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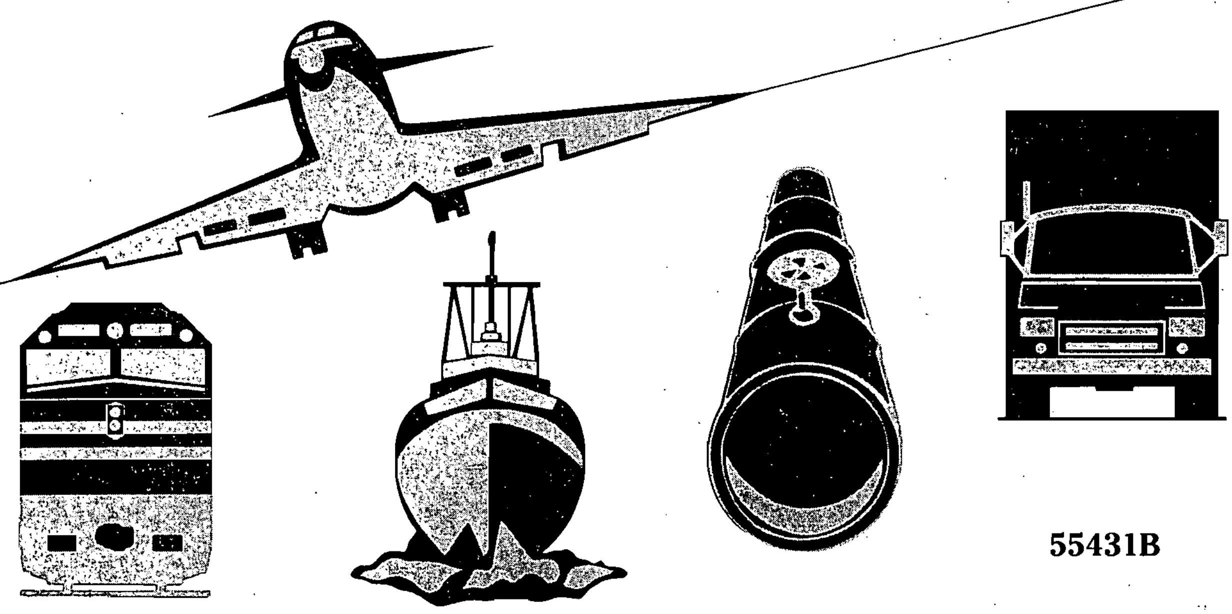
NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

PIPELINE ACCIDENT REPORT

NATURAL GAS EXPLOSION AND FIRE
DEPARMENT OF DEFENSE/ARMY
FORT BENJAMIN HARRISON
INDIANAPOLIS, INDIANA
DECEMBER 9, 1990



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The National Transportation Safety Board is an independent Federal agency dedicated to promoting aviation, railroad, highway, marine, pipeline, and hazardous materials safety. Established in 1967, the agency is mandated by Congress through the Independent Safety Board Act of 1974 to investigate transportation accidents, determine the probable cause of accidents, issue safety recommendations, study transportation safety issues, and evaluate the safety effectiveness of government agencies involved in transportation. The Safety Board makes public its actions and decisions through accident reports, safety studies, special investigation reports, safety recommendations, and statistical reviews.

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PIPELINE ACCIDENT REPORT

ADOPTED: APRIL 8, 1992

NOTATION 5431B

Abstract: On December 9, 1990, a gas system valve between one of Fort Benjamin Harrison's gas distribution systems and a discontinued segment was inadvertently opened, allowing natural gas to enter residential buildings that had previously received their gas from the discontinued segment. Gas accumulating in a building was ignited by one of many available sources, such as electrical switches and appliances, and the resulting explosion killed 2 occupants and injured 24 other persons. One building was destroyed, and two were damaged.

The following safety issues are discussed in this report: preparedness to handle gas system emergencies; qualification and training of employees responsible for pipeline system safety; adequacy of and adherence to standards on mapping, operation, maintenance, design, construction, and testing of gas systems; and adequacy of oversight by the Secretaries of the military services of their gas pipeline systems.

As a result of its investigation, the Safety Board issued safety recommendations to the Secretaries of the military services.

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EXECUTIVE SUMMARY

On December 9, 1990, a gas system valve between one of Fort Benjamin Harrison's gas distribution systems and a discontinued segment was inadvertently opened, allowing natural gas to enter residential buildings that had previously received their gas from the discontinued segment. Gas accumulating in a building was ignited by one of many available sources, such as electrical switches and appliances, and the resulting explosion killed 2 occupants and injured 24 other persons. One building was destroyed, and two were damaged.

The National Transportation Safety Board determines that the probable cause of the natural gas explosion and fire at Fort Benjamin Harrison was the failure of the Army to construct, maintain, and operate the Fort's gas distribution system in accordance with its own and the industry's standards. The result was the inadvertent opening of a valve to a discontinued steel gas main that allowed natural gas to leak into a residential building, where it ignited and exploded.

The following safety issues are discussed in this report:

- preparedness to handle gas system emergencies;
- qualification and training of employees responsible for pipeline system safety;
- adequacy of and adherence to standards on mapping, operation, maintenance, design, construction, and testing of gas systems; and
- adequacy of oversight by the Secretaries of the military services of their gas pipeline systems.

As a result of its investigation, the Safety Board issued safety recommendations to the Secretary of each of the military services.

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

PIPELINE ACCIDENT REPORT

NATURAL GAS EXPLOSION AND FIRE DEPARTMENT OF DEFENSE/ARMY FORT BENJAMIN HARRISON INDIANAPOLIS, INDIANA DECEMBER 9, 1990

INVESTIGATION

Accident

At 5:42 p.m. on December 9, 1990, an occupant of Harrison Village [1] (village), a residential housing complex within the Army's Fort Benjamin Harrison (Fort) near Indianapolis, Indiana, telephoned the Fort's fire department to report the odor of natural gas behind apartment 1035 B on Drumn Drive. (See figure 1.) The Fort's fire department dispatched firefighters, including the assistant fire chief, who served as the incident commander. They arrived at 5:47 p.m. and using a combustible gas indicator, confirmed the presence of gas both outside and inside some of the five apartments in building 1035.

Additional Fort personnel assisted in locating and isolating the gas leak. Despite trying for 3 1/2 hours, they were not successful. About 9:15 p.m., on entering apartment 1025 D, two occupants smelled a very strong odor of natural gas. They decided they should evacuate; but at 9:17 p.m., before they were able to leave, a violent explosion and fire occurred. (See figure 2.) Flames quickly shot through the roof over apartments 1025 C and D, and part of the roof for apartment D was blown more than 100 feet from the building. Burning debris from the building was blown onto the roof of building 1024.

On hearing the explosion and seeing the fire, the incident commander ordered firefighters at the scene to respond. About 9:24 p.m., he ordered that the gas supply for the village be shut off, and the engineer promptly complied. After seeing that building 1025 had been extensively damaged by the explosion, the incident commander ordered firefighters to concentrate on saving the occupants who were trapped in that building, on fighting the fire in building 1024, and on providing exposure protection for building 1026. At least two occupants on the second floor of building 1025 jumped from windows to escape the fire.

The incident commander called on nearby communities for assistance, and several local and State agencies responded. (See appendix C for a list of agencies providing assistance.) As ambulances arrived, the incident commander said that possibly three occupants were trapped in the collapsed portion of building 1025. Within an hour of the explosion, with the assistance of the Fort's emergency

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[1] Harrison Village is a cluster of 48 buildings on Fort Benjamin Harrison that contains 240 apartments for noncommissioned officers and their families.

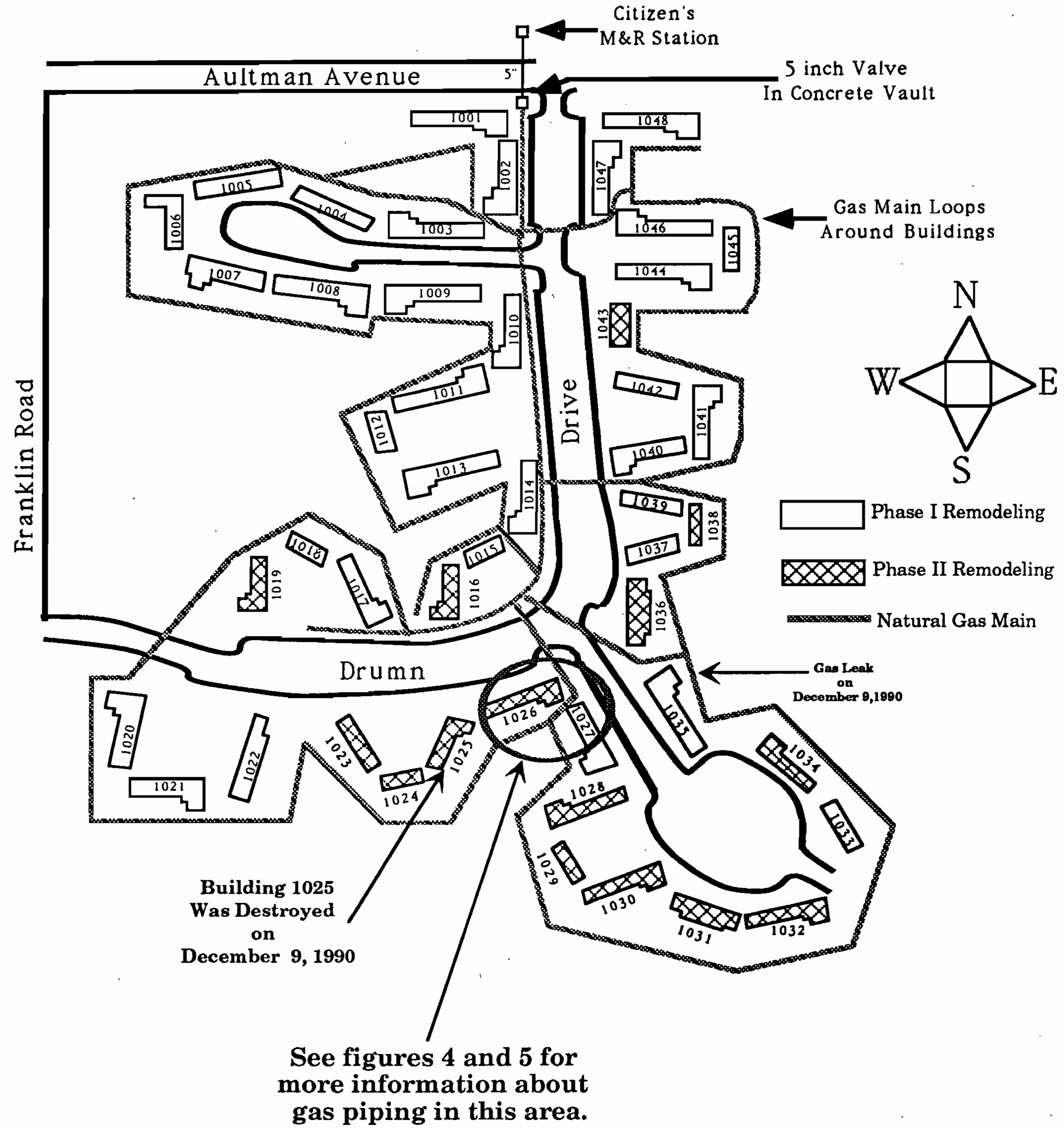

Figure 1.--Schematic of Harrison Village, Fort Benjamin Harrison.

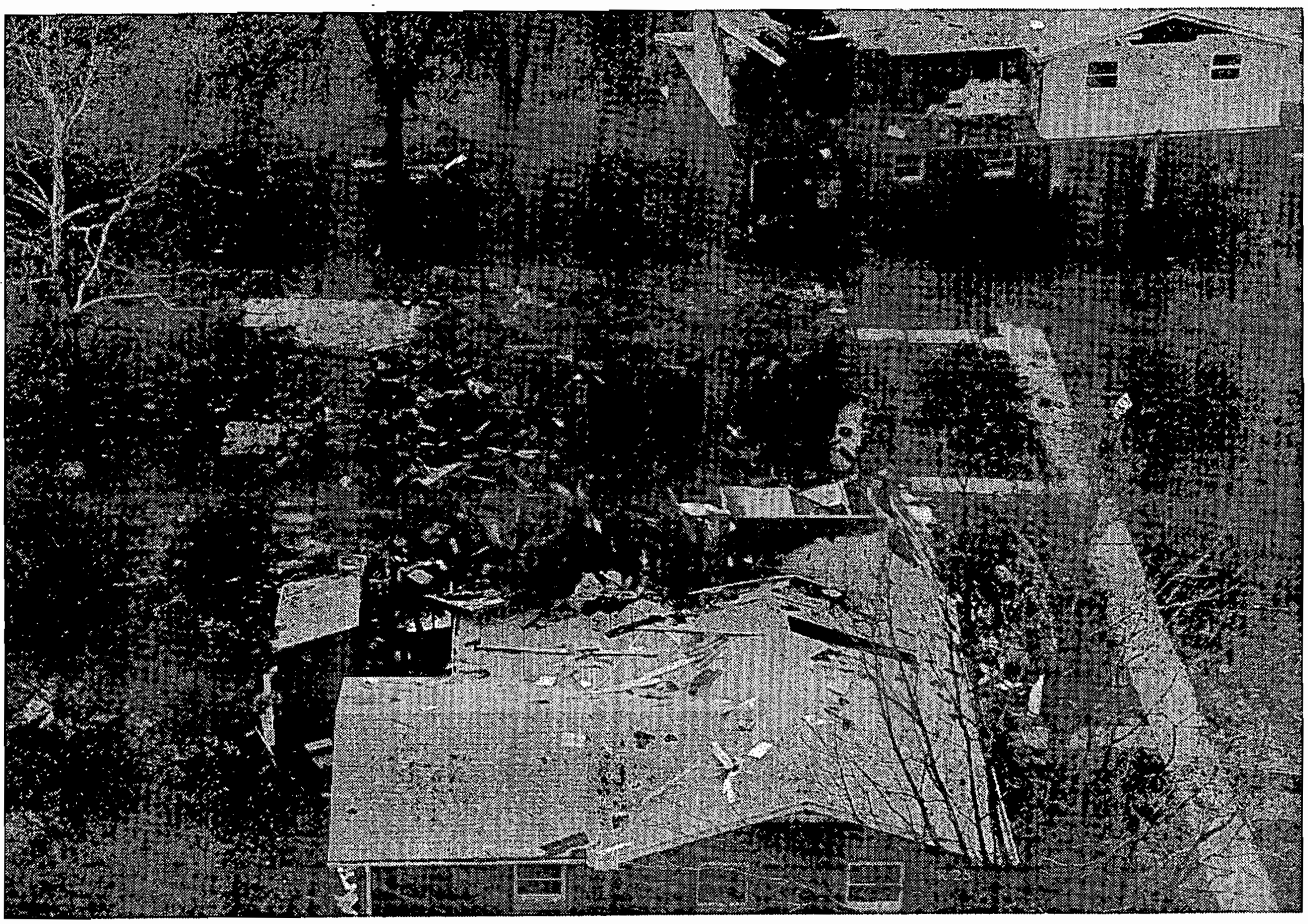

Figure 2.--View of the destroyed and damaged buildings.

operation center, all but one of the occupants had been located. The incident commander established a triage area across Drumn Drive and ordered all emergency units to use a specific radio frequency for on-scene communications.

The fires were brought under control within 1/2 hour of the explosion; within 2 hours, all significant fires had been extinguished.

Preaccident Events

The Fort, which was established in 1903, is in Marion County, Indiana, about 12 miles northeast of Indianapolis. The Army considers it a small base; it covers about 2,500 acres. In addition to the village, the base has 85 housing units that use natural gas.

The Fort is one of several Army installations that are scheduled to be closed in the 1990s. The Fort's management reports to the Army's Training and Doctrine Command and is commanded by a general. At the time of the accident, the Fort was being used to train and equip troops for Operation Desert Storm.

The Fort has the following tenant commands: the Army Finance and Accounting Center, the Army Enlisted Records and Evaluation Center, Readiness Group Harrison, the Public Affairs Proponent Activity, the Hawley Army Community Hospital, and the 123rd Army Reserve Command.

After the Fort's fire department responded to and confirmed the 5:42 p.m. report of gas odor behind apartments 1035 A and B, the fire dispatcher attempted to reach the Fort's night-duty engineer, who was the only Fort maintenance person on duty after normal work hours, to have him locate and repair the leak. The fire dispatcher was unable to contact him because the engineer had left the Fort on his meal break and the portable radio he carried was equipped with a frequency used by the utilities branch, which was different from the fire department's frequency. At 5:55 p.m., the firefighters, assisted by military police (MPs), evacuated five families from the building.

About 6 p.m., the engineer heard about the emergency at the village, and he drove directly there rather than to the plumbing shop, where his service truck and tools were. Although he had the telephone numbers of two plumbers who worked the day shift and could be called after hours, he did not call either one. Earlier that evening he had failed to reach them, and he assumed that both were still not at home. When he arrived, the incident commander briefed him on the gas leak, the results of the combustible gas indicator tests, and the evacuation.

At 6:13 p.m., firefighters directed by the engineer flooded the ground with water in the suspected area of the gas leak. The engineer told the firefighters to look for bubbles in the water. If they found any, they were to mark the spots with sticks so that the areas could be excavated. Although some firefighters thought that they might have seen a few bubbles, they were unable to find the leak.

Efforts to locate the outside, underground gas leak were not successful, and it was decided that the gas supply to the village would have to be shut off. The incident commander was concerned about shutting off the gas supply because of the weather. The temperature was dropping from the day's high of 54° F at 4 p.m. At 6 p.m., it was 42° F, and the wind was out of the southwest at 8 miles per hour. The engineer and the incident commander discussed the situation and decided that they might be able to stop the flow of gas to the leaking main by closing isolation valves near the leak. The incident commander reviewed the fire department's gas distribution map to identify the valves that should be closed, but the map did not show valves on the gas mains.

The incident commander then instructed the MPs to escort the engineer to the plumbing shop to get the map of the gas system stored there for use during emergencies. While he was at the plumbing shop, he got his service truck, which among other items contained pipe wrenches and a valve wrench.[2] The truck did not have plastic-pipe repair equipment or other equipment, such as a probe bar or a combustible gas indicator, for dealing with gas system emergencies. The Fort's fire department had the only combustible gas indicator available at the Fort, and the engineer had never been trained in the use of underground probe bars or hose extensions for combustible gas indicators.

When the engineer returned with the map from the plumbing shop, he and the incident commander found that the scale of the map was too large (1 inch to 800 feet) and did not show the locations of all gas valves. (See figure 3.) The incident commander then ordered the engineer to shut off the gas supply to the village.

About 6:30 p.m., the incident commander told three MPs to warn the occupants of the 210 occupied apartments that they would be without gas and heat because the gas system was being shut down. Some of the occupants were told later that other housing was available, but they were not instructed to evacuate or to take any specific measures, such as not using gas appliances.

The Fort's 5-inch village shut off valve was in a buried concrete vault south of Aultman Avenue; however, neither the engineer nor the incident commander was aware of its existence, nor was it shown on either of the two maps available to them. The engineer did know about the meter and regulator (M&R) station on the north side of Aultman Avenue. (The station was not a part of the Fort's gas system; it belonged to Citizens Gas and Coke Utility Company, the company that supplied the Fort with natural gas.) Even though he had not been trained to operate the valves within the station, he believed that he could shut off the gas to the village at the M&R station. The incident commander told him, along with a firefighter who had a portable radio operating on the fire department frequency, to turn off the gas supply.

The engineer gained access to the fenced and locked M&R station by unlocking the Fort's master lock, which was connected in series with the gas company's lock on a chain that secured the gate. Two valves at the M&R station controlled the gas supply to the Fort from the gas company's 375-psig pressure gas transmission pipeline.[3] One controlled the gas flow to the village, and the other controlled the gas flow to other areas of the Fort. The engineer did not know which valve controlled which.

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[2]A valve wrench fits over the top of a plug valve stem. It is attached to a 5-foot long T-shaped rod so that it can be inserted through a buried valve box and used to operate the valve.

[3]In 1989, the gas company installed a high-pressure gas transmission supply line to the Fort and gas regulators at the station to reduce the pressure from 375 psig to 26 psig, the pressure supplied to the village.

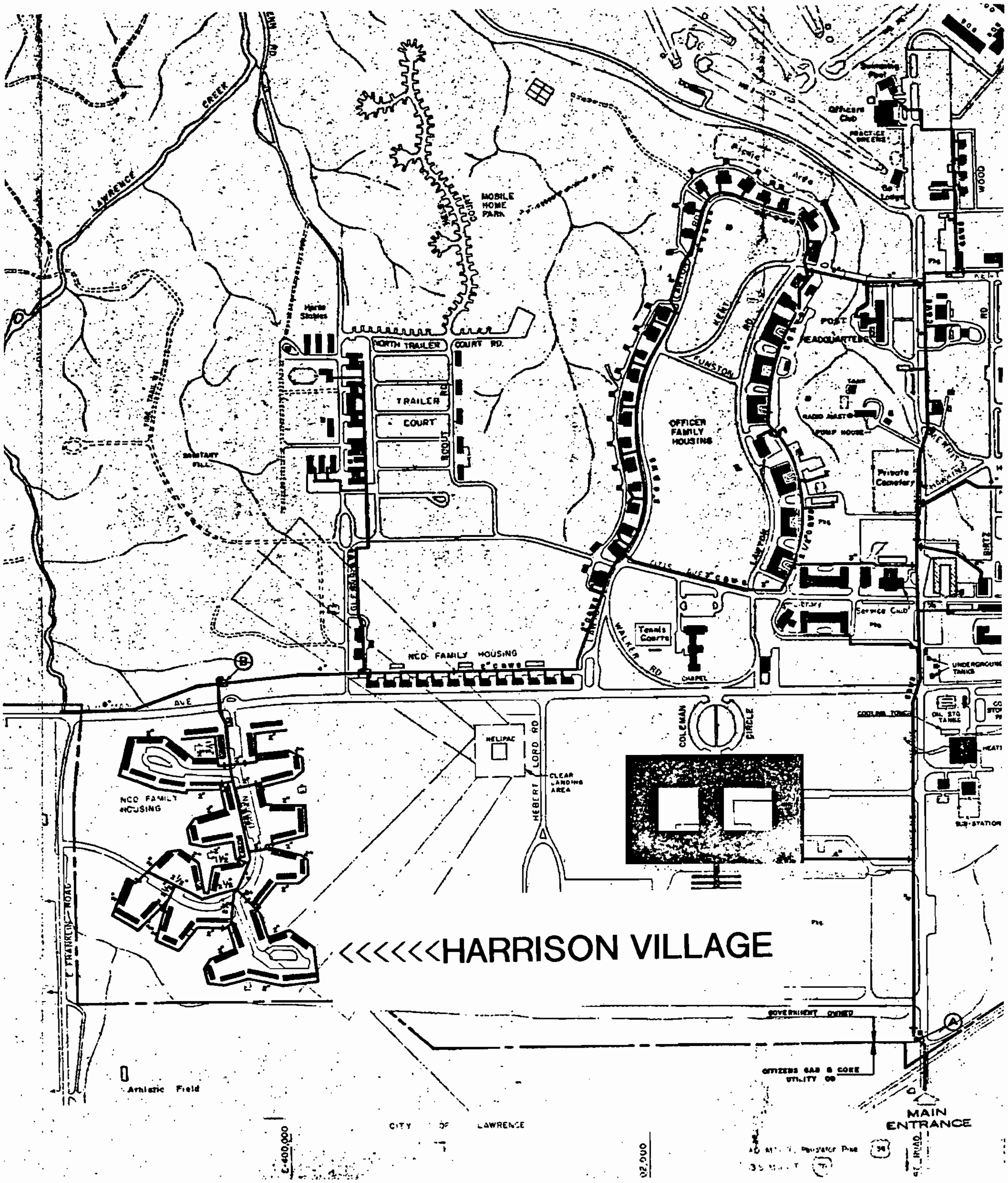

Figure 3.--Harrison Village as shown on the 1982 map brought by the night duty engineer to the village.

He used a pipe wrench to close the two plug valves.[4] [5] He did so, according to the fire control tapes, between 6:33 and 6:50 p.m. To communicate with the incident commander, the engineer had to tell the firefighter the information he wanted transmitted to the incident commander; the firefighter had to radio the message to the fire control dispatcher, who then relayed the message by radio to the incident commander. For several minutes, the engineer attempted to ask the incident commander whether the pressure at the leak site had decreased. Unable to find out, the engineer reopened the valve that he thought controlled the gas supply to other Fort systems, including other family housing units on the west side of the Fort. He left closed the valve he thought controlled the village supply. Next, he told the firefighter to instruct the incident commander to open a service line at a meter to one of the apartments to confirm that the gas supply to the village was off. (The valve that he left closed did control the village gas system. Closing and then reopening the other valve did not cause gas outages or other problems for the rest of the Fort because that distribution system also received gas at a second location on the south side of the Fort.)

After the valve that controlled the village gas system was closed, the pressure dropped below that needed to supply enough gas to sustain combustion. Burners and pilot lights on several gas appliances self-extinguished. The gas pressure dropped after the valve was closed because gas in the village system was being used within some apartments and it was leaking from the gas main behind building 1035. While using the gas kitchen stove, an occupant of apartment 1025 A saw the burner flame self-extinguish. An occupant of 1025 C told the occupant of 1025 A that none of the gas appliances in the building functioned. The residents of building 1025 did not report the gas outage or the gas odors they later detected within their apartments because, based on the information provided earlier by the MPs, they believed that the occurrences were the result of actions taken by the fire department and not a warning of danger.

The fire dispatcher made several attempts to telephone two plumbers at home who worked the day shift and who were on his list of people to be contacted when the gas system needed repairs. Unable to contact either plumber, he telephoned the Directorate of Installation Support (DIS) director about the emergency and about his inability to reach a plumber. Even though the Fort had no maintenance contract or mutual-assistance agreement with the gas company, the DIS director told the dispatcher to ask the gas company for help. The director then went to the village.

At 7:15 p.m., the director arrived at the village, and minutes later the gas company's night serviceman from Indianapolis arrived. The incident commander briefed them; afterward, the director and the serviceman asked the gas company dispatcher to send a two-person gas distribution crew to help. The dispatcher telephoned the gas company's district supervisor at his home. The supervisor told him to call the Fort's emergency telephone numbers listed in the gas company's *Operations and Maintenance Manual* and inform Fort personnel that the gas

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[4] Plug valves are normally used in gas systems and can be turned only 1/4-turn--clockwise to close them or counter clockwise to open them.

[5] According to the gas company's procedures, if a high-pressure main was temporarily shut down, a trained, qualified person was to check pressure on both sides of the valve that was closed to stop the gas flow. Whenever it was necessary to interrupt one or more customers, the gas was to be "turned off at the meter setting of each house located within the limits of the system to be shut down."

company could not send a maintenance crew because it had no agreement with the Fort to repair its gas system. The dispatcher dialed the two numbers, but neither answered. After he told the supervisor what had happened, the supervisor left his home for the village to discuss the situation with the director. A two-man gas company crew who had heard the gas company dispatcher's radio communications about the emergency at the village drove to the village to meet the supervisor.

The engineer recognized that he needed to close at least two valves on either side of the leaking segment to stop the flow of gas to the leak. Between 7 and 7:30 p.m., he and the firefighters searched near building 1035 for valves on the gas main. He found two valve boxes between buildings 1035 and 1036 that appeared to be the valves shown on the 1982 map from the plumbing shop. He said he used his valve wrench to reach and close the plug valves. Next, the incident commander, the engineer, and the DIS director studied the 1982 map, hoping to find valves between buildings 1026 and 1027 that could be used to complete the isolation of the main behind building 1035. One such valve was shown, but the engineer said that he needed two valves. When he and the firefighters expanded the area of search, they found a valve box cap marked *Gas*. Using a wrench, he operated the valve, which had no visible position indicator; he later stated that he remembered that the valve was hard to turn but he did not remember which way he turned it.

By about 7:30 p.m., the odor of gas in the village was minimal. The incident commander and the engineer decided that the control valve for the village at the M&R station should be opened for a short time to determine whether the valves they had operated had isolated the section of the main behind building 1035. The engineer, again accompanied by a firefighter with a fire department radio, went to the M&R station. On the incident commander's orders, he opened the village gas control valve slightly. About a minute later, the dispatcher radioed that the engineer should close the valve. The gas odor had quickly increased at the leak site, convincing the incident commander that either not all the valves necessary to isolate the leaking main had been closed or one of the valves that had been closed was itself leaking.

The fire department's combustible gas indicator was again used to test the soil over the main for leaks. Gas was detected at the service line riser for apartments A and B and in the valve box of the valve behind building 1035. A decision was made to excavate the valve because the highest combustible gas indicator reading was detected in its valve box. Using hand shovels, firefighters began removing the soil around the valve believed to be leaking.

At this time, a DIS plumber and his helper arrived. They were the day-maintenance crew and had been contacted by their foremen. They did not have any better information about the Fort's gas system than did the night-duty engineer. They did not report to the incident commander or help to locate the leak. One did help excavate the valve.

About 8:10 p.m., the gas company district supervisor and the two-man maintenance crew arrived. The supervisor met with the DIS director, who briefed him on the actions taken. They were then taken to the valve thought to be leaking and asked to help repair it. The DIS director did not coordinate these actions, as well as several others, with the incident commander; and likewise, the incident commander took several actions without coordinating them with the DIS director. Also, the incident commander never discussed with the supervisor the operation of the village valves or the valves at the M&R station.

At 8:35 p.m., the valve was fully excavated, and an unidentified person asked to have the gas pressure restored so that the valve could be checked for leaks. The incident commander, through the fire dispatcher and firefighter, told the engineer to again slightly open the village control valve at the M&R station. When, as a result, there was again an odor of gas in the area of the excavated valve, the gas company maintenance crew installed a tool that could be used to squeeze the plastic main[6] to stop the gas flow, and they used a soap and water solution to check the valve for leaks. No leaks were detected.

The gas company crewmembers used their probe bar to make holes in the soil along what they believed to be the route of a connecting gas main. By using a gas company combustible gas indicator equipped with a tube to sample the atmosphere within the holes, they soon identified a leak immediately behind building 1035. The leak was on the connecting main somewhat south of the excavated valve and about 2 feet from a tee fitting that connected the two plastic mains. The crew began to excavate the leak area.[7] The incident commander asked about the danger of fire. One of the crewmembers responded that there was no immediate danger.

At 8:45 p.m., the incident commander by radio ordered the engineer to fully open the valve at the M&R station that supplied gas to the village. The engineer complied and about 9 p.m., in response to the incident commander's direction, he returned to the leak site at the village.

An occupant of building 1020 stated that the gas in his apartment had been depleted before he went outside about 8:45 p.m., but that when he returned about 9 p.m., he detected a strong odor of gas. He opened the windows of the apartment to ventilate it and then relit the pilot lights on the gas range.

At 9:02 p.m., the fire department dispatcher reported by radio to the incident commander, "Be advised that I just had an occupant of 1020 Drumn Drive call and say they still got a strong odor of gas in that area. I'm not sure if you're aware of it or not." The incident commander said that he did know and added, "We should have it probably all over the village at this time." The dispatcher said, "I'll notify anyone else that calls."

Between about 8:45 and 9:15 p.m., additional occupants of at least six apartments west and upwind of building 1035 smelled gas in or around their apartments, but none told the fire department or the MPs. The odor of gas was detected by residents outside buildings 1023 and 1024, for example, and an occupant of apartment 1025 B complained to neighbors about a strong odor of gas within his apartment; he was observed using a piece of cardboard to ventilate the apartment by fanning air through the opened front door.

The incident commander instructed the fire captain to use his combustible gas indicator to check out the leak report from building 1020. The fire captain was busy with other tasks at the time and did not immediately leave to verify the report. At

[6]Between 1987 and 1990, the Corps approved the design and construction of plastic gas mains to replace many of the Fort's steel ones.

[7]The next day, this spot was found to have been the actual leak location. A butt fusion joint in the Phase I plastic main had failed and leaked.

9:17 p.m., before the main behind building 1035 was fully excavated and as two firefighters were walking by the end of building 1025 to investigate the gas odor report from the occupant of building 1020, building 1025 exploded.

Incident Management

The assistant fire chief, in accordance with standing operating procedure No. 7, assumed the responsibility of the incident commander when he responded to the gas odor report. He said that because no one had told him that he was relieved of overall command, he had believed throughout the emergency that he was in command.

The DIS director, a lieutenant colonel, stated that he did not have to formally declare his command of the response actions because, in the case of a hazardous substance spill incident on military installations, the Army's Prevention and Control Plan established the senior officer at the location as the person in charge. On arrival at the scene of the emergency, he was the senior officer. Therefore, according to the plan, he was in overall command of the emergency; and the assistant fire chief, as the senior firefighter (the incident commander), then commanded only the fire suppression activities. The DIS director also stated that because all Fort personnel on the scene work for the DIS director, he believed they recognized him as the person in charge of the emergency response.

Injuries

	Building Occupants	Other	Total
Fatal	2	0	2
Serious	5	0	5
Minor	3	10	13
None	6	0	6
Total	16	10	26

A 5-year old received fatal burns when she was unable to escape from a second-floor bedroom in apartment 1025 C. The other fatality was an adult male who was severely burned during the fire and later died. The 10 nonoccupants who were injured were firefighters and MPs who suffered from smoke inhalation.

Damages

The Army Corps of Engineers (Corps) estimated the explosion and fire damages to buildings 1023 and 1024 at $3,800 and $48,500, respectively. Building 1025 was destroyed, and the estimated loss was $300,000. Total building damage was approximately $352,000. After the accident, the gas company replaced the entire village gas distribution system at a cost of $147,000 to the Army. Also, flexible gas fuel piping and vent pipes within the village were replaced at a cost of $73,000.

Employee Qualification and Training Procedures

The Army did not require gas distribution experience as a prerequisite for personnel employed to manage, supervise, work on, or operate gas systems. The people it used to maintain a gas system usually were plumbers who had general experience working on such piping systems as steam, sewer, and water. The Army also did not have a training school for teaching its personnel gas distribution safety practices; it depended on locally available classes about generic pipe maintenance.

Directorate of Installation Support Director.--The director, a lieutenant colonel in the Corps, was not required to have an engineering degree; however, the man who was DIS director at the time of the accident had both a bachelor's and master's degree in civil engineering. He had been transferred to the Fort in August 1990 after serving as a director of engineering and housing at a base in Germany for 3 years and as a staff engineer of engineering and housing at a major army command (MACOM) for 4 years. He had no prior experience with gas distribution system operations. His training had not included specific information on the design, construction, maintenance, or operations of gas distribution systems. All Fort support operations, including the fire department and utility operations, were under the general management of the DIS director.

Incident Commander.--The assistant fire chief had been the assistant chief for 6 years. About 2 years before the accident, he had attended a gas company training course on the hazards of natural gas, as did all the Fort's firefighters. There had been no formal agreement with the utilities branch about which preplanned actions each party responding to an emergency should take; and before the accident, no written guidelines were available about responding to a leak or other incident involving natural gas.

Chief of the Directorate of Installation Support Utilities Branch.--The chief was required to have an engineering degree. The chief at the time of the accident was a civilian employee who had been a captain in the Army and had a degree in nuclear engineering; however, he had no experience in maintaining or operating natural gas distribution systems. In his 5 years as chief, he had not had, nor was he required to have, training in such systems. He stated that he had hired two pipe fitters and rated them as qualified to work on natural gas systems because they had listed gas piping experience on their civilian resumes. He had not verified their experience. Since their employment, the chief had not required either pipe fitter to be trained in operating or maintaining a distribution system, nor had he required them to be trained in using the tools required to repair gas leaks on plastic gas mains. One of the pipe fitters called the chief about 7 p.m. on the night of the leak. The chief later said that he did not respond to the leak because he "thought I'd just be getting in the way," and he "assumed that they knew what they were doing."

Night-Duty Engineer.--The engineer did not have either a degree or a certificate qualifying him in any engineering discipline, and he did not have any other special qualifications for the position. He had received some on-the-job training in piping and appliances while he worked for a general contractor before he was employed at the Fort, where he had worked the night shift for 10 years. He was the only night-duty engineer from 3:30 p.m. to midnight; and between midnight and 7:30 a.m., no one from the heating, ventilation, and air conditioning (HVAC) shop was on duty. Besides HVAC work, the engineer was also responsible for dealing with gas and water leaks and electrical problems and for making gas service calls to relight pilots on gas ranges, water heaters, and furnaces.

He had received no training on dealing with gas distribution system leaks, nor had he attended any gas-operations or gas-maintenance training schools. He had never been issued a combustible gas indicator or been trained in its use. He was not aware of any written emergency plan about responding to gas leaks, and he had not received a copy of the Army TM 5-654 for the maintenance and operation of gas systems. He did have the home telephone numbers of the two Army day-duty plumbers who could be called at night to repair gas pipe leaks.

Fort's U.S. Corps of Engineers' Project Manager.--The Corps required that its project managers have engineering degrees and an unspecified amount of Corps experience before managing or providing quality assurance services for construction projects. The project manager was responsible for reviewing the Fort's project designs to determine whether they could be constructed, for administering construction contract modifications, and for inspecting the work of contractors to ensure that the contract provisions were met. He held a bachelor's and a master's degree in civil engineering and had worked in the Corps' design division for 2 1/2 years and as a project manager at another fort for 1 1/2 years before becoming the Fort's project manager. He had been the project manager at the Fort for 2 1/2 years before leaving the Corps in April 1990. Before his employment by the Corps, he had had no experience in the design, construction, maintenance, or operation of gas distribution systems, but he had installed gas service lines to houses. During his 4 years with the Corps in design or project management, he had not attended any training classes on gas distribution systems. As a project manager, the only gas system-related training that he had received was a 6-hour course on the heat-fusion joining and inspection of medium-density polyethylene (PE) piping that was taught by a representative of the plastic manufacturer.

Fort's Corps Project Engineer.--The Corps required that its project engineers have an engineering degree and some Corps experience in quality assurance and contract administration on construction projects. The project engineer, located at the Fort and reporting to the Louisville district office, was responsible for administering contracts and performing quality assurance reviews. He had a degree in civil engineering and before becoming a project engineer, he had worked for the Corps for about 8 years, including 1 year as a project manager and about 3 years administering Corps construction grants to the U.S. Environmental Protection Agency. Before his Corps employment, he had worked as a project engineer for the city of Cincinnati. He described his Corps project engineer responsibilities as assisting the area engineer in performing "availability and constructibility" reviews. He characterized the purpose of his review as being to determine whether a project could be constructed rather than to assess the technical adequacy of the design. He had not attended any training on gas distribution systems.

Gas Company District Supervisor.--The gas company district supervisor who responded to the village emergency had been promoted to that position in 1984 because of his experience and training. He had attended numerous courses on gas company procedures and on technical issues. He had not been trained in what to do about an emergency at the Fort, and the gas company's written emergency procedures contained no information on that issue.

Gas Distribution System

Initial System.--In 1952, the village gas system was constructed by a private owner, who had operated it until 1960. The system consisted of 11 loops of 2-inch coated and wrapped steel mains that were installed underground around the 48 apartment buildings then named Wherry Housing. A mixture of liquefied petroleum gas and air (LP-Air) was supplied to the village loops by a 5-inch-diameter steel main on Aultman Avenue and a 5-inch-diameter steel main that became a 4-inch-diameter steel main on the west side of Drumn Drive. The 1952 system map showed that a 2-inch valve had been installed on the gas main behind building 1026 near the main's junction with a 2 1/2-inch main between buildings 1026 and 1027 and a 2-inch main behind building 1027. (After the accident, this valve was found buried underground in the open position and without a valve box to allow operation of the valve.) (See figure 4A.) In 1960, the Army bought the village gas system for $24,388.

The Fort's accounting records and engineering drawings about modifications to the gas system were incomplete and inaccurate for the period from 1960 to 1970. Neither the records nor the drawings indicated the existence of a concrete vault that was probably constructed during the 60s. That vault, which had cracked and deteriorated in the meantime, was just south of Aultman Avenue, and it housed both a 5-inch and a 2 1/2-inch gate valve that had been used to shut off the gas flow to the village during previous emergencies. This vault was not shown on most of the gas maps produced after 1970.

According to a 1964 gas map, a valve had been installed on the 2 -inch gas main between buildings 1026 and 1027, and a valve had been installed on the 2-inch gas main behind building 1027. The map, however, did not include the 2-inch valve that had been installed in 1952 behind building 1026. (See figure 4B.)

<u>Conversion to Natural Gas</u>.--In 1970 and 1971, the village's fuel was changed from LP-Air to natural gas, and the Fort contracted with the gas company to make appropriate modifications to the village's distribution system. The contract called for the gas company to install gas appliance burner orifices appropriate for natural gas, to install new gas service regulators and set them to reduce the then 8- to 12-psig gas system pressure to the 1/4-psig pressure for use in the apartment piping systems, and to install additional anodes to protect the coated buried steel piping. The contract further required the gas company to install 14 new valves on the main loops around the buildings so that if any main segment had to be isolated, not more than three buildings would be deprived of gas. The gas company was also to test the gas system at a pressure of 90 psig and to repair the leaks revealed by the pressure test.

Also in 1970, the Army issued TM 5-654, its gas system operation and maintenance technical manual, which included gas system mapping requirements. It required that maps be large enough to show such details as the location and size of gas lines, the location of valves, and the number assigned to each valve.

A 1970 preconstruction drawing showed the proposed locations of the valves installed at that time and also showed that 1-inch-diameter service lines were located at one end of each building to supply a common gas water heater for each building. The 1970 preconstruction drawing did not show the distance between the buildings and the gas mains, but it did show a 2-inch valve on the main behind building 1027 and a 2-inch valve on the main beside building 1026. It did not show a 2-inch valve on the main behind building 1026 that was included on the 1952 map. (See figure 4C.) The valves shown were numbered.

An approved-for-construction drawing dated 1971 did not show the valve behind building 1027 but did show the valves beside and behind building 1026. (See figure 4D.) This drawing also did not show the distance between the buildings and the gas mains.

<u>1982 Modifications and Maps</u>.--Fort records indicate that the village valves were <u>located and lubricated in 1982</u>. Valve access boxes were raised to ground level, if necessary, to provide access to buried valves; about two dozen leaks were located and repaired; and electrical shorts in the corrosion protection system were corrected. Additional valves to be installed on the system at this time were indicated

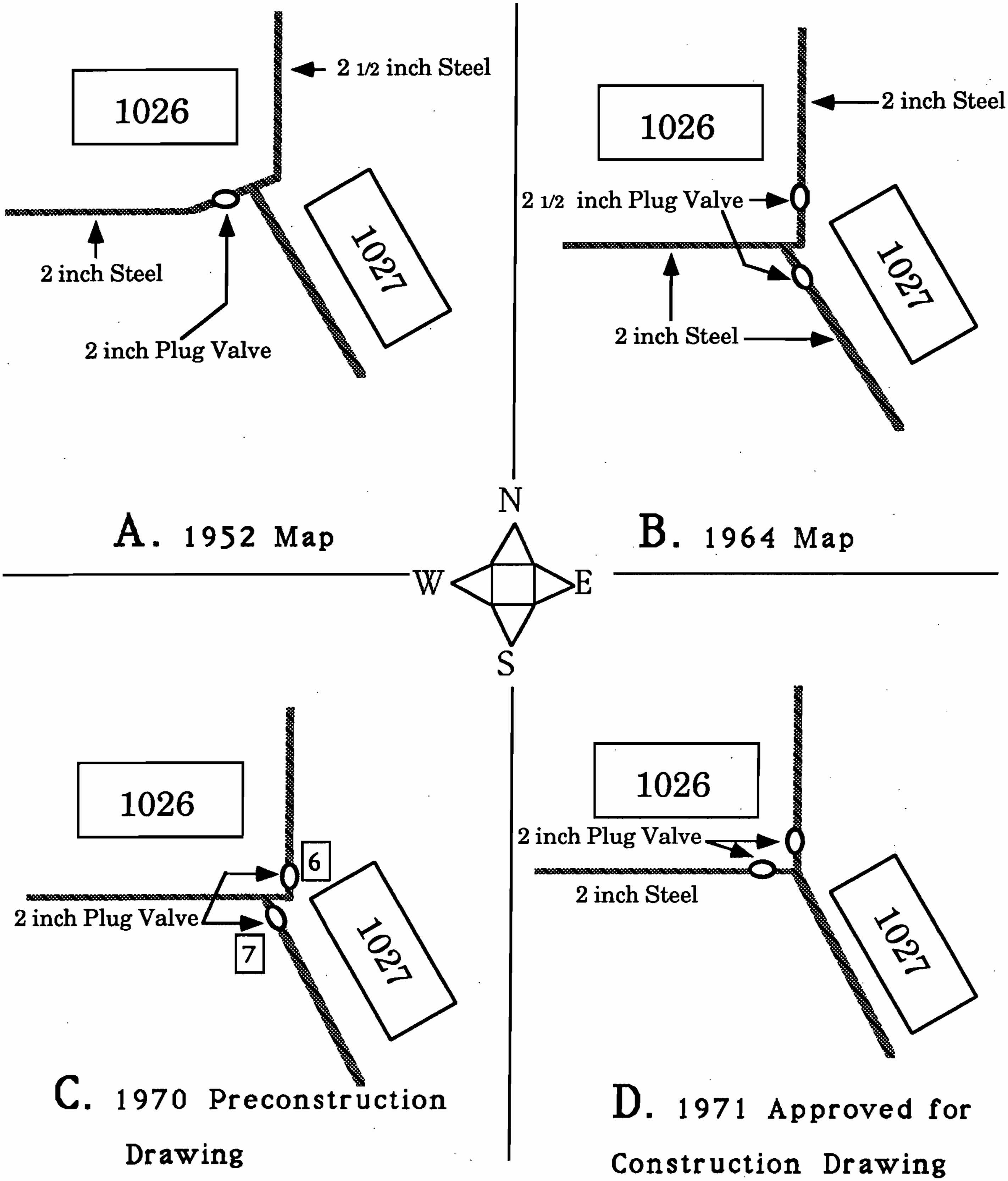

Figure 4.--Valve arrangement between buildings 1026 and 1027 as shown on various Fort documents.

on the drawing, which also showed as a triangle the location of the village shut-off valves south of Aultman Avenue

An August 1982 general gas map (see figure 3), a copy of which the engineer was believed to have obtained from the plumbing shop on the day of the accident and later lost during the emergency, did not show the location of the concrete vault south of Aultman Avenue. It also did not show the precise location of the village's mains because its scale was too large (1 inch to 800 feet). Fewer than half of the system's isolation valves were on the map.

1984 Map.--After the accident, a December 1984 general gas map was found among the Fort's engineering drawings. The map, which had been developed with the aid of a computer, showed the valves installed in 1971 on the main behind buildings 1027 through 1035, but it did not show the concrete vault south of Aultman Avenue or the 2-inch main valve behind building 1027. It indicated that about 700 feet of 2 1/2-inch coated and wrapped steel main that ran parallel to the 4-inch-diameter header and the 5-inch-diameter main on the west side of Drumn Drive had been abandoned. Current Fort property account records did not indicate that a 2 1/2-inch main on Drumn Drive had ever been installed or abandoned.

1987-1990 Modifications and Maps.--In the late 1980s, the Fort's management decided to enlarge and modify the apartments in the village. Because some apartment additions were to be constructed over the gas service lines and parts of the loops that were already there, much of the 2-inch-diameter main and all of the active gas service lines were to be replaced. The Fort asked the Corps to use the DOD *Guide Specifications for Military Family Housing* (DOD Guide) in preparing the modification designs and contracts. Because the Corps considers itself a technical consultant and the military services its clients, it accepted the Fort's choice of the specifications rather than using its own more detailed *Guide Specification for Military Construction* (CEGS-02685).

The DOD guide does not provide guidance about designing, constructing, and testing gas distribution systems. According to the Corps, the document is based on the assumption that private industry routinely constructs family housing units and therefore does not need detailed specifications. The section that addresses gas distribution systems notes that provisions are included for both natural and manufactured gas. It instructs the user to determine which type of gas will be used and to delete those provisions that are not applicable. The DOD guide contains no information on the abandonment of existing systems and no information about plastic pipe materials or fittings.

A Corps representative stated that it was determined that if the work were performed under a single contract, renovation costs for the 48 buildings in the village would exceed the amount Congress had appropriated. Therefore, the work was divided into two phases. Phase I, the modification of 32 buildings, or 166 apartments, was done under a contract for about $5.25 million that was issued on June 29, 1987. The $3 million contract to modify the remaining 16 buildings, or 74 apartments, was issued about 2 years later. The main loops that were replaced in the two phases often were not contiguous, and according to a Corps witness, no one analyzed the effects of the individual phase modifications on the overall gas system. When a building was modified, the gas main segment adjacent to it was replaced at the same time. For example, in the gas main loop around buildings 1027 through 1035, the main segments behind buildings 1027, 1033, and 1035 were replaced during the first phase; the main segments behind buildings 1028 through 1032 and building 1034 were replaced during the second phase; and the main segment between buildings 1032 and 1033 was not replaced.

Phase I.--The engineering division of the Corps' Louisville district selected a private architect/engineer firm to design the modifications, develop the specifications, and prepare the construction drawings for Phase I. The Corps gave him the current DOD guide, and the DIS gave him the gas distribution maps. The architect did not keep the maps, and no one had a record of which ones he had been given. The project manager did not recall the date of the map given to the architect, but he did recall that there were "lots" of dimensional inconsistencies between the actual locations of the main loops and the locations shown on the map.

The Corps' Louisville district reviewed the architect's designs; its engineering division checked their technical completeness, and its construction division determined whether they could be economically constructed. The Corps twice reviewed the architect's work in progress, including the drawings and specifications for the interior and exterior gas piping--once when 30 percent of the work was finished and again when 90 percent was finished. When the architect had completed his work, the Corps reviewed and certified the design and conducted a review meeting with Fort personnel and other interested parties. After the designs were approved, the plans and specifications were put out for bid. The construction drawings and the bid-solicitation document contained more than 300 pages of requirements to be met by the company that won the contract.

The bid-solicitation document addressed the material and construction specifications and acceptance tests for all modifications, including the gas distribution modifications, to be made to buildings and other facilities. According to this document, the gas distribution system was to transport a mixture of manufactured and natural gas at pressures of 5 to 10 psig. The document permitted the use of steel, cast-iron, and wrought-iron pipe and referred to various industry standards on pipe, pipe coating, and valves; but the contractor had to meet only those provisions included in the specifications. The document did not require that the modified gas system meet the applicable provisions of the then current Federal or Corps gas pipeline safety standards or of the generally recognized gas industry standards on design, construction, and testing.

While the contract called for coated steel or cast-iron gas mains, coated steel service lines, and installation of a corrosion protection system, it also called for the use of "drips," or moisture collectors, at low points in the distribution system, which no longer is an industry practice. Fittings installed for future connections were to be closed with metal caps or plugs. There was no requirement that discontinued fittings and pipe be closed or physically separated from the distribution system. Pipe segments could be connected by threaded or mechanical joints, and steel pipe could be welded. The adequacy of the pipe coating was to be tested. The entire gas system was to be tested to ensure that it was "gas tight" by pressuring the system with air to a level consistent with the recommendations of the 1982 ANSI B31.8 *Code for Gas Transmission and Distribution Piping Systems* (Code). (The Corps' office at the Fort did not have a copy of the Code when it reviewed the specifications or when the village was being modified.) The specifications also included requirements about pipe support, quality of backfill materials, and internal cleaning of the new system.

The architect's drawings showed the estimated locations of the existing steel mains and the proposed locations of the new main loops. They did not indicate the locations of existing valves, nor did they detail the manner of, or the specific locations for, connecting the new and existing pipes. The drawings identified the steel pipe segments that were to be abandoned but not the actions necessary to abandon them. Neither pipe locating equipment nor other means were used to confirm or mark the locations of the segments that were to be abandoned.

Before construction started, the contractor realized that DIS personnel preferred plastic to steel piping. He offered to use plastic pipe and to reduce the contract amount by $18,855. The DIS housing management agreed, and on December 4, 1987, the Corps executed a Contract Modification Proposal and Acceptance with the contractor to "furnish and install PE gas piping in lieu of black steel for the new gas distribution system."

The contract modification did not specify either a minimum wall thickness or a design pressure for the pipe, and the Corps project manager stated that he was not familiar with the Department of Transportation's (DOT's) rules about the transportation of natural gas (49 CFR Part 192). The DOD does not have to abide by the requirements of Title 49. Nevertheless, Section 6 c (1) of TM-848-1, an Army technical manual, states that "in view of the rapid progress of technology in the field of plastic pipe materials, engineers should consult the latest issues of the American Gas Association's (AGA) *Plastic Pipe Manual for Gas Service*, Title 49. . .; and the American Society for Testing and Materials (ASTM) standards on plastics."

The Corps did not revise the specifications to reflect the different construction and inspection practices necessitated by the switch from steel pipe to plastic pipe. For example, the Corps did not substitute for the steel welding specifications any requirements about fusing segments of plastic pipe. Also, no change was implemented to address the substantial change in the gas system's corrosion protection that occurred as a result of installing plastic pipe segments into the all-steel gas pipeline.

The contractor and a project manager asked the gas company for a list of the types of PE plastic pipe that it had successfully used. The contractor selected and purchased Dupont Aldyl "A," which is a medium-density plastic PE 2306 that could be purchased in 200-, 500-, or 1,500-foot coils. The 2-inch plastic pipe was rated SRD-11,[8] that is, the average outside diameter was 2.375 inches and the minimum wall thickness was 0.216 inches. Both contract construction personnel and the project manager attended a 6-hour training session given by the pipe manufacturer on how to use the heat fusion equipment to join lengths of plastic pipe. Under the contract modification, Fort personnel were to retain the heat fusion equipment after the contractor had finished so that it would be available for future repair work on the plastic pipe.[9]

The Phase I construction was performed between June 1987 and March 1990. The project manager stated that DIS personnel were initially in charge of locating and operating the gas shutoff valves. However, the DIS maintenance crew's workload later increased greatly, and the project manager assumed its

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[8]Standard Dimension Ratio of 11. The ratio is calculated by dividing the average outside diameter of the pipe by the minimum wall thickness. See American Society for Testing and Materials D-2513.

[9]The heat fusion equipment was not given to the DIS after construction was completed, and Fort personnel were not aware of any similar equipment available at the Fort.

responsibilities even though he had no operating experience or training in that kind of work. The DIS maintenance crews gave him a valve key that allowed him to operate the underground valves as needed to facilitate the construction work. In some instances he was unable to operate them without first using a metal detector to locate the valve boxes, several of which had become buried under as much as 6 inches of dirt.

A Corps representative inspected and approved the Phase I modifications; the plastic mains were tested to 90 psig pressure, and the gas mains then were connected to the existing steel loops using compression couplings. Leaks were sometimes found in the steel mains when they were excavated to be connected to plastic pipe. Those gas leaks were repaired, but further action was not taken to test for other leaks or to determine whether the corrosion protection system had been adversely affected by the installation of the plastic mains. The ends of the steel pipes that were no longer to be used were not sealed, a measure that protects them from the entry of gas or water.

The project engineer and the project manager, the two Corps engineers responsible for checking the construction work, stated that the contractor could be required to perform only the work included in the written specifications and, therefore, was not required to purge or use end closures on the abandoned pipes or to modify the corrosion protection system because that work was not specifically addressed in the contract.

Phase II Modifications.--The Corps used the same architect. At the time the architect was designing modifications for the Phase II gas mains, he did not have detailed information on the as-built locations of Phase I gas mains because a map had not been prepared. Thus, the estimated rather than the actual locations of the gas mains installed during the Phase I work were shown, and the tie-in locations to the Phase I plastic mains were not explicitly shown.

The Corps procedures for review and approval of the architect's work on Phase II were the same as those used with the Phase I designs. The architect produced and provided construction drawings and a 300-page bid-solicitation document for the Phase II work; 3 pages were devoted to the requirements for the gas distribution system. According to the requirements, the system was to distribute a mixture of manufactured and natural gas at 15 to 30 psig pressure. The mains were to be of PE plastic pipe and to be joined by electro-fusion. The service lines were to be of steel pipe; however, steel pipe was not included in the listing of approved materials. The PE pipe and fittings were to conform to ASTM Specification D-2513, standard weight.

The only industry standards mentioned in these specifications were the ones about PE plastic pipe and fittings, about handling coated and wrapped steel pipe, and about valves. The specifications included requirements for such items as regulators, valves boxes, and pipe cutting; however, they did not address such procedures as fusing plastic pipe, installing mechanical couplings, testing, abandoning replaced main sections, protecting steel service lines against corrosion, and connecting new pipe to existing gas mains. Again, no general code or industry standard was included that governed design, construction, and testing of gas distribution systems.

As in the case of the Phase I drawings, the architect neither showed the existing loop shutoff valves that were between or behind the buildings nor specified the locations where the new mains were to be connected to the old ones. A general note on the drawings called for the contractor to relocate the 2-inch steel gas mains from beneath the building additions by installing a new 2-inch gas main. For buildings 1023 through 1026, the then existing 2-inch steel main was not shown to be beneath the building additions; and at building 1026, the existing gas main was shown to be about 10 feet from the new addition. No detailed note similar to the one included in the Phase I drawings called for the existing gas main to be abandoned.

The Phase II modifications began in June 1989. The contractor, who was allowed to choose the type of pipe, selected a high-density PE 3408 pipe that was manufactured by Quail (a black pipe) and conformed to the ASTM Specification D-2513 standard weight pipe. It took about 15 seconds longer to heat the high-density plastic to its fusion temperature than it did to heat the medium-density plastic used in Phase I. According to the project manager, the contractor joined the two types of pipe in at least three places. All three joints leaked when subjected to the 26-psig gas system pressure and had to be cut from the system, and these tie-in joints had to be remade using mechanical couplings. The project manager stated that he recognized the difficulty the contractor was having in heat fusing the dissimilar plastics, but he took no action to prevent the connections being made. The high-density plastic was also used for the gas service lines, except for the segment of the service line above the ground. It was made of steel.

The 2-inch steel main loop behind buildings 1023 through 1026 was isolated from the gas supply by removing a segment of pipe behind building 1023, and the gas was vented to the atmosphere by opening the service line valves at the buildings. Next, the 1-inch-diameter steel service line valves were removed, and the service lines were cut below ground level. The ends of the service lines were left open. No procedure was required by the specifications or used by the contractor to fully purge the segments that were disconnected and left in the ground. The specifications did not require that the disconnected pipe ends be closed.

The project manager stated, "Before we started Phase II, I went around, and we located all the valves that we could locate according to the prints that were given to me, and I found the majority of them." The Phase II contract did not address the contractor's operation of valves to isolate main segments that were to be replaced; however, the project manager stated that he had been instructed that all valves were to be returned to the positions they were found in, whether opened or closed.

The contractor's as-built drawing showed that some of the old steel piping loop between buildings 1027 and 1035 remained. The drawing also indicated that two new valves had been installed during Phase II to replace valves abandoned between buildings 1027 and 1028 and between buildings 1033 and 1034 in that nine-building loop. The steel piping not replaced in the loop was not pressure tested or otherwise checked for leaks, and its corrosion protection system was not tested to determine whether the anodes had remained in electrical contact during the construction and whether the electrical protection was adequate to prevent corrosion.

As in Phase I, neither pipe locating equipment nor other means were used to verify the location of the gas mains as shown on the architect's drawings or to mark the locations and depths of gas mains to be discontinued. The project engineer stated that the Corps and contractor personnel assumed that the new foundations would cut through the discontinued steel pipe, thereby separating the old pipe from the remaining gas system. However, several segments of the steel pipe slated to be discontinued did not cross through a planned foundation, and others were buried deeper than the depth of the new foundations.

According to the project manager, the contractor miscalculated the amount of Quail high-density PE pipe that was needed. The project manager stated that the contractor advised him that a "yellow" high-density PE plastic pipe was purchased from the gas company to complete the work. However, a gas company witness testified that the gas company had never purchased any high-density PE plastic pipe and that all of its plastic pipe was medium density.

1990 Computer-assisted Drawing.--After the accident, the Army prepared a computer-assisted drawing (CAD) of the Fort's gas piping that was based on then existing data on the gas system. The drawing, dated December 1990, did not show any of the plastic piping installed during Phase I or Phase II. Nor did it show the locations of the two valve replacements that had been installed in the main loop adjacent to buildings 1028 and 1034, which could have been used to isolate the leak behind building 1035. The drawing showed the old steel gas main loops sometimes passing under the building additions; many of the old isolation valves were not shown, incorrectly shown, or not accurately located in relation to the buildings.

1990 Plastic Gas Distribution System.--On December 10, 1990, the day after the accident, the Army asked the gas company to repair any remaining leaks in the village gas system, including the one on the plastic piping behind building 1035. In the first 15 minutes of its survey, the company located three leaks. It also closed the valves on the gas service lines and used gas under pressure to test the system. The pressure could not be maintained. The gas company then advised the Fort that it would neither repair nor operate and maintain the village gas system.

The Army decided that it would be easier to have the gas company install and operate a new plastic distribution system than to have the Fort maintain its recently modified one. The company's design, which was installed in a few days by an experienced pipeline contractor, consisted of a single medium-density plastic piping loop with isolation valves strategically located so that no more than five buildings would have to be shut off at one time if the main had to be shut down to repair a leak. All of the previously installed steel header mains (5 inches, 4 inches, and 2 1/2 inches), together with all of the 2-inch plastic mains and 1-inch plastic service lines from Phases I and II, were cut off, purged of gas, capped, and abandoned.

The gas company agreed to operate and maintain the village gas distribution system in compliance with all DOT provisions listed in 49 CFR Part 192. The company also trained the Fort's fire department personnel in responding to gas emergencies with gas company crews, and the village residents were taught how to identify and report gas leaks.

Operation and Maintenance Procedures

The DIS civilian personnel stated that personnel shortages existed in several critical maintenance areas because budget cutbacks had made it impossible to replace employees who had retired. Most of the DIS personnel interviewed during this investigation, including the utilities branch chief, were not aware of the existence of TM 5-654, the Army's manual about gas distribution systems operation and maintenance, and acknowledged that the maintenance schedules included in the manual had not been followed.

When the accident occurred, the TM 5-654 dated November 1970 was current. It prescribed the policy, criteria, and procedures for operating, maintaining, and repairing gas systems. It was a triservice manual and applied to all DOD installations. According to the manual, the Army's facilities engineer, who was the DIS director and a staff officer of the installation commander, was responsible for the operation and maintenance of gas distribution systems and interior gas systems. The DIS director, with the assistance of facilities engineering personnel, was required "to perform the functions necessary to operate, maintain, inspect, survey, repair, alter, modify, plan, and to supervise and train facilities engineering personnel as their duties relate to the installation's gas distribution system and interior gas systems." What follows are the provisions of the TM 5-654 and related information relevant to the circumstances of this accident:

Plastic Mains.--"The testing shall be with gas, air or water as the test medium, at a pressure not less than 1.5 times the maximum operating pressure (or 50 psig, whichever is greater)." The Corps did not establish a maximum operating pressure for the facilities installed in Phase I or Phase II. The project manager and the project engineer acknowledged that they did not refer to the manual in deciding the 90 psig pressure at which the system was to be tested.

Plastic Services.--"The air or gas test should not be less than 50 psig, in a stand-up test for at least 5 minutes." The service lines were tested at the same time that the mains were tested.

Lubricated Plug Valves.--"There should be enough valves available in accessible locations so that any section of the system can be completely isolated without disturbing adjacent sections and can be shut down quickly in an emergency." The procedures called for the isolating valves to be "inspected every 3 months and lubricated every 6 months." The valves on the village system had not been inspected or lubricated during Phase I or II. According to Fort records, the valves had been last lubricated in 1982. No analysis was made of the effect that Phase I and Phase II modifications would have on the spacing of the isolating valves in compliance with the above requirement.

Some of the valve boxes and their covers had been buried beneath as much as 6 inches of dirt, some valve boxes did not have covers, and some of the valve box covers were labeled "water."

Pressure Gauges.--According to the manual, the gas system should have included indicating and recording pressure gauges so that the operating pressure could be measured and maintained. The village system did not have such gauges.

Map Maintenance Management.--The maps of the gas distribution system were required to be drawn to the proper scale to show the location, size, and kind of material of each main and service line. The size, type, make, location, and designated number for each valve in the system were to be shown on the map, together with the location of manholes. None of the maps reviewed during the Safety Board's investigation were completely accurate, nor did any contain all of the information required by this standard. The 1970 and 1971 drawings showed the approximate location of some valves and identified some by number. Later maps reviewed did not include the valve numbers.

Maintenance Management and Emergency Planning.--The manual required;

- [that] all personnel involved in the operation and maintenance of gas systems (including the fire chief) have a complete gas distribution system map and that the system map be of a size adequate to show, among other requirements, the size, type, make, and location of each valve. The gas system map must be kept up-to-date because the successful operation of any system depends greatly upon the accuracy of this map.

- the development of an emergency plan that includes a gas curtailment plan identifying each building, its connected gas load, and the order in which gas service will be discontinued in the event of an emergency.

- the assignment of personnel responsible for carrying out the emergency plan.

- [that] all assigned personnel be provided with accurate distribution system maps and standard operating procedures for the gas curtailment program.

- [that] timed drills for implementing the emergency plan be conducted.

The DIS had not prepared a written emergency plan. The telephone call-out list included names and general job classifications but did not list specific emergency assignments. The day-shift plumbers had greater experience and knowledge of the gas distribution system and its operation, but they were not required to be available for emergency call-outs, and some worked after normal hours for other employers and would not have been readily available.

Repair Equipment.--"Each installation should have on hand the proper material and equipment needed to handle an emergency in the gas distribution system." The DIS did not have a list of available emergency equipment, and no equipment was available for repairing plastic pipe or for squeezing shut segments of plastic pipes that were leaking.

Gas Leaks.--"There should be a record kept of each leak survey and of each leak discovered." The manual clearly described how to detect underground leaks using probe bars and combustible gas indicators. There was no record of any annual leak survey and little documentation on leaks detected or repaired after 1982. During the 1 1/2 years before the accident, the fire department had responded to 20 reports of gas leaks in the village. One fourth of those responses required evacuations.

Emergency Shutoff Procedure.--"When the gas supply to a building(s) has been shut off, service must not be restored until the valve on each service riser and on each piece of gas equipment in the building has been closed."

Precautions in Locating Gas Leaks.--The manual noted that:

> leak detection equipment should be used to check for gas because the sense of smell cannot always be depended upon as gas can lose its odor while traveling through the ground. Those who are assigned to detect leaks must know how to operate the leak detection instruments properly and how to obtain an accurate reading and the meaning of the readings obtained. Personnel must be given periodic training by a qualified technician in the technique of using (and reading) a leak detector.

Fire department personnel were the only Fort personnel that possessed leak detection equipment and the only ones who had received training in its use.

In 1990, engineering consultants updated the manual, which is scheduled to be approved and distributed by the end of 1991. It covers omissions in the old manual and also refers to the DOT pipeline safety regulations, which have more information about how to do a specific task. For example it says, "Each O&M [operation and maintenance] plan must include provisions for shutdown, abandonment, or inactivation of facilities. (49 CFR 191.727)." It includes some provisions of the DOT regulations and of the DOT *Guidance Manual for Operators of Small Gas Systems*: "In cases where the main, together with all the services connected to it, is abandoned, the service line(s) must be capped at end use locations. Also, the main must be sealed at both ends."

The old manual did not directly address the subject of corrosion control. However, the Corps has a small office that deals with corrosion control and its personnel, if requested, will provide on-site assistance. Although the system had repeated corrosion leaks, which was one reason why the DIS wanted plastic pipe, no record indicates that corrective action had been taken. The utilities branch chief, commenting on the importance of monitoring the corrosion control system, said that it was a "nice program" if there were enough personnel to maintain it, but "it's kind of worthless to us. So I didn't even consider it."

Tests and Research

Excavation of the Leak Site behind Building 1035.--The day after the accident, gas company crews excavated the area behind building 1035, where a gas leak had been detected before the explosion and fire. The gas was found to have been leaking from a "pink" pipe at a heat fusion joint near a tie-in of the Phase I and Phase II pipe. A visual examination of the joint revealed that a small section of the inner wall of the pipe joint was not fused together.

Pressure Test of Gas Distribution System.--On December 10, 1990, the day after the accident, when all of the village residents had been evacuated, the village system was tested to see whether it had other leaks that might have caused the accident. The 2-inch Quail high-density PE plastic piping that was 23 feet from the back of the addition to building 1025 was isolated for a pressure test. The two new plastic service lines into the building were capped above ground at the steel risers, and the gas main was capped more that 40 feet away from either end of the building. Air was introduced into the 175-foot-long gas main and increased to a pressure of 30 psig, the pressure at which it remained during the 15-minute test.

The remainder of the system was then similarly tested at 26 psig gas pressure. Within 5 minutes of the beginning of the test, a reduction in pressure of 4 psig was noted. Within 15 minutes, three leaks were found in the Phase I plastic pipe behind buildings 1013, 1015, and 1047. The survey was then stopped.

<u>Test of the Old Steel Distribution System at Building 1025</u>.--The old steel distribution main was located by excavating the two inactive steel service lines found at building 1025. Also, the plastic main behind building 1027 was excavated, a section of this main was removed to permit testing of the steel main behind building 1026, and the valve behind building 1027 was opened. The 2-inch steel piping in the old four-building loop between buildings 1023 and 1026 was pressured with air at 25 psig. The piping failed to retain the air pressure, and a tracer gas consisting of air, ammonia, and cinnamon was injected. Odors were detected in apartments 1026 C and 1024 C and D. Instruments also detected the ammonia in the tracer gas at a crack between the new concrete slab and the old foundation wall of building 1025. Higher readings were obtained at joints between the old and new concrete slabs within apartments C and D and in the hollow cores of their rear exterior walls, which had a veneer of cinder block and brick.

The concrete slab between 1025 C and D was broken and excavated. The excavation established that the ammonia tracer gas was escaping from an old steel service line riser that had been cut but not capped approximately 2 feet below the top of the concrete slab addition. Another excavation outside the footing of the new addition revealed that the old steel main was just outside and within 1 foot of the concrete footing. The bottom of this footing was over the top of the old 1-inch steel service line.

<u>Excavation of the Valves between Buildings 1026 and 1027</u>.--The contractor's as-built drawing of the plastic gas main loop between buildings 1023 and 1026 indicated that there were two "existing valves" on the "existing 2-inch steel" main between buildings 1026 and 1027. Upon excavating between these two valves, a "Y" fitting was found that led to an open 2-inch valve behind building 1026 that was buried without a valve box. This third valve was found in the open position and attached to the east end of the steel piping loop between buildings 1023 and 1026.

The "Y" fitting was supplied by a 2 1/2-inch steel main from the header main on the west side of Drumn Drive. The valve on the 2 1/2-inch main was equipped with a valve stem extension in a valve box that was between the buildings. The valve behind building 1027 was also in a valve box and had an extension on it that came close to the surface of the ground. (See figure 5.)

<u>Excavation of the Phase II Plastic Pipe Tie-In to the Phase I Main</u>.--The black, high-density PE plastic pipe behind buildings 1024 and 1026, when excavated, was found fused into the side inlet of an orange 2-inch plastic tee. According to the testimony of the project manager, the plastic pipe segments fused to the two ends of the tee were also high-density PE plastic that the contractor had purchased from the gas company; however, the gas company reported that it stocked only medium-density PE plastic pipe.

<u>Regulator Tests at Building 1020</u>.--Because gas odors had been detected inside building 1020 F on the night of the accident, the service regulator was tested to determine whether a sudden surge of pressure from 0 psig to 26 psig could have ruptured its diaphragm. If so, the rupture could have allowed high-pressure gas into the house piping that may have extinguished appliance pilot lights.

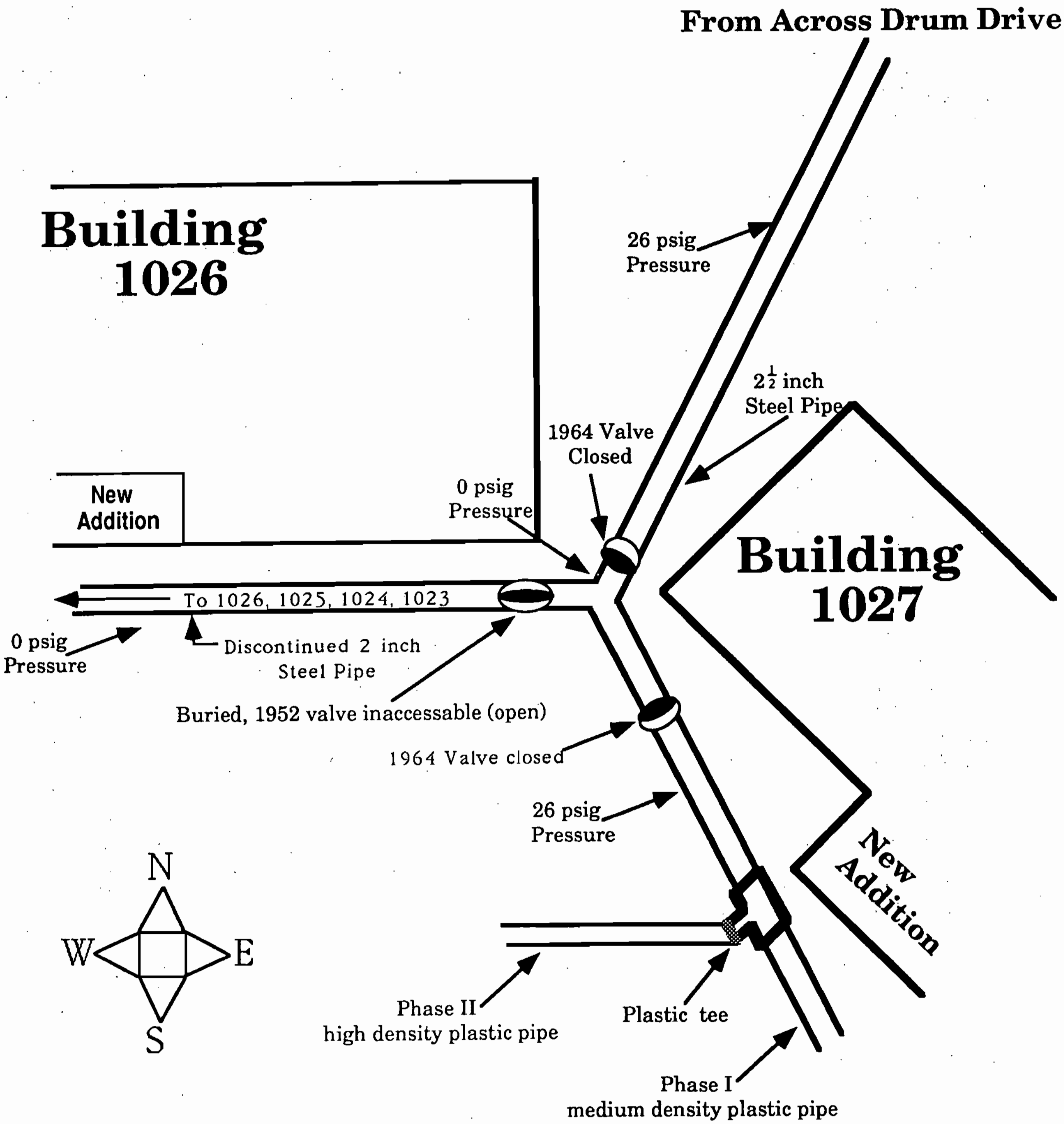

Figure 5.--Schematic showing the gas pipes and valves near buildings 1026 and 1027 as found after the accident.

Air under pressure was used to conduct the test, and a manometer was installed in the apartment fuel piping and on the gas range piping downstream of its appliance regulator to measure the pressures. Air at 26 psig pressure was applied to the service line riser, and the service line riser valve was opened to simulate the turning on of the gas supply at the M&R station. At 0 psig pressure the control valve or the Rockwell 043 service regulator was wide open. When the service line valve was rapidly opened to apply the 26 psig pressure to the regulator, air passed through the regulator orifice and into the 1-inch house service line; the water in the 1/2 psig (14-inch water-column [w.c.]) manometer was blown out of the manometer tube before the service regulator began to function and close at its 12-inch w.c. set point, indicating that the air entering the house fuel piping exceeded, at least momentarily, 14-inch w.c. pressure. Although the gas range appliance regulator was set at 5-inch w.c., the pressure at the range pilot line momentarily increased to 12-inch w.c.

A survey of the appliance safety valves and regulators revealed no failures that would have allowed gas to enter the residence except through the two pilot lights on the range. A visual examination of several service regulator diaphragms within the village uncovered no evidence of tearing or deformation. The aluminum hard-case Rockwell R 275 meters appeared to operate normally.

<u>Laboratory Testing</u>.--Because the gas range in 1025 D had been so badly damaged by heat, the appliances in the apartment were investigated as a possible source of the gas leak. The range and its flexible gas connector pipes, water heaters, and furnaces were sent to the Forensic Metallurgy Associates laboratory in Springfield, Virginia, for analysis.

The gas range had electronic spark igniters that would ignite only the 9,000 Btu/hr top burners or the 20,000 Btu/hr oven burner when the range control knobs were fully on (90 degrees from the off position). If the range controls (after initial burner ignition) were open and the gas supply were then exhausted and reintroduced, raw gas could be released from the burners without being ignited because the electronic ignition ranges did not have an automatic burner valve shutoff. Laboratory analysis of the stove indicated that all of the surface burner controls and the oven/broiler control were off at the time of the accident.

Gas flow and pressure testing of the Rockwell Type 043 service regulator, a Rockwell Type 143 service regulator like the one destroyed by fire that served apartments 1025 C and D, and the Maxitrol RV47CL range regulator indicated that all contained appropriately sized orifices. None leaked gas during the laboratory tests.

<u>Odorant Tests</u>.--Title 49 CFR Part 192 required a check of the quantity of the odorant used in the gas, but the military did not have such a requirement. The Safety Board therefore asked the gas company to provide the results of the weekly odorant tests of its gas system near the Fort. On December 4 and December 11, 1990, the gas company recorded "strong" odors of gas at less than 0.5 percent gas-in-air mixtures. The readings indicated that the gas supplied to the Fort was odorized at a level that exceeded the minimum Federal requirement.

ANALYSIS

Accident

Several possible leak sites were examined. First, the improperly made plastic fusion joint behind building 1035 was considered; however, it leaked a relatively small volume of gas from a small crack in a pipe joint at a location remote from building 1025, the building that exploded. No direct below-ground conduit, such as sewer lines or earth voids, was found through which gas could have flowed unrestricted to building 1025. Therefore, enough gas was unlikely to have migrated underground to fuel the explosion.

The Safety Board considered the possibility that gas entered building 1025 through the gas-appliance pilot-light lines or the range burners when the gas supply was disrupted and then reestablished while the service line valves were open. The tests of the flexible range connector, appliances, and appliance regulators indicated that none was the source of the gas that entered the building. Tests of gas service regulators similar to the one destroyed in the fire showed that a surge in pressure from 0 to 26 psig was insufficient to rupture the regulator diaphragm and allow high-pressure gas to enter the building's pipes. Thus, gas is not likely to have entered building 1025 as a result of the improper operations of the valve at the M&R station.

The third possible source of the gas released into the building was the steel gas main and discontinued service lines that had remained connected to the system after modifications. After the modifications were complete, the buried, inaccessible valve on the discontinued segment of main behind building 1026 was in the open position. The only explanation for why gas had not entered the discontinued main behind building 1026 is that the two accessible valves were closed during the modifications and had remained closed until the day of the accident. If either of these valves had been open, gas would have entered the discontinued main segment and then would have entered buildings 1024, 1025, 1026, and possibly 1023. As shown by postaccident tests, its presence would have been obvious because of the odor. Moreover, the explosion or fire would have occurred earlier.

The engineer stated that he had operated one of the two accessible valves near the east end of building 1026 just before the explosion. Although he intended to close the valve, he did not know in which direction to move a valve to close it. Given his description of his actions, he apparently opened the valve, allowing gas to enter the discontinued steel gas main and service lines, which released gas beneath the concrete slab addition to building 1025. Because the explosion did not occur immediately after the opening of the valve, while the main village valve at the M&R station was only partly open, the pressure in the gas system at that time was probably low or nonexistent.

When the main village valve was later fully opened, gas under system pressure flowed into the discontinued main and service line segments, escaped through the open ends of the service lines beneath the building additions, flowed through foundation cracks, and entered the hollow core block exterior walls. When enough gas had entered building 1025 to form an explosive gas-in-air mixture (5 to 15 percent gas), it was ignited by one of many ignition sources normal to a residence. The tracer gas test results and the documentation of the piping and valves after the accident all support the conclusion that opening one of the two closed isolation valves near the east end of building 1026 released the gas that fueled the explosion.

This accident might have been worse had building 1025 not exploded soon after the valve at the M&R station was fully opened. The discontinued steel main also ran behind buildings 1023, 1024, and 1026, and residents of these buildings had smelled gas just before the explosion. Gas had probably entered these buildings also; however, it was not within the explosive range when an ignition source was present.

Although the engineer's opening of a valve was the last act that led to the explosion, the genesis of the accident was a combination of the Army's inadequacies in managing its natural gas distribution system at the Fort. This analysis includes a discussion of each of the inadequacies: the preparation for responding to gas emergencies, the maintenance and operation of the gas system, the maps, the new construction design process, the inspection and testing of new construction, the qualification and training of personnel, and DOD oversight.

Emergency Response

The incident commander established early control of the response activities. On arrival, he sought to use the knowledge and experience of the engineer, the person left in charge of the distribution system and other Fort utility facilities. Neither the incident commander nor the engineer had been adequately trained in responding to gas distribution system leaks; consequently, they took many inappropriate actions that increased the danger to themselves and the residents of the village.

The engineer told the firefighters to flood with water the area of the suspected leak. He chose flooding as a method of finding leaks because neither he nor the firefighters were properly equipped or trained to detect and pinpoint the location of underground gas leaks. The water sealed the ground surface, preventing any released gas in the ground from venting and potentially causing it to migrate underground through conduits and to enter adjacent buildings. The flooding may have caused the gas to migrate to the valve box, where gas was later detected, and considerable effort was needlessly expended to excavate the valve in search of the leak.

The incident commander and the engineer reviewed the available village gas maps and correctly found them insufficient to identify the location of the valves that needed to be closed to isolate the leaking main segment. The incident commander's decision to shut down the village gas system to minimize the hazard posed by the leak was prudent because he was not able to isolate the leaking segment and had no expert counsel on actions to take.

However, the incident commander did not understand the potential consequences of the actions he was taking, particularly when he twice ordered the gas system valve to be closed and then reopened. Neither he nor the engineer recognized that by shutting down the system while gas was still being used, the system pressure was being reduced; this shutdown could have caused pilot lights and gas burners without safety shutoffs to release gas within buildings when the system pressure became too low to provide sufficient gas to maintain the pilot light flames. This problem, had it been recognized, could have been easily solved by instructing the MPs on how to close the service line valves and by having them close the valves as they advised the residents of the gas outage.

Although the valve was closed, people were still using their gas appliances. Thus, the gas pressure in the main fell sharply and many burner and pilot light flames were extinguished throughout the village, allowing gas to escape within those buildings. Based on the residents' reports of gas odor, gas apparently did enter several buildings in this manner. The potential for releasing gas into buildings through the pilot light lines and range burners also existed when the engineer and the incident commander later decided to again close and reopen the village distribution system valve at the M&R station.

The engineer's closing of the valves at the M&R station and subsequent reopening of the one he believed provided gas to other Fort gas systems potentially threatened the safety of other Fort housing and buildings served by gas.

The engineer's operation of valves without knowing the purpose of each one or the manner in which it operated also threatened the safety of residents and others. Had he been trained and experienced in operating the Fort's gas system, he would have known about the recent modifications; the location of the valves, including the village shutdown valve in the vault on Drumn Drive; and the inadequacies of the maps. The Safety Board believes that the selection of an engineer without the basic knowledge of which direction a valve must be turned to open or close it reflects poorly on the Fort's administration and therefore the safety of the Fort's occupants. In addition, he should have known or had the opportunity to learn the direction in which to turn valves to close or open them and thus should have realized when he tried to operate the valve adjacent to the east end of building 1026 that it was already closed.

The incident commander made critical mistakes in his choice of instructions for the residents. Because he did not understand the hazards associated with gas distribution systems, he did not direct the MPs to tell the residents to stop using their gas appliances while the system was shut down. Also, the residents should have been told to report to the MPs or the incident commander any gas odors they detected in their apartments.

The incident commander's decision to maintain communications with the engineer while the M&R station valves were being operated was prudent. However, by using a firefighter to relay messages between the incident commander and the engineer rather than providing the engineer with a fire department radio, he greatly increased the chances of a misunderstanding. The chances increased further when the incident commander and the firefighter had to communicate through the fire dispatcher.

The DIS director failed to communicate to the incident commander his intention to take charge of the response activities. The DIS director and the incident commander each functioned as if he alone were in charge; they did not inform one another about actions each was taking. Consequently, the incident commander did not know about the communications between the DIS director and the gas company, and the DIS director and the gas company did not know about all actions being taken by the MPs, the engineer, and the firefighters.

The Fort's management was not prepared to deal with natural gas emergencies. It had no formal written emergency plan, as is required for gas operators subject to the DOT's gas safety standards. Furthermore, there was no liaison between the Fort's fire department, the MPs, the Fort's Corps representative (who knew of the gas system modifications), and the DIS utilities branch (which operated the Fort's utility systems). The Fort's management also had not brought together for planning purposes the various operations that would be needed to safely resolve a gas system emergency. Deficiencies in the following areas should have been identified: training, communication, emergency command, availability of essential employees after their normal work hours, test and repair of the inspection equipment, and knowledge of the gas system.

Since this accident, the Army has reported to the Safety Board that the Fort's management has developed procedures for responding to gas system emergencies, that the procedures have been coordinated between the appropriate Fort agencies and the gas company, and that the procedures were tested during a mock gas accident. Mock accidents are to be conducted periodically to ensure that personnel follow proper command and control procedures and correctly handle the emergency. The emphasis will be on realistically assessing the risks in determining the response to be taken. Also, the fire department dispatcher and the night-duty engineer are now able to communicate with each other by radio.

The Army reported that it was also developing an on-scene disaster control group on all its installations to coordinate and guide the actions of military and civilian agencies in responding to emergencies. Additionally, seven Army installations have been surveyed to determine their emergency preparedness; based on the findings of these surveys, the Army will recommend written guidance necessary to handle problems similar to those experienced in the Fort's response to the village gas emergency. The Safety Board is pleased that the Army is correcting the deficiencies identified through this investigation and that it is beginning to address the overall adequacy of the emergency response capabilities of the installations.

Gas System Maintenance and Operation

The provisions of the Army's TM 5-654 (its maintenance and operation manual) were not followed at the Fort. The lack of adherence is evident from the difficulties the Corps representative had in locating valves during the gas system modifications, the inadequacies of the gas system maps, the failure of the utilities branch to periodically inspect the system for leaks and corrosion, the lack of gas system maintenance and documentation, and the fact that many DIS employees had never heard of the manual.

The failure of the Fort's management to carry out the Army's maintenance and operating procedures contributed to the difficulty of locating valves to isolate the leaking segment of pipeline and, after the gas system modifications, to leaving closed the two accessible valves adjacent to the east end of building 1026. If the required quarterly valve inspections and semiannual maintenance had been properly conducted, the inaccessible main line valve behind building 1026 could have been identified, and the problem might have been corrected long before the gas system modifications were begun. Also, during annual inspections of the gas system, the numerous deficiencies in the maps could have been discovered and brought to the attention of the Fort's management.

Documentation of the maintenance, repair, and modification of a gas system is essential to safe operations. The lack of documentation about the village system indicates that the Fort management was not assessing the condition of the system and determining the need for modifications and improvements. A pressure test and leakage survey done after the explosion revealed at least three leaks in the newly installed system. That the fire department had responded to 20 reports of gas leaks within 18 months should have been a warning that the village system was deteriorating and that the threat to the safety of the residents was increasing. Had the fire department management discussed with the DIS director the frequent gas leaks in the village, the discussion might have prompted an overall review of the village gas system that could have revealed the many deficient operating and maintenance conditions.

The maintenance and mapping deficiencies at the Fort were longstanding and were not brought to the attention of Army management before this accident, in part, because inspections were not being performed by knowledgeable persons independent of the Fort's management. State or Federal personnel inspect gas systems that are subject to DOT regulations, and deficiencies identified must be corrected. Gas operators can be ordered to correct specific faults and may also be fined or otherwise penalized. The DOD needs to annually inspect its gas systems using qualified personnel and establish incentives that will induce military-installation management to comply with all provisions of the current maintenance and operation manual.

On August 13, 1991, the engineering division chief of the Army's Directorate of Military Programs told the Safety Board that the local gas company now operates and maintains the village gas system. Consultants experienced in gas system maintenance are inspecting the other Fort gas lines. The Corps is modifying the Army regulations to require installation (Army facility) engineers to establish comprehensive site-specific operation and maintenance plans for installations that operate underground gas lines. Furthermore, the Corps has reviewed and used many of the DOT requirements (49 CFR Part 192) to revise its TM 5-654 (maintenance and operation manual) and applicable Army regulations. The revisions should be published by January 1992. In the interim, each installation has a copy of the draft manual and has been directed to comply with its provisions. The Corps is developing corrosion protection monitoring requirements using both the DOT requirements and industry guides. This document is expected to be completed in January 1992.

The Corps has given each installation a copy of the Office of Pipeline Safety's (DOT) *Guidance Manual for Operators of Small Gas Systems*. That manual explains the Federal gas pipeline safety operating and maintenance requirements and identifies the need for gas system emergency response and safety planning. To encourage compliance, all major Army commands have been given a listing of the documents to be used in the operation, maintenance, and management of gas systems. Also, the Corps is determining the number and kinds of people needed to operate the Army's gas distribution systems safely; but that analysis has been delayed and no date has been set for its completion.

The Army has contracted for the updating of its system maps; the completion date is dependent on future funding. To make information more readily available when modifications are made, the Army now requires contractors to provide two copies of "as-built" maps, one of which is given to the installation operating personnel.

Design Specifications and Procedures

<u>**Specifications**</u>.--The Corps' specifications about the design, construction, and testing of gas pipeline systems at the time the modifications were made to the village gas system were incomplete and did not reflect current industry practices.

The deficient specifications allowed the contractors to design and construct safety-critical facilities without proper regard for safety. Had Corps personnel been knowledgeable about industry practices, they would have been able to establish requirements for the proper abandonment of pipe, procedures for plastic pipe joining, qualifications for people who perform and inspect pipe joining, and the maximum operating pressure for pipelines.

The *Guide Specifications of Military Family Housing*, which was applicable to the design and construction of the village modifications, was even less specific about the design of gas system modifications. (This guide was canceled by the DOD in June 1990, before the accident.) Consequently, the architect had considerable design freedom and was not required to produce a proposal that adequately addressed specifications for the gas system. Also, the architect apparently was not current in his knowledge of gas system design. His specifications allowed the use of cast-iron pipe, which is no longer used by the industry; called for the installation of drips, which are not required on systems transporting dry natural gas; did not permit the use of plastic pipe, which has long been the primary material used by the industry; and did not require proper abandonment of discontinued gas pipes.

<u>Quality Control of Designs</u>.--The Corps' review of the architect's Phase I specifications and installation drawings, which included the gas system specifications, was cursory at best. The Corps could reasonably have been expected to check the architect's specifications to ensure that applicable safety requirements had been incorporated; however, no one at any stage of the review process identified that the architect needed to add abandonment requirements to his specifications.

The Corps had a second opportunity to improve the specifications. When the contractor substituted plastic for the pipe materials specified by the architect, the Corps should have then included plastic-pipe construction experience requirements for the contractor who installed the plastic pipe, required the contractor to qualify through tests the plastic fusion procedure to be used, required the qualification of the contractor's employees who made plastic fusion joints, and established the test pressure for the plastic system by specifying its maximum operating pressure. Additionally, the Corps should have required that its construction inspector be trained in inspecting plastic piping systems, including the making of fusion joints.

The Corps also reviewed the architect's Phase II specifications and, again, did not ask for any changes. The Corps took no exception to the architect's failure to specify the tie-in locations, to the lack of explicit specifications for the plastic pipe (the lack of which later permitted the contractor to select material that was incompatible with the pipe used in the Phase I construction), or to the fact that the locations of the Phase I piping and existing valves were not shown.

<u>System Analysis</u>.--The Corps did not analyze the effect of the proposed modifications on the village gas distribution system. Consequently, it did not recognize that the modifications violated the Army requirements that isolation valves be installed on main loops to minimize disruptions. The Corps also failed to realize that the corrosion control system for the steel pipe would be disrupted by the addition of sections of plastic pipe.

However, the most serious consequence of not analyzing the effect of the modifications on the village system was the failure to recognize the importance of specifying main tie-in locations. Depending on which map was used, a proper analysis should have identified that the tie-in adjacent to buildings 1026 and 1027 should have been located just west of the open valve shown behind building 1026. This would have continued the usefulness of the three valves adjacent to the east end of building 1026 as isolation valves, and it would have necessitated the physical separation from the gas system of the discontinued steel main behind buildings 1023 through 1026. The Phase II piping should have been tied into the steel main, not into the Phase I plastic main. Excavating the area to make the tie-in probably would have exposed the buried open valve, revealing a hazard that required correction. A system analysis would probably have also uncovered some of the mapping errors made over the years and the fact that valves were no longer being numbered as required by TM 5-654. Either finding should have prompted a more detailed investigation to determine the true locations of the mains and valves.

Construction Inspections.--The Corps assigned only one inspector to each modification phase. The inspector was responsible for overseeing all work to be completed under the contract, including the installation of the gas system modifications. Neither inspector had experience in constructing gas systems, and the Corps had provided no training for them.

Even had the inspectors recognized the need to install the gas system differently, they would not have been able to force the contractor to alter his work. Their authority was limited to requiring adherence to those provisions explicitly stated in the contract. Because of the contract's lack of specificity and the inspectors' lack of experience, the contractors were able to construct the gas system as they wished with little or no guidance from the Corps. However, the Corps' inspectors could have, and the Safety Board believes they should have, brought to the attention of their management any issue affecting safety that they were unable to resolve.

On August 13, 1991, the engineering division chief of the Army's Directorate of Military Programs advised the Safety Board of the following: military housing specifications could no longer be used as standards for designing or constructing pipeline systems; the Corps design and construction specifications for pipeline systems had been modified to include applicable provisions of the Federal DOT requirements and of industry-consensus standards, including provisions for abandoning pipe and for qualifying persons who join pipe; and those provisions were now part of any contract that included the construction of gas systems.

The Corps has also made procedural changes that should improve the quality of gas system designs. To avoid the fragmentation of utility system installation or modification, it now recommends that phased construction projects include in the first phase all necessary modifications to the gas and other utility systems. It also recommends the removal of all abandoned gas pipe.

The Corps evaluated its control and quality assurance programs on design projects. It found that each quality assurance team consisted of several junior or journey-level engineers and a senior engineer in each discipline who may or may not have had extensive experience. The Corps concluded that appropriate design experience is required for effective review and that assignment to a quality assurance team is not appropriate training for young, inexperienced engineers. The Corps determined that the team should include only experienced engineers, who would already have been exposed to various design solutions, and that maximum synergistic effects could be achieved by the rotation of experienced engineers between design and review responsibilities. The Corps also determined that the procedures being used in preparing contracts and defining the scope of design services were significantly out of date. Furthermore, often the procedures were not followed.

Qualification and Training of Personnel

Neither the Corps management nor the DIS management responsible for the safety of gas pipelines recognized the hazards posed by the pipelines. When properly controlled, natural gas is a safe, efficient energy source that can be conveniently and unobtrusively provided through buried pipelines. However, to properly control these systems and to ensure gas distribution safety, each person assigned to any aspect of gas system design, construction, inspection, testing, operation, maintenance, or emergency response must be experienced and properly trained and equipped.

None of the Fort's employees interviewed during this investigation were familiar with the provisions of the 20-year-old gas system operation and maintenance manual. None had significant gas system experience. Also, the Army had not given them enough training to ensure that they understood how essential the correct performance of their responsibilities was to the safety of the village residents.

The selection process for personnel did not guarantee that the applicants chosen would have adequate knowledge of and experience with gas systems. No specific minimum qualifications about gas system knowledge and experience had to be met by those responsible for the quality control of the gas system modification designs, for performing critical inspections of the construction, for the gas system operation and maintenance, or for handling gas system emergencies.

On August 13, 1991, 8 months after the accident, the engineering division chief of the Army's Directorate of Military Programs told the Safety Board that Fort utility personnel have now been trained by the gas company in establishing and discontinuing a customer's gas service and in preventive maintenance for valves. The position descriptions of personnel who work with natural gas pipelines were revised to clearly define the gas system work for which they were responsible.

The Corps is evaluating its staffing and training needs for installations that have gas pipeline systems. On July 24, 1991, the Corps issued a bulletin urging that its field personnel responsible for gas system safety attend a course such as DOT's 1-day course that was designed for operators of small basic gas systems. Other training needs are still being reviewed.

Responsibility for Military Gas System

The Secretary of each military service, in addition to his or her primary responsibility for national defense, is responsible for all service-related construction and public-works activities, including gas pipeline systems and their safety. For its 78 gas systems, the Army delegates design and construction responsibilities to the Corps, its engineering command. The Army delegates gas system operation and maintenance responsibilities, including staffing, training, and emergency preparedness, to the other major Army commands.[10]

Chapter 2 of Army Regulation (AR) 420-10, in part, states that the Corps' chief of engineers will provide Army staff supervision and technical direction of facilities engineering and housing; formulate Army policies, objectives, criteria, and standards for facilities engineering and housing activities; develop effective use of internal control review procedures; and conduct staff visits.

In addition, chapter 2 states that the major command will provide command and technical supervision of facilities engineering and housing at assigned military installations; ensure the use of sound work management procedures in planning, programming, setting priorities, performing, evaluating, and reporting; provide qualified and continuous supervision to ensure that approved internal review procedures are followed; and conduct staff visits.

The Army's major commands delegate responsibility for gas systems to the commanding officer of each military installation; the Fort's management reports to the Army's Training and Doctrine Command, its major command. Chapter 2 of AR 420-10 states that the commanding officer of an installation is responsible for facilities engineering and housing at the installation, subinstallations, and support activities; for establishing formal procedures for efficient and effective engineering and housing management; for ensuring that backlogged and deferred maintenance and repair are reduced to, and maintained at, a level consistent with the Army's policy; for applying internal control and review procedures; for identifying deficiencies to the major command for assistance and resolution; and for submitting requests for assistance for work that cannot be accomplished within existing resources and capabilities.

The commanding officer has a military installation support officer who is responsible for the day-to-day management of support operations, such as housing, utilities, fire and police protection, and other services essential to the safe, continued operation of installations. The support officer, like all military officers, is subject to periodic reassignment to other bases. He or she must have an engineering background but is not required to have a working knowledge of all assigned systems and activities. The officer relies greatly on the capabilities of the installation's civilian work force.

AR 420-10 defines the general responsibilities of the various Army commands. The underlying premise of AR 240-10 is that higher-level commands, such as the Training and Doctrine Command, will provide management supervision and technical support and that they will monitor compliance through on-site assessments. However, during the Safety Board's investigation of this accident and during subsequent communications with Army managers, the Safety Board's staff was unable to identify any effective actions by higher commands that met the intent of AR-420-10 with respect to gas system safety. Furthermore, the Safety Board's investigators were unable to identify any effective program for periodically

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[10] Major Army commands are organizational units below the Secretary of the Army that are responsible for Army-wide programs on training, doctrine, intelligence, security, information systems, health, engineering, and the armed forces.

assessing the adequacy of the Army's gas pipeline safety policies, standards, programs, and directives.

Had qualified personnel periodically monitored the Fort's and the Corps' compliance with military gas pipeline safety standards, the problems addressed in this report could have been easily identified. Discussions with Fort personnel responsible for gas system safety would have revealed deficiencies in their knowledge, training, and emergency preparedness. Periodic monitoring would have, before the accident occurred, alerted the Secretary of the Army, the commanding general of the affected major command, the installation commander, and the director of installation support that specific improvements were necessary to ensure the continued safe operation of the village gas system.

The Safety Board is pleased that the Army has recognized the need for and has begun to take corrective actions. Nonetheless, the Army has not yet fully and effectively addressed the lack of oversight that allowed the village gas system to accumulate so many deficiencies without detection.

Consequently, the Safety Board believes that the Office of the Secretary of the Army needs to develop a program to periodically evaluate whether each major command's gas safety program adheres to Army policies and whether each Army installation is adhering to applicable safety standards and directives. To implement such a program, the Army must first evaluate each gas pipeline system to identify and correct deficiencies.

In addition, the Secretary of the Army should require that Army gas system operations comply with the Federal gas pipeline safety standards at 49 CFR 192, and he or she should implement effective qualification standards and training for Army personnel whose responsibilities may affect the safety of Army-operated gas systems. Finally, the Army needs to assess the adequacy of current procedures for selecting contractors and for deciding whether a contractor's work complies with applicable pipeline safety standards.

The Army's gas pipeline safety management program is not unique among the military services. Analogous to the Secretary of the Army, the Secretary of the Navy delegates the responsibility for designing and constructing the Navy's approximate 135 gas systems to the Navy's engineering command, which is the Naval Facilities Engineering Command. The Air Force has not developed an internal engineering capability; it uses the services of the Army and Navy to support its 83 gas systems. Also, like the Army, the Navy and the Air Force delegate day-to-day management of support operations, including gas pipeline systems, to installation commanding officers.

On October 22, 1991, Safety Board staff met with Navy managers responsible for gas safety. They discussed the Navy's gas system policies, including those relating to design, construction, operation, maintenance, emergency preparedness, employee qualifications and experience, and the selection of design and construction contracts. The group also discussed the Fort's problems with system modifications and with emergency responses. The Navy managers acknowledged that the Army and Navy have similar gas system procedures.

Such similarities and common elements, in light of the safety problems identified as a result of this investigation, raise concerns about the adequacy of Navy and Air Force gas system safety programs. Consequently, the Safety Board believes that the Secretaries of the Navy and Air Force also need to assess the adequacy of their gas pipeline systems and their safety oversight programs. In addition, military gas system personnel could benefit from all of the gas system programs, conferences, technical documents, and training that are available through gas industry associations and State and Federal agencies.

CONCLUSIONS

Findings

1. The engineer inadvertently opened a valve leading to a discontinued steel gas main because he was inadequately trained and experienced in operating the Fort's gas system.

2. The discontinued gas main was not properly disconnected, purged of gas, and sealed; thus gas was able to flow into building 1025, where it ignited and exploded.

3. The emergency response personnel and others were unable to identify and locate the valves needed to isolate the leaking segment of plastic main because the maps of the distribution systems were incomplete, inaccurate, and too large in scale to be useful. They had not been kept up to date, and the Army had not insisted that they be corrected even after they were known to be inaccurate.

4. The gas leak developed behind building 1035 because of a plastic pipe fusion joint that was made without the benefit of a qualified fusion procedure and was inspected by a person insufficiently trained and experienced in plastic fusion procedures.

5. The Army Corps of Engineers did not adequately oversee the village gas distribution system modifications made between 1987 and 1990. It did not identify and correct deficient design, material, equipment, and construction specifications and standards.

6. The Fort's management did not demand that the gas distribution system be operated and maintained in accordance with the Army's operation and maintenance requirements, and the Army did not perform sufficient oversight to detect and correct the deficiencies in the gas system modifications.

7. The Fort's management had not developed a written emergency plan for or an effective way of responding to natural gas emergencies.

8. The Army's qualifications and training for its personnel responsible for gas systems were not sufficient to prepare them to perform their duties correctly.

9. The Army did not supply the resources necessary to ensure that all duties essential to the safety of its gas systems were performed correctly.

10. The Army did not oversee its gas distribution system effectively enough to identify and correct safety deficiencies.

11. Current Army gas system practices (design, construction, testing, corrosion protection, operation, and maintenance) are not as complete or as stringent as those imposed by the Federal gas pipeline safety standards at 49 CFR Part 192.

12. The gas system deficiencies identified during the investigation of the December 9, 1990, gas system explosion and fire at the Fort probably exist at other military service installations because the standards, procedures, and practices of each of the military services are similar.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the natural gas explosion and fire at Fort Benjamin Harrison was the failure of the Army to construct, maintain, and operate the Fort's gas distribution system in accordance with its own and the industry's standards. The result was the inadvertent opening of a valve to a discontinued steel gas main that allowed natural gas to leak into a residential building, where it ignited and exploded.

RECOMMENDATIONS

As a result of its investigation, the National Transportation Safety Board made the following recommendations:

--to the Secretary of the Army:

Require that gas pipeline systems that are owned or operated by the Army be managed by persons qualified by experience and training in gas distribution system design, construction, and operations. (Class II, Priority Action) (P-92-6)

Require that all gas pipeline systems that are owned or operated by the Army conform to the operations and maintenance requirements of 49 *Code of Federal Regulations* Part 192, and require that all newly constructed gas pipelines that are owned or operated by the Army conform to the design, construction, and testing requirements of Part 192. (Class II, Priority Action) (P-92-7)

Identify and correct inaccuracies and omissions in maps for gas systems that are owned or operated by the Army. (Class II, Priority Action) (P-92-8)

Initiate annual assessments of adherence to design, construction, maintenance, and operations standards applicable to gas pipeline systems that are owned or operated by the Army, and require that all identified deficiencies be corrected. (Class II, Priority Action) (P-92-9)

Develop and conduct employee training and testing programs to annually qualify employees responsible for tasks, including emergency response ones, that may affect the safety of gas pipeline systems that are owned or operated by the Army. (Class II, Priority Action) (P-92-10)

Equip each employee who has responsibilities that may affect the safety of gas pipeline systems that are owned or operated by the Army with the necessary test, inspection, and repair equipment, and train him/her in the proper use of that equipment. (Class II, Priority Action) (P-92-11)

Explicitly require compliance with applicable U.S. Department of Transportation gas pipeline safety requirements in contracts that affect the construction, repair, and maintenance of gas pipeline systems that are owned or operated by the Army. (Class II, Priority Action) (P-92-12)

Establish standards and procedures to ensure that contracted work on all gas pipeline systems that are owned or operated by the army complies with applicable U.S. Department of Transportation gas pipeline safety requirements. (Class II, Priority Action) (P-92-13)

--to the Secretary of the Navy:

Evaluate the Navy's gas pipeline program to identify and correct any deficient design, construction, operation, and maintenance procedures; inspect Navy gas pipeline systems to identify and correct any conditions that do not comply with Navy gas pipeline system policies and practices; and, if necessary, implement a program for periodically assessing compliance at all command levels with Navy gas pipeline safety policies and standards. (Class II, Priority Action) (P-92-14)

--to the Secretary of the Air Force:

Evaluate the Air Force's gas pipeline program to identify and correct any deficient design, construction, operation, and maintenance procedures; inspect Air Force gas pipeline systems to identify and correct any conditions that do not comply with Air Force gas pipeline system policies and practices; and, if necessary, implement a program for periodically assessing compliance at all command levels with Air Force gas pipeline safety policies and standards. (Class II, Priority Action) (P-92-15)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

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April 8, 1992

APPENDIXES

APPENDIX A

INVESTIGATION AND HEARING

Investigation

The National Transportation Safety Board was notified on December 9, 1990, of the explosion and fire in a four-unit apartment building at Fort Benjamin Harrison near Indianapolis, Indiana. The investigator-in-charge was dispatched from Denver, Colorado, and other members of the investigation team were dispatched from Washington, D.C. Investigative groups were established for pipeline operations and survival factors.

Hearing

No public hearing was conducted in conjunction with this investigation. Staff-conducted depositions were held in Washington, D.C, on January 31, 1991, and in Indianapolis, Indiana, on February 6 and 7, 1991. Parties to these proceedings were the Army and the Citizens Gas and Coke Company.

APPENDIX B

PERSONNEL INFORMATION

Directorate of Installation Support (DIS) Director.--Lieutenant Colonel Gregory J. Miller, 45 years old, was appointed DIS director when he was transferred to Fort Benjamin Harrison, about 4 months before the accident. He had both a bachelor's and a master's degree in civil engineering. He had had no prior experience in operating and maintaining gas distribution systems. His two former assignments with the Army Corps of Engineering had lasted 7 years.

Incident Commander (IC).--Mr. Billy W. Forrester, 35 years old, was the assistant fire chief for the Fort Benjamin Harrison fire department. He had held that position for 6 years; before being promoted to assistant chief, he had been a firefighter at the Fort. Being assistant chief did not require him to have specialized education or training. He had had no experience operating natural gas distribution systems, but had responded to dozens of complaints about gas leaks at the Fort. About 2 years before the accident, he had attended a class given by the Citizens Gas Company about the hazards of natural gas.

Chief of the Utilities Branch.--Mr. Gillian Matthew Dicks, 42 years old, was a supervisor of general engineering in charge of 47 people in the utilities branch. The branch was responsible for operating and maintaining an electrical subyard, a high-voltage distribution system, and interior electrical systems; for operating and maintaining the gas distribution systems; for operating and maintaining the central heating and cooking plant; for maintaining the Fort's heating, ventilation, and air conditioning equipment (HVAC); for maintaining kitchen equipment; and for operating and maintaining the water treatment and distribution system. He had a bachelor of science in nuclear engineering. He had been employed in this position for 5 years. Before that he had been a captain in the Army. He had had no training or experience in gas distribution systems operations or maintenance and had received no training from the Army about the maintenance and operation of gas systems. The utilities branch is part of the Fort DIS.

Night-Duty Engineer.--Mr. Dennis King, 38 years old, worked for the HVAC shop of the Fort DIS. He did not have an engineering degree or certification. During his 10 years in this position, he had not been trained by the Army in gas system operation and maintenance or in handling natural gas distribution system leaks. He had had extensive experience in locating and repairing interior gas piping leaks and was often called upon to light pilot lights on gas appliances.

U.S. Army Corps of Engineers Project Manager.--Mr. Joseph Cattan was in charge of the remodeling construction work done in Harrison Village for most of Phase I and all of Phase II. He had been with the Corps of Engineers for over 5 years as a design, project, and construction engineer. He had both a bachelor's and a master's degree in civil engineering. Before his employment with the Corps, he had had no experience operating gas distribution systems, but he had constructed a few gas service lines into houses. During his employment with the Corps, he had received no training in design, construction, operation, or maintenance of natural gas piping systems. He had had 6 hours training from a representative of a plastic pipe manufacturer on the thermal fusion procedure of joining medium-density PE piping and on visually inspecting the completed joint.

Corps Project Engineer.--Mr. Renato Leonardi, 37 years old, was the Fort Harrison area office project engineer who worked under the Louisville District of the Army Corps of Engineers. He worked on both Phase I and Phase II of the Harrison Village remodeling project. He had a civil engineering degree and had worked at Fort Benjamin Harrison for about 8 years. Before that he had worked several years as a civil engineer for the city of Cincinnati. He had received no training from the Army about the design, construction, or maintenance of gas distribution systems.

Gas Company District Supervisor.--Mr. Norman Kirkhan, 54 years old, was the Citizens Gas and Coke Company employee who responded to the accident. He had worked for the gas company for about 30 years, during which time he had gained his gas distribution system experience. He had supervised gas-company maintenance crews who worked on underground gas lines and customer-service personnel who responded to gas leaks and appliance-repair requests.

APPENDIX C

EMERGENCY RESPONSE ASSISTANCE

The provost marshal arrived at 9:57 p.m. and met with the incident commander; they met on the hour, every hour, throughout the night. In addition to the provost marshal, seven MPs, including one supervisor and six patrolmen, and the following law enforcement units responded:

- 20 Indiana State policemen were assigned traffic control on the scene.

- 35 Marion County sheriff's office employees were assigned crowd control and protection on the scene.

The following fire departments provided mutual aid assistance:

- city of Lawrence
- Indianapolis fire department
- Lawrence Township
- Warren Township

A total of 15 fire suppression units and 124 firefighters responded to the accident. Also, eight rescue units (ambulances) and two helicopters were used to treat and transport the injured to area hospitals.

APPENDIX D

CHRONOLOGY

NATURAL GAS PIPELINE EXPLOSION AND FIRE
U.S. DEPARTMENT OF DEFENSE
FORT BENJAMIN HARRISON
DECEMBER 9, 1990

YEAR	EVENTS
1952	Harrison Village was constructed. A coated and wrapped steel gas system was installed and protected against corrosion. It was designed to distribute a mixture of propane-air gas through 11 gas main loops around the 48 buildings (240 apartments) within the village. The buried 2-inch plug valve behind building 1026 was installed as a part of the initial gas system.
1964	Additional 2-inch plug valves with valve stem extensions were installed on the 2-inch gas mains behind the buildings to provide a sufficient number of valves to shut down any part of the gas system without interrupting service to more than nine buildings. At this time a valve was added behind building 1027. A valve was also installed between buildings 1026 and 1027.
1971	The Harrison Village gas distribution system was converted from a propane-air gas system to a natural gas system. A gas leak survey was performed, identified leaks were repaired, and the corrosion protection system was improved. Additional valves were installed on the 2-inch gas mains so that any segment of the main could be shut down without interrupting the flow of gas to more than three buildings. Large-scale maps showing the gas mains were prepared, and the gas valves were identified by numbers, as required by the new Army Technical Manual TM 5-654.
1982	In the spring, a gas leak survey was performed, leaks identified were repaired, valve access boxes were located and brought up to standard, and the valves were lubricated. A base map showing the gas lines was prepared, but its scale was too large to show the locations of all valves. About one-half of the valves were shown on that map, and none of the valves on the gas main loop around buildings 1027 and 1035 were shown. This was the map kept at the plumbing shop for use during gas system emergencies.

1987	Phase I modifications to Harrison Village and its gas system were designed, and construction was begun. The contract specifications called for metallic pipe (cast-iron, wrought-iron, or steel). The specifications contained little information about the construction procedures to be used, did not require that discontinued piping be physically separated from the gas system and the open ends closed, and did not reflect the correct system operating pressure. Through a contract amendment, the Corps approved the use of plastic gas pipe rather than metallic pipe, but the design, construction, and test provisions of the contract were to amended. This allowed the contractor to select the type of plastic pipe (a medium-density polyethylene plastic) to be used and to perform the construction as he deemed appropriate. The sections of gas mains replaced were not contiguous, and no analysis was performed to assess the effect of this construction on the adequacy of isolation valves to limit the number of buildings that would be without gas service should a main segment be shut down.
1989	Phase II modifications to Harrison Village and its gas system were designed and construction begun. The specifications were not specific as to the type of plastic pipe to be used for the gas system; thus the contractor was able to select a high-density polyethylene plastic pipe. The specifications and drawings did not identify the locations where Phase II plastic mains were to be connected to the then existing gas system; therefore, these tie-in selections were left to the contractor. The construction drawings did not correctly show the locations of mains relative to the buildings and did not show the locations of existing valves. The as-built drawings incorrectly showed the valve locations between buildings 1026 and 1027. At least three thermally fused joints between the Phase I and Phase II plastic pipes leaked when pressure tested, and these connections had to be made using mechanical (compression) couplings. The contractor chose to connect the Phase II plastic pipe directly to the Phase I plastic pipe. In so doing, he limited the potential to isolate (shut down) main segments by operating the existing plug valves on the steel gas main segments.
6/89 to 12/09/90	During the 18 months before the accident, the Fort fire department responded to 20 gas leak reports from Harrison Village. Five of the 20 required evacuation of people from buildings.
12/09/90 5:42 p.m.	A resident of building 1035 reported a gas leak to the Fort fire department

5:47 p.m.

The fire department evacuated five families from the building after it discovered gas inside the buildings.

Neither the fire department's map nor one brought by a night-duty engineer from the plumbing shop showed the location of isolation valves that could be used to shut down the gas main behind building 1035. The incident commander directed MPs to tell families in the village that their gas would be turned off and that they would be unable to cook or heat their apartments. Because the weather was cool and the temperature was expected to drop, the MPs were later instructed to tell residents that other quarters could be made available if anyone wanted to leave; however, no additional residents were required to evacuate.

6:33 p.m.

On instructions from the incident commander to shut down the gas system, the engineer closed two valves at the gas company's meter and regulator station (M&R station). He believed one of the two valves controlled the gas supply to the village. The engineer later reopened the valve he believed controlled the gas supply to Fort locations other than the village.

About 7 p.m. -- 7:30 p.m.

The engineer, the incident commander, and the Directorate of Installation Support (DIS) director again viewed the available maps to identify valves that could be used to isolate the leaking gas main segment. Next, the engineer and firefighters searched the grounds near buildings and located three valves (two near building 1035 and one near building 1027) that the engineer believed might isolate the leaking main segment. He stated that he turned the valves to close them; however, he was not certain which direction, clockwise or counterclockwise, closed the valves. He stated that all he remembered about one of the valves near building 1027 was that it was hard to operate. The engineer then opened the village control valve at the gas company's M&R station. Gas odor was again detected in the area of building 1035, and the village supply valve was again closed at the M&R station.

In an effort to identify the location of the gas leak behind building 1035, the engineer instructed the firefighters to flood the ground with water and to note any locations where bubbles were seen. Although some bubbles were seen, this was not sufficient to locate the area of gas leakage. This action, however, sealed the soil openings, causing the gas to migrate further beneath the ground.

The fire department's combustible gas indicator detected gas in the valve box of a valve behind building 1035. Believing this to be the source of the gas leak, firefighters began to excavate the box.

8:10 p.m. A gas company supervisor and maintenance crew arrived, discussed the situation with the DIS director, and began assisting the firefighters in excavating the valve suspected of being the source of the gas leak. Once excavated, the village gas supply valve at the M&R station was partially opened by the engineer, and it was determined that the valve was not the leak source.

8:45 p.m. Because the odor of gas was not strong and the incident commander had been told that the leak did not threaten village residents, the valve at the M&R station was fully opened.

Shortly thereafter, the odor of gas was detected in and around building 1025, and gas odors were also noted by residents both inside and outside of buildings 1023, 1024, and 1026; but no one notified the Fort's fire department. The fire department dispatcher told the incident commander about a gas odor report from a resident of building 1020, and the incident commander said that it was likely at that time that residents throughout the village would be smelling that gas.

9:17 p.m. As firefighters were passing by building 1025 to investigate the gas leak reported at building 1020, building 1025 exploded and burned.

12/10/90 The Citizens Gas and Coke Company performed leak and pressure tests of the village gas system. It informed the Army that it would not take the responsibility for operating or maintaining the gas system because of the many gas leaks and because there were many conditions that did not conform to the Federal pipeline safety regulations with which the gas company was required to comply. An agreement was worked out between the Army and the gas company for the gas company to install, maintain, and operate a completely new gas distribution system.