of circulation, and we're offering more than enough to install brand new hose in its place. Here's the number to call:

Call 1-800-BUY-BACK Toll Free (1-800-289-2225)

If you have any of this hose, call today. And if you know of anyone else who might have AAH #1 in stock or in use, please notify them. As the world's leading manufacture of belts and hose for all applications, we want to ensure the agricultural industry's continued satisfaction with XYZ's products.

XYZ XYZ Hose Company

Plain Jane, Indiana (based on advertisement actually placed in the Farm Journal Magazine)

In addition to placing the advertisement in the Farm Journal Magazine, XYZ sent the buy-back offer to approximately 9000 farmers' cooperatives. The response to the advertisement was overwhelming. By July of 1988, XYZ received over 500,000 feet of hose, manufactured (and still in use) as far back as the 1950's and 1960's. It should be noted, however, that older hoses were made of rayon, nylon and polyester, and were still robust in many cases.

From 1983 to the present XYZ, as well as several farmers cooperatives, have made out-of-court settlements with those end users adversely affected by the AAH #1 hose. In the Smith case alone, XYZ settled out of court in 1987 for \$1,400,000. As recently as the spring of 1991, XYZ negotiated one-half of an out-of-court settlement with farmer Tom Jones in the amount of \$125,000; the remaining one-

half of the settlement was paid to Jones by the DEF Farmers' Cooperative. Throughout their depositional testimony, XYZ representatives contend that even though their hoses were not dangerous, but rather were abused, they settled out of court because they felt a corporate responsibility to the end user regardless of who was at fault.

When asked why they got out of the anhydrous ammonia hose manufacturing business, XYZ representatives stated that the cost of damages outweighed any benefits to the company (especially since AAH #1 hose manufacturing represented less than five percent of the company's industrial hose sales). More importantly, however, XYZ contends that they realized they were fighting a losing battle. They could not control what the farmers' cooperatives did once they purchased the hose from XYZ. One XYZ representative noted that everyone involved understood the dangers associated with volatile chemicals such as anhydrous ammonia and understood the precautions they must take. But farming is a dangerous business in the best of times, and everyone takes a certain amount of risk using the product because, given the farming population as a whole, disaster strikes so infrequently. In the Smith case alone, XYZ maintains that the hose was left in service too long, and that just one week prior to the disaster, a farmer down the road alerted the farmers' cooperative to a blister in the hose. Thus, for XYZ, the risks just simply outweighed any potential benefits to the company.

The design decision-making problems engineering professionals face involve how to define, assess and manage risk in the light of obligations to the public at large, the particular policies of the corporation employing the engineer, and the design practices of the engineering profession as a whole. In the essay, "Engineering Design: Literature on Social Responsibility Versus Legal Liability," appended to the end of this report, a literature review serves as a catalyst for discussing risk and the decision-making process as it relates to the XYZ case. Bear in mind that, above all, risk assessment is closely tied to the perspective that engineering is a social experiment, that engineers have an implicit social contract with the public they serve, and that professional societies and society codes of ethics play important roles in helping shape the engineering decision-making process.

Ethical Issues Of The XYZ Case Points For Discussion

In his depositional testimony, farmer Bob Smith charged that XYZ manufactured and marketed a dangerous product, that neither XYZ nor the farmers' cooperatives

adequately warned the end users of the dangers associated with the AAH #1 hose, and that XYZ did not assure that the product would be monitored in use. Expert witnesses appearing on Smith's behalf claimed that kinking and temperature had no deleterious effect on the XYZ hose; that, in fact, the XYZ hose simply suffered from defective design, and that the manufacturer had knowingly put the end user at unreasonable risk. These contrary claims against XYZ raise important issues.

These include:

- What happens when professional codes and regulations lag behind technological innovation? What are the engineering and corporate responsibilities to the public in such cases? To help you sort through these ethical issues, consider the literature on risk assessment and engineering/corporate responsibility to the public, as well as the following questions:
- What were the professional and corporate responsibilities of XYZ, the independent research laboratory, and the farmers' cooperatives when introducing an innovative product/design to a relatively scattered, and quite possibly uninformed end user (the farmer)? What are the chemical company's responsibilities, if any? Who is responsible for training end-users (i.e., getting their informed consent to use a product) in the use of products that interact with toxic chemicals the manufacturer, the supplier, or the consumer? What responsibilities do engineers and their corporations have when they release products for public consumption? Should they be responsible for overall design, testing and follow-up? Where does one entity's responsibility end and another's begin?
- If the XYZ AAH #1 hose was inordinately dangerous, rather than abused in use, what risk assessments and in-use monitoring practices should have been employed? How could the engineers involved know how much over-design was too much, and/or how much risk to the end user was too much? How do you, as an engineer, assess such risk?
- If the AAH #1 was a defective product, what was the appropriate corporate response? XYZ discontinued manufacturing the hose, placed advertisements in a farmers' cooperative magazine, and paid out-of-court settlements to those adversely affected by the product, despite their contention that the accidents were not the fault of XYZ. Did XYZ act responsibly? Did they take proper precautions and do enough following the accidents? If so/not, why?

- What happens when there are time lags between written regulations and those innovative products that transcend the current specifications? AAH #1 was an experimental product; therefore, is it possible that written specifications did not take this new material into account? What can engineering professionals do to ensure both safety to the public and protection to the corporate entities they serve? And, how can corporations ensure that the engineers they hire (both internally and as independent consultants) are up-to-date on the literature, and performing competent risk assessments? Can we even make divisions between individual and corporate responsibility when introducing innovative products?
- What prompted XYZ to get out of the anhydrous ammonia hose business? And why, five years after they stopped manufacturing the hose, did XYZ offer buy-backs? Is this standard industry practice, and if not, should it be? What does the language of the buy-back offer suggest, if anything, about XYZ as a corporation? And, from an ethical standpoint, what do XYZ's out-of-court settlements tell us about the corporation's integrity and sense of public responsibility? In the end, can XYZ be hailed as the paradigm of corporate responsibility a company who, despite possible failed innovation, did the right thing? Why or why not?

After working through these questions, can you decide who is culpable in the case of the bursting hose?

Annotated Bibliography

Davis, Michael. "Thinking Like An Engineer: The Place of a Code of Ethics in the Practice of a Profession," in *Philosophy & Public Affairs*, Vol. 20, No. 2, Spring 1991, pp. 150-167. (See also, Davis, Michael, "Explaining Wrongdoing," *Journal of Social Philosophy*, Vol. 20, Numbers 1&2, Spring/Fall 1989, pp. 74- 90.)

In these lucid essays, Davis argues that "a code of professional ethics is central to advising individual engineers how to conduct themselves, to judging their conduct, and ultimately to understanding engineering as a profession." Using the now infamous Challenger disaster as his model, Davis discusses both the evolution of engineering ethics as well as why engineers should obey their professional codes of ethics, from both a pragmatic and ethically responsible point of view. "Must reads" for any graduating engineering student.

Glickman, Theodore S., and Michael Gough (eds.), *Readings in Risk*, Washington, D.C.: Resources for the Future, 1990.

This is an excellent collection of essays on managing technology-induced risk. Of particular worth to engineers are the essays: "Probing the Question of Technology-Induced Risk" and "Choosing and Managing Technology Induced Risk," by M. Granger Morgan; "Defining Risk," by Baruch Fischhoff, Stephen R. Watson, and Chris Hope; "Risk Analysis: Understanding 'How Safe is Safe Enough?'," by Stephen L. Derby and Ralph L. Keeney; "Social Benefit Versus Technological Risk," by Chauncey Starr; and "The Application of Probabilistic Risk Assessment Techniques to Energy Technologies," by Norman C. Rasmussen.

Mayeux, Mansel M. "The Effect of Ammonia On the Tensile Strength of Selected Yarns," in *Transactions of the American Society of Agricultural Engineers (ASAE)*, Vol. 17, No. 6, 1974, pp. 1088-90, 1093.

This 1974 article presents a study for determining what effect ammonia has on the strength of sundry reinforcing yarns. It forms the basis for the discussion of our semi-fictitious case. The objective of the study was to determine some method for testing and evaluating the extent of the ammonia affect. While study findings are inconclusive, the article argues that ammonia in the vapor state affects yarns differently than does ammonia in the liquid state. For example, in the liquid state, AAH #1 is not adversely affected by concentrated aqua ammonia; however, experiences rapid deterioration when it interacts with anhydrous ammonia vapor.

The Fertilizer Institute's (TFI) *Anhydrous Ammonia Operators Manual*, 1976; Rubber Manufacturers Association (RMA) for Maintenance, Testing and Inspection of Anhydrous Ammonia Hose, pp. 1-3 (approved March, 1976; Revised 1980 Form 3527SA, RMAPII2, HTI No. 2, Anhydrous Ammonia Hose); Rubber Manufacturers Association Hose Handbook, 1979, p. 4; American National Standard K61.1., 1972, p. 12, "Hose Specifications"; Occupational Safety and Health Administration Standards for Agriculture 29CFR 1910.111(a), p. 36; National Institute of Occupational Safety and Health (NIOSH), *Working Safely with Anhydrous Ammonia*, 1979, p. 17; and The Fertilizer Institute, *Hose Inspection from the External Visual Inspection Guidelines for Anhydrous Ammonia Nurse Tanks*, pp. 35-36.

The above documents specify industry standards for anhydrous ammonia hose testing and in-use operational safety. The works say that the hose is the weakest

link in anhydrous ammonia operations, and that hose "failure may release chemicals or materials under pressure that could result in serious injury to personnel and property." Standards note that anhydrous ammonia hose has a limited life, and that operators should be cautioned. Additionally, these standards stress that operators must be thoroughly trained in the care and use of the anhydrous ammonia hose.

Notes

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