

Treatment Technologies for Historical Ponds Containing Elemental Phosphorus - Summary and Evaluation

FINAL REPORT

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
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NOTICE

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FOREWORD

The U.S. Environmental Protection Agency (EPA) administers the Superfund program in cooperation with individual states and tribal governments to clean up the nation's uncontrolled hazardous waste sites. One aspect of the Superfund program is conducting long-term remedial response actions at hazardous waste sites listed on the National Priorities List (NPL). These sites are considered to be the most contaminated uncontrolled hazardous waste sites nationwide with the highest priority for investigation and remediation.

The historical operations at the FMC plant area of the Eastern Michaud Flats Superfund site (EMF Site), located near Pocatello, Idaho, managed wastes generated during the manufacturing of elemental white phosphorus (WP) in ponds at the site. The site was added to the NPL in August 1990 and a Record of Decision was signed in 1998 that specified capping 16 historical ponds that contained waste contaminated with WP, metals, and radionuclides. WP is a highly toxic and reactive contaminant and limited information is available about the treatment of WP-containing wastes. Following concerns raised by local stakeholders about the capping remedy, EPA committed to re-evaluate treatment technologies potentially applicable at the EMF Superfund site.

This report includes information about six technologies that may be applicable for the treatment of contaminated soil and sludge in the historical ponds at the EMF site. Information presented in this report is specific to the EMF site; therefore, it may not be applicable to other WP-manufacturing sites. Furthermore, the report is not intended to recommend any specific remedial approach for the EMF site or other sites. It does not consider many other factors, such as risk reduction to human health and the environment, that are critical in choosing a remedial approach for a site.

Because limited information was available about the historical ponds at the EMF site, assumptions using best engineering judgment were made about the characteristics of the waste. Information provided in this report about the applicability of specific technologies to treat the soil and sludge in the historical ponds is based on those assumptions. Costs presented in this report are estimates only, and are also based on those engineering assumptions.

This report is made available by EPA to provide additional information on potentially applicable technologies for the treatment of soil and sludge contaminated with WP, metals, and radionuclides.

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EXECUTIVE SUMMARY

This report provides a summary and evaluation of available information about technologies that have the potential to treat soil and sludge in historical ponds contaminated with elemental white phosphorus (WP), heavy metals, and radionuclides at the Eastern Michaud Flats (EMF) Superfund site located near Pocatello, Idaho. These ponds were used by Astaris Idaho LLC (previously FMC Corporation) during the manufacture of WP from phosphate ore, and received the following wastes: phosphy water, precipitator dust slurry, phosphy solids, slag pit water and solids, and residuals from reclaiming WP in other ponds.

The site was added to the National Priorities List in August 1990 and a Record of Decision (ROD) was signed in June 1998 that included capping 16 historical ponds at the site. Based on concerns raised about the decision to cap the historical ponds, the Technology Innovation Office (now the Technology Innovation Program) of the U.S. Environmental Protection Agency (EPA), Office of Solid Waste and Emergency Response, was requested to evaluate technologies potentially applicable for the treatment of soil and sludge in the historical ponds that contain WP, heavy metals, and radionuclides.

The scope of this report is limited to a summary and review of available information from the technical literature and previous studies about the following:

- The 16 historical ponds identified in the EMF ROD - Ponds 1S-7S, 9S, 10S, and 1E-7E
- Soils and sludges in the historical ponds that are not physically covered by ponds under authority of the Resource Conservation and Recovery Act
- Treatment technologies that have been used or show promise for treatment of WP based on available information

Containment technologies (such as capping) or use of off-site treatment, storage, or disposal facilities (TSDFs) were not examined for this report, although they are discussed as they relate to treatment technologies. The report does not provide recommendations regarding selection of technologies or evaluate non-treatment options (e.g., institutional controls), nor does it compare the costs and benefits for use of any treatment technology or remedial option. That is, the report does not evaluate the treatment technologies using the nine criteria from the Superfund program which includes all factors (e.g., applicable requirements, stakeholder acceptance) necessary to evaluate a remedy. As such, this report is not a feasibility study for remediation of the historical ponds at the EMF site.

Treatment technologies were identified and evaluated based on (1) available information in the technical literature, including previous studies, and work conducted at similar sites; (2) technology performance data; (3) technology application considerations, including technical judgment using information from previous studies of the EMF site and experience in waste site remediation; and (4) cost to implement the technology.

Overall Findings

Six technologies were identified as potentially applicable: solidification/stabilization (S/S); caustic hydrolysis; chemical oxidation; mechanical aeration; incineration; and thermal desorption. The following is a summary and discussion of the findings in this report.

No technology has been used at full-scale to treat waste material similar to that found at EMF.

Only limited information is available in the literature covering the remediation of WP, with fewer than 10 studies identified which discuss the potential use of treatment technologies for WP. This primarily includes studies performed at WP manufacturing facilities and at military facilities. While technologies have been used to treat WP in bench- and pilot-scale studies, no technologies were identified as having been used for full-scale treatment.

No new treatment technologies have emerged as potentially applicable since the EMF Feasibility Study. The six technologies in this report were identified in the Feasibility Study report prepared in 1996.

Other WP manufacturing facilities primarily used capping as the remedy for similar waste. Eight other WP manufacturing sites were identified that have similar contaminated historical ponds as the EMF site. Six of the eight sites have installed or plan to install caps. For the two remaining sites, one (Rhodia, Silver Bow, Montana) indicated that the ponds are not under corrective action, and the other (Stauffer, Tarpon Springs, Florida) is evaluating a remedy of *in situ* S/S (see discussion below).

Minimal performance data currently exist for use of the six technologies to treat similar waste material as found at EMF. Performance data were identified for treatment of WP using chemical oxidation, mechanical aeration, and incineration. However, these data are not for treatment of wastes in historical ponds at a WP manufacturing facility. Performance data for chemical oxidation and mechanical

aeration are for work at bench- and pilot-scale, while data for incineration are for ordnance wastes with a higher percentage of WP than found in the historical ponds.

Thermal desorption was used for the treatment of WP in contaminated soil. Recent attempts to obtain specific information on the project revealed that the technology vendor was sold to another company. Personnel at this company were not familiar with the current availability of the technology. Therefore, it is unknown if the WP-contaminated soil was similar to waste material as found at EMF and no specific performance data were available for review.

No performance data were identified for treatment of WP using S/S and caustic hydrolysis. Both technologies have been considered for the treatment of similar waste material at WP manufacturing sites. The Stauffer site in Tarpon Springs, Florida is planning to test *in situ* S/S in 2003. Although the information from this test program could be used to evaluate the effectiveness of S/S at EMF, the test program at Tarpon Springs may not be an accurate predictor of performance on the EMF waste. Reasons for this include: the type of phosphate ore used at Tarpon Springs is different from that used at EMF, elemental phosphorus is not a primary contaminant at Tarpon Springs, and the scale of the Tarpon Springs site is smaller. Caustic hydrolysis was considered for use at the Rhodia site in Silver Bow, Montana. In addition, caustic hydrolysis was identified as the Land Disposal Restrictions treatment technology for process wastes at EMF, but construction of this technology was halted with the plant shutdown.

Additional testing would be necessary to assess whether treatment technologies could perform adequately across a range of contaminant concentrations and properties of the waste material as found at EMF. Limited site characterization data are available and the historical ponds are assumed to be heterogeneous in physical and chemical composition. Therefore, extensive site assessment and treatability testing would be needed to verify the potential for any technology to treat the soil and sludge at EMF. Treatability tests would include evaluating how the technology would perform for the specific matrices in the different ponds, and the variations in performance across the range of concentrations and physical properties.

Although the six technologies are at various stages of commercial development, the technologies would all require testing to establish that they could perform reliably for the waste material in the historical ponds. S/S, chemical oxidation, incineration, and thermal desorption have been applied commercially at

full-scale for site remediation, but have not been used to treat WP pond material. Caustic hydrolysis and mechanical aeration have not been used extensively for site remediation, and significant developmental testing would be entailed for scale-up along with treatability testing. Developmental and treatability testing for the six technologies would require additional time and resources to undertake.

A series of technologies may be necessary to collectively treat all the types of contaminants. The soil and sludge in the historical ponds contain multiple types of contaminants which all may require treatment. For example, incineration, thermal desorption, mechanical aeration, and chemical oxidation show potential to treat WP, but would not be able to treat heavy metals or radionuclides. In these cases, an additional treatment process would likely be needed, such as S/S, using what is often referred to as a “treatment train”.

Of the six technologies, only S/S and caustic hydrolysis have the potential to be effective for treatment of heavy metals and radionuclides. S/S is applied frequently at full-scale to reduce the mobility of heavy metals (radionuclides are expected to behave in a manner similar to heavy metals) at contaminated sites. Caustic hydrolysis would convert heavy metals to metal oxides and hydroxides, which generally are less soluble than the metal compounds, and could be removed by filtration or settling processes.

Residuals from treatment, such as solid, liquid, or gaseous materials, would require further management. Residual management may include characterizing and transporting these residuals to a storage or disposal facility (on- or off-site), or performing further treatment (such as for off gases) prior to release to the environment.

Soil and sludge may require preprocessing to homogenize the material for use by treatment technologies. Preprocessing may include crushing, grinding, or milling, to break up large masses of soil and sludge. For both *ex situ* and *in situ* technologies, preprocessing may be necessary depending on the distribution of contaminants in the ponds and the methods used to implement the treatment technologies.

The estimated volume of waste material to treat (500,000 cubic yards) would entail a large remediation project, including significant engineering issues. The physical layout of the site, where historical ponds are located near RCRA ponds, structures, and slag piles, may impact the implementation

of a treatment technology, including the need for space to stage equipment or to store material before or after treatment.

Site workers would need to follow stringent health and safety precautions about handling soil or sludge containing WP. WP is an inorganic compound that ignites spontaneously in warm air. It is toxic by ingestion and inhalation and skin contact with WP causes burns. Site workers would likely need to use Level C personal protective equipment (respiratory and skin contact protection) when conducting work on the soil or sludge in the historical ponds. In addition, health and safety precautions related to metals and radionuclides would also have to be considered.

The cost to implement any of the six treatment technologies would be high, based on the criteria used to identify high cost projects by EPA's National Remedy Review Board (NRRB). The NRRB identifies high cost remedial actions as those that cost more than \$30 million or more than \$10 million and 50 percent greater in cost than the least costly cleanup alternative.

Although the technology cost estimates in this report could be above or below the actual costs, the actual total treatment costs are likely to be higher. Specifically, the technology costs estimates do not include costs for associated project components, such as excavation (if required), preprocessing of waste material, health and safety (such as ambient gas control), and residual management, which could be integral parts of a remediation project at the EMF site using any of the six technologies.

Important Considerations

For this report, several assumptions were made about pond characteristics based on what is known about the ponds and experience with site cleanups. Therefore, the evaluations put forth for each technology are dependent on these assumptions and limited available characterization data. Should the information on the characteristics of the historical ponds change, the analysis of the treatment technologies provided in this report may also need to be modified.

Quantitative cleanup levels have not been identified for WP, heavy metals, or radionuclides in the soil and sludge in historical ponds at the EMF site. Therefore, treatment technologies could not be evaluated against their capability to reach specified cleanup levels at the site. This report discusses technology

performance in general terms, focusing on the technology's ability to reduce the concentration, volume, or mobility of a mixture of contaminants in a heterogeneous soil and sludge matrix.

The level of uncertainty for the cost estimates provided in this report to implement the six technologies at the EMF site is high. The estimates presented in this report represent a range of possible costs for the treatment of the EMF waste. This range is highly dependent on the assumptions used to characterize the historical ponds and the specific design and operating conditions used for implementing the technology. It should be noted that historical cost data of technology applications indicate costs are highly variable, impacted by many factors, and that those factors are site-specific.

1.0 INTRODUCTION

The Technology Innovation Office (now the Technology Innovation Program) of the U.S. Environmental Protection Agency (EPA), Office of Solid Waste and Emergency Response (OSWER), has prepared this report to summarize and evaluate information about the potential use of existing or new technologies to treat soil and sludge in historical ponds contaminated with elemental white phosphorus (WP) at the Eastern Michaud Flats (EMF) Superfund site located near Pocatello, Idaho.

The intended audience for this report is the stakeholders for the EMF site, including EPA regional, state, Shoshone-Bannock tribal representatives, and other interested parties. The report addresses issues specific to treatment of historical ponds containing WP, while providing relatively little overall background information about hazardous site remediation.

Background

The EMF Superfund site (EPA ID no. IDD98466610) is located in southeastern Idaho approximately 2.5 miles northwest of Pocatello, Idaho. The site includes two adjacent phosphate ore processing plants – the J.R. Simplot Company Don Plant (Simplot) and the Astaris Idaho LLC (now owned by FMC, LLC Idaho) Elemental Phosphorus Plant (Astaris facility). The Astaris facility processes phosphate ore into WP, and the historical ponds at this facility are the subject of this report. Production of WP at the Astaris facility has recently shut down permanently.

The Astaris facility began operation in the 1940s. From 1954 to 1981, phoshy water, precipitator dust slurry, and other wastes from WP manufacturing were disposed of in ponds at the site. The soil and sludge in these ponds is contaminated with WP; heavy metals, such as antimony, arsenic, beryllium, boron, cadmium, lead, manganese, mercury, nickel, selenium, silver, thallium, vanadium, and zinc; and radionuclides that contribute to gross alpha and gross beta contamination. Groundwater at the site was found to have elevated concentrations of major ions and arsenic, lithium, manganese, total phosphorus, selenium, boron, barium, cobalt, and fluoride. No significant concentrations of organic compounds were detected in soil or groundwater at the site. (FMC, FS, 1996)

The EMF site was added to the National Priorities List (NPL) in August 1990 and the Remedial Investigation and Feasibility Study (RI/FS) were performed between 1991 and 1996. A Record of

Decision (ROD) was signed in June 1998 that included capping the 16 historical ponds with a soil cover of at least 12 inches.

In addition, the ROD provided an overall summary of site risks in terms of human health and ecological receptors, including potential release mechanisms and routes of exposure. The release mechanisms were identified as infiltration/percolation and exposure to media such as groundwater and homegrown produce, meat, and dairy products. Routes of exposure were identified as ingestion or dermal contact to nearby residents. For two of the historical ponds, air emissions were identified as a potential release mechanism, with inhalation as the route of exposure. (EPA, 1998) The risk to human health and the environment posed by WP is due to either direct contact with the waste or exposure of the waste to oxygen or water, which could result in the generation of hazardous by-products that could result in direct exposure or inhalation. There has been no indication that WP is migrating from the surface impoundments or the historic pond areas into groundwater. (EPA, 2002)

The 16 historical ponds, shown in Figure 1-1, consist of Ponds 1S-7S, 9S, 10S, and 1E-7E. All 16 ponds are being addressed under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Table 1-1 summarizes available information about these ponds, documented in the RI report. (FMC, 1995), FS report (FMC, 1996), and ROD (EPA, 1998) This table includes a description of the size of the pond, the years of active operation, types of materials disposed, cover materials, estimated volume of “phossey” waste, and other information.

The historical ponds range in size from 0.5 to 10.4 acres per pond, with a total areal extent of 52.3 acres. Fifteen of the ponds are unlined; one pond, Pond 10S is lined. As shown in Figure 1-1, nine of the historical ponds have been partially or fully buried by the Resource Conservation and Recovery Act (RCRA)-regulated lined ponds or ferrophos storage areas. These include Ponds 3S, 6S, 7S, 1E, 2E, 3E, 5E, 6E, and 7E. The estimated area of these historical ponds that have been covered is 34 acres (about 70 percent of the original total surface area of the historical ponds).

The stratigraphy of the site is generally described as discontinuous layers of unconsolidated sediments deposited on an erosional surface that was incised in volcanic bedrock. Deposits of windblown silt (loess) and a colluvial silt mantle of variable thickness covers the study area. The loess layer ranges from 2 to more than 100 feet (ft) thick and is calcareous. In the vicinity of the ponds the thickness of the loess is approximately 30 ft or more. The native soils are generally alkaline (pH of 7 or greater) because of

Figure 1-1. Location of Historical Ponds at Astaris Facility (FMC, 1996)

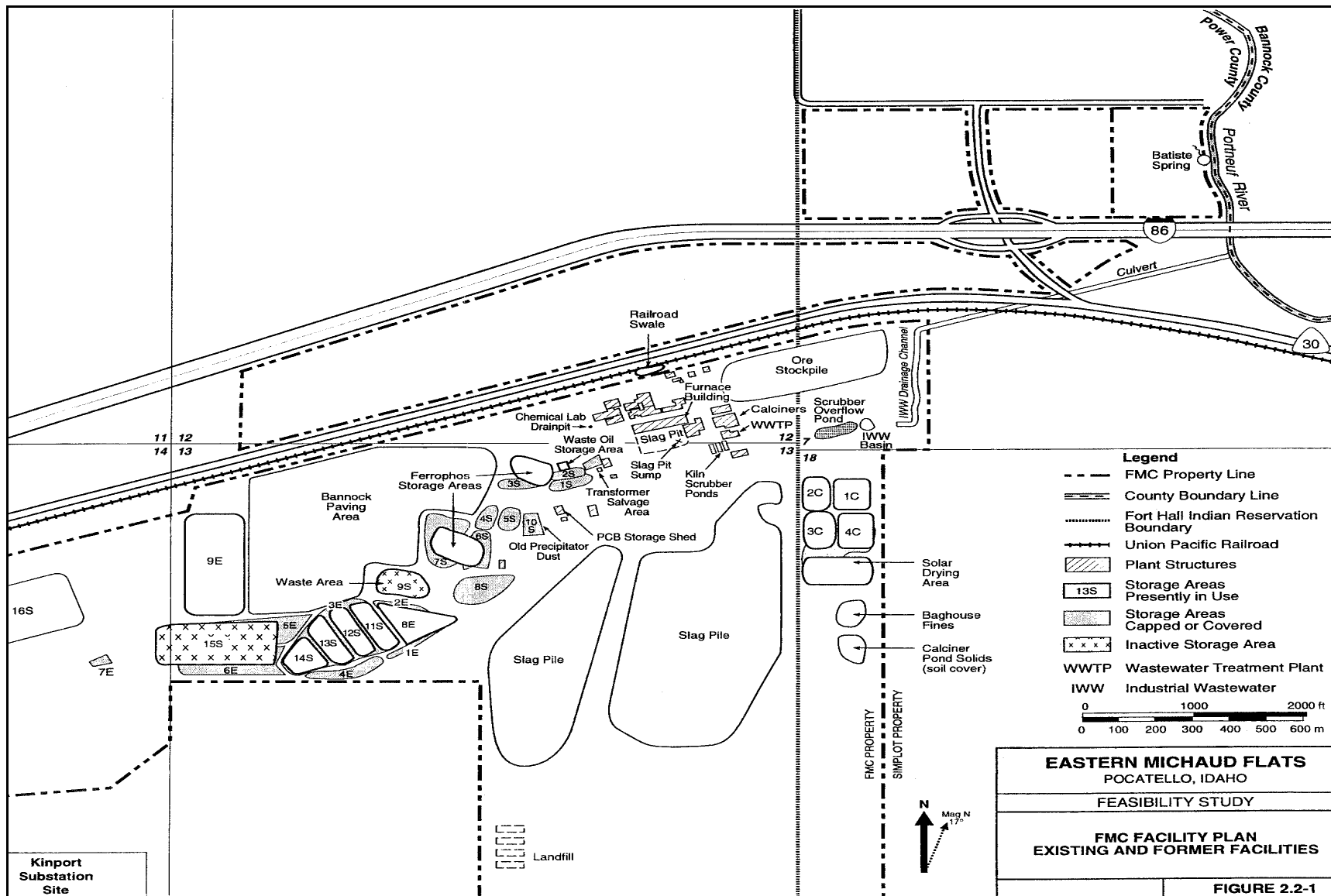


Table 1-1. Eastern Michaud Flats Superfund Site - Characteristics of Historical Ponds

Pond	Size (acres)	Active Life	When Pond Dried/ Backfilled	Material Disposed in Pond	Cover Material(s)	"Phossey" Waste Volume (cubic yards)	Other Notes
1S	0.5	1954 to Oct. 1961	1972	Phossey water and phossey solids	Slag, soil	2,400	Initially hauled in slurry truck; pipeline installed in 1957. P ₄ was reclaimed to plant twice per year from 1966-1972. Assumed not covered.
2S	0.8	1955 to Oct. 1961	1972	Phossey water and phossey solids	Slag, soil	875	P ₄ was reclaimed to plant twice a year until September 1965. P ₄ continued to be reclaimed to plant twice per year from 1966-1972. Assumed not covered.
3S	1.2	Nov. 1961 to June 1965	Dec. 1976	Precipitator dust slurry; slag pit water and solids; phossey water and phossey solids; residuals from P ₄ reclaim operation on ponds 1S and 2S and east end of 3S	Capped with 3 ft of soil, then covered with crushed slag	8,800	Settled solids were routinely dug out twice a year until 1965. P ₄ in east end was reclaimed in 1972-1976; approximately 100 ft of east end was filled with slag after reclaiming; this area is not capped as is the rest of the former pond. Assumed 50% covered.
4S	0.8	Apr. 1966 to Mar. 1967	July 1976	Precipitator dust slurry	Capped with 3 to 6 ft of soil	6,500	Assumed not covered.
5S	1.0	July 1965 to Mar. 1967	Mar. 1976	Phossey water and phossey solids	Capped with baghouse dust; precipitator dust slurry; fluid bed drier product prills and dust; slag; final soil cap on top	8,500	Very difficult to dry because of pyrophoric contents; fine solids would not support cover weight. Assumed not covered.
6S	2.3	Apr. 1967 to Feb. 1969	July 1976	Precipitator dust slurry; some phossey water and phossey solids in NE corner	Capped with soil; south end partially filled with slag and paved with asphalt for use as a new slag haul road	24,600	New slag haul road over south end. Assumed 50% covered.

Table 1-1. Eastern Michaud Flats Superfund Site - Characteristics of Historical Ponds (continued)

Pond	Size (acres)	Active Life	When Pond Dried/ Backfilled	Material Disposed in Pond	Cover Material(s)	"Phosy" Waste Volume (cubic yards)	Other Notes
7S	3.6	Mar. 1969 to Sept. 1970	Jan. 1980	Precipitator dust slurry with phosy hot spots	Two high - P ₄ areas capped with cement; entire area capped with 6 to 10 ft of pit-run slag, then 3 ft of soil	18,200	New slag haul road over south end; this site is not byproduct ferrophosphorus stockpile, approximately 25 ft high. Assumed 50% covered.
9S	4.0	1971 to 1974 (?)	Nov. 1980	Precipitator dust slurry; slag pit water and solids. Material dried and sold	Not capped	0 (3)	Contents were dried in place and about 20 to 25 ft dug out for outside sales; small quantity remains in place. Assumed not covered.
10S	1.0	Not identified	Not identified	Fluid bed dryer slurry	Capped	Not identified	Lined pond. Assumed not covered.
1E	1.9	Apr. 1965 to Fall 1982	Oct. 1980	Phosy water and carryover fine solids from upstream ponds; precipitator dust slurry and dried slurry; Material dried and sold	Not capped	9,000	Filled with dredged precipitator dust slurry from fluid bed drier surge pond in fall of 1982. Assumed 90% covered.
2E	3.3	Apr. 1965 to Oct. 1967	1977	Phosy water and carryover fine solids from upstream ponds	Site is beneath current Phase IV ponds (8E)	0 (1)	Site was used for storage of precipitator slurry fluid bed drier product, then dug out for lined pond 8E construction in 1984; residual precipitator dust sent to 4E site. Some material was removed and sold. Assumed 90% covered.
3E	10.4	May 1967 to Sept. 1970	1980	Phosy water and carryover fine solids from upstream ponds	Site is beneath current Phase IV ponds (11S-14S)	0 (1)	Contents dug out for construction of new lined ponds in 1980; this site now occupied by lined ponds 11S, 12S, 13S, and 14S. Assumed 100% covered.

Table 1-1. Eastern Michaud Flats Superfund Site - Characteristics of Historical Ponds (continued)

Pond	Size (acres)	Active Life	When Pond Dried/ Backfilled	Material Disposed in Pond	Cover Material(s)	"Phossey" Waste Volume (cubic yards)	Other Notes
4E	1.8	May 1967 to 1980	Oct. 1980	Phossey water and carryover fine solids from upstream ponds; precipitator dust slurry overflow	Not capped	29,000	Received precipitator slurry from fluid bed drier slurry pond in fall of 1982. Some material removed and sold. Assumed not covered.
5E	6.6	Apr. 1968 to 1972-73(?)	1981	Phossey water and very minor carryover fine solids from upstream ponds	Site is beneath current Pond 15S	0 (1)	Dried gray settled soil (4" to 6") placed in area just south of new 15S lined pond. New lined pond 15S was built on this site in 1982. Assumed 95% covered.
6E	6.7	Nov. 1968 to 1980-81	1981	Same as 5E	Same as 5E	0 (1)	Same as 5E. Assumed 95% covered.
7E	4.3	Dec. 1969 to 1980-81	1981	Received phossey water only a few seasons; no solids observed in 7E	Not capped	0 (2)	Eastern ± 150 ft used for construction of lined pond 15S (1982) and 9E (1986). Assumed 50% covered.

- (1) Material was removed and placed in another pond or sold. New ponds were constructed over all or part of the area occupied by this pond.
(2) Most of the pond was removed during construction of another pond (Pond 15S).
(3) Pond 9S was excavated and used as a storage area for precipitator slurry solids.

Sources: FMC RI; FMC FS (Table 4.1-1), 1996; ROD (Table 1) 1998.

their calcareous nature, and have little structure. Depths to groundwater in the shallow aquifer range from 170 ft below ground surface (bgs) in the Bannock Range area to 55 ft bgs in the Michaud Flats area, and less in the area near EMF. The site is located in a semi-arid region, with approximately 11 inches of total precipitation a year. (FMC, FS, 1996)

Scope

Representatives of the Shoshone-Bannock Tribes, one of the stakeholders for the EMF site, have raised concerns about the decision to cap the historical ponds. Following a meeting with the Tribes and a letter by EPA's OSWER Assistant Administrator, the Technology Innovation Program committed to work with EPA Region 10 and the Tribal Business Council to evaluate technologies potentially applicable for the treatment of historical ponds that contain WP.

The scope of this report is limited to a summary and review of available information from the technical literature and previous studies about the following:

- The 16 historical ponds identified in the EMF ROD - Ponds 1S-7S, 9S, 10S, and 1E-7E
- Soils and sludges in the 16 historical ponds that are not physically covered by RCRA ponds
- Treatment technologies (commercially-available and not commercially-available) that have been used or have shown promise for treatment of WP

For each treatment technology, this report provides an evaluation of how it could potentially be applied for on-site treatment of WP as well as for heavy metals and radionuclides in the historical ponds, and discusses its strengths and limitations, performance, costs, preprocessing requirements, material removal and handling (if necessary), residual management, status of development, and prior use on WP. No testing of treatment technologies (e.g., in a laboratory or at a pilot-scale) was performed as part of the preparation of this report.

This report does not address the following:

- Containment technologies (e.g., capping) or other non-treatment remedies (e.g., off site disposal)
- Reclamation or reuse of pond materials, such as with Astaris production facilities
- Using a combination of technologies to collectively treat all the types of contaminants
- Recommendations regarding selection of technologies (i.e., which technologies would be most appropriate for the EMF site)
- Analysis of risk to human health and the environment posed by the historical ponds and how a technology or series of technologies would reduce risk

As these items are necessary components to the complete evaluation of the effectiveness of any site-specific remedy, this report is not intended to be a feasibility study for remediation of the historical ponds at the EMF site.

Overview of Methodology

Information about the properties of WP, heavy metals, and radionuclides, the types of activities performed at other WP manufacturing plants, and the characteristics of the historical ponds at the EMF site was reviewed. Based on this information, technologies potentially applicable to the EMF site were identified and evaluated.

Because the properties of WP are not widely understood, this report includes a brief summary of WP physical and chemical properties, as well as health and safety concerns with human exposure. The properties of heavy metals and radionuclides are widely known and well documented in technical literature (for example, see fact sheets provided by EPA's Office of Groundwater and Drinking Water at <www.epa.gov/OGWDW/hfacts.html>, EPA's Technology Screening Guide for Radioactively Contaminated Sites at <<http://www.epa.gov/superfund/resources/radiation/pdf/techguide.pdf>>, and the Radiation Effects Research Foundation at <www.rerf.or.jp/eigo/experhp/rerfhome.htm>), and therefore specific considerations related to their treatment are not described in this report.

At least ten manufacturing facilities across the U.S. that produce WP have been identified, and eight of those sites have used unlined ponds for disposal of phosphy water and other wastes. Information about these sites provide background about historical ponds at WP manufacturing sites. While the basic process for manufacturing WP from phosphate ore did not vary substantially among facilities, the characteristics of the phosphate ore as well as end-of-pipe treatment varied among regions and sites, resulting in differences in contaminants and concentrations in ponds between them. For example, the ores in Idaho are different from those in Tennessee or Florida, yielding different types and concentrations of WP, heavy metals, and radionuclides.

To identify treatment technologies for the historical ponds at the EMF site, it was necessary to develop a conceptual understanding of the characteristics of soil and sludge in those ponds, as well as the fate and transport of WP in the ponds, including transformation processes such as oxidation and hydrolysis. Available data were combined with information available for the RCRA ponds, as well as assumptions

about the physical and chemical characteristics of the ponds, to develop a conceptual understanding of the historical ponds.

Data Sources

Sources of information used for this report included files from EPA Region 10, including the ROD and the RI/FS for EMF, and correspondence with key staff in EPA regional offices and states, and file reviews. An open literature search of the Online Computer Library Center Inc. (OCLC) was conducted in October 2001, using the following key words: white phosphorus, elemental phosphorus, and remediation. A complete list of references used in preparation of this report is provided in Section 7.0.

Fewer than 10 studies were identified concerning the use of treatment technologies for WP in soil and sludge, either at other WP manufacturing facilities or in other applications. Some of this work was done in support of WP manufacturing facilities and some in support of military operations (WP is used in certain types of military ordnance). Much of that work was limited in scope, and follow-on work/studies were not identified. No studies were identified from international sources, although an exhaustive search was not conducted.

In the mid-1990s, the U.S. Army Corps of Engineers (USACE) prepared a report, "Summary and Evaluation for White Phosphorus Remediation: A Literature Review", Technical Report IRRP-96-7, that summarized available information about remediation of WP. (Rivera, 1996) The report included bench- and pilot-scale data for six treatment technologies and two non-treatment remedial technologies, primarily for use on WP in military operations. At the time of the report, the U.S. Army had identified WP as a contaminant of concern in soil and water at military training and munitions production facilities. However, the Army since has down-graded its level of concern with WP, and the Army researchers who prepared the USACE report did not perform any follow-up actions to further evaluate treatment technologies for WP.

A search of available documents (e.g., reports, articles, and conference proceedings), including the results of the search performed using the OCLC, showed that most of the studies were performed in the early 1990s. The only recent work (since 1996) was that performed by the U.S. Army at a Superfund site in Alaska (Eagle River Flats) where there were waterfowl deaths because of WP contamination in pond

sediments. At that site, the Army evaluated use of pond draining as a means to reduce the concentration of WP in sediments.

A search for technology vendors who have demonstrated treatment for WP was conducted in February 2002 using EPA's REACHIT online database. EPA REACHIT, available at <www.epareachit.org>, provides information about more than 1,200 technologies and 1,600 sites where treatment technologies have been used. The search revealed two vendors who claimed to have treated WP. However, after reviewing the information, the two vendors likely performed treatment of phosphate compounds instead of WP.

Important Considerations

Available data provide limited information about the nature and extent of contamination and of the physical characteristics of the historical ponds at the EMF site. Data are available from 14 soil borings in and near 7 disposal ponds. Therefore, several assumptions were made about the physical and chemical characteristics of the historical ponds based on what is known at the EMF site and experience with site remediation. Should further work change the information on the pond characteristics, the assumptions and evaluations of treatment technologies provided in this report would also likely need to be modified.

Quantitative cleanup levels have not been identified for WP, heavy metals, or radionuclides in the soil and sludge in historical ponds at the EMF site. Therefore, treatment technologies could not be evaluated against their capability to reach specified cleanup levels at the site. Since cleanup levels have not been identified, this report discusses technology performance in general terms, focusing on the technology's ability to reduce the concentration, volume, or mobility of a mixture of contaminants in a heterogeneous soil and sludge matrix.

As presented in this report, the uncertainty associated with cost estimates discussed in this report for the six technologies is high. The cost estimates include only treatment costs, not associated project components, such as excavation, preprocessing of waste material, health and safety, and residual management, which likely would significantly increase total project costs. It should be noted that historical cost data of technology applications indicate costs are highly variable, impacted by many factors, and that those factors are site-specific.

Report Organization

The remainder of this report is organized as follows:

- Section 2 provides a brief summary of the properties of WP, including its physical and chemical properties, and health and safety concerns
- Section 3 discusses activities at WP manufacturing sites other than the EMF site
- Section 4 presents a conceptual description of the historical ponds at the EMF site, including the fate and transport of WP in the historical ponds
- Section 5 describes the types of technologies that may potentially be applicable to treatment of historical ponds, including an overview of attributes necessary for any applicable treatment technology
- Section 6 provides an overall summary and discussion of the findings in this report
- Section 7 lists the references used in the report preparation

2.0 PROPERTIES OF ELEMENTAL PHOSPHORUS

This section provides an overview of the physical and chemical properties of elemental phosphorus and provides a brief summary of its effects on human health and safety.

Physical Properties

Elemental phosphorus exists in three distinct configurations called allotropes, all with the same molecular weight (123.89), but each differing significantly from the other allotropes in physical and chemical characteristics. The chemical formula for all allotropes of elemental phosphorus is P₄; however, they have different names according to their respective colors, including black, red, violet, and white (sometimes called yellow due to impurities). The EMF facility was involved exclusively in the production of the white (or yellow) allotrope of phosphorus; therefore the remainder of this section will not discuss the other allotropes. WP is a waxy solid that may be colorless, white, or yellow, and has a garlic-like odor. Table 2-1 provides a summary of some of the physical properties of WP, and shows that it is relatively insoluble in water, with a solubility of 3 mg/L at 15 °C.

Table 2-1. Physical Properties of Elemental White Phosphorus

Physical Property	Characteristic
Chemical Formula	P ₄
Appearance	White (sometimes colorless or yellow) waxy solid
Boiling Point	280.5°C
Density	1.82 g/cm ³ at 20°C
Flash Point	Spontaneously ignites in air above 30°C (moist air)
Melting Point	44.1°C
Molecular Weight	123.89
Solubility	Water - 3 mg/L at 15 ⁰ C
Vapor Pressure	0.026 mm Hg at 20°C
Volatility	May be ignited by heat, sparks, or flame

Sources: Rivera, 1996; Van Wazer, 1972.

Chemical Properties

The primary processes for chemical transformation of WP are oxidation and hydrolysis. In a solid phase such as soil, WP oxidizes spontaneously with oxygen in air (when the concentration of WP is \$1,000

mg/kg) to form phosphorus pentoxide (P_4O_{10} , commonly expressed as P_2O_5), which exists as a particulate at ambient conditions. Phosphorus pentoxide has a strong affinity for water and will react with water (hydrolyze), including moisture from the atmosphere, to form various phosphorus acids. The primary by-product from oxidation of WP is orthophosphoric acid. (FMC, Attachment A, Not Dated)

In pure water, dissolved WP is rapidly oxidized by dissolved oxygen (DO) to form various forms of soluble phosphorus acids, including $H_2PO_4^-$, HPO_4^{2-} , and PO_4^{3-} . In water with other dissolved ions, and depending on environmental conditions such as pH and Eh, these acids may be further converted to a solid metal phosphate compound such as calcium phosphate. The rate of phosphorus oxidation in water is governed by the form of the phosphorus (dissolved or suspended), DO concentration, salt concentration, metal ion concentration, pH, and temperature. As shown in Table 2-2, the oxidation rate increases with increasing concentrations of dissolved phosphorus, DO, metal ion, pH, and temperature.

Table 2-2. Factors Affecting Oxidation Rate

Factor	Affect on Rate of Oxidation
Increased proportion of suspended elemental phosphorus	Decreased
Increased proportion of dissolved elemental phosphorus	Increased
Increased dissolved oxygen concentration	Increased
Increased salt concentration	Decreased
Increased metal ion concentration	Increased
Increased pH Value (>6)	Increased
Increased temperature	Increased

Source: Rivera, 1996.

WP also is hydrolyzed in water to form phosphine (PH_3) and lesser amounts of phosphorus acids. Phosphine is a toxic gas that has a low solubility, and thus is expected to migrate from the water to the air; the portion of phosphine that dissolves is generally oxidized to form the above-mentioned forms of phosphorus acids. The rate of hydrolysis of WP is enhanced by an increase in the pH of the water reacting with the WP. (USACE, 1996)

Health and Safety Concerns

WP is a toxic inorganic substance, and when ignited, gives off an irritating smoke. A fatal dose of WP ranges from 1 to 16 mg of WP per kg body weight, depending on how the phosphorus is ingested. The permissible exposure limit for a workplace is 0.1 mg/m^3 . When inhaled, it is not known whether the

contaminant will enter directly into the blood stream. Ingestion of WP may cause abdominal pain, jaundice, liver damage, kidney damage, eye damage, shock, coma, and death. The most common effect of chronic WP poisoning is necrosis of the mandible (deformation of the lower jaw) commonly referred to as “phossy jaw” followed by damage to the teeth. Chronic poisoning from long-term absorption, particularly through the lungs and through the gastrointestinal tracts, leads to a generalized form of weakness accompanied by anemia, loss of appetite, diarrhea, and pallor. Seriously affected bones may become brittle, leading to spontaneous fractures. WP also is very damaging to the eyes. Some of the symptoms that have been reported following inhalation of WP are photophobia with myosis, dilation of pupils, retinal hemorrhage, congestion of blood vessels, and, in rare instances, optic neuritis (a lesion of a nerve). (U.S. Army Center for Health Promotion and Preventive Medicine, 1965)

Because WP ignites spontaneously in warm air and could cause severe damage if in contact with the skin, burns are the most common hazard. Workers commonly maintain a water blanket or slurry form of phosphorus-containing materials to limit its exposure to air. WP reacts with carbon dioxide at elevated temperatures to produce phosphorus pentoxide and carbon monoxide; thus, carbon dioxide extinguishers should not be used to extinguish WP fires.

Additional information about the toxicological and health effects of WP are provided in *Toxicological Profile for White Phosphorus*. (ATSDR, 1997)

3.0 OVERVIEW OF ELEMENTAL PHOSPHORUS ELECTRIC ARC FURNACE MANUFACTURING SITES

This section provides a summary of information about ten WP electric arc furnace (EAF) manufacturing sites and remedies for historical ponds containing WP at those sites. Table 3-1 provides a summary of information about these facilities (EMF is discussed in Section 4.0), including site name and location, the type of contaminants and characteristics of the historical (unlined) ponds, remedy selection, other remedies considered, health and safety issues, current status, regulatory background, points of contact, and sources of information.

In addition, information is provided about seven military facilities where WP was identified to provide additional context (WP is used in certain types of military ordnance, however these are not EAF manufacturing sites). Table 3-2 provides a summary of information for the military facilities, including site name and location, site characteristics, point of contact, and source of information.

In the EAF process, WP is produced from phosphate ore. The ore is formed into briquettes and calcined to drive off moisture, remove organic matter, and hardened for further processing. The calcined briquettes, also called nodules, are blended with coke and silica to form a mixture that is fed into electric arc furnaces. Within the furnaces, the ore is reduced to produce WP in vapor form. WP is recovered by water spray condensers, collected as a liquid in sumps, and pumped to a product storage area for shipment or into tanks for interim storage. (FMC, 1996).

Of the ten WP EAF manufacturing sites, eight have unlined ponds and two did not provide information about whether they have unlined ponds. The following eight sites that manufactured WP using EAF have unlined ponds:

- Monsanto Chemical Company (Solutia), Soda Springs, Idaho
- Stauffer Chemical Company (Rhodia, Inc.), Silver Bow, Montana
- Stauffer Chemical Company, Tarpon Springs, Florida
- Exxon Mobil ElectroPhos Division, Mulberry, Florida
- Agrifos Nichols Plant, Nichols, Florida
- Stauffer Chemical Company (Rhone-Poulenc), Mt. Pleasant, Tennessee
- Monsanto Chemical Company, Columbia, Tennessee
- Albright and Wilson America Limited Phosphorus Plant, Long Harbor, Newfoundland, Canada

Table 3-1. Summary of Information About WP Electric Arc Furnace Manufacturing Sites

Types of Contaminants in the Historical (Unlined) Ponds	Characterization of the Unlined Ponds or of the Site	Remedy Selection for Unlined Ponds	Other Remedies Considered for Unlined Ponds	Health & Safety Issues	Current Status	Regulatory Background	Point of Contact	Source of Information
Monsanto Chemical Company (Solutia, Inc.), Soda Springs Idaho								
WP, radionuclides such as radium-226, lead-210, and uranium-238, arsenic, beryllium, selenium, and zinc.	Phoshy water was disposed of in unlined ponds at this site. The manufacturing process used a distilling process to capture elemental phosphorus, thereby resulting in less phosphorus in the waste. The phoshy water was expected to have very little sediment. Additional characterization data are not available.	The remedy selected in the ROD was either institutional controls or excavation of contaminated soils and replacement with clean soil, and disposal of the contaminated soils within the plant. The ponds containing WP have been capped and the site is currently undergoing groundwater monitoring.	1. No further action 2. Groundwater monitoring 3. Land use and access restrictions, and groundwater monitoring 4. <i>In situ</i> biological treatment (phytoremediation), land use and access restrictions, and groundwater monitoring 5. Soil excavation/replacement/containment on-site, and groundwater monitoring	Information not provided	The unlined ponds have been capped and the site is currently undergoing groundwater monitoring.	CERCLA	Wallace Reid, EPA (206) 553-1728	ROD, April 30, 1997 Telephone conversation with Wallace Reid, EPA, Jan. 2002

Table 3-1. Summary of Information About WP Electric Arc Furnace Manufacturing Sites (continued)

Types of Contaminants in the Historical (Unlined) Ponds	Characterization of the Unlined Ponds or of the Site	Remedy Selection for Unlined Ponds	Other Remedies Considered for Unlined Ponds	Health & Safety Issues	Current Status	Regulatory Background	Point of Contact	Source of Information
Stauffer Chemical Company (Rhodia Inc.), Silver Bow (Butte) Montana								
WP, arsenic, barium, cadmium, chromium, lead, and mercury.	<p>Phossey water was disposed of in unlined ponds at this site. In addition, sludge was disposed of in a concrete clarifier. The clarifier is approximately 100 ft in diameter, and is an open-topped, in-ground unit that is constructed of reinforced concrete, and contains 400,000 - 500,000 gallons of sludge, with an estimated 20 to 40 percent WP. The clarifier may have a bottom, but it is believed to have leaked, and the exact integrity of the clarifier is not known. Rhodia does not want to remove and treat the wastes from the clarifier because they believe it would be too risky for workers and too expensive. Corrective action alternatives for the clarifier are being reviewed under a RCRA § 7003 order, and corrective action is expected to be conducted under the order.</p> <p>Average background gamma radiation levels at the site ranged from 19 to 170 microRoentgens (: R) per hour. Gamma radiation closest to the clarifier ranged from 65 to 90 : R/hr. No data were provided that the clarifier material would have a gamma radiation level any higher than 95 : R/hr.</p>	The unlined ponds at this site are not currently under any form of corrective action.	<p>Remedies under consideration for contents of the clarifier include:</p> <ol style="list-style-type: none"> 1. Soil cap 2. Enhanced cap, with multi-layer, multi-material cover 3. Off-site incineration 4. On-site phosphorus recovery (roaster process*) 5. On-site incineration 6. Zimpro reactor process with caustic hydrolysis of phosphorus wastes at elevated temperatures and pressure 7. Recovering phosphorus at Solutia facility in Columbia, Tennessee 8. Recovering elemental phosphorus as phosphoric acid at the Rhodia Phosphoric Acid production facility 9. Recovering elemental phosphorus at the Glen Springs Holding Company phosphorus facility in Columbia, Tennessee 10. Recovering phosphorus as phosphoric acid at the Samancor Phosphoric Acid production facility located in Meyerton, Gauteng Province, South Africa <p>*A roaster process was used to treat waste while the plant was in operation. The plant currently does not use a roaster, as it was dismantled when the plant ceased operations.</p>	Information not provided, except general reference to elevated risk to workers concerning removal and treatment of clarifier materials.	Not an operating facility. Rhodia, prepared a waste plan, dated November 16, 2001, as required under RCRA § 7003 Order, Docket No. RCRA-8-2000-07, for management and disposition of the clarifier contents. Site-wide corrective action is not currently being addressed. For clarifier waste, EPA has conducted a study on options for treating this material. In negotiations with the potentially responsible party (PRP) about possible treatment.	RCRA EPA Handler ID MTD05755854 6	Rosemary Rowe, EPA (406) 457-5020	Rosemary Rowe, EPA, Oct. 29, 2001. Waste Plan, Rhodia Silver Bow Plant, Butte, Montana, November 16, 2001. E-mail from Rosemary Rowe, February 27, 2002.

Table 3-1. Summary of Information About WP Electric Arc Furnace Manufacturing Sites (continued)

Types of Contaminants in the Historical (Unlined) Ponds	Characterization of the Unlined Ponds or of the Site	Remedy Selection for Unlined Ponds	Other Remedies Considered for Unlined Ponds	Health & Safety Issues	Current Status	Regulatory Background	Point of Contact	Source of Information
Stauffer Chemical Company Operable Unit 1, Tarpon Springs Florida								
Soil and pond material is contaminated with arsenic, antimony, beryllium, cadmium, chromium, lead, fluoride, WP, thallium, radium-226, radon-222, polonium-210, and PAHs (RPM stated that radionuclides were of particular concern - specifically radium 226 because of community concerns.)	Phosphy water was disposed in unlined ponds at this site. Site characterization data are available in the Stauffer Management Company Final RI/FS Work Plan. The maximum detected concentrations in soil/waste for arsenic are 127 mg/kg, antimony - 32.3 mg/kg, beryllium - 6 mg/kg, WP - 0.854 mg/kg, thallium - 13.4 mg/kg, and radium 226 - 73.8 pCi/g.	The remedy selected in the ROD is <i>in situ</i> solidification/stabilization (S/S) of pond material and contaminated soil below the water table in the on-site consolidation areas. <i>In situ</i> S/S would be performed by injecting and mixing binding agents into the saturated pond material to form a solid, low permeability mix. Treatment technologies considered after the screening process in addition to the S/S process were: 1. Conversion to phosphoric acid 2. Incineration 3. Aqueous oxidation 4. Low temperature air oxidation.	1. No action with continued monitoring 2. Institutional controls 3. Consolidation and cover of radiological and chemical waste material on site 4. Consolidation and cover with additional remediation of radiologically and chemically contaminated soil for future residential use. 5. Consolidation and capping radiological and chemical waste material on site 6. Consolidation and capping with additional remediation of radiologically and chemically contaminated soil for future residential use 7. Consolidation, capping, and saturated zone source control for commercial use 8. Consolidation, capping, and saturated zone source control for residential use 9. Consolidation, stabilization, and cover for commercial use 10. Consolidation, stabilization, and cover for residential use.	Health and Safety Plan prepared that included worker safety procedures for well installation and soil sampling.	Not an operating facility. Currently undergoing additional studies to address community concerns (including treatability studies to evaluate the performance of the stabilized material).	CERCLA EPA CERCLIS ID FLD01059601 3	Nestor Young, EPA (404) 562-8812	ROD, July 2, 1998. Final RI/FS Work Plan, Roy F. Weston, Inc., February 1, 1993. Telephone conversations with Nestor Young, EPA, July and Oct. 2, 2001. S/S Treatability Studies Work Plan, December 2000. E-mail from Nestor Young, February 28, 2002.

Table 3-1. Summary of Information About WP Electric Arc Furnace Manufacturing Sites (continued)

Types of Contaminants in the Historical (Unlined) Ponds	Characterization of the Unlined Ponds or of the Site	Remedy Selection for Unlined Ponds	Other Remedies Considered for Unlined Ponds	Health & Safety Issues	Current Status	Regulatory Background	Point of Contact	Source of Information
Exxon Mobil ElectroPhos Division, Mulberry, Florida								
Arsenic - 0.013 ppm, cyanide - 0.36 ppm, fluoride - 7.9 ppm, ortho-phosphate - 5.96 ppm, and total phosphorus - 6.83 ppm.	Phossey water was discharged from the plant to sedimentation ponds, then to chemical neutralization ponds and additional sedimentation ponds, and finally to clear-water ponds (old mine cuts) for water reuse. The clear water ponds are upgradient of the phossey water ponds and presently discharge through a NPDES permitted outfall during high rainfall events. There have been no recent water quality violations from this outfall. Total calculated area is approximately 30 acres.	According to Florida DEP, the phossey water ponds were backfilled with overburden (500,000 to 550,000 cubic yards) to a depth of approximately 5 ft over the phosphorus sludges and the water was transferred through a recirculation system to a liming station for treatment. Closure plans were submitted in May 1986. Surficial and intermediate aquifer monitor wells were installed circa 1976 surrounding the phossey water ponds.	Information not provided.	Levels in surficial aquifer wells down-gradient of the ponds exceeded water quality standards for gross alpha, radium, fluoride, pH, and TDS. Detection of elemental phosphorus impacts in groundwater and cyanide exceedances in surface monitor stations were discovered.	Not an operating facility. Enforcement commenced by the Florida DEP in 1995, and the facility recently agreed to install a low permeability soil-bentonite slurry wall around the perimeter of the phossey water ponds and down to the confining unit, a HDPE liner over the top of the ponds, and to continue the monitoring program.	Information not provided EPA Handler ID FLD07086428 5, NPDES Permit No. FL0002666	David Clowes, Florida DEP (813) 744-6100 x 139	EPA report, June 4, 1997. CERCLIS 3 Wasteland Database for Region 4 (queried November 6, 2001). Conversation with David Clowes, FDEP on November 13, 2001. Memo from Florida DEP to Sunitha Ravi, Tetra Tech EM Inc., January 28, 2002.

Table 3-1. Summary of Information About WP Electric Arc Furnace Manufacturing Sites (continued)

Types of Contaminants in the Historical (Unlined) Ponds	Characterization of the Unlined Ponds or of the Site	Remedy Selection for Unlined Ponds	Other Remedies Considered for Unlined Ponds	Health & Safety Issues	Current Status	Regulatory Background	Point of Contact	Source of Information
Agrifos Nichols Plant, Nichols, Florida								
Arsenic - 0.013 ppm, cyanide - 0.36 ppm, fluoride - 23.75 to 111.11 ppm, ortho-phosphate - 5.96 ppm, and total phosphorus - 6.83 ppm.	Phoshy water was disposed in three unlined ponds covering an area of 18.6 acres at this site. Additionally, wastewater from a sulfuric and phosphoric acid fertilizer manufacturing plant was also deposited in the ponds.	According to Florida DEP, one of the phoshy water ponds was covered with an earthen cap in the late 1950's. The other two ponds were used until 1978 and then closed. The closure involved backfilling the individual phoshy ponds with overburden (approximately 200,000 cubic yards) to a depth of about 2 ft over the elemental phosphorus sludges, and transferring the water through the recirculation system to a liming station for treatment. Additionally, drums of sludge were apparently buried adjacent to the ponds. Closure plans were submitted in November 1984. Past and/or present elevated levels of arsenic, sodium, fluoride, TDS, gross alpha, and radium have been identified in surficial and intermediate aquifer monitoring wells.	Information not provided.	Mining by Agrifos in the area has been curtailed due to groundwater contamination.	A joint contamination assessment of the facilities was conducted although further assessment may be necessary due to the location of the ponds within the areas of contamination from adjacent phosphate fertilizer manufacturing facility.	Information not provided. EPA Handler ID FLD00410640 7, NPDES Permit No. FLA132454	David Clowes, Florida DEP (813) 744-6100 x 139	EPA report, June 4, 1997. CERCLIS 3 Wasteland Database for Region 4 (queried November 6, 2001). Conversation with David Clowes, FDEP on November 13, 2001. Memo from Florida DEP to Sunitha Ravi, Tetra Tech EM Inc., January 28, 2002.

Table 3-1. Summary of Information About WP Electric Arc Furnace Manufacturing Sites (continued)

Types of Contaminants in the Historical (Unlined) Ponds	Characterization of the Unlined Ponds or of the Site	Remedy Selection for Unlined Ponds	Other Remedies Considered for Unlined Ponds	Health & Safety Issues	Current Status	Regulatory Background	Point of Contact	Source of Information
Stauffer Chemical Company (Rhone Poulenc) Mt. Pleasant, Tennessee								
Information not provided.	Phossey water was disposed in unlined ponds.	The ponds were capped per a 1998 Amended Closure Plan.	Information not provided.	Information not provided.	Not an operating facility.	RCRA EPA Handler ID TND00061039 4	Brad Martin, Tennessee DEC (617) 687-7113 Dennis Lampley, Tennessee DEC (931) 840-4162	EPA report, June 4, 1997. CERCLIS 3 Wasteland Database for Region 4 (queried November 6, 2001).
Monsanto Chemical Company, Columbia, Tennessee								
WP and fluoride.	Phossey water was disposed in an unlined pond at this site. Water was drained from the pond and treated at an on-site wastewater treatment plant.	Areas at the site contaminated with elemental phosphorus were capped.	Information not provided.	Information not provided.	The elemental phosphorus manufacturing facility was shut down in October, 1986.	RCRA EPA Handler ID TND00404810 4	Robert Gibbs, Tennessee DEC (931) 840-4165 Grady Clark, Solutia Inc. (931) 380-9329	EPA report, June 4, 1997. CERCLIS 3 Wasteland Database for Region 4 (queried on November 6, 2000). Conversation with Mr. Clark of Solutia, Inc. on November 13, 2001 and April 30, 2002. Conversation with Ms. Apple, Tennessee DEC on November 14, 2001.

Table 3-1. Summary of Information About WP Electric Arc Furnace Manufacturing Sites (continued)

Types of Contaminants in the Historical (Unlined) Ponds	Characterization of the Unlined Ponds or of the Site	Remedy Selection for Unlined Ponds	Other Remedies Considered for Unlined Ponds	Health & Safety Issues	Current Status	Regulatory Background	Point of Contact	Source of Information
Albright and Wilson America Limited Phosphorus Plant (Rhodia, Inc.), Long Harbor, Newfoundland, Canada								
WP, cyanide, arsenic, fluoride, cadmium, and ammonia.	Dust-contaminated phosphorus, known as "mud" was stored in several mud holes on site.	Elemental phosphorus from phosphorus containing mud was recovered on site. Mud holes were decommissioned using <i>in situ</i> containment (capped). Twenty monitoring wells were installed around the ponds for groundwater monitoring.	The two other remedies that were considered were mud still treatment and landfilling. Treatment technologies were considered but determined to be non-feasible, including burning in tanks or pits, rotary kiln, high pressure oxidation, steam distillation, hypochlorite washing, oxidation/aeration under water, solvent extraction, sludge-to-fertilizer extraction, <i>in situ</i> chemical oxidation, and <i>in situ</i> vitrification.	Potential hazards identified for <i>in situ</i> containment were those associated with worker exposure to WP mud, WP sludge, debris, and phosphy water, as well as groundwater contaminated by leachate.	The plant ceased operations in 1989. Decommissioning began in 1996, with the majority of activities completed by 2000. Geological modeling performed over a 100 year period predicted the WP would not migrate significant distances (i.e., less than 1 meter).	Canada - Environmental Assessment Act, EIS completed January 1996	Dexter Pittman, Department of Environment, Government of Newfoundland and Labrador at (709) 729-6771	Review of Pond 8S Closure Plan, Volume 1 and 2, FMC Corporation (Actual title unavailable) (20 pages), January 23, 1998, EPA. Fact Sheet No. 20, Albright and Wilson America Limited; available on the Internet < http://slv2000.qc.ec.gc.ca/bibliotheque/centre_docum/protection/liste_aceueil_a.htm >. Conversation with Mr. Pittman on February 6, 2002. E-mail from Dexter Pittman, March 12, 2002

Table 3-1. Summary of Information About WP Electric Arc Furnace Manufacturing Sites (continued)

Types of Contaminants in the Historical (Unlined) Ponds	Characterization of the Unlined Ponds or of the Site	Remedy Selection for Unlined Ponds	Other Remedies Considered for Unlined Ponds	Health & Safety Issues	Current Status	Regulatory Background	Point of Contact	Source of Information
U.S. Tennessee Valley Authority (TVA) National Fertilizer Development Center, Muscle Shoals, Alabama								
Information not provided.	130,000 liters of phosphorus sludge was stored in rail cars and tanks and the remaining sludges were buried as entombments at the site.	The entombments consists of phosphorus sludge with one foot of crushed limestone placed on the top. A six-inch thick concrete cap was constructed on the top of the limestone layer.	Information not provided.	Information not provided.	Not an operating facility. Site preliminary assessment completed on July 28, 1988. No further remedial action planned (NFRAP) at site.	Information not provided. EPA ID # AL3640090004	Ann Godfrey, EPA (404) 562-8919 Doug Murphy, Crane Army Ammunition Activity (256) 386-2268	Review of Pond 8S Closure Plan, Volume 1 and 2, FMC Corporation (Actual title unavailable) (20 pages), January 23, 1998, EPA.
Oldbury Electrochemical Company, Niagara Falls, New York								
Information not provided.	Information not provided, including whether phosphy water was disposed in unlined ponds and characteristics of such ponds.	Information not provided.	Information not provided.	Information not provided.	Not an operating facility. Oldbury Electrochemical Company was acquired by Hooker Electrochemical Company in 1956. Hooker was acquired by Occidental Chemical Corporation in 1968. Information about current status not provided.	Information not provided.	Michael Negrelli, EPA (212) 637-4278	Kirk-Othmer Encyclopedia of Chemical Technology, 2 nd Edition, Vol. 15, 1972.

Table 3-2. Summary of Information About Selected Military Facilities Using Elemental Phosphorus

Site Name, Location	Site Characterization	Point of Contact	Source of Information
Eagle River Flats, Fort Richardson, Anchorage, Alaska	Sediments were identified as contaminated with elemental phosphorus from its use in ordnance. Elevated waterfowl mortality was reported in the 1980s which resulted from the ingestion of elemental phosphorus particles in the sediments.	Michael R. Walsh, U.S. Army Corps of Engineers (USACE) Cold Regions Research and Engineering Laboratory (CRREL) (603) 646-4363	Collins, 1999
Crane Army Ammunition Plant, Indiana	Soil and sludge were not reported as contaminated with WP; rather site stored munitions containing WP.	Randall W. Burcham, Crane Army Ammunition Activity, Crane, Indiana (812) 854-1353	Burcham, 1991
Military Installations with the Presence of Elemental Phosphorus¹			
Fort McCoy, Madison, Wisconsin	Number of samples where elemental phosphorus was detected per total number of samples evaluated: 11/45 Highest reported concentration of elemental phosphorus: 58 mg/kg	Information not provided.	Rivera, October 1996.
Yakima Training Center, Yakima, Washington	Number of samples where elemental phosphorus was detected per total number of samples evaluated: 3/27 Highest reported concentration of elemental phosphorus: 430 mg/kg	Information not provided.	Rivera, October 1996.
Fort Bragg, North Carolina	Number of samples where elemental phosphorus was detected per total number of samples evaluated: 7/90 Highest reported concentration of elemental phosphorus: 0.1 mg/kg	Information not provided.	Rivera, October 1996.

Table 3-2. Summary of Information About Selected Military Facilities Using Elemental Phosphorus (continued)

Site Name, Location	Site Characterization	Point of Contact	Source of Information
Fort Riley, Fort Riley, Kansas	Number of samples where elemental phosphorus was detected per total number of samples evaluated: 3/24 Highest reported concentration of elemental phosphorus: 0.24 mg/kg	Information not provided.	Rivera, October 1996.
Fort Drum, Fort Drum, New York	Number of samples where elemental phosphorus was detected per total number of samples evaluated: 11/45 Highest reported concentration of elemental phosphorus: 0.023 mg/kg	Information not provided.	Rivera, October 1996.

1. USACE evaluated military installations where elemental phosphorus might be present and identified these five sites as those where the risk of contamination from elemental phosphorus was high.

Overview of Elemental Phosphorus Electric Arc Furnace Manufacturing Sites

Information was not provided about whether the following two EAF sites have unlined ponds:

- U.S. TVA National Fertilizer Development Center, Muscle Shoals, Alabama
- Oldbury Electrochemical Company, Niagara Falls, New York

Of these ten sites, only Monsanto, Soda Springs currently is operating as a manufacturer of WP.

Of the eight sites with unlined ponds, six have installed or plan to install caps for the unlined ponds. Of the remaining two sites, at one site (in Silver Bow Montana), the ponds are not under corrective action, and at another site (in Tarpon Springs Florida), solidification/stabilization in combination with the consolidation and capping of contaminated material has been selected as a remedy for the ponds. The following is a brief summary of key information provided in Table 3-1 for sites with unlined ponds.

At the Monsanto Chemical Company (Solutia), Soda Springs, Idaho site, regulated under CERCLA, the manufacturing process used a distillation step to recover WP, and, therefore, the unlined ponds are expected to contain less WP than found at EMF. The unlined ponds at the Soda Springs site have been capped and the site currently is undergoing groundwater monitoring. At the Stauffer Chemical Company (Rhodia, Inc.), Silver Bow, Montana site, regulated under RCRA, the unlined ponds are not under corrective action. However, a concrete clarifier used to contain WP-contaminated sludge is being studied for possible corrective action. At the Stauffer Chemical Company, Tarpon Springs, Florida site, regulated under CERCLA, the remedy selected for the unlined ponds is *in situ* solidification and stabilization (see further discussion in Section 5.0 and in Appendix A). At the Exxon Mobil ElectroPhos Division, Mulberry, Florida site, regulated under CERCLA, the facility recently agreed to install a high-density polyethylene (HDPE) liner over the top of the ponds and a low-permeability slurry wall around the perimeter of the ponds, and to continue groundwater monitoring. At the Agrifos Nichols Plant, Nichols, Florida site (regulatory background not provided), one unlined pond was covered with an earthen cap in the 1950s, and two other unlined ponds were backfilled with overburden after 1978 to a depth of two feet. These ponds are located within an area that is contaminated by a phosphate fertilizer manufacturing facility. At the Stauffer Chemical Company (Rhone-Poulenc), Mt. Pleasant, Tennessee site, the unlined ponds were capped under a 1998 Amended Closure Plan. At the Monsanto Chemical Company, Columbia, Tennessee site, an unlined pond was drained and capped. At the Albright and Wilson, Newfoundland, Canada site, unlined ponds (referred to as “mud holes”) were capped. Use of treatment technologies was considered for this site but determined not to be feasible.

Two of the seven military facilities performed treatment for WP (Eagle River Flats and Crane Army Ammunition plant), and these are discussed further in Section 5.0.

4.0 OVERVIEW OF HISTORICAL PONDS AT EMF

This section provides an overview of the physical and chemical characteristics of the historical ponds at the EMF site, and the fate and transport of WP in the ponds. Limited information was available to characterize the historical ponds at the EMF site. The RI/FS and ROD for EMF provide only general descriptions for many of the ponds and do not identify the specific physical and chemical characteristics of each pond, such as concentration and distribution of specific contaminants or moisture content within and across the 16 historical ponds (although data for samples from several of the ponds was presented, as discussed below). For the purposes of this report, several assumptions were made about pond characteristics using technical judgment, based on what is known about the ponds and experience with site cleanups.

Sixteen historical ponds are addressed in this report - 15 unlined ponds (Ponds 1S through 7S, 9S, and 1E through 7E) and one lined pond (Pond 10S), all of which are being addressed under CERCLA.

One unlined pond at EMF, Pond 8S, is not included in this report because it is currently being addressed under RCRA. However, available data about the characteristics of this pond, which handled wastes similar to that of the historical ponds, provides a better understanding of the characteristics of the historical ponds at EMF. In 1993-1994, a time-critical removal action under CERCLA was performed by FMC to remove the hydraulic head and perform interim capping of Pond 8S. Under this action, Pond 8S was dewatered, filled with sand and slag, and covered. This pond became subject to regulation under RCRA in March 1990. The Pond 8S RCRA closure plan was approved by EPA in August 1998 and FMC completed and certified the closure in 1999. Pond 8S is currently being monitored under a RCRA post-closure plan.

Physical Characteristics

The historical ponds were used during manufacture of WP from phosphate ore from the 1950s to 1981. During this time, the ponds received the following wastes: phosphy water, precipitator dust slurry, phosphy solids, slag pit water and solids, and residuals from reclaiming WP in other ponds. Phosphy water is an aqueous stream that contacted WP during its manufacture and contains elevated levels of WP. Precipitator dust slurry is the result of the furnace process electrostatic precipitators dry dust that consists of unreacted (unmelted) ore and WP that condenses in the precipitators prior to WP product recovery in

the wet condensers. The dry precipitator dust was slurried with water to prevent WP oxidation and to convey the dust to the ponds.

WP was reclaimed from six of the ponds as part of operating the pond, with some ponds reclaimed on a regular basis (e.g., twice each year for Ponds 1S, 2S, and 3S) or on a one-time basis (e.g., Pond 9S to a depth of 25 ft bgs, 2E, and 4E). Reclamation consisted of excavating pond materials or oxidizing WP in the pond. Information was not provided about how the WP was oxidized at that time. The reclaimed areas of Pond 3S were filled in with slag. Portions of other ponds were covered by stockpiled materials, (e.g., Pond 7S has a ferrophosphorus stockpile approximately 25 ft high), or were reused as precipitator dust slurry sedimentation ponds.

In the 1970s, free liquid was removed (i.e., pond dried) from seven of the ponds that were no longer in use, with free liquids removed from eight other ponds between 1980 and 1981 (information was not provided about the year that Pond 10S had liquids removed). After drying, eight ponds were covered with a variety of materials including soil, slag, crushed slag, baghouse dust, fluid bed drier product prills, asphalt paving, and cement. Examples of covers include capping with 3 to 6 ft of soil, slag, a paved asphalt road, cement, and 6 to 10 ft of pit-run slag. In addition, nine ponds were covered by RCRA lined ponds or ferrophos storage. Most of the ponds were regraded to direct surface precipitation away from the ponds.

Assumption About Depth of Contaminated Soil and Sludge in Ponds: The assumed maximum depth of contaminated soil and sludge in the historical ponds is 20 ft. It is assumed that the ponds were originally constructed to a depth of 10 ft, but that there was downward migration of contaminants in ponds that had a sustained hydraulic head, or where materials were integrated in fill, causing contamination of soil to a depth of as much as 20 ft. The EMF RI report notes the depth of fill, the maximum depth of impacted soil encountered, and the predominant constituents exceeding representative levels at this maximum depth for each area or investigation within the FMC area. The maximum depth of impacted soil associated with the historic FMC ponds (at which a sustained hydraulic head was present during operation) was 180 feet bgs (Pond 6S). Reference to a maximum depth of impact of 20 ft bgs in this report refers to an estimated general thickness of fill (for example, phospy pond sediments) and fill that had been mechanically mixed with the underlying native soils. Because of the physical activities performed during pond operation, such as excavation/reclamation and oxidation, as well as filling with a variety of materials, the actual depths of contaminated soil and sludge in the ponds may be less than 20 ft. Further, it is likely that depths vary within a given pond and from one pond to another. For example, one pond may contain a

substantial amount of fill such as slag that would not contain elevated levels of contaminants; in this example, the depth may be less than 20 ft.

Basis: The soil boring data show that most of the contamination is in the top 10 ft of the ponds. Further, these data identify no phosphy wastes at depths greater than 10 ft. However, data also show that there is some contamination at depths from 10 to 20 ft, in the native soil (for example, see Table 4-1 for soil borings F034B in Pond 9S, F033B in Pond 1E, and F024B in Pond 4E, all with elevated levels of WP at depths of approximately 20 ft). Soil boring data show substantially little contamination below 20 ft.

Assumption About Volume of Contaminated Soil and Sludge in Ponds: The assumed total volume of contaminated soil and sludge in the historical ponds is approximately 500,000 cubic yards (CY), based on a depth of 20 ft and an areal extent of 16 acres. It is likely that some of the ponds only have contamination in the upper 10 ft; therefore, this estimate may be high. In addition, information in the FS shows that the total volume of contaminated soil and sludge in the 16 historical ponds is approximately 120,000 CY. The FS estimate is based on a volume per pond "which contain constituents of potential concern at levels which conceivably could require remedial action". No further information was provided about how the volume per pond was identified in the FS.

Basis: The maximum contamination depth was assumed to be 20 ft, and the areal extent of ponds that have not been covered by RCRA ponds or ferrophos storage was calculated as 16 acres.

Assumption About Heterogeneity of Ponds: The contents of the ponds are assumed to have substantial physical and chemical variation (heterogeneity) throughout the vertical profile and across the areal extent, both within and across ponds.

Basis: Pond contents consist of phosphy wastes, slag, fill, dust, solids, gravel, and a variety of types of silty materials. These materials were disposed of in ponds as they were available. In addition, soil borings (Table 4-2) show heterogeneity within the vertical profile and across the areal extent of selected ponds.

Assumption About Matrix Characteristics of Ponds: The moisture content of the ponds is assumed to be "medium", with the ponds not fully-saturated or completely dry. Due to the pond heterogeneity, it is likely that the moisture content varies within and among ponds. The density of pond materials is assumed to be 1.5 tons/CY.

Basis: All free liquids have been removed from the ponds. Because the site is in a semi-arid area, with average precipitation of 11 inches per year, there is relatively little moisture that enters the ponds and it is likely that some moisture in the ponds is removed by evaporation or runoff. The density of silty soils is reported to range from approximately 95 to 125 pounds per cubic foot (lbs/ft³) (Lindenburg, 1986). Using an average density of 110 lbs/ft³ corresponds to 1.5 tons/CY.

Chemical Characteristics

Table 4-1 provides a summary of soil boring results for samples collected during the RI in or adjacent to 7 ponds to a depth up to 20 ft. Soil samples were collected from three borings located near Pond 7S, three borings located near Pond 8S, two borings in Pond 9S, two borings located within the boundary of former Pond 1E, one boring in former Pond 4E, two borings in former Pond 5E, and two borings in former Pond 6E. While Pond 8S is not addressed by this report, the data from soil borings collected near the pond help to describe the characteristics of soil located near the historical ponds. The samples collected from soil borings were analyzed for total phosphorus, other constituents (metals and nonmetals), and radiological parameters (gross alpha and gross beta). Table 4-1 shows elevated concentrations of total phosphorus, as well as other constituents including cadmium, fluoride, and zinc. Maximum concentrations shown in Table 4-1 include total phosphorus at 86,000 mg/kg (8.6%), cadmium at 5,610 mg/kg, chromium at 278 mg/kg, copper at 221 mg/kg, fluoride at 44,800 mg/kg, and lead at 1,300 mg/kg. Gross alpha levels were measured as high as 1,530 picocuries per gram (pCi/g) and gross beta as high as 1,070 pCi/g. In addition, the RCRA ponds at the site have been found to emit hydrogen cyanide and phosphine in areas of low or high pH. The cyanide resulted from the reaction of nitrogen with the carbon in the reduction furnace.

The results show the concentration of total phosphorus, but do not identify the fraction that is WP. Total phosphorus results include WP, phosphate, and other phosphorus-containing compounds. For other constituents, only those constituents that are reported by the RI as greater than background (shown in the RI as the representative range) are summarized in Table 4-1. Results for individual radionuclides were not reported for these samples.

Soil characteristics were noted during description of the soil borings, and are summarized in Table 4-2. The descriptions of materials encountered during borehole drilling included “pure precipitator dust,” “phosy solids,” slag, and fill. According to the RPM, there is likely to be a heterogeneous mixture of materials present in the soil/sludge within these ponds.

Outside of the ponds, the contaminants of potential concern in the soil, as identified in the ROD, include antimony, arsenic, beryllium, boron, cadmium, fluoride, lead-210, manganese, mercury, nickel, polonium-210, potassium-40, selenium, silver, thallium, uranium-238, vanadium, and zinc. In addition, gross alpha and gross beta contamination were identified as being of concern.

Although individual radionuclides were not analyzed for in the soil, the RI identified specific radionuclides based on an analysis of the data for gross alpha and beta. Radon also was identified for its potential to infiltrate buildings under alternate future commercial or industrial uses of the site. With radionuclides, the primary alpha emitters at the site were identified as uranium-238, uranium-234, thorium-230, radium-226, and polonium-210. The primary beta emitters were identified as lead-210 and potassium-40. The activity of radium-226 ranged from 4 to 24% of the gross alpha measurements.

Assumption About Source of Contamination: The only source for chemical contaminants in the soil and sludge in the unlined ponds (WP, heavy metals, and radionuclides) is assumed to be the constituents found in the phosphate ore processed at the site and in the by-products/wastes from manufacturing WP, and no contamination is associated with the relatively small amounts of reagents, catalysts, or fuels used to manufacture elemental phosphorus.

Basis: Soil boring data show that the contaminants found in the unlined ponds are the constituents expected to be present based on the content of phosphate ore.

Assumption About Percentage of Phosphorus in Selected By-products/Wastes: Among the by-products/wastes from the manufacture of WP, it is assumed that phosphy water and precipitator dust had a relatively higher percentage of phosphorus than other wastes such as slag pit water and solids, and residuals from reclaiming WP in other ponds.

Basis: Soil boring data showed relatively higher concentrations of phosphorus in ponds where phosphy water and precipitator dust had been disposed. Data for Pond 1E (sample at 0.5 ft) showed a total phosphorus concentration of 8.6 percent, and soil boring logs show the material that was sampled consisted of various materials including precipitator dust and phosphy water solids. This sample had the highest concentration of phosphorus measured in any of the available soil borings.

Assumption About Contaminant Concentrations in Historical Ponds: Table 4-3 shows a summary of the average contaminant concentrations of soil and sludge in historical ponds, assuming that the

concentrations are the same as the average contaminant concentrations in phossey sediment generated during production of WP. As this table shows, the ponds contain heavy metals such as arsenic, cadmium, chromium, vanadium, and zinc at levels as high as 26,000 mg/kg, fluoride as high as 17,000 mg/kg, total phosphorus as high as 28,000 mg/kg (2.8%), and radionuclides as high as 780 pCi/g. These concentrations range as high as 1,000 times higher than soil background concentrations. For example, total phosphorus ranges as high as 500 times higher than soil background. As mentioned above, the ponds are heterogeneous, and the concentrations of contaminants are non-uniform throughout the pond, with some portions of a pond exhibiting relatively higher concentrations (such as areas where wastes were stored or where a sustained hydraulic head was present), while other portions of a pond would have relatively lower concentrations (such as where fill was added to a pond).

Basis: The contaminant concentrations in phossey sediments disposed of in RCRA ponds likely are similar to those disposed of in historical ponds. Further, soil borings were performed only in a limited number of historical ponds and data from these borings likely are not as accurate as RCRA data at capturing the expected average of concentrations for wastes that were disposed in historical ponds.

Assumption About Distribution of Total Phosphorus in Ponds: Only a relatively small fraction of the total phosphorus measured is assumed to be in the elemental form.

Basis: The range of total phosphorus concentrations of 21,300 to 28,000 mg/kg estimated to be present in waste materials in the ponds consists of WP, as well as other forms of phosphorus such as phosphate. As discussed above, there were a number of actions taken to reclaim phosphorus from some of the ponds. WP is the main product from the facility and efforts likely were made to reduce product losses to the waste ponds and to reclaim the product from the ponds.

Fate and Transport of Elemental Phosphorus

The following discussion about fate and transport of WP is based on technical judgment using information presented in Section 2.0, what is known about the ponds, and experience with site cleanups. (FMC FS, 1996, and FMC, 1997a). In the historical ponds at EMF, WP likely would not exhibit substantial oxidation or hydrolysis, nor would it likely be transported from the ponds, leaving it to remain in the soil and sludge as WP. The oxidation and hydrolysis of WP would be limited primarily because of its relatively low solubility in water (3 mg/L), as well as the limited amount of oxygen expected to be present. Because the ponds contain no free liquids and are covered, the only available moisture likely

will be due to the moisture content of the soil and sludge prior to being covered, or the relatively small amount that enters the pond from percolation of rainwater and snowmelt (annual precipitation of 11 inches).

In this environment, WP that is dissolved in the soil and sludge moisture would be hydrolyzed to form phosphine and lesser amounts of phosphoric acid. However, the hydrolysis of WP is a slow process, especially under limited moisture conditions. The limited amount of DO present in the soil and sludge would react with phosphorus to form various types of soluble phosphorus acid ions, and, depending on environmental conditions, these ions may be further converted to a solid metal phosphate compound such as calcium phosphate. The rate of biological transformation of WP, which results in the same soluble forms of phosphorus acids as are produced through hydrolysis and oxidation, is even slower than with the chemical transformation processes.

For these reasons, the expected fate of WP is to remain in the ponds as WP or as a solid metal phosphate. This conclusion is further supported by research that demonstrates that chemical and biological transformation of WP in soils and sediments, where partial pressures of oxygen are low, will be very slow (Spanggord et al , 1983).

Oxidation of WP through contact with atmospheric oxygen would occur in portions of ponds that have not been covered, or as oxygen diffuses through the soil or slag cover and contacts phosphorus particles. Given that pond covers may be several feet thick, may have other oxygen-absorbing compounds in the cover, soil, and sludge, and phosphorus particles may be as deep as 20 ft below ground surface in the ponds, it is unlikely there will be substantial oxidation of WP in the ponds at this time through contact with atmospheric oxygen. In addition, the phosphorus particles may be present in dispersed locations throughout the ponds, and, even if there were an area of the pond with a more direct channel for delivering oxygen to the soil and sludge, it might not be in the area where the phosphorus particles are present. It is likely that any phosphorus that is in readily-accessible locations (e.g., near the surface, near sources of oxygen) was oxidized earlier in that period of time and would no longer be available as WP.

The direct transport of WP from the ponds to groundwater would be limited primarily because of its relatively low solubility in water (3 mg/L), as well as the limited amount of available moisture, even during the active life of the ponds. The by-products from oxidation, hydrolysis, and biological transformation of WP, including phosphorus acids, are highly soluble in water, but these compounds are not expected to be generated at high enough concentrations or at high enough rates in the sludges and

soils to cause large-scale transport of phosphorus acids to the groundwater, except where a substantial hydraulic head within an unlined pond was present during operation.

The expected low rate of phosphorus migration to the groundwater, relative to the amount of phosphorus that was originally pumped to the ponds, is demonstrated by the low concentrations of total phosphorus (generally between 10 and 100 mg/L) in the groundwater that were presented in the FS. The FS showed the maximum concentration of total phosphorus as follows: central FMC area - 34.25 mg/L, eastern FMC area - 96.8 mg/L, northern FMC properties (Michaud) - 7.61 mg/L, northern FMC properties (Bannock) - 29.63 mg/L, southwest FMC area (Michaud) - 52.6 mg/L, and southwest FMC area (Bannock) - 665 mg/L. Within historical ponds, the concentrations of total phosphorus in the soils and sludge after closure ranged from 1,640 to 59,700 mg/kg.

The total phosphorus in the groundwater has been found, by concurrent analyses of groundwater samples for both total phosphorus and orthophosphate, to be almost entirely orthophosphate. Orthophosphate is less toxic to humans, plants, and animals than WP. However, orthophosphate can stimulate plant growth, and thus has the potential to cause algal blooms in surface water bodies that are hydraulically connected to groundwater.

WP contained in ponds would not be released directly to the air as its elemental form, but may be released as phosphorus pentoxide or phosphine gases from the surface of the ponds. However, the slow rate of the hydrolysis reactions, combined with the effects of dilution of the gas in the outside atmosphere, are expected to result in low, environmentally insignificant concentrations of these gases. The rate of gas generation and the emission rate of the gas after it is generated are expected to be even lower in filled ponds than in those same ponds before they were filled, primarily because of the limited availability of soil moisture. In addition, any gas that is generated would be in soil-pore spaces where it may undergo oxidation and hydrolysis to phosphoric acid. (FMC, 1997a)

Table 4-1. Soil Boring Results for Surface (less than 20 ft) of Unlined Ponds (1)

Pond	Soil Boring (2)	Sample Depth (ft below ground surface)	Total Phosphorus (mg/kg)	Other Constituents (mg/kg)	Radiological Parameters (pCi/g)
7S	F055B	3	8,240	Cadmium 154 Chromium 139 Copper 27.9 Fluoride 4,720 Lead 30.8 Nickel 31.4 Silver 17.2 Vanadium 153 Zinc 2,940	Gross Alpha: 16.6 Gross Beta: 22.6
		5	8,940	Cadmium 32.2 Zinc 801	Gross Alpha: 46 Gross Beta: 42
7S	F056B	5	9,530	Cadmium 33.7 Chromium 114 Copper 21.3 Fluoride 2,630 Nickel 31.6 Vanadium 148 Zinc 437	Gross Alpha: 25.4 Gross Beta: 32.5
		7	51,400	Cadmium 5,610 Chromium 242 Cobalt 19.3 Copper 221 Fluoride 44,800 Lead 1300 Manganese 1,240 Molybdenum 26.9 Nickel 38.1 Selenium 24.4 Silver 786 Vanadium 149 Zinc 499,000	Gross Alpha: 1,530 Gross Beta: 1,070
7S	F057B	5	2,230	Cadmium 27.1 Chromium 33.7 Fluoride 890 Zinc 485	Gross Alpha: 31.4 Gross Beta: 28.1
		7	12,700	Cadmium 235 Chromium 109 Copper 28.3 Fluoride 3,330 Lead 56.9 Molybdenum 4.7 Nickel 29.4 Selenium 9.1 Silver 30 Vanadium 117 Zinc 3,860	Gross Alpha: 47.4 Gross Beta: 34.9

Table 4-1. Soil Boring Results for Surface (less than 20 ft) of Unlined Ponds (1) (Continued)

Pond	Soil Boring (2)	Sample Depth (ft below ground surface)	Total Phosphorus (mg/kg)	Other Constituents (mg/kg)	Radiological Parameters (pCi/g)
8S	B12	0	774	None different from background	Not measured
8S	B12	10	9,980	Cadmium 535 Chromium 154 Copper 40.8 Fluoride 7,030 Lead 137 Nickel 35.7 Selenium 6.7 Silver 56 Vanadium 138 Zinc 10,800	Gross Alpha: 143 Gross Beta: 117
		20	1,610	Fluoride 784	Gross Alpha: 8.3 Gross Beta: 20
8S	B13	0	699	None different from background	Not measured
		10	3,250	Cadmium 15.2 Zinc 637	Gross Alpha: 6.9 Gross Beta: 14.8
		20	992	Zinc 52.7	Gross Alpha: 11.3 Gross Beta: 20.2
8S	B150	1	954	None different from background	Not measured
		2	612	None different from background	Not measured
		10	4,080	Cadmium 13.5 Chromium 178 Fluoride 11,400 Vanadium 157 Zinc 239	Gross Alpha: 172 Gross Beta: 84
		20	1,630	Zinc 64	Gross Alpha: 8.7 Gross Beta: 18.7

Table 4-1. Soil Boring Results for Surface (less than 20 ft) of Unlined Ponds (1) (Continued)

Pond	Soil Boring (2)	Sample Depth (ft below ground surface)	Total Phosphorus (mg/kg)	Other Constituents (mg/kg)	Radiological Parameters (pCi/g)
9S	B-2	0.5	74,100	Cadmium 4,150 Chromium 216 Copper 141 Lead 574 Selenium 73.4 Silver 69.9 Vanadium 183 Zinc 52,600	Not measured
		6.5	1,970	Zinc 180	Not measured
		11.5	1,810	Zinc 67.2	Not measured
9S	F034B	5	2,730	Cadmium 25.1 Fluoride 1,980 Zinc 366	Gross Alpha: 32.1 Gross Beta: 47.3
		10	1,870	Fluoride 2,120 Zinc 146	Gross Alpha: 11.6 Gross Beta: 25
		15	767	Zinc 210	Gross Alpha: 31.8 Gross Beta: 42.9
		20	477	Orthophosphate 53.1	Gross Alpha: 7.72 Gross Beta: 18
1E	F033B	4.5	6,410	Boron 50.6 Chromium 51.8 Copper 22.9 Fluoride 4,130 Lead 79.6 Zinc 7,320	Gross Alpha: 23.9 Gross Beta: 34.6
		9.5	2,380	Fluoride 1,460 Zinc 295	Gross Alpha: 19.8 Gross Beta: 37.5
		14.5	1,900	Cadmium 3.9 Fluoride 1,560 Nickel 17.6 Zinc 174	Gross Alpha: 114 Gross Beta: 152
		19.5	1,630	Fluoride 1,210 Zinc 75.7	Gross Alpha: 20 Gross Beta: 30.9
1E	B-1	0.5	86,000	Cadmium 5,110 Chromium 278 Copper 155 Lead 683 Selenium 77.6 Silver 79.6 Vanadium 234 Zinc 69,800	Not measured
		6.5	5,770	Zinc 1,590	Not measured
		11.5	2,820	Zinc 1,070	Not measured

Table 4-1. Soil Boring Results for Surface (less than 20 ft) of Unlined Ponds (1) (Continued)

Pond	Soil Boring (2)	Sample Depth (ft below ground surface)	Total Phosphorus (mg/kg)	Other Constituents (mg/kg)	Radiological Parameters (pCi/g)
4E	F024B	0	25,700	Boron 54.6 Cadmium 918 Chromium 55.9 Copper 41.4 Fluoride 8,030 Lead 157 Molybdenum 6.5 Potassium 15,700 Selenium 11.3 Silver 87.1 Vanadium 55 Zinc 15,200	Gross Alpha: 95.3 Gross Beta: 113
		10	1,640	Fluoride 1,510 Potassium 8,000 Zinc 85.3	Gross Alpha: 16.1 Gross Beta: 25
		20	1,160	Fluoride 810 Potassium 5,900	Gross Alpha: 18.5 Gross Beta: 26.2
5E	B-114	5.5	3,440	Cadmium 21.7 Potassium 6,170 Silver 2.5 Zinc 1,720	Not measured

Table 4-1. Soil Boring Results for Surface (less than 20 ft) of Unlined Ponds (1) (Continued)

Pond	Soil Boring (2)	Sample Depth (ft below ground surface)	Total Phosphorus (mg/kg)	Other Constituents (mg/kg)	Radiological Parameters (pCi/g)
5E	F025B	5	12,300	Boron 28.4 Cadmium 532 Chromium 48.2 Copper 25 Fluoride 7,670 Lead 106 Potassium 11,900 Selenium 5.6 Sodium 1,050 Silver 61 Zinc 11,600	Gross Alpha: 111.1 Gross Beta: 113.8
		10	33,600	Boron 67.9 Cadmium 2,080 Chromium 108 Copper 57.3 Fluoride 35,000 Lead 360 Nickel 24.9 Potassium 23,700 Selenium 18.6 Silver 152 Sodium 2,710 Vanadium 78 Zinc 200,000	Gross Alpha: 303 Gross Beta: 265
		20	1,630	Fluoride 1,120 Potassium 5,790	Gross Alpha: 26.4 Gross Beta: 27.7
6E	B-130	16	1,700	Potassium 6,250 Zinc 66.5	Not measured
6E	F026B	0	1,400	Fluoride 1,610	Gross Alpha: 22.3 Gross Beta: 21.4
		10	1,640	Fluoride 1,570 Potassium 4,430	Gross Alpha: 16.8 Gross Beta: 23.3

Source: FMC RI

- (1) Results show the concentration of total phosphorus, but do not identify the fraction that is WP. Total phosphorus results would include elemental, phosphate, and other phosphorus-containing compounds that might be present. For other constituents, only those constituents that are reported by the RI as greater than background (shown in the RI as the representative range) are summarized in Table 4-1. Results for individual radionuclides were not reported.
- (2) Soil borings for Ponds 7S and 8S were performed near the ponds but not within the pond boundaries.

Table 4-2. Summary of Soil Characteristics Noted in Soil Boring Activities

Pond	Borehole (1)	Depth (ft)	Description
7S	F055B	3	Brown silty material
		5	Brown silty material
	F056B	5	Tan-brown silt
		7	Tan to black silt, precipitator dust
	F057B	5	Tan silt
		7	Tan sand/silt, gray clay with precipitator dust
8S	B12	0	Black clayey fill with phossey water solids or precipitator dust
		10	Black clayey fill with phossey water solids or precipitator dust
		20	Brown silt
	B13	0	Slag gravel fill
		10	Dark brown sandy silt fill
		20	Brown silt
	B150	1	Slag
		2	Slag
		10	Slag
		20	No description
9S	B-2	0.5	Dark gray to black slag fill
		6.5	Yellowish brown silt, just below fill/soil interface
		11.5	Yellowish brown silt
	F034B	5	Pale brown silt
		10	Pale brown silt
		20	Reddish, yellow sandy gravel
1E	F033B	4.5	Brownish yellow silt, slag fill
		9.5	Brownish yellow silt
		14.5	Brownish yellow silt
		19.5	Brownish yellow silt
	B1	0.5	Dark gray silty sand fill, slag with precipitator dust or phossey water solids to 4.5 ft
		6.5	Very pale orange silt
		11.5	Very pale orange silt
4E	F024B	0	Slag
		10	Brown silt fill with precipitator dust or phossey water solids fill
		20	Brown silt
5E	B114	0	Slag, gravel fill
		5.5	Grayish brown silt slag with phossey solids
		21	Dark yellowish brown silt
	F025B	5	Dark olive gray silt with phossey water solids
		20	Yellowish brown silt
6E	B130	16	Yellowish brown silt
	F026B	0	Light yellowish brown silt
		10	Light yellowish brown silt
7E	F162B	16	Pale, yellowish brown gravelly sand

Source: FMC RI, 1996

(1) Soil borings for Ponds 7S and 8S were performed near the ponds but not within the pond boundaries.

Table 4-3. Average Range of Concentrations for Selected Constituent in Historical Ponds

Constituent	Units	Soil Background Level	Estimated Concentration in Historical Ponds
Arsenic	mg/kg	7.7	20.4 - 256
Cadmium	mg/kg	1.9	1,100 - 2,040
Chromium	mg/kg	27.5	71.6 - 133
Fluoride	mg/kg	600	8,600 - 17,100
Phosphorus (total)	mg/kg	672	21,300 - 28,000
Vanadium	mg/kg	45.4	42.9 - 93.4
Zinc	mg/kg	52.8	10,400 - 26,600
Gross Alpha	pCi/g	NC	71.1 - 289
Gross Beta	pCi/g	NC	254 - 783
Lead-210	pCi/g	6.36	204 - 465
Potassium-40	pCi/g	20.5	13.1 - 27.4
Uranium-238	pCi/g	3.88	ND (5)

NC - Not Calculated

ND - Not Detected (detection limit)

Source: FMC FS, Table 2.2-1, 1996 (data for Ponds 8S, 11S, 12S, and 15S)

5.0 TREATMENT TECHNOLOGIES FOR SOIL AND SLUDGE IN HISTORICAL PONDS

Section 4.0 provided an overview of the historical ponds at EMF, based on available data and several assumptions, and showed that the portions of the historical ponds of interest for this report:

- Cover a total area of approximately 16 acres and extend to a depth of 20 ft
- Contain approximately 500,000 cubic yards (CY) of soil and sludge
- Are contaminated with WP, at concentrations as high as 2.8 percent, as well as heavy metals and radionuclides
- Are heterogeneous in physical and chemical composition
- Are covered with 3 to 10 ft of soil or slag

This section describes the types of technologies that may be applicable for treatment of soil and sludge in historical ponds at the EMF site. It includes an overview of the methodology used in identifying and evaluating potential treatment technologies, discusses several attributes that are important for implementing any treatment technology (referred to as “cross-technology considerations”), and provides a description of specific remedial technologies. First, excavation is described, followed by six treatment technologies where data have been identified concerning their potential for use at historical ponds at a WP-manufacturing site.

Methodology for Identifying and Evaluating Potential Treatment Technologies

Commercially-available treatment technologies were identified that have been used to reduce the concentration, volume, or mobility of WP, heavy metals, and radionuclides in soil and sludge. In addition, technologies were identified that are not commercially available but have shown promise for treating WP. Containment technologies were not considered.

Both *ex situ* and *in situ* technologies may be applicable for treatment of soil and sludge in unlined ponds containing WP. *Ex situ* technologies require excavation of soil and sludge followed by either disposal or use of an above-ground treatment technology. When using *ex situ* technologies, there are additional resources involved for performing excavation and disposal of treated residues than are required when using *in situ* technologies. *In situ* technologies require addition of physical, chemical, or biological agents directly to the soil and sludge without removal from the ponds. Some technologies, such as solidification/stabilization or chemical oxidation, can be performed on either an *ex situ* or *in situ* basis. *Ex situ* technologies require that a portion of the site be used to implement the technology, including

possibly staging the soil and sludge prior to and after treatment. Technologies that involve *in situ* treatment would need to consider the effects of treatment on the physical and chemical characteristics of the ponds.

The six specific treatment technologies discussed in this report include processes where the mechanism is based on chemical fixation (1), hydrolysis (1), oxidation (2), and thermal treatment (2).

- Solidification/Stabilization (S/S) - S/S is a commercially-available chemical fixation technology commonly used to reduce the mobility of heavy metals and radionuclides in matrices such as soil and sludge, and was identified in the EMF FS as a technology retained for further consideration for treatment of soils and solids at the Astaris (previously FMC) Subarea. In addition, it was selected for further testing on unlined ponds at a WP manufacturing facility in Tarpon Springs, Florida. While typically performed *ex situ*, S/S also may be performed by injecting and mixing stabilizing agents into unexcavated soil or sludge (i.e., *in situ*).
- Caustic Hydrolysis - Caustic hydrolysis was selected for treatment of process waste streams containing WP at the EMF site and hydrolysis was identified in the EMF FS as a technology retained for further consideration for treatment of soils and solids at the Astaris Subarea. The construction of a caustic hydrolysis system was approximately 95 percent complete when Astaris stopped production of WP.
- Chemical Oxidation - Chemical oxidation was identified in the EMF FS as a technology retained for further consideration for treatment of soils and solids at the Astaris Subarea. The Tennessee Valley Authority (TVA) reported that sludge containing WP would be oxidized when reacted with nitric and sulfuric acids. Researchers at the University of Alabama developed and tested a high speed air dispersion process to oxidize WP in a batch, stirred-tank reactor, and the USACE reported about several types of oxidants that can oxidize WP.
- Mechanical Aeration - A mechanical aeration system has been suggested by the USACE that could be used to increase the exposure of WP particles to oxygen and increases its rate of oxidation. The USACE described several studies that were conducted to evaluate the degradation of WP in solutions with varying amounts of DO and mixing intensities.
- Incineration - Along with open burning, incineration was identified by the United Nations as a recommended method for disposal of wastes containing WP (ATSDR, 1997). Incineration is a commercially-available thermal treatment technology that could be used to oxidize WP and reduce the volume of material requiring further treatment or disposal. Since 1990, the Crane Army Ammunition Activity has used a rotary kiln furnace to oxidize WP from ordnance, and a hydrator to convert the residual stream to phosphoric acid.
- Thermal Desorption - Thermal desorption is a commercially-available technology that involves heating the soil and sludge (directly or indirectly) to cause contaminants to volatilize and separate from the solid matrices without combustion. The USACE reported that 300 tons of WP-contaminated soil were treated using thermal desorption at a site in Ogden, Utah. Thermal desorption was reported as capable of removing WP, though the mechanism was not identified.

In addition to the six technologies listed above, pond pumping has been used to treat sediments contaminated with WP. Pond pumping involves removal of free liquids from a pond and exposing pond solids to ambient air and increase its rate of oxidation. At the Eagle River Flats military impact area contaminated with WP, the U.S. Army Cold Regions Research & Engineering Laboratory (CRREL) conducted a two-year feasibility study of a pond pumping system. However, at the EMF site, free liquids were removed more than 20 years ago, and it is not clear how additional pumping would be conducted at this time.

The six technologies were evaluated primarily based on how they would be applied for treatment of WP in the historical ponds at EMF. Therefore, in some cases, additional technologies may need to be considered for the treatment of heavy metals and radionuclides. The specific factors that were used to evaluate each technology are (1) the mechanism by which the technology would treat WP as well as heavy metals and radionuclides; (2) available data about where the technology previously has been used; (3) engineering considerations, such as material handling, pretreatment, residual management, and health and safety; (4) technology performance data; and (5) cost to implement the technology.

No testing of technologies was performed as part of this evaluation. Additional treatability testing would be needed to verify the potential for a given technology to treat the historical ponds at EMF. Treatability tests include evaluating how a particular treatment technology would perform for the specific matrices in the historical ponds, and the variations in performance across the range of concentrations and properties of the ponds. Results from such testing also could be used during the detailed design of a full-scale system, and for estimating the cost of such a system.

Performance. As discussed in Section 1.0, limited data are available in the technical literature concerning the performance of specific technologies for treating WP in soil and sludge. No full-scale remediation projects are known to have been implemented to treat waste material similar to that found at EMF. For this report, technical judgement was required for a qualitative assessment of expected performance. When data were not available, the technology was evaluated based on its operational principles and how those principles would affect WP, based on the physical and chemical properties of WP.

Radionuclides and heavy metals have differences in their physical and chemical properties and the treatment of radionuclides may require specific engineering considerations. However, radionuclides are

expected to behave similarly to heavy metals during treatment, and these two types of contaminants are referred to as heavy metals in the remainder of this section, except as noted. In addition, all heavy metals present were considered as one group of contaminants in this evaluation, recognizing that there are differences in physical and chemical properties among specific heavy metals (e.g., arsenic and selenium behave differently than cadmium and zinc). These types of differences are discussed in a variety of reference materials, such as:

- EPA Technology Screening Guide for Radioactively Contaminated Sites (EPA 402-R-96-017) (Available on-line at <www.epa.gov/superfund/resources/radiation/pdf/techguide.pdf>)
- FRTR Screening Matrix and Reference Guide (December 4, 2001) (Available on line at <www.frtr.gov/matrix2/>)

Also as discussed in Section 1.0, no quantitative contaminant cleanup levels have been specified for soil and sludge in the historical ponds. Therefore, this report discusses technology performance in general terms, and does not draw conclusions about specific technologies or groups of technologies that may be appropriate for use in treating historical ponds at EMF.

Cost. As mentioned in Section 1.0, cost information provided for each treatment technology has a great deal of uncertainty, given the limited amount of available data about the ponds, about use of technologies to treat historical ponds at WP manufacturing sites, and use of technologies to treat soil and sludge containing WP. Given these uncertainties, this report provides cost estimates as a range of costs, and provides an analysis of the sensitivity of the cost estimates. Technology cost was estimated for treating all 500,000 CY of contaminated soil and sludge estimated to be in the historical ponds at EMF. For compatibility on unit costs (cost per unit of measure) among technologies, calculated costs assume a density for pond materials of 1.5 tons per CY (refer to discussion of density in Section 4.0).

Cost data for specific technologies are based on information in commonly-used databases of remediation market cost information and in other publicly-available sources. These include publications such as *RS Means Environmental Remediation Cost Data - Unit Price, 8th Annual Edition*; 2002; published by Environmental Cost Handling Options and Solutions (ECHOS, 2002), *RSMeans Heavy Construction Cost Data, 16th Annual Edition*, published by RSMeans Company, Inc., (RSMeans, 2002), and *Remediation Technology Cost Compendium-Year 2000* (EPA, 2001). The unit cost information from ECHOS is based

on the costs for use of a technology at a typical remediation site, with minimal health and safety concerns (referred to as Level E, which ECHOS calls “normal conditions”). ECHOS reports that performing work at Safety Level C (which includes respiratory protection and other more significant activities) would increase labor costs by 80% and equipment costs by 33%, while working at Level B (which includes all the requirement of Level C plus supplied air respiratory protection) would increase labor costs by 140% and equipment costs by 67%.

The base unit costs in ECHOS do not include costs for design, testing, oversight, contingency, profit, or more stringent safety precautions (use of more stringent safety precautions would entail higher costs for use of a technology). The application of a specific technology at a remediation site typically includes costs for all of these items, however the estimates provided in this section are only for use of the treatment technology and do not refer to the entire site cleanup.

Also as mentioned in Section 1.0, the estimates in this report focus specifically on the cost of treatment and, in many cases, do not include costs for associated project components, such as excavation, preprocessing of waste material, health and safety (such as ambient gas control), and residual management (to treat heavy metals, if not treated by the primary treatment technology or disposal of treated solids). The magnitude of the costs of these associated project components could vary significantly depending on the specific characteristics of the material treated and treatment goals for the site.

An analysis was conducted to generally compare the magnitude of these associated costs to the cost of treatment under assumed site conditions and project requirements. A rough estimate showed that, while the treatment cost likely would make up a bulk of the overall project cost, these costs of associated project components likely would add 15 to 75 percent to the total project cost. This estimate for the associated costs is based on specific assumptions, including that the waste material will be able to be handled as a bulk solid rather than as a slurry and that the residual material and treated soil generated during treatment will be able to be managed on-site at the EMF site rather than requiring off-site disposal. If these assumptions are determined not to be reasonable after further site characterization or treatability testing, estimates of total project costs could increase significantly. For example, material handling costs could be increased by a factor of 10 if the waste material must be handled as slurries or disposal costs of residuals could increase substantially if off-site disposal is required. In addition to these cost factors, off-

site disposal of waste or residuals from treatment at the EMF site may be challenging due to the relatively few disposal sites that likely would take this waste.

Sources of Information. In addition to the ECHOS database and EPA's Cost Compendium, sources of information used for this evaluation include remedial efforts conducted previously or considered for use at the EMF site and other WP manufacturing sites, including those described in the FS for the EMF and Tarpon Springs sites, reports about WP remediation prepared by the USACE Waterways Experiment Station (WES) and Cold Regions Research and Engineering Laboratory (CRREL), published articles about WP treatment, the *Remediation Technology Screening Matrix*, and *Cost and Performance Case Studies*, both provided by the Federal Remediation Technologies Roundtable (available on line at <www.frtr.gov>) as well as information provided by specific technology vendors. Additional information about technology vendors was obtained from a search of EPA Remediation and Characterization Innovative Technologies (REACH IT <www.epareachit.org>), a comprehensive database of remedial technology information available on the internet, for treatment of phosphorus (search conducted February 2002).

Cross-Technology Considerations

The implementation of any applicable treatment technology would include the following cross-technology considerations:

Limited Information About Pond Characteristics - Because of the uncertainties about the physical and chemical characteristics of each pond, a treatment technology would need to be sufficiently robust and capable of treating soil and sludge that may be substantially different from that identified in Section 4.0 of this report. The characteristics of the soil and sludge likely vary within a pond and from one pond to the next, and the treatment technology would need to be able to perform adequately across a range of conditions.

Limited Information About Technology Performance and Cost - WP manufacturing facilities have closed unlined ponds in the past; however, no information could be located in the technical literature concerning any treatment that may have been used in closing the ponds. In addition, technology vendors have provided minimal information about the performance or cost for using specific technologies to treat soil and sludge containing WP. The technologies identified in this report for treating this material would need

to be tested in both laboratory and field settings for interested parties to have an adequate degree of confidence that they would be effective when implemented on a broad scale.

Health and Safety - WP is reactive in air and needs to be stored under water or in an oxygen-deficient environment. Treatment technologies that require excavation or other movement of soil or sludge, or that generate dust, may cause WP to become exposed to air. Plant workers and treatment technology operators would need to follow stringent health and safety precautions about handling soil or sludge containing WP. In addition, treatment technologies considered for the soil and sludge must be able to accommodate the presence of WP, even if the technology is being used to treat other contaminants such as heavy metals and radionuclides. Health and safety issues related to the treatment of radionuclides and heavy metals would also have to be considered.

Multiple Contaminant Types - The soil and sludge contains multiple types of contaminants, such as WP, heavy metals, and radionuclides, all of which may require treatment. It may be necessary to use a series of technologies that collectively would be able to treat all the types of contaminants. The use of a series of technologies is often referred to as a “treatment train”.

Logistical Concerns - The historical ponds cover a physically-wide area and the facility has a variety of other ponds, structures, waste piles, and production operations near the ponds. In addition, in some cases there are newer, lined ponds adjacent to parts of the ponds which likely have engineered berms and piping or other material transfer equipment nearby. Technologies that require excavation would need to consider the possible changes in structural stability of remaining ponds, as well as issues associated with accessing the soil and sludge in the ponds. Other relevant logistical issues include the need for storage facilities, construction management, operation support, and control of ambient gas generated during treatment (for example, the potential need to construct a tent over excavation or treatment areas to collect and control ambient emissions).

Excavation

Excavation is the removal of contaminated soil or sludge by use of mechanical equipment. Excavation equipment ranges widely from hand tools, such as pick axes and shovels, to backhoes, front end loaders, clamshells, draglines, and hydraulic dredging equipment, depending on the amount of material to be

excavated, the total depth of the excavation, moisture content, and the space allowed at the site for staging of excavated material.

Mechanism. Excavation physically removes contaminated soil and sludge from historical ponds before treatment using *ex situ* technologies or off-site disposal, and is a common approach for performing site cleanups. Excavation reduces the amount of contaminated soil and sludge in the ponds, and hence the potential for migration of WP and heavy metals from the ponds. Confirmation sampling is used to verify that contaminated materials have been removed. Excavation does not reduce the concentration of the contaminants in the soil and sludge. Therefore, the excavated material requires additional treatment prior to disposal. As discussed in Section 1.0, off-site disposal is not included within the scope of this report.

Available data. Ponds at the EMF site were partially excavated when active (i.e., more than 20 years ago). No information was available about how or where the excavation process was performed at EMF.

Engineering considerations. WP in the soils and sludges may degrade into phosphorus pentoxide or phosphine gases, or ignite spontaneously when soil and sludge is exposed to air. These gases and spontaneous ignition may pose risks to workers during the excavation process. To minimize these potential risks, safety training; special personal protective equipment (PPE), including respirators; and emissions control equipment or structures would be needed. To reduce the potential for uncontrolled burning, water is generally added and mechanically mixed with the soil and sludge prior to removal, resulting in an aqueous slurry that is less prone to spontaneous ignition. The slurry would then be pumped from the pond, using equipment such as centrifugal pumps or hydraulic dredges or excavators. It may be necessary to perform pretreatment by crushing, grinding, or milling to break up large masses of soil or slag prior to slurring.

The cover material on the ponds may need to be partially or fully removed to excavate the contaminated soil and sludge. In addition, ponds located around or near aboveground and below-ground structures may require the use of underpinning or sheet piling to stabilize the structure prior to excavation, or exploratory excavation and hand-digging. Shoring or sloping may be required in sandy soil to maintain trench wall stability.

During the excavation or slurring operations, air quality monitoring may be required. Use of mechanical equipment to physically move soil and sludge may expose the waste material to air and water. As

discussed in Section 2.0, this exposure may generate fugitive air emissions, such as phosphine gas, and these emissions may lead to elevated concentrations of dust or specific chemicals at down-gradient receptor points. If these concentrations exceed allowable standards, it may be necessary to use engineering controls on the excavation and slurring operations, or to limit or reduce the quantity of soil that can be excavated daily. It may be necessary to conduct these activities within a containment structure (e.g., a tent) that incorporates air scrubber or carbon adsorption treatment equipment to control ambient emissions and protect workers.

Performance. Excavation would remove contaminated soil and sludge from the ponds, but would not reduce the mass of contaminants. By adding water to the materials, the concentration of contaminants would be decreased based on the amount of water added.

Cost. The estimated unit cost reported by ECHOS for hydraulic excavation is \$6/CY for a 3 CY trench excavator, loose rock, 14 to 20 ft deep, and 104 CY/hour. If applied to the 500,000 CY of soil and sludge at EMF, the total cost for excavation would be approximately \$3 million. ECHOS reports costs for trench hydraulic excavators ranging from \$1 to 6 per CY, depending on type of material to be excavated, and rate and depth of excavation. As discussed above, if the ponds materials are slurried for health and safety reasons, the material may need to be removed using a dredging technique, such as hydraulic dredging. The average estimated unit cost reported by RSMMeans of \$9.08/CY for hydraulic dredging is \$7.30/CY minimum and \$10.85/CY maximum. If applied to the 500,000 CY of soil and sludge at EMF, the total cost for excavation would be approximately \$4.5 million. RSMMeans assumes that 2,000 gallons of water per CY of solid material is required during hydraulic dredging, increasing the volume of the material that must be treated by approximately tenfold.

The costs for excavation and dredging identified in ECHOS assume minimal precautions taken to address health and safety concerns (Level E). Because of the presence of WP in the pond materials, a higher level of safety would need to be used, and these would result in higher costs for excavation. Excavation or dredging using a higher level of safety equipment (say Level C) also would take longer to perform than work done under Level E, because of the time needed for activities such as decontamination and monitoring, thus increasing the cost for operating labor. Additional factors that affect excavation and dredging costs include extent of underground infrastructure and need for shoring. Nearby structures and extensive infrastructure, along with increasing depth of contamination tends to raise the costs. Therefore,

the actual cost for excavation or dredging at the EMF site would likely be considerably more than the cost estimate of \$3 to 4.5 million.

Solidification/Stabilization

Solidification/Stabilization (S/S) involves mixing a waste with binding agents, such as Portland cement, to create a slurry, paste, or other semi-liquid state, and then providing time and conditions (e.g., temperature, humidity) for the mixture to set or cure into a solid form. The S/S process may also include the addition of pH adjustment agents or other additives such as sulfur compounds. Key operating parameters for an S/S process include the type and concentration of binding agents and other additives, the proportion of stabilizing agents to waste, and the amount of time and conditions for curing.

Mechanism. S/S reduces the mobility of contaminants in a matrix through both physical and chemical means. The S/S process physically binds or encloses contaminants within a stabilized mass and chemically converts the contaminants into less soluble, mobile, or toxic forms. S/S is an established technology for treatment of heavy metals and radionuclides (for example, see the *Solidification/Stabilization Resource Guide; EPA, 1999*, and *Solidification/Stabilization Use at Superfund Sites; EPA 2000*). Depending on the type and concentration of binding agents and other additives, S/S may be able to reduce the mobility of WP, heavy metals, and radionuclides in pond material.

Available data. No data have been identified on the effectiveness of S/S for treatment of WP in ponds, and treatability testing likely would need to be performed to identify agents and additives that would be effective. For the Stauffer Management Company (SMC) Superfund site, a WP manufacturing site in Tarpon Springs, Florida, EPA selected *in situ* S/S as the remedy for pond material and contaminated soil containing WP, heavy metals, and radionuclides. While the Tarpon Springs site is similar to the EMF site in that it also was used to manufacture WP, there are many differences between these two sites; specifically, the scale of the Tarpon Springs site is much smaller and elemental phosphorus is not a primary contaminant at the Tarpon Springs site. Therefore, a direct comparison between these two sites may not be appropriate. A summary of the planned remedial activities at the Tarpon Springs site is provided in Appendix A.

At the Tarpon Springs site, a two-step process is being planned to identify a mix design for use of *in situ* S/S for pond materials (identified as CaF sludge, gray dust, and black silty sand). In the first step, S/S

agents will be identified based on available literature, past experience, material availability, and potential applicability. In the second step, laboratory testing will be performed to evaluate the effectiveness of the S/S agents. The system will be designed to operate with reagents injected into the pond materials. The Explanation of Significant Differences (ESD) for Tarpon Springs (EPA, 1999) required that S/S material achieve a minimum unconfined compressive strength (UCS) of 50 pounds per square inch (psi) and a maximum permeability of 1×10^{-5} cm/sec.

The consultant at Tarpon Springs reported that the agents to be tested might include coal combustion fly ash, Portland cement, lime products (such as quicklime, hydrated lime, and lime kiln dust), cement kiln dust, and soluble silicates. They suggested that Portland cement used in combination with silicate likely would be the “preferred means” to implement *in situ* S/S, although it had not yet been tested at that site. They reported that Portland cement is likely to be more readily available and of higher quality than other reagents at the site.

The S/S treatment planned for Tarpon Springs includes control of fugitive dust emissions and extensive ambient air monitoring. To reduce fugitive dust, the injection process likely will use water-slurried S/S reagents and subsurface mixing. (O’Brien & Gere, 2000)

The S/S test program at Tarpon Springs is expected to take place in 2003; however, a specific schedule has not yet been identified. Project managers are working with the local community to plan the testing for this site. (Madalinski, 2002a) It should be noted that the type of phosphate ore at Tarpon Springs is different from that used at EMF, with a relatively higher concentration of radium-226, and successful results from the test program at Tarpon Springs would not necessarily mean that a similar test of S/S would be successful at EMF. Table 5-1 contains a summary comparing the contaminants in the pond materials at the Tarpons Springs site to the EMF site.

Table 5-1. Comparison of Contaminants in Pond Materials

	Tarpon Springs Site	EMF Site
Primary Contaminants		
Metals/Inorganics	As, Sb, Be, Tl	As, Cd, Cr, Fl, V, Zn
Radionuclides	Ra-226	Pb-210, K-40, U-238, Gross Alpha, Gross Beta
Other	PAHs	None
Maximum Phosphorus Concentrations		
Total	Not provided	86,000 mg/kg
Elemental	0.854 mg/kg	Not provided

Note: Most Tarpon Springs pond material does not contain WP.
Sources: EPA Region 4, 1998; EPA 1998

The ROD for Tarpon Springs identified the total present worth cost for the selected remedy as \$9,356,000. It is important to note that this cost includes the *in situ* S/S process, as well as excavation, consolidation, and capping of selected contaminated soil, and institutional controls. The FS for Tarpon Springs shows a total volume of 14,795 cubic yards to be treated with S/S, at depths as great as 19 ft, with a corresponding capital cost of \$750,000 and no O&M costs. (Weston, 1996) The capital cost of \$750,000 corresponds to a calculated unit cost of \$50/CY.

Engineering considerations. At the EMF site, S/S might be applied *ex situ* or *in situ*, and for some or all of the ponds. For areas to be treated that contain WP, special precautions would be needed to address safety concerns. Pre-processing of soil and sludge may be necessary to break up larger masses, such as agglomerated WP. If used *in situ*, it may be necessary to inject chemicals through existing covers. If used *ex situ*, soil and sludge would need to be excavated, and the solid residual from treatment (stabilized mass) would need to be disposed or backfilled.

If S/S were conducted *ex situ*, the engineering considerations associated with excavation would need to be addressed. Some portion of the excavated soil would likely require storage or staging prior to S/S. The storage structure or staging area would need to include features that protect the health and safety of on-site workers and prevent the release of soil or potentially hazardous off-gasses. S/S equipment would require space for mixing and setting equipment. Soil and sludge may require crushing, grinding, milling, or other pretreatment to break up large masses of soil or slag and to homogenize the soil.

In situ S/S would reduce the health and safety hazards associated with excavation. While performing *in situ* S/S on surface soils, safety precautions similar to those used for excavation may be required.

However, *in situ* S/S at greater depths would present less of a hazard to site workers because workers would not come into direct contact with contaminated soil. However, large masses of slag or other subsurface obstructions may impede the distribution of S/S binders and reagents and prevent uniform mixing of the soil.

Bench- and pilot-scale treatability testing would be necessary to identify a mixture of S/S binding agents and additives, time, and environmental conditions, that would be effective for treating the contaminants.

For *in situ* S/S, the immobilized soil would be left in place. For *ex situ* S/S, the immobilized soil would need to be backfilled or disposed. Metals are generally less likely to leach when disposed of in a dry, high pH environment like the one found at EMF. However, some metals such as arsenic may be more likely to leach in a high pH environment.

Performance. S/S would reduce the mobility of heavy metals, thus reducing the potential for these contaminants to migrate to the groundwater. However, S/S has not been demonstrated on WP and it is difficult to estimate the anticipated level of effectiveness for pond materials without performing treatability studies. S/S changes the pH of the soil and sludge, and this could lead to an increase in the amount of phosphine gas generated. Depending on environmental conditions, there may also be concerns about the long-term performance. In addition, the heterogeneity of the pond materials may make it difficult to achieve uniform distribution of stabilizing agents throughout the ponds, due to the heterogeneous nature of the ponds. This may lead to a reduced overall effectiveness for use of S/S, especially when performed *in situ*. Data in the technical literature show that S/S can reduce the leachability of heavy metals to below the levels identified for the RCRA toxicity characteristic (TC). (EPA, 2000)

Cost. The estimated unit cost of *in situ* S/S at Tarpon Springs (\$50/CY), if applied to all of the 500,000 CY of soil and sludge at EMF, would result in a total treatment cost of \$25 million. This assumes that all pond materials are treated with *in situ* S/S using a process similar to that considered for use at Tarpon Springs. Performing *ex situ* S/S likely would result in a higher cost because of the additional efforts needed for material handling. In addition, *ex situ* S/S would involve costs for excavation of the ponds and disposal of residuals. S/S involves increasing material volume, which may lead to higher costs for

disposal. Further, should there be elevated levels of radionuclides present, the cost for landfilling treatment residues would be relatively higher.

A commonly-used source of remediation market cost information (ECHOS) reports a unit cost for *ex situ* S/S using Portland cement (Type I, bulk) of \$78/ton. For other stabilizing agents, ECHOS reports unit costs ranging from less than \$10/ton (e.g., bottom ash at \$2.11/ton, fly ash [Class F] at \$9.00/ton, cement kiln dust at \$6.50/ton, and lime at \$7.50/ton) to more than \$100/ton (e.g., Portland cement Type K at \$105/ton, sodium silicate at \$280/ton). Assuming a unit cost of \$78/ton and a density of 1.5 tons/CY (corresponding to \$117/CY), the total cost for treatment of 500,000 CY of soil and sludge would be approximately \$60 million.

Caustic Hydrolysis

Caustic hydrolysis is a chemical process where WP reacts with lime and water at elevated temperature and pressure to form various phosphite and phosphate compounds, as well as phosphine. This technology uses complex processing equipment operated by personnel with a relatively higher level of training. Key operating parameters include the amount of lime and water added, reaction pH, as well as the reactor temperature and pressure. The process is based on the chemical transformation of WP by hydrolysis, as discussed in Section 2.0. Caustic hydrolysis would reduce the concentration of WP, but depending on the pH used, may result in the generation of significant amounts of phosphine gas as a by-product.

Mechanism. Caustic hydrolysis would convert WP in soil and sludge to various phosphite and phosphate compounds, and heavy metals to metal oxides and hydroxides. The metal oxides and hydroxides generally are less soluble than the metal compounds, and could be removed by filtration or settling.

Available data. No data have been identified on the effectiveness of caustic hydrolysis for treatment of WP in ponds. However, before deciding to stop the manufacture of WP, EMF had partially constructed a Land Disposal Restrictions (LDR) waste treatment system that is based on use of caustic hydrolysis for treatment of hazardous wastes containing WP. The system was designed to respond to a Consent Decree for the RCRA LDR, and to provide for plant water storage and recycle requirements. In addition to hazardous waste streams, accumulated solids in Pond 18 (not a historical pond) had been planned to be dredged and sent to the LDR treatment facility for clarification and treatment. (Meyer, 2002)

The LDR treatment facility includes size reduction equipment, reactor feed tanks, high-pressure waste and lime feed pumps, static mixers, reactor vessels, flash separators, flash vapor condensers, treated slurry coolers, solids blowdown tanks, and pumps for blowdown and treated slurry transfer.

The LDR system consists of three reactor feed tanks operated in parallel. The feed tanks maintain a slurry temperature of 150 °F, a WP concentration of 2.15 percent, a suspended solids concentration of 18 percent, a retention time of 12 hours, and a throughput of 50 gpm. The reactor has a limitation on the maximum suspended solid diameter present in its feed, and size reduction of solids to 100 microns (pretreatment) may be needed.

The reactors are designed to operate at temperatures of up to 464 °F and pressures of up to 600 psig. Waste slurry is pressurized and fed to the reactors at a design rate of 25 gpm. Lime (20 percent slurry) is injected into the reactor feed line upstream of a static in-line mixer. High-pressure steam is injected into the lower portion of the reactor to bring the slurry temperature up to the target level. Several chemical reactions are expected to occur in the reactors, including reaction of WP with lime and water to form calcium biphosphite, calcium hypophosphite, calcium phosphate, phosphine gas, and hydrogen gas, and reaction of cyanide compounds with water to form gases such as ammonia.

Slurry material from the reactors is treated using lime for pH adjustment, and then filtered using a press. Aqueous effluent from the press is treated with hydrogen peroxide and discharged or reused, while solid residue (filter cake) is mixed with cement kiln dust to stabilize heavy metals prior to land disposal.

Gases generated in the reactors are treated using a thermal oxidizer to form a nominal 40 percent phosphoric acid product stream that is intended to be distributed as a commercial product. Additional equipment used to control air emissions includes a quench tank, quench vapor-liquid separator, particulate scrubber, and polishing filter.

According to staff in EPA Region 10, the LDR system that is partially constructed at EMF has many operational requirements (e.g., injection rates, particulate size cutoffs) that potentially could make treatment of the waste from the historic ponds infeasible. For example, the process waste planned to be treated by the LDR system would be more uniform than the waste in the historical ponds, and therefore would require little or no pre-processing prior to treatment. As of December 2001, construction of the

caustic hydrolysis system at the site was 95 percent complete, but has been halted due to the plant shut-down. (Madalinski, 2001)

Engineering considerations. Caustic hydrolysis is an *ex situ* treatment technology and engineering considerations associated with excavation would need to be addressed, including storage or staging structures that include features to protect the health and safety of on-site workers and prevent the release of soil or potentially hazardous off-gasses.

Modifications (specific activities not identified) to the existing, partially-completed caustic hydrolysis system would be required prior to it being used for treatment of historical pond material. If the existing caustic hydrolysis unit could not be used, a new unit would need to be designed and constructed, and space would need to be identified on site for the unit and associated equipment. Some of the likely modifications that would be required to the existing system in order to treat the waste from the historic ponds are described below.

Pond material may need to be pretreated, such as crushed, ground, or milled, prior to caustic hydrolysis to break up larger masses of soil or slag and homogenize the material. The caustic hydrolysis treatment process may also result in the evolution of hazardous off-gasses, such as phosphine, and off-gasses from the treatment system will likely require collection and treatment. The existing on-site caustic hydrolysis unit is designed to produce a marketable phosphoric acid product from the off-gas. Additional characterization of the historical pond materials may be necessary to determine whether a marketable product could be generated from the off-gas from treatment of these materials.

The caustic hydrolysis process would also generate a slurry of treated soil and water. The slurry would need to be dewatered, and the resulting liquid and solid waste streams further managed. The liquid waste stream would likely require pH adjustment, and may require additional treatment depending on concentrations of metals or other contaminants present. The solids from dewatering may need to be treated by S/S prior to disposal to immobilize metal contaminants.

Performance. Caustic hydrolysis is a robust technology that would be capable of treating soil and sludge that may have substantial variations in characteristics (e.g., concentrations of WP and other contaminants, moisture content), to reduce the concentration of WP and heavy metals. Given that the ponds are not well characterized, use of a robust technology like caustic hydrolysis would lead to a higher likelihood that

technology performance would be more uniform across pond materials. However, the existing system at the site was designed to handle a specific and mostly homogeneous waste stream, rather than the more complex and heterogeneous material from the historic ponds. Therefore, additional testing and analysis would be required to determine the modifications to the existing system that would be necessary to adequately treat the pond materials.

Cost. According to EPA Region 10, approximately \$120 million already has been invested in the LDR treatment plant. An additional \$13.5 million would be needed to complete plant construction, and \$12 to \$15 million would be needed for startup and testing, according to FMC. This plant was designed to receive a slurry material and to treat material from a RCRA pond (Pond 18) at the site. The cost to retrofit the plant to treat material from the historic (CERCLA) ponds would be \$30 to \$35 million – not including additional O&M costs to treat the pond material. This estimate was provided by FMC and made prior to the closing of the manufacturing facility. The constituents from the non-CERCLA and CERCLA ponds are similar although the properties of the materials likely would be different in part because the CERCLA ponds are older than the slurry materials the plant was designed to receive. (Meyer, 2002)

Chemical Oxidation

Chemical oxidation involves the addition of chemical agents to react with contaminants in the soil and sludge to form oxidized by-products. Two types of *ex situ* chemical oxidation technologies have been identified to treat WP: (1) nitric/sulfuric acid, and (2) oxygen, using a high speed air dispersion (HSAD) process. The acid oxidation technology was developed and tested by researchers at TVA on sludge containing WP. The effluent from this process was then reacted with ammonia to produce a nitrogen- and phosphate-containing plant nutrient. The HSAD technology was developed and tested by researchers at the University of Alabama on sludge from Astaris (previously FMC), TVA, and Occidental Chemical. These processes are based on the chemical transformation of WP by oxidation, as discussed in Section 2.0.

In addition, others have suggested the possibility of performing chemical oxidation *in situ*, using a flushing process (i.e., adding chemical oxidants to the pond materials, either through injection or an alternative method for distributing the oxidants). *In situ* flushing has been demonstrated at remediation

sites contaminated with a variety of chemicals, however no information was identified about its possible use for treatment of WP, and it is not discussed further in this report. (FRTR, 2002)

Mechanism. Chemical oxidation would convert WP to various phosphate compounds, however it would not reduce the concentration of heavy metals.

Available data. Available data are presented separately for the nitric/sulfuric acid and HSAD processes. *Nitric/Sulfuric Acid Oxidation:* TVA tested the nitric acid reaction process in a laboratory from 1991 to 1992, and constructed a pilot plant in 1993. For the laboratory test, a 55-gallon drum of WP sludge that contains 7.5-7.9 percent WP was collected. Approximately 1 liter of sludge per batch was mixed with acid, antifoam agent, and air in a glass vessel 90 mm ID by 122 cm height. The reactor contents were heated to between 102-110 °C, agitated with a magnetic stirrer-heater, and held at the reaction temperature for 2 hours. In the first series of tests, sludge was reacted with nitric acid (57-70 percent). These reactions reduced WP to 5.9-9.9 mg/kg, and produced orthophosphate (47-57 percent of total phosphorus), orthophosphite (43-53 percent), and large amounts of nitrogen oxide gases. The relatively large fraction of orthophosphite produced was identified as problematic, since these compounds are toxic to plants at high concentrations.

In a second series of tests, sludge was reacted with a mixture of sulfuric and nitric acids (weight ratio of sulfuric to nitric acids ranged from 1:3 to 3:2). These reactions reduced WP to 0.8-3.2 mg/kg, and produced orthophosphate (50-98 percent of the total phosphorus). These results showed that the fraction of total WP converted to orthophosphate was more than 90 percent when the sulfuric to nitric acid ratio was 1:1 or higher.

In 1992, a bench-scale facility designed to process approximately 20 liters of sludge per batch was constructed and operated. This facility had a 316 stainless steel reactor that was 66 cm diameter by 100 cm high, and was operated with an acid ratio of 1:1. The results from the bench-scale tests were similar to those from the laboratory test with WP in the reactor product ranging from 0.3-3 mg/kg, and orthophosphate making up 97-99 percent of the total phosphorus. (Edwards, 1995)

A pilot plant was constructed in 1993 that was capable of processing 380 liters of sludge per batch. TVA reported that operation of the pilot plant was successful with approximately 30,000 lbs of WP sludge converted to phosphate fertilizer. Operational concerns included sludge granulation, and the generation

of relatively large amounts of fertilizer and nitrogen oxide gases that would require further management or disposal. They reported that operation on a larger scale may not be manageable because of these concerns. TVA already had access to granulation facilities, but this could be a major concern if there were none at a site because the granulation process is difficult to carry out. Results from the pilot study were not published, and in-house data are not readily accessible. (Sherrill, 2002) Information was not provided about the cost for construction or operation of the pilot plant or current status of the plant.

HSAD: Researchers at the University of Alabama developed and tested a HSAD technology to treat sludges generated during production of WP. In this process, sludge is first treated to remove particles greater than 48 mesh. Underflow material is treated in the HSAD wet oxidation process (reactor) by sparging in air and oxygen, and agitating the sludge. Key operating parameters include oxygen and sludge concentrations, and agitation intensity. The researchers reported that as long as the sludge temperature was higher than 43°C, temperature was not a significant operating parameter. In the reactor, WP is rapidly oxidized, with the test samples generally treated in less than one hour.

Tests were conducted using 180 gram samples of filtered sludge (source of sludge not identified), oxygen concentrations of 20, 50, and 80 percent, sludge concentrations of 3.75, 7.5, and 15 percent, and agitation intensities of 4,000, 6,000, and 8,000 rpm. The sludge sample contained WP at 44,000 mg/kg (4.4 percent). Table 5-2 provides a summary of the analytical data obtained during the test of the Astaris sludge.

These results show that the concentration of WP was reduced substantially, but increased for heavy metals. The toxicity characteristic leaching procedure (TCLP) results show that treatment residuals exceed the TCLP limits for cadmium, chromium, and lead. The researchers indicated that treated solids and liquids may have to be further treated for heavy metals before release to the environment (Jefcoat, 1995). Information was not provided about the projected cost for construction or operation of a full-scale facility using this technology.

The USACE reported that other oxidants also may be effective for treatment of WP, including ozone, sodium hypochlorite, potassium permanganate, silver oxide, zinc metal, and potassium hydroxide. The USACE stated that these oxidants have not been field tested, and that the feasibility of applying these to sediments would need additional research and experimental work. (USACE, 1996)

Engineering considerations. If chemical oxidation were conducted *ex situ*, the engineering considerations associated with excavation would need to be addressed. Some portion of the excavated soil would likely need storage or staging prior to treatment, with the storage structure or staging area having features that protect the health and safety of on-site workers and prevent the release of soil or potentially hazardous off-gasses.

At the EMF site, chemical oxidation might be applied by construction of a chemical reactor and treatment using either sulfuric/nitric acid or the HSAD process. Construction of an above-ground processing system, with associated design and operational considerations, would be needed for chemical oxidation. Extensive developmental testing in a bench- or pilot-scale facility would be needed prior to construction of a full-scale treatment facility. On-site treatment would require space on site for the chemical oxidation unit and associated equipment. The nitric/sulfuric acid process involves the storage and use of strong acids, which generally need special equipment and handling procedures. Preprocessing of pond material using crushing, grinding, or milling prior to treatment to break up larger masses of soil or slag and homogenize the material may be needed for both the nitric/sulfuric acid oxidation and HSAD processes.

Table 5-2. Analytical Results from HSAD Sludge Test

Constituent	Concentration Before Treatment	Concentration After Treatment
Total Waste Analysis Results - mg/kg		
WP - from solid residue	44,000	37
WP - from supernatant solution	160	0.08
Cadmium	0.018	95
Calcium	8.54	2,290
Chloride	59.5	174
Chromium	0.006	10.0
Copper	0.013	0.34
Fluoride	112	1,750
Lead	0.312	18
Magnesium	3.99	310
Nitrate	ND	ND
Nitrite	ND	ND
Phosphate	1,116	6,440
Phosphite	1,645	2,400
Sulfate	52.9	150
Zinc	1.064	2,275
TCLP Results - mg/L		
<i>Reacted Solids</i>		
Cadmium	NR	47.0
Calcium	NR	377
Chromium	NR	3.0
Copper	NR	9.0
Lead	NR	8.0
Magnesium	NR	9.0
Zinc	NR	43.7
<i>Reacted Liquids</i>		
Cadmium	NR	67.0
Calcium	NR	77.0
Chromium	NR	12.0
Copper	NR	7.0
Lead	NR	30.0
Magnesium	NR	185
Zinc	NR	430

ND - not detected
 NR - not reported
 Source: Jefcoat, 1995

Both processes also are likely to generate hazardous off-gasses, such as phosphine, that would need to be collected and treated prior to release to the atmosphere. EPA Region 10 has also noted that the pond material also has the potential to release hydrogen cyanide at the lower pH conditions that are associated with chemical oxidation. Both processes generate a sludge residue, which would need to be dewatered, and the resulting liquid and solid waste streams further managed. The liquid waste stream from the nitric/sulfuric acid process would likely need pH adjustment and additional treatment to remove metals dissolved by the strong acids used in the process. Solid residues from the nitric/sulfuric acid process may be able to be sold for their commercial value as a fertilizer, or, if residual metal concentrations are too high, disposed of as a by-product. For both processes, S/S of solids from dewatering may be needed prior to disposal, to further treat the heavy metals present. Although there may commercial outlets for the liquid and solid waste streams generated by this treatment, it is also possible that the waste streams will be deemed to be hazardous waste and will require transport and disposal at a permitted hazardous waste disposal facility.

Performance. Analytical data available from the two chemical oxidation processes discussed above indicate that the concentration of WP in the reactor product ranged from 0.08 to 37 mg/kg, depending on process used and initial concentration. The HSAD process showed an increase in concentrations of heavy metals, with some results exceeding the TCLP, while data were not provided about the concentration of heavy metals in the reactor product from the acid treatment process. It is likely that acid treatment would also increase the concentrations of heavy metals in the reactor product due to the solubility of heavy metals in acidic conditions. Further treatment of reactor product for heavy metals likely would be necessary for using either technology.

Cost. Information was not provided about the cost for using either of these technologies on a full-scale basis to treat 500,000 CY of pond material. The costs for use of this technology would likely be higher than *ex situ* S/S (estimated as \$60 million) because of the need for additional capital equipment. Both S/S and chemical oxidation technologies require chemical reaction equipment (e.g., reactor, piping, mixing) and the chemical oxidation processes likely would have additional costs for pretreatment (e.g., size reduction), treatment of heavy metals, emission controls, and possibly for disposal of solid residues containing radionuclides.

Mechanical Aeration

Mechanical aeration is the use of physical equipment, such as a mixer, to agitate a solid or slurry material and expose the material to ambient conditions, where ambient oxygen would react with and oxidize WP. The USACE indicated that a mechanical aeration system could be used *in situ* or in a vessel (*ex situ*) to expose WP particles to oxygen. In addition to mixing rate, operational parameters that would affect performance would include the concentration of dissolved oxygen (DO), matrix effects, depth of treatment, temperature, and pH. The USACE stated that mechanical aeration has not been field tested, and that the feasibility of applying this to WP-contaminated sediments would need additional research and experimental work. They did not suggest a design for an *in situ* system. (Rivera, 1996)

Mechanism. Mechanical aeration would convert WP to various phosphate compounds, however it would not reduce the concentration of heavy metals. Aeration will also convert elemental phosphorus to phosphine or to phosphorus pentoxide.

Available data. The USACE provided a summary of research performed by Lai, and showed that use of mechanical aeration would reduce the concentration of WP in an aqueous solution from near 1,000 ug/L to less than 10 ug/L in 60 days. They also provided results from experiments that showed that mixing at 30 and 60 rpm released WP 4 and 6 times faster than without mixing, respectively. (Rivera, 1996)

Engineering considerations. At the EMF site, mechanical aeration might be applied *in situ* or *ex situ* to treat the ponds. When applied *in situ*, a mechanical aeration system likely would need some type of hydraulic or pneumatic injection and mixing equipment. When applied *ex situ*, excavation of pond materials, and construction and operation of a reactor vessel would be needed.

If mechanical aeration were conducted *ex situ*, the engineering considerations associated with excavation would need to be addressed. Some portion of the excavated soil would likely need storage or staging prior to treatment, with the storage structure or staging area having features that protect the health and safety of on-site workers and prevent the release of soil or potentially hazardous off-gasses. Aeration equipment would need space for processing equipment. Pretreatment of soil and sludge may include crushing, grinding, or milling to break up large masses of soil or slag and to homogenize the soil. Both *in situ* and *ex situ* aeration would likely generate hazardous off gasses, such as phosphine, during treatment that would need to be collected and treated. Emissions during *in situ* aeration likely would be more

difficult to control than during *ex situ* aeration because the treatment reaction would not be conducted in a controlled, engineered environment.

In situ mechanical aeration would reduce the health and safety hazards associated with excavation. However, large masses of slag or other subsurface obstructions may impede the distribution of air and prevent uniform mixing of the soil.

Bench- and pilot-scale treatability testing would be necessary to identify the processing equipment, time, and environmental conditions that would be effective for treating the contaminants.

For *in situ* treatment, the aerated soil would be left in place. For *ex situ* treatment, the aerated soil would need to be backfilled or disposed.

Performance. Information was not provided about the effectiveness of using mechanical aeration to treat soil and sludge containing WP *in situ* or in a vessel. Mechanical aeration would likely reduce the concentrations of WP particles that are exposed to oxygen, based on the results provided by the USACE. However, it is not known whether aeration would be able to reduce the concentrations of WP to below cleanup goals (which have not been established) or how well the oxygen would be distributed throughout the pond materials, given the heterogeneous nature of the ponds. Mechanical aeration would not reduce the concentrations of heavy metals in the ponds, and another treatment method, such as S/S, would be needed to treat heavy metals.

Cost. Information was not provided about the cost for using mechanical aeration technology to treat 500,000 CY of pond material. The cost for use of this technology would likely be at least as much as for use of S/S (\$25 million for *in situ*, \$60 million for *ex situ*). Both technologies require mechanical injection equipment (for chemicals or oxygen) and the mechanical aeration process likely would have additional costs for treatment of heavy metals. If used *ex situ*, there might be additional costs for disposal of solid residues containing radionuclides.

Incineration

Incineration is a thermal process where soil, sludge, or other wastes are treated at elevated temperatures (1,400 to 2,200°F) to volatilize and combust contaminants. Incinerators typically are constructed using primary and secondary combustion chambers, and use a variety of off-gas treatment equipment, including filtration, wet-scrubbing, electrostatic precipitator, baghouse, vapor-phase carbon adsorption, and thermal oxidation.

The technology is typically used for treatment of organic compounds such as hydrocarbons and to reduce waste volume, and its use for that purpose is well documented (for example, see Cost and Performance Remediation Case Studies [FRTR, 2001]). Incineration of hazardous wastes has regulatory requirements for destruction and removal efficiency (DRE) and stack emissions.

Mechanism. Incineration of excavated pond material would reduce the concentration of WP and volume of pond material. WP would be oxidized and natural organic matter in the soil and sludge would be converted to carbon dioxide and water. Oxidized WP would be captured by off-gas treatment systems such as scrubbers and treated further or discharged as a by-product. Heavy metals in the pond materials would not be oxidized, and mainly would be concentrated in the residual ash from the incinerator. More volatile heavy metals, such as arsenic, likely would be volatilized.

Available data. The U.S. Army has constructed and operated a facility to convert WP in ordnance to phosphoric acid using a rotary kiln furnace. The facility, referred to as WP to Phosphoric Acid Conversion (WP-PAC), is located at the Crane Army Ammunition Activity (CAAA), in Crane, Indiana. A pilot plant for this facility was designed by the Army at the Tooele Army Depot and operated over a 4-month period in the early 1980s, producing 2.2 million pounds of acid. The facility was subsequently moved to CAAA with the transition completed by 1990.

At the WP-PAC facility, a hole is punched in ordnance using a 115 ton hydraulic press at ambient temperature, exposing the WP in the ordnance to oxygen. The ordnance items are then pushed into the first section of a rotating kiln furnace. The heat in the furnace melts the WP, which then flows out of the punched hole. The WP is then burned in the oxygen rich furnace to form phosphorus pentoxide. The Army reported that there is complete burning of the WP in the furnace. The final section of the furnace

melts and oxidizes any remaining WP. No data were provided to identify the concentrations of WP in residual materials.

Off-gases from the furnace, containing phosphorus pentoxide, are pulled through water-jacketed ductwork into a co-flow/counterflow hydrator, at a temperature of approximately 650°C. Seventy to eighty percent of the phosphoric acid is produced in the hydrator. Product acid is filtered to remove suspended solids greater than or equal to 1 micron, and the acid is transferred to storage tanks. Exhaust gases from the hydrator flow to a variable throat venturi scrubber unit, at a temperature of approximately 140°C. The venturi has two tangential nozzles that spray dilute acid into the gas stream in the throat area, and hydrate residual phosphorus pentoxide.

As of August 1991, the facility had operated for more than 7,000 hours, and 1.5 million rounds containing 4.3 million pounds of WP had been processed to form 18 million pounds of phosphoric acid.

Environmental permitting was limited to notifying the Indiana Department of Environmental Management of an air pollution source. The Army reported that no permit was required under RCRA because the facility converts hazardous waste into a usable product (Burcham, 1991). Information was not provided about the current status of the WP-PAC facility and whether it might be available for use by commercial companies such as WP manufacturers. In addition, information was not provided about the cost for construction or operation of the WP-PAC facility.

Engineering considerations. At the EMF site, incineration might be applied to treat pond materials contaminated with WP. Construction of an on-site incinerator would involve a potentially wide range of requirements associated with siting, permitting, and operation. Use of an off-site incinerator (e.g., at a commercial treatment, storage, or disposal facility [TSDF]) would involve transportation of the pond materials to the off-site location, raising additional safety issues concerning the potential exposure of populations other than plant workers to WP. However, a discussion of off-site treatment is not within the scope of this report.

If incineration were performed at EMF, the engineering considerations associated with excavation would need to be addressed. Some portion of the excavated soil would likely need to be stored or staged prior to treatment, using structures/areas including features that protect the health and safety of on-site workers and prevent the release of soil or potentially hazardous off-gasses. Space also would be needed for incineration and off-gas treatment equipment at the site. Soil and sludge may need to be pretreated by

crushing, grinding, or milling to break up large masses of soil or slag and to homogenize the soil, however this type of pretreatment likely would be less than for other, less robust technologies. Incineration would likely generate hazardous off gasses, such as phosphine, during treatment which would need to be collected and treated.

Incineration typically requires performance of a trial burn prior to use at full-scale. A trial burn is used to test the DRE and stack emissions during treatment of one or more difficult-to-treat compounds, and is used to help determine incinerator operating conditions. Additional operational concerns include quantity of fuel needed to sustain combustion and the potential for slagging. The soil and sludge in the historical ponds have relatively low BTU values, and, when slurried during excavation, would likely have a relatively high moisture content (see discussion on excavation). Therefore, the amount of fuel required to incinerate soil with a low BTU value would need to be considered. The elevated concentrations of inorganic contaminants and minerals in the sludge and soil may result in slagging, which may be retained in the incinerator ash and reduce throughput. (EPA, 1998a)

The high temperatures used in incineration will likely cause some of the metal contaminants in the soil, such as arsenic, cadmium, polonium, and lead to volatilize or fume, resulting in metals in the incinerator off-gas. The incinerator will need to be equipped with appropriate air pollution control devices to control emissions of these toxic metals. Metal contaminants are likely also to be retained in the incinerator ash, and additional treatment of the ash, such as with S/S, may be required prior to disposal.

Performance. Incineration is a robust technology that would be capable of treating soil and sludge that may have substantial variations in characteristics (e.g., concentrations of WP and other contaminants, moisture content) to reduce the concentration of WP and heavy metals. Given that the ponds are not well characterized, use of a robust technology like incineration would lead to a higher likelihood that technology performance would be more uniform across pond materials. Data from the CAAA showed that incineration is effective in reducing the concentrations of WP in ordnance, and is likely to be similarly effective for oxidizing WP particles in sludge and soil.

Incineration may be a more likely technology for pond materials that have relatively high concentrations of WP, but low concentrations of heavy metals. Data available in the technical literature shows that incineration concentrates the mass of heavy metals, including radionuclides, in the residual ash from an incinerator. (EPA, 1998a)

Cost. The estimated unit cost for on-site incineration reported by ECHOS is \$310/ton. If applied to the 500,000 CY of soil and sludge at EMF, the total treatment cost would be approximately \$230 million. EPA's *Remediation Technology Cost Compendium-Year 2000* reported calculated unit costs for incineration of soil and sludge as ranging from \$160/ton to \$1,400/ton. Typically, there are economies-of-scale when treating relatively larger quantities and the actual cost for treating a relatively large volume may be closer to the lower end of this range. Assuming a unit cost of \$160/ton, the total cost for treatment of 500,000 CY of soil and sludge would be approximately \$120 million. As with other *ex situ* technologies, this cost would be in addition to that for performing excavation.

Thermal Desorption

Thermal desorption is used to treat soil and sludge by heating (directly or indirectly) to volatilize contaminants and separate them from the solid matrices without combustion. The temperatures used in a thermal desorber are lower than in an incinerator, generally on the order of 200°F to 600°F. The volatilized contaminants (vapors) are collected and generally are treated by one or more off-gas treatment technologies. Types of off-gas treatment include filtration, wet-scrubbing, electrostatic precipitator, baghouse, vapor-phase carbon adsorption, and thermal oxidation. Common configurations include rotary kiln, thermal screw, and infrared (with infrared treatment, soil and sludge to be treated typically are placed in a 5 CY tray [rectangular box]). The rotary kiln and thermal screw typically operate on a continuous basis, with heat applied by combustion of hydrocarbon sources, while the infrared system operates on a batch basis.

The technology is typically used for treatment of organic compounds such as hydrocarbons and to reduce waste volume, and its use for that purpose is well documented (for example, see *Cost and Performance Remediation Case Studies.*) (FRTR, 2001)

Mechanism. Thermal desorption would reduce the concentrations of WP through volatilization, and WP vapors could be recovered by treatment of the off gases. Thermal desorption would not reduce the concentrations of heavy metals in the ponds.

Available data. The USACE reported that a patented infrared system, operating on a batch basis, was used to treat 300 tons of WP-contaminated soil in Ogden, Utah at a cost of \$80,000 (\$267/ton). The treatment system was provided by McLaren-Hart Environmental Engineering Corporation; however, the

source of the WP-contaminated soil and the period of operation for the treatment was not provided. Operational parameters included a soil treatment temperature of 260°F, an average treatment time of 1 hr 40 minutes, treatment of 107 soil batches (nominally 5 CY each), and a total treatment time of 4 days. The USACE reported that one instance of auto-ignition of WP was detected inside the desorber and that the condition was controlled (control method not identified). Information was not provided about the concentrations of WP or other contaminants in the soil before or after treatment, or about the disposition of treatment residuals. (USACE, 1996)

Recent attempts to contact McLaren-Hart revealed that the company was sold to ENSR. ENSR personnel were not familiar with the current availability of the infrared desorption unit. (Stewart, 2001)

Engineering considerations. Thermal desorption is an *ex situ* technology and the engineering considerations associated with excavation would need to be addressed. Some portion of the excavated soil would likely need to be stored or staged prior to treatment with the structure/area needing to include features that protect the health and safety of on-site workers and prevent the release of soil or potentially hazardous off-gasses. Space for thermal desorption and off-gas treatment equipment would be needed at the site. Pretreatment of soil and sludge including crushing, grinding, or milling may be needed to break up large masses of soil or slag and to homogenize the material.

Operational concerns include quantity of fuel needed to sustain desorption and possible fire or explosion hazards. The soil and sludge in the historical ponds have relatively low BTU values, and, when slurried during excavation, would likely have a relatively high moisture content (see discussion on excavation). Therefore, thermal desorption would likely require a significant consumption of fuel in order to reach and maintain treatment temperatures. Hot spots of WP contamination may present a fire or explosion hazard if it spontaneously ignites during the thermal desorption process.

Thermal desorption temperatures generally do not cause metals to volatilize or fume. Therefore, metal contamination in the off-gas will likely not occur. However, thermal desorption off-gasses may contain hazardous chemicals, such as phosphine, and require collection and treatment. Thermal desorption does not treat metals, and these will be retained in the solid residue from desorption. S/S or other treatment of solid residues may be needed prior to disposal.

Performance. Information was not provided about the effectiveness of using thermal desorption to treat WP. This technology would likely reduce the concentrations of WP through volatilization, and that WP vapors could then be recovered through off gas treatment. Thermal desorption generally does not reduce the concentrations of heavy metals in soil or sludge (at higher temperatures it may reduce the concentration of some more volatile metals).

Cost. The estimated unit cost reported by the USACE is \$267/ton. If applied to the 500,000 CY of soil and sludge at EMF, the total treatment cost would be approximately \$200 million. ECHOS reports that the cost for thermal desorption ranges from \$24 to \$97 per ton treated, corresponding to a projected total cost ranging from \$18 to \$73 million for treatment of 500,000 CY of soil and sludge. EPA's *Remediation Technology Cost Compendium-Year 2000* reported calculated unit costs for treatment of more than 100,000 tons of soil as less than \$50/ton, within the range provided by ECHOS. Using a unit cost of \$50/ton for the 500,000 CY of soil and sludge at the EMF site, the total treatment cost would be approximately \$38 million. These cost estimates are only for the use of thermal desorption and do not include the costs for excavation of soil and sludge, or for disposal of treated materials.

6.0 SUMMARY AND DISCUSSION OF FINDINGS

A summary and review of available information from the technical literature and previous studies was conducted to identify potentially applicable treatment technologies for soil and sludge in the historical ponds contaminated with WP, heavy metals, and radionuclides at the EMF Superfund site. No testing of treatment technologies (e.g., in a laboratory or at a pilot-scale) was performed for this report.

Limited information was available to characterize the historical ponds. For this report, several assumptions were made about pond characteristics based on what is known about the ponds and experience with site cleanups. The portions of the historical ponds not covered by RCRA ponds cover a total area of approximately 16 acres and extend to a depth of 20 ft; contain approximately 500,000 cubic yards of soil and sludge; are contaminated with WP, heavy metals, and radionuclides (radionuclides are expected to behave in a manner similar to heavy metals relative to treatment); and are heterogeneous in physical and chemical composition. WP in the historical ponds at EMF would likely remain in the pond soil and sludge as WP or as a solid metal phosphate. WP would not exhibit substantial oxidation or hydrolysis, which are the major degradation processes for WP, nor likely be transported from the ponds.

Specific factors used to evaluate each technology were based on (1) the mechanism by which the technology would treat WP, heavy metals, and radionuclides; (2) available data about where the technology previously has been used or work conducted at similar sites; (3) engineering considerations, such as material handling, pretreatment, residual management, and health and safety; (4) technology performance data, in terms of reducing the concentration, volume, or mobility of WP, heavy metals, and radionuclides; and (5) cost to implement the technology.

The following technologies were identified as potentially applicable:

- S/S
- Caustic Hydrolysis
- Chemical Oxidation
- Mechanical Aeration
- Incineration
- Thermal Desorption

None of the six technologies has been used at full-scale to treat waste material similar to that found at EMF. Only limited information about remediation of WP is provided in the available literature with fewer than 10 studies identified about the use of treatment technologies for WP. This primarily includes studies performed at WP manufacturing facilities and at military facilities. The six technologies were identified in the EMF Feasibility Study (FS) report prepared in 1996. That is, no new treatment technologies have emerged as potentially applicable to treat the historical ponds since the FS report.

The remedy used for similar waste at other WP manufacturing facilities was primarily capping. Eight other WP manufacturing sites were identified that have similar contaminated unlined ponds as the EMF site. Six of the eight sites have installed or plan to install caps. Of the remaining two sites, one site (Rhodia, Silver Bow, Montana) indicated that the ponds are not under corrective action, and another site (Stauffer Management Company, Tarpon Springs, Florida) is evaluating a remedy of *in situ* S/S.

From information currently available, minimal performance data exists for using the six technologies to treat similar waste material as found at EMF. Performance data were identified for treatment of WP using chemical oxidation, mechanical aeration, and incineration. However, these data are not for treatment of wastes in historical ponds at a WP manufacturing facility. Performance data for chemical oxidation and mechanical aeration are for work at bench- and pilot-scale, while data for incineration are for ordnance wastes with a higher percentage of WP than found in the historical ponds.

Thermal desorption was used for the treatment of WP in contaminated soil. Recent attempts to obtain specific information on the project revealed that the technology vendor was sold to another company. Personnel at this company were not familiar with the current availability of the technology. Therefore, it is unknown if the WP-contaminated soil was similar to waste material as found at EMF and no specific performance data were available for review.

No performance data were identified for treatment of WP using S/S and caustic hydrolysis. Both technologies have been under consideration to treat similar waste material at WP manufacturing sites. The Stauffer site in Tarpon Springs, Florida is planning to test *in situ* S/S in 2003. The test program involves identifying S/S agents and evaluating the effectiveness of the S/S agents through laboratory testing. Although the information gained from this test program could be used to evaluate the effectiveness of S/S at EMF, the test program at Tarpon Springs may not be an accurate predictor. The type of phosphate ore used at Tarpon Springs is different from that used at EMF (e.g., concentration of

the contaminant radium-226 being relatively higher and concentrations of WP being relatively lower at the Tarpon Springs site). Therefore, the results from the test program at Tarpon Springs would not necessarily mean similar results at EMF. A summary of the Stauffer site is included as Appendix A. Caustic hydrolysis was considered for use at the Rhodia site in Silver Bow (Butte), Montana. In addition, caustic hydrolysis was identified as the Land Disposal Restrictions treatment technology for process wastes at EMF, but construction of this technology was halted with the plant shutdown.

Additional testing would be necessary to assess whether treatment technologies could perform adequately across a range of contaminant concentrations and properties of the waste material. Extensive site assessment and treatability testing would be needed to verify the potential for any technology to treat the substantial physical and chemical heterogeneity of the ponds at EMF. Treatability tests would include evaluating how the technology would perform for the specific matrices in the different ponds, and the variations in performance across the range of concentrations and physical properties.

Although the six technologies are at various stages of commercial development, all of these technologies would require testing to establish that they could perform reliably on the waste material in the historical ponds. S/S, chemical oxidation, incineration, and thermal desorption have been applied commercially at full-scale for site remediation, but have not been used to treat WP pond material. Caustic hydrolysis and mechanical aeration have not been used extensively for site remediation, and significant developmental testing would be entailed for scale-up along with the treatability testing identified above. Developmental and treatability testing for the six technologies would require additional time and resources to undertake.

The soil and sludge in the historical ponds contain multiple types of contaminants which all may require treatment. Therefore, a series of technologies may be necessary to collectively treat all the types of contaminants. However, incineration, thermal desorption, mechanical aeration, and chemical oxidation would not be able to treat heavy metals or radionuclides. In these cases, an additional treatment process would likely be needed, such as S/S, using what is often referred to as a “treatment train”.

Of the six technologies, only S/S and caustic hydrolysis have the potential to be effective for treatment of heavy metals and radionuclides. S/S is applied frequently at full-scale to reduce the mobility of heavy metals at contaminated sites. Caustic hydrolysis would convert heavy metals to metal oxides and hydroxides, which generally are less soluble than the metal compounds, and could be removed by filtration or settling processes.

In applying any of the six technologies to treat the historical ponds at EMF, there are several cross-technology considerations. Soil and sludge may require preprocessing such as crushing, grinding, or milling, to break up large masses of soil and sludge and to homogenize the soil. Preprocessing may be necessary for both *ex situ* and *in situ* technologies, depending on the distribution of contaminants in the ponds and the methods used to implement the treatment technologies. Residuals from treatment, such as solid, liquid, or gaseous residues, would require further management. Residuals management may include characterizing and transporting these residuals to a storage or disposal facility (on- or off-site), or performing further treatment (such as for off gases) prior to release to the environment, which could significantly increase overall treatment costs.

The estimated volume of waste material to treat (500,000 cubic yards) would entail a large construction project, including significant engineering issues. The physical layout of the site, where historical ponds are located near RCRA ponds, structures, and slag piles, may impact the implementation of a treatment technology, including the need for space to stage equipment or to store material before or after treatment.

WP is an inorganic compound that ignites spontaneously in warm air. It is toxic by ingestion and inhalation and skin contact with WP causes burns. Therefore, site workers would need to follow stringent health and safety precautions about handling soil or sludge containing WP. Level C personal protective equipment (respiratory and skin contact protection) would likely need to be used when conducting work on the soil or sludge in the historical ponds. In addition, health and safety precautions related to metals and radionuclides would also have to be considered.

Based on the criteria used to identify high cost projects by EPA's National Remedy Review Board (NRRB), the specific costs to implement any of the six treatment technologies would be high. The NRRB identifies high cost remedial actions as those that cost more than \$30 million or more than \$10 million and 50 percent greater in cost than the least costly cleanup alternative. The estimated treatment costs for the six technologies identified range from \$25 to \$230 million per technology, depending on type of technology and whether it is performed *ex situ* or *in situ*, as well as the assumptions presented in Section 4.

The level of uncertainty for the cost estimates provided in this report to implement the six technologies at the EMF site is high. The estimates presented in this report represent a range of possible costs for the treatment of the EMF waste. This range is highly dependent on the assumptions used to characterize the

historical ponds and the specific design and operating conditions used for implementing the technology. It should be noted that the review of historical cost data of technology applications indicate costs are highly variable, impacted by many factors, and that those factors are site-specific.

Although the technology cost estimates in this report could be above or below the actual costs, the actual total treatment costs are likely to be higher. Specifically, the technology costs estimates do not include costs for associated project components, such as excavation (if required), preprocessing of waste material, health and safety (such as ambient gas control), and residual management, which could be integral parts of a remediation project at the EMF site using any of the six technologies. For example, all the *ex situ* technologies would incur costs for excavation, preprocessing of contaminated material, and disposal of treatment residuals. Costs for associated components, such as excavation, preprocessing of waste material, health and safety, and residual management likely would add 15 to 75 percent to the cost of treatment using any of the six technologies. This estimate for the associated costs is based on specific assumptions, including that the waste material will be able to be handled as a bulk solid rather than as a slurry and that the residual material and treated soil generated during treatment will be able to be managed on-site at the EMF site rather than requiring off-site disposal. If these assumptions are determined not to be reasonable after further site characterization or treatability testing, estimates of total project costs could increase significantly. For example, material handling costs could be increased by a factor of 10 if the waste material must be handled as slurries or disposal costs of residuals could increase substantially if off-site disposal is required. In addition to these cost factors, off-site disposal of waste or residuals from treatment at the EMF site may be challenging due to the relatively few disposal sites that likely would take this waste.

7.0 REFERENCES

- ATSDR. 1997. Toxicological Profile For White Phosphorus. Prepared by Sciences International, Inc. under subcontract to Research Triangle Institute, Under Contract No. 205-93-0606. September.
- Brannen, John V., Organic Solutions, 2001. Fax to Susan Stewart, Tetra Tech EM Inc. Information About Remediation Plus. October 8.
- Burcham, Randall W., Crane Army Ammunition Plant. 1991. White Phosphorus to Phosphoric Acid Conversion Facility, Presented at the International Seminar on Demilitarization Technology for Explosives and Explosives Ordnance. November.
- Collins, Charles M., USACE-CRREL. 1999. Remediation of a White Phosphorus Contaminated Salt Marsh, Eagle River Flats, Alaska, Alaska Section, American Water Resources Association, Northern Abstract for Brown Bag. February.
- Edwards, Ronald E., Jack M. Sullivan, and Oscar E. Moore, TVA. 1995. Recovery of Phosphates from Elemental Phosphorus-Bearing Wastes. American Chemical Society. Environmental Research Center, Tennessee Valley Authority.
- Environmental Cost Handling Options and Solutions (ECHOS). 2002. RS Means Environmental Remediation Cost Data - Unit Price, 8th Annual Edition.
- EPA. 2002. Memorandum from Michael F. Gearheard, Director, Office of Environmental Cleanup, EPA, Region 10 to Walter W. Kovalick, Jr., Ph.D., Director, Technology Innovation Office, EPA Office of Solid Waste and Emergency Response, regarding Region 10 Comments on the Draft Report of 4/30/2002 to Evaluate "Treatment Technologies for Historical Ponds Containing Elemental Phosphorus - Summary and Evaluation". July 2.
- EPA. 2001. Remediation Technology Cost Compendium - Year 2000. EPA 542-R-01-009. September.
- EPA. 1998. Superfund Record of Decision for EMF Contamination, Pocatello, Idaho. EPA 541-R-98-034. June.
- EPA. 1998a. On-Site Incineration: Overview of Superfund Operating Experience. EPA 542-R-97-012. March.
- EPA REACH IT. 2002. EPA Remediation and Characterization Innovative Technologies Web Site. www.epareachit.org. February.
- FMC. 2001. LDR Waste Treatment System Engineering Package Update. September.
- FMC. 1996. Remedial Investigation for EMF Site. August.
- FMC. 1996. Feasibility Study for EMF Site. August.
- FMC. 1997a. FMC letter to EPA, Information Responding to EPA and Tribal Comments on Pond 8S Closure Plan, Attachment A - Fate of Phosphorus in Phossey Waste Pond Solids, FMC, Pocatello.

- FMC. 1997b. FMC letter to EPA, Information Responding to EPA and Tribal Comments on Pond 8S Closure Plan, Attachment B - Summary of Evaluation of Alternatives for Soils/Solids Excavation, Ex-Situ Treatment, and In-Situ Treatment.
- FRTR. 2001. Screening Matrix and Reference Guide. 3rd Edition. Federal Remediation Technologies Roundtable. Available on line at www.frtr.gov/matrix2/. December 4.
- FRTR. 2001a. Cost and Performance Remediation Case Studies and Related Information. Second Edition. EPA 542-C-01-003. May.
- Hunter, Craig, Tetra Tech EM Inc., 2001. Summary of Meeting with Wallace Reid, U.S..EPA Region 10. October 28.
- Jefcoat, Irvin A., and Sundeep Potluri, Univ. of Alabama. 1995. "Removal of Elemental Phosphorus from Electric Furnace Sludges of Various Origins." *Environmental Progress*, Vol. 14, No. 2. May.
- Lindeburg, Michael R., P.E., 1986. *Civil Engineering Reference Manual*, Fourth Edition. Professional Publications, Inc., San Carlos CA.
- Madalinski, Kelly, EPA/TIO. 2002. Personal Communications with Wallace Reid and Linda Meyer, EPA/Region 10. January.
- Madalinski, Kelly, EPA/TIO. 2002a. Personal Communications with Nestor Young, EPA/Region 4. January.
- Madalinski, Kelly, EPA/TIO. 2001. Personal Communications with Wallace Reid, Linda Meyer, Nick Ceto, EPA/Region 10. December
- Madalinski, Kelly, EPA/TIO. 2001a. Personal Communications with Trudy Olin and Steve Pranger, USACE-WES. July.
- Madalinski, Kelly, EPA/TIO. 2001b. Personal Communications with Dennis Teefy and Wayne Sisk, USAEC. July.
- Madalinski, Kelly, EPA/TIO. 2001c. Personal Communications with John Austin, Bill Kline, and Steve Hoffman, EPA/OSW. September-October.
- Mathews, Joseph B., Olin Corp., and Irvin A. Jefcoat, Univ. of Alabama. 1997. "Isothermal Oxidation of White Phosphorus Dispersed in Water in a Stirred-Tank Reactor". *Journal of the Air and Waste Management Association*, Vol. 47:1103-1110. October.
- Meyer, Linda, EPA Region 10. 2002. E-mail to Kelly Madalinski, EPA/TIO, Regarding LDR System Questions. March 22.
- Meyer, Linda, EPA Region 10. 1998. Review of Pond 8S Closure Plan, Volume 1 and 2, FMC Corporation. January.
- O'Brien & Gere Engineers, Inc. 2000. Solidification/Stabilization Treatability Studies Work Plan, Stauffer Management Company, Tarpon Springs, Florida. December.

- Rivera, Yilda B., Trudy Olin, and Mark R. Brika, USACE, Waterways Experiment Station. 1996. Summary and Evaluation for White Phosphorus Remediation: A Literature Review, Technical Report IRRP-96-7. October.
- RSMMeans. 2002. Heavy Construction Cost Data, 16th Edition.
- Sherrill, Mary, Tetra Tech EM Inc. 2002. Telecon with Ronald E. Edwards, TVA, Information About Oxidation Process Used at TVA. February 8.
- Spangord, Ronald J., Rewick, Robert, U.S. Army, et al. 1985. Environmental Fate of White Phosphorus/Felt and Red Phosphorus/Butyl Rubber Military Screening Smokes.
- Stewart, Susan, Tetra Tech EM Inc. 2001. Telecon with Hassan Armeni, McLaren Hart/ENSR, Information About Infrared LTTD. October 18.
- Stewart, Susan, Tetra Tech EM Inc. 2001a. Telecon with John V. Brannen, Organic Solutions. Information About Remediation Plus. September 27.
- U.S. Army Center for Health Promotion and Preventive Medicine. 2001. Detailed Facts About White Phosphorus. Available on line at www.apgea.army.mil/dts/docs/detwp.pdf. November
- U.S. Army Material Command Regulation 385-103. 1965. Safety Guide for the Processing, Handling, and Decontamination of White Phosphorus. December.
- U.S. Department of Defense, Virtual Naval Hospital. 2001. "Chemical Burns and White Phosphorus Injury". Emergency War Surgery NATO Handbook, Chapter III: Burn Injury. <http://www.vnh.org/EWSurg/ch03/03ChemicalBurns.html>. Searched December.
- Walsh, Michael R., Marianne E. Walsh, and Charles M. Collins. 2000. "Method for Attenuation of White Phosphorus Contamination in Wetlands". Journal of Environmental Engineering. November.
- Walsh, Michael R., Walsh, Marianne E., Collins, Charles M., USACE-CRREL. 1999. "Enhanced Natural Remediation of White-Phosphorus Contaminated Wetlands Through Controlled Pond Draining" CRREL Report 99-10. November.
- Walsh, Michael R., Walsh, Marianne E., Collins, Charles M., USACE-CRREL. 1999. "Remediation Methods for White Phosphorus Contamination in a Coastal Salt Marsh". Environmental Conservation. 26 (2): 112-124

ADDITIONAL SOURCES OF INFORMATION

- ATSDR. 1997. White Phosphorus, CAS #7723-14-0, Fact Sheet. September.
- ATSDR. 1997. Public Health Statement for White Phosphorus. September.
- Bersanti, Dan, Plant Manager, Rhodia, Inc. 2001. Waste Plan - Volumes I and II. Rhodia Silver Bow Plant, Butte, Montana, November.
- Chem Expo. 1997. "Phosphorus- Chemical Profile."
<<http://www.chemexpo.com/news/PROFILEjan20.cfm>>
- Darling, Marie, USACE-CRREL. 2001. CRREL, Army Clean Up Contaminated Alaskan Marsh, Engineer Update, Army Internet Site. Searched October.
- EPA. 2000. Solidification/Stabilization Use at Superfund Sites. EPA 542-R-00-010. September.
- EPA. 1999. Solidification/Stabilization Resource Guide. EPA 542-B-99-002.
- EPA. 1998. Record of Decision for Stauffer Chemical Tarpon Springs Site, Tarpon Springs, Pinellas County, Florida. July.
- EPA. 1997. Elemental Phosphorus Facilities Operating in the U.S. in 1980 Using Electric Arc Furnace Method.
- EPA. 1996. Technology Screening Guide for Radioactively Contaminated Sites. EPA 402-R-96-017. November. <http://www.epa.gov/superfund/resources/radiation/pdf/techguide.pdf>
- Environmental Yellow Pages 2001 - Phosphorus. October.
<<http://www.enviroyellowpages.com/chemicals/elementphosphorus.htm>>
- Henderson, Scott. 1997. Telecon with Ed Greutert about Albright-Wilson Phosphorus Facility Closure. November.
- Nam, Sae-Im, Walsh, Michael R., Collins, Charles M., USACE-CRREL. 1999. Eagle River Flats Remediation Project, Comprehensive Bibliography-1950-1998, Special Report 99-13. August.
- Racine, Charles H., Walsh, Marianne E., et al. 1992. Waterfowl Mortality in Eagle River Flats, Alaska. The Role of Munitions Residues, CRREL Report, 92-5. May.
- Racine, Charles H., Walsh, Marianne E., USACE, CRREL, et al. 1993. White Phosphorus Contamination of Salt Marsh Pond Sediments at Eagle River Flats, Alaska, CRREL Report.
- Roy F. Weston, Inc. 1996. Stauffer Management Company, Tarpon Springs, Florida Site, Final Feasibility Study Report. January.
- Van Wazer, John R., Monsanto Company. 1972. "Phosphorus and the Phosphides". Kirk-Othmer Encyclopedia of Chemical Technology, 2nd Edition, Volume 15.

- Walsh, Michael R. and Collins, Charles M., USACE-CRREL. 1998. Dredging as Remediation for White-Phosphorus Contamination at Eagle River Flats, Alaska, CRREL Report 98-5. August.
- Walsh, Michael R., Walsh, Marianne E., Collins, Charles M. 1997. "Method for Attenuation of White Phosphorus Contamination in Wetlands", Journal of Environmental Engineering.
- Walsh, Michael R., Chamberlain, Edwin J., Henry, Karen S., Garfield, Donald E., Sorenson, Ed, USACE-CRREL. 1996. "Dredging in an Active Artillery Impact Area, Eagle River Flats, Alaska" Special Report, 96-22.
- Walsh, Marianne E., Collins, Charles M., Racine, Charles H., USACE-CRREL. 1996. "Persistence of White Phosphorus Particles in Salt Marsh Sediments". Environmental Toxicology and Chemistry. Volume 15, No. 6.
- Walsh, Marianne E., Taylor, Susan. 1996. Development of an Analytical Method for White Phosphorus (P4) in Water and Sediment Using Solid Phase Microextraction, Special Report 96-16.
- Walsh, Marianne E., Collins, Charles M. 1995. Persistence of White Phosphorus Particles in Sediment, CRREL Report 95-23.
- Walsh, Marianne E., USACE, CRREL. 1995. Analytical Method for White Phosphorus in Water, Environmental Contamination and Toxicology.
- Walsh, Marianne E., Taylor, Susan. 1993. "Analytical Method for White Phosphorus Residues in Munitions-Contaminated Sediments". Analytica, Chimica Acta, 282.
- Walsh, Michael R., USACE-CRREL. Not dated. Dredging Contaminated Sediments at an Active Impact Range: an Ordnance Avoidance Success. Army Internet Site. <http://hnd.usace.army.mil/oew/news/dredge.html>. Searched October 2001.

APPENDIX A

SUMMARY OF STAUFFER CHEMICAL COMPANY, TARPON SPRING, FL Planned Remediation of Unlined Ponds Using *in situ* Solidification/Stabilization

Site Background

The 130 acre Stauffer Chemical Company plant in Tarpon Springs, Pinellas County, Florida, produced elemental phosphorus using an electric arc furnace process from 1947 until it shut down in 1981. Stauffer Chemical Company purchased the plant from Victor Chemical Company in 1960. (EPA, 1999) and the plant was decommissioned and dismantled in 1983. The divestiture of the Stauffer Chemical Company in 1987 resulted in the formation of the Stauffer Management Company (SMC). The SMC site was listed on the National Priorities List (NPL) in 1994. (Weston, 1996)

The plant is located on the Anclote River which flows into the Gulf of Mexico. The plant site layout consists of a former phosphate processing area, former elemental phosphorus production facilities, and administrative buildings. Land use in the surrounding locality includes light industry, commercial establishments, and residential properties along with some undeveloped land. (Weston, 1996)

Approximately 10,000 people live within one mile of SMC. (EPA, 1999)

Approximately 300,000 cubic yards of soil, pond sediments, and slag at the SMC plant is contaminated with radionuclides, metals, and elemental phosphorus. (EPA, 1999) Subsurface soil samples collected during the remedial investigation detected arsenic, lead, fluoride, and total phosphorus as well as the radiological components of gross alpha, gross beta, radium-226, radon-222, and polonium-210 in the subsurface soil. The results from surface soil sampling indicated that the surface soil is primarily contaminated with radionuclides found in the uranium decay chain, such as radium-226. Surface soil sampling also detected other chemical contaminants including arsenic, antimony, beryllium, cadmium, chromium, thallium, PAHs, and fluoride. Elemental phosphorus has not been found in any locations other than in pond material on the site.

Groundwater sampling identified elevated levels of inorganics and radionuclides in the surficial aquifer and deeper Floridian aquifer. Samples taken from private wells in the Tarpon Springs area detected contaminants at concentrations below their maximum contaminant levels (MCLs). Surface water and

sediment samples taken from the Anclote River and the Myers Cove area located directly adjacent to the site did not contain site-related contamination above background levels.

Seventeen unlined waste ponds containing process wastes are located in the phosphate processing area. These ponds no longer contain water but still contain waste material that was disposed after elemental phosphorus production. In some locations, the waste material extends to depths below the groundwater table. Results from approximately 150 borings indicate the extent of contamination in the pond material extends as deep as 19 ft below ground surface. Elemental phosphorus contamination was found in the ponds at depths up to 15 feet below ground surface. Radiological levels detected in the ponds exceed residential and commercial use standards. Table A-1 shows the maximum concentrations of the contaminants that were detected in samples of the pond materials, as well as the site cleanup standard for each contaminant. (EPA, 1999)

Table A-1. Contaminants of Concern and Corresponding Concentrations at SMC (EPA, 1999)

Contaminant	Maximum Detected Concentration	Cleanup Standard
Arsenic	205 mg/L	21.1 mg/L
Antimony	52.0 mg/L	28.1 mg/L
Beryllium	2.0 mg/L	120 mg/L
Elemental Phosphorus	0.854 mg/L	1.4 mg/L
Thallium	37.0 mg/L	1.4 mg/L
Radium-226	34.0 pCi/g	5 pCi/g
Radium-226 Dose	35 uR/hr	20 uR/hr

A baseline risk assessment for the SMC site indicates that the primary exposure pathways for chemical contaminants at the site are inhalation, ingestion, and dermal contact with contaminated soil and slag. The exposure pathways for radiological contaminants on the site are incidental ingestion of soil, ingestion of vegetation grown on contaminated soil, direct irradiation by contaminated soil, inhalation of radon, incidental ingestion of sediment, ingestion of groundwater, or irradiation by roadbed material.

Results from the risk assessment show that on-site maintenance workers could potentially be exposed to site-related contaminants in surface soil or fugitive dust emissions during landscaping, mowing, and other outdoor activities. The risk assessment also modeled the air pathway from the site to determine if nearby residents are at risk for exposure to contaminated air particulates. The results show that fugitive dust is not an exposure pathway for particulate emissions to the surrounding community.

The risk assessment determined that current off-site residents may potentially be exposed to site-related contaminants present in surface water and sediment via fishing and/or swimming in the Anclote river. The river is classified as suitable for fishing and swimming and is the receptor of groundwater from the site. The risk assessment also determined that exposure pathways for future on-site residents are incidental ingestion and dermal contact of contaminated soil as well as ingestion of drinking water from local groundwater wells.

Environmental Setting

Hydrogeology

Two aquifers, a surficial aquifer and the Floridian aquifer, lie beneath Pinellas County and SMC. Overall groundwater flow is to the southwest toward the Anclote River. The depth to the surficial aquifer is approximately 8 feet and is separated from the Floridian aquifer by a semi-confining bed of clay. (EPA, 1999) The water table rises and falls within the surficial aquifer with influence from precipitation, tidal changes, and changes in atmospheric pressure. (EPA, 1998). The Floridian aquifer is composed of a thick sequence of carbonate rocks which are connected to one another. (Weston, 1996) The depth to the Floridian aquifer ranges from 17 to 37 feet below the surface. (EPA, 1999) This aquifer provides most of the public water supply for Pinellas County. (Weston, 1996)

Geology

SMC is located on the Gulf Coastal Lowland Physiographic Province. This province is made up of unconsolidated fine sand with interbeds of clay and marl, fossiliferous limestone and dolomite, and gypsiferous limestone and dolomite. The carbonate rocks that underlie Pinellas County range in thickness from 10,000 to 12,000 feet and form a Peninsular Arch which trends in the northwest direction. This arch is the dominant surface substructure in southwest Florida. (EPA, 1998)

Surficial sand and the Hawthorn Formation are the two distinct stratigraphic units that are exposed in Pinellas County. The surficial sand consists of a thin veneer of fine sand with clay, marl, and phosphorite interbeds. The Hawthorne Formation is thicker and consists of variable strata of a calcareous sand and a sandy clay containing black phosphate nodules and chert. (EPA, 1998)

Remedy Selection and Status of Unlined Ponds

Over the past 15 years, numerous studies have been conducted at SMC in efforts to delineate the nature and extent of contamination at the site. Table 2 provides a chronology of these studies with a brief description of each study, year the work was completed, and the firm that completed the work. (EPA, 1999)

In 1998, U.S. EPA signed a Record of Decision (ROD) that outlines remediation efforts for the pond sediments, contaminated soil below the water table, and in the on-site consolidation areas at SMC. These efforts include *in situ* solidification/stabilization (S/S) of contaminated soils below the water table, excavation of contaminated soils, consolidation and capping of contaminated soils over the material treated by *in situ* S/S, and enforcement of institutional controls to prohibit residential use of the property.

In situ S/S would be performed on the unlined pond material at SMC by injecting and mixing binding agents into the saturated pond material to form a solid, low permeability mix. The Final Feasibility Study Report indicates a total volume of 15,000 cubic yards of pond material would be treated by S/S at depths as great as 19 feet. In December 2000, a S/S work plan was prepared that summarizes the methodology that will be used to determine the best approach to conducting S/S. An Explanation of Significant Differences (ESD) incorporated into the 1998 ROD requires that S/S material achieve a minimum unconfined compressive strength (UCS) of 50 pounds per square inch and a maximum permeability of 1×10^{-5} cm/sec. Coal combustion fly ash, Portland cement, lime products (such as quicklime, hydrated lime, and lime kiln dust), cement kiln dust, and soluble silicates will be evaluated to determine which is the best S/S agent. In addition to the use of S/S for pond sediments and contaminated soil, extensive ambient air monitoring will also be implemented. To reduce fugitive dust, the injection process likely will use water-slurried S/S reagents and subsurface mixing. (O'Brien & Gere, 2000) The S/S test program at SMC is expected to take place in 2003; however, a specific schedule has not yet been identified. (Madalinski, 2002)

Remedial Cost

The ROD (EPA, 1998) for the SMC site identified that the total present worth cost for the selected remedy is \$9,356,000. This cost includes the S/S process, as well as excavation, consolidation, and capping of selected contaminated soil, and institutional controls. The treatment of the pond material was

estimated to cost \$750,000 for 15,000 cubic yards, corresponding to a calculated unit cost of \$50 per cubic yard. (Weston, 1996) Further remedial cost estimates for the site are currently being developed by the Corps of Engineers.

**Table A-2. Past Studies at Tarpon Springs Site
(EPA, 1999)**

Type of Study	Conducted by	Year	Description
Hydrogeologic Assessment	Seaburn and Robertson, Inc.	1987	Study the hydrogeologic characteristics of the surficial and Floridian aquifers at the site
Final Expanded Site Investigation	NUS, Inc.	1989	Evaluate surface soils, groundwater, subsurface soils, groundwater in surficial and Floridian aquifers, surface water in the Anclote River
Interim Final Listing Site Inspection	NUS, Inc.	1991	Evaluate surface soils at school nearby, re-sample groundwater, collect sediment samples from Anclote River
Radiological Studies	PBS&J	1990	Conducted external gamma radiation surveys of roadways, ponds
Site Sampling Program	Weston	1989-90	Soil and pond sampling
Environmental Sampling Program	Weston	1991	Characterize soil and disposal pond materials
Sediment Sampling Program	Weston	1991	Collected 13 sediment samples from the Anclote River
Elemental Phosphorus Borings Program	Weston	1991	Collected samples from 47 phosphorus soil borings
Treatability Study - Bench Scale Oxidation Study	Weston	1991	Evaluate performance of various oxidizers in treating elemental phosphorus
Chemical Oxidation of Phosphorus Study	unknown	unknown	Determine feasibility of oxidizing elemental phosphorus clarifier using Nitric Acid
Phosphorus Recovery, Bench Scale, and Treatability Testing Studies	unknown	unknown	Determine if elemental phosphorus can be recovered, separated from other materials and effectively treated on-site. Excavation and treatment difficult.
Treatability Study-Solidification/Stabilization Study of Pond Wastes	Weston	1991	Evaluated various stabilization mixes to see which would meet strength and economic feasibility requirements
Soil Depth Cover Study	Weston	1994	Recommended 24 inch soil cover to minimize gamma radiation dose
Soil/Slag Leachability Study	Parsons Engineering	1997	Determined that contaminants leaching from soil and slag in the slag field are minimal
Asbestos Sampling	Parsons Engineering	1998	Asbestos Sampling-on-site and air

Type of Study	Conducted by	Year	Description
Final Remedial Investigation Report	Weston	1993	Evaluated all media
Elemental Phosphorus Soil and Groundwater Sampling Program	unknown	1994	Distinguish between elemental and total phosphorus
Background soil sampling for arsenic and beryllium	unknown	1999	Background levels below State of Florida cleanup levels

References

O'Brien & Gere Engineers, Inc. 2000. Solidification/Stabilization Treatability Studies Work Plan, Stauffer Management Company, Tarpon Springs, Florida. December.

Roy F. Weston, Inc. 1996. Stauffer Management Company Tarpon Springs, Florida Site Final Feasibility Study Report. January.

U.S. Environmental Protection Agency (EPA). 1999. Site Briefing for Stauffer Chemical Company Superfund Site, Tarpon Springs, Florida. November 29.

EPA. 1998. Record of Decision, The Decision Summary, Operable Unit 1, Stauffer Chemical Tarpon Springs, Pinellas County, Florida. July 2.

Madalinski, Kelly, EPA/TIO. 2002. Personal Communications with Nestor Young, EPA. December.