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RESPONSE AND CLEANUP EFFORTS ASSOCIATED WITH THE WHITE PHOSPHORUS RELEASE, MIAMISBURG, OHIO*

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Summary

On July 8, 1986, local, state, and Federal personnel responded to a train derailment and subsequent fire of a tanker car containing white phosphorus in Miamisburg, Ohio. For a period of 5 days, fire departments from Miamisburg and up to 14 nearby communities fought the fire, which was caused by the gradual release of 12,000 gallons of air-reactive white phosphorus. During this period, approximately 30,000 area residents were evacuated and 166 people were treated at local hospitals. Response support was provided by numerous agencies/governmental units, including: the city of Miamisburg; the Dayton Area Hazardous Materials Team; fire departments in Montgomery County; The Miami Valley Disaster Services Authority; the Ohio Environmental Protection Agency; the U.S. Environmental Protection Agency; the Roy F. Weston Technical Assistance Team; the U.S. Department of Transportation; and the American Railroad Association. Initial support was focused on protecting the public health and welfare and on maximizing containment of the released materials. Subsequent to extinguishing the fire, large-scale cleanup operations commenced that included the treatment of contaminated water, soil, and river sediments. This paper summarizes these efforts and discusses the activities taken by the major agencies involved in the rapid response to the incident in Miamisburg, Ohio.

Introduction

The CSX train derailment and subsequent white phosphorus fire in Miamisburg, Ohio, (Fig. 1) set into motion a large and highly trained network of

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***The views and opinions expressed within this paper are those of the authors, and do not necessarily reflect those of the Roy F. Weston, Inc., the Ohio Environmental Protection Agency, or the United States Environmental Protection Agency.

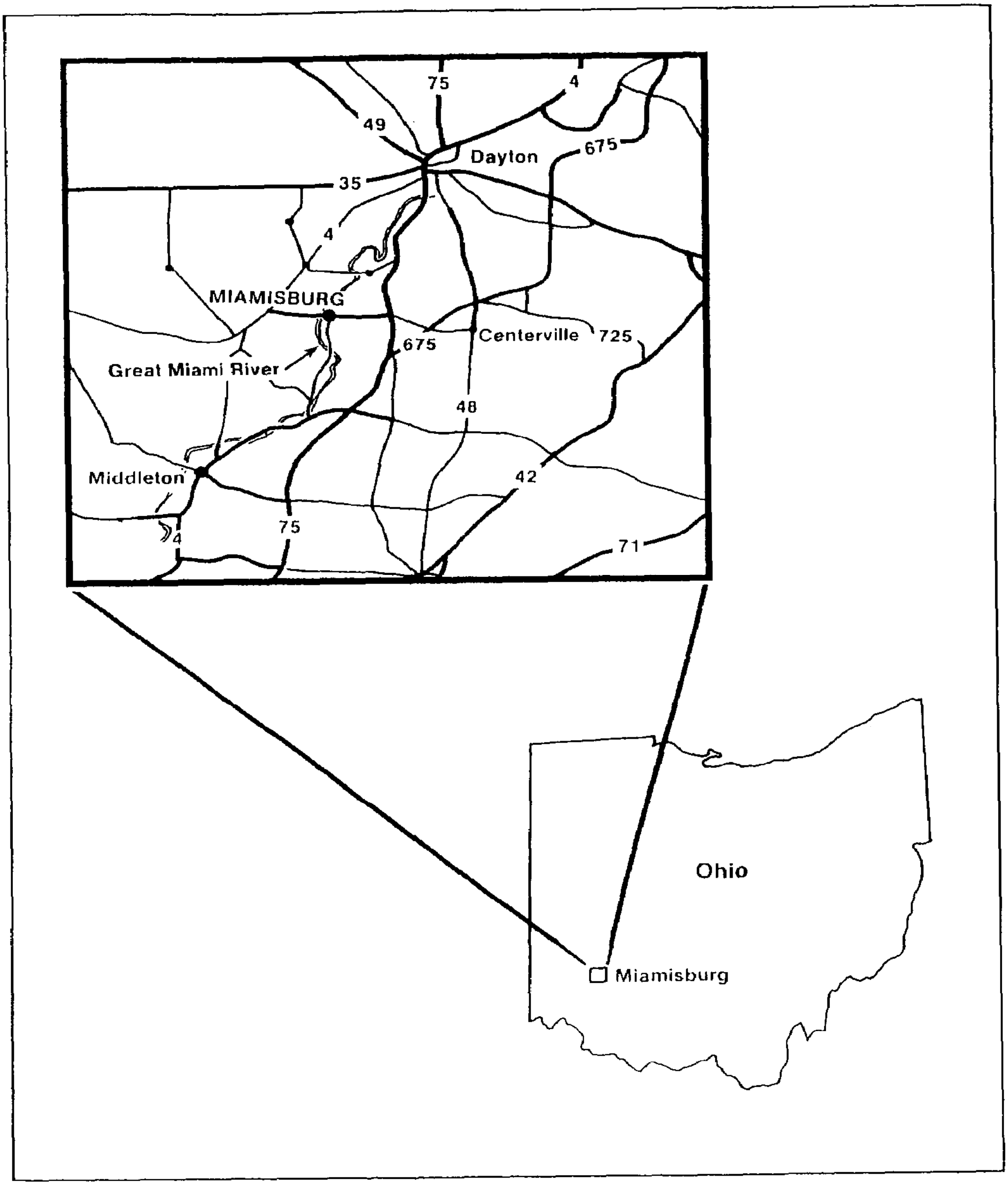

Fig. 1. Site location map, white phosphorus fire, Miamisburg, Ohio.

governmental, disaster relief, and environmental response professionals. A coordinated response to the white phosphorus release began on July 8, 1986 (the day of the derailment), and continued through stabilization and initial remediation stages; remediation efforts continued into the spring of 1987. Emergency preparedness, stabilization, and remediation aspects of the response effort that may be applied to future similar emergency situations are the focus of this paper.

Emergency preparedness

A freigth train derailment in 1978 resulted in the deaths of three Miamisburg residents. That incident emphasized to officials from the city of Miamisburg and the surrounding communities that a comprehensive emergency preparedness program was essential. Since 1978, these communities have undertaken significant steps to increase their ability to respond to hazardous materials emergencies. Specifically, these efforts have been in the areas of disaster planning and response personnel training.

Disaster planning, a fundamental component of any emergency response program, was a key element in the successful response to the white phosphorus release. During the months prior to the fire, the local contingency plan had been updated. This plan outlined proper chain-of-command, identified available resources, and provided guidelines for activation of the Dayton Area Hazardous Materials Team (Hazmat) and the local Mutual Aid System. The Hazmat Team, created in 1981, consists of fire fighters who have received special training and equipment. The Mutual Aid System is an organizational and communications network of local communities enabling neighboring municipalities to deploy response personnel and equipment in emergency situations. Both the Hazmat Team and Mutual Aid System were activated immediately following the white phosphorus release.

Nationally, only about 25% of an estimated 2 million people in the emergency response network (including local police and fire department personnel) have received adequate training to effectively manage a hazardous materials emergency [1]. In contrast, in the 8 years between the 1978 freight train derailment and the white phosphorus release, the Miamisburg response personnel had received significant specialized training. During simulation training, the Fire Chief, City Manager, and a police lieutenant had received instruction in disaster management and the basics of the incident command system. Similar training provided for fire fighters concentrated on disaster planning, hazardous materials responses, and railway emergencies.

Although the previous discussion focuses on the preparedness aspects of Miamisburg and surrounding communities, significant response efforts were also expended by state and Federal agencies. Rapid response by these agencies (conducted under state, regional, and national contingency plans) revealed the high degree of readiness maintained at the state and Federal level as well.

Emergency response

Initial situation

The white-phosphorus-filled tank car was in the middle of a 44-car train traveling south on CSX (Baltimore and Ohio) tracks from Toledo, Ohio, to Cincinnati, Ohio. Approximately 12,000 gallons (ca. 40,000 l) of white phosphorus (heated to a liquid state for ease in handling) were being shipped from Enco of Islington, Ontario, to an Albright and Wilson Company plant in Fernald, Ohio, for processing into phosphoric acid.

Investigators reported that all routine safety procedures were followed prior to the derailment. The tracks were inspected regularly (as recently as May 13, 1986, and repaired on June 17, 1986), speed limits were observed (the train reportedly was traveling at 1 mph below the 45 mph (~75 km/h) limit), and no evidence of drug or alcohol use by the train personnel was discovered. During shipment, approximately 2500 lb of water (~1100 kg) blanketed the 170,000 to 175,000 lb (12,000 gal) of white phosphorus, in accordance with standard handling practices. The temperature of the white phosphorus was maintained at 45 °C by a layer of insulation between the two steel layers of the train car.

Cars involved in the 15-car derailment included: three cars with automobiles and auto parts, one car of animal tallow, one car of newsprint, a car-load of sulfur, and the car-load of white phosphorus. The train had made a stop in Dayton before heading south along the Great Miami River towards Cincinnati and was crossing a bridge over Bear Creek west of downtown Miamisburg at about 4:30 p.m. when the derailment occurred. During the derailment, witnesses noticed rocks being hurled by the car wheels. The car carrying the white phosphorus reportedly burst into flames almost immediately after it derailed and came to rest near the bridge (Fig. 2). Initial reports indicated that the derailment was caused by a "sun kink", an uncommon, heat-related misalignment of the tracks.

The dispatcher at the Miamisburg Fire Department was alerted to the train derailment by three different sources. After reviewing the hazards associated with white phosphorus, the Fire Chief activated all fire personnel, initiated an evacuation of downwind areas, and requested assistance through the Mutual Aid System.

The Miamisburg Fire Department then requested assistance from the regional Hazmat Team, the Miami Valley Disaster Services Authority, and the Ohio EPA (OEPA) Emergency Response Team. Technical information was requested from Chemtrec, and, as a result, Phosnet (a phosphorus substance hotline) was activated. Phosnet then contacted Monsanto (a manufacturer of white phosphorus) and Albright and Wilson (the consignee of the shipment). Information obtained from Monsanto and various technical sources revealed that white phosphorus, when burned in dry air, generates phosphoric anhydride (phosphoric acid) as a combustion by-product. In addition to being cor-

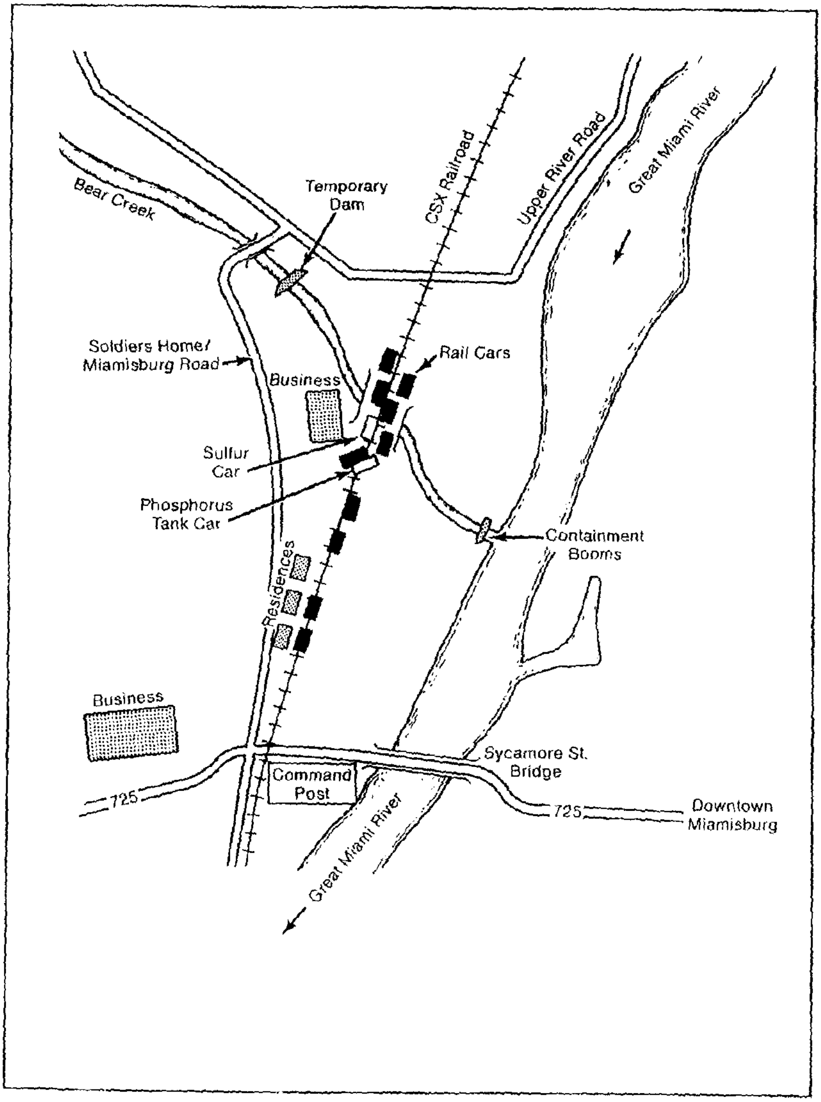

Fig. 2. Site map, Miamisburg white phosphorus release. Adapted from: "White Phosphorus Ignites in the Miamisburg Derailment", Fire Command, October 1986, p. 32.

rosive to skin and tissue, exposure to phosphoric anhydride may cause severe gastrointestinal irritation, nausea, vomiting, and breathing difficulties.

A major complication during the initial release was the presence of a leaking tanker of sulfur adjacent to the white phosphorus tanker. Because of the juxtaposition of the two tankers, phosphorus pentasulfide could be generated from the combination of phosphorus and sulfur vapors. Phosphorus pentasulfide is readily converted, in the presence of moisture, to hydrogen sulfide gas and phosphoric acid. Hydrogen sulfide is a rapid systemic poison that induces respiratory paralysis with consequent asphyxia at high concentrations (1000 ppm). Serious health effects such as central nervous system distress, pulmonary edema, and gastrointestinal disturbances may be observed at lower concentrations (50 to 250 ppm).

As a result of the hazards posed by the burning phosphorus, an estimated 12,000 to 17,000 people were evacuated from the Miamisburg area, which was designated a disaster area by Governor Celeste less than 2 h after the derailment. Approximately 170 people were treated at local hospitals for shortness of breath, burning eyes, and nausea.

Response organization

Early stages of the Miamisburg response, with hundreds of people responding, demonstrated the need for contingency plans that detail and establish response authorities and procedures for setup of communications systems, a command post, an emergency operations center, and procurement of supplies.

Primary response authority during the white phosphorus release remained with the local Fire Chief. The issuance of a State of Emergency by the major of Miamisburg gave the City Manager authority to protect the health and welfare of the municipality. Other fire chiefs from neighboring communities were consulted in the decision-making process, but the final decisions were always made by the City Manager and the Fire Chief. Technically, the Fire Chief controlled the fire ground and the City Manager controlled the command post. Both, however, were involved in decisions concerning the evacuation and actions to the derailed train car.

As the emergency progressed, personnel were grouped into response teams, which were designed to undertake specific emergency actions and to brief the Fire Chief and City Manager on technical matters. Generally, the responsibilities of the response teams were: fire fighting, incident evaluation, air monitoring, creek and river response, technical information support, command area support, and emergency operations support. A comparison of the effectiveness of the groups revealed that the teams with a central coordinator better utilized their personnel; e.g., the state had a coordinator for the eight separate agencies that responded, but other groups were not similarly organized. For instance, in the groups without a central coordinator, conflicts arose over possible approaches to and responsibility for responding to the white phosphorus release; these conflicts ultimately limited the effectiveness of these groups. The groups coordinated by a central person from the state of Ohio, on the other hand, worked effectively together and each had clearly defined roles. This problem may have been averted if teams had been organized earlier, during the early stages of the response, with more clearly defined responsibilities.

Because each group of responders required communications capabilities, existing telephone systems were rapidly overburdened. Supplementary communications capabilities (both intra-site and extra-site) were provided through the use of emergency telephone lines. In addition, communication vans, ham radios, and cellular telephones eased the demands upon land-line communications systems.

The on-scene responders were relieved of the responsibility of informing the public by the Governor of Ohio, who created an emergency group (comprised of state employees) to staff a 24-h emergency information service. This emergency information line rang directly into the Emergency Operations Center. Local news agencies also assisted by providing knowledgeable and accurate reports for the residents. News reports were often based on information presented by the response groups at news conferences.

News conferences were often conducted near the command post (on-site focal point for all response activities), which was established at the railway crossing at Sycamore Street (Fig. 2). This location, approximately 500 yd (450 m) upwind of the derailment, provided an unobstructed view of the site and access to several arterial roads for easy access by responders and reporters.

During the early stages of the response, the command post became extremely congested as communications lines were laid and more responders arrived on site. This congestion was relieved after response teams (with designated leaders permitted in the command post) were developed, and the Emergency Operations Center (EOC) was established in the Miamisburg City Hall, approximately 1 mile east of the site.

Most of the responders, especially the technical information and support teams, were restricted to the EOC to minimize health risks and increase the efficiency of the command post operations. After the EOC was set up, on the fourth day of the response, the teams were able to coordinate their activities more effectively, and technical information was more efficiently conveyed to the City Manager and/or Fire Chief. In accordance with the local contingency plan, the EOC was chaired by the City Manager, with spokespersons for the response teams and agencies present for comment and consultation.

In addition to establishment of the EOC, the Miamisburg contingency plan also included procedures for evacuations and mobilization of equipment. The evacuations were organized by the Miamisburg Police Department, which divided the city into sectors and coordinated transport to the pre-arranged evacuation center (the Dayton Convention Center). Emergency support groups, such as the Red Cross, provided sleeping materials for the evacuees and food for the on-site workers. Local restaurants also donated food for site workers.

Components of stabilization efforts

The response teams focused on four main problem areas associated with the white phosphorus release: controlling the fire in the burning tank car, isolating the white phosphorus car from other cars, minimizing releases into Bear Creek and the Great Miami River, and monitoring the plume released during the fire. Fire control and tank car isolation measures were undertaken by the local fire departments; water release minimization and air monitoring were tasked to state and Federal agencies. Although the major response components were interrelated, they are analyzed separately in the following section, which outlines the major activities during the emergency response and describes options that were available to the Fire Chief and City Manager.

Fire control

The responders were confronted with many potential health problems from the burning tank car of white phosphorus. As was described previously, when phosphorus burns in dry air, it may produce anhydrous phosphoric acid, which is water-reactive. Phosphine may also be produced in alkaline conditions. To prevent possible exposure to these chemicals, response personnel working near the site were equipped with self-contained breathing devices. In addition, a restricted area and a decontamination zone were established.

After responding to the fire, the Fire Chief received advice from Chemtrec and Monsanto, who recommended that the fire be extinguished; subsequently, initial extinguishment procedures consisted of drenching the tanker with approximately 5000 gpm ($\sim$18,500 l/min) of water from deluge guns (supplied by hydrants and drafting off the river). The goals of the extinguishment procedures were: 1) to deprive the phosphorus of oxygen by maintaining a water mist over the product, and 2) to lower the temperature of the car below the auto-ignition point for white phosphorus.

At the end of the first day of the incident, the Fire Chief believed that the fire was under control. But the flames increased at the end of the second day of the response when the road bed supporting the tanker eroded, causing the tanker to shift and release phosphorus into the creek. Further options for extinguishing the fire included sealing the holes in the tanker, applying foam or dry chemicals to the tanker, burying the tanker in wet sand, or rolling the tanker into a wet sand pit. These options were rejected because of the difficulties in applying a patch, unavailability of the foam, instability of the area supporting the tanker, and uncertainty of the strength of the tanker car, respectively. With no other viable options posed, the Fire Chief decided to let the white phosphorus fire burn out as rapidly as possible.

Two primary alternatives to increase the burn rate were considered by the Fire Chief and City Manager. The first, proposed by CSX and their contractors, was to manually open the manways and washouts on the car and move the car to a level area, which would expose more of the white phosphorus to air. A second alternative, recommended by detonation experts, consisted of opening the tanker remotely, which would minimize direct exposure by the workers to phosphorus fumes and flames. Because detonation could also set off uncontrolled explosions, the Fire Chief and City Manager decided on the first alternative; thus, on the afternoon of the third day, CSX and cleanup contractor personnel opened the manways and washouts on the tanker. The air flow was enhanced by a fan, which blew over the openings, and a 4-inch-diameter ($\sim$10 cm) woven-steel line, which forced 3700 cfm of air ($\sim$1 m^3/min) into the car.

The burn rate was increased once again on the fourth day by moving the car to a level area, thus enabling more of the phosphorus to be exposed to the air. These actions so accelerated the burn rate of the white phosphorus that only a few inches of product were left inside the tanker when the fire was finally extinguished during the morning of the fifth day.

Car isolation

Another major concern of the responders was the unstable and precarious position of the tanker, dangerously suspended near the bridge over Bear Creek. Any shift and subsequent release from the car could significantly contaminate the Great Miami River and later impact the Ohio River, which it joins at Cincinnati, approximately 50 miles south of Miamisburg.

Response personnel were also extremely concerned about the proximity of the sulfur car to the white phosphorus car. If the white phosphorus and sulfur made contact, phosphorus pentasulfide could be formed; phosphorus pentasulfide, in the presence of moisture, could liberate hydrogen sulfide and phosphoric acid. (Samples collected following the incident by the Roy F. Weston Technical Assistance Team (TAT) contained both phosphorus and sulfur, thereby indicating that these materials mixed during the incident). Initially, the responders could not get close enough to the tank cars to determine the location of the sulfur car. The response workers were also unable to relocate the sulfur tanker because of damage to the bridge and blockage from derailment debris.

Moving the white phosphorus tank car was considered hazardous by the Fire Chief and City Manager because the tanker was built in 1966, and thus was exempt from the stringent safety regulations established in 1970. Consequently, a contingency plan was developed to roll the white phosphorus tank car into a wet sand pit if the tanker suddenly developed a leak and began to release the white phosphorus. In addition, a diversion ditch was excavated to reroute Bear Creek around the emergency area. Fortunately, the tanker remained intact when it was moved 35 ft during the evening of the fourth day.

During final extinguishment operations on the fifth day, the white phosphorus tanker was moved approximately 180 ft south to a sand pit and allowed to cool. This enabled cleanup procedures to commence in the main area of contamination.

Release minimization

During the response, several thousand gallons of phosphorus and animal tallow were released into Bear Creek and the Great Miami River, which resulted in a 16-mile fish kill (from the colloidal phosphorus and animal tallow coating the gills). Initially, containment booms were placed by the Ohio EPA at the confluence of Bear Creek and the Great Miami River. These booms retained approximately 1200 to 1500 yd^2 (960–1200 m^2) of animal tallow (specific gravity = 0.86), which was removed by a subcontractor to the response contractor hired by the railroad. On the fourth night, however, the booms were washed out be increased water stream discharge from storms.

Efforts to limit the spread of the white phosphorus, which is heavier than water (specific gravity = 1.82), were initiated on the third day of the response. A dam was constructed of gravel, sand, and soil upstream of the derailment on Bear Creek to prevent Bear Creek from washing the phosphorus into the Great Miami River. Water trapped behind the dam was pumped onto adjacent farmland with equipment supplied by the fire departments; the water, however, recharged the creek through drain tiles in the fields. The upstream dam was slowly dismantled early in the morning of the fourth day to prevent the water that had backed up behind the dam from scouring the creek banks and releasing more white phosphorus.

The response crew attempted to build a new dam later the fourth day, as part of the contingency plan for the tank moving operations. This dam, which was constructed of fallen trees, sand, gravel, cobbles, and debris, connected the southern bank to the central bridge pier. In addition to the dam, a 75-ft section of Bear Creek was to be diverted north, and re-enter Bear Creek, to create a pit in which to bury the phosphorus tanker, if necessary. Heavy equipment supplied by "Operation Bulldozer", a Miami Valley emergency equipment program, was used throughout the fourth day of the response, but time restrictions prevented adequate compaction of the soils. This dam was also breached, allowing scouring of sediments and an additional release of phosphorus to the Great Miami River.

The creek was finally diverted during cleanup operations. Earlier diversion of the creek probably would have minimized the quantities of phosphorus and tallow released into the Great Miami River and prevented the massive fish kill.

River water samples collected by the OEPA throughout the incident indicated above-background levels of sulfur and phosphorus compounds. The OEPA also monitored river pH levels, which remained near neutral.

Air monitoring and sampling

The results of air monitoring conducted by the U.S. EPA Environmental Response Team (ERT) and TAT indicated that the health of the community

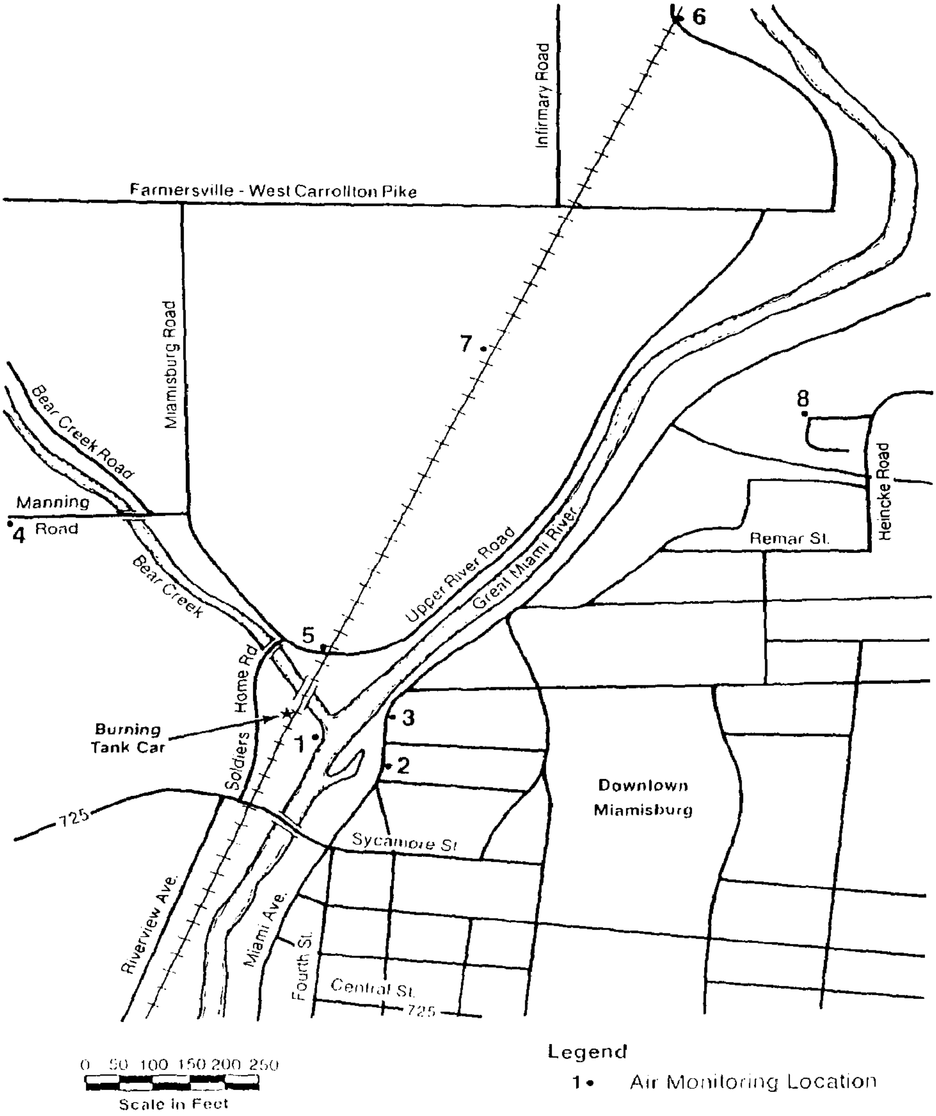

Fig. 3. Air monitoring locations, Miamisburg white phosphorus release.

was protected by the evacuation of Miamisburg and the surrounding towns. According to ERT data collected during the response, elevated levels of particulates and phosphoric acid were present in the plume [3].

At the beginning of the response, the great quantities of water used on the white phosphorus tank car probably also knocked down dangerous particulates

TABLE 1

Air monitoring results Miamisburg white phosphorus incident

Sample location	Time[1] (h)	Total particulates		TIP/[2] PID (ppm)	Acid filters		Detector tubes[3]		
		Miniram (mg/m^3)	Filters (mg/m^3)		H_3PO_4 (mg/m^3)	H_2SO_4 (mg/m^3)	PH_3 (ppm)	SO_2 (ppm)	H_2S (ppm)
	Day 2 (July 9, 1986)								
1	3:30 p.m.	ND	NA	1.0	NA	NA	ND	ND	ND
1	4:30 p.m.	0.5	NA	2.4	NA	NA	ND	ND	ND
2	6:30 p.m.	ND	NA	7.0	NA	NA	ND	ND	ND
2	8:00 p.m.	59.0	NA	13.0	NA	NA	ND	ND	ND
3	6:30 p.m.	53.0	NA	12.0	NA	NA	ND	ND	ND
3	8:00 p.m.	40.0	NA	9.0	NA	NA	ND	ND	ND
	Day 3 (July 10, 1986)								
4	5:20 p.m.	5.0	<5.0	NA	2.44	<2.4	NA	NA	NA
	Day 4 (July 11, 1986)								
5	11:43 a.m.	1.5	5.1	NA	2.05	<1.6	NA	NA	NA
6	1:14 p.m.	ND	5.4	NA	<0.09	<1.7	NA	NA	NA
5	3:45 p.m.	0.08	3.8	NA	2.02	<1.2	NA	NA	NA
5	4:36 p.m.	ND	ND	NA	10.0	ND	NA	NA	NA
7	3:57 p.m.	0.5	2.6	NA	<0.05	<1.2	NA	NA	NA
8	3:50 p.m.	0.8	<4.0	NA	<0.08	<1.8	NA	NA	NA

[1]Prevailing wind conditions: day 2: 10 mph, 285°; days 3 and 4: 9–13 mph, 190°–215°.
[2]TIP and PID are photoionization detectors used to monitor for organic vapors.
[3]Detector tubes used: PH_3 = phosphine, SO_2 = sulfur dioxide, H_2S = hydrogen sulfide.
ND = not detected, NA = not analyzed.

generated from the fire. Air monitoring conducted when the fire was smoldering and emitting a light plume detected low levels (0.5 mg/m^3) of particulates on the Miniram real-time aerosol monitor and only 2.4 ppm of organic and/or inorganic compounds on the Photovac TIP (Fig. 3 and Table 1). Throughout the response, no contaminants were detected with Draeger sampling tubes (hydrogen sulfide, phosphine, and sulfur dioxide).

After the fire escalated at 6:04 p.m. on the second day, particulate levels exceeded 40 mg/m^3 during three reading periods, and the Photovac TIP recorded levels near 10 ppm. The Centers for Disease Control recommended an alert level of 0.25 mg/m^3 and an action level of 1.0 mg/m^3 for real-time Miniram (total particulates) readings. These levels were based on the phosphoric acid Threshold Limit Value (TLV) of 1.0 mg/m^3 [4].

Aerosol filter samples collected beneath the plume on the third and fourth days of the response contained levels of particulates as high as 5.4 mg/m^3, and levels of phosphoric acid up to 10.0 mg/m^3. The particulate levels were lower than the TLV for nuisance dust in the work place (10 mg/m^3), but the phosphoric acid exceeded the TLV of 1 mg/m^3 in four samples.

No efforts were made to control the particulate levels as the tanker burned on the third and fourth days. Misting the plume might have reduced the particulate and phosphoric acid concentrations, but the misting nozzle was not available.

Data collected by the ERT and TAT, along with tracking information from personnel in helicopters, were provided as input for an air contaminant plume model used by scientists from the Monsanto Mound Facility. This computer model was never fully functional because it required real-time phosphorous data, which was not available at the site. Since the Miamisburg incident, a real-time phosphorus analyzer has been developed and used at other white phosphorus fires [5].

Components of remediation efforts

After the fire was extinguished, the white phosphorus car was moved to a sand pit and secured on July 12, 1986. The tank car placement was chosen to avoid interference with remedial cleanup activities, which included: temporary relocation of the stream bed to facilitate cleanup operations; removal and treatment of contaminated soil and stream sediment; treatment and disposal of contaminated water; and groundwater monitoring. Remedial activities were undertaken by a cleanup contractor hired by the railroad; OEPA personnel monitored the cleanup actions.

Stream bed relocation

Because the sediments in the section of Bear Creek between the railroad bridge and the confluence with the Great Miami River contained the greatest quantities of white phosphorus and sulfur, this section was isolated by creating three lagoons, from which sediments could be removed and water could be treated. These lagoons were created in the original Bear Creek channel after a new channel was excavated. The new channel, which paralleled the north side of Bear Creek, began 50 ft upstream of the railroad bridge and continued downstream to the Great Miami River (Fig. 4).

Soil and creek sediment removal and treatment

After contaminated soil from the railroad bed and sediments from the stream bed were excavated, they were stockpiled for treatment. The following processes for removing/treating the white phosphorus in the soil and sediment were considered by the cleanup contractor: 1) reaction of the phosphorus by heating the contaminated material in a modified-asphalt drier; 2) oxidation of the phosphorus by adding hydrogen peroxide to the contaminated material; 3) physical separation of the white phosphorus from the soil and sediment by

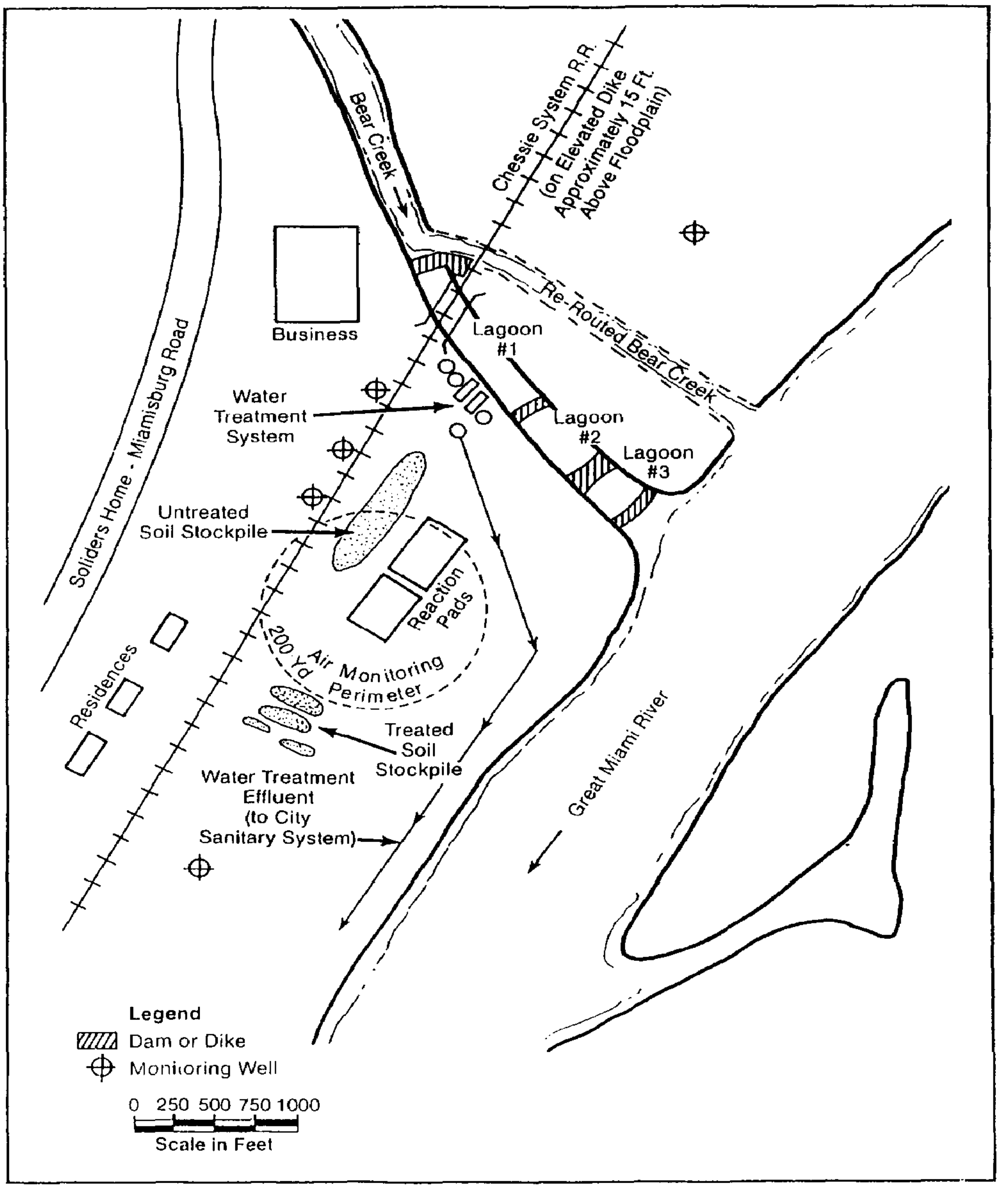

Fig. 4. Site remediation components, Miamisburg white phosphorous release.

heating the mixture to the phosphorus melting point; 4) treatment of the contaminated soil and sediment at an off-site location; 5) reaction of the phosphorus by exposing the contaminated material on an open-air pad; and 6) reaction of the phosphorus by exposing the contaminated material on a pad enclosed within a containment structure, which would collect fumes generated in the reaction process. After evaluating the options on the basis of feasibility, effectiveness, costs, and time constraints, option 5, the open-air reaction process, was chosen.

Pilot scale tests of the open-air reaction process were conducted on a 20 ft$\times$30 ft steel pad constructed on site. In the first step of the process, the contaminated material was placed on the pad and spread to a thickness of 6- to 8-in. with a front-end loader. Next, a tractor with a cultivator disc attachment turned the material, which enabled air to react with the white phosphorus. The contaminated material was turned until the air/phosphorus reaction was completed and smoke stopped emanating from the reaction pad.

After completion of testing, two 1/2-acre ($\sim$2 km^2) asphalt reaction pads with curbs were constructed on which to treat/react the white phosphorus-contaminated material. Minor changes were made to the process: propane blowers were attached at the rear of the tractors to increase the rate of reaction, and a 3 percent to 8 percent hydrogen peroxide solution was added to the contaminated material (to oxidize the elemental phosphorus to a phosphate product) to ensure that the phosphorus concentration in the material was less than 10 ppm. At levels less than 10 ppm, the material did not exhibit ignitable characteristics and, consequently, was not characterized as a hazardous waste based on ignitability. Approximately 7500 yd^3 ($\sim$5.7 10^3 m^3) of material was treated and disposed.

The amount of time required to react the soil ranged from 12 to 24 h. Moisture content and phosphorus concentration were the two major factors influencing reaction time, with the latter being most important. To prevent the addition of moisture to the soil from precipitation, untreated stockpiles were covered with tarps.

Prior to treatment, soils and sediments were passed through a rock sorting machine to prevent damage to equipment on the pad. During the sorting process, large chunks of sulfur were removed for disposal at a sanitary landfill.

Air monitoring was conducted during the phosphorus reaction process to ensure that no hazardous fumes were released from the site. Although the threat to the center of Miamisburg, approximately 1 mile east of the site, was low, residents in a row of six houses, located within 1/4 of a mile from the treatment area, were potentially at risk. Depending on the quantity of smoke generated and wind direction, the residents at these houses had the potential to be exposed during remediation activities. To ensure the safety of these residents, the OEPA Air Pollution Division set the maximum allowable exposure limit (based on an adjusted Time Weighted Average) for phosphoric acid at 0.02 mg/m^3.

Gilian pumps were used to collect air samples onto 0.8-μm cellulose ester cassette filters, which were then analyzed for phosphoric acid. Sample locations were located at a maximum of 200 yd from the pad, 100 yd closer than the nearest residence. Samples were collected four times per day, with at least one sample drawn during each new load of material.

The first few hours of reaction for each load of contaminated material generated the greatest concentration of smoke; the concentrations of most samples collected during these periods, however, were below the action level. Under certain conditions (night-time, high-humidity), however, sample results exceeded 0.02 mg/m^3, which was of concern when the prevailing winds directed the smoke towards the nearby residences. To minimize the risk to the residents, the operating procedures were changed: smoke-generating activities were curtailed when the prevailing winds directed the smoke towards the houses, and work was conducted only during daylight hours.

Lagoon water and sediment treatment

After most of the contaminated sediments were removed from the three lagoons formed in Bear Creek, water was pumped from the lagoons and treated with hydrogen peroxide. The process consisted of pumping water from the lagoons into rapid mixing tanks, where a 35 percent solution of hydrogen peroxide was added. The water was then transferred to a holding tank, where the peroxide level was monitored and minor mixing and sedimentation occurred. After the sediments settled out, the water was pumped to a final holding tank for testing of pH and peroxide levels. If the levels were acceptable, the water was pumped through a sand filter to a sanitary sewer line. Conditions for discharge were: 1) pH between 6 and 9; 2) excess hydrogen peroxide available; and 3) elemental phosphorus levels at 20 μg/l or less. Samples analyzed for sulfates and phosphates were within OEPA discharge limits.

Because of the high permeability of the stream sediments and the shallow depth to groundwater, recharge to the lagoons exceeded pumping capacity. To treat the remaining sediments and water in the lagoons that could not be removed, *in situ* treatment was initiated. The phosphorus was oxidized in the lagoons with 4000 gallons of peroxide, and agitated to facilitate mixing. An 8 to 10% hydrogen peroxide solution was injected into the subsurface sediments with a high-pressure spray system that was attached to the bucket of an excavator. Initial sampling indicated phosphorus levels in the lagoon sediments to be as high as 4500 ppm. After 10 days of treatment, phosphorus levels were below 300 ppm.

In order to lower the phosphorus levels further, an additional 4000 gallons of peroxide was mixed with the sediments and reacted for 15 days. After that time, no levels above 100 ppm were detected. At levels less than 100 ppm, the natural oxidation process of white phosphorus was expected to further reduce the white phosphorus levels in the sediments. (Sediment samples collected 1 year later indicated white phosphorus levels less than 4.4 ppm).

Groundwater monitoring

The well field for the city of Miamisburg was located approximately 1 mile downstream of the spill site (along the flood plain of the Great Miami River). Although it was assumed that no immediate threat to the well field existed, a groundwater monitoring program was developed. Five observation wells were installed at the site: one was up-gradient, three were in the vicinity of the spill, and one was down-gradient. The top of the 10-ft long well screens were installed 2 ft above the water table (approximately 15 ft from the ground surface). Samples were analyzed for elemental phosphorus, total phosphorus, phosphate, sulfate, and sulfide; background data were generated from samples collected from other wells in the area. At the time of publication, the OEPA had not released conclusions concerning the well data.

Site restoration

After treatment of soil, sediment, and water was completed, the diversion channel was backfilled, and Bear Creek was reopened to flow in its original channel. The asphalt pads used during soil treatment were removed, and the area was graded and seeded.

Additional work was performed in the spring of 1987 in the Great Miami River, when river levels dropped downstream of Bear Creek. The sediments contained sufficient levels of white phosphorus to cause a smoke reaction upon exposure to air. These sediments were removed along the banks of the Great Miami River, and the elemental phosphorus was reacted.

Also during the spring of 1987, a small fish kill occurred. Creek sediment samples indicated elevated levels of hydrogen sulfide, which is toxic to fish at low concentrations. Hydrogen sulfide was believed to have been generated from the reaction of the elemental sulfur in the creek sediment.

Conclusions

The white phosphorus release on July 8, 1986, in Miamisburg, Ohio required the largest evacuation in the United States ever caused by a train derailment. During the 92- h emergency response, 14 fire departments, 8 state agencies, 3 Federal agencies, and several local emergency organizations assisted the city of Miamisburg and the Dayton Area Hazardous Materials Team in extinguishing the white phosphorus fire. Medical monitoring conducted by the state of Ohio in the months following the emergency indicated that the white phosphorus release did not cause any significant long-term health effects. A significant fish kill occurred, however, from releases of white phosphorus, sulfur, and animal tallow into Bear Creek and the Great Miami River. This fish kill may have been minimized if Bear Creek had been diverted around the spill area during the initial stages of the incident.

Despite the fish kill, the white phosphorus response may be considered a success. The success of the emergency response actions may be attributed to effective training of the local fire fighters, thorough contingency planning, and creative organization and coordination of responders. After the responders were assigned to specific action teams, the site command post became less congested and a chain-of-command became apparent. Many of the action teams were based in the Emergency Operations Center, which further minimized the command post congestion.

During the 12-week cleanup period, 7500 yd^3 of white phosphorus-contaminated soil was reacted and 1.5 million gallons of water was treated. Water and sediments were isolated in Bear Creek after a dam and diversion channel were constructed. Following the completion of cleanup activities, the diversion structures were dismantled, and the site was returned to its original condition.

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