FIREWORKS PLANT EXPLOSION
Jennings, OK
June 25, 1985

NFPA INTERNATIONAL

FIRE INVESTIGATIONS

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Summary Investigation Report

Aerlex Fireworks Plant Explosion
Jennings, Oklahoma
June 25, 1985
21 Killed, 5 Injured

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The non-profit technical and educational organization: To promote the science and improve the methods of fire protection and prevention; to obtain and circulate information on these subjects and to secure the co-operation of its members and the public in establishing proper safeguards against loss of life and property by fire.

ABSTRACT

At 9:35 a.m. on June 25, 1985, a series of explosions and subsequent fires occurred at the site of the Aerlex Fireworks Manufacturing Corporation, near the town of Jennings, Oklahoma. In all, 21 people were killed and 5 injured in what was the second-deadliest fireworks factory explosion in the United States reported to the NFPA between 1950 and 1986.

The company was federally licensed by the U.S. Department of the Treasury/ Bureau of Alcohol, Tobacco and Firearms (ATF) and produced approximately 90% display-type special fireworks and 10% common fireworks. As a result of increased demand created by the upcoming July 4th holiday, the plant had temporarily increased its staff and extended the hours of operation.

As determined by the Oklahoma State Fire Marshal's Office, the incident was most likely the result of careless unloading of pyrotechnic materials from a pickup truck to an adjacent assembly building. Investigators estimate that it was only a matter of seconds from the initial ignition before the explosions, which were felt 13 miles away, leveled most of the facility. Factors such as unbarricaded process buildings coupled with the quantity and type of explosive composition on hand are believed to be responsible for the magnitude of the loss.

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INTRODUCTION

The National Fire Protection Association (NFPA) investigated the Aerlex fireworks plant explosion in order to document and analyze significant factors that resulted in the loss of life and property and to report lessons learned for loss-prevention purposes.

The NFPA became aware of the plant explosion on the day of its occurrence. Greg Kyte, Fire Protection Specialist in the Fire Investigations and Applied Research Division, traveled to Jennings, Oklahoma, to document the facts related to the incident. Entry to the scene and data collection activities were made possible through the cooperation of the Oklahoma State Fire Marshal's Office.

This report is another of NFPA's studies of incidents having particularly important educational or technical interest. The information presented is based on the best data available during the on-site data collection phase and during the report development process. It is not NFPA's intention that this report pass judgement on, or fix liability for, the loss of life or property resulting from this incident.

This report describes firesafety conditions at the Aerlex fireworks plant and presents findings on factors contributing to the loss of life, based on NFPA's analysis of collected data and observations during the investigation. NFPA's codes and standards were used as criteria for this analysis so that conditions at the facility on the day of the incident could be compared with current fire protection practices. It is recognized that these codes and standards may not have been in effect during construction or operation of the plant. NFPA has not analyzed the facility as to compliance with the codes and standards which were in existence when the Aerlex fireworks plant was built or during its operation.

The cooperation and assistance of State Fire Marshal Fred H. Rucker, Jr. and Agent Shelly Phillips of the Oklahoma State Fire Marshal's Office, William W. White, Area Director of the U.S. Department of Labor/Occupational Safety and Health Administration (OSHA), and the U.S. Department of the Treasury/Bureau of Alcohol, Tobacco and Firearms (ATF) is greatly appreciated.

BACKGROUND

Historical Perspective

Modern pyrotechnics, or the "art of fire," had its beginnings with the discovery and development of black powder, most likely by the Chinese well before 1000 A.D.. The ingredients -- potassium nitrate, charcoal, and sulfur -- were all well known to ancient civilizations.[1] Progression to explosives and the creation of firecrackers soon followed when it was discovered that black powder produced noise if ignited while confined in a sealed tube. Most early items primarily produced noise, but as the modern chemical industry grew during the 1800s and early 1900s, the fireworks industry shifted toward color and other visual effects and away from simple noise.[2]

Fireworks manufacturing remains very much a labor-intensive industry, with little automation and most of the larger items being packed by hand. The presence of bulk explosive compositions poses potential fire and explosion hazards to employees, especially those conducting mixing and loading operations.[3] Accidents can and do happen in all industries, but only in pyrotechnics is a relatively minor accident so likely to trigger such a large consequence.

There are important distinctions between explosives and pyrotechnics with regard to safety. In general, pyrotechnics are less sensitive to shock and impact and more sensitive to spark and flame than explosives are. The degree of confinement of pyrotechnics by packaging, building, or barricade plays a

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[1]Conkling, J.A., "Chemistry of Fireworks," Chemical and Engineering News, June 29, 1981, pp 24-32.

[2]McLain, J.H., Pyrotechnics -- From the Viewpoint of Solid State Chemistry, (The Franklin Institute Press, Philadelphia, 1980.)

[3]Conkling, J.A., 1981., op. cit.

primary role in the potential for damage. However, the widespread belief that no pyrotechnic mix can undergo a high-order explosion unless confined by packaging is incorrect.[4]

In 1948, the fireworks industry, consisting of fragmented groups, united to found the American Pyrotechnics Association. The organization has worked together with government agencies and the NFPA to promote safety in the field.

A concerted effort between the fireworks industry and the Technical Committee on Explosives of the National Fire Protection Association resulted in the development of NFPA 44A, Code for the Manufacture, Transportation, and Storage of Fireworks. In 1980, responsibility for this document was transferred to the Committee on Pyrotechnics, which led to the text being redesignated NFPA 1124.

The code is intended to supplement existing federal, state, or local regulations and to provide reasonable safety in the manufacture, transportation, and storage of fireworks. It addresses such areas as:

- permits and licenses
- record keeping and reporting
- site security and quantities of explosives
- separation distances and building construction
- heat, light, and electrical equipment
- occupant load limits and means of egress
- fire and explosion prevention
- storage and transportation procedures.

Fireworks are classified by the U.S. Department of Transportation (DOT) as either Class B or Class C explosives according to the amount of explosive composition. The U.S. Department of Transportation and the U.S. Department of the Treasury/Bureau of Alcohol, Tobacco and Firearms (ATF) regulate the transport, storage, purchase, and use of Class B explosives, which include

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[4]McLain, J.H., 1980., op. cit.

display-type special fireworks. On the other hand, common fireworks, classified as Class C explosives, are required to comply with the construction, chemical composition, and labeling regulations of the U.S. Consumer Product Safety Commission.

Regulations involving the manufacturing aspect of fireworks production fall under the authority of the U.S. Department of Labor/Occupational Safety and Health Administration (OSHA). Fireworks manufacturers are not required to be licensed by OSHA in order to operate their plants, so compliance with safety regulations is not assured.

The Manufacturing Complex

The Aerlex Fireworks Manufacturing Corporation was located on a 40-acre tract in the rural community of Jennings, Oklahoma. The facility was comprised of 20 buildings spread over an area of approximately 6 acres (see Figure 1). With the exception of a remotely located magazine and Building R, the structures inside the compound were built of wood frame construction set on concrete slabs. The magazine was constructed of reinforced concrete masonry and Building R was a metal structure set on a concrete base.

The company produced approximately 90% special fireworks and 10% common fireworks. During the summer, temporary employees were hired to assemble common fireworks in Building R while full-time employees manufactured special fireworks in other buildings. The most popular item among the special fireworks was their three-inch-diameter cylindrical aerial shell.

Some of the most hazardous operations conducted at the site involved the production of stars (see Glossary), which were used to provide bursts of dazzling color. These marble-sized pellets were made in Buildings G, H, I, and J and transferred to Building T for the drying process. Stars were then utilized during the assembly process at Buildings B and L. Building B is where cylindrical-shaped aerial shells were made while ball-shaped Japanese-style aerial shells were assembled at Building L.

This incident marked the second time a fire and explosion had occurred at the plant since its opening in 1973. The first incident, allegedly caused by spilled powder, happened in 1979. On that occasion, a rapidly developing fire and subsequent explosion occurred in Building R; however, no one was injured as employees had time to evacuate the area.

The fireworks plant was operating under a license from ATF which permitted them to manufacture, warehouse, distribute, sell, and display fireworks and black powder products.[5] The ATF had recently inspected the facility. ATF inspections do not involve assessment of safety conditions relative to the assembly of pyrotechnic devices such as ignition prevention or separation of process buildings, but are concerned with three primary areas: licensing, record keeping, and storage. They regulate the construction and separation of magazines from other buildings and the distribution of explosive compositions.

Day-to-day safety precautions could have been enforced by OSHA; however, they did not know the plant existed prior to the incident, and consequently had never inspected it during the twelve years the plant had operated. Companies are not subjected to random inspections when their annual record of "lost workday" accidents[6] is below the national average for all industries unless complaints from employees are received. Even though fireworks

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[5]Any person engaged in the business of importing, manufacturing, or dealing in fireworks shall possess a valid federal license or permit, where required by Title XI, Regulation of Explosives, of the Crime Control Act of 1970 (18 United States Code, Chapter 40) and shall comply with all applicable state and local laws and regulations.

[6]Fatalities are not included in this computation.

manufacturing is considered a high-hazard process, it has been grouped with industries involved with less hazardous operations. As a group, those industries have traditionally not been targeted by OSHA for inspection. In addition, state and local fire officials were not charged by law with the responsibility or authority to conduct inspections or enforce regulations essential to the safe operation of this plant.

THE INCIDENT

Emergency Notification and Response

At 9:35 a.m. on June 25, 1985, members of the Cleveland Fire Department reported hearing a series of explosions. The largest explosion actually caused the lay-in tile ceiling in the fire station to momentarily raise and then drop. From outside of the station, a white mushroom-shaped cloud an estimated half-mile high became visible. Shortly thereafter, fire department dispatch received notification by telephone of an explosion and fire at the Aerlex fireworks plant located approximately 12 miles away in the community of Jennings.

A lieutenant of the Oklahoma Highway Patrol (OHP), also in Cleveland at that time, reported hearing the explosions. He left to investigate the occurrence and arrived at the plant site some 10 minutes later just as a Pawnee County deputy sheriff arrived. In their initial size-up, the officers located a number of persons with varying degrees of trauma, including cuts and burns. The lieutenant radioed the Cleveland Fire Department to report there were numerous fires and the need for medical assistance. Fire departments from the surrounding communities of Pawnee, Jennings, Peninsula, Oilton, Terlton, and Cleveland responded to the scene.

Upon their arrival, emergency personnel rendered first aid to the injured and transported them to area hospitals for further medical treatment. Firefighters commenced fire suppression operations in order to extinguish numerous fires inside the facility and surrounding property. The explosions started brush fires that burned several acres of land to a distance of a half-mile from the blast site. Very soon after arrival of emergency personnel, the scene was blocked off and secured by the OHP. A temporary morgue was set up to serve as a location to collect the remains of those killed in the incident. The fatalities were transported to the State Medical Examiner's Office in Tulsa. Although employees were scattered throughout the complex at the time of the explosions, the majority of those that were killed were located inside Building R and Building O, and in the vicinity of Building B.

Representatives from ATF arrived at the complex early that day and assumed control of the scene after all of the bodies had been recovered. Agents from the Oklahoma State Fire Marshal's Office were on site to conduct their own investigation and provide assistance to the federal authorities. National Guard troops were called out to maintain security, and the ATF National Response Team was activated and dispatched to the scene.

By 12:00 noon the next day, the National Response Team had arrived and begun work. Their first task was to search for and locate any residual explosives that might have still existed and constituted a hazard. An initial walk-through of the area was conducted followed by a shoulder-to-shoulder search starting at the furthermost point explosives were thought to have been projected. The combination of explosions and fire consumed most of the hazardous materials; however, these searches did result in the recovery of 10 to 15 pounds of explosive material. Residual bulk chemicals, consistent with the production of fireworks, were also located and properly disposed of either by leaching methods or by burning the material.

Damage Survey

After the plant site was cleared of hazardous materials, the investigation continued to determine the cause of the disaster. On-site examination of the facility plus interviews of plant employees yielded information relative to the quantities and types of explosives on hand and the destructive effects of them on certain plant buildings. The following information is the result of those efforts.

At Building B, the process had included having several containers of various colored stars on hand along with cardboard cylinder shell casings, some partially assembled shells, and a stock of finished aerial shells. Evidence of two major depressions in the 18 ft by 26 ft unreinforced concrete slab verify that there were bulk supplies of stars and shells inside Building B. The depressions, one measuring approximately 38 inches deep and the other 30 inches deep, were the result of separate explosions. Interviews with survivors indicate that approximately 1,000 pounds of Class B fireworks were on hand in the shell assembly building on that day.

The largest structure in the complex, Building R, was located an estimated 200 ft from Building B. The building measured 50 ft by 100 ft and consisted of a lift room, tool room, assembly area for the production of Class C fireworks, and storage areas. There were an estimated 10,700 pounds of mixed chemicals and 1,175 pounds of Class B fireworks in the structure that day. Examination of the building site showed evidence of three separate areas of explosion.

Building S, measuring 10 ft by 15 ft stood 60 ft from Building R and was used for the storage of bulk chemicals consistent with the production of stars. The building, including its foundation, was totally destroyed. Further evidence of an explosion was the shattered and seared earth in the area where the building had stood.

Another explosion site was the 10 ft by 15 ft storage shed located 48 ft north of Building S. The structure, designated Building T, was used as a drying area in the production of stars.

Witness Accounts

Interviews provided information concerning employee activities prior to the explosions. The best indication of what actually occurred on the morning of the incident is the testimony provided by two survivors, both of whom were in close proximity to the initial explosions. The witnesses and one employee who was killed, were in the process of making fuses. They had strung match material between two trees and were using a drill to twist it.

The first account was given by the plant owner's brother-in-law, who served as manager of the facility. He was positioned about 95 ft from Building B in close proximity to the northern most tree (see Figure 2). His co-workers were located near the tree to the south, approximately 50 ft from Building B. He recalled seeing one employee standing in the bed of the pickup truck (Vehicle 15) parked adjacent to Building B, holding a container of finished stars. The second employee involved with the unloading process was standing on the ground near the left rear wheel of the truck. As the employee carrying the container stepped off the rear of the truck, his knees buckled. The container of stars hit the ground and the employee fell through the doorway of Building B. Suddenly, the explosion occurred. The plant manager then recalled being down on the ground and the area around him was black. He got to his feet and started running toward the west with the other survivor following him.

The account was given by the other survivor as follows. Two employees were unloading 20-gallon galvanized cans of finished stars from the truck to the shell assembly building. Two of the containers were slid across the truck bed and then set on the ground. As the third container was slid across the bed, a sudden, large explosion occurred.

Flash-and-sound powder, produced on the north end of the compound at Mill 1 and Mill 2 (Buildings I and J respectively), had just been transported in the truck to a storage magazine located on a hill to the far south of the compound (not shown on Figure 1). The second witness believed that some of the powder had been inadvertently spilled on the truck bed during the previous trip. The friction created by the galvanized metal containers being slid across the steel truck bed could have easily ignited the powder, producing a flash fire, and triggered an explosion of the stars.

Flash-and-sound powders are extremely hazardous because they can mass explode during either manufacture or shipment. They are among the most sensitive to moisture and must be kept dry to prevent spontaneous combustion and explosion. A commonly encountered flash-and-sound mixture, potassium perchlorate and sulfur, has an ignition temperature of 560°C (1040°F) and can explode when a spark occurs.[7]

Based on eyewitness testimony and physical evidence, there is little doubt that the origin of the fire and explosions was in the area of assembly Building B and the truck (Vehicle 15). The witness closest to the truck reported hearing the sound of metal containers being slid across the truck bed. He beleived that some containers had already been unloaded and another was in the process just moments prior to the incident. Evidence of the occurrence of an explosion in the bed of the truck supports the belief that containers of pyrotechnic material were still on the truck when the incident took place. The truck roof was pushed upward, the cab forced forward on the driver's side, and both sides of the truck were blown off along with the tailgate. The truck and an automobile parked nearby were hurled several feet by the force of the explosions.

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[7]McLain, J.H., 1980., op. cit.

ANALYSIS

Code Application

ATF regulations do not address safety conditions relative to fireworks assembly but rather deal primarily with licensing, record keeping, and storage. There appears to have been no major violation of ATF regulations and one of the few surviving structures was a magazine that complied with ATF requirements.

Numerous facts relative to safety at the plant were documented by OSHA following the incident.

1. Employees involved with the processing of explosive or pyrotechnic composition were not required to wear cotton (non-static producing) work clothes or conductive footwear. In lieu of these requirements, spray-on Static Guard was used.

2. Work clothing that had been contaminated by pyrotechnic materials was permitted to be worn while on break and outside of the plant.

3. Process buildings were absent of properly grounded conductive flooring.

4. Electrical equipment and wiring methods were not approved for hazardous locations; i.e., conductors were not run in conduit, and common duplex electrical outlets, snap switches, and fuse boxes were used. Production equipment, including motors, were not suitable for their hazardous locations.

5. Vehicles used for transporting explosive materials were not placarded, equipped with portable fire extinguishers, or provided with with non-sparking material to cover loading surfaces.

6. Spark-producing metal containers were used to transport pyrotechnic material and cargo was not covered by a flame- and moisture-proof tarpaulin while being transported.

7. Proper separation distances and barriers were not maintained between other process buildings and non-process buildings relative to the quantities and types of explosive composition on hand.

As a result of the investigation conducted by OSHA, Aerlex was cited for 13 violations with proposed fines amounting to $58,000. This represents the largest proposed penalty ever assessed by OSHA against a fireworks manufacturer.

NFPA 1124, Code for the Manufacture, Transportation, and Storage of Fireworks, addresses the danger involved in fireworks manufacturing by requiring minimum separation distances, based on the quantity and type of explosives, between buildings on the plant site. The code presents methods for strict monitoring of plant operations by requiring detailed record keeping. It also includes minimum recommendations to reduce the likelihood of an ignition and, if an ignition should occur, to minimize the potential for the explosion/fire to spread throughout the plant.

Based on observations by OSHA investigators, there appears to have been numerous deviations from the requirements of NFPA 1124, although only some of the deviations could be considered directly related to the extensive loss of life and property in this incident. Interviews with plant workers provided important information regarding the types and amounts of explosive composition on hand at various locations in the facility. At Building R, there were an estimated 10,700 lb of mixed chemicals and 1,175 lb of Class B special fireworks. At assembly Building B, where the initial explosions occurred, there were an estimated 1,000 lb of Class B special fireworks. Paragraph 2-10.3 of NFPA 1124 states that "no more than 500 lb (227 kg) of pyrotechnic or explosive composition shall be permitted at one time in a finishing or an assembly building". Although the amounts of explosives actually on hand are estimates, it is apparent that Buildings B and R did not comply with that code requirement.

In the event that an accidental ignition occurs resulting in the destruction of the building of fire origin, it is important to reduce or eliminate the possibility of other buildings becoming involved. For that reason, NFPA 1124 requires that plant operations dealing with Class B fireworks be adequately shielded from other buildings with barricades. It was evident based on inspection of the premises that no building within the complex that processed Class B fireworks was barricaded.

Summary

ATF reports indicate that this incident occurred during the transportation and handling of finished stars. Due to the explosions and fire damage, the exact point of origin could not be determined. An investigation by the Oklahoma State Fire Marshal's Office indicates a strong probability that the incident was caused when a quantity of spilled flash-and-sound powder was ignited by friction created when galvanized metal cans containing stars were slid across the steel truck bed.

The initial explosions resulted in the destruction of Building B and adjacent vehicles. The subsequent rain of burning stars most likely fell into numerous other pyrotechnic stock, very susceptible to ignition, and these bulk supplies also exploded. The chain of events as described is consistent with the physical evidence observed during the on-site survey and with the testimony of survivors of the incident. Unfortunately, the investigation was not able to determine the exact cause, as those persons involved in the unloading activity did not survive the incident.

In the aftermath of this tragedy, legislation was introduced and passed by the state of Oklahoma in order to strengthen regulations of fireworks manufacturing plants in the state. Senate Bill 353 charges the Oklahoma State Fire Marshal's Office with the responsibility and authority to enforce the provisions of NFPA 1124, Code for the Manufacture, Transportation, and Storage of Fireworks. The new law also gives the Fire Marshal's Office the authority to inspect plants biannually, to license plants to operate, and to immediately shut down a facility when there is imminent danger to persons or property.

Since this incident, OSHA has been given a directive to inspect all fireworks manufacturers having more than ten employees. That task is to be completed between the period of January 4, 1986 and July 15, 1986.

Since 1983, at least 43 persons have died in fireworks manufacturing incidents. While most of the fatalities have occurred at unregulated facilities, strict fire and explosion prevention measures are needed by legitimate operators, as well, to ensure their safe operation.

Although federal licensure controls some aspects of fireworks plant operation, the day-to-day safety practices relating to actual manufacturing activity are not addressed. Only through the adoption and enforcement of safety provisions such as those specified in NFPA 1124, Code for the Manufacture, Transportation, and Storage of Fireworks, by state or local officials can the gap be bridged and reasonable safety obtained.

APPENDICES

Glossary of Terms[8]

Barricade A natural or artificial barrier that will effectively screen a building from the effects of an explosion in another building containing explosives. To be effective, a barricade must be of such a height that a straight line from the top of any sidewall of a building containing explosives to the eave line of any building will pass through the barricade.

Black powder 75 parts potassium nitrate, 15 parts charcoal, and 10 parts sulfur. Principle propellant in aerial items.

Common fireworks are classified by the U.S. Department of Transportation (DOT) as Class C explosives. Ground devices are limited to 50 mg of explosive composition and 130 mg for aerial devices.

Flash-and-sound powder A commonly found combination of potassium perchlorate ($K\ ClO_4$) blended with aluminum (Al) or sulfur (S) to produce a flash-and-sound mix.

Magazine Any building meeting the requirements of the code for the storage of black powder and special fireworks.

Non-process building Any office building, warehouse, or other building in a fireworks plant where no fireworks or explosive compositions are processed or stored.

Process building Any mixing building; any building in which pyrotechnic or explosive composition is pressed or otherwise prepared for finish and assembly; any finishing or assembly building; any building in which fireworks are prepared for shipment. If a pyrotechnic or explosive composition, while in process, is stored in a process building, the building is still considered a process building.

Pyrotechnic composition A chemical mixture which, upon burning and without explosion, produces visible, brilliant displays, bright lights, or sounds.

Screen barricade Any barrier that will contain the embers and debris from a fire or deflagration in a process building, thus preventing propagation of fire to other buildings or areas. The barrier should extend from floor level to a height such that a straight line from the top of any sidewall of the donor building to the eave line of any exposed building intercepts the screen at a point not less than 5 feet from the top of the screen. The top 5 feet of the screen shall be inclined towards the donor building at an angle of 30 to 45 degrees.

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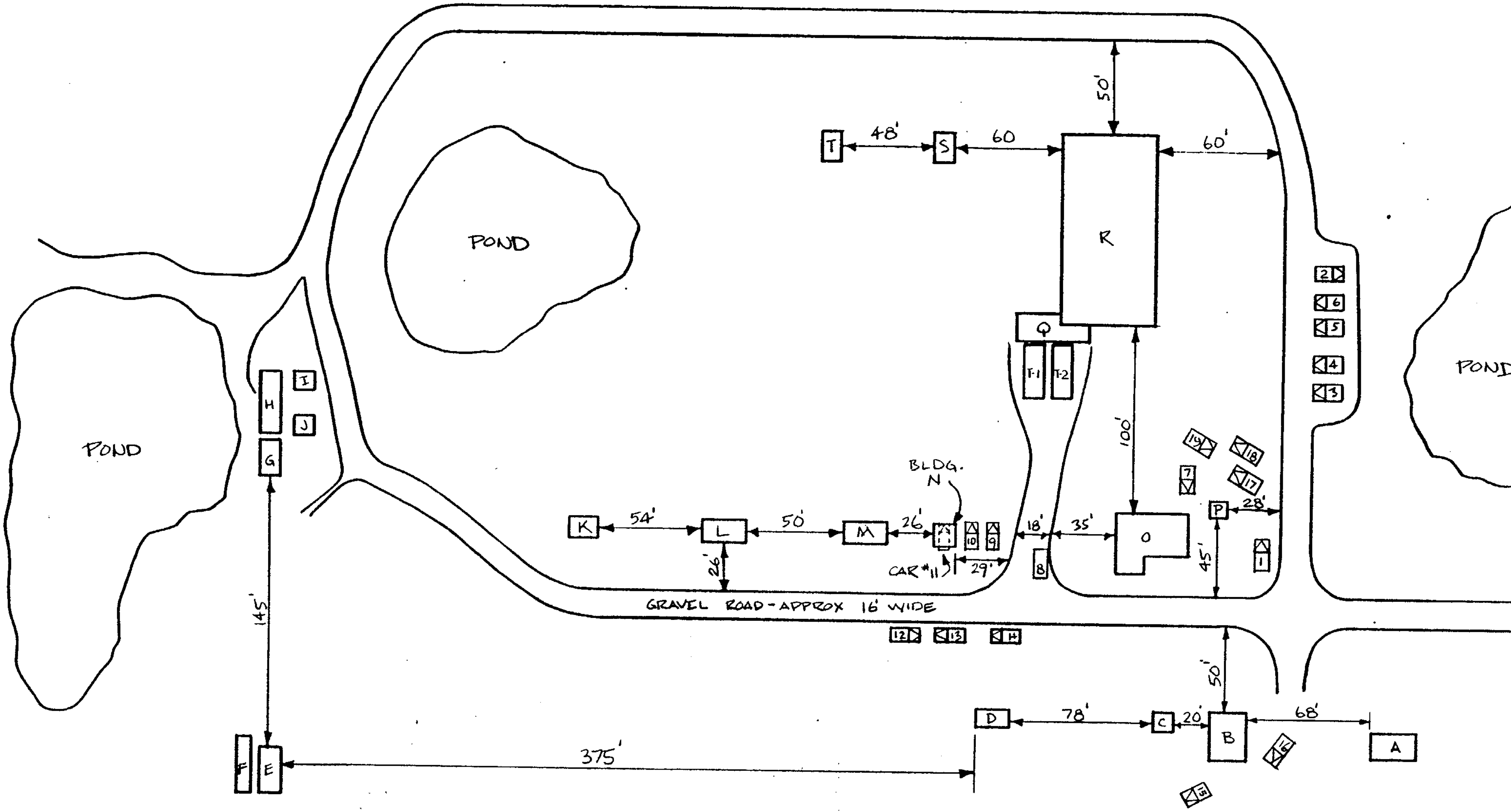
[8] The majority of term explanations were taken from Section 1-4 of NFPA 1124, Code for the Manufacture, Transportation, and Storage of Fireworks.

Special fireworks are classified by DOT as Class B explosives. They are intended to be fired by trained personnel and cover devices that exceed the explosive composition limits of common fireworks.

Storage building A building in which Class C fireworks are stored, but in which no processing is being performed.

Stars pellets of pressed pyrotechnic composition that burn with bright color.



BUILDINGS

A. HOT RICE DRY ROOM 12x25
B. ASSEMBLY ROOM 18x26
C. CARPORT - B 12x12
D. BLACK POWDER MILL 15x18
E. STAR STORAGE 12x24
F. TRAILER STORAGE 8x30
G. GUNPOWDER DRY ROOM 10x18
H. ROOFED WORK AREA 10x36
I. MILL #1 10x10
J. MILL #2 10x10
K. PUMP ROOM (RICE COMETS) 12x16
L. BALL SHELL ROOM (ASSEM.) 12x24
M. DRY ROOM - CLASS C 12x24
N. CARPORT - A 12x12
O. OFFICE/BREAK ROOM
P. UTILITY BUILDING
Q. TRUCK DOCK 14x40
R. WAREHOUSE 50x100 (LIFT ROOM & STORAGE)
S. CHEMICAL STORAGE 10x15
T. CHLORATE STARS 10x15

FIGURE 1

AERLEX FIREWORKS MANUFACTURING COMPLEX - JENNINGS, OKLAHOMA

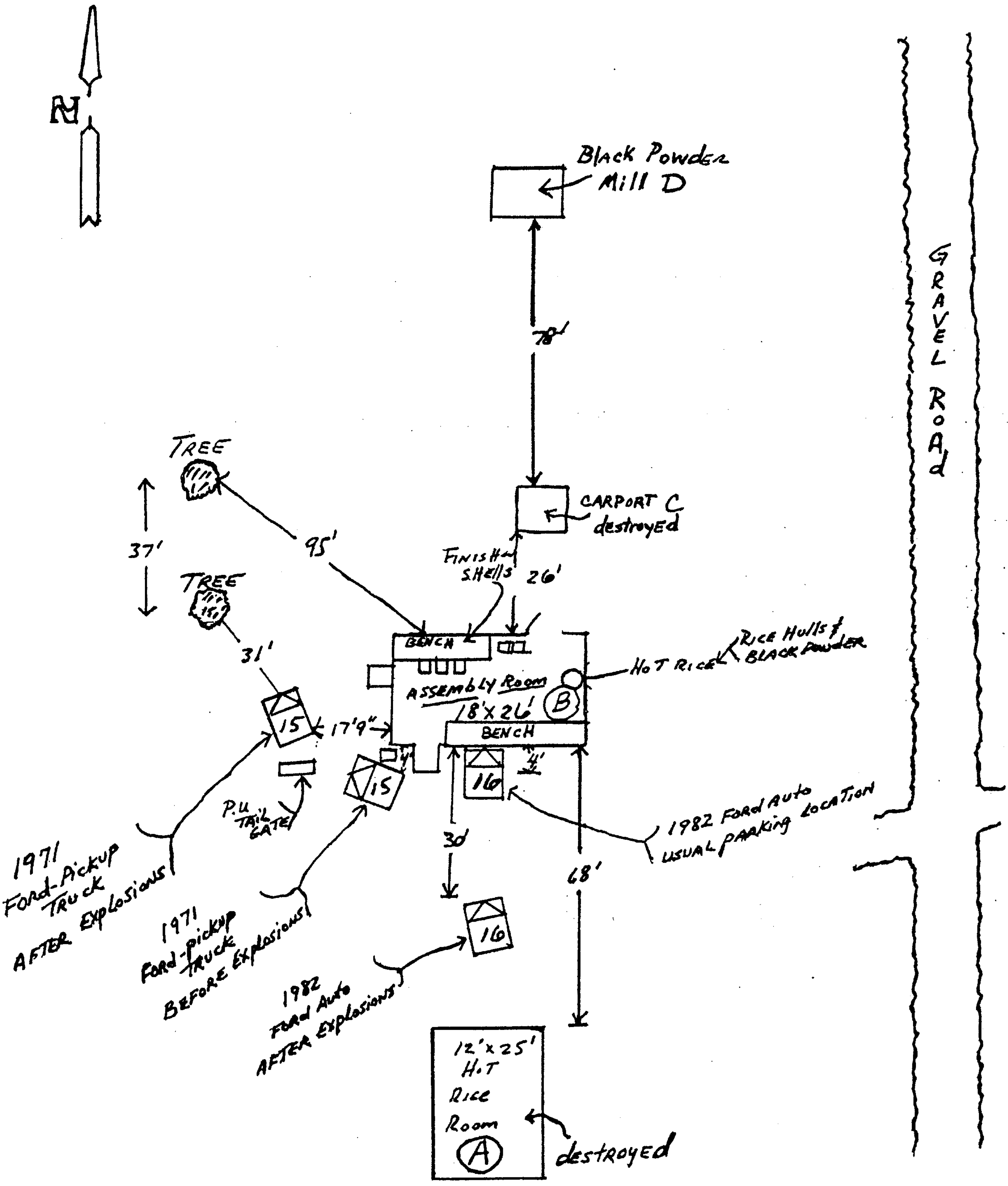


FIGURE 2

AERLEX CORP.

NOT TO SCALE.