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ANL/EVS/TM-15/2

Independent Review of Elemental Phosphorus Remediation at the Eastern Michaud Flats FMC Operable Unit near Pocatello, Idaho

Environmental Science Division

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Independent Review of Elemental Phosphorus Remediation at the Eastern Michaud Flats FMC Operable Unit near Pocatello, Idaho

by
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NOTATION

APE	Army peculiar equipment
ARAR	applicable or relevant and appropriate requirement
Argonne	Argonne National Laboratory
A&W	Albright & Wilson
B&P	bench- and pilot-scale
CAMU	corrective action management unit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
CO	carbon monoxide
COC	contaminant(s) of concern
COTS	commercial off-the-shelf
CSM	Conceptual Site Model
DNAPL	dense non-aqueous phase liquid
EMF	Eastern Michaud Flats
EPA	U.S. Environmental Protection Agency
ETT	excavation and treatment technology
FeP	ferrophos
FS	feasibility study
HAPP	hydraulically activated pipeline pigging
IROD	Interim Record of Decision
IRODA	Interim Record of Decision Amendment
ISL	*in situ* leaching
LDR	land disposal restriction
LD50	lethal dose 50
NCP	National Contingency Plan
NCV	national capacity variance
NORM	naturally occurring radioactive material
NPV	net present value
OOM	order of magnitude
OSHA	Occupational Safety and Health Administration
OU	operable unit

P4	elemental phosphorus
P&T	pump and treat
PH_3	phosphine gas
PIRC	post-incineration residual conditioning
PPE	personal protective equipment
PRG	preliminary remediation goal
psig	pound(s) per square inch gauge
RA	remedial action
RAAP	Ravenna Army Ammunition Plant
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
ROD	Record of Decision
RSL	regional screening level
RU	remediation unit
SCS	soil cleanup standard
SME	subject matter expert
TCLP	toxicity characteristic leaching procedure
TENORM	technologically enhanced naturally occurring radioactive material
Tribes	Shoshone-Bannock Tribes
TSD	treatment, storage, and disposal
UC	underlying constituent
USC	undocumented surface condition
UTS	universal treatment standard
VOC	volatile organic compound
WAC	waste acceptance criterion (criteria)
WAO	wet air oxidation
WMA	waste management area
wt%	weight percent
WTS	waste treatment system

UNITS OF MEASURE

atm	atmosphere
Btu	British thermal unit(s)
°C	degree(s) Celsius
cP	centipoise
cm^3	cubic centimeter(s)
ft	foot (feet)
ft^3	cubic foot (feet)
°F	degree(s) Fahrenheit
g	gram(s)
gal	gallon(s)
gpm	gallon(s) per minute
in.	inch(es)
$in.^2$	square inch(es)
kg	kilogram(s)
kWh	kilowatt-hour(s)
L	liter(s)
lb	pound(s)
m^2	square meter(s)
mg	milligram(s)
ppm	part(s) per million
yd^3	cubic yard(s)

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INDEPENDENT REVIEW OF ELEMENTAL PHOSPHORUS REMEDIATION AT THE EASTERN MICHAUD FLATS FMC OPERABLE UNIT NEAR POCATELLO, IDAHO

by

L.E. Martino, J.J. Jerden, Jr., T.A. Kimmell, and J. Quinn

ABSTRACT

Elemental phosphorus (P4) was manufactured from phosphate ore at FMC's Pocatello, Idaho, facility (referred to throughout this report as the FMC operable unit [OU]), located on privately owned land within the Shoshone-Bannock Tribes' Fort Hall Indian Reservation. The now-closed facility includes disposal sites regulated under the Resource Conservation and Recovery Act, as amended, and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended. In September 2012, the U.S. Environmental Protection Agency (EPA) issued an Interim Amendment to the Record of Decision for the CERCLA waste disposal sites on the FMC OU. The EPA determined that capping was the preferred approach for the long-term management of the disposal sites. However, the Shoshone-Bannock Tribes (Tribes) favor the permanent removal and/or treatment of P4. To address the Tribes' concerns about the results of the CERCLA process, the EPA and the Tribes agreed to have Argonne National Laboratory (Argonne) perform an independent review of excavation and treatment technologies (ETTs). This report documents how the independent review was conducted and presents the results of the review.

Argonne's Review Team examined *in situ* treatment technologies and *ex situ* ETTs. The ETTs evaluated by the Review Team are in various stages of maturity; some are available for use immediately, and others are in a theoretical or conceptual phase and will require a long lead time for development. In some cases, uncertainties about the Conceptual Site Model (CSM) prevented a full evaluation of ETTs. As a result, the Review Team recommends focusing only on mature ETTs that have a proven track record and that have been used successfully either at the former FMC facility or at other sites where P4 was handled. In addition to the most significant consideration (i.e., risk to site workers during implementation of the selected alternative), a decision to excavate and treat P4 waste would have several additional impacts, including the following:

- Impacts on community health and safety,

- Impacts on the environment, and
- Impacts on schedule and cost.

If, despite risks to workers and these potential impacts, stakeholders decide that P4 wastes need to be excavated and treated, the Review Team determined that a number of the ETTs examined warrant further consideration for the treatment of P4 waste that has been characterized (for example, P4 waste present in the historical ponds). Nevertheless, concerns about the health and safety of site investigation workers using then-available investigation approaches prevented the collection of subsurface samples containing P4 from large areas of the site (e.g., the railroad swale, the vadose zone beneath the Furnace Building, and the abandoned railcars), As a result, the contaminant CSM in those particular areas was not refined enough to allow the Review Team to draw conclusions about using some of the ETTs to treat P4 waste in those areas. The readiness of an ETT for implementation varies depending on many factors, including stakeholder input, permitting, and remedial action construction requirements. Technologies that could be ready for use in the near term (within 1 year) include the following: mechanical excavation, containment technologies, off-site incineration, and drying and mechanical mixing under a tent structure. Technologies that could be ready for use in the mid-term (1 to 2 years) include cutter suction dredging, thermal-hydraulic dredging, and underground pipeline cleaning technologies. Technologies requiring a longer lead time (2 to 5 years) include on-site incineration, a land disposal restriction waste treatment system, an Albright & Wilson batch mud still, post-treatment on-site disposal, and post-treatment off-site disposal.

EXECUTIVE SUMMARY

In September 2012, the U.S. Environmental Protection Agency (EPA) issued an Interim Amendment to the Record of Decision for the FMC Operable Unit (OU), Eastern Michaud Flats Superfund site in Pocatello, Idaho (EPA Region 10 2012a). In the *Supplemental Remedial Investigation/Feasibility Study* (*Supplemental RI/FS*), a review was conducted of technologies that could be implemented to address elemental phosphorus (P4) in the soil (the principal threat waste) (MWH 2010). Throughout this report, P4 is used to refer to the highly reactive, toxic allotrope of elemental phosphorus also known as white or yellow phosphorus. On the basis of that review and the Comprehensive Environmental Response, Compensation, and Liability Act's (CERCLA's) nine criteria, the EPA determined that capping was the preferred approach. However, the Shoshone-Bannock Tribes (Tribes), who are major stakeholders, favor the permanent removal and/or treatment of P4. The Tribes have expressed concerns regarding the previous review of potential treatment technologies. To address their concerns, the EPA agreed to commission an independent review of excavation and treatment technologies (ETTs) for soils contaminated with P4 to supplement the original assessment of potential ETTs.

The EPA and the Tribes agreed that the review should be conducted by an independent, objective entity capable of assembling researchers with world-class expertise in the subject matter. The EPA believes, and the Tribes have concurred, that Argonne National Laboratory (Argonne) has this capability. The EPA and the Tribes agreed to a framework for how the independent review is to be performed. This review framework is described in the July 1, 2014, document included in this report as Appendix A: Independent Review of Elemental Phosphorus Remediation at Eastern Michaud Flats, FMC Operable Unit, Work Order, per Interagency Agreement EPA DW-89-92291201/Proposal P-08125 (hereinafter called the "Work Order"). As the EPA indicates in the Work Order, the results of this independent review will ultimately supplement the previous evaluation of treatment technologies conducted pursuant to the *Supplemental RI/FS*.

Argonne submitted a Response to the Work Order, referred to as the Technical Proposal, on September 29, 2014. The Technical Proposal, included in this report as Appendix B, described the process for establishing an expert Review Team and proposed a scope of work for performing the independent review. The Review Team performed the following tasks to address the Work Order:

- Reviewed existing site characterization information,
- Reviewed technologies,
- Evaluated applicability of technologies,
- Proposed evaluation parameters, and
- Documented results in a report.

The Review Team learned that due to site investigation worker health and safety issues, site investigators have avoided collecting any samples that contain P4. Therefore, only sparse site characterization data are available to indicate where the P4 is and is not located throughout the site. Although its vertical and lateral distributions is not well defined, it is inferred that P4 can be found in the soil at the site at various concentrations, ranging from just above the analytical detection limit to its nearly pure form. Except at low temperatures, P4 oxidizes almost instantaneously upon exposure to air, releasing toxic gases. Red phosphorus and, in some cases, other compounds containing phosphorus are also present. Industrial process infrastructure (e.g., the underground pipelines used to convey gases from the electric arc furnaces to the calciner) could contain nearly pure P4, especially if the P4 in the pipelines has not been exposed to air. Railcars that are suspected to contain highly concentrated P4 are also buried at the site. As a result of the site's product- and waste-handling practices, P4 in various forms has affected the native soil at the site, which is composed of silt, sandy silt, sand, gravel, gravelly silt, and cobbles.

P4 waste is present at the former FMC plant in waste disposal units that underwent closure under the Resource Conservation and Recovery Act (RCRA) and that are now being managed under RCRA post-closure plans. P4 waste is also present in portions of the plant that were not regulated under RCRA (hereinafter called non-RCRA areas). This independent review did not focus on the closed disposal sites regulated under RCRA. In some cases, however, the closed RCRA units are on top of or adjacent to the non-RCRA areas. The Review Team did not evaluate whether or not the proximity of the non-RCRA areas to the closed disposal sites regulated under RCRA would affect the ability to implement the ETTs discussed in this independent review.

Working with the EPA and the Tribes, Argonne proposed draft and draft final versions of the ETT review parameters from September 2014 to February 2015. The final version of the ETT review parameters includes the following:

- Process maturity,
- Limitations,
- Time to implement (not including permitting and approvals),
- Effectiveness of removing and/or treating P4 on site,
- Process safety for site workers during implementation,
- Community health and safety during implementation,
- Impacts to the environment during implementation,
- Post-implementation impacts on the environment and the community, and
- Overall discussion of advantages and disadvantages.

After examining the issues at the FMC OU and the regulatory history at the site over the years, removal or remedial actions that were taken at similar sites in the past, and potential ETTs that might be applied, Argonne identified a number of principles that influenced the way the independent review was performed. These are as follows:

- Technologies to safely excavate, size, create waste feed materials, and temporarily store P4 waste in preparation for treatment in a "downstream" ETT appear to exist (hereinafter called "ancillary technologies").

- Site worker safety issues associated with the implementation of any *ex situ* ETTs appear to be comparable to the site worker safety issues associated with the original manufacturing process for producing, packaging, and transporting P4 and managing P4 waste. Appropriate engineering controls and personal protective equipment (PPE) can be used to control worker exposure during remediation activity in compliance with worker protection regulations under the Occupational Safety and Health Administration.

- Any water requirements for ETTs (including water needs for ETT implementation and the potential for accentuating contaminant migration) can be addressed by modifications to the groundwater pump-and-treat system required in the Interim Record of Decision.

For the purposes of this independent review, the Review Team considered an ETT a technology that can excavate and/or treat P4 waste or that can reclaim P4 for reuse or produce a P4 by-product. ETTs include technologies that can treat P4 *in situ*. Furthermore, ETTs also include the ancillary technologies required to store, sample, size, and blend the waste feed for a treatment technology. P4 waste includes process waste, soil, and debris (in this case, debris is any man-made object) containing or contaminated with P4.

Potential ETTs that could be implemented at the FMC OU were researched extensively. The research focused on P4 ETTs but also considered how to deal with heavy metals and radionuclides that might be present in significant amounts at various locations within the FMC OU. The Review Team, recognizing that P4 and P4 by-products (post-treatment) have value, also examined recovery technologies. Landfill options were examined only insofar as they could be used to address residuals that remained after P4 was removed from soil and debris and/or treated to reduce its concentration to acceptable levels.

During the research, a number of ETTs were identified. The Review Team prepared a draft, draft final, and final list of ETTs. The final list includes only the ETTs that the Review Team felt offered a reasonable potential for successfully and safely addressing the P4 waste. Only those technologies that made this cut are examined in detail in this report, using the ETT review parameters cited above. The technologies were categorized into groups depending on their application, as follows:

- *In situ* technologies (subsurface treatment);

- Excavation-related technologies;

- *Ex situ* treatment technologies, including both on-site and off-site treatment; and

- *Ex situ* (off-site) disposal technologies.

In addition, the Review Team felt that the logistical and treatment problems posed by underground piping and buried railcars warranted special consideration. Technologies addressing these special cases are also included.

The Review Team examined in detail 18 ETTs that potentially could be applicable for excavating and treating P4 waste at the FMC OU. The technologies examined ranged in maturity from a theoretical or conceptual stage to a mature technology that has been used to treat P4 waste in real-world, full-scale systems.

Although the *in situ* ETTs examined are potentially applicable to the FMC OU, uncertainties pertaining to both the Conceptual Site Model (CSM) and the *in situ* ETTs suggest that further consideration of these technologies *in situ* is not warranted because subsurface remediation, regardless of which ETT was implemented, would be incomplete. In addition, the *in situ* ETTs, with or without containment technology, would involve significant safety and cost issues, which would primarily be associated with the need to refine the CSM and perform bench- and pilot-scale studies.

The Review Team decided that several ETTs did not warrant further consideration; these included solvent stirred batch reactor, wet air oxidation, and technologies considered for abandoned railcars. Further consideration of wet air oxidation is not warranted due to operational issues. The solvent still batch reactor was rejected because the process is only at the bench-scale stage. Insufficient information is available to determine whether or not an excavation or treatment technology would be specifically applicable to the abandoned rail cars. A refined CSM is necessary before the Review Team could determine whether any excavation or treatment technology warrants further consideration.

After the evaluation process, the Review Team determined that the following ETTs warrant further consideration:

- Containment technologies,
- Mechanical excavation,
- Cutter suction dredging,
- Thermal hydraulic dredging,
- On-site incineration,
- Drying-mechanical mixing under a tent structure,
- Albright & Wilson (A&W) batch mud still,
- Land disposal restriction (LDR) waste treatment system (WTS),
- Off-site incineration facility,
- Post-treatment on-site disposal,
- Post-treatment off-site disposal, and
- Underground pipeline cleaning technologies.

In addition to the most significant consideration (risk to site workers during implementation), a decision to excavate and treat P4 waste would have several effects. These include the following:

- Impacts on community health and safety,
- Impacts on the environment, and
- Impacts on schedule and cost.

If, despite this risk and these impacts, stakeholders determine there is a need to excavate and treat P4 wastes, then the Review Team concludes that several of the ETTs could be used in combination to treat only a subset of the P4 waste present at the site. Concerns about the health and safety of investigation site workers using the then-available investigation approaches prevented the collection of subsurface samples containing P4 from large areas of the site, including, for example, the railroad swale, the vadose zone beneath the Furnace Building, and the abandoned railcars. It appears that no attempt was made to experiment with or to use alternative characterization methods (such as modified PPE, nonintrusive techniques, remotely controlled sample collection equipment, cryogenics, etc.) as part of the investigation. As a result, the CSM in those particular areas is not refined enough to allow a full evaluation of ETTs and to allow the Review Team to draw conclusions about the efficacy of the ETTs examined. However, in other areas of the site, for example, the historical ponds, process knowledge (information about the process waste stream discharged to the historical ponds), and the information gathered during both the CERCLA investigations and the RCRA-related investigations, provide the information needed to determine whether or not the ETTs considered warrant further consideration for P4 in those areas. The readiness of an ETT for implementation varies depending on many factors, such as stakeholder input, permitting, and remedial action construction requirements. Technologies ready in the near-term (within 1 year) include mechanical excavation, containment technologies, off-site incineration, and drying and mechanical mixing under a tent structure. Technologies that could be ready in the mid-term (1 to 2 years) include cutter suction dredging, thermal-hydraulic dredging, and underground pipeline cleaning technologies. Technologies requiring a longer lead time (2 to 5 years) include on-site incineration, LDR WTS, A&W batch mud still, post-treatment on-site disposal, and post-treatment off-site disposal.

1 INTRODUCTION

1.1 SUMMARY OF ISSUES AT THE FMC OPERABLE UNIT

Elemental phosphorus (P4) was manufactured from phosphate ore at FMC's Pocatello, Idaho, facility (referred to throughout this report as the FMC Operable Unit [OU]), located on 1,400 acres of privately owned land within the Shoshone-Bannock Tribes' Fort Hall Indian reservation (land that is referred to as "Eastern Michaud Flats" or EMF). In 1990, FMC was the world's largest producer of P4. Operating from 1949 until 2001, FMC (or predecessor P4 manufacturers) processed about 1.4 million tons of shale ore per year, produced 250 million lb of P4 per year, and generated about 1,360,000 tons of hazardous waste per year (FMC 2000) (Figure 1-1). The FMC plant closed in 2001.

In September 2012, the U.S. Environmental Protection Agency (EPA) issued an Interim Amendment to the Record of Decision for the EMF Superfund site in Pocatello, Idaho (EPA Region 10 2012a). In the *Supplemental Remedial Investigation/Feasibility Study* (*Supplemental RI/FS*), a review of technologies that could be implemented to address the P4 in the soil (the principal threat waste) was conducted (MWH 2010). On the basis of that review and using the Comprehensive Environmental Response, Compensation, and Liability Act's (CERCLA's) nine criteria, the EPA determined that capping was the preferred approach. However, the Shoshone-Bannock Tribes (Tribes) favor the permanent removal and/or treatment of contaminants. The Tribes have expressed concerns regarding the previous review conducted on potential treatment technologies. To address the Tribes' concerns, the EPA agreed to commission an independent review of excavation and treatment technologies (ETTs) for soils contaminated with P4 to supplement the assessment of potential ETTs.

FIGURE 1-1 FMC Operable Unit

For the purposes of this independent review, P4 waste is considered process waste (i.e., waste created by the P4 manufacturing process) and also soil contaminated with P4 and debris (man-made materials) contaminated with P4. An ETT is a technology that can excavate and/or treat P4 waste. Technologies that can treat P4 waste *in situ* were also considered ETTs. Furthermore, ETTs include the ancillary technologies required to store, sample, size, and blend the waste feed for a treatment technology.

1.2 ARGONNE'S ROLE AS AN INDEPENDENT REVIEWER

The EPA is committed to working closely with the Tribes in framing and conducting this independent review of ETTs for soil contaminated with P4. The EPA and the Tribes agreed that the review should be conducted by an independent, objective entity capable of assembling researchers with world-class expertise in the subject matter. The EPA believes, and the Tribes have concurred, that Argonne National Laboratory (Argonne) has this capability. The EPA and the Tribes agreed to a framework for how the independent review is to be performed. This review framework is described in the July 1, 2014, document included in this report as Appendix A: Independent Review of Elemental Phosphorus Remediation at Eastern Michaud Flats, FMC Operable Unit, Work Order, per Interagency Agreement EPA DW-89-92291201/Proposal P-08125, (hereinafter called the "Work Order") Argonne National Laboratory, Environmental Science Division. As EPA indicates in the Work Order, the results of this independent review will ultimately supplement the previous evaluation of treatment technologies conducted pursuant to the *Supplemental RI/FS*.

To address the concerns of the Tribes, Argonne submitted a Response to the Work Order, referred to as the Technical Proposal, on September 29, 2014. The Technical Proposal, included here as Appendix B, describes how the Review Team initially planned to perform Phase 1 of the Work Order, which involved researching, reviewing, evaluating, and reporting on ETTs for the FMC OU. This independent review summarizes the results from Phase 1 of the Work Order.

1.3 ESTABLISHMENT OF THE REVIEW TEAM

The Review Team consists of four Argonne staff members who are subject matter experts (SMEs). Information on the team members and their related expertise follows here:

- Louis Martino, Environmental Systems Engineer, Argonne. Mr. Martino is an SME in the investigation and remediation of sites associated with chemical warfare agents and military munitions. He functioned as the project manager, health and safety officer, and field team manager for the RI/FS and the collection of samples related to the ecological risk assessment for the White Phosphorus Pits at Aberdeen Proving Ground. Mr. Martino was the Argonne project manager for the *Final Independent Design Review: Simplot Site Eastern Michaud Flats Superfund Site, Pocatello, Idaho* (EPA-542-R-09-006), of August 2009. Mr. Martino is an SME in performing feasibility studies and making cost estimates for implementing remediation technologies. He is also an expert on key regulatory frameworks that would likely have an impact on the feasibility of ETTs and their ability to be implemented, including the Resource Conservation and Recovery Act (RCRA) Land Disposal Restrictions (LDRs).

- James Jerden, PhD, Geochemist, Argonne. Dr. Jerden is an expert on the reactive transport of contaminants and environmental mineralogy. He has more than a decade of experience in characterizing and modeling the processes by which radionuclides and other metals are transported into the biosphere. His recent work has focused on the speciation and mineralogy of actinides and phosphorus in the environment.

- Todd Kimmell, Senior Environmental Analyst, Argonne. Mr. Kimmell has participated in a number of National Research Council committees involved in chemical weapons demilitarization, including several that have dealt with determining appropriate actions for chemical weapons disposed of at various sites across the United States. He has also supported several cleanup projects under RCRA and CERCLA at military sites within the United States, and he has been involved at a national level with guidance and training programs involving the remediation of hazardous waste sites. Mr. Kimmell is an SME on key regulatory frameworks that are likely to have an impact on the feasibility and the ability to implement CERCLA removal and remedial actions. He is also an expert in areas of hazardous waste characterization under RCRA and RCRA LDRs.

- John Quinn, PhD, PE, Principal Hydrogeologist, Argonne. Dr. Quinn has expertise in hydrogeology, data visualization, and remediation technology and had prior experience working on the *Final Independent Design Review: Simplot Site Eastern Michaud Flats Superfund Site, Pocatello, Idaho* (EPA-542-R-09-006), of August 2009. Dr. Quinn also participated in the review of a remedial systems evaluation of the Homestake Mine in New Mexico and in a data gap analysis of Dover Gas Light Company's Delaware site.

Each member of the team has completed an Argonne-required form that identifies affiliations or activities that would constitute any conflicts of interest related to participating on the Review Team. No member of the team has worked for FMC or currently works for FMC.

1.4 AGREED-UPON SCOPE OF WORK

The Review Team performed the following tasks to address the Work Order:

- *Reviewed existing site characterization information.* The team reviewed existing information regarding site-specific conditions, such as site contamination profiles and the evolving Conceptual Site Model (CSM). No additional sampling was commissioned or undertaken to support this review. The focus of the review was on those aspects of the CSM that relate specifically to P4, its chemical reactions, and its by-products in the soil at the FMC OU and on the aspects that could affect implementation of an ETT at the site. Impacted soil that could be encountered at the site includes silt, sand, gravel, cobbles, sandy silt, and gravelly silt. Other contaminants or media were evaluated as needed, since it is likely that the radiological and chemical constituents of concern that are present, their RCRA reactivity characteristics, and the myriad nonsoil media found throughout the site (e.g., plant infrastructure [concrete foundations, asphalt, underground piping, sumps, storm drains, sumps], slag, metal scrap, pollution control sludge) could have a profound impact on the efficacy of an ETT. This task included a site visit and walkover and a review of historical site information.

- *Reviewed technologies.* This review identified technologies found in (1) existing literature; (2) applied research; and (3) bench-scale, pilot-scale, and/or operational situations that would be relevant to the conditions found at the FMC OU. The review also covered technologies evaluated previously at the FMC site. Opportunities for combining ETTs or using one or more ETTs in different locations at the FMC site were explored.

- *Evaluated applicability.* The identified ETTs were evaluated for their applicability to the conditions found throughout the FMC OU. The site was divided into areas based on the Review Team's understanding of how the P4 that was present related to the ETTs evaluated.

- *Proposed parameters.* The Review Team proposed parameters to be used to evaluate the ETTs. The Review Team prepared draft and final versions of the parameters, hereinafter referred to as "ETT Review Parameters." As a starting point, here is a list of those parameters:

  - Efficacy and feasibility (technical merits),
  - Advantages,
  - Disadvantages,
  - Limitations,
  - Time to implement,
  - Effectiveness of removing and/or treating P4, and
  - Health and safety.

As specified in the July 1, 2014, Work Order from the EPA and the Tribes, the review did not include an evaluation of ETTs against the set of nine CERCLA criteria. However, in evaluating the "technical merits" called out above, Argonne considered specific criteria that could be considered similar to aspects of the nine CERCLA criteria.

1.5 STRUCTURE OF REPORT

As specified in the technical response from Argonne, the report is structured as follows:

- Summary of the work to be performed;

- Description of the ETTs, including the identification of other sites where ETTs have been used both domestically and internationally;

- Description of the ETTs that warrant further consideration;

- Summary on the use of ETTs at those sites and their applicability to the FMC OU; and

- Identification of data gaps. For the ETTs examined, data gaps were identified for all applicable technologies needed to implement the ETTs at the site. In the case of ETTs that did not warrant a detailed examination because of the existence of data gaps, the Review Team identified further studies needed to fill those gaps.

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2 BACKGROUND

2.1 FMC SITE DESCRIPTION

Elemental phosphorus (P4) was produced at the FMC OU using phosphate-bearing shale ore originating from two different regional mine sites. Ore was shipped to the facility via rail, and it was either processed immediately or stockpiled. The ore was formed into briquettes, and the briquettes were calcined in rotary kilns. By 1968, the briquettes were calcined using traveling grate calciners. The calcined briquettes were either stockpiled or immediately blended with coke and quartzite to create a feedstock for electric arc furnaces. The four electric arc furnaces produced gaseous P4, carbon monoxide (CO) gas, slag, and “ferrophos” (FeP). The P4 gas was condensed into a liquid and then stored before being shipped off site as product. Electrostatic precipitators were located “downstream” of the phosphorus furnaces. Prior to 1955, precipitator solids were handled dry; after 1955, a slurry system was installed.

The manufacturing process, pollution control requirements, and product-handling practices resulted in the generation of high-volume and diverse waste streams that contained chemical and radiological constituents of concern, including P4 and other forms of phosphorus. For example, the water that was used to isolate the P4 product from contact with air (known as “phossy water”) was managed in a series of surface impoundments. Phossy water and the associated “phossy solids” were likely to contain P4. Process water used to make a slurry from precipitator dust generated during furnace operations was also likely to contain P4 and was managed in surface impoundments. The piping system (some of which was underground), which was used to route CO gas from furnaces to the kilns at first and to the calciners later, might also have contained P4. The slag created during furnace operations was also expected to contain P4. Surface impoundments (some of which were newly constructed to meet minimum technology requirements under RCRA) and on-site landfills were used to manage plant waste streams (that included, but were not limited to, phossy water, phossy solids, precipitator slurry, slag, and slag-related soil and debris) and treatment residuals from kiln and calciner off-gas treatment. In some cases, the presence of P4 could only be inferred, because field sampling teams were either cautioned against or prohibited from exposing P4 containing subsurface materials to the air during the performance of the *Supplemental RI* (MWH 2009).

2.2 SITE UNDERSTANDING/CONCEPTUAL SITE MODEL

White phosphorus is acutely toxic and poisonous, with a fatal dose for humans around 50 mg. White phosphorus will spontaneously ignite in air at temperatures greater than 30°C (86°F); therefore, in addition to keeping P4 under water whenever possible, another generally applicable safety precaution is to work with P4 only under cold conditions (Rivera et al. 1996). The physical and chemical properties of P4 that could affect the ETTs discussed below include its melting point of 44°C, its densities of 1.828 g/cm^3 (solid) and 1.745 g/cm^3 (liquid at 44.5°C), its vapor pressures of 3.4E-5 atm at 20^{o}C and 1.0E-3 atm at 76.6°C, and its solubility of approximately 4 mg/L at 25°C in water (Rivera et al. 1996).

Oxidation of P4 results in a number of different gaseous phosphorus species, the most abundant of which is P_2O_5 (Rivera et al. 1996). When exposed to water or humid air, P_2O_5 is converted to phosphoric acid. This process can occur within human lungs after inhalation of P_2O_5, thus causing severe irritation. White phosphorus reacts to form phosphine gas (PH3) in moist, anoxic environments such as subsurface sediments and soils. The rate of this reaction increases dramatically with increasing pH (above 7) (Rivera et al. 1996). Phosphine gas is flammable and highly toxic with an auto-ignition temperature of 38°C and an LD50 (median dose) of 3 mg/kg. As with the oxidation/ignition hazard, the risk of PH3 production can be mitigated by working with P4 at low temperatures (at least below 30°C) (Rivera et al. 1996).

In addition to the acute inhalation hazard and dermal hazards associated with skin contact, chronic poisoning due to long-term exposure to P4-related vapors and gases poses significant risks that need to be accounted for in assessing site worker safety. Chronic exposure to P4 vapors and associated gases can cause necrosis of the jaw bone (phossy-jaw) and damage to lungs, eyes, bones, and the gastrointestinal tract (Rivera et al. 1996).

Soil co-located with other environmental media (surface water, sediment, and groundwater) or plant infrastructure that could have been affected by P4 is known or suspected to be present in the following remediation units (RUs) or areas of the FMC OU (Figure 2-1):

- RU 1 – Furnace Building, secondary condenser, and loading dock; present possibly due to leaks and spills from production processes and waste management and/or injection of waste or excess P4;

- RU 2 – Slag pit; present due to leaks and spills from production processes and waste management;

- RU 13 – Pond 8S recovery process area and metal scrap preparation area; present due to management of waste materials in the adjacent old pond area;

- RU 19c – Railcars (also known as “buried railcars” or “abandoned railcars”); present because they were filled with P4 sludge and then buried in the slag pile (RU 19);

- RU 22b – Old pond area; present due to management and disposal of P4-containing soil and debris;

- RU 22c – Railroad swale; present due to phossy water spills entering stormwater sewers and discharging to the stormwater retention pond;

- Areas containing underground piping or sewer lines; present because they carried phossy water, precipitator slurry, or CO gas and could thus potentially contain residual P4 or because they might have leaked P4 (RUs 1, 2, 3, 8, 12, 13, 22b, and 24); and

- P4 in the capillary fringe above the groundwater in RUs 3 and 7.

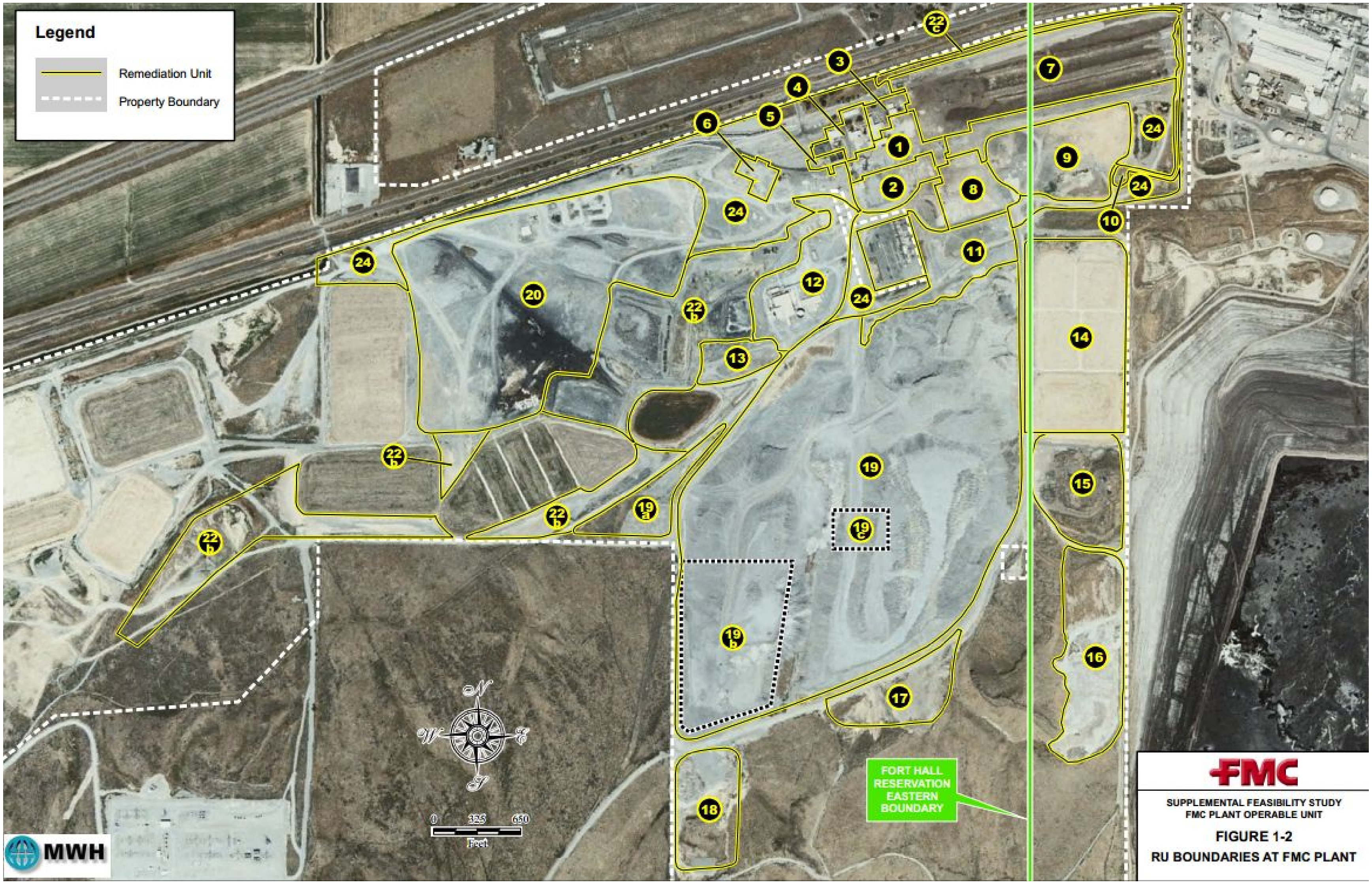

FIGURE 2-1 RU Boundaries at the FMC Plant (Source: MWH 2010)

The P4 that is present in the soil at the site could be encountered at various concentrations, ranging from just above the analytical detection limit to its nearly pure state. Since P4 oxidizes almost instantaneously upon exposure to air (except at low temperatures), oxidation by-products, such as red phosphorus and, in some cases, phosphate minerals, are probably also present. Industrial processes (e.g., the pipelines used to convey CO gas from the electric arc furnaces to the calciner) could contain nearly pure P4, especially if the P4 in the pipelines has not been exposed to air. The buried railcars in RU 19c reportedly contain P4 sludge with concentrations ranging from 75% to 95%, as reported in Appendix B of the *Supplemental FS*, or with P4 sludge concentrations ranging from 10% to 25%, as reported in the main text of the *Supplemental FS* (MWH 2010). The correct P4 concentration is unknown to the Review Team. Various forms of P4 from the site's product- and waste-handling practices has affected the native soil at the site, which is composed of silt, sandy silt, sand, gravel, gravelly silt, and cobbles.

Production processes and waste-handling practices have changed over time. Some of the surface impoundments used to handle the phossy water and the precipitator slurry were defined as hazardous waste management units under RCRA and were closed under EPA-approved RCRA closure plans. The rotary kilns were replaced with traveling grate calciners in 1968. Off-gas from the kilns and calciners was treated with wet scrubbers. Scrubber liquor blowdown was managed in both lined and unlined surface impoundments, some of which were deconstructed and placed in the RCRA units. In addition, slag handling practices have also changed over time. Table 2-1 summarizes the amounts of phosphorus that could potentially be present in the various RUs listed. The distribution of the P4 waste present at the site is roughly as follows: about 10,870 tons of P4 waste with P4 concentrations ranging from 0.25% to 20% are present in about 482,224 yd^3 of fill. The more concentrated P4 waste present in the capillary fringe, the railcars, and underground piping contains about 7,500 tons of P4 waste with P4 concentrations greater than 20% present in 2,800,000 yd^3 of fill. Figure 2-2 depicts the mass of P4 present in the historical ponds and railroad swale in relation to the mass of P4 present in the railcars, piping, and capillary fringe.

The contaminant CSM is somewhat refined for some RUs and is almost hypothetical for other RUs. As discussed below, there are few or no sample results to characterize the presence of P4 in the deep subsurface (e.g., the capillary fringe and the vadose zone beneath the Furnace Building). However, process knowledge can be used to characterize the contents of the waste present in the historical ponds. In addition, borings have been collected adjacent to or within several of the historical ponds, resulting in additional information that contributes greatly to the contaminant CSM for the historical ponds. Investigators have even described soil borings collected from historical ponds within RU 22B as "pure precipitator dust" and "phossy solids" (EPA 2003).

TABLE 2-1 Location, Mass, Likely Concentration, Aerial Extent, Relative Depth (to Native Soil or P4), and Fill Volume of P4-Containing Areas

Location	Maximum P4 Mass (tons)	Likely P4 Concentration (wt%)	Area (acres)	Depth to Native Soil or to P4 (ft)	Total Fill Volume (yd^3)[a]
Capillary fringe, RU 1, RU 2, RA-B	5,470	50	7.8	90 to P4	2,500,000
Pond 7S, RU 22b, RA-C	4,420	20	3.6	20	116,160
Pond 6S, RU 22b, RA-C	3,000	10	2.3	20	74,213
Railcars, RU 19c, RA-F	2,000	25[b]	2.7	120 to P4[b]	300,000
Pond 3S, RU 22b, RA-C	1,070	10	1.2	20	38,720
Pond 5S, RU 22b, RA-C	1,000	10	1	20	32,267
Pond 4S, RU 22b, RA-C	790	10	0.8	20	25,813
Pond 10S, RU 22b, RA-C	390	10	1	20	32,267
Pond 2S, RU 22b, RA-C	100	10	0.8	20	25,813
Pond 8S Material, RU 13, RA-C	60	0.25	3.6	23	66,630
Pond 1S, RU 22b, RA-C	30	1	0.5	20	16,133
Railroad swale, RU 22b, RA-C	10	1	2.4	14	54,208
Piping in RUs 1, 2, 3, 8, 12, 13, 22b, 24	3-30	Up to 100	–[c,d]	10	–[d]

[a] Rough estimate based on simple geometric calculation: area × depth to native soil.

[b] Since Table 2-1 was published (in MWH 2010), FMC has removed 20 to 40 ft of slag from the top of the slag pile to other areas at the site.

[c] In contrast to this concentration, Appendix B of the *Supplemental FS* reports a percent concentration ranging from 75% to 95%.

[d] A dash indicates not applicable (i.e., there is no area or fill associated with piping).

Source: Table 2-1 in the *Supplemental FS* (MWH 2010).

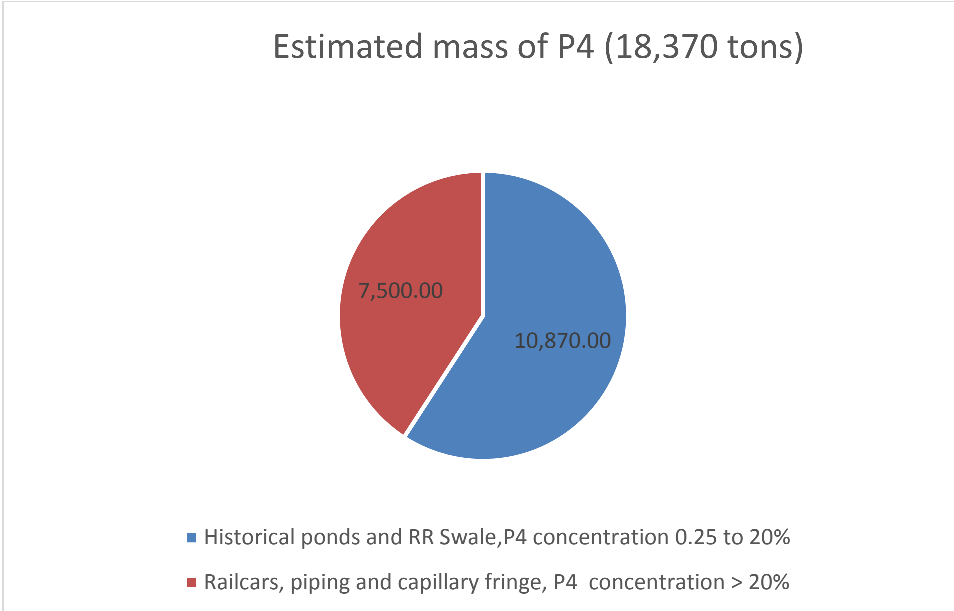

FIGURE 2-2 Estimated Mass and Concentrations of P4 Present at the FMC OU

Section 4.2 of the *Supplemental RI* (FMC 2009) describes the P4 operations in RU 1 and RU 2 and the locations of P4 sumps and tanks. The CSM for the Furnace Building vicinity assumes that warm, liquid P4 migrated downward from the sumps and tanks (Figures 2-3 and 2-4). Figures in various FMC documents show a circular area in RU 1 and RU 2 labeled the 44°C isotherm. A temperature of 44°C is the melting point of P4. It is not clear from the available information whether the mapped isotherm is current or historical, surficial or to depth, or measured or theoretical. The CSM description states that the P4 migrated through the approximately 80- to 85-ft vadose zone as a liquid to the capillary fringe and moved along the capillary fringe in the direction of groundwater flow (to the northeast).

A different aspect of the CSM for the deep Furnace Building P4 is the possibility of an injection well(s) used to dispose of impure or excess pure P4. On the basis of discussions at the September 21, 2015, meeting at the Fort Hall Tribal Business Council, the injection well was said to be at the west end of the Furnace Building and was used to dispose of P4 waste near the water table. The piping was warmed by circulating hot water through a double casing to prevent clogging. Some of the P4 was pure but was excess once the railcars were full. This practice continued until the early 1990s when the well was hidden by a slab of concrete. An online database of wells was searched for a possible injection well(s) at the west end of the Furnace Building (Idaho Department of Water Resources 2015); however, the data in this source are only as recent as 1992, so the existence of an older injection well could not be confirmed.

It is possible that P4 beneath the Furnace Building is present due to both the use of an injection well and the infiltration of P4 leaked from sumps and tanks. The former would explain the deep P4 observed in several boreholes (described below); the latter would explain any P4 in the thick unsaturated zone and also possibly the deep P4.

Only sparse site characterization data are available to indicate where the P4 is and is not. Its distribution vertically and laterally is not well defined. The soil borings that were completed for the *Supplemental RI* were done to define the future cap boundary for RU 1 (Figure 2-3), and the drilling and sampling plan seemed to address areas far from where P4 would be expected. Three borings encountered P4 northeast (hydraulically downgradient) of the RU 1 and RU 2 area and were quickly abandoned once the P4 was detected. On the basis of this precedence, it is difficult to propose field activities (using conventional investigation techniques and routine health and safety protocols) that would require any drilling or sampling of subsurface materials that could potentially contain P4. There are obvious worker safety issues connected with collecting split spoon samples or having auger cuttings that reach the surface.

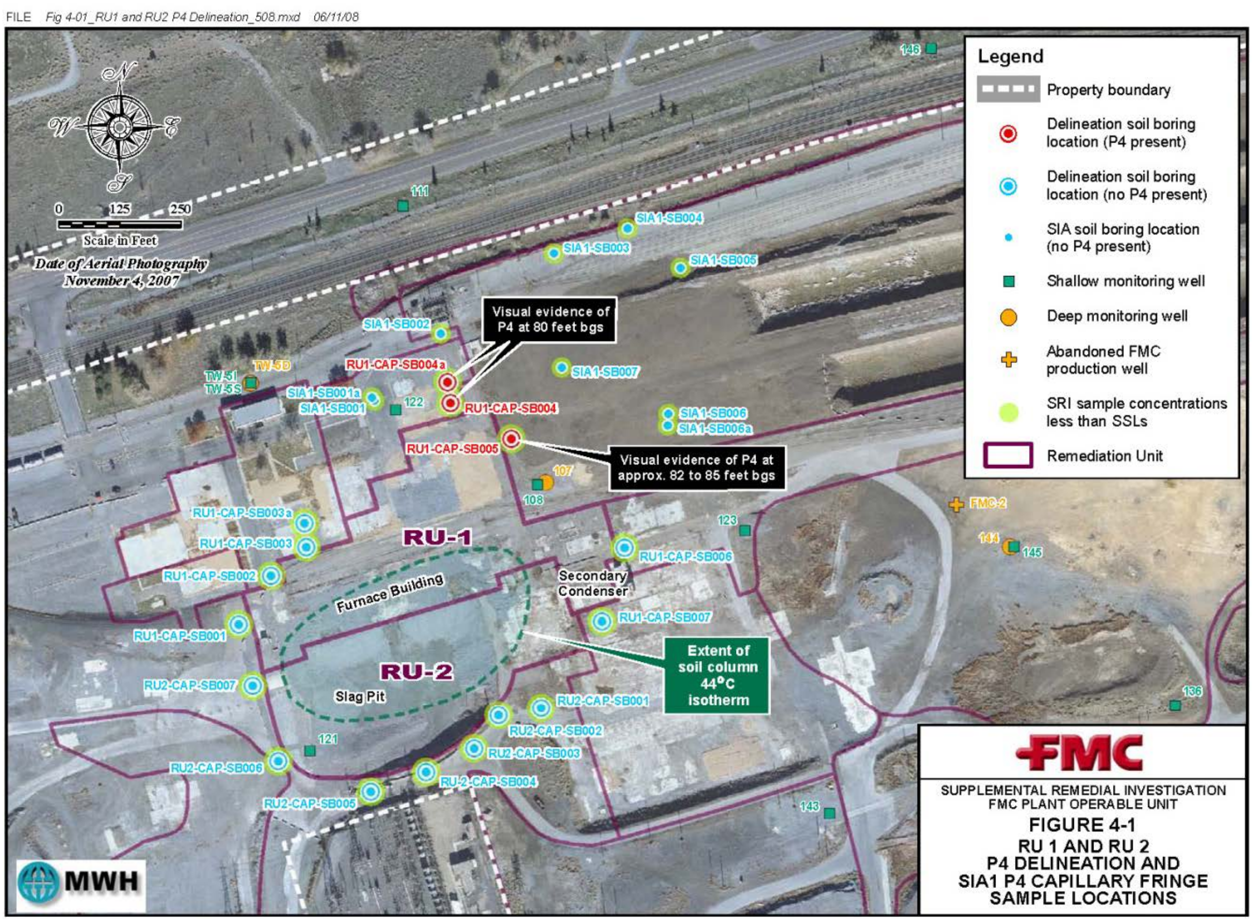

FIGURE 2-3 Characterization Data for P4 near the Furnace Building (Source: FMC 2009, Figure 4-1)

Of the soil borings drilled in RU 1 and RU 2 (Figures 2-3 and 2-4), Borings 004, 004a, and 005 encountered P4, each at about 80 ft deep. This location is just above the saturated zone according to equipotential contour maps. According to the drilling logs, the conditions at various depths in the thick unsaturated zone above the P4 ranged from dry to slightly moist to moist. The unsaturated zone at the three holes was logged as being of various textures of silt/sand/gravel, consistent with alluvial deposition. Split spoon samples collected at 10-ft intervals suggest silt with fine sand, fine-to-coarse sand with gravel, and fine-to-coarse sandy fine and coarse gravel, respectively, in the final sample collected at each borehole.

The CSM for the Furnace Building vicinity therefore includes P4 in two subsurface zones (Figure 2-4):

1. In the unsaturated zone (ignore the perfectly shaped impact zones in the figure), which is completely uncharacterized; and

2. In the capillary fringe, which is characterized only by three soil borings and is completely unbounded.

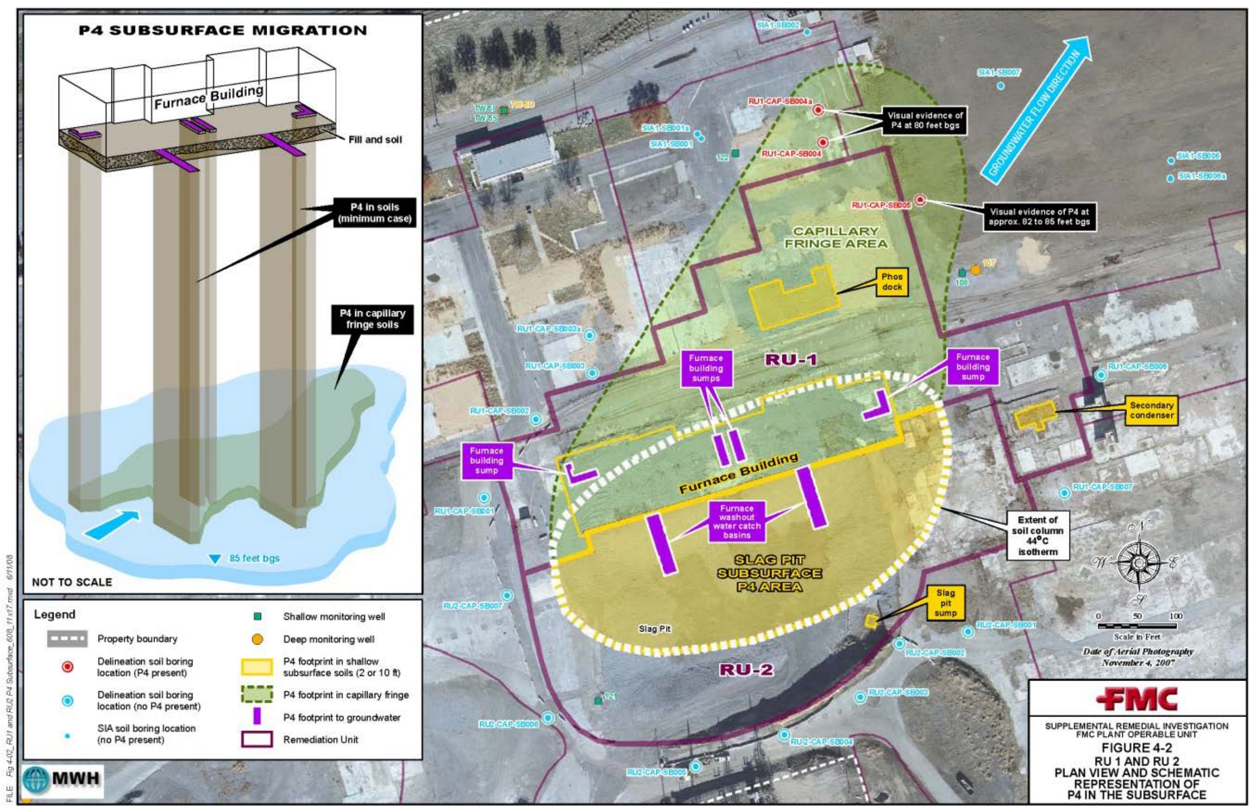

FIGURE 2-4 Plan View and Simplified Representation of P4 in the Subsurface (Source: FMC 2009, Figure 4-2)

The characterization of the P4 in the Furnace Building vicinity was minimal. Conceptually, the *Supplemental RI* (FMC 2009) depicts molten P4 in Furnace Building tanks and sumps as traveling vertically downward approximately 80 ft to the water table. There the P4 traveled in the capillary fringe zone, presumably in the northeasterly direction of the hydraulic gradient of the groundwater.

The melting point of P4 is 44°C. Since molten slag was periodically tapped from the electric arc furnaces and drained to a slag pit, any P4 that escaped from the Furnace Building was probably warmer than the melting point of P4 (FMC 2009). To add to the CSM, any liquid P4 in the thick unsaturated zone would have traveled downward through the alluvial sediments, consuming residual oxygen (if any) in the void spaces through exothermic reaction. It would have cooled along its vertical pathway, losing heat to the sediments, but it would have still been a liquid above 44°C when it reached the capillary fringe. There it would have flowed northeastward based on the groundwater's hydraulic gradient. In the capillary fringe zone, the P4 would have lost heat more rapidly to both the sediments and especially to the groundwater, generating steam if the temperature was above 100°C. Alternatively, the P4 could have been released near the water table by a heated injection well system. It is possible that both transport mechanisms could have been in effect. In either case, the P4 may have built up as a mass or "blob" of an unknown thickness as it flowed and cooled to a waxy solid, filling the void spaces in the sediments. The extent of the blob is estimated only by evidence of smoking augers from three soil borings (Figure 2-4). The distribution of the P4 in the 80-ft-thick unsaturated zone is largely uncharacterized and unknown. The 44°C isotherm was modeled by investigators (FMC 2009). The depiction of P4 subsurface presence and migration in Figure 2-4 is based on that model. The absence of good information about the presence of P4 in the subsurface makes evaluating bench-scale, pilot-scale, and certainly full-scale *in situ* ETTs difficult. Bench- and pilot-scale testing for *in situ* ETTs is essential, as discussed in Section 5.1. As important as such testing is for the evaluation of ETTs, bench- and pilot-scale testing is also needed to better understand how P4 has behaved in the subsurface. As discussed in Section 6.2, some understanding of the specific retention of P4 in the subsurface is needed before pilot- or bench-scale ETT studies can be planned.

2.3 REGULATORY BACKGROUND FOR THE EVALUATION OF ETTS

The former FMC plant is regulated under both RCRA, as amended, and CERCLA, as amended.[1] P4 waste is present at the former FMC plant in waste disposal units that are being managed under RCRA post-closure plans. P4 waste is also present in portions of the plant that were not regulated under RCRA (hereinafter called non-RCRA areas) that are regulated under CERCLA, as amended. This independent review did not focus on the closed disposal sites that

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[1] RCRA regulation of process wastes from the beneficiation of minerals and ores is affected by the Bevill amendments and exemptions. The Bevill exemption for waste generated during the production of P4, except furnace off-gas solids, ended on March 3, 1990. The exemption for furnace off-gas solids ended on July 23, 1990. Upon the lifting of the Bevill exemption, beneficiation wastes that were hazardous waste were subject to RCRA regulation. Exempt wastes disposed of prior to the lifting of the Bevill exemption would not be subject to RCRA (provided they are not subsequently managed in a way that triggers RCRA) but can be and are being addressed under CERCLA. See http://www3.epa.gov/epawaste/nonhaz/industrial/special/ for details.

are regulated under RCRA post-closure plans. In some cases, the closed RCRA units are on top of or adjacent to the non-RCRA areas (Figure 2-5). The Review Team did not evaluate whether or not the proximity of the non-RCRA areas to the closed disposal sites regulated under RCRA would affect the ability to implement the *ex situ* ETTs discussed in this independent review.

2.4 INTERIM RECORD OF DECISION AMENDMENT AND CLEANUP PLAN

In September 2012, EPA Region 10 released the *Interim Record of Decision Amendment (IRODA) for the EMF Superfund Site FMC OU* (EPA Region 10 2012a). The *IRODA* represents the current plan for remediation of the FMC OU. This plan focuses on elemental phosphorus, metals, and radiation in soils, fill, and groundwater. The *IRODA* is summarized here because some of the proposed remedial actions, including the groundwater pump and treat (P&T) system, informed the way the Review Team performed the evaluation of ETTs. The *IRODA* calls for placing an engineered cap over contaminated soils to protect human health and the environment. The cap is designed to prevent rain and melting snow from filtering through the contaminated areas and polluting the groundwater below. The plan also requires treatment to clean the groundwater before it reaches local springs or the Portneuf River. The EPA indicates that the remediation plan was developed after careful consideration of extensive comments that it received during the public comment period on the September 2011 *Proposed IRODA Plan* (EPA Region 10 2011).

The 2012 *IRODA* (EPA Region 10 2012a) includes the following remedial actions:

- Installing a protective cap to provide a barrier to underlying contamination and to prevent water from moving through the contamination and polluting the groundwater;

- Adding about 12 in. of soil over some areas to prevent exposure to radiation from polluted areas;

- Cleaning elemental phosphorus from underground concrete pipes;

- Installing a groundwater extraction and treatment system to keep pollution from local springs and the Portneuf River;

- Installing barriers, such as additional fencing, after the caps are constructed to further limit site access;

- Placing restrictions on future site use and prohibiting some activities, such as digging in capped areas and using contaminated groundwater; and

- Developing and implementing a long-term monitoring and maintenance program for the groundwater treatment system, caps, and other barriers.

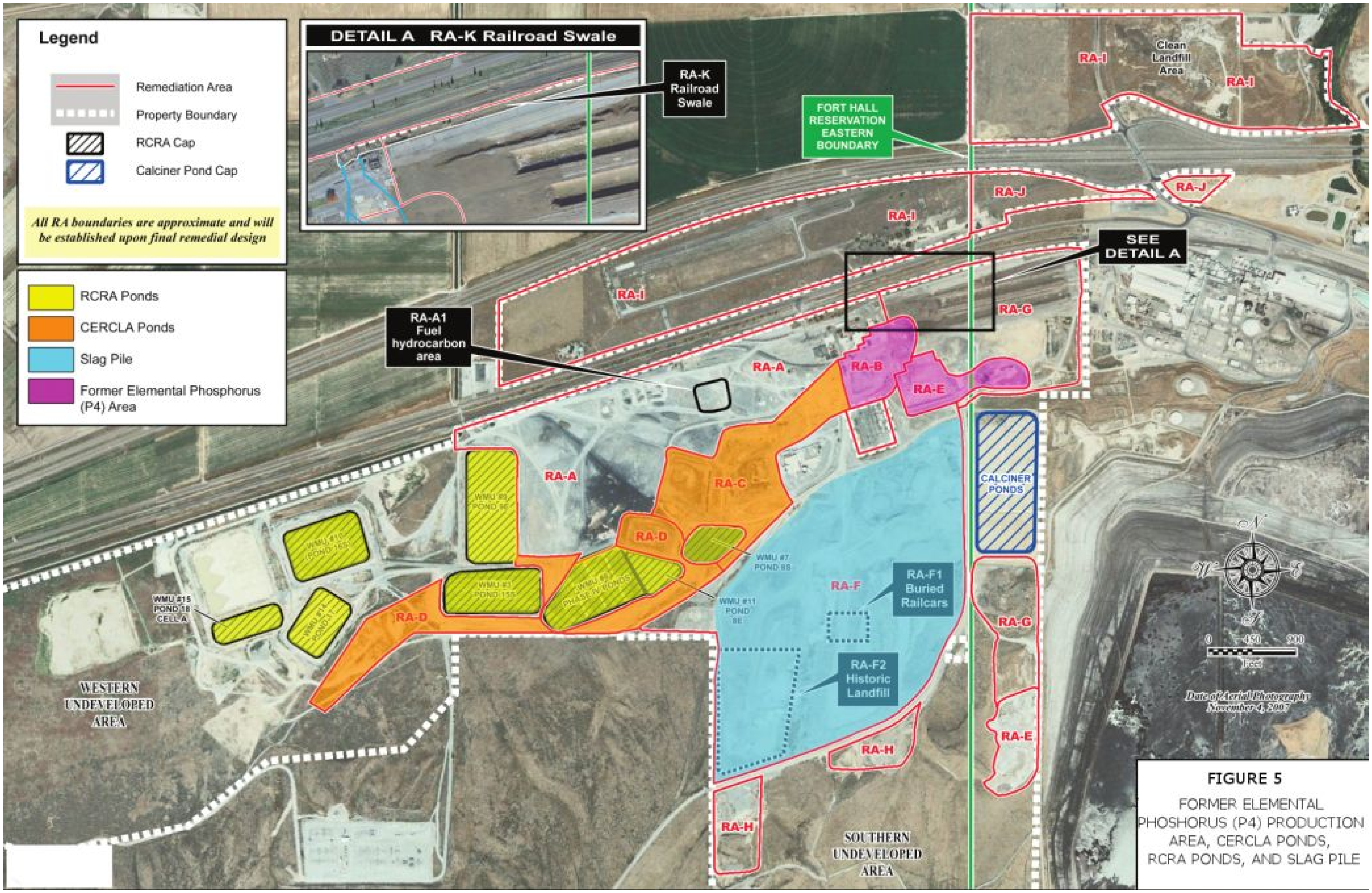

FIGURE 2-5 RCRA and CERCLA Disposal Sites (Source: FMC 2009, Figure 5)

Additional alternatives previously screened and considered by EPA may be reviewed by examining the *IRODA* (EPA Region 10 2012a).

The EPA indicated in its fact sheet released in October 2010 (EPA Region 10 2012b) that:

> This cleanup plan, details work for the former FMC plant that was not included in the original 1998 Record of Decision. Once the groundwater treatment system is in operation, predictions on how long it will take to meet our goals and whether changes are required to ensure cleanup goals are met can be more accurately determined. In addition, EPA has not yet determined if the recently adopted Shoshone-Bannock Tribal Soil Cleanup Standards apply to the cleanup. For these reasons, this plan is considered “interim” and a “final” cleanup plan will be developed in the future.

As of the date of writing of this report, Argonne believes that the EPA has not yet determined how to address the Shoshone-Bannock Tribal Soil Cleanup Standards. These cleanup standards are further addressed in Section 2.5 of this report.

Background information and the Superfund process flowchart for the FMC property, taken from the 2012 EPA fact sheet, are shown in Figure 2-6 (EPA Region 10 2012b).

2.5 APPLICABLE REGULATORY CRITERIA AND CLEANUP LEVELS

2.5.1 Principal Threat Waste at the FMC OU

On the basis of the assumption that soil and debris that contain P4 at the FMC OU could be subject to some form of active remediation (as opposed to cap and cover), several different types of cleanup criteria would be applicable. First, note that according to the *IRODA*, the EPA considers P4 to be the principal threat waste at the FMC OU (EPA Region 10 2012a):

> EPA has identified elemental phosphorus existing in concentrations exceeding 1,000 parts per million (ppm) in soil as a source material and principal threat waste at the FMC OU, because it will present a significant risk to human health and the environment should exposure occur. The National Contingency Plan (NCP) establishes an expectation that EPA will use treatment to address the principal threats posed by contaminants at a site wherever practicable (NCP Section 300.430(a)(1)(iii)(A)).
>
> Principal threat wastes are those source materials considered to be highly toxic or highly mobile that generally cannot be reliably contained or would present a significant risk to human health or the environment should exposure occur. EPA’s decision to treat these wastes is made on a site specific basis through a detailed analysis of the alternatives using the nine remedy selection criteria.

Background

The former FMC phosphorus processing plant is located mostly on the Fort Hall Reservation near Pocatello, Idaho, and is within the Eastern Michaud Flats Superfund Site. FMC manufactured elemental phosphorus at their plant from 1940 until December 2001.

While FMC was in operation, elemental phosphorus from spills and leaks during production, storage, and handling contaminated the property and polluted the water below which, in turn, has also polluted the Portneuf River.

Elemental phosphorus now can be found down to 85 feet below the surface on FMC property. Elemental phosphorus can explode and burn uncontrollably when it is exposed to air.

Slag (a byproduct of processing phosphate ore), used as fill and stored in mountain-sized piles on site, emits dangerous gamma radiation.

Exposure to elemental phosphorus and other contaminants at the levels found at the former FMC plant is dangerous to people, animals, and the environment.

This cleanup plan, called an *Interim Record of Decision Amendment*, details work for the former FMC plant that was not included in the original 1998 Record of Decision. EPA will be monitoring the soil, air, and groundwater to ensure that the remedies outlined in the new plan are meeting our goals, and adjustments will be made if needed.

Once the groundwater treatment system is in operation, predictions on how long it will take to meet our goals and whether changes are required to ensure cleanup goals are met can be more accurately determined. In addition, EPA has not yet determined if the recently adopted Shoshone-Bannock Tribal Soil Cleanup Standards apply to the cleanup. For these reasons, this plan is considered "interim" and a "final" cleanup plan will be developed in the future.

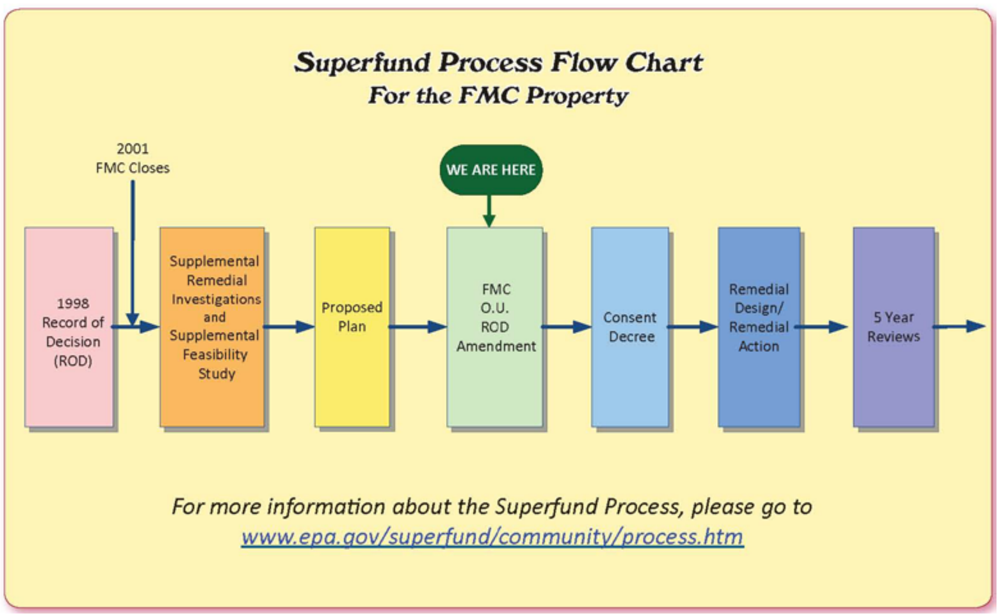

FIGURE 2-6 Project Background and Superfund Process Flow Chart (Source: EPA Region 10 2012b)

> Elemental phosphorus is a RCRA ignitable and reactive waste and is also a principal threat waste that has physical properties unlike most contaminants of concern (COC) encountered in environmental response actions. Because of its unique properties, managing elemental phosphorus requires special handling techniques not only for routine handling but also for emergency response.

It is clear from this statement that P4 — and presumably soil and debris containing P4 — are considered to be a RCRA ignitable and reactive waste, meaning that soil and debris containing significant amounts of P4, once exhumed, would exhibit the RCRA characteristics of ignitability and reactivity, and possibly also the RCRA toxicity characteristic. These RCRA hazardous waste characteristics are described next.

2.5.2 RCRA Hazardous Waste Characteristics

Several of the RCRA hazardous waste characteristics are regulatory criteria that would be applicable to any form of active remediation being done by using an ETT at the FMC OU. These include the RCRA characteristics of ignitability, reactivity, and toxicity.

2.5.2.1 Ignitability Characteristic (40 CFR 261.21)

With regard to the RCRA characteristic of ignitability, ignitable waste is defined as follows (the following list is directly quoted from regulation):

“1. It is a liquid other than an aqueous solution containing less than 24 percent alcohol by volume and has flash point less than 60°C (140°F), as determined by a Pensky-Martens Closed Cup Tester, using the test method specified in ASTM Standard D 93-79 or D 93-80 (incorporated by reference, see § 260.11), or a Setaflash Closed Cup Tester, using the test method specified in ASTM Standard D 3278-78 (incorporated by reference, see § 260.11).

2. It is not a liquid and is capable, under standard temperature and pressure, of causing fire through friction, absorption of moisture, or spontaneous chemical changes; and, when ignited, burns so vigorously and persistently that it creates a hazard.

3. It is an ignitable compressed gas.

4. It is an oxidizer. An oxidizer for the purpose of this subchapter is a substance such as a chlorate, permanganate, inorganic peroxide, or a nitrate, that yields oxygen readily to stimulate the combustion of organic matter (see Note 4).”

Because P4 is not a liquid at standard temperature and pressure, it would not meet the first criterion listed above. However, it would be considered ignitable under the second criterion. Not all soil and debris containing P4 would meet the RCRA ignitability characteristic, however, because there would be a concentration of P4 in the soil and debris below which the soil and debris would not necessarily be ignitable. Argonne interprets the 2012 *IRODA* statement that "EPA has identified elemental phosphorus existing in concentrations exceeding 1,000 parts per million (ppm) in soil as a source material and principal threat waste" as the concentration cutoff for what would be a RCRA ignitability characteristic hazardous waste. In other words, soil and debris containing P4 at a concentration equal to or above 1,000 ppm/kg (i.e., 1,000 mg/kg) would be considered ignitable. It then follows that soil and debris treated either to remove P4 to below this level or to alter the form of P4 so that it would no longer be ignitable would also render the soil/debris nonignitable.

2.5.2.2 Reactivity Characteristic (40 CFR 261.23)

Similarly, exhumed soil and debris containing P4 above a certain level or activity at the FMC site would also meet the RCRA characteristic of reactivity. According to the RCRA reactivity characteristic, soil or debris would be reactive if one or all of the following were true (the following list is directly quoted from regulation):

"…1. It is normally unstable and readily undergoes violent change without detonating.

2. It reacts violently with water.

3. It forms potentially explosive mixtures with water.

4. When mixed with water, it generates toxic gases, vapors, or fumes in a quantity sufficient to present a danger to human health or the environment.

5. It is a cyanide- or sulfide-bearing waste, which, when exposed to pH conditions between 2 and 12.5, can generate toxic gases, vapors or fumes in a quantity sufficient to present a danger to human health or the environment.

6. It is capable of detonation or explosive reaction if it is subjected to a strong initiating source or if heated under confinement.

7. It is readily capable of detonation or explosive decomposition or reaction at standard temperature and pressure.

8. It is a forbidden explosive as defined in 49 CFR 173.54, or is a Division 1.1, 1.2, or 1.3 explosive as defined in 49 CFR 173.50 and 173.53.

(b) A solid waste that exhibits the characteristic of reactivity has the EPA Hazardous Waste Number of D003."

The propensity of P4 to spontaneously smoke and ignite, as well as evolve phosphine and other toxic gases, would cause soil and debris containing P4 to meet the RCRA reactivity characteristic. As is the case for the RCRA ignitability characteristic, there is a level or concentration of P4 in soil and debris that would be low enough so that soil and debris would not smoke or ignite or so that amounts of phosphine or other toxic gases would not evolve to a significant degree. Soil and debris containing P4 below this level would be considered nonreactive under the RCRA definition. As is the case for the RCRA ignitability characteristic, Argonne interprets the 2012 *IRODA* statement that “EPA has identified elemental phosphorus existing in concentrations exceeding 1,000 parts per million (ppm) in soil as a source material and principal threat waste” as the concentration cutoff for what would be a RCRA reactive characteristic hazardous waste. In other words, soil and debris containing P4 at a concentration equal to or above 1,000 ppm (i.e., 1,000 mg/kg) would be considered reactive. It then follows that soil and debris treated either to remove P4 to below this level or to alter the form of P4 so that it is no longer reactive would also render the soil/debris nonreactive.

Argonne therefore presumes that soil or debris exhumed from the FMC OU that contains P4 in concentrations equal to or greater than 1,000 mg/kg would meet the RCRA characteristics of ignitability and reactivity.

Argonne notes that EPA has not established a minimum P4 level in wastes to define whether or not such wastes would meet the RCRA ignitability or reactivity characteristic criteria. Argonne’s connection of the *IRODA’s* definition of a CERCLA Principal Threat Waste (a P4 concentration exceeding 1,000 mg/kg) is made in an attempt to establish a concentration for P4 in waste that would define that waste as RCRA ignitable and RCRA reactive. This is necessary because, if the P4 contaminated soil and debris at the FMC OU is to be actively remediated, a de facto definition of what would be considered the cutoff for ignitability and reactivity specifically addressing P4 content is needed. In addition, the RCRA LDRs for these characteristics, which specify a “deactivation” treatment requirement, would need to be satisfied, unless, as indicated above, EPA elects to waive these requirements through one of the statutory applicable or relevant and appropriate requirement (ARAR) waiver approaches.

The RCRA consent decree required FMC to treat the P4-contaminated wastes by “permanently and irreversibly bonding the waste into the molecular structure of a solid product such that the treated waste will not undergo changes that cause it to release toxic gases in concentrations greater than 0.3 ppm phosphine or 10.0 ppm hydrogen cyanide, or leach heavy metals in concentrations greater than applicable LDR Universal Treatment Standards.” These treatment requirements, as laid out in the RCRA consent decree, are insufficient as a definitive cutoff for P4 content and the RCRA characteristics of ignitability and reactivity. Simply defining phosphine and hydrogen cyanide emissions is inadequate as a measure of reactivity. These emissions are a function of many different variables, including temperature, atmospheric pressure, and soil moisture content, just to name a few; more important, however, these properties do not address ignitability. A more definitive definition is needed, preferably one that is quantitative as well as readily straightforward to implement (i.e., a simple analytical method). A simple concentration cutoff of P4 within wastes that may be exhumed is most desirable. Should the FMC OU be actively remediated at some point in the future, Argonne’s connection of the *IRODA’s* definition of a CERCLA Principal Threat Waste (a P4 concentration exceeding 1,000 mg/kg) to the RCRA ignitability and reactivity characteristics may be considered an interim starting point in the eventual establishment of a cutoff for P4 content for RCRA ignitability and reactivity (EPA 1999).

2.5.2.3 Toxicity Characteristic (40 CFR 261.24)

Since soil and debris at the FMC OU are also known to contain heavy metals, the soil and debris that are exhumed from the OU may also meet the RCRA toxicity characteristic. For this characteristic, a leaching test known as the toxicity characteristic leaching procedure (TCLP) is used to determine whether heavy metals and some toxic organic compounds could leach from a waste at levels above the specified concentrations. It is possible that some of the soil and debris at the FMC OU could exhibit the RCRA toxicity characteristic.

2.5.3 LDR Treatment Standards (40 CFR Part 268)

RCRA LDRs for waste, soil, and debris (hereinafter "P4 waste") meeting the ignitability or reactivity characteristics require that the treatment standard called "deactivation" be applied so that the P4 waste is rendered no longer ignitable or reactive. The premise behind the LDR treatment requirements for these RCRA characteristics is that P4 waste would still pose a hazard if it had one or more characteristics and was disposed of on land, even if the P4 waste was placed in a properly designed, operated, and permitted hazardous waste landfill. Hence, under the LDR program, P4 waste that meets a RCRA characteristic would not be permitted to be land-disposed. Treatment would be required to "decharacterize" the P4 waste. For P4 waste exhumed from the FMC OU, Argonne presumes that treatment would need to meet the 1,000-mg/kg requirement to achieve deactivation for the characteristics of ignitability and reactivity.

The P4 waste soil and debris maintained below the ground surface that contained P4 above levels that would classify them as RCRA ignitable or reactive (if exhumed) would retain their reactive or ignitable characteristic. The P4 waste that stayed buried and was not exposed to air or oxidizing conditions in general would retain its ignitable and reactive properties.

In addition to removing the hazardous properties of wastes that cause them to meet a RCRA characteristic, the LDRs for characteristic wastes also require treatment to meet universal treatment standards for "underlying constituents." Underlying constituents in this case would include heavy metals. The P4 waste throughout the FMC site would likely require additional treatment to meet the LDR underlying constituents requirement for some of these heavy metals, even if it did not exhibit the RCRA toxicity characteristic.

Hence, P4 waste at FMC treated to remove the characteristics of ignitability and reactivity would require further treatment to satisfy the LDR requirements for underlying constituents. Before the LDR treatment plant constructed at the FMC site closed in 2001, it included a stabilization treatment process (encapsulation in a cement mixture) that was used after the removal of P4 in order to satisfy the LDR requirement for underlying constituents for heavy metals. This technology, or a similar technology, could be applied as part of the remediation, if needed, to address heavy metals and radionuclides (although radionuclides are not regulated under RCRA). However, regulations under RCRA's hazardous waste site cleanup program allow alternatives to be used for further treatment, as discussed next.

2.5.4 RCRA Corrective Action (Cleanup) Requirements and CERCLA Cleanup

Under RCRA corrective action requirements for cleanup of hazardous waste sites (40 CFR 264, Subpart F), facilities have the option, with regulatory approval, to consolidate wastes on site in a corrective action management unit (CAMU). Disposal of contaminated media in the on-site CAMU may be done under a reduced set of requirements (for example, without meeting LDRs) if such disposal can be shown to be protective of human health and the environment. Most CAMUs are, in essence, landfills and may require liners, caps, and groundwater monitoring, but the option of not needing to meet LDRs for underlying constituents (assuming the remedy could be shown to be protective of human health and the environment) is potentially applicable to the FMC OU if it were to employ a CAMU. Although the EPA may be reluctant to waive the requirement to decharacterize soil and debris exhumed from the site for ignitability or reactivity, it may be amenable to allowing soil and debris to be managed in a CAMU, but, again, only if it could be shown that doing so would remain protective of human health and the environment.

The FMC site is regulated under both RCRA and CERCLA. The CERCLA FMC OU does not include the portion of the site regulated by RCRA post-closure plans, the so-called “RCRA ponds.” However, the CAMU option may be brought in to the CERCLA action through ARARs. Management of remediation wastes at a CERCLA site may be conducted in a CERCLA land disposal unit that is “CAMU-like.” In other words, soil and debris that do not meet some or all LDR requirements for underlying constituents would be able to be managed in a CERCLA land disposal unit as part of an overall remedy, as long as it met CERCLA requirements and was approved by the regulator.

2.5.5 Soil Remediation Levels

The LDR deactivation requirements for the RCRA characteristics of ignitability and reactivity, and potentially for underlying hazardous constituents, are not the only treatment standards that may be applicable to soil and debris at the FMC OU. Another type of criterion that may be applicable to the FMC site is soil remediation level. EPA Region 10 published a set of soil remediation levels in the *IRODA* (EPA Region 10 2012a; see Table 9 on page 242). The levels are provided in Table 2-2. Footnote (c) to the table indicates that there are currently no soil remediation levels for phosphorus or elemental phosphorus in soils.

The EPA has established extensive cleanup programs under RCRA and CERCLA, and cleanup levels for contaminants in various environmental media have been established, in some cases by EPA Headquarters and some EPA regions. These types of levels have been known by many names and acronyms over the years. EPA Regions 3 and 9 have established regional screening levels that can serve as the basis for the development of cleanup levels. These levels are identified as regional screening levels (RSLs). These are human health-based target levels for hazardous waste site cleanups, and they have the potential to be applied at both RCRA and CERCLA sites within the regions. These “targets” may then be adjusted either up or down to address site-specific conditions including environmental sensitivity (e.g., endangered species). Also, these target cleanup levels are typically available for both residential areas and for

TABLE 2-2 Contaminants of Concern in Soil and Cleanup Levels for Risk Drivers for the FMC OU

Contaminants of Concern	Units	Cleanup Levels Industrial[a,b]
Antimony	mg/kg	150
Arsenic	mg/kg	
Beryllium	mg/kg	
Boron	mg/kg	
Cadmium	mg/kg	39
Fluoride	mg/kg	49,000
Gross alpha	pCi/g[d]	
Gross beta	pCi/g[d]	
Lead-210	pCi/g	
Manganese	mg/kg	
Mercury	mg/kg	
Nickel	mg/kg	
Phosphorus (elemental)[c]	mg/kg	–
Polonium-210	pCi/g	
Potassium-40	pCi/g	
Radium-226	pCi/g[d]	3.8
Radon	pCi/g[d,e]	
Selenium	mg/kg	
Silver	mg/kg	
Thallium	mg/kg	
Thorium-230	pCi/g	
Uranium-238	mg/kg	
Vanadium	mg/kg	
Zinc	mg/kg	

[a] Cleanup levels are provided for COCs associated with worker risk at the former operations area or Northern Properties.

[b] The cleanup level cited is the lower cleanup between the outdoor/commercial/industrial worker and construction worker preliminary remediation goal (PRG) from the *Supplemental FS Work Plan*.

[c] There are currently no soil remediation levels for phosphorus or elemental phosphorus in soils.

[d] Individual radionuclides potentially responsible for elevated gross alpha and beta levels are also COCs.

[e] Retained as a COC mainly for evaluation of potential radon infiltration into buildings under alternate future commercial or industrial uses of the site.

Source: Table 9 in the *IRODA* (EPA Region 10 2012a).

industrial areas, with those for residential areas being more stringent (i.e., having lower target concentrations). Although these standards were developed by only some EPA regions, other EPA regions regularly refer to them during cleanups.

As indicated on its website, EPA Region 9 established an RSL for P4; it is 1.6 mg/kg for residential areas and 23 mg/kg for industrial areas (EPA Region 9 2015).

As can be seen, the human health-based RSLs for P4 are probably lower than the levels below which the waste would be considered to meet a RCRA ignitability or reactivity characteristic. Therefore, the FMC OU site, once cleaned up, would likely be considered for a future industrial site rather than a future residential area. Hence, and assuming that active remediation of the FMC OU site would be considered further, the 23-mg/kg cleanup requirement for P4 could be considered the starting point for developing a soil remediation goal for P4 at the site.

It should be noted, however, that EPA Headquarters and the EPA regions (collectively) as well as individual EPA regions often have different policies and procedures. Hence, EPA Region 3 and 9 RSLs may not be accepted by other EPA regions, including Region 10 in which the FMC site is located. Nevertheless, the RSL for P4 would be a “To Be Considered” but not an ARAR under CERCLA since RSLs are not standards, requirements, criteria, or limitations under federal or state environmental law.

2.5.5.1 Shoshone-Bannock Tribes Soil Remediation Levels

In addition to these types of levels established by the EPA, other governmental organizations may have also established cleanup levels for hazardous waste sites. As indicated in the *IRODA* (EPA Region 10 2012a), “EPA is initiating remedial actions under an Interim ROD Amendment because of uncertainties regarding the timeframe for groundwater cleanup and the uncertain status of December 2010 Soil Cleanup Standards by the Shoshone-Bannock Tribes as Applicable or Relevant and Appropriate Requirements (ARAR) under CERCLA.” The Tribes’ Soil Cleanup Standards (SCSs) may be examined at http://www.sbtribes-ewmp.com/EWMP_Soil_Cleanup_Standards_Contaminated_Prop.html (Shoshone-Bannock Tribes 2010).

The *IRODA* (EPA Region 10 2012a) further states:

> Hence, in December 2010, the Tribes promulgated stringent SCS that require, among other things, excavation and/or treatment of all buried elemental phosphorus on the Fort Hall Reservation. Among the Tribes’ stated goals in promulgating the SCS is restoring all land within the Reservation to its original state prior to the contamination that the standards are designed to address. This selected interim amended remedy does not meet these standards. However, because of the interim nature of this action, ARARs do not have to be met at this time. EPA is evaluating the Tribes’ standards to determine whether these regulations may be ARARs. This evaluation will require careful federal review to determine whether these unique and potentially precedential SCS should be fully

> evaluated prior to a decision as to whether all or a part of the SCS are ARARs. CERCLA requires that ARARs must be met or waived upon completion of remedial action. At the time that EPA selects a final remedy, EPA will more definitively address groundwater restoration within a reasonable restoration timeframe, will determine whether all or a part of the Tribal SCS are ARARs, and will if necessary determine the applicability of the ARAR waiver provisions in §121(d)(4) of CERCLA. EPA will consult with the Tribes on the selection of the final remedy, including consideration of any proposed waiver or waivers.

It is clear that in some cases the Shoshone-Bannock Tribes' cleanup standard for P4 in soil would entail complete removal, which typically is interpreted to entail removal to the extent that no contaminant that is detectable when using validated and approved analytical techniques. However, the SCS specifically provides in §1.1 that "The Tribes recognize, however, that there are situations where use of Commercial/Industrial Cleanup Standards rather than Unrestricted Use standards may be appropriate, or where attainment of the Cleanup Standards may be technically impracticable." The Tribes also specify, however, that "The SCS do require soils that exhibit the characteristics of ignitability or reactivity to be treated to eliminate those characteristics, or else the soils must be removed from the site (Part 4)." Hence, it appears that the Tribes' SCS would permit application of a cleanup standard other than complete removal of P4, as long as the remaining media would no longer exhibit the RCRA characteristics of ignitability and reactivity. This would entail developing a set of criteria that would establish a de facto definition of RCRA ignitability and reactivity, specifically due to P4 content, as well as an alternate numerical cleanup standard for media that contains P4 below RCRA ignitability and reactivity characteristic levels.

2.5.6 Occupational Safety and Health Administration Requirements (29 CFR Part 1910)

Compliance with Occupational Safety and Health Act (OSHA) requirements is an important part of any hazardous waste site cleanup. Concerns for worker exposure during active remediation efforts in Remedial Action (RA) units where hazards are understood (e.g., RA units such as the historical ponds where process knowledge can be used to establish site worker risks) would be no greater than those for exposure during the original industrial processes for producing, packaging, and transporting P4, and for managing soil and debris created as a result. For those RA units where process knowledge is absent and where the CSM is not refined, there would be greater site worker risks. Nevertheless, appropriate engineering controls and PPE can be used to control worker exposure during remediation activities, in compliance with worker protection regulations under OSHA. Where site worker risks are not well understood (e.g., if subsurface samples potentially containing P4 are collected during any future CSM refinement activities), unknown hazards would need to be addressed accordingly with conservatively safe PPE, monitoring, and sampling approaches to comply with OSHA.

2.5.7 Other Criteria or Standards of Note

The extensive literature review conducted by Argonne for this project is described in Chapter 3.7 of this report. The literature review revealed that other criteria have been applied for other P4 cleanup projects in the United States. Two of these are summarized below.

- *Miamisburg, Ohio*. In 1986 in Miamisburg, a tanker car containing 40,000 L of liquid P4 (45°C) derailed and burst into flames next to a stream feeding the Great Miami River, which leads to the Ohio River (Scoville et al. 1989). Most of the contaminated stream sediment was removed and treated by exposing the sediment on open-air asphalt pads. The sediment was treated for 12 to 24 hours — the amount of time required to reduce the P4 to less than 10 mg/kg. At concentrations of less than 10 mg/kg, the material was not deemed to be ignitable (Walsh 2009).

- *Stauffer Chemical Site, Florida*. The ROD for a CERCLA site outside Tarpon Springs, Florida, where P4 was produced from 1947 to 1981, indicates that site remediation took place to remove P4 contamination. Because the site was located near residential areas, a residential cleanup level (1.4 mg/kg) was applied. The removal operation was conducted under a tent, and the material that was removed was disposed of at a Monsanto site (EPA Region 4 2013).

2.5.8 Applicable Regulatory Criteria and Cleanup Level Summary

In this document, Argonne has assumed that a treatment of soil and debris that would result in P4 levels below 1,000 ppm (mg/kg) would render the soil and debris nonignitable and nonreactive according to the RCRA definitions of ignitability and reactivity. However, an ETT might instead have to achieve a P4 cleanup level in soil as low as the EPA RSL of 23 mg/kg or as low as a cleanup level established by the Tribes.

The end state of the application of a suite of ETTs for active remediation of the FMC OU would be that all contaminated media no longer exhibit the RCRA characteristics of ignitability and reactivity, that P4 is removed to acceptable cleanup levels, and that RCRA LDRs are satisfied for heavy metals and other constituents, as appropriate. There are two possible exceptions to this suggested end state. First, and as allowed by CERCLA, EPA could, with adequate justification, choose to waive certain requirements through one of the statutory ARAR waiver approaches (http://www2.epa.gov/superfund/applicable-or-relevant-and-appropriate-requirements-arars). This may be especially applicable to RCRA LDRs. Second, and as stated previously, the CSM would have to be improved to permit adequate understanding of heavy deposits of P4, such as that underlying the Furnace Building and that contained within the buried railcars.

3 TECHNICAL APPROACH

3.1 OVERVIEW

The technical approach of the Review Team consisted of gathering information, conducting an analysis, and then assessing ETTs against agreed-upon review and evaluation parameters. Information gathering included a review of the literature, a site tour, a presentation by the Tribes, a response to Argonne-authored questions by both FMC and the Tribes, and telephone communications with state and federal regulators and the designers of ETTs. The Review Team then developed a list of ETTs with the potential to address waste containing P4 at the FMC OU site. The team narrowed that list down to a number of ETTs for detailed consideration. Finally, the team assessed the ETTs on that target list against the review and evaluation parameters.

3.2 INFORMATION REVIEW AND ANALYSIS AND SITE TOUR, SEPTEMBER 2014

As a starting point, the Review Team examined the open literature and the information sources cited in the Work Order (Appendix A). Argonne staff were taken on a site tour of the FMC OU in September 2014. While in Pocatello, Idaho, for the site tour, the Argonne staff visited the Idaho State University Library's Government Documents Repository located at 850 South 9th Avenue in Pocatello. Sources of information were also gathered throughout the term of the project. Literature examined and cited is summarized in Section 3.7.

3.3 SHOSHONE-BANNOCK TRIBES' PRESENTATION, FEBRUARY 6, 2015

In addition to gathering information during the site visit, the Argonne staff members were given a presentation by the Tribes via teleconference on February 6, 2015. The content of the presentation, which is included in this report as Appendix C, is summarized here. The presentation described issues at the FMC site, covering a historical perspective, impacts on the environment, and an assessment of the technologies used to contain, treat, and monitor P4. ETT-related points highlighted at the time of the presentation included (1) the inadequacy of closing and capping the RCRA pond, as evidenced by the release of phosphine, hydrogen cyanide, and H_2S that escaped from temperature monitoring points; (2) the inability to measure the release of P4-related gases that do occur; and (3) the lack of testing for ETTs due to reasons related to risk and economics.

3.4 QUESTIONS DIRECTED TO SUBJECT MATTER EXPERTS AND STATE AND FEDERAL REGULATORS

Argonne directed a number of questions to FMC during the review process. The questions are included as Appendix D of this report. Appendix E has the FMC-generated responses to the questions. Appendix F contains the Tribes' responses to the questions and their comments on the FMC-generated responses. In addition, Argonne contacted and interviewed environmental regulators from the State of Idaho, from EPA Region 10, and from states where other P4 remediation operations had occurred or were ongoing. Several experts who had experience in P4 production, transportation, sale, reuse, and remediation were contacted by e-mail and, with their permission, interviewed. The experts who were interviewed will remain anonymous. Although Argonne gained a lot of information from these interviews, only information that could be corroborated from actual documentation was used in preparing this report.

3.5 EXPANDED LITERATURE SEARCH

Argonne received approval to begin this project in April 2014. Although specific elements of the project, such as the evaluation parameters to be used for the ETTs, were still being negotiated among Argonne, the EPA, and the Tribes at that time, Argonne began a literature search that focused on the FMC site. Included in this search were the following:

- The history of the FMC site, from startup in the 1940s to closure in 2001, including technologies employed during the P4 production process;
- The history of the FMC site as it relates to the Superfund program, from listing in 1990 to the present time;
- Regulatory actions that had occurred at the FMC site;
- Environmental investigations that had been conducted at the FMC site;
- Superfund decision documents (e.g., RODs) issued for the FMC site;
- Similar documentation related to the neighboring J.R. Simplot site adjacent to the FMC site;
- The general environment around the FMC site, including everything from climate to geology;
- The structure of the Tribal, local, and State governments in and around the FMC site;
- The natural history pertaining to the area in and around the FMC site;
- The cultural history pertaining to the FMC site, especially as it relates to the Shoshone-Bannock Tribes; and
- The history of public involvement in environmental matters pertaining to the FMC site.

Argonne then expanded its review by focusing on technologies that might be employed to remediate P4 at the site, including planned technologies (i.e., cap and cover) and other technologies that could be employed, including more active technologies involving actual removal and treatment of the soil and debris containing P4. Argonne researched information about sites within the United States where P4 was known to be present and had been evaluated or remediated, including the following:

- Monsanto Chemical Company (Solutia), Soda Springs, Idaho;
- 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; and
- Occidental Petroleum, Glenn Springs, Ducktown, Tennessee.

Argonne researched P4 handling sites within the United States where P4 was currently being evaluated or where remediation was ongoing. These included the Rhodia Silverbow RCRA Site in Montana. Argonne also identified U.S. sites where there had been emergency response incidents and where P4 might have been released and remediated, including the 1986 Miamisburg, Ohio, train derailment and white phosphorous release.

Argonne also attempted to research the body of international literature for places where P4 might have been remediated in the past or where remediation was ongoing. Some information was available about the A&W America Limited phosphorus plant in Long Harbor, Newfoundland, Canada. Argonne also learned that at least one French contractor, Chiresa, had experience in dismantling tanks containing P4 (Chiresa AG 2008). There was also some information about several locations in Mexico where P4 was recovered or remediated, but there was no documentation in the open literature regarding any actions that were taken or results that were achieved. In general, however, information about P4 handling at international sites seems to be lacking in the open literature.

Argonne expanded its search further to determine ancillary information related to P4 remediation. The topics included the following:

- What the potential is for the recovery of P4 for reuse or resale as a product (as opposed to remediation);

- How military organizations have approached the deactivation or recovery of P4 (white phosphorus, WP, Willie Peter) from obsolete munitions; and

- How other industries deal with phosphorus or by-products that involve P4.

Argonne then researched other technologies that might have some application to the remediation or recovery of P4 at the FMC site. This effort covered not only remediation technologies but also technologies used in the chemical industry in general.

Overall, Argonne accessed hundreds of websites and reviewed many more than 100 different publications that could have a bearing on the task. For a list of references cited in this report, please see Chapter 9.

3.6 DRAFT, DRAFT FINAL, AND FINAL REVIEW AND EVALUATION PARAMETERS

Working with the EPA and the Tribes, Argonne proposed draft and draft final versions of the ETT review parameters from September 2014 to February 2015. The final version of the ETT review parameters and a description of each one were agreed upon on February 23, 2015 (Table 3-1).

3.7 PRESENTATION OF FINDINGS FROM THE DRAFT REPORT

The Review Team submitted a draft version of the report to the Tribes and the EPA on September 8, 2015. The Review Team presented the results of key findings from the Draft report to the Fort Hall Business Council, in the Fort Hall Council Chambers on September 21, 2015. All members of the Review Team (listed in Chapter 1) participated in the presentation. The presentation was followed by a morning and afternoon question-and-answer session. A follow-up webinar presentation was also provided to representatives of EPA who could not attend the meeting in Fort Hall. The webinar meeting occurred on September 28, 2015. This meeting was attended by all members of the Review Team, representatives of the Tribes, and EPA staff members.

3.8 RESPONSE TO COMMENTS AND THE FINAL REPORT

On the basis of information presented at the Fort Hall Business Council meeting, the follow-up webinar meeting, and the content of the Draft report, the Tribes and EPA produced a series of comments. The Review Team responded to the comments by including a discussion and/or the actual language used to address the comments. The Tribes' comments and Review Team responses can be found in Appendix G. The EPA comments and Review Team responses can be found in Appendix H. Also included is a summary of changes required during final review by Argonne's editorial staff and Argonne's technical content review staff (Appendix I). This Final version of the Independent Review report includes changes in the Draft version

TABLE 3-1 Description of ETT Review Parameters[a]

ETT Review Parameter	Description of Parameter
Process maturity	An assessment of the developmental phase of the ETT demonstrated at laboratory/pilot scale and ETT technologies that have been permitted or otherwise approved and used for P4.
Limitations	Factors that could constrain or preclude the implementation of the ETT, including, but not limited to, soil type, pH, moisture, cost, weather conditions, and the need for bench- and pilot-scale testing. Also any issues associated with off-site transportation and disposal of P4 material.
Time to implement (not including permitting and approvals)	Time to excavate and/or treat P4 in soil.
Effectiveness of removing and/or treating P4 in soil	The effectiveness in the short and long term of an ETT in removing the health hazards associated with P4 in soil; achieving soil screening levels for P4; or rendering P4 safe for the transportation of impacted soil to an off-site location for treatment and/or disposal.
Process safety for site workers during implementation	Health and safety impacts on site workers associated with the ETT during implementation.
Community health and safety during implementation	Health and safety impacts on the surrounding community associated with the ETT during implementation.
Impacts to the environment during implementation	Impacts to environmental media at the site, including soil, air, surface water, and groundwater associated with the ETT during implementation.
Post-implementation impacts on the environment and the community	Impacts to the community and to the environment associated with the ETT after implementation for example, in the case of on-site ETT, releases to air, surface water, and groundwater associated with treatment operations. In the case of a technology located off-site, nuisance and safety hazards associated with off-site shipment of waste.
Overall discussion of advantages and disadvantages	A summary in tabular format.

[a] The Work Order directed the Review Team to not include CERCLA's nine evaluation criteria, one of which is cost, as evaluation parameters. However, EPA and the Tribes agreed that cost could be included in the content of the review and evaluation parameter referred to as "Limitations."

needed to address the Tribes' and EPA's comments and to address editorial and technical issues noted in the Draft version.

Cost as a limitation factor has been included to allow a rough order of magnitude (OOM) comparison with the ETTs evaluated. The net present value (NPV) cost of Alternatives 5 through 7 in the September 2010 Proposed Plan (which included excavation and treatment) is an estimated $405 million to $950 million, based upon high and low volume estimate assumptions about the (largely uncharacterized) mass of subsurface P4 (EPA 2010). Since some ETTs also involve excavation followed by treatment, the NPV determined for Alternatives 5 through 7 provides a comparable OOM estimate.

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4 GUIDING PRINCIPLES FOR THE INDEPENDENT REVIEW AND THE IDENTIFICATION OF POTENTIALLY APPLICABLE ETTS

After examining the issues at the FMC OU and the regulatory history at the site over the years, removal or remedial actions that were taken at similar sites in the past, and potential ETTs that might be applied, Argonne identified a number of principles that influenced the way the independent review was performed. They are as follows:

- It appears that technologies to safely excavate, size, create waste feed materials, and temporarily store P4 waste in preparation for treatment in a "downstream" ETT exist (hereinafter, these are called "ancillary technologies").

- Site worker safety issues associated with the implementation of any *ex situ* ETTs appear to be comparable to the site worker safety issues associated with the original manufacturing process for producing, packaging, and transporting P4 and managing P4 waste. Appropriate engineering controls and PPE can be used to control worker exposure during remediation activity in compliance with worker protection regulations under OSHA.

- Any water requirements for ETTs (including water needs for ETT implementation and the potential for accentuating contaminant migration) can be addressed by modifications to the groundwater P&T system required in the *IROD.*[2]

Potential ETTs that could be implemented at the FMC OU were researched extensively. The research focused on P4 ETTs but also considered how to deal with heavy metals and radionuclides that might be present in significant amounts at various locations within the FMC OU. In addition, the Review Team examined ETTs that were in all stages of development and use, including ETTs in a conceptual, bench-, pilot-, or full-scale of development/use. The Review Team, recognizing that P4 and P4 by-products (post-treatment) have value, also examined recovery technologies. Landfill options were examined only insofar as they could be used to address residuals that remained after P4 was removed from soil and debris and/or treated to reduce its concentration to acceptable levels.

While the FMC OU is a CERCLA cleanup site, the waste that may be produced as a result of active remediation at the site is subject to RCRA regulatory requirements. Wastes exhumed from the site become immediately subject to RCRA's waste management requirements, as do facilities that may be used to treat or otherwise manage these wastes, and also residuals remaining if and when these wastes are treated in some fashion. As RCRA requirements are considered during the CERCLA ARAR process, it is imperative that RCRA

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[2] Water use would mainly be required to manage the risks associated with excavation (whether by mechanical or by hydraulic means). As a result, the removal of P4 waste and processing by ancillary technologies could proceed in phases dictated by water requirements (should water requirements be a limiting factor).

requirements are adequately addressed in determining management requirements for wastes that are exhumed from the site and also for waste treatment residuals. In addition, and as allowed by CERCLA, EPA could, with adequate justification, choose to waive certain requirements through one of the statutory ARAR waiver approaches (see http://www2.epa.gov/superfund/applicable-or-relevant-and-appropriate-requirements-arars). Most notable of the RCRA requirements applicable to wastes that may be exhumed from the site and for treatment residuals are the RCRA LDR requirements, which are discussed frequently in this report. In accordance with these requirements, wastes determined to be hazardous must be treated in accordance with strict requirements before they can be land-disposed. RCRA LDRs and requirements for treatment, storage, and disposal facilities may be pertinent to some of the ETTs discussed in this report, in particular, those designed to remove the RCRA characteristics of ignitability and reactivity from the waste (i.e., address the P4) and also to address heavy metals that may be contained in remediation waste or in treatment residuals.

During the research, a number of ETTs were identified. The Review Team prepared a draft, draft final, and final list of ETTs. The final list includes only the ETTs that the Review Team felt offered a reasonable potential for successfully and safely addressing the P4 waste. Only those technologies that made this cut are examined in detail in this report. The technologies were categorized into groups depending on their application, as follows:

- *In situ* technologies (subsurface treatment);
- Excavation-related technologies;
- *Ex situ* treatment technologies, including both on and off site; and
- *Ex situ* (off-site) disposal technologies.

In addition, the Review Team felt that the logistical and treatment problems posed by underground piping and the railcars warranted special consideration. Technologies addressing these special cases are also included.

In reference to a key issue — whether P4 can be safety excavated — the Review Team arrived at different conclusions than other parties. On the basis of a review of information, it appears that a subset of the P4 waste present at the site can be safely excavated. There appears to be a history of sludge removal from the ponds at the FMC plant. The FMC response included in Appendix E of the *Independent Design Review* report includes several references to excavation. Appendix E describes both dredging and mechanical excavation activities involving Ponds 8s, 8e, and 9e, as well as Ponds 15s and 18. Furthermore, the LDR WTS was designed to treat sludge dredged from Pond 8S. Pond 8s dredge was designed as a component of the LDR WTS. In an EPA-authored reference, reclamation processes consisting of excavating pond materials is described as having occurred at historical ponds 1s, 2s, 3s, 9s, 2e, and 4e (EPA 2003).

The excavation of P4 is also addressed at other P4 plants. The *Clarifier Treatability Study Phase 3 Report* on the Rhodia/Solvay Site, Silver Bow, Montana (which was not available when the IRODA was prepared) contains a description of the removal of clarifier sludge from the clarifier by use of a Cat 320 excavator (Franklin Engineering Group 2012). Also of interest is a description of mechanical excavation in the Phase 1 report on the same Rhodia/Solvay Clarifier. "Conventional earth working equipment, such as tracked excavators, back hoes, and clam shells, can be used to excavate the solidified sludge and transfer it to a shipping container or processing system. With careful operation, the phosphorus can be transferred with a water cover in the bucket to minimize mass burning" (Franklin Engineering Group 2007).

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5 POTENTIALLY APPLICABLE EXCAVATION AND TREATMENT TECHNOLOGIES

In situ ETTs are discussed in Section 5.1. *Ex situ* ETTs are discussed in Sections 5.2 and 5.3. It appears that P4 is present in a pure or nearly pure state in some portions of the former FMC plant. The "treatment" aspect of some ETTs includes both the treatment of P4 waste and the process steps for the recovery of P4 or P4 by-products for resale/reuse. Conceptually, soil and debris targeted for ETTs can be "triaged," in that there could be three fractions to be addressed:

1. P4 waste that can be "mined" and recycled and/or reused as P4 without treatment;

2. P4 waste that requires treatment with an ETT, resulting in either the generation of a reusable by-product like P4 or phosphoric acid or a waste residual; and

3. P4 waste that does not require treatment with an ETT. P4 waste that would not require treatment is waste that meets agreed-upon treatment requirements established for the second fraction. Some waste present at the site would presumably already meet such treatment requirements.

The ETTs considered for evaluation are listed as follows:

- *In situ* technologies
  - Injection of steam in direct push or vibrated caissons/wells or parallel horizontal wells; melting and pumping of P4
  - Solvent leach and recovery by using benign solvents
  - *In situ* oxidation of P4 via oxidant leaching or forced air oxidation
  - Containment of P4 by using grout, injection curtain, waterloo barrier, sheet piling, etc.

- *Ex situ* excavation technologies
  - Mechanical excavation
  - Cutter-suction dredging with needed sizing preparation, pipelines, and water source
  - Thermal-hydraulic dredging with needed sizing preparation, pipelines, and water source

- *Ex situ* treatment technologies
  - On-site incineration
  - Drying/mechanical mixing with containment
  - A&W mud still batch process
  - Anoxic caustic hydrolysis, metals precipitation, filtration, and stabilization (LDR treatment plant)
  - Wet air oxidation (pilot tested by Zimpro®)

- Solvent stirred batch reactor
- Off-site incineration with associated railroad tank car loader/unloader

- Disposal technologies (considered for P4 waste that has already been treated)
  - On-site disposal in a CAMU or similar CERCLA unit
  - Off-site disposal

- Piping and railcars
  - Buried piping by using both *in situ* and *ex situ* approaches
  - Buried railcars by using both *in situ* and *ex situ* approaches

5.1 *IN SITU* TECHNOLOGIES (SUBSURFACE TREATMENT)

5.1.1 Thermal Treatment and Recovery

5.1.1.1 Description

The melting point of P4 is 44°C (111°F). On the basis of the CSM for the Furnace Building (see Section 2.4), the hot, liquid P4 percolated through the thick unsaturated zone reached the water table at a depth of about 80 ft and flowed to the northeast. Presumably, it cooled as it flowed as a result of heat transfer to both the unsaturated formation and the underlying groundwater. The result was a mass of waxy, solid P4 that filled the voids in the sediments at depth. The volume, thickness, and areal extent of this material are unknown. Presumably, a residual amount of solid P4 also remains in the unsaturated zone; this volume is completely uncharacterized.

Heating the subsurface P4 to a temperature above 44°C would cause it to flow and allow at least some of it to be recovered by using pumping wells. Inorganic hazardous constituents present would be brought to the surface along with the P4 mobilized by the heating method. Different options are available for heating the formation.

Thermal conduction that involves electrical heaters suspended in vertical holes is a technology that is used to remediate sites contaminated with volatile organic compounds (VOCs). In this situation, heating to a temperature of 100°C drives off the VOCs effectively. For example, in the largest *in situ* thermal desorption project undertaken to date (Heron et al. 2015), a 3.2-acre site was remediated by using more than 900 thermal conduction heater wells targeting multiple depths. Such heater borings and their casings can be installed by vibratory push or by augering. The treatment just mentioned lasted 238 days and required a total of 23 million kWh. Electrical heaters, along with recovery wells, have also been used in pilot studies of *in situ* retorting of oil shale. Electrical heaters are probably used only in vertical holes and not in directional drilling applications.

Electrical resistance heating has been used at VOC sites to bring the formation to steaming temperatures (>100°C) and drastically reduce VOC concentrations quickly (e.g., Tersus Environmental, LLC 2015). This approach relies on drilling or push methods to install electrodes in the subsurface. Electrical current flows among the electrodes in the target volume, which heats up. Recovery wells or a vacuum system at the surface are used to collect the VOCs. Formation temperatures above 44°C would melt P4.

Steam methods can also be used in remedial efforts or energy production. Steam can be used to target dense, nonaqueous-phase liquids in conjunction with the use of vapor recovery wells. In one example, 63 vertical or angled steam injection wells were used in a 3-acre target zone (Kramer et al. 2015). Steam has been used for many decades in enhanced oil recovery applications. The steam is used to heat the formation so that the hydrocarbons are more free-flowing and can be extracted more completely by pumping wells. It is possible to perform directional drilling in order to have wells be horizontal at a target depth. A series of parallel, horizontal steam injection wells through or just below the deep P4 at the Furnace Building could heat the P4 to temperatures above 44°C. Each horizontal steam well could be underlain by a horizontal recovery well, or a network of vertical wells could be installed over the treatment area, in order to recover some portion of the P4. However, the pumped water and molten P4 might not remain above 44°C during its transport to the surface, which would result in deposition of the P4 in the subsurface well casings.

Direction drilling is accomplished by using mud rotary drilling techniques. Formation material, including P4, would be circulated to the surface. The wet drilling mud would help prevent exposure of the drilling fluids to air, and the mud pit could be maintained with a covering of water, but there would be a degree of risk involved with managing the drilling fluid.

Recovery wells in any thermal application would need pumps that could handle a mixture of water and molten P4 (viscosity of 1.69 cP, specific gravity of 1.8) to be lifted almost 90 ft. The pumped P4 would need to remain above 44°C during its upward travel; presumably, it would remain warm due to the heat in the formation. Upon reaching the surface, the combined water and molten P4 would need to flow (remaining above 44°C) to a submerged discharge point in a water-containing water tank, trough, or impoundment. Here the P4 would settle, cool, and solidify below the water.

The heating methods just described, if initially applied to the unsaturated zone at the Furnace Building, would likely promote downward migration of the P4 to the cooled mass at a depth of about 80 ft. However, as discussed next, there is no current understanding of how much residual P4 remains in the thick unsaturated zone, and there is not yet any laboratory study to assess whether applying heat to a formation sample containing P4 would promote effective downward draining of the P4.

5.1.1.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

An important problem associated with any thermal application is that heating the deep P4 would allow it to flow. Without lateral containment, the mass of P4 would resume flowing with the hydraulic gradient. In addition, the injection of steam at or beneath the mass could result in a mounding of the equipotential surface, causing the P4 to flow radially in all directions. As discussed elsewhere, if the thick unsaturated zone could be removed (depending on the presence of residual P4, which has not been characterized) through a major earth-moving project in the Furnace Building vicinity, then containment could be implemented over a much smaller vertical work area.

It would be wise to invest in a pilot-scale laboratory study to determine whether P4 within alluvial sediments would drain through the sediments efficiently or if a significant proportion would be retained.

The consideration of a thermal method should be based on the understanding that, despite any efforts to extract the subsurface P4, much of the contaminant mass would remain in the subsurface. Inorganic hazardous constituents present in the P4 that could not be mobilized by the heating method would remain in the subsurface. This would occur even if the value of the recovered P4 was high enough to invest in a thorough amount of heating and a large number of recovery points. The amount remaining would be difficult to characterize safely because in past site characterizations, a precedent to avoid drilling into the P4 was set.

5.1.1.3 Assessment Based on ETT Review Parameters

The evaluation results are shown in Table 5-1.

5.1.1.4 Overall Likelihood of Success at FMC

Thermal treatment and recovery approaches at FMC would require a large investment for installing necessary equipment and creating a containment boundary, with or without large-scale overburden removal. The worker safety issues would be significant. In the end, much of the P4 would remain in place, although the amount would not be easy or safe to characterize, given the precedent set by past site characterization.

5.1.2 Solvent Leaching and Recovery Using Benign Solvents

5.1.2.1 Description

Conceptually, it is possible to leach a target material type from a formation by using a solvent and to extract the desired material by using pumping wells. Elemental phosphorus is soluble only sparingly in water. Hazardous inorganic constituents present in P4 would be soluble in water but only sparingly soluble in the organic solvents mentioned below. It is only slightly soluble in alcohol (C_2H_6O), ether, and benzene (C_6H_6). It is very soluble in carbon disulfide (CS_2), phosphorus chloride (PCl_3), phosphorus oxychloride ($POCl_3$), liquid sulfur dioxide (SO_2),

TABLE 5-1 Assessment of Thermal Treatment and Recovery Based on ETT Review Parameters

Review Parameter	Thermal Treatment and Recovery
Process maturity	Mature for the remediation of some waste. The potential application of the technology for the treatment of P4 waste is conceptual only.
Limitations	Incomplete recovery. P4 mass is likely to spread unless containment is also applied. May or may not address residual P4 currently in the thick unsaturated zone.
Time to implement (not including permitting and approvals)	Estimated time is 5 years for installation, with or without large-scale earth-moving to remove much of overburden. Estimated time is 10 years for operations.
Effectiveness of removing and/or treating P4 in soil	Approach would collect some portion of the large subsurface mass for reuse; however, an unquantified but probably a large portion of the mass would remain.
Process safety for site workers during implementation	Methods that rely on augering or mud rotary drilling (i.e., directional drilling) would bring P4 to the surface, resulting in a significant health and safety issue. It is expected that if direct push methods were used, there would be only a minimal amount of P4 on withdrawn drill rod or casing, since they would be rubbed clean on clean, shallow soils. With regard to extracted P4, significant safety and management issues would need to be addressed.
Community health and safety during implementation	Management of any auger cuttings or mud pit drilling fluids would be a source of P4 and associated chemicals.
Impacts to the environment during implementation	There would be general impacts due to heavy equipment. The ultimate disposal of any drilling mud after processing for P4 would need to be addressed.
Post-implementation impacts on the environment and the community	These would not be significant.
Overall discussion of advantages and disadvantages	The main advantage would be that deep (>80-ft) subsurface P4-bearing zones could be remediated without the need for a large, open-pit-type excavation operation. Another advantage is that some portion of the deep P4 would be removed for reuse or sale. The disadvantages are: • incomplete recovery (i.e., much of the P4 would remain despite the effort and cost invested), • numerous safety concerns, • high cost of power for electrical methods, • mobilization of flowing P4 unless lateral containment is used, • high cost of containment, • high cost for possible removal of the overburden, and • the purity of the P4 that would be recovered is unknown.

and liquid ammonia (NH_3) (Rivera et al. 1996). Each of these chemicals, however, would significantly degrade groundwater quality; their use would probably not be permitted by regulators.

P4 is also soluble in turpentine or mineral oil (Merck Index 1952). Both of these have the additional benefit of wetting any particulates of P4 brought to the surface and thereby reducing their exposure to oxygen. They are also less dense than water, so they would remain on top of the water table, ideally within a containment cell around the remediation area. However, they are unlikely to be permitted for use because of the long-lasting impact they would have on groundwater in a large volume of the aquifer.

Another alternative is the use of food oils. P4 is soluble in almond oil and olive oil. Its solubility in other, less expensive oils has likely not been evaluated *(*Merck Index 2001*).*Table 5-2 lists the approximate prices for a range of food oils in 2015. Release of food oil in the subsurface would not result in the significant degradation of water quality that would be caused by the other types of solvents described above. Food oil would float on the water table, so it could remain within a containment cell as it is recirculated during the solvent leaching process. It would also coat any P4 particulates brought to the surface, limiting their contact with air.

Using solvents without having bounding containment could result in excessive losses of those solvents in lateral directions. This is a critical consideration with regard to any expensive, benign solvent. (See containment discussion in Section 5.1.4 regarding the potential use of a technology such as freeze walls, sealed sheet piling, a slurry wall, or a grout curtain.) It may be possible to excavate much of the overburden in the Furnace Building vicinity (depending on the presence of residual P4 in the thick unsaturated zone) to reduce the effort that would be needed to install a containment system.

TABLE 5-2 Approximate Prices for Food Oils in 2015

Oil	Approximate Price (U.S. $/metric ton)
Coconut	1,000
Olive	5,000
Palm kernel	1,000
Palm	600
Peanut	1,400
Rapeseed	700
Soybean	700
Sunflower	900

Source: IndexMundi (2015).

5.1.2.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

Note that solvent extraction was ruled out as a viable technology for the Rhodia (Silver Bow) white phosphorus site (Barr 2014).

The benign solvents mentioned above would have significant costs, since numerous tank cars would be required for a project having the estimated magnitude of the deep P4 project at the Furnace Building. The installation of a containment cell could reduce solvent losses but would be very expensive at the scale and depth required in the vicinity of the Furnace Building.

Laboratory studies of the solubility of P4 in food oils or other benign solvents would be necessary before making any further investment to study the solvent leaching approach.

The consideration of a solvent extraction method should be based on the understanding that, despite any efforts to extract the subsurface P4, much of the contaminant mass would remain in the subsurface because the circulation of solvents within the target zone would be incomplete due to incomplete dissolution of the P4 and especially due to textural heterogeneities in the subsurface geologic materials. These heterogeneities would result in the solvent being circulated more in coarser-grained zones and less in finer-grained zones. This would occur even if the value of the recovered P4 was high enough to invest in the approach and include a high number of recovery points. The amount remaining would be difficult to characterize safely because in past site characterizations, a precedent was set to avoid drilling into the P4.

5.1.2.3 Assessment Based on Review Parameters

The evaluation results are shown in Table 5-3.

5.1.2.4 Overall Likelihood of Success at FMC

Solvent extraction methods at FMC would require a large investment to purchase sufficient quantities of an appropriate benign solvent, the installation of necessary equipment, and the creation of a containment boundary with or without large-scale overburden removal. The worker safety issues would be significant. In the end, much of the P4 would remain in place, although the amount would not be easy or safe to characterize, given the precedent set during past site characterization.

5.1.3 *In situ* Oxidation of P4

5.1.3.1 Description

A possible *in situ* remediation concept relevant to the FMC site is the in-place oxidation of white phosphorus and the recovery of the reaction products via a system of injection/extraction wells. The development of such a method could be achieved by adapting the proven methods and technologies used in the *in situ* oxidative leach mining of uranium and copper (e.g., IAEA 2001). This approach would involve delivering a heated oxidant-bearing solvent (e.g., oxygenated groundwater) to the P4-contaminated zone at a controlled rate and recovering the reaction products via a set of injection and extraction wells. The oxidant solution would be heated to greater than 45°C to cause the P4 grains or masses to melt; this would facilitate water flow and mixing and avoid the formation of phosphorus oxide rinds that are known to inhibit oxidation.

TABLE 5-3 Assessment of Solvent Leaching and Recovery Using Benign Solvent Based on ETT Review Parameters

Review Parameter	Solvent Leaching and Recovery Using Benign Solvents
Process maturity	Mature for broadly defined solvent leaching. Immature for use of food oils. Application of the technology to address P4 waste is conceptual only.
Limitations	Incomplete recovery. P4 mass is likely to spread unless containment is also applied. Residual P4 currently in the thick unsaturated zone may or may not be addressed.
Time to implement (not including permitting and approvals)	Estimated time is 5 years for installation, with or without large-scale earth-moving to remove much of the overburden. Estimated time is 10 years for operations.
Effectiveness of removing and/or treating P4 in soil	Approach would collect some portion of the large subsurface mass for reuse; however, an unquantified but probably a large portion of the mass would remain.
Process safety for site workers during implementation	Well installation that relies on augering or mud rotary drilling would bring P4 to the surface, resulting in a significant health and safety issue. It is expected that if direct push methods were used, there would be only a minimal amount of P4 on withdrawn drill rod or casing, since they would be rubbed clean on clean, shallow soils. With regard to the P4 dissolved in the benign solvent, significant safety and management issues would need to be addressed.
Community health and safety during implementation	Management of any auger cuttings or mud pit drilling fluids would be a source of P4 and associated chemicals.
Impacts to the environment during implementation	There would be general impacts due to heavy equipment. The ultimate disposal of any drilling mud after processing for P4 and the ultimate disposal of benign solvent would need to be addressed.

TABLE 5-3 (Cont.)

Review Parameter	Solvent Leaching and Recovery Using Benign Solvents
Post-implementation impacts on the environment and the community	Not applicable.
Overall discussion of advantages and disadvantages	The main advantage would be that deep (>80-ft) subsurface P4-bearing zones could be remediated without the need for a large, open-pit-type excavation operation. Another advantage would be that some portion of the deep P4 would be removed for reuse or sale. The disadvantages would be: • incomplete recovery (i.e., much of the P4 would remain despite the effort and cost invested), • numerous safety concerns, • high cost of benign solvent, • mobilization of dissolved-phase P4 unless lateral containment was used, • high cost of containment, and • high cost for possible removal of the overburden.

A conceptual picture of how this method could be applied to a deep subsurface white phosphorus mass at the FMC site is shown in Figure 5-1. The top image in the figure shows a plan view of one of the many types of injection/extraction well patterns used for *in situ* leach mining along with idealized water flow paths. The middle image is a schematic cross section through a deep subsurface P4-contaminated zone, such as that associated with the Furnace Building (RU 1, RU 2, RA-B) at the FMC site. The bottom image is a schematic drawing of the key processes at the soil/sediment grain scale, which involve both the melting and oxidation of P4 particles.

The recovered products would consist primarily of hypophosphorus acid (H_3PO_2), phosphorus acid (H_3PO_3), and phosphoric acid (H_3PO_4), which could be neutralized by an ancillary process such as the one shown in Figure 5-2. After the solution has been neutralized, it would be refortified with the oxidant and reused at the extraction site. Due to the possible release of P4 vapor, phosphine gas, and P_2O_5 smoke, the extraction well area would probably need to be enclosed within a pitched structure equipped with appropriate air monitoring and gas treatment capabilities (see ancillary processes described in Section 5.2.1). The effectiveness of this method would be assessed by monitoring the phosphorus content of the effluent at the extraction wells and also the exploratory bore holes around the extraction zone to determine the zone of influence of the injection well.

In the *in situ* leach mining industry, the most effective method for avoiding the unwanted spread of the solvent or product within an aquifer is hydraulic isolation (hydraulic barrier) (IAEA 2001). This involves a set of auxiliary injection and extraction wells strategically placed (possibly vertically staged) to direct flow in the desired direction and to remove any potentially contaminated solutions that are missed by the primary product extraction wells. It is anticipated that a hydraulic barrier well system would be needed at the FMC site.

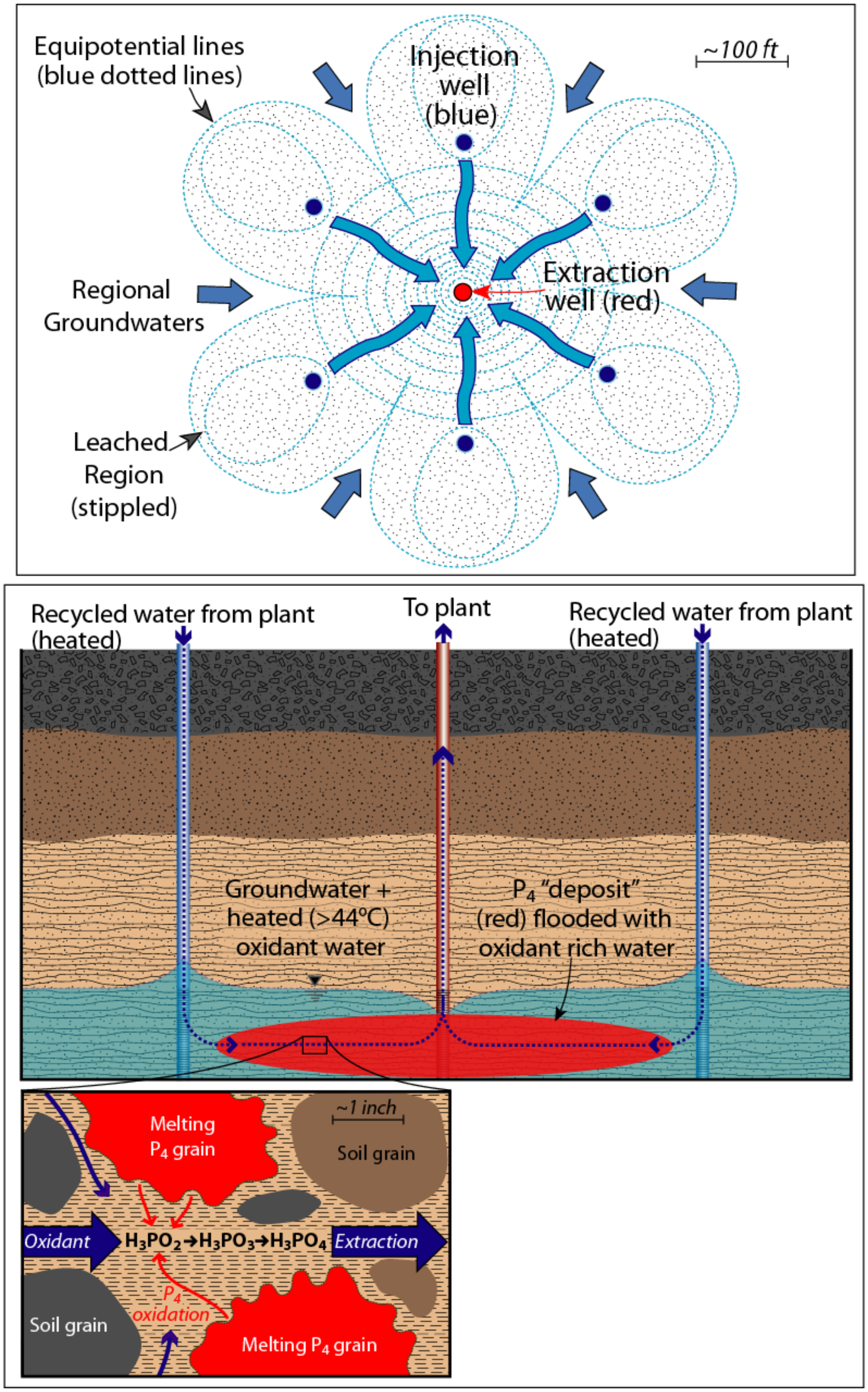

FIGURE 5-1 Conceptual Diagram of *In situ* Oxidation of P4 Based on Analogy with Oxidative Leach Mining (The map at the top is a view of a commonly used well pattern [IAEA 2001]. The cross section in the middle roughly represents the P4 contamination associated with Furnace Building RA-B. The schematic at the bottom highlights key processes at the grain scale.)

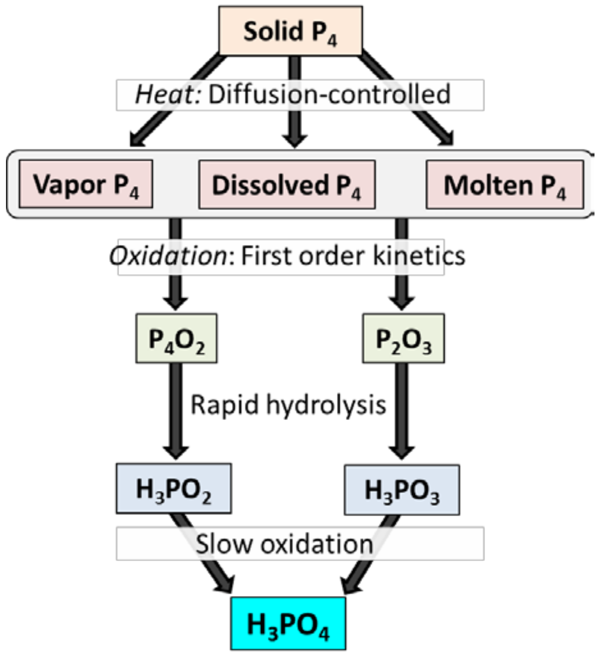

FIGURE 5-2 Reaction Path Diagram (This summarizes the key reactions that must be accounted for in the development and implementation of white phosphorus remediation by *in situ* oxidation.)
(Source: Adapted from Sullivan et al. 1979)

The oxidation reactions for converting white phosphorus to phosphoric acid are well known, and their rates can be moderated by hosting the reactions within a solvent such as water. The use of water mitigates the major hazard involved with this treatment method, which is the ignition and uncontrolled burning (and associated toxic gas release) of the subsurface white phosphorus. The water pumped into the P4-bearing zone would be heated to a temperature higher than the melting point of white phosphorus (44°C) to avoid the formation of oxide layers that act as oxidant diffusion barriers and to increase the contact of the oxygenated water with P4 grains.

The only practical solvent to use for this technique would be local groundwater; however, there are a number of relevant oxidants that could be used. Ozone (O_3) and sodium hypochlorite (NaClO) are the top examples of alternative oxidants, and both have been shown to increase the rate of white phosphorus oxidation relative to dissolved oxygen. Experiments have shown that the rate of oxidation of white phosphorus by dissolved oxygen can be described, in general, by first-order reaction kinetics. The details of the major reaction pathways that must be quantified and accounted for in designing oxidative treatment methods for white phosphorus are summarized in Figure 5-2. In addition, pH and temperature also play key rate-determining roles.

For this method to work efficiently, the oxygenated water needs to be supplied to the P4 zone at a rate faster than it is depleted by the oxidation reactions. Determining this flow rate (rate of injection/extraction) must be based on a detailed hydrologic investigation of the contaminated soil/sediment volume of interest. Furthermore, to fully assess the applicability of *in situ* oxidation of white phosphorus, the amount of oxygen naturally taken up by the host soil/sediment matrix (oxygen demand), the pore water pH, and the buffering capacity must be known.

Therefore, the design and implementation of an *in situ* oxidative remediation method for white phosphorus would require a significant number of both laboratory and field investigations. The stages involved to design this method would be similar to those used to design *in situ* leach mining operations, as summarized in Table 5-4.

TABLE 5-4 Principal Stages in a Design Study for *In situ* Leach Mining[a]

Stage of Exploration	Investigation Target	Investigation Task	Major Research Type
Initial evaluation	Conduct preliminary feasibility study	Determine leaching properties of representative samples of deposit and host aquifer materials	Conduct laboratory leach tests on core samples
Preliminary investigation	Establish feasibility: Justify parameters for *in situ* field tests and select appropriate test sites	Determine leaching properties of host aquifer as part of controlled field tests	Conduct *in situ* leach testing without processing the target deposit
Detailed investigation	Synthesize field and laboratory test results and design full-scale operation	Develop a quantitative, predictive model of the entire operation (i.e., full-scale leaching and recovery of deposit material)	Conduct pilot tests within the deposit to confirm key sensitivities of the model
Implementation	Implement full-scale operations based on pilot-test results and model sensitivities	Use the model to optimize process parameters	Optimize parameters based on recovery efficiency

[a] Adapted from IAEA (2001). The same design approach would be used to develop an *in situ* oxidation and leaching operation for deep subsurface white phosphorus.

5.1.3.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

This *in situ*-method is most appropriate for deep subsurface white-phosphorus-contaminated zones that are not amenable to excavation. Specifically, it is for the deep (>80-ft) subsurface phosphorus mass present at the capillary fringe downgradient from the Furnace Building in RU 1 and RA-B. It is also conceivable that an oxidant leach method could be developed for contaminated zones in the railroad swale (RU 22c, RA-G), because in the swale, excavation is complicated by the impracticality of flooding that location.

Site-specific pilot studies would be required to demonstrate the feasibility of this method. The chemistry is well known from bench-scale experiments, but it is unclear how the kinetics of key reactions would be influenced by the physical and chemical characteristics of the P4-hosting soils and sediments. Furthermore, the hydrology of the white-phosphorus-bearing zones needs to be well understood to design the injection/extraction well system. A recommended first step in further evaluating this method would be to have technical discussions with experts from the *in situ* leach mining industry.

5.1.3.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-5.

5.1.3.4 Overall Likelihood of Success at FMC

With a number of years of well-planned pilot studies and a detailed site characterization project, this method could probably be successfully implemented at RA-B and RA-G of the FMC site. It is anticipated that the main difficulty would be quantifying the extent of decontamination after the method was implemented.

5.1.4 Containment Technologies

5.1.4.1 Description

P4 waste is present at the FMC site primarily in the form of a waxy solid. It is therefore essentially immobile, since its solubility is very low. Very little P4 mass is being transported in the groundwater at FMC, and a containment technology is not needed for the P4 itself. But containment technologies might be necessary, depending on the type of remedial design. For example, *in situ* treatment technologies involving the use of solvents would benefit from a containment system to isolate the treatment area, preventing both the solvent and the target compound from escaping and blocking groundwater flow into the treatment zone.

TABLE 5-5 Assessment of *In situ* Oxidant Leaching Based on ETT Review Parameters

Review Parameter	*In situ* Oxidant Leaching
Process maturity	This was tested at laboratory scale but not tested at full scale for P4 treatment. It requires pilot tests.
Limitations	There is a danger of causing the ignition and uncontrolled burning of subsurface white phosphorus. This hazard would be mitigated by delivering the oxidant in an aqueous solution that is hot enough to melt the P4 and thus facilitate good mixing with the solution. It would also be difficult to quantify the success of the method (i.e., the extent of decontamination). A significant number of exploratory drill holes would be required, both before and after the method was implemented.
Time to implement (not including permitting and approvals)	Due to the lack of maturity of this method and the need for pilot studies and a detailed site characterization, the implementation of this method would probably require 3 or more years.
Effectiveness of removing and/or treating P4 in soil	This method is known to work at laboratory scale, but an *in situ* application would require pilot-scale studies to determine if the favorable reaction kinetics would scale up and apply in a heterogeneous soil/sediment matrix. The effectiveness of this method would be assessed by monitoring the phosphorus content of the effluent at the extraction wells and exploratory auger holes around the extraction zone to determine the zone of influence of the injection well.
Process safety for site workers during implementation	There would be a high risk to site workers due to P4 ignition (burns), phosphine released from disturbed soils (poisoning), and P_2O_5/phosphoric acid generation (acid inhalation). The risk would be mitigated by keeping all P4-bearing materials saturated and under water and by capturing and treating gases and appropriate PPE.
Community health and safety during implementation	Unmitigated risk would be high due to the possible release of particulate P4, phosphine, and P_2O_5/phosphoric acid vapors. The risk would be mitigated by enclosing the injection/extraction well site and off-gas treatment process.
Impacts to the environment during implementation	Unmitigated risk would be significant. Air quality could be affected by the release of particulate P4, phosphine, and P_2O_5/phosphoric acid vapors. Groundwater could be affected by the downward transport of contaminants, with infiltration occurring below the injection wells. The risk would be mitigated by containment of the site and gas treatment and hydraulic containment wells (P&T).
Post-implementation impacts on the environment and the community	The region where this method was applied would contain a large number of boreholes, and the local groundwater table would be disturbed by the injection/extraction wells. There is a possibility the phosphoric acid would be transported away from the injection well region, which could be detrimental to local ecosystem. This hazard would be mitigated by properly designing the extraction well system. If this method is successful, no long-term effects from it are predicted.

TABLE 5-5 (Cont.)

Review Parameter	*In situ* Oxidant Leaching
Overall discussion of advantages and disadvantages	The main advantage would be that deep (>80-ft) subsurface P4-bearing zones could be remediated without the need for a large, open-pit-type excavation operation. The chemistry is well known and deactivates the main hazard associated with P4: its pyrophoric nature. This ETT would probably be acceptable from a permitting standpoint, with a risk mitigation plan based on proven technologies (air treatment enclosure, hydraulic containment wells, and/or hydrologic/reactive barriers) and with successful pilot studies having been performed and having received appropriate quality assurance/quality control. The disadvantages would be the: • need for pilot studies, • considerable effort needed for site characterization, • difficultly in quantifying the extent of P4 decontamination after the method was implemented, and • hazards involved with a possible run-away oxidation reaction leading to ignition and an uncontrolled burn.

One type of containment technology is known as freeze wall. Freeze wall technology has been used in environmental and energy applications (e.g., to stop contaminated groundwater discharge at Fukushima or to establish cell boundaries during *in situ* oil shale retorting) to create a flow barrier by chilling the formation to freeze the groundwater. This involves drilling numerous vertical holes for circulating refrigerant. It requires a significant amount of electrical power. It is possible to install a freeze wall to a great depth; some applications cover several hundred vertical feet.

A second type of containment technology is sheet piling. Sheet piling involves interconnected steel pieces being successively driven into the subsurface to create a wall. With the use of tiebacks, the wall height can be about 10 ft if excavation takes place along one side of the wall. Reaching great depths would necessitate a series of telescoping lifts.

A third type of containment technology is a slurry wall. This is constructed by a trencher that can reach down to 80 ft in depth (Dewind 2015). As the trench is excavated, it is backfilled with low-permeability materials to create a groundwater flow barrier.

5.1.4.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

At FMC, containment technology could be used in conjunction with *in situ* remedial technologies to address the deep P4 at the Furnace Building. For example, solvent extraction performed in the Furnace Building vicinity would benefit from the installation of some type of containment to prevent lateral losses of the solvent liquid. The cost of containment would be significant, however, and the cost of estimated benign solvent losses over the duration of remediation would need to be compared with the cost of containment.

The cost of containment could be significantly reduced if different approaches were used in the thick unsaturated zone instead of the capillary fringe approach. For example, if careful site characterization indicated that the unsaturated zone had negligible amounts of P4, then excavation to remove the overburden could reduce the overburden's thickness above the concentrated P4 at the capillary fringe from about 80 ft to, for example, 20 ft. Thus a layer of alluvial deposits would be maintained between workers and the P4, and ideally air would not be allowed to diffuse down into the concentrated P4. Although the earth-moving costs would be substantial, the containment would be much more cost effective, and the volume of solvent would be greatly reduced. The amount of P4 present in the overburden, however, could be significant, as described in Section 5.2.

At FMC, during the installation of a freeze wall to support benign solvent extraction at the Furnace Building, drilling (augering) through subsurface P4 would need to be avoided. Because the site is poorly characterized, the overall length of the bounding freeze wall cannot be optimally reduced. The areal extent of assumed P4 in the capillary zone suggests that a freeze wall would be cost-prohibitive due to installation and operational (i.e., power) costs. At FMC, a freeze wall could be installed to a depth below the P4 at the capillary fringe (i.e., to a depth of about 90 ft below current grade). One consideration related to a freeze wall is that it would be unbounded across the bottom of the established treatment cell. The use of a benign solvent lighter than water would allow the solvent to remain in the cell if the freeze wall extended into the saturated zone, since the solvent would be buoyed up by the groundwater.

Multiple sheet pile cells would need to be nested together with successively smaller areas in order to reach P4 at about 80 ft deep. Coarse gravel can be penetrated during the installation of sheet piling. Cobbles can be handled, but boulders cannot (Lee 2015). The Waterloo barrier® is a special form of sheet piling that involves the injection of a sealant into a sheet pile wall during its construction. This would improve the performance of a sheet pile containment wall in the lateral direction. A rough estimate of the cost of a Waterloo barrier is $35 (Canadian) per vertical square foot installed (Lee 2015). At FMC, this technology could be used only if the upper 60 to 70 ft of the unsaturated zone had negligible amounts of P4. Otherwise, each telescoping sheet pile cell extending from the current ground surface would need an unbounded bottom, and benign solvents used in solvent extraction would be expected to have continuous downward losses.

The deep trencher would not reach the full thickness of the P4 at the water table. Approximately 10 ft of surficial material would need to be removed to allow the equipment to reach the proper depth a bit below the deep P4 deposit. If the unsaturated zone did not have any significant P4 contamination, then large-scale earth-moving could be performed to remove alluvium and allow the capillary fringe depth to be reached with a shallower trench.

A containment barrier could also be installed as a grout curtain. In this approach, injection tubes are pushed into the subsurface, and grout is injected across a desired depth interval. Injection holes are spaced sufficiently close to create a barrier to groundwater flow.

5.1.4.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-6.

5.1.4.4 Overall Likelihood of Success at FMC

Although the extent of the concentrated P4 at the capillary fringe zone has not been characterized, the estimated mass and concentration of P4 (shown in Figure 2-2) suggest that it could be present in an area measuring roughly 900 × 600 ft. The cost for using any one of the three containment technologies to support benign solvent extraction, therefore, would be prohibitive. The cost for large-scale earth-moving of the overburden materials (if it is determined that they do not have a significant amount of P4) would be substantial, but it would result in a tremendous savings over the cost of any other selected containment method.

TABLE 5-6 Assessment of Containment Technologies Based on ETT Review Parameters

Review Parameter	Containment Technologies
Process maturity	Mature, but the technology has never been applied to P4 waste.
Limitations	• These technologies do not excavate or remediate, but they could be used in conjunction with *in situ* remediation technologies to address deep P4. • The NPV estimate for Alternatives 5 through 7 in the September 2010 *Proposed Plan* would be a comparable to the OOM estimate to implement this ETT in conjunction with an excavation, treatment, and disposal ETT.
Time to implement (not including permitting and approvals)	Identifying a containment approach could take up to 1 year. Estimated time is 5 years for installation, with or without large-scale earth-moving to remove much of the overburden.
Effectiveness of removing and/or treating P4 in soil	Not applicable.
Process safety for site workers during implementation	The degree of safety would be tied to how conservatively large the containment boundary surrounding the poorly characterized Furnace Building vicinity was, and to whether P4 was present in the thick unsaturated zone or whether it was not (which would allow for safe earth-moving).
Community health and safety during implementation	Not applicable.
Impacts to the environment during implementation	There would be general impacts due to heavy equipment. Drill cutting disposal would be associated with a freeze wall and deep trenching.
Post-implementation impacts on the environment and the community	Not applicable.
Overall discussion of advantages and disadvantages	A possible advantage would be the conservation of expensive benign solvent or the containment of heated, flowing P4. Disadvantages would be the high cost of installation for all three methods and the high cost of power for a freeze wall. The cost could be reduced if a large portion of the overburden could be excavated safely (which would depend on whether there was uncharacterized P4 in the thick unsaturated zone).

5.2 *EX SITU* EXCAVATION TECHNOLOGIES

5.2.1 Ancillary Technologies

In order for P4 waste (i.e., waste or soil or debris contaminated with P4) to be treated by an *ex situ* technology, a suite of ancillary technologies would have to be applied to excavate, store, sample, size, and blend excavated waste to meet the acceptance criteria of the treatment technology selected. The excavation of P4 waste would produce process residuals that would require treatment. Before the excavation project could be started, a strategy for treating excavated waste as part of, or in parallel with, excavation would need to be determined in order to avoid the accumulation of any new hazardous materials. The three main process residual streams that would have to be treated during excavation are as follows:

1. Phosphine (PH_3) and P4 gases, which accumulate due to disproportionation and sublimation of P4 and are released when P4-rich materials are disturbed;

2. Phosphorus pentoxide (P_2O_5) gas from P4 oxidation, which reacts with water to form phosphoric acid; and

3. Aqueous solutions with minor amounts of dissolved and particulate P4 (phossy water).

These process residual streams can be treated by straightforward, well-established chemical processes, examples of which are summarized in Figures 5-3, 5-4, and 5-5. Conventionally, the phosphine and P4 gas residuals are destroyed in a ~750°C thermal oxidizer, and the resulting P_2O_5 can be converted to phosphoric acid in an in-line quenching chamber (Franklin Engineering Group 2007). The resulting phosphoric acid can be marketed as a product or neutralized by using calcium hydroxide or an equivalent base.

Aqueous solutions that have come in contact with white-phosphorus-bearing materials will contain relatively low concentrations (mg/L range) of dissolved and suspended P4. These solutions are conventionally treated in a hydrolysis reactor that converts P4 to phosphine (Franklin Engineering Group 2007). The phosphine can then be burned in the thermal oxidation process (Figure 5-3). For a more detailed summary of the three processes shown in Figures 5-3 through 5-5, see Franklin Engineering Group (2007).

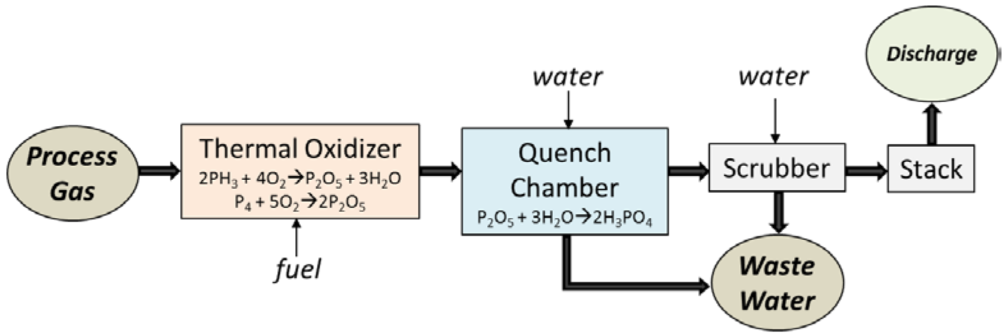

FIGURE 5-3 Generic Flow Diagram for Treating P4-, P_2O_5-, H_3PO_4-, and PH_3-Bearing Gases Released during the Excavation of White-Phosphorus-Rich Materials (Source: Adapted from Franklin Engineering Group 2007)

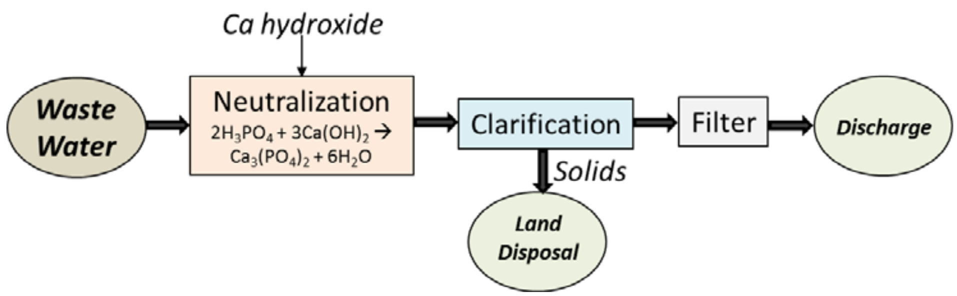

FIGURE 5-4 Generic Flow Diagram for Treating Phosphoric Acid Wastewater Produced from Treating Gases Captured during the Excavation of White-Phosphorus-Rich Materials (Source: Adapted from Franklin Engineering Group 2007)

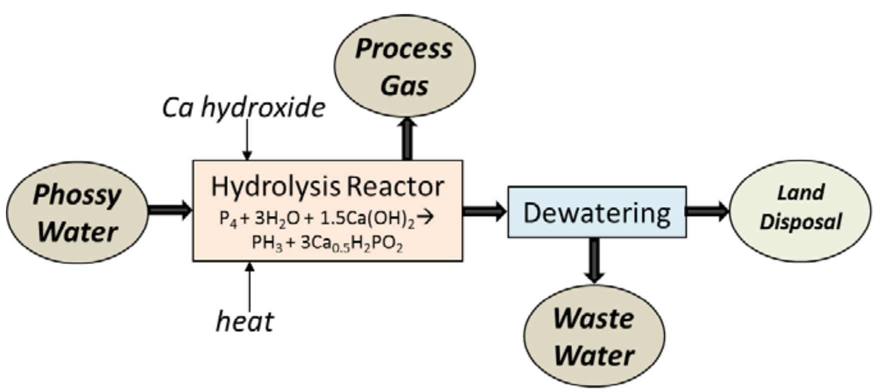

FIGURE 5-5 Generic Flow Diagram for Treating P4-Bearing Water Produced during the Excavation of White-Phosphorus-Bearing Materials (Source: Adapted from Franklin Engineering Group 2007)

5.2.2 Mechanical Excavation Technologies

5.2.2.1 Description

Traditional earth-working equipment could be used to excavate and move material contaminated with white phosphorus, provided that the hazards posed by its pyrophoric nature and corrosive reactive off-gases were mitigated. Mechanical excavation could proceed with tracked or wheeled vehicles (backhoes, front-end loaders, bulldozers, crane/clamshells, bobcat-type units, etc.). Excavation footprints could be accessed by using layback excavation benches, shoring, freeze walls, and trench boxes. Trench boxes and shoring might be particularly effective for excavating a linear feature like an underground pipeline. Materials containing approximately 1,000 mg/kg or more of P4 are hazardous and would thus require specific hazard mitigation steps (FMC 2009). The pyrophoric hazard could be mitigated by performing the excavation when ambient temperatures are below 30°C (or by controlling temperature in a temporary structure erected over the excavation site) and/or by keeping the white-phosphorus-bearing materials covered and saturated with water, while the off-gas from the excavation site could be captured and treated. The off-gas treatment would involve enclosing the excavation site in a temporary structure with a slight negative pressure and passing the enclosure atmosphere through an air pollution control system. One approach for using a temporary structure is described in Section 5.3.2, "Drying/Mechanical Mixing with Containment." A generalized flow diagram for a typical treatment process for gases released during the mechanical excavation of white phosphorus is shown in Figure 5-3.

Ideally, the heavy equipment used for excavating white phosphorus materials would be autonomous or remotely operated to minimize risk to workers, and any personnel within the excavation enclosure would wear PPE appropriate for working with white phosphorus, airborne P_2O_5 particulate, phosphoric acid vapors, and phosphine gas. Remotely operated equipment is available commercially. The selection of equipment is somewhat limited, but the equipment has been used at the Hanford Reservation (Badden and Seely 2010) in Washington State. Mechanical excavation would also produce an aqueous process stream that would require treatment. Any water that would come into contact with the phosphorus-bearing materials might contain dissolved and/or particulate white phosphorus as well as other contaminant metals and thus would have to be captured and treated. A standard process for treating water that has come into contact with elemental phosphorus is summarized in Figure 5-5. The water that is treated for white phosphorus could then be returned to the excavation site.

Controlled experiments and field observations indicate that that soils and sediments containing less than 1,000 mg/kg of white phosphorus do not smoke (Appendix K of FMC 2009); that is, they do not emit observable amounts of P_2O_5. Therefore, it is likely that the excavation of materials containing less than 0.1 weight percent (wt%) P4 would not require an enclosure or gas treatment. However, thorough characterization of the materials in question would need to be performed prior to open-air excavation. Furthermore, phosphine gas is colorless, and it can be released when P4-bearing materials are disturbed. Tests for subsurface phosphine and aboveground monitoring should thus be performed even at excavation sites shown to contain relatively low concentrations of white phosphorus.

5.2.2.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

With proper hazard mitigation, mechanical excavation would be applicable to all of the contaminated regions, except possibly the deep (i.e., more than 80 ft deep) subsurface phosphorus mass present at the capillary fringe downgradient from the Furnace Building in RU-A and RU-B. Exhumation of the P4 at the capillary fringe would require a pit that is 90 ft deep and 1,500 ft in diameter and the removal of 2.5 million yd^3 of potentially contaminated soil/fill (FMC 2010).

Excavation of white-phosphorus-bearing material in the railroad swale (RU 22c, RA-G) would likely have to be performed by mechanical excavation due to the impracticality of dredging a site that does not lend itself to flooding and contains coarse-grained gravels throughout the subsurface. As discussed next, the most promising excavation technique for the former ponds (RU 22b, RA-C) is likely cutter suction dredging, but mechanical excavation would still be needed to prepare the pond sites for flooding and perhaps to remove slag layers that overlie the P4-bearing pond sludge/sediments.

Mechanical excavation would also be the only applicable method for the white-phosphorus-bearing railcars buried in the slag pile. This would likely involve the removal of most of the slag (~300,000 yd^3, according to FMC 2010) by open-air excavation (justified by low concentrations of P4), followed by excavation, removal, and/or *in situ* treatment of the railcars within a negative pressure enclosure and an associated off-gas treatment process.

In all applicable regions, the initial excavation effort would likely involve removing an overburden consisting of variable thicknesses of slag, soil, and, in some areas, asphalt and concrete. If it is known that the overburden materials are free of P4, they could be removed by open-air mechanical excavation. Excavated residuals that were only slightly contaminated with P4 might be able to be treated by mechanical mixing with containment, as discussed in Section 5.3.2. However, when excavation approached horizons known or suspected to contain ≥0.1 wt% P4, appropriate hazard mitigation systems (excavation enclosure, gas and residuals treatment) should be in place. The excavation project would be coupled to one or more *ex situ* treatment processes (discussed next) to provide a constant feed of materials.

5.2.2.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-7.

5.2.2.4 Overall Likelihood of Success at FMC

Mechanical excavation has been used historically at the FMC site to maintain white-phosphorus-bearing impoundments (ponds) and is currently being used in recent and ongoing regrading activities. Furthermore, during the construction of the LDR plant, approximately 6 yd^3 of white-phosphorus-bearing materials were mechanically excavated, transferred to 55-gal drums, and shipped off site for incineration (FMC 2009). Therefore, there is a precedent for

TABLE 5-7 Assessment of Mechanical Excavation Based on ETT Review Parameters

Review Parameter	Mechanical Excavation
Process maturity	Mature.
Limitations	• There are worker health and safety limitations. P4 must be kept under water to avoid ignition; high levels of phosphine gas can be released when P4 materials are disturbed; and the P_2O_5 from inevitable P4 burning reacts with moisture to form phosphoric acid. • The major limitation of mechanical excavation with regard to former pond sites is that, once they are flooded, the P4- bearing layers would probably not support the weight of heavy equipment. • The NPV estimate for Alternatives 5 through 7 in the September 2010 Proposed Plan would be a comparable OOM estimate to implement this ETT in conjunction with a treatment and disposal ETT.
Time to implement (not including permitting and approvals)	Could be implemented immediately.
Effectiveness of removing and/or treating P4 in soil	Would remove P4 waste. Would not remove hazardous characteristics of materials. Requires a treatment ETT to treat P4.
Process safety for site workers during implementation	There would be a high risk to site workers due to P4 ignition (burns), phosphine released from disturbed soils (poisoning), and P_2O_5/phosphoric acid generation (acid inhalation). The risk could be mitigated by flooding the excavation site, capturing and treating gases, and using appropriate PPE.
Community health and safety during implementation	Unmitigated risk would be high due to the possible release of particulate P4, phosphine, and P_2O_5/phosphoric acid vapors. The risk would be mitigated by enclosing the excavation site and using an off-gas treatment process.
Impacts to the environment during implementation	Unmitigated risk would be significant. Air quality could be affected by the release of particulate P4, phosphine, and P_2O_5/phosphoric acid vapors. Groundwater could be affected by the downward transport of contaminants, with infiltration occurring below the flooded excavation site. The risk would be mitigated by containment of the excavation site, gas treatment, and the use of hydraulic containment wells (P&T).
Post-implementation impacts on the environment and the community	None. The excavated site would be filled with uncontaminated (treated) soil.
Overall discussion of advantages and disadvantages	The main advantage of mechanical excavation methods over hydraulic ones is their simplicity. Mechanical excavation does not require suction pump systems that must be maintained and can be clogged by oversized debris. The main disadvantage is the high safety and environmental risks associated with P4 ignition, phosphine gas, P_2O_5/acid vapors, and contaminant transport beneath the excavation site. The mitigation of these hazards for sites with more than 1,000 mg/kg of P4 would require that the excavation site be fully enclosed in a negative-pressure enclosure with an attached air pollution treatment facility. Therefore, mechanical excavation would be most appropriate for regions with low concentrations of P4 (below 1,000 mg/kg) and regions that are not amenable to dredging.

using mechanical excavation to move P4-bearing materials at the FMC site. However, the excavation of the thousands of tons of white-phosphorus-rich materials in the former ponds and railroad swale would require new, large-scale hazard mitigation systems, such as flooding the excavation site with water and using gas capture and treatment.

A possible complication associated with any method that involves the use of large volumes of water at the excavation site is the transport of contaminants with the water that seeps into the subsurface below the excavation zone. In this scenario, soluble forms of contaminants (e.g., $HAsO_4^{2-}$, $HAsO_2$[aq], UO_2^{2+}) could be leached from the excavation volume and transported toward the water table by percolation. Hydraulic containment wells (pump and reuse at excavation site) and/or hydrologic/reactive barriers could be used to mitigate contaminant mobilization; however, the design of such barriers would need to be assessed on a site-by-site basis.

It is recognized that the use of mechanical excavation to extract the amount (more than 500,000 yd^3) of P4-bearing materials from the former ponds represents a unique challenge due to the fire and off-gas hazards. These hazards could be largely mitigated, however, by using existing technologies. The major limitation of mechanical excavation at the FMC site is that the soft, water-saturated, white-phosphorus-bearing soil/sludge materials would probably not support the weight of heavy equipment, such as backhoes and tracked excavators. (A rule-of-thumb weight for a two-wheeled backhoe capable of digging to a 15-ft depth is 15,000 lb, and most relevantly sized tracked excavators weigh more than this.) Since operating heavy equipment on a soft, unstable surface poses unacceptable risks, it is likely that long-reach excavators would be required to excavate the former ponds. Site-specific analyses are required to assess the applicability of standard long-reach excavators (with a 50- to 100-ft reach) to the former ponds. Pond 7S might prove to be particularly challenging due to its relatively large areal extent. Other complications associated with applying mechanical excavation to the FMC site include these:

- Inefficiency of physically “shoveling” hazardous mud while trying to avoid any localized drying that would lead to pyrophoric residues,
- Related complications of using remotely operated heavy machinery, and
- Installation and operation of a site enclosure and a gas capture/treatment system.

Mechanical excavation does have a significant advantage over methods that use pumping and pipelines (dredging and hydraulic exaction, discussed next) in that it does not require size reduction at the point of excavation and is not subject to shutdowns due to clogged pipes.

The overall likelihood of successfully using mechanical excavation, with constant water cover and off-gas treatment, at the FMC site is deemed high for all regions capable of supporting heavy machinery. It is envisioned that mechanical excavation would be used for site preparation and the removal of slag and other hard fill materials that contain only low or suspected amounts of white phosphorus. The removal of materials with P4 contents of more than 1 wt% (e.g., in the bulk of Ponds 1S, 2S, 3S, 4S, 5S, 6S, 7S, and 10S) would probably be accomplished most efficiently and safely by using a remotely operated hydraulic dredging technique.

5.2.3 Cutter Suction Dredging

5.2.3.1 Description

A cutter suction dredge is a slurry excavator consisting of a rotating cutter head fitted with an opening through which loosened materials are pumped. The cutter head is submerged in the water-saturated materials being dredged. The material is "chopped" by a steel cutter at the site of excavation to facilitate pumping of the excavated slurry.

Franklin Engineering Group (2007) reported that a long-reach excavator with a cutter suction dredge head was designed for use at the Glenn Springs white phosphorus site, while a remotely operated floating cutter suction dredge was designed for use at the FMC Idaho site. These dredge designs were targeted to provide the needed mass-per-time feeds for specific site treatment plants. The dredging plan for the FMC site involved producing and pumping a 3 to 8 wt% suspended solids slurry at 350 gallons per minute (gpm) to achieve an overall dredge rate of 113,400 gal of slurry per day (FMC 2000). The Glenn Springs dredging system was based on pumping 1,800 gpm of sludge by using an 8-in. pipeline that would allow for solids no larger than 3 in. The FMC dredge system pipeline was 4 in. in diameter and could allow 0.5-in. solids to pass. The dredging plans at both the Glenn Springs and the FMC sites involved a set of unit processes that ultimately dewatered the excavated slurries and returned the process water back to the excavation site to maintain the desired water level.

State-of-the-art, commercially available, cutter suction dredges designed specifically for use in contaminated ponds and lagoons might be directly applicable to the former ponds at the FMC site. Of specific interest are the small- to medium-sized, remotely operated units that come as either amphibious tracked dredges or pontoon-floated automated dredges. State-of-the-art, commercially available cutter suction dredges generally offer the following relevant features:

- Can be remote controlled by radio from 500 ft away or programmed for full automation,
- Have 40- to 60-horsepower submersible slurry pumps,
- Can sense and adjust to the topography of the pond bottom being dredged,
- Can automatically maintain the delivery of a constant solids concentration (10 to 30 wt% solids), and
- Contain only a minimal number of moving mechanical parts (there are only four moving parts on a typical modern remote dredge).

Two examples of commercially available dredge units are shown in Figures 5-6 and 5-7.

Treatment processes generally have an optimum waste acceptance criterion that should be met for the technology to work successfully. To operate efficiently and consistently, most white phosphorus treatment processes require a feed that is physically consistent in terms of particle size and solids concentration. This would require a feed preparation step between cutter suction dredging and treatment. FMC Patent 4,492,627 describes a sequence of technologies that could be used to produce a physically consistent process feed from cutter suction dredging of the former ponds at the FMC site. This patent shows that the slurry of P4-bearing rock and soil collected by a cutter suction dredge could be prepared for treatment by a number of separation steps, such as conducting physical screening, melting oversized masses of P4, and using hydrocyclones and centrifugation for particle size separation. Some of the key particle sizing steps detailed in FMC Patent 4,492,627 are summarized in Figure 5-8.

FIGURE 5-6 Tracked Radio-Remote-Controlled Cutter Suction Dredge (Source: Photos from Liquid Waste Technology, LLC, ROV SRD-6E specifications brochure)

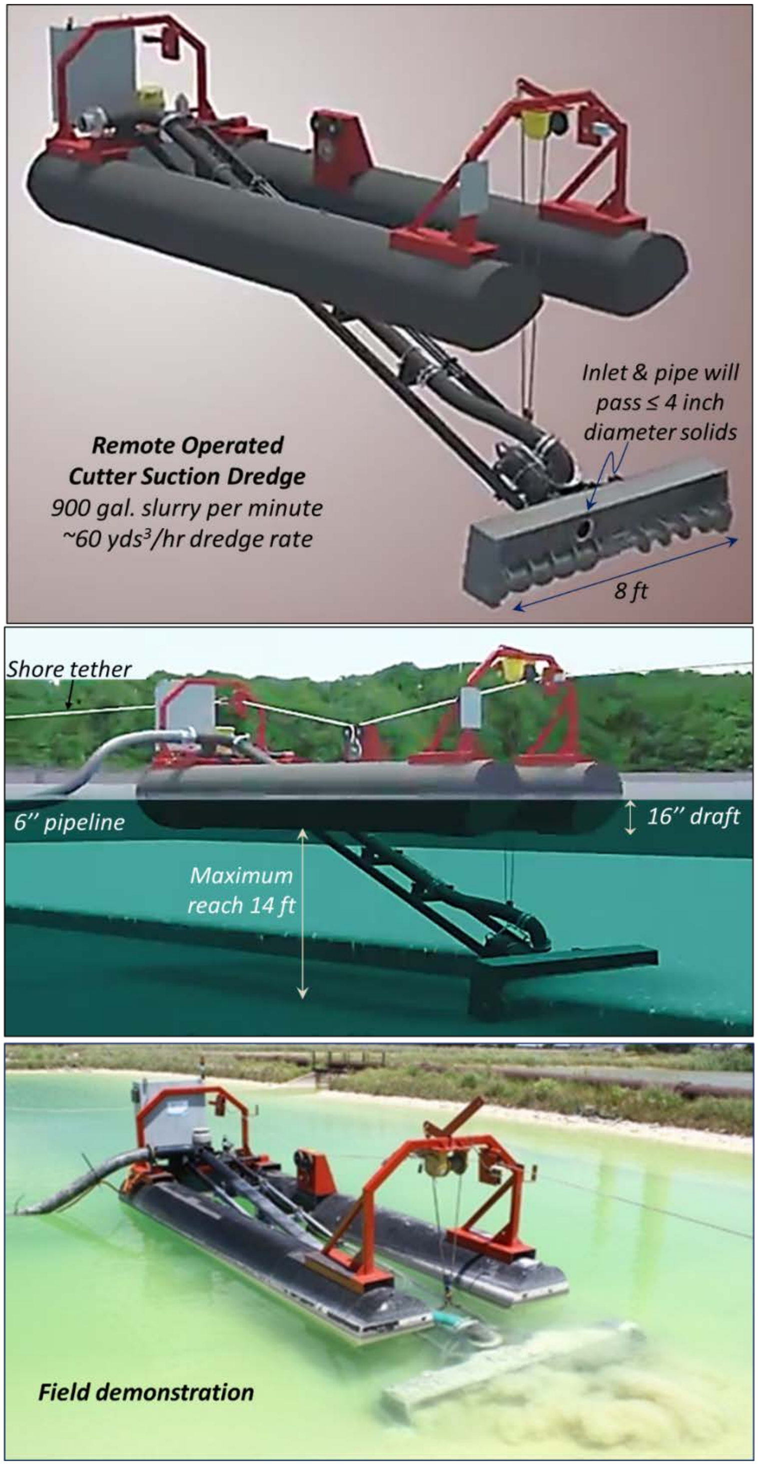

FIGURE 5-7 Pontoon Floated Radio-Remote-Controlled Cutter Suction Dredge (Source: Photos from Liquid Waste Technology, LLC, Mud Cat 50E specifications brochure)

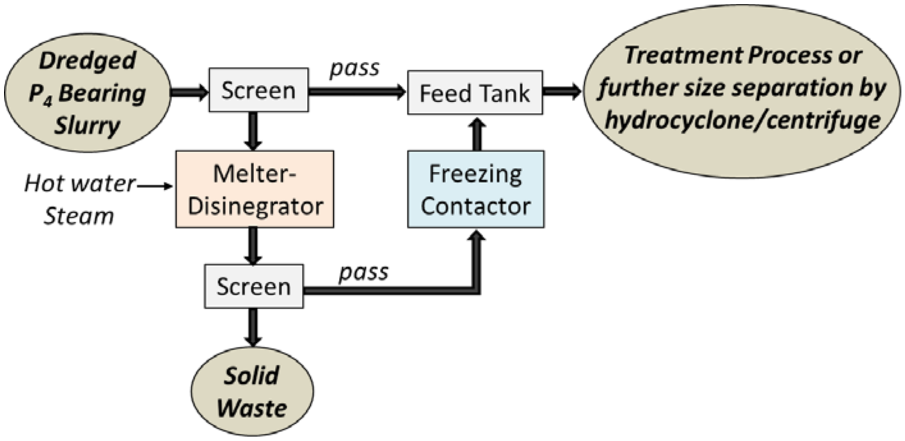

FIGURE 5-8 Generic Flow Diagram for Size Reduction Treatment before Chemical Processing (Source: Adapted from FMC Patent 4,492,627)

5.2.3.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

Cutter suction dredging is applicable to the former ponds in RU 22b (RA-C and RA-D), provided that they can be flooded so that a slurry of approximately 30 wt% (or less) of suspended solid can be produced at the excavation site. The three generic options for mounting the cutter suction head are:

- Tracked submersible excavators,
- Pontoon-mounted dredge, and
- Long-reach excavators.

Remotely operated, submersible, cutter suction excavators, such as the one shown in Figure 5-6, offer a good deal of flexibility and are directly applicable to all white-phosphorus-contaminated regions at the FMC site that are amenable to at least localized flooding. Remotely operated, pontoon-mounted, cutter suction dredges, such as the one shown in Figure 5-7, are also directly applicable to the FMC site but would require at least 16 in. of freeboard water to operate. An advantage of the floated dredges is that the cutter suction head can be mounted on a winch-controlled boom that can readily reach 14-ft depths, and commercially available units can be customized for deeper maximum reaches. The long-reach, excavator-mounted cutter suction dredge is probably the least promising of the three types because it would be considerably more complicated to operate and could be difficult to properly stabilize along the soft mud banks of the ponds being excavated.

Figure 5-9 is a conceptual diagram for the use of cutter suction dredging for the excavation of one of the former ponds at the FMC site.

5.2.2.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-8.

5.2.3.4 Overall Likelihood of Success at FMC

As mentioned, a possible complication associated with any method that involves flooding a contaminated region is the possible transport of contaminants with infiltration. In this scenario, soluble forms of contaminants (e.g., $HAsO_4^{2-}$, $HAsO_2$[aq], UO_2^{2+}) could be leached from the excavation volume and transported toward the water table. This process could be mitigated by the use of hydraulic containment wells (pump and reuse at excavation site) and/or hydrologic/reactive barriers.

Another possible complication associated with this method would involve the type and size of the materials being dredged. Large pieces of quartzite or slag used as fill materials in the former ponds at the FMC site might not be amenable to size reduction by the cutter end and would thus be rejected by the suction system. If such large pieces of debris were encountered and hindered the dredge's progress, they would have to be removed by using a long-reach excavator. Furthermore, large pieces of solidified P4 might also be encountered; however, these pieces could be dredged by using thermal-hydraulic methods (summarized next) involving the use of steam to melt P4 at the cutter suction head.

Practical experience has shown that localized ignition of white phosphorus cannot be completely avoided with cutter suction. Occasionally, the cutter suction parts and other internals would have to be exposed to air for maintenance reasons. Hazards associated with the inevitable burning and smoking of white phosphorus during maintenance of these dredging systems would have to be mitigated. This could be done with the use of slightly negative-pressure enclosures into which the cutter suction parts would be moved for servicing and cleaning as needed.

If the risk of subsurface contaminant mobilization was mitigated, cutter suction dredging would have a high likelihood of success as a front-end process for the excavation and treatment of the white-phosphorus-bearing materials in the RU 22c (RA-C, RA-D) former ponds. However, mechanical excavation methods would probably need to precede the cutter suction dredging to remove the slag overburdens from some of the former pond areas and to prepare the sites for flooding.

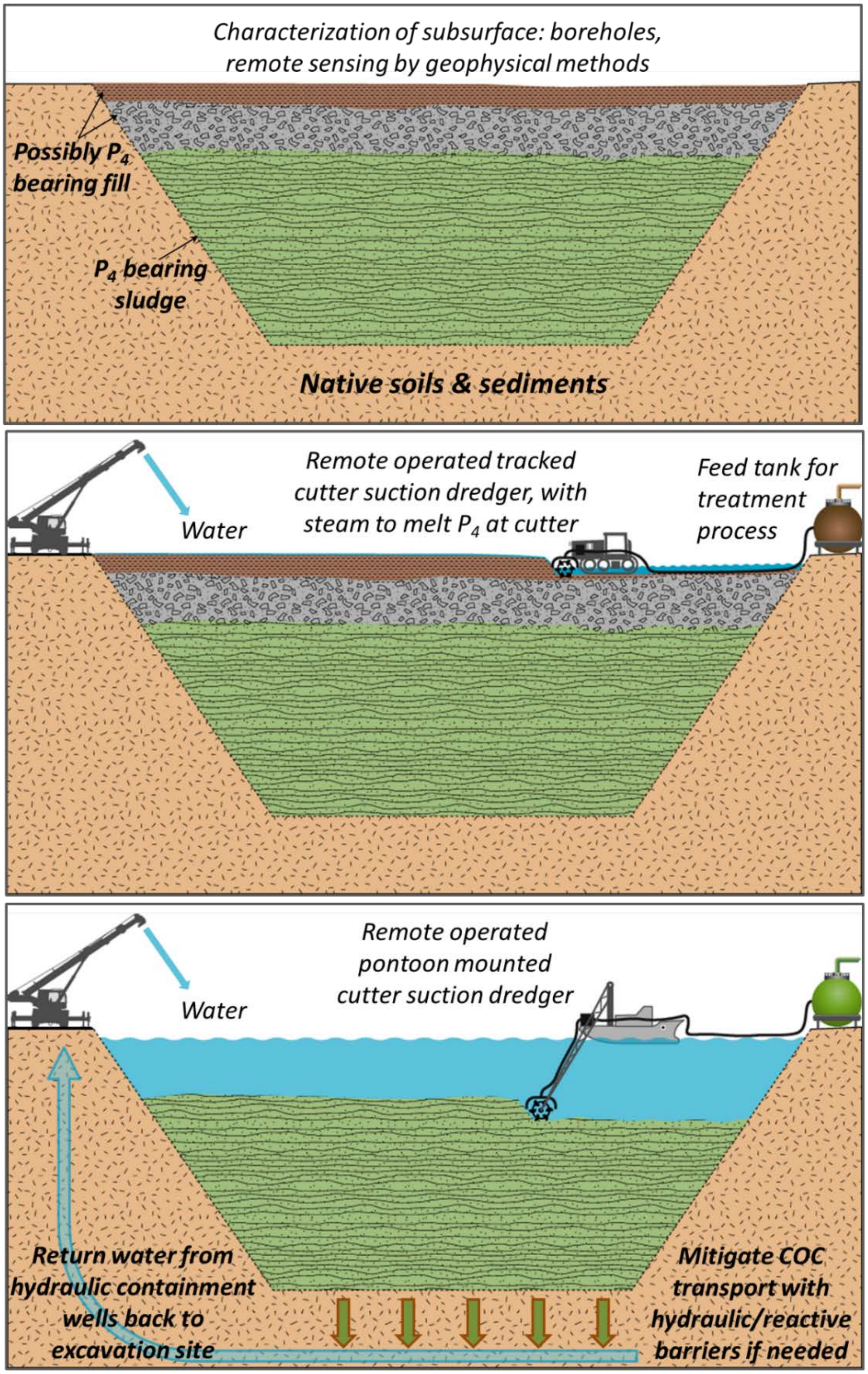

FIGURE 5-9 Conceptual Diagrams (not to scale) Showing a Possible Sequence of Steps for Excavating White-Phosphorus-Bearing Materials from a Flooded P4 Impoundment (Source: developed by Argonne)

TABLE 5-8 Assessment of Cutter Suction Dredging Based on ETT Review Parameters

Review Parameter	Cutter Section Dredging
Process maturity	Mature.
Limitations	• This method requires complete flooding of the excavation site. A constant, large supply of water is needed to keep the excavation site flooded and to maintain the pond's water level. • The NPV estimate for Alternatives 5 through 7 in the September 2010 Proposed Plan would be a comparable OOM estimate to implement this ETT in conjunction with a treatment and disposal ETT.
Time to implement (not including permitting and approvals)	This method could be implemented immediately if an adequate water supply is available.
Effectiveness of removing and/or treating P4 in soil	This method would remove P4-bearing materials. It would not remove hazardous characteristics of materials. Excavated P4 waste would have to be subjected to a treatment technology.
Process safety for site workers during implementation	There would be a high risk to site workers due to P4 ignition (burns), phosphine released from disturbed soils (poisoning), and P_2O_5/phosphoric acid generation (acid inhalation). The risk would be mitigated by flooding the excavation site and by doing the excavation by using remotely operated dredges. Phosphine gas would be monitored (both site and personnel monitoring). Maintenance on dredge parts would be performed in a negative-pressure enclosure with gas treatment and with workers who were wearing appropriate PPE.
Community health and safety during implementation	Accidental drying at the excavation site would have significant community health and safety consequences due to the possible release of particulate P4, phosphine, and P_2O_5/phosphoric acid vapors. The risk would be mitigated by maintaining a large volume of excess water at the excavation site along with sand for smothering P4 fires.
Impacts to the environment during implementation	The unmitigated risk would be significant. Air could be affected by the release of particulate P4, phosphine, and P_2O_5/phosphoric acid vapors. Groundwater could be affected by the downward transport of contaminants, with infiltration occurring below the flooded excavation site. The risk would be mitigated by keeping the excavation site flooded and containing the site groundwater by hydraulic containment (P&T wells).
Post-implementation impacts on the environment and the community	The excavated site would be filled with uncontaminated (treated) soil.
Overall discussion of advantages and disadvantages	The main advantage of cutter suction dredging over mechanical excavation is that it would be performed remotely, thus greatly reducing worker health and safety risks. Furthermore, the removal and transport of P4 materials as a slurry (~10 wt% solids) would minimize the risk of large masses of P4-bearing materials drying out and igniting. The overall advantage is that it would minimize the risk to workers. Its main disadvantages would be its need for large volumes of water and the inevitable equipment failure and complications (e.g., clogging of pumps and pipes) associated with its use.

5.2.4 Thermal-Hydraulic Dredging

5.2.4.1 Description

Another option for removing white phosphorus from contaminated soil and sediments involves melting and pumping the P4 at the site of excavation. Due to its low melting point (around 44ºC), white phosphorus can be melted by hot water or steam applied at the front of a modified cutter suction dredge. This approach has been used in phosphorus treatment plants by supplying heat through a steam-jacketed cylinder surrounding the suction pump (Franklin Engineering Group 2007).

An advantage to the thermal-hydraulic dredge technique is that large pieces of pure P4 or P4-cemented aggregates that would be rejected by the screen on the cutter suction intake could be broken down (melted) using the thermal-hydraulic method and sucked up by the pumping system. The general disadvantages to the application of heat at the cutter suction tip are the added energy costs and the fact that the equipment is more complicated to operate and maintain.

5.2.4.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

The applicability is the same as that for cutter suction dredging. In fact, the thermal-hydraulic dredge method is essentially a modification or added feature of the cutter suction method. As discussed in the section on cutter suction dredging, this technology would require a feed preparation step between cutter suction dredging and any treatment technology, such as the preparation step depicted in Figure 5-8.

5.2.4.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-9.

5.2.4.4 Overall Likelihood of Success at FMC

The likelihood of success would be the same as that for cutter suction dredging in that it would be high for locations that could be flooded.

TABLE 5-9 Assessment of Thermal Hydraulic Dredging Based on ETT Review Parameters

Review Parameter	Thermal Hydraulic Dredging
Process maturity	Mature.
Limitations	This method requires complete flooding of the excavation site. A constant, large supply of water is needed to keep the excavation site flooded and to maintain the pond's water level. The NPV estimate for Alternatives 5 through 7 in the September 2010 Proposed Plan would be a comparable OOM estimate to implement this ETT in conjunction with a treatment and disposal ETT.
Time to implement (not including permitting and approvals)	This method could be implemented immediately if there was an adequate water supply.
Effectiveness of removing and/or treating P4 in soil	This method would remove P4-bearing materials. It would not remove the hazardous characteristics of the materials. Excavated P4 waste would have to be subjected to a treatment technology.
Process safety for site workers during implementation	• There would be a high risk to site workers due to P4 ignition (burns), phosphine released from disturbed soils (poisoning), and P_2O_5/phosphoric acid generation (acid inhalation). The risk would be mitigated by flooding the excavation site and doing the excavation by using a remotely operated thermal-hydraulic excavator. Phosphine gas would be monitored (both site and personnel monitoring). • Maintenance on dredge parts would be performed in a negative-pressure enclosure with gas treatment and by workers wearing appropriate PPE.
Community health and safety during implementation	Accidental drying at the excavation site would have significant community health and safety consequences due to the possible release of particulate P4, phosphine, and P_2O_5/phosphoric acid vapors. The risk would be mitigated by maintaining a large volume of excess water at the excavation site and also sand for smothering P4 fires.
Impacts to the environment during implementation	The unmitigated risk would be significant. Air could be affected by the release of particulate P4, phosphine, and P_2O_5/phosphoric acid vapors. Groundwater could be affected by the downward transport of contaminants, with infiltration occurring below the flooded excavation site. The risk would be mitigated by keeping the excavation site flooded and containing the site groundwater by hydraulic containment (P&T wells).
Post-implementation impacts on the environment and the community	The excavated site would be filled with uncontaminated (treated) soil.
Overall discussion of advantages and disadvantages	The main advantage of thermal-hydraulic dredging over mechanical excavation and cutter suction dredging is that it could be performed remotely, thus greatly reducing worker health and safety risks, and it would minimize the chance of the pump and pipeline becoming clogged due to large pieces of P4 (would be melted prior to suction). Furthermore, the removal and transport of P4 materials as a slurry (~10 wt% solids) would minimize the risk of large masses of P4-bearing materials drying out and igniting. The overall advantage would be minimizing the risk to workers. The main disadvantages of the method would be the need for large volumes of water, thermal input, and the inevitable equipment failure and complications (e.g., clogging of pumps and pipes by rocks) associated with its use.

5.2.5 Summary on Appling Excavation Methods to the FMC Site

Table 5-10 matches the major white-phosphorus-bearing regions at the FMC site with the most promising excavation method for each region. All three excavation methods would require large amounts of water. Cutter suction dredging and thermal-hydraulic dredging would require the complete flooding of former pond sites, all of which were dewatered prior to 1982. The most likely source of water for excavation would be groundwater extracted as part of a hydraulic containment program (P&T) designed to prevent contaminants associated with the P4-containing soil and debris from downgradient migration and going off site. The hydraulic containment plan discussed in MWH (2010) states that a groundwater extraction rate of 530 gpm would be required. This supply of 3,780 yd^3 of water per day would be adequate supply for excavation.

To put these numbers in perspective, here are some data. It is estimated that the total volume of P4 wastes and fill in the former ponds is 595,820 yd^3 (FMC 2010). Based on the assumption that there is 50% porosity, the former ponds contain 297,910 yd^3 of void space that needs to be saturated before or during excavation. Based on a groundwater extraction rate of 530 gpm (3,780 yd^3 of water per day), there would be enough water to fully saturate the former ponds in approximately 79 days.

Observations during site investigations revealed that in some places, the crushed slag fill had become compacted and formed solid layers up to several feet thick (FMC 2010). The presence of these relatively dense layers would be revealed by geophysical surveys of the excavation site during the characterization and planning phase of the excavation project (e.g., by ground-penetrating radar or seismic reflection). Such layers would likely require removal using mechanical excavation techniques.

Process knowledge regarding the addition of white-phosphorus-bearing materials to the former pond impoundments indicates that the P4 concentration in these materials would likely vary considerably. It is noted in MWH (2010) that the addition of precipitator slurry to the ponds might have concentrated the white phosphorus due to the method of discharge. It was observed that P4 was in a molten state within the discharge pipe (>44°C), but it rapidly solidified upon entering the lower-temperature pond sediments. It thus formed highly concentrated masses or a monolith of P4 at the pipe outlet. The discharge pipes were moved periodically to evenly distribute the P4-containing soil and debris within the ponds, so these highly concentrated masses of P4 would be distributed throughout the impoundments (MWH 2010). It is possible that the blades on the cutter suction dredge head will not be able to cut through the solid masses of P4. These masses could be readily broken down, however, by using a steam lance fitted to the dredge head.

Due to the variability of the characteristics of the white-phosphorus-bearing material in each remediation area, it is likely that all three excavation methods would play important roles in removing the P4-containing soil and debris for treatment. All three methods have unique sets of advantages and disadvantages that make them complimentary to each other.

TABLE 5-10 Most Promising Excavation Method for Each White Phosphorus-Bearing Region of the FMC Site[a]

Location	Max. P4 Mass (tons)	Likely P4 Conc. (wt%)	Area (acres)	Depth to Native Soil or to P4 (ft)	Total Fill Volume (yd^3)[b]	Best Excavation Method
Capillary fringe, RU 1, RU 2, RA-B	5,470	50	7.8	90 to P4	2,500,000[c]	*In situ* treatment or mechanical excavation (open pit)
Pond 7S, RU 22b, RA-C	4,420	20	3.6	20	116,160	Cutter suction dredging
Pond 6S, RU 22b, RA-C	3,000	10	2.3	20	74,213	Cutter suction dredging
Railcars, RU 19, RA-F	2,000	25	–[d]	120 to P4	300,000[c]	Mechanical excavation
Pond 3S, RU 22b, RA-C	1,070	10	1.2	20	38,720	Cutter suction dredging
Pond 5S, RU 22b, RA-C	1,000	10	1	20	32,267	Cutter suction dredging
Pond 4S, RU 22b, RA-C	790	10	0.8	20	25,813	Cutter suction dredging
Pond 10S, RU 22b, RA-C	390	10	1	20	32,267	Cutter suction dredging
Pond 2S, RU 22b, RA-C	100	10	0.8	20	25,813	Cutter suction dredging
8S material, RU 13, RA-C	60	0.25	3.6	23	66,630	Mechanical excavation
Pond 1S, RU 22b, RA-C	30	1	0.5	20	16,133	Cutter suction dredging
Railroad swale, RU 22b, RA-C	10	1	2.4	14	54,208	Mechanical excavation
Subsurface pipes, throughout RA-B, RA-C	Unknown	Up to 100	–	10	–	Mechanical excavation
RU 19c, 21 buried railcars	200–2,000	10–25	–	80–100	–	Mechanical excavation, see Section 5.5.2

[a] The criteria used for determining the most promising methods are presented in Tables 5-1, 5-2, and 5-3.

[b] Rough estimate based on simple geometric calculation: area × depth to native soil.

[c] From MWH (2010).

[d] Dash means not applicable.

5.3 *EX SITU* TREATMENT TECHNOLOGIES

5.3.1 On-Site Incineration

5.3.1.1 Description

Incinerators are used for the treatment of both liquid and solid waste streams. As discussed in Section 5.3.7, full-scale incineration facilities are located throughout the United States. In addition, mobile, transportable incinerators are sometimes temporarily installed and operated at a given waste management site. There are a number of different types of incinerators, including these four:

- Rotary kilns,
- Fluidized-bed units,
- Liquid injection units, and
- Fixed hearth units.

The rotary kiln design is of interest for a number of reasons. Rotary kiln incineration systems are flexible, allowing liquids, solids, and sludge having wide variations in heating value to be treated simultaneously. A rotary kiln incineration system consists of four fundamental parts: (1) waste feed system, (2) combustion chamber, (3) solid residuals handling component, and (4) air pollution control component. Waste can be fed into the combustion component by diverse feed systems, such as ram feeders and sludge feed systems, or by liquid injection systems. The combustion component consists of a refractory-lined cylinder that is tilted at a slight angle. The combustion chamber rotates around its long axis during operations, causing the solids to move in a downgradient direction toward the exit of the kiln and into a solids/ash-handling area. Air handling equipment is used to evacuate combustion by-products from the combustion chamber for treatment (potentially in a secondary combustion chamber) and in air pollution control equipment.

5.3.1.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

FMC acknowledged that incineration technology is potentially applicable to P4 waste (MWH 2009, 2010). Using on-site incineration as an ETT for the volume of waste found in historical ponds would have to be preceded by one or more of the ancillary technologies discussed in Section 5.2. Because dredged historical pond residuals would be saturated or nearly saturated, dredged waste residuals would probably need to be at least partially dewatered prior to the waste feed process. Partially dewatered waste and any excavated soil would have a low British thermal unit (Btu) value and would require large amounts of energy to ensure incineration occurs at design temperatures. Incineration would result in the release of large amounts of carbon dioxide, a greenhouse gas. Waste residuals would need to be physically preprocessed (crushed, ground, etc.) and blended to suit the waste acceptance criteria (WAC) required for optimal operation of the incinerator technology.

Thermal technologies such as incineration have been designated as at least one of the recommended technologies that could be used to deactivate RCRA characteristics, such as ignitability (D001) and reactivity (D003), prior to land disposal. The LDR treatment standards were promulgated to provide protections should any hazardous waste be destined for land disposal. As a result, the awareness of a recommended technology like incineration that is meant to achieve a protective standard prior to land disposal informs the consideration of ETTs in this report. Excavating residuals from the historical ponds would trigger the LDRs, since the residuals would likely be considered hazardous because of D001 and/or D003 characteristics. Since incineration is listed as a recommended technology for deactivating the noted RCRA characteristics, incineration is applicable for consideration as an ETT.

Incineration technology has a fairly extensive track record. Transportable rotary kiln incinerators have been used at a number of national and international sites. Since 1982, on-site incineration has been used as a treatment technology at a Superfund site more than 40 times (EPA 2013). No mobile, transportable incinerator investigated by Argonne was used to treat P4-containing waste. However, on-site incineration at the Bayou Bonfouca Superfund site in Slidell, Louisiana, did require the dredging and dewatering of sediment prior to incineration. Approximately 165,000 yd^3 of sediments contaminated with polyaromatic hydrocarbons were treated in a rotary kiln incinerator at a rate of approximately 25 tons/hr (EPA 2001). The volumes of the treatment residuals (165,000 yd^3 at Bayou Bonfouca and 500,000 yd^3 in the historical ponds) are comparable in terms of scale. The fact that sediment was dredged and dewatered prior to incineration makes the incineration history at Bayou Bonfouca somewhat analogous to how the historical ponds would need to be addressed, and it demonstrates the feasibility of dredging, dewatering, and then incinerating a waste stream.

In addition, a rotary-kiln-type design appears to be particularly applicable for treating residuals containing P4 in the historical ponds. There are at least two examples of rotary-kiln-type incinerators being used to treat the P4 contained in military munitions.

Spreewerk Lubben (*in situ* leaching or ISL) operates what is referred to as an Army peculiar equipment (APE) rotary kiln incinerator that is used to decharacterize munitions containing white phosphorus (Spreewerk 2007). Figure 5-10 depicts the APE incinerator in Lubben, Germany. The system includes a conveyor feed system, afterburner, and slurry feed system with thick wall retort sections. It reportedly meets stringent German environmental standards and North Atlantic Treaty Organization safety regulations.

FIGURE 5-10 Spreewerk Lubben (ISL) Rotary Kiln Incinerator (Source: Wilkinson and Watt, 2006)

Since approximately 1989, the Army has operated a modified rotary kiln furnace to process white-phosphorus-containing military munitions. The facility has the capacity to process 11,500 lb of white phosphorus per day. The APE design provides for the collection and modification of heated vapors, thereby allowing for the production of 48,000 lb of 75% concentrated phosphoric acid. The efficient, state-of-the-art system provides for removing the hazards associated with elemental phosphorus while repurposing the phosphorus as phosphoric acid that can be used in downstream manufacturing operations (Howell 2014; Rainey and Zaugg 1990).

Bench-scale and/or pilot-scale studies might have value with regard to implementing this ETT. Studies might be needed to determine the optimum incinerator waste acceptance criteria in terms of parameters like percent moisture, percent P4 content, waste size, etc. Studies might also be needed to determine whether phosphoric acid recovery is economically and technically viable, and, if it is, how to identify and divert the recoverable P4 stream from all the residuals generated by the excavation ETT. Studies might also be required if or whether incinerator residuals can achieve the RCRA universal treatment standards (UTSs).

5.3.1.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-11.

TABLE 5-11 On-Site Incineration Based on ET Review Parameters

Review and Evaluation Parameter	On-Site Incineration
Process maturity	Mature, with full-scale systems designed to treat white-phosphorus-containing military munitions in operation.
Limitations	• The parameter discussion for excavation technology in Section 5.2 applies. • Stakeholder acceptance for on-site incineration, on-site disposal of incinerator residuals, or transport of incinerator residuals off site would be required. • Feed materials would require dewatering and blending to meet moisture and other incinerator WAC; the higher the moisture content, the higher the energy requirements. • Incinerator by-products (ash, slag, emissions, wastewater) would require additional treatment. • The NPV estimate for Alternatives 5 through 7 in the September 2010 Proposed Plan would be a comparable OOM estimate to implement this ETT in conjunction with an excavation and disposal ETT.
Time to implement (not including permitting and approvals)	The time needed to plan for ancillary technology and excavation support and handling incinerator by-products is estimated to be 1 year. The time needed to incinerate waste is estimated to be more than 10 years.
Effectiveness of removing and/or treating P4 on site	• The technology is considered to be effective at removing P4 risks. • Incineration alone would not be likely to address underlying constituents (UCs). • Post-incineration residual conditioning (PIRC) would be required for UCs. • A CAMU, a CERCLA disposal site, or an off-site disposal site would need to meet the disposal site's WAC, including the criteria related to the waste's naturally occurring radioactive material (NORM) content, if applicable.
Process safety for site workers during implementation	The parameter discussion for excavation technology in Section 5.2 applies. For ancillary technology and incineration, moderate risks would be mitigated by project planning and the regulatory environment.
Community health and safety during implementation	• The parameter discussion for excavation technology in Section 5.2 applies. • For incineration alone, risks would be low to moderate. • For PIRC, it is assumed risks would be low. • Risks might be created from transporting incinerator residuals off site by truck or by rail.
Impacts to the environment during implementation	• The parameter discussion for excavation technology in Section 5.2 applies. • For incineration or PIRC, impacts on soil would be minimal. Incinerator air emissions might be comparable (in terms of risk) with emissions that occurred when the Pocatello plant was operating.

TABLE 5-11 (Cont.)

Review and Evaluation Parameter	On-Site Incineration
	• Permit requirements would tend to mitigate the impact of emissions to air or surface water. • Any treated wastewater could be reused for ancillary technology.
Post-implementation impacts on the environment and the community	The parameter discussion for excavation technology in Section 5.2 applies. The P4-associated risks would be removed within the areas that could be excavated. The remediated footprint could be repurposed.
Overall discussion of advantages and disadvantages	Advantages would be as follows: • The process is mature. • The reactivity and ignitability components could be removed. • Phosphorus could be reclaimed and marketed as phosphoric acid. • Incinerator residuals could be disposed of on site in a CAMU without treatment or in a non-CAMU with treatment. Disadvantages would be as follows: • It might be difficult to gain regulatory and public acceptance of the on-site incineration technology. • It might be difficult to gain stakeholder acceptance if incinerator residuals have to be transported on public roads for off-site land disposal. • Incineration residuals would require treatment to achieve LDRs (if the waste were to be disposed of at a non-CAMU facility on site). • The NORM content of the incineration residuals could limit or preclude the use of off-site disposal sites.

5.3.1.4 Overall Likelihood of Success at FMC

The likelihood of achieving success at the former FMC plant would depend on several factors, including these:

- Public acceptance of and regulatory approval for constructing and operating a mobile incinerator;

- Being able to design and operate an excavation technology, ancillary technologies, and stage accumulated dredged materials so that incinerator WAC could be achieved; and

- The fate of waste residuals from the incinerator. Public acceptance is needed to dispose of waste on land on the former FMC plant grounds or to allow incinerator residuals to be transported from the former FMC site to an off-site disposal facility.

If stakeholder acceptance was obtained and if regulatory approval was granted, this ETT would have a moderate to high chance of achieving success at the former FMC plant. The maturity of the process suggests that the technology could readily remove the ignitability and reactivity components associated with the P4 waste. If the P4 present could be recovered and re-purposed as phosphoric acid, and if the decharacterized waste residuals from the incinerator could be disposed of in a CAMU on site, the ETT would probably have a high chance of success.

5.3.2 Drying/Mechanical Mixing with Containment

5.3.2.1 Description

In July 1986, in Miamisburg, Ohio, a railroad tank car containing 12,000 gal of liquid P4 (approximately 40,000 L, 170,000–175,000 lb) derailed and burst into flames next to Bear Creek, a stream leading to the Great Miami River. The P4 within the railcar was covered with 2,500 lb of water to preclude oxidation, and the car was maintained at a constant 45°C to keep the P4 in a liquid state during transport. As a result of the derailment, the railcar was compromised, and both the P4 and the water overlying it were released to the environment (Scoville et al. 1989).

The initial emergency response effort was quite extensive, involving evacuations, fire-fighting equipment, the Ohio Environmental Protection Agency, the Ohio governor’s office, the Miamisburg city manager and staff, federal agencies, police, hazardous materials specialists, air monitoring crews, SMEs, and a number of emergency support groups. Initially, fire and emergency response crews tried to put out the fire, but eventually, the railcar was moved to a more isolated area where the fire was allowed to burn itself out. It took more than five days for the fire to subside (State of Ohio Disaster Services Agency 1986).

It was estimated that several thousand gallons of P4 escaped into the surrounding soil and stream sediments. In addition, copious amounts of water were used to try to blanket the P4 and limit further oxidation (Scoville et al. 1989). While this water helped to minimize the amount of smoke and particulates that escaped from the response area, it is likely that it also increased the amount of media contaminated with P4.

P4-containing soil and stream sediment were removed and treated by exposing the sediment to the open air on bermed asphalt pads that were specially built to treat the P4-containing soil and sediment. Each pad was approximately 2,000 m^2 (about 0.5 acre), and the contaminated soil and sediment were placed on each pad to a depth of 15 to 20 cm (Scoville et al. 1989).

The soil and sediment were first passed through a sorting machine to remove rocks and thereby minimize damage to the equipment being used to cultivate the contaminated soil and sediment. After the sediment was placed on the pads, tractors with cultivator disks were used to turn it so the P4 would be constantly exposed to the air, thus increasing the rate of oxidation. The soil and sediment were also heated by propane heater blowers attached to the rear of the tractor, and hydrogen peroxide was used to enhance oxidation (Scoville et al. 1989).

The soil and sediment were treated for a period of 12 to 24 hours — the amount of time needed to reduce the P4 to less than 10 mg/kg. It was determined that the material would no longer be ignitable once the P4 was reduced to concentrations of less than 10 mg/kg in the material. Estimates were made that 7,500 yd^3 of soil and sediment were treated over a period of approximately 12 weeks (Scoville et al. 1989).

In addition to open-air drying/mechanical mixing, a number of other remediation alternatives were also considered. These included the following:

- Reaction of the P4 by heating the soil and sediment in a modified asphalt drier,

- Oxidation of the P4 by adding hydrogen peroxide to the soil and sediment,

- Physical separation of the P4 from the soil and sediment by heating the mixture to the P4 melting point, and

- Reaction of the P4 by exposing the soil and sediment to air on a pad enclosed within a containment structure.

Based on evaluations of feasibility, cost effectiveness, and time constraints, the open-air drying/mechanical mixing approach was selected. Although the cultivation operation could have been conducted under a containment structure, emissions of reaction products to the open air were kept to allowable levels (i.e., <0.02 mg/m^3 of phosphoric acid). Work was curtailed, however, when the direction of the wind was toward the closest houses. Work was conducted only during daylight hours (Scoville et al. 1989).

The Miamisburg incident and the resulting remediation effort were the basis for considering drying/mechanical mixing with a containment option for application to FMC.

The use of a containment structure was optional because, as was the case for the Miamisburg remediation, FMC might be able to conduct this type of operation in the open air and still meet emission requirements. Argonne notes, however, that it might be more difficult for the EPA to approve an open-air option and for the public to accept it. This possibility is especially likely when the proximity of Highway 86 and other infrastructure to the FMC site is taken into consideration. However, if FMC could demonstrate that the operation can be conducted safely, with emissions being below acceptable levels in open air, this option could be considered further. An additional advantage of employing a containment structure would be its ability to keep “the elements” away from the treatment area. In this manner, added precipitation could be precluded, and operations would not be affected by temperature extremes or the direction or speed of the wind.

Use of a containment structure during P4 remediation was applied at a P4 site located outside Tarpon Springs, Florida (EPA Region 4 2013). In this case, the containment structure was referred to as a “tent,” so it might not have been an airtight structure.

The type of containment structure Argonne is suggesting for this particular option is depicted in Figure 5-11. The containment structure could be built over an impervious pad, such as the pad used at the Miamisburg site, or it could be situated on the ground surface itself. If it is placed over an impervious pad, a portion of the area under the structure could consist of a remediation parcel, and the other portion could be reserved for the impervious surface.

These types of containment structures can be built in various sizes and are in common use in some industries. For example, similar devices have been used for years for remediating sites that contain chemical weapons or that are contaminated with chemical warfare agents (National Research Council 2012).

Furthermore, these structures could be equipped with an off-gas treatment system in order to meet requirements for emissions before the exit into the environment. Also, a negative-air-pressure system could be used in tandem with the emissions control to continually draw contaminated air above the treatment surface and into the off-gas treatment system. Air monitors could be placed in designated locations within the structure to help establish worker protection requirements and select appropriate PPE. In addition, special lighting could be employed inside the structure to help deal with the limited vision associated with off-gassing from P4-contaminated materials. Lighting would also allow for 24-hour operation if it was needed. Fans could be used to draw emissions from the contaminated media into the off-gas treatment system more quickly; this too could help improve vision within the structure. Another option — automated tractors with disking equipment, which are often used in farm applications — could be employed to limit the need for personnel to work inside the structure. Finally, the inside

FIGURE 5-11 Example of Containment Structure (Source: Mahaffey Fabric Structures 2015)

environment of the structure could be air conditioned to maintain the temperature below that which would cause P4 to spontaneously ignite or oxidize.

In addition, this type of structure is considered transportable; it could be moved from location to location as remediation is completed at one portion of the site and started at another. This might be the ideal situation for FMC, considering the difficulties involved in minimizing oxidation if contaminated media were to be transported from one location on site into the containment structure instead of being treated under the structure at the point of extraction. Multiple containment units could also be employed, as deemed appropriate, to speed the remediation effort.

The drying/mechanical mixing with a containment option could also be combined with some type of on-site disposal for residuals that remained after treatment and contained heavy metals or other underlying constituents that did not meet LDR treatment standards. For example, residual solids might be disposed of on site as part of the CERCLA remedy, or they might be placed on site in a RCRA CAMU. On-site disposal is discussed further in Section 5.4.1.

5.3.2.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

The drying/mechanical mixing with a containment option is applicable to the FMC site. Ideally, the P4 in soil and debris with high P4 concentrations could be recovered (e.g., in material with 1%–10% and higher P4 concentrations). Residuals with P4 concentrations that are less than the low percentage levels (including residuals left over from treatment to remove recoverable P4) might be most suitable for this treatment option. The added advantage of not subjecting soil and debris with higher percentage level concentrations of P4 to this treatment option is that soil and debris with these concentrations could burn or smoke excessively, making worker conditions difficult or dangerous.

Open-air drying/mechanical mixing was shown to be successful at the Miamisburg, Ohio, site. Application of this technology under a containment structure (tent) for P4 remediation was shown to be successful at the Stauffer chemical site in Florida.

While drying/mechanical mixing with and without a containment structure have been applied successfully in the past, bench-scale and pilot-scale studies would be helpful. Bench-scale testing could help, for example, in determining whether the technology could be applied safely and meet air emission requirements at FMC without a containment structure. Furthermore, these studies could be employed to evaluate other factors like these:

- Ideal ranges for P4 concentrations,
- Utility of using heat to enhance oxidation (as employed at the Miamisburg site),
- Utility of using oxidants such as hydrogen peroxide to enhance oxidation (as employed at the Miamisburg site),

- Throughput,
- Working conditions (potential for fires and visibility issues), and
- Appropriate levels of PPE.

If it can be shown during bench- and pilot-scale testing that drying/mechanical mixing can be done safely without a containment structure, the remediation effort would likely be more efficient and less costly.

Another item mentioned above is throughput. To use this technology, it would be important to be able to estimate how much time would be needed to treat soil and residuals that contained optimal P4 levels. At the Miamisburg site, it is estimated that 7,500 yd^3 of soil and sediment were treated over a period of about 12 weeks (Scoville et al. 1989). At this rate, and considering that the FMC site would contain much larger amounts of P4-contaminated soil and debris that could be amenable to this technology, treatment could take many years at the FMC site. However, multiple units could be employed, as could options that might increase the reaction rates. Bench- and pilot-scale testing might be especially helpful for estimating throughput.

5.3.2.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-12.

5.3.2.4 Overall Likelihood of Success at FMC

The overall likelihood of success of the drying/mechanical mixing with containment option appears to be favorable. This technology has been applied previously at a P4 rail spill site in Miamisburg, Ohio (without a containment structure), and it has been used at the Stauffer Chemical P4 remediation site outside Tarpon Springs, Florida (with a containment structure).

This technology would likely be effective for soil and debris containing a relatively low amount of P4. The EPA, Region 9 RSL for an industrial setting for P4 is 23 mg/kg. The 23-mg/kg level could be considered the target level for treatment of P4 soil and debris. This technology would likely not be desirable for soil and debris containing moderate to large amounts of P4, due to potential for large fires and excessive emissions that could result in low visibility and possibly exceedances of emission requirements. The upper limit for P4-containing soil and debris using this ETT is estimated to be between 1,000 and 10,000 mg/kg, perhaps up to 100,000 mg/kg. The upper limit concentration should be evaluated during bench-scale and pilot-scale testing to determine the optimum upper level concentration of P4 that would be amenable to this type of treatment.

TABLE 5-12 Drying/Mechanical Mixing with Containment Option Based on ETT Review Parameters

Review Parameter	Drying/Mechanical Mixing with Containment Option
Process maturity	• Drying/mechanical mixing (open-air oxidation) was applied at a P4 train derailment site in Miamisburg, Ohio, in 1986, with acceptable results. No containment structure or emission controls were used, and the result was that “smoke” was released to the environment. Emission requirements were met by limiting operations to specific weather conditions. • Although the drying/mechanical mixing process has not been used recently, it is considered a full-scale technology. However, bench-scale or pilot-scale testing might be helpful in establishing operating conditions.
Limitations	• The primary impediment associated with this method is that it would be limited to contaminated media with P4 concentrations between 23 and 1,000 mg/kg up to 10,000 mg/kg or possibly even higher (approaching 100,000 mg/kg). This technology is not recommended for highly concentrated P4 soil and debris. • Another limitation is that the process might require prior sorting of contaminated media to remove large rocks or similar materials, since these can damage mechanical mixing equipment. • A further limitation is that the process would require large areas for application (e.g., up to possibly 0.5 acre or more). • Residuals from drying/mechanical mixing would require additional waste treatment to comply with RCRA LDRs, or they could be managed in an on-site CERCLA landfill or in a RCRA CAMU. • The NPV estimate for Alternatives 5 through 7 in the September 2010 Proposed Plan would be a comparable OOM estimate to implement this ETT in conjunction with treatment (for the more concentrated P4 levels), and a disposal ETT.
Time to implement (not including permitting and approvals)	• If a football-field-sized plot was used (e.g., 50 × 100 yd), and if the contaminated media depth was 5 to 8 in., and if it took 24 hours to reduce the P4 concentration to less than 23 mg/kg, and also if the long lead times for site and materials preparation and removal of treated media were considered, about 22,500 ft^3 of media could be treated every 5 to 7 days. • The time needed for implementation would depend on the total amount of contaminated media within the range of P4 concentration between 23 and 1,000 mg/kg and possibly up to 10,000 mg/kg or higher.
Effectiveness of removing and/or treating P4 on site	• The process might be able to be enhanced through the use of various oxidants. For example, hydrogen peroxide was applied at the 1986 derailment site to increase P4 oxidation rates. • Drying/mechanical mixing would be effective in reducing P4 concentrations to less than 23 mg/kg. • Residuals would need to meet RCRA LDRs, or they could be managed in either a RCRA CAMU or a CERCLA landfill or sent to off-site disposal.

TABLE 5-12 (Cont.)

Review Parameter	Drying/Mechanical Mixing with Containment Option
Process safety for site workers during implementation	• The safety risk for drying/mechanical mixing could be considered moderate to high. • Appropriate engineering controls and PPE might bring worker risks to acceptable levels.
Community health and safety during implementation	• The health risk to the community from this process could be considered moderate. The health risk would be low if a containment device were employed. • Appropriate engineering controls (e.g., an airtight sprung structure over a remediation site with emission controls) might facilitate community acceptance.
Impacts to the environment during implementation	• Open-air drying/mechanical mixing would have a moderate to high impact on the environment, even if air emission requirements could be met. • A properly constructed and operated drying site with containment would have minimal impacts to soil, surface water, and groundwater.
Post-implementation impacts on the environment and the community	Assuming that all contaminated P4 materials that were in the range of 23 to 1,000 mg/kg and possibly up to 10,000 mg/kg or higher were treated in the drying/mechanical mixing process, post-implementation impacts would be limited to any waste residuals that were left behind (e.g., in an on-site CERCLA landfill or a RCRA CAMU).
Overall discussion of advantages and disadvantages	The advantages are as follows: • It is a proven technology, although it has not been used recently. • It employs a simple design and is easily understood. • It could remove most of the P4 from moderately contaminated media in the 23 to 1,000 mg/kg and possibly up to 10,000 mg/kg or higher. • If a containment structure was employed, gases emitted during treatment would be collected and passed through emission controls prior to their release. • It is anticipated that public approval would be favorable. The disadvantages are as follows: • It could be applied only to moderately contaminated media. • The media would require a significant amount of preparation (e.g., sorting to remove large rocks). • It would require long lead times before the actual treatment in order to prepare the media and the plot and would also require long times after the treatment to remove the treated media. • Waste residuals would require further treatment to meet RCRA LDRs; they could be managed in a CERCLA landfill or in a RCRA CAMU. • The cost would be high relative to the cost of cap and cover options.

5.3.3 A&W Mud Still Batch Process

5.3.3.1 Description

The A&W mud still is basically a batch distillation process wherein P4-containing materials are placed in a metal container and heated to drive off water and recover P4. The A&W process was patented in 1978 and has been used to treat P4-containing materials at three facilities. One primary advantage of the mud still over other technologies is that the still can handle monolithic chunks (e.g., slag, rocks) as long as they can fit into it. Hence, the mud still would not require prior mechanical sorting or grinding to reduce the size of the chunks to be treated unless they were very large (Franklin Engineering Group 2007). Another salient attribute of the mud still is that it is a recovery process, so the P4 can be recovered and sold as product.

Operation of the mud still is actually fairly simple. P4-containing materials are loaded into the still, which is then gradually heated to a temperature of 1,112°F. The P4 is driven off at a temperature of 522°F. Red phosphorus is driven off as the temperature approaches 1,112°F. The P4 is condensed and concentrated, and although it contains some impurities, it can be sold as product. Noncondensible gases, including PH_3, H_2, and N_2 are thermally treated, and scrubbers are used to reduce particulate emissions. After it cools down, the recovered P4 is removed and the still is emptied of residuals and then reloaded with another batch of raw material. The process for a single batch can take 20 to 30 hours (Franklin Engineering Group 2007).

Use of the mud still has been studied extensively at the Silver Bow RCRA site located outside Butte, Montana (Franklin Engineering Group 2007, 2011, 2012; Barr 2014). The mud still that was tested at the Silver Bow site was fabricated in order to test the mud still concept. It consisted of a section of 24-in. Schedule 40 stainless steel pipe, with a flat plate for a bottom and a stainless steel flange at the top for attaching a lid. The lid was also equipped with an agitator to promote heat transfer and improve efficiency. Once filled, the still assembly was placed inside an electric furnace, where heating occurred. The design capacity for the device used during the treatability study was about 3 ft^3 of clarifier material (Franklin Engineering Group 2012).

The Silver Bow site is similar to FMC in many respects. Owned initially by Rhodia Inc., the site smelted slag and produced P4. It started operations in the early 1950s and closed them in 1997. The site was subject to RCRA corrective action (cleanup requirements) via a RCRA 7003 Order that was issued in 2000. Rhodia conducted extensive work to comply with the 7003 Order. In 2011, Solvay S.A. acquired Rhodia, and Rhodia, Inc., became a member of the Solvay Group (Barr 2014).

The clarifier at the former Rhodia, Inc., phosphorus manufacturing facility in Silver Bow, Montana, contains phosphorus-rich waste. The clarifier is 100 ft in diameter, 12 ft deep, and open-topped, and it contains about 500,000 gal of phosphorus solids. The P4 contained in the solids is estimated to be about 20% by volume. The remaining material in the clarifier consists of water and solids, including phosphate, coke, and silica dust (Franklin Engineering Group 2007, 2011, 2012; Barr 2014).

Noncondensible gases produced by the mud still, including phosphine, hydrogen, and nitrogen, would be treated in a thermal oxidizer, and scrubbers would be installed to remove particulates. Permitting of the unit under Clean Air Act requirements would thus be necessary.

Residual solids remaining in the still after treatment would be collected and disposed of. The solids are subject to the RCRA regulations. Although the residual solids would no longer exhibit the RCRA characteristics of ignitability and reactivity (because P4 would have been driven off), they might contain heavy metals. Therefore, the residual solids might require additional treatment to meet RCRA LDR requirements (Franklin Engineering Group 2007).

In lieu of treating the mud still residuals to meet LDR requirements, the A&W mud still technology could also be combined with some type of on-site disposal to deal with residuals that remained after treatment and contained heavy metals or other underlying constituents that did not meet LDR treatment standards. For example, Solvay is proposing to manage the residual solids on site after treatment by using the mud still in a RCRA CAMU. On-site disposal is discussed further in Section 5.4.1.

The A&W mud still is likely to be chosen as the technology to treat the material in the Solvay clarifier. Solvay has indicated that the P4 that is recovered from the mud still could be used at some of its other facilities. Further, Solvay has indicated in the February 2014 Draft Supplemental Waste Report (P42) (Barr 2014):

> Future Commercial Operations – This facility could serve as a viable commercial P4 recovery facility for managing similar materials from other elemental phosphorus facilities. If Solvay decides to pursue commercial operations, then RCRA permitting pertaining to storage of hazardous waste might be required, and Solvay would obtain any required permit.

The mud still has been tested extensively at the Silver Bow site and shown to be a viable option for treating the material in the clarifier and recovering P4 (Franklin Engineering Group 2011, 2012). A simplistic flow diagram of the mud still process is depicted in Figure 5-12. A photograph of the mud still in operation at the Silver Bow site is shown in Figure 5-13.

5.3.3.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

The A&W mud still is directly applicable to FMC soil and residuals that contain P4. During the Silver Bow treatability study testing, however, it was learned that the process could be especially well-suited for certain types of soils and residuals. The FMC Phase 3 treatability study report (Franklin Engineering Group 2012) states:

> Mixtures of clarifier feeds that are high in phosphorus and high in residual solids are more difficult to treat using this process. These types of feeds result in run times of excessive length, appear to cause excessive boiling and scaling of residual solids on the walls of the still, and unless left for an excessively long time can leave residues contaminated with elemental phosphorus. Because of this issue, some material in the clarifier may not be amenable to treatment using the still.

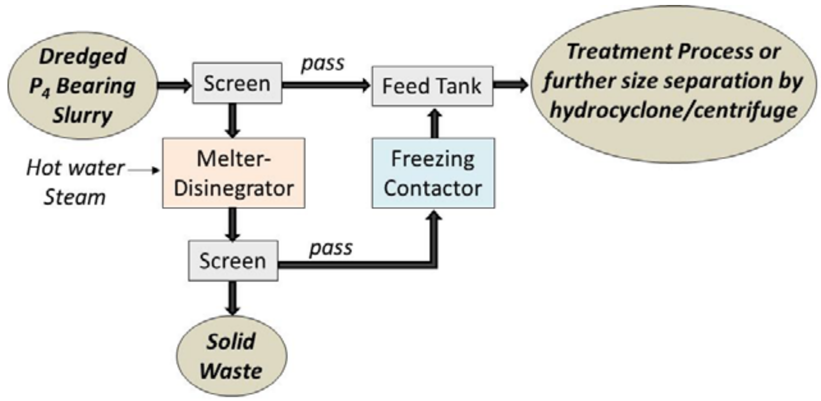

FIGURE 5-12 Flow Diagram of Mud Still Process (Source: Franklin Engineering Group 2007)

FIGURE 5-13 Mud Still in Operation (Source: Franklin Engineering Group 2012)

From these words, one could conclude that soils and residuals that contain high amounts of solids and P4 might not be directly amenable to treatment in the mud still. Some preparation of the soil and residuals might be needed to ensure that materials placed in the mud still could be successfully and efficiently treated. Since it is likely that some of the soil and residuals present at FMC might need to be excavated and pumped to treatment facilities, the material introduced into the mud still would likely have a reasonable amount of water added in order to improve consistency and flow and minimize oxidation. This could afford an opportunity to pre-prepare materials before their emplacement in the mud still.

Moreover, soil and residuals excavated from the FMC site that contain high amounts of P4 should perhaps not be treated in the mud still. Highly concentrated soils and residuals (e.g., those containing 60%–70% P4 or more) might be able to be containerized, shipped, and treated as product material. In essence, the excavation of soil and residuals with high amounts of P4 might be considered more of a mining operation than a remedial operation, resulting in a product and not a waste material.

Similarly, soil and residuals excavated from the FMC site that contain low amounts of P4 (e.g., more than 23 mg/kg and up to low percentage levels) might also not be ideal for treatment in the mud still. Soils and residuals with low P4 concentrations might make the mud still operations inefficient. This possibility has yet to be evaluated, because clarifier materials tested during the treatability study at Silver Bow contained P4 at approximately 20% by volume. Materials with low levels of P4 were not tested at the Silver Bow site. Hence, if the mud still were to be considered further for FMC, bench-scale and/or pilot-scale studies would be useful for determining the optimal range in feed materials with respect to FMC soil and debris and P4 concentrations.

Bench-scale studies would also be helpful in determining throughput, including throughput as a function of P4 and solids loading. As indicated above, the design capacity for the device used during the treatability study was about 3 ft^3 of clarifier material, and it took 20 to 30 hours to complete treatment of a single batch (Franklin Engineering Group 2012). While it is likely that a commercial-scale unit would have a higher capacity and also perhaps operate more efficiently, throughput would nevertheless be limited. Throughput would need to be examined and evaluated against other viable technologies.

Note also that even though it is uncertain, it is likely that a mud still will be employed at the Silver Bow site. A number of other alternatives, including capping and off-site incineration, were evaluated, but it appeared that the mud still has some distinct advantages over those alternatives. Most notable is its ability to recover much of the P4 and use it as product. No other alternative that was explored offered this advantage.

The timing of decisions at the Silver Bow site is also uncertain. Should a decision be made to use the mud still at Silver Bow, a production-scale unit would need to be designed and built. Also it is likely that a pilot-scale facility would need to run prior to full-scale application. It could be several years after a decision was made on Silver Bow before the facility would begin to treat waste materials. Nevertheless, it would be highly advisable, if the mud still is an acceptable alternative for FMC, to put off a final decision for FMC until after the mud still has operated at Silver Bow for some time. The stakeholders at FMC could then benefit from observing progress, issues, and possible success at Silver Bow and use the knowledge as input when making a decision on whether to employ the mud still at FMC.

5.3.3.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-13.

TABLE 5-13 Assessment of A&W Mud Still Based on ETT Review Parameters

Review Parameter	Batch Mud Still
Process maturity	• The mud still process was patented in 1978 (A&W mud still). A batch mud still process has been used at three facilities for P4 sludge treatment. A three-phase treatability study for the mud still was conducted for the Silver Bow site in Montana. • The process requires significant upgrades for a commercial-scale unit. • The batch mud still process is considered a pilot-scale technology.
Limitations	• The primary impediment associated with the batch mud still process is low throughput. Applying the pilot-scale unit to treat the material in the Silver Bow clarifier (500,000 gal) would take more than 100 years. The FMC materials that require treatment are much larger than the materials in the Silver Bow clarifier. • Another limitation of the batch mud still is that mixtures of waste feeds that are high in P4 and high in residual solids are more difficult to treat. • Application to mostly solid materials (e.g., soils and slags) is unproven. Water might need to be added to solids to facilitate distillation. • Using the batch mud still to treat materials with less than 1,000 mg/kg of P4, or possibly even less than 10,000 mg/kg, would probably be inefficient. • Liquid effluent and solid residuals from batch mud still operation would require additional waste treatment to comply with RCRA LDRs, or they could be managed as part of an on-site CERCLA remedy or a RCRA CAMU. • The batch mud still process requires significant scale-up from go from pilot scale to full scale. • The NPV estimate for Alternatives 5 through 7 in the September 2010 Proposed Plan would be a comparable OOM estimate to implement this ETT in conjunction with an excavation and disposal ETT.

TABLE 5-13 (Cont.)

Review Parameter	Batch Mud Still
Time to implement (not including permitting and approvals)	• Applying the pilot-scale unit to treat the material in the Silver Bow clarifier (500,000 gal) would take more than 100 years. The FMC materials requiring treatment are much larger than the materials in the Silver Bow clarifier. • Operating larger-batch units or a number of units in tandem could significantly increase throughput.
Effectiveness of removing and/or treating P4 on site	• The batch mud still could be highly effective in removing P4 from waste materials. • Recovered P4 could be sold as product. • Residuals would need to meet RCRA LDRs, or they could be managed in a CAMU or as part of an on-site CERCLA remedy, or they might be sent off site for disposal.
Process safety for site workers during implementation	• The process safety risk for the batch mud still process could be considered moderate to high. • Appropriate engineering controls and PPE might bring worker risks to acceptable levels.
Community health and safety during implementation	• The process health risk for the community for the mud still process could be considered moderate. • Appropriate engineering controls (e.g., an airtight sprung structure over the remediation site, with emission controls) might bring the community risk to acceptable levels.
Impacts to the environment during implementation	• A properly constructed and operated batch mud still process would have minimal impacts on soil, surface water, and groundwater. • The batch mud still process would generate air emissions of potentially toxic gases. • Air releases of toxic gasses from the batch mud still process could be controlled with off-gas treatment or if the operations were performed under an airtight structure with emission controls.
Post-implementation impacts on the environment and the community	If all moderately to heavily contaminated P4 materials were treated in the batch mud still process, post-implementation impacts would be limited to any waste residuals that were left behind (e.g., treated to meet RCRA LDRs or managed as part of an on-site CERCLA remedy or in a CAMU).
Overall discussion of advantages and disadvantages	The advantages are as follows: • It is a proven technology through the pilot scale at present. • It can remove most of the P4 from on-site materials. • P4 generated during mud still batch treatment could be sold. • It is anticipated that public approval would be favorable.

TABLE 5-13 (Cont.)

Review Parameter	Batch Mud Still
Overall discussion of advantages and disadvantages (Cont.)	The disadvantages are as follows: • The batch mud still's application to mostly solid materials (e.g., soils and slags) is unproven. • Throughput would be low unless larger or multiple units were applied. • Using the process to treat materials with less than 1,000 mg/kg of P4, or possibly even less than 10,000 mg/kg, would likely be inefficient. • Waste residuals would require further treatment to meet RCRA LDRs, or they could be managed as part of an on-site CERCLA remedy or in a CAMU. • The cost of the process is high relative to cap and cover options.

5.3.3.4 Overall Likelihood of Success at FMC

The overall likelihood of success of the A&W mud still looks favorable. This technology has been applied previously at several sites, including a recent treatability study at the Silver Bow Site in Montana. This site is similar in several respects to the FMC site. Solvay has even suggested that the mud still might be able to be applied commercially for other P4 recovery operations.

However, it appears that there may be an optimal solids and P4 loading for materials that would be treated by the mud still. Whereas the technology would likely be effective with regard to soil and debris containing a moderate amount of P4, it might not be effective with regard to soil and debris containing moderately high or low levels of P4. As indicated in the Silver Bow Phase 3 treatability study, mixtures of clarifier feeds that are high in phosphorus and in residual solids are more difficult to treat by using this process. Soil and debris might, however, be pre-processed before being placed in the mud still to optimize its treatment potential. A significant amount of bench-scale and pilot-scale testing would likely be needed to determine optimal material feeds and operating conditions.

5.3.4 Land Disposal Restriction Waste Treatment System (anoxic caustic hydrolysis, metals precipitation, filtration, stabilization)

5.3.4.1 Description

The land disposal restriction (LDR) waste treatment system (WTS) is based on an anoxic process design. In general, lime and waste are combined under pressure in a heated reactor. Solids generated in the reactor are precipitated, filtered, and stabilized with additives. Exit gas rich in phosphine and hydrogen is treated. The system was designed as an anoxic process that uses caustic hydrolysis under an elevated temperature and pressure. It was designed and built to handle soil and debris (wastes) generated by the then-active FMC plant.

The treatment system was also designed to treat about 113,400 gal/day of slurry dredged from Pond 18. Accumulated solids from Pond 18 that consisted of suspended solids at 3–8 wt% with P4 concentrations at 0–50 wt% were to be dredged and sent to a clarifier before being treated in the LDR WTS. The dredged slurry was to be sent to two lamella (inclined plate) clarifiers (referred to as an “inlet waste separator”) capable of producing an underflow slurry of 20 wt%. Overflow was to be gravity-fed to a pond overflow collection tank. This tank was to be back-flushed to the pond during any pause in dredging to prevent the line from plugging. The underflow was heated in pond underflow slurry tanks to prevent temperatures from dropping below the temperature at which the phosphorus in the waste solid strainers would freeze (113°F).

The remainder of the LDR WTS plant consisted of the following unit operations:

- Size reduction mill to control the size of waste feed from the waste solid strainers;
- Reactor feed system consisting of three 6-hour storage tanks to provide for filling, testing, and feed equalization;
- Reactor system consisting of two identical reactors designed to operate at up to 600 psig and 464°F;
- Filtration system;
- Wet filter cake stabilization system;
- Residual management system consisting of roll-off boxes to allow residuals to be transported off site for disposal; the LDR WTS would have produced 243 yd^3 of residuals per day, or about 15 × 20 yd^3 of roll-offs with soil and debris going to an FMC silica mine (Fyock 1999);
- LDR WTS off-gas treatment system consisting of a thermal oxidizer system, a two-stage particulate scrubber system, a flare backup system, and a quench blowdown tank to remove accumulated solids and phosphoric acid; and
- Phosphoric acid storage and loading system.

5.3.4.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

The LDR WTS is directly applicable to FMC. Bench-scale and pilot-scale studies using the technology have already been performed. A full-scale version of the LDR WTS was constructed at the FMC Pocatello site. The LDR WTS was designed and built specifically to treat

P4-containing solids and sediments present in the historical ponds. In particular, the design features that focus on the excavation, blending, dewatering, sizing, and treatment of residuals from Pond 18 seem to be directly applicable to the treatment of the waste present in the non-RCRA historical ponds.

5.3.4.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-14.

TABLE 5-14 Assessment of LDR WTS (anoxic caustic hydrolysis, metals precipitation, filtration, and stabilization) Based on ETT Review Parameters

Review Parameter	LDR WTS
Process maturity	Mature, with a full-scale system designed and constructed, but never operated.
Limitations	• The parameter discussion for the excavation technology in Section 5.2 applies. • Not all P4 waste could be excavated. • Waste acceptance would be needed. The feed materials would require dewatering and blending to meet moisture and other LDR WTS WAC. • The NPV estimate for Alternatives 5 through 7 in the September 2010 Proposed Plan would be a comparable OOM estimate to implement this ETT in conjunction with an excavation and disposal ETT.
Time to implement (not including permitting and approvals)	The amount of time is unknown; however, the LDR WTS was designed to treat Pond 18 residuals in 5 years (Haselberger 2000). Estimated time is 5 years for installation. Estimated time is 10 years for operations.
Effectiveness of removing and/or treating P4 on site	The LDR WTS is considered to be effective at removing P4 risks and treating residuals to address underlying constituents.
Process safety for site workers during implementation	The parameter discussion for the excavation technology in Section 5.2 applies. Risks for operating the LDR WTS are considered to be low to moderate and could be mitigated by design and regulatory controls.
Community health and safety during implementation	The parameter discussion for the excavation technology in Section 5.2 applies. Risks for operating the LDR WTS are comparable to the risks that existed when the FMC plant was operational.
Impacts to the environment during implementation	The parameter discussion for the excavation technology in Section 5.2 applies. Impacts on soil and surface water would be minimal. Air emissions would be controlled, and they may be comparable (in terms of risk) to air emissions that occurred when the Pocatello plant was operating.

TABLE 5-14 (Cont.)

Review Parameter	LDR WTS
Post-implementation impacts on the environment and the community	The parameter discussion for the excavation technology in Section 5.2 applies. With regard to P4 waste that could be accessed by excavation equipment, P4-associated risks from historical pond residuals (residuals located near the surface) would be removed. The remediated historical pond footprint could be reused as brownfield.
Overall discussion of advantages and disadvantages	The advantages are as follows: • The water source needed for the excavation footprint would be available from the LDR WTS clarifier or groundwater P&T system. • The process is mature. • The reactivity/ignitability characteristics could be removed. • Reclaimed land could be reused as brownfield. • The phosphorus could be reclaimed and marketed as phosphoric acid. • The LDR WTS residuals could be disposed of on site or in an off-site landfill. The disadvantages are as follows: • It would be difficult to get regulatory and public acceptance. • The parameter discussion for the excavation technology in Section 5.2 applies. • LDR WTS residuals might require additional treatment to meet WAC at on-site or off-site disposal sites.

5.3.4.4 Overall Likelihood of Success at FMC

Given the fact that the LDR WTS was designed and built specifically for the treatment of soil and debris generated by the FMC plant, the likelihood of its success there appears to be high.

5.3.5 Wet Air Oxidation

5.3.5.1 Description

In order to meet requirements in the FMC Pocatello RCRA Consent Decree of July 13, 1999, FMC evaluated more than 50 waste management technologies capable of treating phossy waste. One technology evaluated was wet air oxidation (WAO) (MWH 1999). The WAO process involves the oxidation of organics or inorganics in water by using oxygen as the oxidizer. In WAO, the oxidation reactions occur in a reactor at elevated temperatures (150–320°C or 275–600°F) and pressures (10–220 barg [barg is the pressure, in bars, above or below atmospheric pressure of 0°C] or 150–3,200 lb/in.^{2} gauge or psig) (Siemens 2015).

A pilot-scale WAO evaluation was performed at the US Filter/Zimpro facility in Rothschild, Wisconsin, in 1998 (Figure 5-14). The pilot-scale evaluation also included lime adjustment of treated slurry and filtration of lime-adjusted slurry. It was determined that the WAO process could acceptably treat phossy wastes. Treatment followed by filtration and stabilization was proven to be effective in treating materials to meet RCRA LDR standards and other Consent Decree requirements (MWH 1999).

5.3.5.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

FMC performed pilot-scale studies using WAO. FMC demonstrated that WAO, followed by the conditioning and treatment of solid residuals and the treatment of off-gases, could successfully treat soil and debris from the former FMC plant. However, pilot-scale studies suggested that the WAO technology did not compare favorably with the anoxic process; the WAO process was viewed as being more complicated and less robust. The WAO process requires greater control of operational parameters and more heating and more efficient transport of oxygen into the slurry. The WAO process requires an N_2 purge. The process could pose wet-cake-handling issues that would require lime adjustment before filtration and stabilization in order to meet Consent Decree requirements. In addition, the design, operation, and permitting

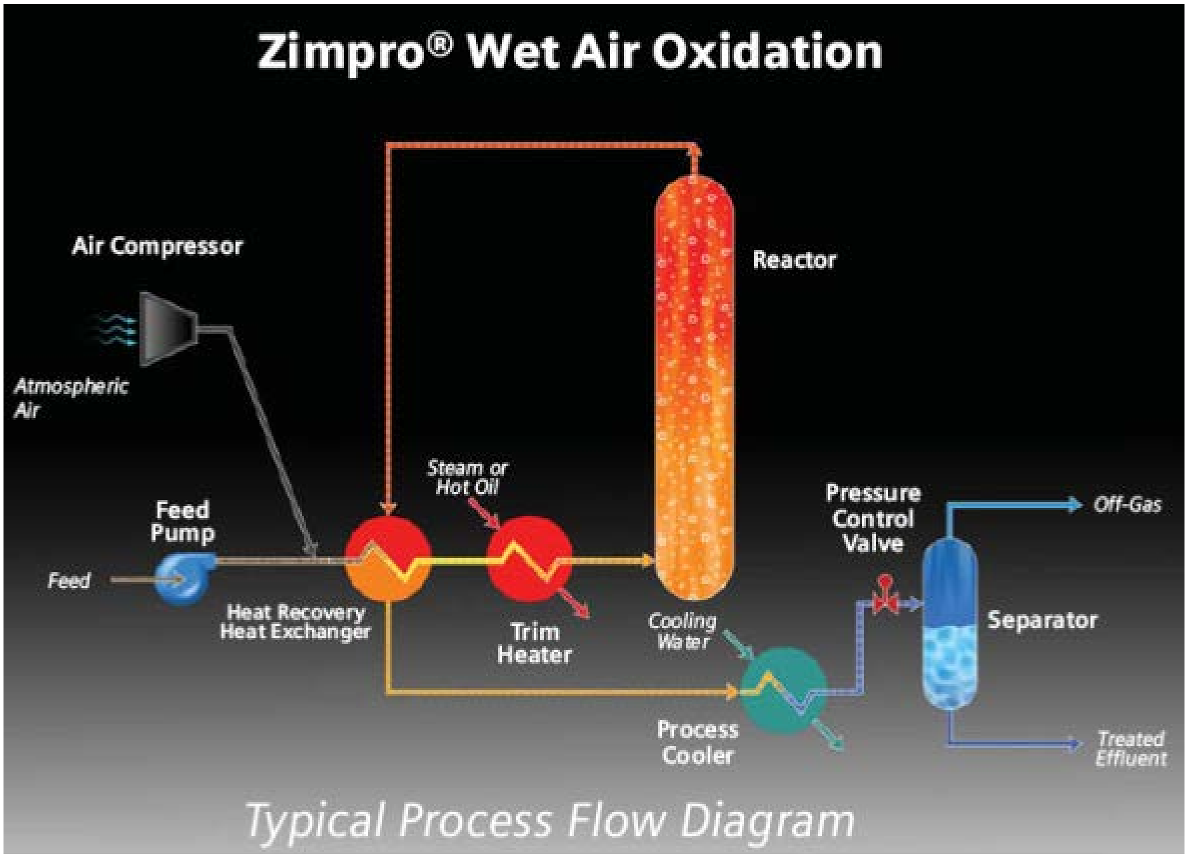

FIGURE 5-14 Typical Process Flow Diagram for Zimpro® Wet Air Oxidation (Siemens Energy, Inc.)

requirements for the air pollution control aspects of the WAO could also be problematic (MWH 1999). FMC acknowledged additional technical challenges for using this technology.

5.3.5.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-15.

5.3.5.4 Overall Likelihood of Success at FMC

It is unlikely that WAO would achieve success at FMC without a protracted pilot-scale study and a full-scale design effort. A pilot-scale study demonstrated that WAO is more complicated and less robust than the anoxic caustic hydrolysis design and that strict control of operational parameters would be needed for the technology to succeed.

TABLE 5-15 Assessment of Wet Air Oxidation Based on ETT Review Parameters

Review Parameter	Wet Air Oxidation
Process maturity	It is considered mature within the waste treatment industry with regard to treating a variety of waste streams. Only a pilot-scale version has been assessed for treating P4.
Limitations	• The parameter discussion for the excavation technology in Section 5.2 applies. • Not all P4 waste could be excavated. • Testing did not specifically address historical pond residuals but instead focused on phossy wastes from the FMC plant. • Full-scale design and operating requirements are unknown. • The NPV estimate for Alternatives 5 through 7 in the September 2010 Proposed Plan would be a comparable OOM estimate to implement this ETT in conjunction with an excavation and disposal ETT.
Time to implement (not including permitting and approvals)	Due to the lack of maturity of this method, the need for pilot studies, and the need for detailed site characterization, it is estimated that 3 to 5 years for pilot-scale studies and construction would be needed to implement it and that 10 years would be required for operations.
Effectiveness of removing and/or treating P4 on site	A pilot-scale version of the WAO was shown to be effective at destroying 100% of the P4 and 96%–98% of the cyanide present in the phossy waste tested.
Process safety for site workers during implementation	The parameter discussion for the excavation technology in Section 5.2 applies. Because this is a totally enclosed system, meeting design and operating requirements could mitigate the risk to site workers.
Community health and safety during implementation	The parameter discussion for the excavation technology in Section 5.2 applies. Meeting design and operating requirements could mitigate risks to the community.

TABLE 5-15 (Cont.)

Review Parameter	Wet Air Oxidation
Impacts to the environment during implementation	The parameter discussion for the excavation technology in Section 5.2 applies. Meeting design and operating requirements should limit the impacts from any air emissions and water discharges.
Post-implementation impacts on the environment and the community	If design and operational hurdles could be overcome, P4-associated risks from historical pond residuals that could be accessed by the excavation technology would be removed. The remediated historical pond footprint could be reused as brownfield.

Overall discussion of advantages and disadvantages	The advantages are as follows: • Pilot-scale testing has been performed. • The waste could be decharacterized. • The air emissions could be controlled. • The residuals could be disposed of on site or in an off-site landfill. The disadvantages are as follows: • Testing and design work would be required to advance from pilot scale to full scale. • It is not known whether the technology could be used to treat soil, sediment, and debris containing P4 waste. • It would be difficult to get regulatory and public acceptance. • Operating parameters and conditions could make operations difficult. • The residuals might require treatment to achieve WAC at on-site or off-site disposal sites.

5.3.6 Solvent Stirred Batch Reactor

5.3.6.1 Description

Elemental phosphorus is a nonpolar compound due to the coordination symmetry of the P-P bonds in the tetra-phosphors molecule. As such, its solubility in strongly polar solvents like water is limited (about 0.003 g/L), while its solubility in nonpolar solvents is relatively high (Table 5-16). Therefore, it is conceivable that nonpolar solvents could be used to treat P4-bearing materials by using a solvent extraction method. This would involve mixing soils and sediments contaminated with white phosphorus with a nonpolar, water-immiscible solvent in a stirred and heated reactor, which would cause P4 dissolution, and then recovering the P4-rich solvent for further processing.

A starting place for developing this method would be to scale up the well-established solvent extraction procedure used to prepare white-phosphorus-bearing samples for analysis by

TABLE 5-16 Solubility of White Phosphorus in Selected Solvents

Solvent	Solubility (g/L)	Disadvantages
Toluene	~30 (similar to benzene)	Flammable
Benzene	28.6	Carcinogen
Ethanol	25	Flammable
Chloroform	25	Anesthetic
Ether	9.8	Flammable, anesthetic
Water	0.003	None
Olive oil	12.5	None
Carbon disulfide	1,250	Flammable, toxic

Acetone	Low solubility	None
Methanol	Low solubility	None

Source: Adapted from Rivera et al. 1996.

gas chromatography (EPA Method 7580, white phosphorus by solvent extraction and gas chromatography). This treatment method would involve the following steps:

- Loading wet (water-saturated), white-phosphorus-bearing soil/sediment into a stainless steel stirred batch reactor vessel,
- Adding solvent,
- Conducting mechanical mixing and heating to achieve the optimal reaction kinetics, and
- Distilling the reacted solvent to recover P4.

The solvent would be recycled and used for multiple extractions.

5.3.6.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

Although this method is technically possible, it has a number of disadvantages that would make its application for a full-scale remediation project unattractive relative to other methods discussed in this report. One of the key disadvantages is the toxic nature of the most effective solvents for this method (benzene, toluene, carbon disulfide, etc.). As shown in Table 5-16, there are some relatively benign chemicals that could be used (oils); however, these solvents are not commonly used as white phosphorous extractants (no reports of their use were found), so extensive laboratory testing would be required to assess their mixing properties and reaction kinetics.

5.3.6.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-17.

TABLE 5-17 Assessment of Solvent Stirred Batch Reactor Based on ETT Review Parameters

Review Parameter	Solvent Stirred Batch Reactor
Process maturity	Conceptual. The process would require laboratory research and development.

Limitations	Tested solvents for this method are toxic and/or flammable (benzene, toluene, carbon disulfide). There is a lack of scalable laboratory test data.
Time to implement (not including permitting and approvals)	Due to immaturity of this method and the need for laboratory studies, it is estimated that 5 or more years would be needed to implement it.
Effectiveness of removing and/or treating P4 on site	Its effectiveness has not yet been determined. This method has been used for relatively small analytical samples, but there are no relevant data on its effectiveness as a large-scale remediation method for P4.
Process safety for site workers during implementation	There would be a high risk to site workers due to P4 ignition (burns), phosphine release from disturbed soils (poisoning), and P_2O_5/phosphoric acid generation (acid inhalation). The risk would be mitigated by keeping all P4-bearing materials saturated and under water, as well as by capturing and treating gases and using appropriate PPE. There would be additional risks if toxic, flammable solvents were used.
Community health and safety during implementation	The unmitigated risk would be high due to possible releases of particulate P4, phosphine, and P_2O_5/phosphoric acid vapors. The risk would be mitigated by treatment plant engineering and by using ancillary treatment technologies.
Impacts to the environment during implementation	The unmitigated risk would be significant. The air quality could be affected by the release of particulate P4, phosphine, and P_2O_5/phosphoric acid vapors. The risk would be mitigated by treatment plant engineering and by using ancillary treatment technologies.
Post-implementation impacts on the environment and the community	There would be no impact on the environment or the community if a properly engineered treatment plant and applicable ancillary treatment technologies were available.
Overall discussion of advantages and disadvantages	• The main advantage of this method is that, since it is a batch process, it would require minimal processing of the feed material. As long as the P4-bearing feed could be well mixed mechanically, there would be little need for particle size reduction or phase separation. • The main disadvantage is that this process has been demonstrated on only relatively small analytical samples by using toxic solvent. There are no scalable data for this process that involve the use of a benign solvent.

5.3.6.4 Overall Likelihood of Success at FMC

Unless there is a considerable research and development effort, this method has a low likelihood of success for use on materials excavated from the FMC site.

5.3.7 Off-Site Incineration

5.3.7.1 Description

In the mid-1990s, FMC performed an extensive nationwide survey as part of a national capacity variance (NCV) to provide for a variance from compliance with the LDRs. FMC surveyed more than 160 RCRA treatment, storage, and disposal (TSD) vendors, including disposal, wastewater treatment, and incineration facilities. In general, the TSD facilities that were surveyed refused to accept waste from the FMC Pocatello plant for a number of reasons, including the volume of the waste, phosphine gas hazards, the possible presence of technologically enhanced naturally occurring radioactive material (TENORM), and the waste streams' reactivity and/or ignitability. As determined by the NCV survey, only one facility could have accepted about 8% of the annual waste stream generated at that time. However, FMC indicated that even to take advantage of that off-site capacity, purchasing the required fleet of railcars and building and operating a waste-loading facility for off-site transport would be cost prohibitive (FMC 1996).

However, the waste profile of the former FMC plant and the volume of waste that requires treatment have changed since that NCV survey was prepared. The manufacturing of P4 no longer occurs, so process waste streams are no longer generated. For example, only remediation waste streams would be created if the historical ponds were to be remediated. Under a remediation-only program, some remediation residuals might remain on site for reclamation or treatment, and only some residuals might need to be diverted to an off-site TSD facility for subsequent treatment and disposal. In addition, since the NCV survey was performed, the universe of TSD facilities has changed, permitting requirements for some TSDs might have changed, and WAC might have changed.

In referring to the incineration of P4-containing residuals from a clarifier at the Solvay Plant in Butte, Montana, Franklin Engineering Group (2007) noted that "fully mature commercial technology with competitive pricing is available." (In this case, the incinerator described was a rotary kiln incinerator, and the waste feed system would involve P4 that is containerized in drums.) For example, treatment of white-phosphorus-containing waste from the remediation of Open Demolition Area #2 at the Ravenna Army Ammunition Plant (RAAP) in Ravenna, Ohio, involved containerizing the waste intended for shipment to an off-site incinerator. According to the waste management plan, approximately 1,000 drums containing white-phosphorus-contaminated soil and debris were managed by topping the drums with water to maintain saturation and then shipping the waste from RAAP to the Veolia incineration facility in Sauget, Illinois. Pure or bulk white-phosphorus waste was managed in 30-gal drums, while white-phosphorus-contaminated soil and debris were managed in 55-gal drums (USACE 2011).

According to a Right-to-Know Network 2014 reporting summary, about 172 tons of reactive waste (most of which was assumed to be the waste generated from remediating white-phosphorus-contaminated soil) was shipped from RAAP to the Veolia facility in 2011.

5.3.7.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

FMC has acknowledged that incineration technology is potentially applicable to small volumes of P4 waste (MWH 2009). The applicability of this ETT to the large volume of P4 waste present at the site depends on (1) waste acceptance by the off-site incinerator at an off-site TSD facility and (2) the feasibility of transporting waste residuals off site. Performing a waste acceptance survey is outside the scope of this independent review. As indicated in the Case by Case Extension discussed in Section 5.3.7.1, the presence of NORM in the waste stream has, in the past, precluded some off-site facilities from accepting P4 waste. The Review Team has not determined if the NORM content would be an issue for off-site incinerators at the present time. However, the NORM content of the P4 waste may add to the complexity and cost for the treatment of P4 waste and the off-site disposal of incinerator residuals. It is unknown whether waste residuals generated as part of a historical pond remediation program might now be acceptable at an off-site TSD facility. Also unknown is the volume of waste that could be accepted by any TSD facility that can accept P4-containing waste. However, as noted in Section 5.3.7.1, there are commercial incinerators that can accept P4-containing waste. Given the fact that pure P4 has been transported off site by rail in the past, it is feasible that waste residuals containing P4 could be loaded and transported to an off-site TSD facility by rail.

5.3.7.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-18.

5.3.7.4 Overall Likelihood of Success at FMC

This technology would involve process steps at FMC, the transportation of P4 waste to a destination TSD facility via road or rail corridors, incineration at the destination TSD facility, and finally the disposal of the waste residuals. Ancillary technologies would probably be capable of excavating P4 waste from the FMC site. Excavated waste could be placed in containers and covered with a water layer relatively easily; this was demonstrated when soil and debris were shipped to the Zimpro facility for treatability studies. However, an extraordinary number of drums would be required, and the amount of truck traffic required to transport the drums could be a nuisance and would represent a risk of transportation accidents. It would be more expeditious to use a bulk-to-bulk handling process for the soil and debris by transporting the excavated soil and debris by railcar. This ETT would probably not succeed at FMC, except with regard to treating a small subset of the P4 waste at the site.

TABLE 5-18 Assessment of Off-Site TSD Facility Based on ETT Review Parameters

Review Parameter	Off-Site TSD Facility
Process maturity	Mature. Off-site TSD facilities already exist.
Limitations	• The parameter discussion for the excavation technology in Section 5.2 applies. • Not all P4 waste is accessible by the excavation technology. • A TSD facility that will accept the waste needs to be identified. • A dedicated fleet of railcars suitable for transporting a U.S. Department of Transportation flammable solid might be required, and a railcar loading and unloading facility might need to be built. • Risks might be created from transporting hazardous waste in containers by truck or by rail. • The NPV estimate for Alternatives 5 through 7 in the September 2010 Proposed Plan would be a comparable OOM estimate to implement this ETT in conjunction with an excavation and treatment ETT.
Time to implement (not including permitting and approvals)	The time needed to plan for ancillary technology and excavation support and constructing waste loading systems is estimated to be 1 year. The time needed to excavate and off-load waste at the site is estimated to be more than 10 years.
Effectiveness of removing and/or treating P4 on site	Off-site TSD facilities probably have a series of treatment units that could treat P4, including rotary kiln-type incinerators with associated air pollution control equipment and incinerator waste solids residual handling.
Process safety for site workers during implementation	The parameter discussion for the excavation technology in Section 5.2 applies. The risk associated with ancillary technologies used for storage before off-site transport could be mitigated.
Community health and safety during implementation	The parameter discussion for the excavation technology in Section 5.2 applies. Community health and safety could be affected by truck or rail transit of a hazardous material.
Impacts to the environment during implementation	The parameter discussion for the excavation technology in Section 5.2 applies. With regard to loading railcars, impacts on the environment would be comparable to the impacts that occurred when the plant was operating.
Post-implementation impacts on the environment and the community	The parameter discussion for the excavation technology in Section 5.2 applies. P4-associated risks from historical pond residuals (residuals located near the surface) would be removed. The remediated historical pond footprint could be reused.
Overall discussion of advantages and disadvantages	The advantages are as follows: • The parameter discussion for the excavation technology in Section 5.2 applies. • The process is mature. • Reclaimed land could be reused. • There would be zero emissions since treatment would occur in an off-site TSD facility.

TABLE 5-18 (Cont.)

Review Parameter	Off-Site TSD Facility
Overall discussion of advantages and disadvantages (Cont.)	The disadvantages are as follows: • It might be difficult to find a TSD facility that would dedicate the needed process capacity to excavated waste. • The parameter discussion for the excavation technology in Section 5.2 applies. • It might be difficult to get regulatory and public acceptance at the waste generation point (FMC Pocatello) and at the state hosting the off-site TSD facility. • After initial treatment, additional treatment might be required to meet WAC at off-site disposal facilities. Both the initial treatment facility and any final off-site disposal facility may have to accept waste containing NORM. The NORM content of the waste may add to the complexity and cost. • Transport by containers in trucks would be prohibitively expensive and create risks associated with truck transit on roads. • Transit by rail would also involve some transport risk and might require a dedicated fleet of railcars and the construction and/or modification of loading and off-loading capability. • This ETT would likely exceed the $81.6 million NPV cost for Soil Alternative 4, the most expensive soil alternative evaluated in the *Supplemental FS* (MWH 2010).

5.4 *EX SITU* DISPOSAL TECHNOLOGIES

5.4.1 On-Site Disposal

5.4.1.1 Description

One option that could be applied to the FMC site is on-site disposal. The remediation plan presented in the 2012 *IRODA* proposes a system of caps and covers, with institutional controls and gas and groundwater monitoring, for the FMC site. Specifically, the *IRODA* calls for installing a protective cap. The purpose of the cap would be to provide a barrier to underlying contamination and to prevent water from moving through the contamination and polluting the groundwater. The cap in this case would be placed over existing soil and debris in an untreated form. With use of this option, P4 would remain as it is; it would retain its ignitable and reactive characteristics. The soil and debris would also continue to contain underlying hazardous constituents, specifically heavy metals, and some portion of these soils and debris could be defined as NORM. The cap would minimize infiltration of water and therefore minimize the leaching of P4, heavy metals, and radionuclides into the subsurface.

These types of "disposal-in-place" remedies have been applied at numerous RCRA and CERCLA sites across the United States in the last 30 years. They have been shown to be effective in reducing risks to human health and the environment, mostly because the exposure pathway is minimized or eliminated altogether. However, only rarely have these types of remedies been approved of for soil and debris that are reactive and ignitable, such as P4. These types of remedial options (i.e., on-site disposal options) are not presented in this document for soils and debris containing P4 above the cleanup level of 23 mg/kg. However, on-site disposal of residuals that remain after P4 has been removed to acceptable levels by treatment is examined herein.

Several different disposal options are available. For example, Solvay is proposing to manage the residuals left over after operation of the mud still, along with materials from some of the other solid waste management units on site, in a CAMU (Barr 2014). CAMUs allow for the management of remediation soil and debris in land-based units without having to meet LDRs and potentially other RCRA requirements (e.g., liners, leachate collection systems), as long as it can be demonstrated that the CAMU will be protective of human health and the environment.

For CERCLA sites, such as FMC, the RCRA CAMU option for management of residuals can be brought in via the CERCLA ARAR process. CERCLA remedial options, however, can include the placement of remediation soil and debris that do not meet RCRA LDRs into CAMU-like, land-based disposal units. Consideration of a RCRA CAMU for FMC through the CERCLA ARAR process is therefore not necessary, but the concept is the same.

Regardless of whether a RCRA CAMU or a CERCLA on-site land disposal remedy is considered for residuals left over after some form of active P4 treatment, this option is very attractive simply because of the tremendous volume of treated residuals that would be generated at the FMC site were these materials instead subject to active treatment to meet LDRs. For example, via a solidification-type process, the volume of treated material that would be created would be excessively large. This is assumed by considering that cement or cement-like pozzolanic materials would be added to the soil and debris requiring treatment, increasing its volume significantly.

5.4.1.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

Disposal of treated waste and soils and debris that have been treated to remove P4 in an on-site CAMU or CERCLA on-site land disposal unit is applicable to FMC. Considering the amount of P4 that would have to be removed, along with the threat of its ignitability and reactivity, the primary remaining concern with regard to the FMC site is heavy metal and NORM contamination. While stabilization could be used to reduce metal and radionuclide leachability, this option would be very costly and would produce a very large amount of material that would still need to be disposed of. The same outcome could be accomplished with a CAMU or a CERCLA remedy that included a cap designed to minimize permeability. No bench-scale or pilot-scale studies would be warranted.

5.4.1.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-19.

5.4.1.4 Overall Likelihood of Success at FMC

Disposal of treated waste and soils and debris that have been treated to remove P4 in an on-site CAMU or CERCLA on-site land disposal unit at FMC has a very high likelihood of success. Considering the amount of P4 that would have to be removed, along with the threat of its ignitability and reactivity, the primary remaining concern for the FMC site would be heavy metal and NORM contamination. A well-designed land disposal unit with an engineered cap that minimized permeability would be protective of human health and the environment as long as the cap was adequately maintained.

5.4.2 Off-Site Disposal

5.4.2.1 Description

Unlike on-site disposal, which for this analysis is limited to waste and soil and debris from which P4 has been removed or treated down to an acceptable level, off-site disposal is considered here for the full range of waste and soil and debris that contain P4 above levels of concern. This represents a very large amount of waste and soil and debris for which it would take thousands, if not hundreds of thousands, of truck loads or railcars to remove. It would also be difficult, if not impossible, to find an off-site permitted RCRA disposal facility that would accept this amount of waste. More likely, a new RCRA-permitted facility would need to be established to accept the waste, because the amount involved could overwhelm a typical land disposal facility.

Such a facility could be overwhelmed not only because of the huge volume of material but also because if the waste and P4-contaminated soil and debris were moved off-site, the receiving facility would need to ensure that RCRA LDRs were achieved not just for the P4 materials but also for the heavy metals as well. Furthermore, the presence of radionuclides and potential NORM classification might make the acceptance of all the P4 waste problematic. Alternatively, P4 waste could be treated at the FMC site and then transported to an off-site location. Treatment could include addressing RCRA LDRs. However, the receiving facility would need to be permitted to accept the treated P4-contaminated soil and debris, and the regulator in the receiving state would need to approve the facility. In addition, the local public would need to be agreeable to having such a facility nearby; otherwise, there could be years of delays during the facility permitting process.

TABLE 5-19 Assessment of On-Site Disposal in a CERCLA Landfill Based on ETT Review Parameters

Review Parameter	On-Site Disposal in CERCLA Landfill (equivalent to a RCRA CAMU)
Process maturity	• Full-scale maturity. • Securing a CERCLA on-site disposal remedy is a common remedial approach.
Limitations	• There are no known impediments. • The NPV estimate for Alternatives 5 through 7 in the September 2010 Proposed Plan would be a comparable OOM estimate to implement this ETT in conjunction with an excavation and treatment ETT.
Time to implement (not including permitting and approvals)	• Landfilling of residuals after P4 has been removed might be able to begin immediately upon regulatory approval. • The time needed for implementation would depend on the total amount of contaminated media.
Effectiveness of removing and/or treating P4 on site	CERCLA on-site disposal would minimize further migration of contaminants from the site, but it would neither remove nor treat any low-level P4 remaining in the soil or media.
Process safety for site workers during implementation	The process safety risks for CERCLA on-site disposal would be related to the residuals from which P4 could not be readily recovered, and they would be similar to the risks from typical hazardous waste landfill operations. Risks would be considered moderate to high. Appropriate engineering controls and PPE would bring worker risks to acceptable levels.
Community health and safety during implementation	• The process health risks for CERCLA on-site disposal would be related to residuals from which P4 could not be readily recovered, and they would be similar to the risks from typical hazardous waste landfill operations. Risks would be considered low to moderate. • Appropriate engineering controls (e.g., dust suppression, daily cover) would bring the community risk to acceptable levels.
Impacts to the environment during implementation	A properly constructed CERCLA on-site disposal remedy that would meet the design criteria for residuals from which P4 could not be readily recovered would have minimal impacts on the soil, surface water, and groundwater.
Post-implementation impacts on the environment and the community	• Assuming that all residuals from which P4 has been removed to acceptable levels were placed in the CERCLA on-site disposal unit, post-implementation impacts would be minimal. • Institutional controls would address potential impacts on the environment and community.
Overall discussion of advantages and disadvantages	The advantages would be as follows: • This option could be applied only to P4 residuals that could not be readily recovered. • It is a proven technology. • It has a simple design and is easily understood. • It is anticipated that public approval would be favorable.

TABLE 5-19 (Cont.)

Review Parameter	On-Site Disposal in CERCLA Landfill (equivalent to a RCRA CAMU)
Overall discussion of advantages and disadvantages (Cont.)	The disadvantages are as follows: • Sorting materials before implementing the on-site CERCLA disposal remedy could result in worker and environmental exposure. • A large volume of material might need to be landfilled. • It would require siting on an appropriate portion of FMC property. • Its cost would be high relative to the cost of cap and cover options.

5.4.2.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

From a technology perspective, off-site disposal is applicable for FMC. However, if the waste and soil and debris were sent off site, RCRA LDRs would have to be satisfied. The receiving facility would need to treat the FMC waste and soil and debris to remove P4 to the point where the waste and soil and debris no longer exhibited the characteristics of ignitability and reactivity. UCs (primarily heavy metals) would need to be addressed as well. Here, stabilization would be the most appropriate technology. Once the P4 and heavy metals were addressed, the waste, soil, and debris would no longer be considered hazardous waste and would be considered nonhazardous. The waste, soil, and debris could be disposed of as nonhazardous solid waste, but there would be other options too, including potential reuse as fill material. Bench-scale and pilot-scale studies of the off-site disposal alternative might be useful, particularly if the means of addressing P4 and heavy metals would involve a new or innovative treatment technology.

5.4.2.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-20.

5.4.2.4 Overall Likelihood of Success at FMC

Although the off-site disposal approach is applicable to FMC soil and debris, it is unlikely to be considered. The cost of sending all contaminated FMC soil and debris off site would be considerably higher than the cost of any on-site alternative. This off-site disposal approach might succeed for a small subset of the P4 waste after it has been treated.

TABLE 5-20 Assessment of Off-Site Disposal Based on ETT Review Parameters

Review Parameter	Off-Site Treatment/Disposal
Process maturity	Full-scale maturity. Sending P4 materials off site would require the same safeguards as those applied to the product.
Limitations	• There would be a large number of shipments of waste soil and debris via truck or rail over potentially many years. • The NPV estimate for Alternatives 5 through 7 in the September 2010 Proposed Plan would be a comparable OOM estimate to implement this ETT in conjunction with an excavation and treatment ETT.
Time to implement (not including permitting and approvals)	• Off-site shipments could begin immediately upon regulatory approval. • The time needed for implementation would depend on the total amount of soil and debris that needed to be shipped off site. • There would be a large number of shipments of waste soil and debris via truck or rail over potentially many years.
Effectiveness of removing and/or treating P4 on site	The removal of soil and debris would take years but would be effective.
Process safety for site workers during implementation	• The process safety risks to workers from off-site shipments would be similar to those from a typical hazardous waste transport operation. • The risks would be considered moderate to high.
Community health and safety during implementation	The process safety risk for community health and safety from off-site shipments would be similar to those from a typical hazardous waste transport operation. The risks would be considered moderate.
Impacts to the environment during implementation	The removal of soil and debris would take years but would be effective, with a minimal impact on the environment.
Post-implementation impacts on the environment and the community	Assuming that all P4-contaminated materials above established levels were sent off site, post-implementation impacts would be minimal.
Overall discussion of advantages and disadvantages	The advantages are as follows: • The technology could be applied to all P4 residuals at concentrations above established cleanup levels. • It has a simple design and is easily understood. • It is anticipated that public approval at the FMC site would be favorable. The disadvantages are as follows: • A large volume of material might need to be sent off site, which could take many years. • Public approval at the receiving site might be problematic. • The cost of transporting treated P4 waste to an off-site disposal facility would be high relative to the cost of on-site disposal of treated P4 waste.

5.5 Abandoned Railcars and Underground Piping

5.5.1 Underground Piping

5.5.1.1 Description

Residuals containing P4 are likely to be present in both process-related and stormwater-related underground pipes located at the FMC OU (Figure 5-15). As reported in the *Supplemental FS* (MWH 2010), underground piping may contain residual P4. These underground process pipes and stormwater lines are present in RUs 1, 2, 3, 8, 12, 13, 22b, and 24. The process-related piping is constructed of mild steel. The 16-in. stormwater piping in RU 1 and RU 3 is constructed of concrete (MWH 2010). The stormwater piping was cleaned out in the spring of 2015, and it still might be in the process of being cleaned out via the use of in-line hydraulic flushing methods (FMC Idaho 2015; also see Shoshone-Bannock Tribes' Responses to Argonne's Questions and Comments on FMC's Responses of June 2015 [Appendix F]). The amount of waste present in the underground pipeline was summarized in Table 2-1.

Pipelines and sumps that could have been used to handle P4 are summarized in Table 5-21. Also summarized in the table are the RUs where the pipelines are located, the purposes of the pipelines, the sizes and minimum and maximum depths of the pipelines, the materials of construction, and whether or not the pipeline was abandoned in place. In addition to the pipelines summarized in Table 5-21, there are other pipelines associated with closed RCRA ponds that might contain P4 or P4 by-products.

A waste management scenario somewhat similar to the one in which there is the presence of a very hazardous waste (P4-containing residuals) within underground pipelines can be found at the U.S. Department of Energy's Hanford Reservation. At the Hanford Reservation, there are 7 to 8 miles of pipelines in Waste Management Area (WMA) C that contain about 1,200 gal of radioactive waste. Closure options being considered for the WMA included removing the contents of the pipelines by hydraulic pigging, grouting the pipelines in place, or abandoning the pipelines in place should WMA C be closed as a landfill. A number of the technologies considered for the Hanford Reservation could potentially be used at the FMC site (Badden et al. 2013). These technologies that could be used to address the remaining underground piping include both *ex situ* and *in situ* closure ETTs.

Ex situ excavation could proceed, as discussed in Section 5.1. Portions of pipelines could be flooded, either through the pipeline or external to the pipeline. Pipeline removal could proceed in segments. Conventional excavation techniques could then be used to access the flooded pipeline. Sectionalized portions of the pipeline could be placed in a water bath at the ground surface in preparation for subsequent handling. Subsequent handling could include treating sections in an on-site incinerator, for example. Alternatively, excavation could proceed as discussed in Section 5.3.2, with the excavation process encapsulated in a mobile instant structure (a sprung instant structure or similar structure), with the pressure/air controlled by using

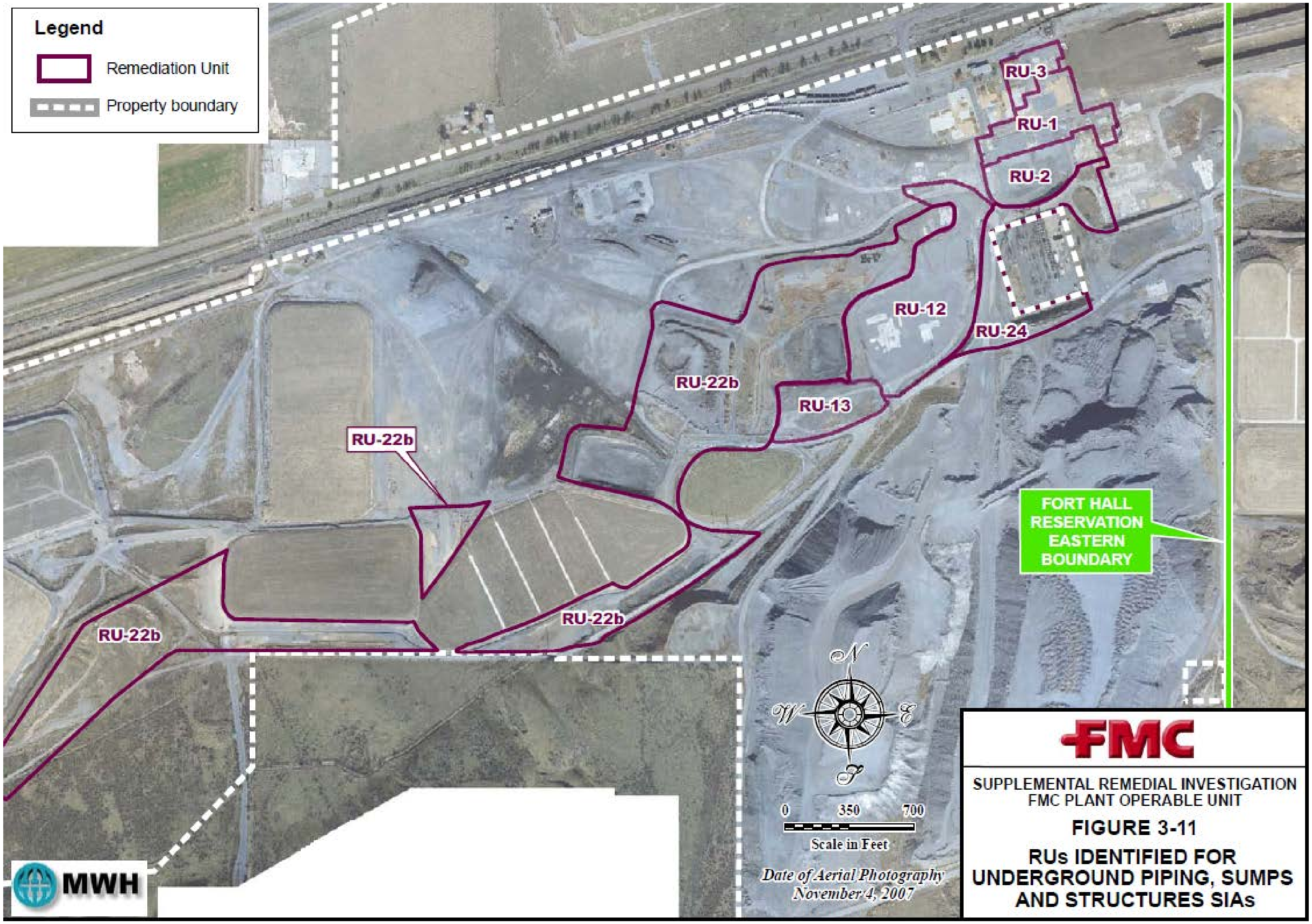

FIGURE 5-15 RUs Identified as Containing Underground Piping, Sumps, and Structures (Source: FMC 2009)

TABLE 5-21 Pipes with Possible Deposits of P4 and Phossy Solids (mixture of P4 and "dirt")

RU	ID	Utility	Size (in.)	Min. Depth (ft bgs)	Max. Depth (ft bgs)	Material	Status
1	20	Precipitator slurry	6	2	3	Carbon steel	Abandoned in place
1	21	Phossy water	6	2	3	Carbon steel	Abandoned in place
1	42	Storm drain	15	5	8	Reinforced concrete	In use – site drainage
1	43	Storm drain	15	5	8	Reinforced concrete	In use – site drainage
1	53	Phossy water	18	8	10	Carbon steel	Abandoned in place
1	54	Storm drain	16	5	8	Reinforced concrete	In use – site drainage
1	66	Storm drain	10	3	5	Carbon steel	Abandoned in place
1	S1	Phossy water sump	1,000 gal	6	8	Stainless steel	Pumped, deconned, and abandoned in place
1	S2	Furnace Building P4 storage sumps	Varies	6	8	Reinforced concrete	Lining removed, deconned, backfilled with silica
1	S3	Phos dock sumps	Varies	10	12	Reinforced concrete	Lining removed, deconned, backfilled with silica
1	S4	Secondary condenser area phos sump	Varies	?	?	Stainless steel	Lining removed, deconned, backfilled with silica
2	23	Phossy water	6	2	3	Carbon steel	Abandoned in place
2	24	Precipitator slurry	3	2	3	Carbon steel	Abandoned in place
2	25	Phossy water	4	2	3	Carbon steel	Abandoned in place
2	66	Storm drain from kiln building to slag pit	10	3	5	Carbon steel	Abandoned in place
2	69	P4 recovery line	3	2	3	Carbon steel	Abandoned in place
2	70	Phossy water	4	2	3	Carbon steel	Abandoned in place
2	79	Phossy water	4	2	3	Carbon steel	Abandoned in place
2	80	Precipitator slurry	3	2	3	Carbon steel	Abandoned in place
2	81	Precipitator slurry	4	2	3	Carbon steel	Abandoned in place
2	83	Slag pit dewatering	6	2	3	Carbon steel	Abandoned in place
2	84	Slag pit dewatering	6	2	3	Carbon steel	Abandoned in place
3	42	Storm drain	15	5	8	Reinforced concrete	In use – site drainage
3	43	Storm drain	15	5	8	Reinforced concrete	In use – site drainage
3	54	Storm drain	15	5	8	Reinforced concrete	In use – site drainage
3	F36	P4 decon building foundation	NA[a]	0	5	Reinforced concrete	Deconned, backfilled with silica
4	90	Storm drain	15	5	8	Reinforced concrete	In use – site drainage
8	66	Storm drain from kiln building to slag pit	10	3	5	Carbon steel	Abandoned in place
8	68	Calciner CO lines	14	3	5	Carbon steel	Abandoned in place
12	20	Precipitator slurry	6	2	3	Carbon steel	Abandoned in place

TABLE 5-21 (Cont.)

RU	ID	Utility	Size (in.)	Min. Depth (ft bgs)	Max. Depth (ft bgs)	Material	Status
12	21	Phossy water	6	2	3	Carbon steel	Abandoned in place
12	69	P4 recovery line	3	2	3	Carbon steel	Abandoned in place
12	78	Precipitator slurry	4	2	3	Carbon steel	Abandoned in place
12	79	Phossy water	4	2	3	Carbon steel	Abandoned in place
12	80	Precipitator slurry	3	2	3	Carbon steel	Abandoned in place
12	81	Precipitator slurry	4	2	3	Carbon steel	Abandoned in place
12	83	Slag pit dewatering	6	2	4	Carbon steel	Abandoned in place
12	84	Slag pit dewatering	6	2	4	Carbon steel	Abandoned in place
22b	20	Precipitator slurry	6	2	3	Carbon steel	Abandoned in place
22b	21	Phossy water	6	2	3	Carbon steel	Abandoned in place
22b	23	Slag pit dewatering	6	2	3	Carbon steel	Abandoned in place
22b	24	Precipitator slurry	3	2	3	Carbon steel	Abandoned in place
22b	25	Slag pit dewatering	6	2	3	Carbon steel	Abandoned in place
22b	27	Phossy water	6	2	3	Carbon steel	Abandoned in place
24	20	Precipitator slurry	6	2	3	Carbon steel	Abandoned in place
24	21	Phossy water	6	2	3	Carbon steel	Abandoned in place
24	23	Phossy water	6	2	3	Carbon steel	Abandoned in place
24	24	Precipitator slurry	3	2	3	Carbon steel	Abandoned in place
24	25	Phossy water	4	2	3	Carbon steel	Abandoned in place
24	69	P4 recovery line	3	2	3	Carbon steel	Abandoned in place
24	70	Phossy water	4	2	3	Carbon steel	Abandoned in place
24	78	Precipitator slurry	4	2	3	Carbon steel	Abandoned in place
24	79	Phossy water	4	2	3	Carbon steel	Abandoned in place
24	80	Precipitator slurry	3	2	3	Carbon steel	Abandoned in place
24	81	Precipitator slurry	4	2	3	Carbon steel	Abandoned in place
24	90	Storm drain	15	5	8	Reinforced concrete	In use – site drainage

[a] NA = not applicable.

Source: FMC (2009); Table 4-51.

remotely controlled excavating equipment, a high-vacuum soil extraction system (Guzzler™),[3] or a system similar to that used to excavate radiologically contaminated soil at the Hanford Reservation in Washington State (Badden and Seely 2010).

In situ pipeline residual extraction could be done by using a flushing approach similar to one used on concrete storm sewers and/or pipeline pigging involving a utility pig, such as a brush, scraper, or hydraulically activated pipeline pig (Stoltze 2007). A combined approach involving *in situ* inspection and pipeline content removal might be applicable to FMC. Pigging involves the insertion of devices for cleaning or inspecting pipelines. Pigs can be retrofitted with video cameras (with an illumination or infrared source), flammable gas sensors, chemical sensors, field-portable analytical systems, and/or remotely operated sampling equipment. Devices can be inserted via drains, valves, diversion boxes, manholes, flanges, etc. Pigging can be limited by the configuration of pipelines, since pigs are typically tethered or self-propelled and work best in straight sections of pipelines. In particular, hydraulically activated pipeline pigging (HAPP™) or similar pigs could be used to both inspect and clean out pipelines with structural integrity, assuming the cleaning action could remove any solidified P4-containing residuals. The HAPP approach is somewhat similar to the approach already being used to clean out the storm sewers at the site. Basically, hydraulically activated cleaning jets could be used to clean interior pipeline surfaces. However, process pipelines could contain pure or relatively pure P4, which would make the HAPP of process pipelines different than cleaning out the storm sewers that contained dilute P4-containing soil and debris.

Pigging was not considered a viable technology for the Hanford Reservation contamination scenario discussed above because (1) hydraulic pigging would require the introduction of significant volumes of water under pressure to both activate and move the pig and (2) the selected remedial alternative at the Hanford Reservation involved abandoning the pipelines in place. However, at the FMC site, the introduction of water would be necessary in order to address the hazards associated with P4 within a given pipeline. Water and pipeline residuals generated during pipeline cleaning could be treated by using the P4-deactivating/recovery/disposal method selected to address other P4-containing soil and debris at the site.

5.5.1.2 Applicability to FMC and Value of Bench-Scale and Pilot-Scale Studies

A combination of an *in situ* approach and an *ex situ* approach might be required to remove underground piping at the former FMC plant. *In situ* approaches might offer the best option from a worker safety standpoint, since air emissions could be controlled with engineering controls. However, for cases in which pipelines have collapsed or where P4-containing residuals have solidified and cannot be moved by cleaning, an *ex situ* approach might be needed. *Ex situ* approaches would have applicability similar to that described in the excavation discussion in Section 5.2. Sloping, benching, and laybacks might not be the best approach for pipeline

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[3] Guzzler™ is a vacuum-based system used to selectively remove soil/waste after it has been broken up by a high-pressure water stream. Guzzler is a registered trademark of Guzzler Manufacturing, Inc., Streator, Illinois (Badden and Seely 2010).

removal. Shoring might be the best approach for removing a linear feature like a pipeline, and it would limit the amount of soil requiring excavation. Workers would have to be protected from cave-ins as well as from the hazards associated with P4. Protective systems for excavations would have to meet the requirements found in 29 CFR 1926.652 (Part 1926, "Safety Regulations for Construction," Subpart P, "Excavations"). Excavations deeper than 20 ft would have to be designed by a registered professional engineer.

Should an *ex situ* approach involving pipeline excavation and removal be used, the presence of pure, or relatively pure, P4 in some pipelines would necessitate extraordinary preparations and could involve approaches that address water flooding and involve isolating sections of pipelines before removal. Pilot-scale studies, including studies on the removal of representative (in terms of materials of construction, depth, linearity, etc.) sections of piping, used with *ex situ* approaches would probably be needed to determine the viability of the *ex situ* removal of piping.

Pilot-scale *in situ* studies, including the use of pigging (HAPP or similar methods) on sections of piping representative of different construction materials, diameters, configurations, pig entrance and egress points, etc. would probably be needed to determine the viability of pigging technology. Furthermore, pilot-scale testing on a section of piping would also be needed to establish the best techniques for recovering pipeline residuals that were mobilized by the hydraulic action of the pig.

5.5.1.3 Assessment Based on Review and Evaluation Parameters

The evaluation results are shown in Table 5-22.

5.5.1.4 Overall Likelihood of Success at FMC

It appears that a combination of *in situ* and *ex situ* approaches could succeed at the FMC OU.

5.5.2 Abandoned Railroad Tank Cars

5.5.2.1 Description

Twenty-one railroad tank cars are present in RU 19c, which is about 2.7 acres in size and is located in the center of the slag pile (RU 19). The railcars were placed at the then-southern edge of the slag pile in 1964 and were covered with native soil. The amount and purity of the P4 sludge present in the railcars are uncertain. As reported in Appendix B of the *Supplemental FS*, the sludge was nearly pure (95% P4), and the capacity of the railcars was 10% to 25%. Here is language from Appendix B of the *Supplemental FS*:

TABLE 5-22 Assessment of Underground Pipeline Cleaning Technologies Based on ETT Review Parameters

Review Parameter	Underground Pipeline Cleaning Technologies
Process maturity	*In situ* technologies for the inspection and removal of pipeline contents are fully mature. *Ex situ* technologies for the removal of pipeline and pipeline P4 content are not mature.
Limitations	• *In situ* technologies would be limited by pipeline sections that have failed structurally or by plugs of process waste that could not be removed. *In situ* technologies might also be limited by pipeline configurations and turns, valves, and sumps present in the pipeline. • Pipelines would have to be filled with water, or the pipeline transect would have to be flooded in order to remove pipelines with *ex situ* technologies. • Whether methods were performed *in situ* or *ex situ*, pipes would have to be decontaminated, and waste residuals would have to be treated/recovered.
Time to implement (not including permitting and approvals)	Estimated time is 1 year for planning. Estimated time is 3 years for operations.
Effectiveness of removing and/or treating P4 on site	*In situ* technologies used in intact pipelines would probably be effective at removing P4 from the pipelines. *Ex situ* pipeline removal would require process steps for crimping and cutting pipeline sections, placing pipeline sections in a water bath, and then removing P4 from and decontaminating the pipelines.
Process safety for site workers during implementation	• Process safety for site workers during implementation of *in situ* technologies could be managed with engineering controls and PPE. • Worker safety for *ex situ* technologies could also be managed with engineering controls and PPE, but process steps would have to be rigorously planned and evaluated because of potential unknown factors.
Community health and safety during implementation	The risk to community health and safety could be mitigated by well-planned and executed actions.
Impacts to the environment during implementation	*Ex situ* technologies could result in impacts as described for the excavation technologies in Section 5.2. *In situ* approaches should result in minimal impacts on the environment.
Post-implementation impacts on the environment and the community	There should be few or no impacts on the environment and community after implementation.
Overall discussion of advantages and disadvantages	The advantages are as follows: • *In situ* technologies were successfully applied in the storm drain pipelines and should function for the other pipelines. • *In situ* technologies offer the potential to control emissions to air and to help capture any decontamination fluids. • *In situ* technologies could be used to remove plugs of P4 product in a relatively controlled environment. • *Ex situ* technologies could be used to address collapsed pipelines or plugs that could not be otherwise removed by using *in situ* technologies.

TABLE 5-22 (Cont.)

Review Parameter	Underground Pipeline Cleaning Technologies
Overall discussion of advantages and disadvantages (Cont.)	The disadvantages are as follows: • Pipeline collapses or pipeline configurations could preclude the use of *in situ* technologies. • The chemical environment could damage *in situ* equipment. • Either *in situ* or *ex situ* technologies could require the use of large volumes of water.

> **"1.3.3 Description of P4 Sludge Generation and Management**
> P4 was typically very pure, white phosphorus. However, due to a number of process variables, ore, silica and/or coke dust, along with other condensables would pass through the electrostatic precipitator in trace amounts and end up with the liquid P4 product. These insolubles would rise to the top of the liquid P4 as it was stored in a liquid state and eventually concentrate to form what was referred to as P4 sludge. The sludge typically ranged from 75 to 95% P4. The P4 sludge was much more viscous and would not easily pump from the sumps and tanks. Therefore, over time P4 sludge would build up within the storage vessels and railcars."

And as reported in Section 2.2.2 of Appendix B:

> **"2.2.2 Contents of the Railcars**
> As described in Section 1.0, it is expected that the railcars contain about 10 to 25% of their total capacity as P4 sludge. However, it is not known if the railcars were filled with water or nitrogen prior to transportation to the slag pile area for burial."

Ironically, the information in Appendix B of the *Supplemental FS* conflicts with the information that summarizes the contents of the railcars in the main body of the same Supplemental FS report: The *Supplemental FS* reports in **2.3.3.4 Railroad Cars in Slag Pile (RU 19c)** "that the railcars contain an estimated 10 to 25% P4 sludge." Also included in the main body of the *Supplemental FS* is the following: "<u>Summary of Pertinent SFS Information for RU 19c:</u>

- P4 concentrations of the sludge within the railcars range from 10 to 25%"

It appears that the main text of the Supplemental FS transposed the percent capacity and percent purity.

Sludge resulted from both the manufacturing process and from shipping P4 in railcars. Given the high concentration of P4 in the sludge (concentrated to 25% or higher), efforts were expended to try to reclaim the P4 in the sludge by cleaning out the tank cars used for transshipment of P4 and feeding the sludge back into the furnace. Reportedly, P4 sludge was periodically removed from inside railcars used to ship P4 by using a combination of pumping, steam cleaning, and manual scraping and shoveling (MWH 2010).

It appears that in addition to using railcars to ship P4 product, railcars may have also been used for staging or storing P4 sludge over an unspecified time frame. Thirty railcars were used for such storage. In the case of the tank cars used for storage, cleaning sometimes involved removing internal steam coils first and then cleaning the railcars. Cleaned cars were reportedly scrapped or sold intact. After what are described as “near-miss accidents” (and perhaps efforts expended cleaning nine railcars), nine railcars were cleaned and then scrapped. Twenty-one railcars were removed from their trucks (wheels) and disposed of in the slag pile (MWH 2010).

The capacity of a railcar is 15,000 gal. The total capacity of all railcars is 315,000 gal. The P4 sludge volume present in all of the railcars ranges from 31,500 to 78,750 gal. The mass of P4 present in the railcars has been estimated to range from 200 to 2,000 tons. After the railcars were placed at the edge of the slag pile, the railcars were covered with slag. Based on the known original native soil elevation, it has been estimated that the railcars have been buried beneath 80 to 120 ft of slag. Slag overlying the railcars was removed during regrading operations in 2015, so it is likely that the railcars are now buried beneath less than 80 ft of slag (Appendix C). The slag present in the RU and overlying the railcars is described as mostly uncrushed slag containing slag ranging in size from 1/4 in. to boulder size (MWH 2010).

The slag covering the railroad tank cars and the slag located throughout the FMC OU likely contains P4. As reported in the Shoshone-Bannock Tribes’ Comments on FMC’s May 18, 2015, Responses to Argonne’s Questions of April 21, 2015, P4 material is contained in the slag material. Appendix C documents numerous USCs associated with the unplanned identification of P4 during slag movement. When P4 is uncovered, it is covered with sand and/or allowed to burn until P_2O_5 smoke is no longer visible, after which the reacted material is moved to a staging area (Appendix C).

Figure 5-16 is a photograph of site visitors standing at or near the level of native soil (before the 2015 regrading operation). The railcars are buried beneath the slag pile on the right side of the photograph. Figure 5-17 is another photograph of the slag pile. Both Figures 5-16 and 5-17 depict the ranges in particle size present in the slag pile. Note that some of the slag was deposited as a liquid, which flowed and then hardened while cooling.

5.5.2.2 Applicability to FMC and the Value of Bench-Scale and Pilot-Scale Testing

Several of the ETTs already discussed in this document have the potential to address the P4 present in the abandoned railcars. However, the presence of such large quantities of potentially highly concentrated P4 in the 21 railcars (potentially 2,000 tons or 78,500 gal) creates a unique and risky hazardous materials cleanup challenge. Responding to this hazardous materials cleanup challenge requires additional information gathering, planning, and pilot-scale testing before implementing any ETT.

FIGURE 5-16 Site Visitors Standing at or Near the Level of Native Soil (Source: provided by Argonne)

At a minimum, a more refined CSM is needed, including a better or complete understanding of the location, configuration, and condition of the railcars. The conflict regarding the relative purity of the P4 present in the railcars (25% versus 95%) is another uncertainty that could be resolved if the abandoned railcar CSM is refined in the future. The assessment of the railcars should take full advantage of techniques like geospatial analysis using aerial photography and of environmental geophysics (including ground penetrating radar, seismic reflection, seismic refraction, two- and three-dimensional resistivity, and magnetics) to gain the understanding needed to plan how to address the P4 content of the railcars. Geophysical assessments should proceed iteratively as slag and soil layers are removed. Planning should integrate a number of *in situ* and *ex situ* ETTs already discussed. Planning should incorporate potentially first removing slag to gain access to the railcar disposal site with the intent to conduct any additional geophysics needed to refine the CSM and to prepare for opening a tank car in order to perform either bench- or pilot-scale studies or full-scale P4 removal.

FIGURE 5-17 Slag Pile (Source: provided by Argonne)

Slag removal could proceed using an *ex situ* excavation method, as described in Section 5.2. If a 3:1 slope would be required to safely gain access to the railcar disposal site, it has been estimated that more than 300,000 yd^3 of slag would need to be removed (MWH 2010). Presumably, as USCs occur during slag excavation, exposed P4 could be allowed to react in open air or under a structure as described in Section 5.3.2. The P4 identified during slag removal could also be staged in a water-filled drop tank and then recovered by using the batch mud still described in Section 5.3.3.

After slag is removed, the soil covering the railcars would need to be carefully removed to gain access to the railcars. Planning would need to address how to respond to a USC involving P4 that has leaked or that is continuing to leak from a railcar during the operation. Planning might also involve collecting additional soil samples adjacent to the buried railcars to determine whether or not leakage has occurred. Railcars with similar characteristics should then be grouped (as needed) for performing bench-scale and pilot-scale studies and for implementing an ETT.

Water present in the railcars would have to be removed and treated, potentially in the treatment system for the groundwater P&T system. An inert atmosphere could then be created in the test railcar(s) in preparation for an ETT. ETTs potentially applicable for the railroad tank cars include doing internal tank washing using high-pressure tank cleaning systems and/or using vegetable oil to solubilize and wash P4 sludge. A number of different internal tank cleaning technologies are available for railroad tank cars, bulk aboveground fuel storage tanks, and underground storage tanks. An example of a high-pressure tank cleaning system is manufactured by Holland Applied Technologies (http://www.hollandapt.com/static.asp?path=3586,10444). Any sludge mobilized by the cleaning system could be vacuumed from the railcar by using a Guzzler or similar vacuum technology. Other potentially applicable technologies include a sluice nozzle and robotic arm vacuum recovery system designed to remove high-level radioactive waste from tanks at the Hanford Reservation (http://www.osti.gov/scitech/servlets/purl/1011436-). Sludge removed from railcars would then need to be packaged and either treated on site in the ETT selected to treat other P4 waste or transferred from bulk to containers and shipped off site for incineration.

Tank cleaning systems are typically water-based. Given the poor solubility of P4 in water, another approach might be to substitute vegetable oil for water in the tank washing system. The solubility of P4 in oil was discussed for a potential *in situ* ETT (Section 5.1.2). An assessment of the feasibility of using vegetable oil as a solvent and/or using any one of numerous internal tank cleaning systems should be evaluated with bench- and pilot-scale testing. Bench- and pilot-scale testing can also provide useful information about the treatability of any P4 sludge that is extracted from the rail cars.

The results of the internal tank washing procedure can be used to determine whether or not the railcars can be filled with sand and abandoned in place, or whether the railcars need to be opened up to allow the manual removal of P4 sludge by using the techniques developed by FMC for the routine maintenance of railcars. There is also some precedent for the manual removal of P4 from tanks, as referenced on the Chiresa website (Chiresa AG 2008). The step-by-step requirements for such an ETT have been discussed generally in the *Supplemental FS* (MWH 2010).

5.5.2.3 Assessment Based on Review Parameters

An assessment of the suggested ETTs for the abandoned railcars is included in Table 5-23.

TABLE 5-23 Assessment of Abandoned Railcar Technologies Based on ETT Review Parameters

Review Parameter	Abandoned Railcar ETTs
Process maturity	• *Ex situ* technologies for the removal of slag are mature. • Practices for handling USCs are mature. • Recovery of any mined P4 from slag in a mud still is mature. • Remotely operated internal tank cleaning technologies are mature, but not for the removal of P4 sludge. • The efficacy of using vegetable oil for P4 sludge removal is unknown. • Manual cleaning of railcars is mature.
Limitations	Slag removal coupled with exposing the abandoned railcar disposal site could result in uncontrollable emissions. Worker health and safety risks would be significant. However, the railcars could be cut open rather than being cleaned out using confined space entry requirements.
Time to implement (not including permitting and approvals)	Estimated time is 1 year for refining the CSM and planning the operation. Estimated time is 1 year for pilot-scale studies. Estimated time is 3 years for operations.
Effectiveness of removing and/or treating P4 on site	• *Ex situ* excavation technologies would be effective in exposing and handling P4 USCs during slag removal. The effectiveness of removal P4 sludge using remotely operated equipment is unknown. • Past practices suggest that manual cleaning of the railroad tank cars was effective. P4 sludge could be containerized and treated off site in an incinerator.
Process safety for site workers during implementation	• Process safety for site workers during slag removal and during manual entry of railcars could be managed with engineering controls and PPE. • Worker safety for the performance of remotely operated internal tank cleaning technologies could also be managed with engineering controls and PPE, but process steps would have to be rigorously planned and evaluated because of potential unknown factors.
Community health and safety during implementation	The risk to community health and safety could be mitigated by well planned and executed actions.
Impacts on the environment during implementation	*Ex situ* excavation technologies could result in impacts as described for the excavation technologies in Section 5.2. If the railcars lack integrity and have leaked P4 into the environment, exposing the railcar disposal site could result in significant emissions to the environment.
Post-implementation impacts on the environment and the community	There should be little or no impact on the environment and community after implementation.

TABLE 5-23 (Cont.)

Review Parameter	Underground Pipeline Cleaning Technologies
Overall discussion of advantages and disadvantages	The advantages are as follows: • Slag removal has been successfully applied already. Methods to address P4 releases during USCs have been developed. • Remotely operated *in situ* tank technologies offer the potential to control emissions to air, minimize site worker risks and to help capture any sludge decontamination fluids. • Past practices can be used to manually clean railcars that cannot be completely remediated using internal tank cleaning technologies. The disadvantages are as follows: • Removing 120 ft of slag and exposing the railroad car disposal site could disturb or damage the railcars, causing the release of P4 and uncontrolled air emissions. • Additional refinement of the CSM and the performance of needed bench-scale and pilot-scale tests could take several years. • Remotely operated tank cleaning equipment or the manual entry and cleaning of the railroad tank cars could represent a significant site worker risk. • High-pressure water jets could damage the integrity of the 60+-year-old railroad tank cars.

5.5.2.4 Overall Likelihood of Success

Uncertainties regarding the CSM, the condition of the railcars, and the results of needed bench-scale and pilot-scale testing make it difficult to predict whether or not the P4 sludge could be excavated and treated.

6 ASSESSMENT OF APPLICABLE EXCAVATION AND TREATMENT TECHNOLOGIES

6.1 REPORTING MATRIX

The Review Team examined 18 potentially applicable ETTs for excavating and treating P4 waste at the FMC OU (Table 6-1). The technologies examined ranged in maturity from a theoretical or conceptual stage to real-world examples of treating P4 waste in full-scale systems. Recognizing that P4 waste is present at depths as great as 85 ft below ground surface, the Review Team investigated the efficacy of ETTs that could treat P4 *in situ*. The Review Team also investigated the efficacy of numerous *ex situ* technologies that could access P4 waste present within the reach of conventional excavation equipment or that could access P4 waste beyond the reach of conventional excavation equipment if operated in conjunction with shoring, sloping, benching, and laybacks. We examined ETTs that could be used to handle P4 waste on site and/or off site. The Review Team examined underground pipelines and the abandoned railcars separately. As discussed in the main text and reflected in Table 6-1, multiple specialized technologies would probably be required to address these relics (underground pipelines and abandoned rail cars) of the former FMC plant. Furthermore, as discussed in the main text, several of the ETTs examined and summarized in Table 6-1 would have to be operated either simultaneously or in series to address P4 waste.

6.2 EVALUATIONS

In addition to a listing of the pipeline remediation technologies and technologies applicable to the abandoned railcars considered by the Review Team, Table 6-1 summarizes an evaluation of ETTs as specified in the Work Order (Appendix A). Information about whether bench- and pilot-scale studies have been performed, and whether full-scale versions of the ETTs have been used, is also summarized. Table 6-1 indicates sites where the ETT has been used, whether the ETT is applicable to the FMC site, and the ETTs that warrant further consideration.

6.2.1 *In situ* Technologies

The *in situ* ETTs evaluated involved thermal treatment and recovery, solvent leaching, and oxidant leaching. In order to focus the primary treatment, recovery, or leaching action of the *in situ* ETT, a containment technology would need to be used along with the ETT chosen. However, there are more considerable uncertainties associated with applying these *in situ* ETTs than is the case for the examined *ex situ* ETTs. These uncertainties fall into two categories: uncertainties about the CSM and uncertainties about the *in situ* ETTs.

Conceptually, the *in situ* ETTs have some merit; in order to function, however, the *in situ* ETTs must target a mass of P4 in the subsurface. Due to worker health and safety issues, site investigators have strived to avoid collecting any samples that contain P4. As a result, the

TABLE 6-1 Excavation and Treatment Technology Report Matrix

	Response for "Findings" from Work Order of July 1, 2014				
ETT[a]	Bench- and Pilot-Scale (B&P-Scale) Studies	Full-Scale Design	Sites Where an ETT Has Been Used	Use and Applicability of ETTs at FMC	ETTs That Warrant Further Consideration
In situ Thermal Treatment and Recovery	B&P-scale studies would be needed to determine viability of ETT	Must be preceded by B&P-scale studies	No reference on use for P4 remediation found	Applicability unknown	Further consideration not warranted
In situ Solvent Leaching and Recovery Using Benign Solvents	B&P-scale studies would be needed to determine viability of ETT	Must be preceded by B&P-scale studies	No reference on use for P4 remediation found	Applicability unknown	Further consideration not warranted
In situ Oxidant Leaching	B&P-scale studies would be needed to determine viability of ETT	Must be preceded by B&P-scale studies	No reference on use for P4 remediation found	Applicability unknown	Further consideration not warranted
Containment Technologies	Pilot-scale studies would be needed to determine viability of ETT	Full-scale applications have been deployed (but not at P4 sites)	No reference on use for P4 remediation found	Applicability unknown	Further consideration not warranted
Mechanical Excavation	Not required	Full-scale applications have been deployed	FMC, Idaho, Rhodia/Solvay, Silver Bow Montana (as related to the *Supplemental FS*)	Applicable at FMC	This ETT warrants further consideration
Cutter Suction Dredging	Not required	Full-scale applications have been deployed	Glenn Springs, Occidental Petroleum	Applicable at FMC	This ETT warrants further consideration
Thermal-Hydraulic Dredging	Not required	Full-scale applications have been deployed	References found indicating use to manage wastewater treatment at a unnamed production facility	Applicable at FMC	This ETT warrants further consideration
On-Site Incineration	B&P-scale studies may be required to determine incinerator and post-treatment disposal site waste acceptance criteria (WAC)	Full-scale applications have been deployed	Technology such as an APE incinerator crane conversion plant; APE incinerator in Lubben, Germany; Veolia incineration facility in Sauget, Illinois (for RAAP P4 wastes)	Applicable at FMC	This ETT warrants further consideration

TABLE 6-1 (Cont.)

	Response for "Findings" from Work Order of July 1, 2014				
ETT[a]	Bench- and Pilot-Scale (B&P-Scale) Studies	Full-Scale Design	Sites Where an ETT Has Been Used	Use and Applicability of ETTs at FMC	ETTs That Warrant Further Consideration
Drying/Mechanical Mixing under Tent Structure	May be required to determine concentration limit for P4 waste handling	Full-scale applications have been deployed	P4 train derailment, Miamisburg, Ohio; and Stauffer Site, Tarpon Springs, Florida (tent structure alone; no mixing)	Applicable at FMC	This ETT warrants further consideration
A&W Batch Mud Still	B&P-scale studies completed for other sites; B&P-scale studies specific to FMC P4 waste may be required	Full-scale applications have been deployed, but B&P-scale studies specific to FMC will inform full-scale design	Rhodia/Solvay, Silver Bow, Montana	Applicable at FMC	This ETT warrants further consideration
LDR Waste Treatment System	B&P-scale studies may be required to determine WAC and post-treatment sludge conditioning to meet land disposal WAC	Full-scale application has been deployed	FMC, Idaho	Applicable at FMC	This ETT warrants further consideration
Wet Air Oxidation	Pilot-scale studies performed	Pilot-scale results did not support full-scale testing	No reference on use for P4 remediation found	Not applicable	Further consideration not warranted
Solvent Stirred Batch Reactor	Needed before full-scale design	Must be preceded by B&P-scale studies	No reference on use for P4 remediation found	Not applicable	Further consideration not warranted
Off-Site Incineration Facility	May be required to ensure waste meets WAC of incineration facility	Full-scale applications known	APE incinerator in Lubben, Germany; Veolia incineration facility in Sauget, Illinois (for RAAP P4 wastes); P4 wastes from FMC Idaho Site have also been incinerated	Applicable at FMC	This ETT warrants further consideration
Post-Treatment On-Site Disposal	May be required to ensure waste meets WAC of disposal site	Full-scale applications known	Disposal has occurred at multiple P4 sites; no reference for on-site disposal of P4 waste after treatment was found	Applicable at FMC	This ETT warrants further consideration

TABLE 6-1 (Cont.)

	Response for "Findings" from Work Order of July 1, 2014				
ETT[a]	Bench- and Pilot-Scale (B&P-Scale) Studies	Full-Scale Design	Sites Where an ETT Has Been Used	Use and Applicability of ETTs at FMC	ETTs That Warrant Further Consideration
Post-Treatment Off-Site Disposal	May be required to ensure waste meets WAC of disposal site	Full-scale applications known	Incinerator residues from the RAAP were land disposed off site; incinerator residuals from FMC, Idaho, were disposed of off site	Applicable at FMC	This ETT warrants further consideration
Underground Pipeline Cleaning Technologies	Needed before full-scale implementa-tion	Full-scale applications for some pipelines at FMC are known	Storm sewer cleanout, FMC, Idaho	Applicable at FMC	This ETT warrants further consideration
ETTs to Address Abandoned Railcars	Needed before full-scale design	Must be preceded by B&P-scale studies	Miamisburg, Ohio, train derailment; phosphorus railcar derailment, Fairfield, California	Not applicable	Further consideration not warranted until the CSM can be refined

[a] "Treatment" includes P4 and P4 by-product reuse and recovery.

distribution of the P4 in the 85-ft unsaturated zone, the capillary fringe, and the saturated zone is completely uncharacterized and unknown. The depiction of P4 in the subsurface (Figure 2.3) is nothing more than an inference or best guess. The inferred contaminant CSM may or may not be true. The P4 may also have behaved like a dense nonaqueous phase liquid (DNAPL) and be present as DNAPL-like "ganglia," blobs, and smear zones in a more widespread, dispersed contaminant mass than is depicted. Such a dispersed contaminant distribution may be more amenable to treatment using *in situ* ETTs. However, since only limited attempts have been made to characterize subsurface P4 because of investigation worker health and safety concerns, the identification and evaluation of *in situ* ETTs are difficult. As a result, the site CSM is not refined enough to indicate with certainty whether a defined mass of P4 can be specifically located and targeted for treatment with an *in situ* ETT. The CSM would have to be refined before B&P studies are designed or undertaken.

Understanding the specific retention of P4 (i.e., the amount of P4 naturally retained on soil particles) would be important for evaluating how successful an *in situ* technology can be. Specific retention is a property described as the ratio of the volume of water that a rock or sediment retains against the pull of gravity to the total volume of the rock or sediment (Fetter 1988). Essentially, it describes how much moisture remains if a saturated soil drains to an unsaturated condition. This concept can be applied to other liquids moving through soil or sediment. The literature lacks examples of the specific retention of P4. An estimation of specific retention would improve understanding of the expected distribution of residual P4 in the unsaturated zone. It would also be important for designing and evaluating *in situ* technologies.

To estimate the specific retention of P4, a set of experiments could be performed with vertical cylinders (e.g., 4-in. pipes mounted vertically in a warehouse) full of alluvial materials (with a range of grain sizes to match characteristic site alluvium). The temperature of the cylinders and surroundings should be 50–70°C. The temperature of the escaped liquid P4 is not known. Various amounts of P4 heated to various temperatures (this could be refined if that information were published) could be released at the top of each cylinder and, after cooling, their extent in the tube could be documented. Note that the repacked alluvial sediments in the tubes would represent disturbed samples, and their permeability would be much larger than that in the study area. This experiment poses a serious risk of P4 oxidizing in air and producing a great deal of smoke and heat. One way to resolve this issue would be to conduct the experiment in an inert atmosphere glove box.

Another approach for estimating the residual in the unsaturated zone would be to model it, relying on a range of estimates for the unknown P4 release temperature, the subsurface temperature, thermodynamics, and alluvium properties.

There are also uncertainties associated with the *in situ* ETTs. To some extent, these uncertainties could be assessed with bench- and pilot-scale studies. At a minimum, bench- and pilot-scale studies would be needed to determine the following:

- Whether the *in situ* ETT treatment regime can be used to mobilize and cause the P4 or P4 reaction by-product to flow toward an extraction point;

- Appropriate construction materials for the well points (e.g., mild steel, stainless steel, PVC, etc.);

- How to safely place injection and extraction well points using direct push technology, air rotary, mud rotary, hollow stem auguring, or sonic drilling techniques;

- How to inject or introduce the *in situ* ETT-specific treatment regime;

- Approaches for pumping P4 and P4 reaction by-products from the extraction points to the surface for subsequent handling by an *ex situ* ETT; and

- Methods for measuring the success of the *in situ* ETT being used.

A containment technology could be used in conjunction with a selected *in situ* ETT to improve the effectiveness of the *in situ* ETT and to reduce the cost of the ETT (subject to the cost-effectiveness of the containment system). Although the *in situ* ETTs are potentially applicable to the FMC OU, uncertainties pertaining to both the CSM and the *in situ* ETTs suggest that further consideration of these *in situ* ETTs is not warranted because the subsurface remediation, regardless of the ETT implemented, would be incomplete. In addition, the *in situ* ETTs, with or without containment technology, would involve significant safety and cost issues.

6.2.2 *Ex situ* Technologies

It appears that P4 is present in a pure or nearly pure state in some portions of the former FMC plant. As noted during the grading operations performed in 2015, P4 exists throughout the materials in the near surface. The "treatment" aspect of some ETTs includes both the treatment of P4 waste and the process steps for the recovery of P4 or P4 by-products for resale/reuse. Conceptually, as discussed in Section 5, any P4 waste subject to remediation can be "triaged," in that there could be three fractions to be addressed:

1. P4 waste that can be "mined" and recycled and/or reused as P4 without treatment;

2. P4 waste that requires treatment with an ETT, resulting in either the generation of a reusable by-product like P4 or phosphoric acid or a waste residual; and

3. P4 waste that does not require treatment with an ETT.

The Review Team evaluated a number of technologies that could be used to excavate P4 waste and then treat, recover P4 or P4 by-products in the waste on-site, or transport the waste off site for treatment and recovery and/or disposal (Table 6-1). The Review Team also identified a number of principles that influenced the way the ETTs were selected for evaluation and the way the evaluation was performed (see Section 4). On the basis of these general principles, and assuming P4 waste can be triaged as noted above, it appears that a number of technologies could be used to both excavate and treat P4 waste.

6.2.2.1 *Ex situ* Excavation and Ancillary Technologies

A number of approaches have been used to excavate P4 waste, both at FMC in the past and at other locations; these approaches include mechanical excavation, cutter suction dredging, and thermal-hydraulic dredging. As indicated in Table 5-10, the best excavation method depends on the area to be excavated. Experience has been gained using these excavation methods at the FMC Idaho facility and at other P4 manufacturing facilities. Based upon a review of archival documents, it appears that that FMC used dredging systems or processes in the past to recover P4 in wastewater pond sediment, aid in constructing new ponds, or aid in refurbishing existing ponds. The *Supplemental FS* mentions that in the 1980s a process to recover P4 from historical impoundment pond 8S was "developed, built, and tested" and then closed and removed in 1993. The more recently constructed LDR WTS was designed with the capacity to treat dredged P4 wastes from Pond 18, a waste stream similar to the one that produced the P4 waste present in the historical ponds.

It appears that FMC has also gained considerable experience with dry excavation methods that disturb P4 in the subsurface. Appendix C documents numerous USCs associated with the unplanned identification of P4 during slag movement. USCs can include either uncovering P4 and allowing it to burn until P_2O_5 smoke is no longer visible or covering P4 with sand. In the event slag needs to be moved to gain access to a P4 excavation area, experience gained when moving slag as part of the regrading project may be useful.

Due to P4 hazards such as the creation of P_2O_5 smoke, excavation would have to be followed up immediately with a suite of ancillary technologies in order to safely stage, store, sample, size, and blend the excavated waste to meet the acceptance criteria of whatever "downstream" ETT is selected. Before the excavation project could be started, a strategy for segregating and staging (triaging) P4 waste as part of the excavation process would need to be developed.

For example, post-excavation, P4 waste causing USCs could be allowed to burn in the open (or within a covered structure, per Section 5.3.2). More concentrated P4 waste could be kept submerged in a container prior to treatment or recovery/reuse as off-specification P4.

As noted above, the LDR WTS was designed and built specifically to treat dredged P4-containing solids and sediments somewhat similar to the P4 waste present in the historical ponds. In particular, the LDR WTS design features that focus on the excavation, blending, dewatering, sizing, and treatment of residuals from Pond 18 seem to be directly applicable to the treatment of the waste present in the non-RCRA historical ponds.

The P4 waste would be relatively benign if kept submerged, so copious amounts of water may need to be added to an excavation footprint. However, as inferred in the guiding principles, sufficient water is assumed to be available for such an endeavor from the groundwater P&T system to be constructed and operated as part of the *IRODA*. Furthermore, contaminant migration caused or exacerbated by the use of water during excavation could be addressed by modifications to the groundwater P&T system.

Each of the three excavation ETTs examined by the Review Team is applicable to at least a subset of the P4 waste at the FMC site. Each of the three excavation ETTs warrants further consideration.

6.2.2.2 *Ex situ* Treatment Technologies

The WAO and solvent still batch reactor do not warrant further consideration. Incineration (either on or off site), A&W batch mud still, the LDR WTS, and drying/mechanical mixing under a covered structure (such as a tent) warrant further consideration.

WAO

Although B&P scale studies demonstrated the efficacy of WAO, pilot-scale studies indicated that operation of a full-scale WAO facility would be difficult. The WAO process requires exacting control of operational parameters, an N_2 purge, and special wet-cake handling issues, and it would face challenging design, operation, and permitting requirements for the associated air pollution control system. Furthermore, the WAO process did not compare favorably with the anoxic caustic hydrolysis process, which is the basis of the LDR WTS, an *ex situ* ETT described later in this section.

Solvent Still Batch Reactor

The solvent-stirred batch reactor *ex situ* treatment ETT is at an early bench-scale or conceptual stage. The basis for this *ex situ* treatment ETT is the solvent extraction procedure used to prepare samples for analysis by gas chromatography (EPA Method 7580). Laboratory testing has been performed, which involves the solvent extraction procedure preparatory to EPA Method 7580 (EPA 2015). As noted in Table 6-1, B&P studies would be required. For pilot- and full-scale solvent operation, large quantities of relatively toxic solvents would be required. The solvent still batch reactor does not warrant further consideration.

On-Site or Off-Site Incineration

The P4 waste has been treated by rotary kiln-type incineration technology at several domestic and international locations. The rotary kiln design is of interest for a number of reasons. Rotary kiln incineration systems are flexible, allowing simultaneous treatment of liquids, solids, and sludge with wide variations in heating value. FMC acknowledged that incineration technology is potentially applicable to P4 waste (MWH 2009, 2010). In at least two instances, FMC excavated small amounts of P4 waste (during slag ladling foundation upgrades and while installing utilities for the LDR WTS) and sent containers of waste off site for incineration. However, in the *Supplemental FS*, incineration was rejected because P4 waste excavation, preparatory to incineration, was not considered a viable option by FMC. The Review Team disagrees in that there appears to be a long history of P4 waste excavation at the FMC OU, which suggests that P4 waste could be excavated and staged in preparation for treating it using methods such as incineration. Furthermore, recent advances in relevant remote dredging technologies, such as those summarized in Section 5.2, make the development of a safe P4 waste excavation strategy feasible. As a result, the Review Team has determined that a rotary kiln-type incineration design is applicable to a subset of the P4 waste at the FMC OU.

Transportable incinerators have been used at a number of Superfund sites, as discussed in Section 5. The amount of P4 waste to be treated at the FMC OU may warrant the installation of a more-or-less permanent incinerator design, should the on-site incineration option be selected. An on-site incinerator would also need to address emissions and residuals. There is some potential that a useful by-product, phosphoric acid, could be generated as part of the incineration process as is the case with the APE incinerator design for the Crane Army Ammunition Plant in Indiana.

For the off-site incineration option, the transportation of P4 waste off site is a major consideration. Since P4 waste is relatively benign if submerged in water, it can be transported in a water bath in containers or railcars. However, for the off-site incineration option, the transport of P4 over either public roads or railroad corridors from the FMC plant to the destination off-site incinerator is a major drawback. Depending upon the amount of P4 waste targeted for excavation, a large number of containers and numerous truck trips (or transportation by rail) would be required for transport. If a large quantity of P4 waste is to be excavated in a short period of time, a dedicated fleet of trucks (or railcars) may be required. Fewer railcars and train trips would be required, but the number of railcars and train trips would still be substantial. When compared to a no action approach, increased truck and train trips could result in increased accident frequency and a nuisance to stakeholders.

For the on-site incineration option, waste residuals will also be created that could be handled in an on-site disposal facility or that may need to be transported to an off-site disposal facility. Incinerator residuals may need to undergo waste conditioning to meet LDR UTSs, whether or not the incinerator residuals are disposed of on site. As discussed in Chapter 4, however, residuals could be placed in an on-site CAMU or CAMU-like CERCLA unit without meeting LDRs, as long as such disposal could be demonstrated to be acceptable, considering risks to human health and the environment. If incinerator residuals are transported to an off-site disposal facility, there could also be truck traffic nuisance and accident factors to address, and incinerator residuals would have to meet the WAC of the off-site disposal facility.

Despite the issues associated with the off-site transport of either P4 waste or incinerator residuals, the *ex situ* treatment ETTs of on- or off-site incineration warrants further consideration.

Drying/Mechanical with or without Containment

The Review Team has determined that this *ex situ* treatment ETT is applicable to a subset of the P4 waste at the FMC OU. This technology may be applied with or without a containment structure. In particular, this technology could be used to control the emissions from the USCs described in Appendix C, mechanical excavation of P4 waste, or the implementation of other ETTs, including, for example, the excavation of underground pipelines. Bench- and pilot-scale studies may be needed to identify the optimal concentration of P4 waste that could be handled with or without a containment structure and associated air pollution control equipment. However, this ETT is a developed technology; a full-scale version of the ETT was used for the Miamisburg, Ohio, incident. As a result, this *ex situ* treatment ETT warrants further consideration.

A&W Batch Mud Still

The Review Team has determined that this *ex situ* treatment ETT is applicable to a subset of the P4 waste at the FMC OU. This technology was examined as part of a RCRA corrective action study meant to address P4 waste present in a clarifier at the Rhodia/Solvay facility in

Silver Bow, Montana. After the treatability studies, the technology could possibly be selected as a component of the corrective action for the P4 waste clarifier. Using the batch mud still to treat materials with of P4 waste concentrations of <10%, would probably be inefficient. Residuals in the clarifier at the Rhodia/Solvay plant contain P4 at concentrations of around 20%. Any waste residuals generated by the batch mud still would need to be disposed of in either an on-site or an off-site landfill (and conditioned, if needed, to meet LDR UTSs).

Because this is a batch process, the throughput capacity of this ETT is small. This could be overcome by constructing several mud stills. Among the many positive aspects of this ETT is that P4 waste can be processed sufficiently to create a recyclable/reusable P4 product (along with some process waste). Some B&P-scale studies may be needed to establish the best operating conditions and the batch mud still waste acceptance criteria (WAC) WAC for the subset of P4 waste from the FMC OU to be treated. Given the fact that the ETT could be selected as a component of the corrective action plan for the Rhodia/Solvay site, this *ex situ* treatment ETT warrants further consideration. It may be advisable, however, should the mud still be selected at Rhodia/Solvay, to follow the activities and determine possible use at the FMC OU based on application at that site.

Land Disposal Restriction Waste Treatment System

This *ex situ* treatment ETT included waste feed, waste treatment, off-gas treatment, and residual handling systems specifically designed to treat wastes from the manufacturing process and to treat dredged waste from Pond 18. As designed, the LDR WTS could treat suspended solids ranging from 3 to 8 wt% with concentrations of P4 ranging from 0% to 50%. As a result, with some design modifications, this ETT is applicable to a subset of the P4 waste at the FMC OU. Unit treatment steps in the design included dredge material handling systems, waste solid strainers, a size reduction mill, and a feed system to provide for pre-treatment testing and feed equalization. The design also included dual chemical reactors, a wet filter cake stabilization system, residual waste management, and an off-gas treatment system that produces both waste residuals and a reusable by-product, phosphoric acid. As designed, waste residuals would be disposed of in an off-site landfill (and conditioned, if needed, to meet LDR UTSs).

Given that some P4 waste would need to be heavily irrigated during mechanical excavation, and perhaps saturated if produced by flooding and dredging an excavation footprint, P4 wastes generated during excavation may be somewhat similar to the Pond 18 waste the system was designed to accept. In addition, experience gained in performing B&P-scale testing—and designing and constructing (although not operating the system since the FMC Plant was shut down due to increased power costs)—the treatment system can be leveraged to modify the design to allow treatment of many kinds of P4 waste. Although the LDR WTS probably could not be used to treat P4-contaminated debris such as piping and concrete blocks, this *ex situ* treatment ETT warrants further consideration.

Ex situ Post-Treatment Disposal: On or Off Site

Disposal in place has been practiced at a number of P4 manufacturing facilities and at the FMC OU. For the purposes of this independent review, the Review Team evaluated the disposal of residuals after the P4 content was treated. Whether or not land disposal occurs post-treatment in an on-site or off-site disposal facility, disposal of P4 waste post-treatment is applicable. In fact, land disposal of P4 treatment residuals would be essential, given that any P4 treatment technology would produce a waste stream that would have to be disposed of.

The treatment of P4 residuals disposed of off site would have to meet the RCRA LDR UTSs. For example, at one time FMC planned to dispose of LDR WTS waste solids as a nonhazardous waste that meets RCRA LDR UTSs in a silica mine. In contrast, P4 treatment residuals disposed on site could potentially be managed in an alternative land disposal unit such as a RCRA CAMU or a CERCLA on-site land disposal unit. For example, Rhodia/Solvay, Inc., suggests that some of the residuals from the batch mud still could be managed in an on-site CAMU.

If P4 treatment residuals are transported to an off-site disposal facility, there could be truck traffic nuisance and accident factors to address. However, despite the issues associated with the off-site transport of P4 treatment residuals, the *ex situ* treatment land disposal ETTs of on- or off-site disposal warrants further consideration.

Underground Pipeline ETTs

FMC has performed underground pipeline cleaning at the FMC OU (or is in the process of performing pipeline cleanout). Both external and internal pipeline cleaning technologies have a proven track record. The Review Team has determined that underground pipeline ETTs are applicable to FMC. Resources will have to be devoted to performing B&P testing to determine the viability of technologies, but commercial off-the-shelf (COTS) technologies may be well suited to cleaning out the underground pipeline network at the FMC OU. Should the pipelines be degraded or clogged, site managers also have the option of excavating sections of pipeline that cannot be cleaned with internal cleaning technologies. Cleaned pipelines could be abandoned in place and filled with inert material. They may also be removed by excavation and incinerated. Excavated pipeline sections would require either decontamination on-site or shipment for treatment off-site, for example using incineration technology. Residuals collected from cleaning out the pipeline would also have to be containerized and treated, perhaps in a treatment ETT selected for the FMC or in an off-site incineration facility.

Given the success already achieved in cleaning out the storm sewer underground pipelines, and given the existence of COTS technologies for pipeline cleaning, underground pipeline ETTs warrant further consideration.

Abandoned Railcar ETTs

Several of the ETTs discussed in this document have the potential to treat the P4 waste present in the abandoned railcars. However, there is not sufficient information available to determine whether or not an ETT would be specifically applicable to the abandoned railcars. The presence of large quantities of nearly pure P4 in the railcars creates a unique and risky hazardous material challenge that should not be undertaken unless and until the CSM is refined. A refined CSM is necessary before the Review Team can determine whether any excavation or treatment ETT warrants further consideration. At this time, a viable approach appears to be to leave the abandoned railcars in place. This approach is somewhat similar to the approach used for the Fairfield, California, railcar spill incident in Suisin Marsh, in that the overturned railcars were covered with a concrete cap and institutional/physical controls are used to prevent the site from being disturbed.

7 RECOMMENDATIONS

In addition to the most significant consideration (risk to site workers during implementation), a decision to excavate and treat P4 waste will have several effects, including the following:

- Impacts on community health and safety,
- Impacts on the environment, and
- Impacts on schedule and cost.

If, despite this risk and these impacts, stakeholders determine there is a need to excavate and treat P4 wastes, then a number of the ETTs either singly or in combination could be used to address a subset of the P4 waste. However, the ETTs are in various stages of maturity; some ETTs are available for use immediately, and other ETTs are in a theoretical or conceptual phase that will require a long lead time for development. The ETTs in a theoretical or conceptual phase will require a dedicated funding source to develop a one of a kind customized adaption of the ETT to address the unique aspects of P4 remediation. There is no guarantee that after development the technologies can be used successfully to excavate and treat P4. As a result, the Review Team recommends focusing only on mature ETTs with a proven track record that have been used either at the former FMC plant or at another site where P4 was handled. These ETTs could be used to excavate and treat P4 present in the FMC OU (Table 7-1).

Should the decision be made to excavate and treat P4 waste, project plans would need to consider containment technologies, in conjunction with excavation and cutter suction dredging and thermal-hydraulic dredging ETTs, in order to excavate and stage P4 waste for subsequent handling. In particular, mechanical excavation techniques are well suited to move surface soil and soil present at intermediate depths, and to create the slopes and benches or to install the shoring protection systems needed to excavate deep soil. As a possible alternative, operations could be conducted during colder seasons to minimize emissions.

Each of the three excavation ETTs may be potentially applicable to deep soil. To date, FMS has moved millions of cubic yards of slag (Appendix F). Sloping and benching to achieve excavation depths in excess of 85 ft would require the movement of millions of cubic yards of material. Soil contaminated with high concentrations of P4 may require hydraulic rather than mechanical excavation. Containment technologies, for example freeze wall technology, could be used to help create an excavation footprint that could be flooded or saturated during soil removal. Nevertheless, techniques such as sloping and benching in order to access P4 waste present at the CERCLA ponds could impact the RCRA ponds in proximity to the excavation footprint. Although the site operating history indicates that surface and intermediate soil layers will allow water to be impounded, it is not known whether or not deep soil layers can be used to create a flooded excavation footprint. In addition, site remediation worker risks will increase as the depth of the excavation increases, due to the risk of cave-ins and the potential for exposure to phosphine gas and phosphoric acid emissions.

P4 could be treated with a number of ETTs. Each ETT has advantages and disadvantages, as noted in the review parameter tables discussed for each ETT. Depending on the P4 waste identified for excavation and treatment, excavated P4 waste could be initially staged, and less-contaminated portions could be treated using drying and mechanical mixing under a tent structure. The readiness of an ETT to be used to excavate or treat P4 waste has been designated in Table 7-1. Readiness in this case is an estimate based on best professional judgment. The timespans noted for readiness are most useful when comparing ETTs to each other in that some ETTs probably require more preparation time before implementation than others. The accuracy of the timespan estimate is best for the "near-term" readiness category. For example, the near-term category (within 1 year) is estimated to be correct for technologies with real world examples that are available currently. By way of example, as noted in the text, P4 waste from FMC and other sites has been mechanically excavated, containerized, and shipped off site for treatment in an off-site incinerator. Accuracy decreases for the mid-term and the long-term readiness category. The ETTs that could be readied in the mid-term would require a longer preparation time because the ETTs (dredging or the pipe cleaning technologies) would likely require a water component involving modifications and operation of the P&T system (to provide access to a water source) and may include preparing containment features to allow for the excavation footprint to be flooded. ETTs in the long-term readiness category are assumed to require a longer lead time to address design and approval requirements and waste acceptance criteria.

Technologies ready in the near-term (within 1 year) include mechanical excavation, containment technologies, off-site incineration, and drying mechanical mixing under a tent structure.

Technologies that could be readied in the mid-term (1 to 2 years) include cutter suction dredging, thermal-hydraulic dredging, and underground pipeline cleaning technologies.

Technologies requiring a longer lead time (2 to 5 years) include on-site incineration, LDR WTS, A&W batch mud still, post-treatment on-site disposal, and post-treatment off-site disposal.

If a decision is made to excavate and treat P4 waste, stakeholders could proceed as follows:

- Identify the P4 waste to be excavated and treated;

- As part of the P4 excavation project plan development process, refine the existing CSM of the three-dimensional distribution of P4 to be excavated and treated (the model should address the anticipated P4 concentrations and the physical and chemical characteristics of the host media);

- Determine whether the risk to site investigators created by collecting samples containing P4 as needed to refine the CSM are acceptable (if the CSM cannot be sufficiently refined, an excavation and treatment plan robust and flexible enough to characterize, stage, and treat P4 waste as excavation occurs will need to be developed);

- Select the treatment technologies required to treat the identified waste within the desired schedule;

- Select the excavation and ancillary technologies required to excavate and stage the identified waste in preparation for treatment;

- Determine the sequence of actions, including plan development, applications, and approvals; and

- Implement the actions.

TABLE 7-1 Readiness of Technologies for Excavating or Treating P4 Waste[a]

ETT	P4 Waste Type				
	Process Waste[b]	Contaminated Surface Soil[c]	Contaminated Soil at Intermediate Depth[d]	Contaminated Deep Soil[e]	Contaminated Debris[f]
Containment Technologies	✓	✓	✓	Potentially applicable	✓
Mechanical Excavation	✓	✓	✓	Potentially applicable	✓
Cutter Suction Dredging	✓	✓	✓	Potentially applicable	Not applicable
Thermal-Hydraulic Dredging	✓	✓	✓	Potentially applicable	Not applicable
On-Site Incineration	✓	✓	✓	✓	✓
Drying – Mechanical Mixing under Tent Structure	Not applicable	✓	✓	✓	Not applicable
A&W Batch Mud Still	✓	✓	Not applicable	Not applicable	Not applicable
LDR Waste Treatment System	✓	✓	✓	✓	Not applicable
Off-Site Incineration Facility	✓	✓	✓	✓	✓
Post-Treatment On-Site Disposal	✓	✓	✓	✓	✓
Post-Treatment Off-Site Disposal	✓	✓	✓	✓	✓
Underground Pipeline Cleaning Technologies	✓	✓	✓	Not applicable	✓

[a] A checkmark indicates the ETT could be used to excavate and/or treat a subset of the P4 waste at the FMC OU. The color green indicates a technology that could be ready in the short-term (within 1 year); blue indicates a technology that could be ready in the mid-term (1 to 2 years); yellow indicates a technology that could be ready in the long term (3 to 5 years). "Treatment" includes P4/P4 by-product reuse and recovery.

[b] "Process waste" includes phossy water, phossy solids, precipitator slurry, slag, and slag-related and treatment residuals from kiln and calciner off-gas treatment.

[c] "Surface soil" is soil that can be safely accessed by site workers using benching, sloping, or laybacks.

[d] "Intermediate depth" in this case includes soil that is present at depths at which shoring is required to comply with Subpart P, "Excavations," of 29 CFR 1926.652 (i.e., Part 1926, "Safety Regulations for Construction") to address the potential for cave-ins.

[e] "Deep soil" in this case is soils in excavations that are more than 20 ft deep; excavations would have to be designed by a professional engineer to satisfy 29 CFR 1926.652. Benching or 3:1 sloping required to excavate deep soil would likely affect RCRA ponds. Risks to remediation workers due to cave-ins and exposure to phosphine and phosphoric acid may increase with an increase in excavation depth.

[f] "Contaminated debris" includes man-made items, such as concrete, reinforced concrete, piping, tanks, lumber, and sheet metal.

8 SUMMARY AND CONCLUSIONS

In September 2012, the EPA issued an *IROD* for the FMC Operable Unit in Pocatello, Idaho (EPA Region 10 2012a). In the *Supplemental RI/FS*, a review of technologies that could be implemented to address the P4 in the soil (the principal threat waste) was conducted (MWH 2010). On the basis of that review and CERCLA's nine criteria, the EPA determined that capping was the preferred approach. However, the Tribes favor the permanent removal and/or treatment of contaminants. The Tribes have expressed concerns regarding the previous review conducted on potential treatment technologies. To address the Tribes' concerns, the EPA and the Tribes agreed to have Argonne perform an independent review of technologies, referred to as ETTs, which could be used to treat the principal threat waste. The framework of how the independent review was to be performed was arrived at by consensus and documented in a Work Order. The Work Order was developed during a face-to-face meeting with EPA and the Tribes and was refined in a follow-up teleconference in the spring and summer of 2014. For the purposes of this independent review, an ETT was assumed to be a technology that can excavate and/or treat P4 waste. The P4 was assumed to be process waste, soil, and debris (debris in this case being considered a man-made object containing or contaminated with P4).

In response to the Work Order, Argonne established an expert Review Team to perform the tasks established in the Work Order. In part, the Work Order directed the Review Team to identify ETTs that warranted further consideration. *Since some ETTs also involve excavation*

During the research, a number of ETTs were identified. The Review Team prepared a draft, draft final, and final list of ETTs. The final list includes only the ETTs that the Review Team felt offered reasonable potential for successfully and safely addressing the P4 waste. Only those technologies that made this cut are examined in detail in this report. The technologies were categorized into groups depending on their application, as follows:

- *In situ* technologies (subsurface treatment);
- Excavation-related technologies;
- *Ex situ* treatment technologies, including both on and off site; and
- *Ex situ* (off-site) disposal technologies.

In addition, the Review Team felt that the logistical and treatment problems posed by underground piping and abandoned railcars warranted special consideration. Technologies addressing these special cases were also included.

The Review Team examined in detail 18 ETTs that could potentially be applicable for excavating and treating P4 waste at the FMC OU. The technologies examined ranged in maturity from theoretical or conceptual stages to real-world examples of treating P4 waste in full-scale systems.

Although the *in situ* ETTs examined are potentially applicable to the FMC OU, uncertainties pertaining to both the CSM and the *in situ* ETTs suggest that further consideration of *in situ* ETTs is not warranted because the subsurface remediation, regardless of the ETT implemented, would be incomplete. In addition, the *in situ* ETTs, with or without containment technology, would involve significant safety and cost issues. The health and safety concerns would be caused by the need to perform additional site characterization work.

The Review Team decided that several *ex situ* ETTs did not warrant further consideration; these included solvent-stirred batch reactor, WAO, and technologies considered for abandoned railcars. Further consideration of WAO is not warranted due to operational issues. The solvent still batch reactor was rejected because the process is only in the bench-scale stage. Insufficient information is available to determine whether or not an excavation or treatment ETT would be specifically applicable to the abandoned railcars. A refined railcar CSM is necessary before the Review Team can determine whether any excavation or treatment ETT warrants further consideration.

After the evaluation process, the Review Team determined that the following ETTs warrant further consideration:

- Containment technologies,
- Mechanical excavation,
- Cutter suction dredging,
- Thermal-hydraulic dredging,
- On-site incineration,
- Drying – mechanical mixing under tent structure,
- A&W batch mud still,
- LDR waste treatment system,
- Off-site incineration facility,
- Post-treatment on-site disposal,

- Post-treatment off-site disposal, and

- Underground pipeline cleaning technologies.

In addition to the most significant consideration, risk to site workers during implementation, a decision to excavate and treat P4 waste will have several effects, including the following:

- Impacts on community health and safety,

- Impacts on the environment, and

- Impacts on schedule and cost.

If, despite this risk and these impacts, stakeholders determine there is a need to excavate and treat P4 wastes, then the Review Team concludes that several of the ETTs could be used in combination to treat only a subset of the P4 waste present at the site. Concerns about the health and safety of investigation site workers using the then-available investigation approaches prevented the collection of subsurface samples containing P4 from large areas of the site, including, for example, the railroad swale, the vadose zone beneath the Furnace Building, and the abandoned railcars. It appears that no attempt was made to experiment with or to use alternative characterization methods (such as modified PPE), nonintrusive techniques, remotely controlled sample collection equipment, cryogenics, etc.) as part of the investigation. As a result, the CSM in those particular areas is not refined enough to allow a full evaluation of ETTs and to allow the Review Team to draw conclusions about the efficacy of the ETTs examined. However, in other areas of the site, for example, the historical ponds, process knowledge (information about process waste stream discharged to the historical ponds) and the information gathered during both the CERCLA investigations and the RCRA-related investigations provide the information needed to determine whether or not the ETTs considered warrant further consideration for treating P4 those areas. The readiness of an ETT for implementation varies depending on many factors, including stakeholder input, permitting, and remedial action construction requirements. Technologies ready in the near term (within 1 year) include mechanical excavation, containment technologies, off-site incineration, and drying and mechanical mixing under a tent structure. Technologies that could be ready in the mid-term (1 to 2 years) include cutter suction dredging, thermal-hydraulic dredging, and underground pipeline cleaning technologies. Technologies requiring a longer lead time (2 to 5 years) include on-site incineration, LDR WTS, A&W batch mud still, post-treatment on-site disposal, and post-treatment off-site disposal.

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40 CFR 261.23, RCRA Reactivity Characteristic.

40 CFR 261.24, RCRA Toxicity Characteristic.

40 CFR Part 268, RCRA Land Disposal Restrictions.

40 CFR 268.40, RCRA Land Disposal Restrictions, Underlying Constituents.

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APPENDIX A:

INDEPENDENT REVIEW OF ELEMENTAL PHOSPHORUS REMEDIATION AT EASTERN MICHAUD FLATS, FMC OPERABLE UNIT, WORK ORDER

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Independent Review of Elemental Phosphorus Remediation at Eastern Michaud Flats, FMC Operable Unit

Work Order

Interagency Agreement EPA DW-89-92291201 / Proposal P-08125 Argonne National Lab, Environmental Science Division

7/1/2014

Background: Elemental phosphorous was mined from phosphate ore. In 1990, FMC's Pocatello Idaho facility, located on 1,400 acres of privately owned land within the Shoshone-Bannock Tribes' Fort Hall Indian reservation, was the world's largest producer of elemental phosphorus. Operating since 1949, FMC processed 1.4 million tons of shale ore per year, producing about 250 million pounds of elemental phosphorus a year, and over 26,455 pounds per year of ignitable and reactive hazardous waste. In September 2012, the EPA issued an Interim Record of Decision Amendment for the FMC Operable Unit at the Eastern Michaud Flats Superfund site in Pocatello, Idaho. In the Remedial Investigation/Feasibility Study (RI/FS), a review of technologies that could be implemented to address the elemental phosphorous in soil (the principal threat waste) was conducted. Based on that review and using CERCLA's nine criteria, EPA determined that capping was the preferred approach. However, the Shoshone-Bannock Tribes (Tribes) favor the permanent removal of and/or treatment of contaminants. The Tribes have expressed concerns regarding the previous review conducted on potential treatment technologies. To address the Tribes' concerns, EPA has agreed to commission an Independent Review of excavation and treatment technologies (ETT) for soils contaminated with elemental phosphorous to supplement the assessment of potential ETT.

Purpose: The U.S. Environmental Protection Agency (EPA) is committed to working closely with the Tribes in framing and conducting this Independent Review of ETT for soil contaminated with elemental phosphorous. The EPA and the Tribes agree that such a review should be conducted by an independent, objective entity capable of assembling world-class expertise on the subject matter. The EPA believes, and the Tribes concur, that the Argonne National Laboratory (ANL) offers these attributes. The results of this effort will ultimately supplement the previous evaluation of treatment technologies conducted pursuant to the RI/FS and will be added to the record for the final remedy decision related to the FMC Operable Unit.

The Review: The Independent Review of ETT will be conducted in one or possibly two phases. Phase 1 is the subject of this Work Order and will involve researching, reviewing and evaluating, pursuant to the criteria listed below, possible ETT relative to the FMC OU. Phase 2 of this effort may be undertaken if the EPA, with input from the Tribes, determines that the results of Phase 1 merit additional evaluation. (Note: The results from Phase 1 may lead to additional work, including bench or pilot treatability studies. Funding for work beyond Phase 1 has not been secured by EPA and will be dependent on available resources.) Though Phase 2 is mentioned here for context, it does not imply EPA has chosen ANL for potential Phase 2 work.

Argonne and its Expert Review Team will take appropriate measures to ensure they perform their work with the maximum independence possible. Issues they may encounter include attempts by outside parties to provide unsolicited input (e.g., by EPA, the Tribes or the PRP). Argonne will notify the EPA PO by email or phone communication if such events occur and will document any such issues in its monthly progress reports to the EPA PO. For convenience, "List of Available Technical Information" is appended to this Work Order.

The Scope of Phase 1:

Establishment of an Expert Review Team and Conflict of Interest Plan

- To form the Review Team, Argonne will identify, select, and if necessary enter into a contractual relationship with individuals who have expertise in technical areas relevant to this evaluation. Types of expertise must include, but are not limited to, the following as applied to remedial technologies:
    - Soil gases and chemistry as related to elemental phosphorus, its chemical reactions and byproducts
    - Contaminant fate and transport of elemental phosphorus and its related compounds in various media, with knowledge of and/or experience in excavation of ignitable and reactive elemental phosphorus
    - Ex situ or in situ treatment of elemental phosphorus
- Argonne will determine the number and affiliation of the members of the Review Team. Argonne will develop a *Conflict of Interest (COI) Plan* that identifies affiliations or activities that would constitute COI related to participation on the Review Team.

ETT Review Scope

- Review of Existing Site Characterization Information – Existing information regarding site-specific conditions, such as contaminant concentrations and locations, will be provided to the Review Team. No additional sampling will be commissioned or undertaken to support this review.
- Extent of Review – The review will encompass ETT for elemental phosphorus, its chemical reactions and byproducts in the soil at the FMC OU. Other contaminants or media will not be evaluated unless it is determined that they impact the efficacy of an ETT.
- Technologies – The review will identify technologies (in situ and ex situ) from existing literature, applied research, bench-scale, pilot and/or operational situations that are relevant to the conditions found at the FMC OU. This review may include exploring opportunities of combining or using one or more ETT in different locations at the existing OU.
- Applicability – For those ETT identified, the review will evaluate their applicability to the conditions found at FMC throughout the OU or any areas of the FMC OU. The site may be divided into areas based on horizontal, vertical, or other factors depending on the applicability of various ETT.
- Review Parameters – As a starting point, the list below contains the ETT review parameters EPA and the Tribes have identified. Argonne may suggest additional parameters and define the following and any additional parameters in their Technical Proposal:
    - Efficacy and Feasibility (Technical merits)
        - Advantages
        - Disadvantages
        - Limitations
        - Time to implement
        - Effectiveness of removing and/or treating elemental phosphorus
        - Health and Safety

The review will not contain an evaluation of ETT against the CERCLA nine criteria. (This directive is not intended to exclude technical criteria, but an evaluation against the CERCLA nine criteria is the purview of the EPA.)

- Findings:
  - ETT that warrant further consideration
  - Data gaps / research needs that limited ETT independent review
    - Identify the need for additional studies to fill data gaps
  - Identify sites where ETT has been performed both domestically and internationally, and summarize the use and applicability of ETT at those sites to the FMC OU

Products:

To maintain independence, these deliverables need to be transmitted electronically (email) to a contact list, which will be provided by the PO and which will include both parties. (However, discussions and reports about cost, effort, and general administration of the Interagency Agreement (IA) shall take place only between ANL/DOE and the EPA PO.)

- Technical proposal: EPA and the Tribes indicating Argonne's plan for implementing the work order (proposed team membership, resumes, suggested review parameters and definition of review parameters). Argonne will provide its cost proposal only to EPA.
- Argonne will provide a *Draft Report* to EPA and the Tribes for review and comment followed by a *Final Report*. The *Final Report* will contain a detailed description of the methodology used to conduct the review, as well as the components described above.
- Argonne will prepare a *Response to Comments on Draft Report* as a separate product.
- Argonne will prepare and present a PowerPoint presentation to EPA and the Tribes that summarizes the contents of the *Draft Report*. The presentation will occur shortly after delivery of the *Draft Report.*

Status Reports: As part of the monthly IA reporting, Argonne will provide a brief status update of the effort, such as the general stage of the review, the percentage completed, and any changes in the schedule. This status will be shared with the EPA team members and the Shoshone-Bannock Tribes. The Status Report is not to contain any cost or invoice information. The EPA Project Officer will approve invoices based on the reported progress and address any issues associated with costs and level of effort (costs and LOE reported in standard IA-wide, regular monthly reports to PO).

Schedule: The review process from the signing of the Work Order by the EPA Project Officer (PO) through the submittal of the draft Report may take up to 4 months. The EPA and Tribal review of the draft Report will take approximately 2 months. Argonne will deliver the *Final Report* and the *Response to Comments* approximately 2 months after receiving EPA and Tribal comments and approval by the EPA Project Officer that the deliverables satisfy the requirements of the Work Order. It is expected that the project will be completed within 8 months from the date of approval of the Work Order by the EPA PO.

Preferred Schedule Outline:

- July 2014
  - Argonne submits technical proposal for review by EPA and the Tribes

- EPA PO approves technical proposal after concurrence from the Tribes

- August thru December 2014
  - Argonne begins effort with Expert Review Team
  - Argonne, Expert Review Team, EPA and Tribes conduct technical site visit (Dates TBD; the Tribes indicated their availability the weeks of 9/8, 9/15, and 9/22/2014 for the site visit)
  - Argonne and Expert Review Team conduct review independently
  - Argonne delivers *Draft Report* to EPA and Tribes jointly
- January-February 2015 (Months 13-14)
  - Argonne gives *Presentation* summarizing draft report (e.g., webinar) jointly to EPA and Tribes, including the Fort Hall Business Council
  - EPA and Tribes review *Draft Report* and each transmit any *Comments on Draft Report* to Argonne and to each other
- March 2015 (Month 15):
  - Argonne prepares and issues final *Report* and *Response to Comments* to EPA and Tribes jointly (planned for March 31, 2015)

Attachment

List of Available Technical Information

[List of available reference material and Internet links of potential use to Expert Review Team, as a starting point. This list is not intended to be an exclusive list of technical information for the Expert Review Team.]

1. Eastern Michaud Flats Contamination Website
2. Interim Record of Decision Amendment for the Eastern Michaud Flats Superfund Site, FMC Operable Unit (PDF) (299 pp, 19MB) - October 2012
3. Site-Wide Gas Assessment Report for FMC Operable Unit (PDF) (196 pp, 24MB) - December 2010
4. 1998 Superfund Record of Decision (ROD) ID Number: EPA/541/R-98/034 Text Only (PDF) (172 pp, 285K)- June 8, 1998
5. 1998 Superfund Record of Decision (ROD) ID Number: EPA/541/R-98/034 with Maps/Tables (PDF) (227 pp, 15MB) - June 8, 1998
   a. 1998 ROD color Figures (PDF) (9 pp, 6MB)
6. FMC Plant OU – Interim CERCLA 2009 Groundwater Monitoring Report (PDF) (173 pp, 2MB) - February 2011
7. Ready for Reuse Determination FMC Plant Operable Unit, SRIA Parcels 4 to 6 (PDF) (29 pp, 12MB) - November 2010
8. FMC Supplemental Feasibility Study (PDF) (413 pp, 27MB) - July 2010
9. FMC Supplemental Feasibility Study Appendices (PDF) (1038 pp, 34MB) - July 2010
10. FMC Supplemental Feasibility Study Revised Work Plan (PDF) (271 pp, 8.6MB) - March 2010
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17. Treatment Technologies for Historical Ponds Containing Elemental Phosphorus - Summary and Evaluation (PDF) (98pp) USEPA EPA 542-R-03-013, August 2003
18. Administrative Record Index (PDF) (111 pp, 433K)
19. Summary of Pertinent Issues, Phosphine Gas Emissions, Closed Pond 16S, FMC Manufacturing Site, Pocatello, ID. U.S. EPA ORD Review completed by Shaw Environmental, Inc. as a subcontractor to Eastern Research Group, Inc. for EPA Office of Research and Development and EPA Region X. January 2010. [Electronic copy of this memorandum and attachments provided by EPA OSRTI directly to Argonne as it is currently unavailable via a website.]
20. 2006 UAO (http://yosemite.epa.gov/r10/CLEANUP.NSF/sites/emichaud/$FILE/Boyd-Uni%20Admin%20Order%20for%20Removal%20Action.pdf) and Appendices (http://yosemite.epa.gov/r10/CLEANUP.NSF/sites/emichaud/$FILE/FMC%20Pond%2016sow12_13_06_final.pdf and http://yosemite.epa.gov/r10/CLEANUP.NSF/sites/emichaud/$FILE/Boyd-ApprovalTimeCriticalRemoval.pdf)
21. 2010 UAO (http://yosemite.epa.gov/r10/CLEANUP.NSF/sites/emichaud/$FILE/rcra_ponds_uao_061410.pdf)

22. 1999 RCRA CD (http://yosemite.epa.gov/r10/CLEANUP.NSF/webpage/RCRA%20Hazardous%20Waste%20Management%20at%20FMC?OpenDocument)

END

Independent Review of Elemental Phosphorus Remediation at Eastern Michaud Flats, FMC Operable Unit

Work Order

Interagency Agreement EPA DW-89-92291201 / Proposal P-08125 Argonne National Lab, Environmental Science Division

7/1/2014

Revised Attachment (9/10/14)
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17. Treatment Technologies for Historical Ponds Containing Elemental Phosphorus - Summary and Evaluation (PDF) (98pp) USEPA EPA 542-R-03-013, August 2003
18. Administrative Record Index (PDF) (111 pp, 433K)
19. Summary of Pertinent Issues, Phosphine Gas Emissions, Closed Pond 16S, FMC Manufacturing Site, Pocatello, ID. U.S. EPA ORD Review completed by Shaw Environmental, Inc. as a subcontractor to Eastern Research Group, Inc. for EPA Office of Research and Development and EPA Region X. January 2010. [Electronic copy of this memorandum and

attachments provided by EPA OSRTI directly to Argonne as it is currently unavailable via a website.]
20. 2006 UAO (http://yosemite.epa.gov/r10/CLEANUP.NSF/sites/emichaud/$FILE/Boyd-Uni%20Admin%20Order%20for%20Removal%20Action.pdf) and Appendices (http://yosemite.epa.gov/r10/CLEANUP.NSF/sites/emichaud/$FILE/FMC%20Pond%2016sow12_13_06_final.pdf and http://yosemite.epa.gov/r10/CLEANUP.NSF/sites/emichaud/$FILE/Boyd-ApprovalTimeCriticalRemoval.pdf)
21. 2010 UAO (http://yosemite.epa.gov/r10/CLEANUP.NSF/sites/emichaud/$FILE/rcra_ponds_uao_061410.pdf)
22. 1999 RCRA CD (http://yosemite.epa.gov/r10/CLEANUP.NSF/webpage/RCRA%20Hazardous%20Waste%20Management%20at%20FMC?OpenDocument)
23. Feasibility Report, FMC Subarea, for the Eastern Michaud Flats Site. FMC Corporation, April 1997. [Available to download on EPA OneDrive]
24. Clarifier Waste Treatability Study, Phase 1 Report. Franklin engineering group, inc. prepared for Rhodia, Inc. October, 2007. [EPA will provide this document when received. *Note: Provided 10/2/14*]
25. Clarifier Waste Treatability Study, Phase 2 Report, Pilot Test Design and Testing. Franklin engineering group, inc. prepared for Rhodia, Inc. February 2011. [Available to download on EPA OneDrive]
26. Clarifier Waste Treatability Study, Phase 3 Report, Pilot Plant Operation. Franklin engineering group, inc. prepared for Rhodia, Inc. February 2012. [Available to download on EPA OneDrive]
27. Draft Supplemental Waste Plan, Clarifier Materials, Silver Bow Plant. Barr Engineering Company. Prepared for Solvay USA, Inc. February 2014. [Available to download on EPA OneDrive]
28. Shoshone-Bannock Tribes Environment Waste Management Program Soil Cleanup Standards for Contaminated Properties. Shoshone-Bannock Tribes. April 15, 2010. http://sbtribes-ewmp.com/documents/Brownfields_2011/13.)%20Soil%20Clean-Up%20Standards.pdf.

END

APPENDIX B:

TECHNICAL PROPOSAL

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Independent Review of Elemental Phosphorus Remediation at Eastern Michaud Flats, FMC Operable Unit

Background

Elemental phosphorus was produced at a site (hereafter the "FMC Operable Unit) on 1,450 acres of privately owned land near Pocatello, Idaho within the Shoshone-Bannock Tribes' (Tribes) Fort Hall Indian Reservation from about 1949 until 2001. From 2002 through 2006, the facility process units were decommissioned and the facility infrastructure was demolished to ground level. The FMC Operable Unit is currently undergoing investigation and cleanup under Superfund (CERCLA). The Tribes favor the permanent removal of and/or treatment of contaminants contained in soil and would like an Independent Review of Excavation and Treatment Technologies (ETT) that can be used to address elemental phosphorus contamination in soil at the site. Phosphorus associated with the manufacturing process at the site can be present in several forms, the common form being white phosphorus, a compound with the chemical formula P_4 which is also referred to as WP or P4. Elemental phosphorus is highly reactive and can exist as a number of other compounds including red phosphorus, which is essentially an oxidized form of P4. P4 has the potential to oxidize spontaneously and burn vigorously when in contact with air, wherein the P4 degrades to red phosphorus and other compounds containing phosphorus. Under certain conditions, P4 also has the potential to produce phosphine gas. Phosphine gas (PH_3), is a colorless, odorless, toxic gas, and has been detected within the now-closed facility's process areas and waste management units.

Product and Waste Handling Processes

Elemental phosphorus was produced at the FMC Operable Unit using phosphate-bearing shale ore originating from two different regional mine sites. Ore was shipped to the facility via rail and was either processed immediately or stockpiled. The ore was formed into briquettes and then calcined first in rotary kilns and then by 1968 with traveling grate calciners. The calcined briquettes were either stockpiled or immediately blended with coke and quartzite to create a feedstock for electric arc furnaces. The four electric arc furnaces produced gaseous elemental phosphorus, carbon monoxide gas, slag and ferrophos (FeP). The elemental phosphorus gas was condensed into a liquid and then stored prior to shipment off-site as product. Electrostatic precipitators were located "downstream" of the phosphorus furnaces. Precipitator solids were handled dry prior to 1955. After 1955, a slurry system was installed.

The manufacturing process, pollution control requirements, and product handling practices resulted in the generation of high volume and diverse waste streams containing chemical and radiological constituents of concern including P4 and other forms of phosphorus. For example the water that was used to isolate the P4 product from contact with air (known as: "phossy water"), were managed in a series of surface impoundments. Phossy water and the associated "phossy solids" likely contain P4. Process water used to slurry precipitator dust generated during furnace operations likely contains P4 and was also managed in surface impoundments. The piping system (some of which was underground piping) used to route carbon monoxide gas from furnaces first to the kilns and then later to the calciners may contain P4. Slag created during furnace operations is also expected to contain P4. Surface impoundments (some of which were newly constructed to meet minimum technology requirements under RCRA) and onsite landfills were used to manage plant waste streams including, but not limited to: phossy water, phossy solids, precipitator slurry, slag and slag-related wastes; and treatment residuals from kiln and calciner off-gas treatment. In some cases the presence of P4 can only be inferred because field sampling teams were prohibited from exposing P4-containing subsurface materials to the air during the performance of the Supplemental Remedial Investigation (January 2010).

Contamination in FMC Operable Unit Remediation Units

Soil co-located with other environmental media (surface water, sediment, and groundwater) or plant infrastructure that could have been impacted by P4 are known or suspected to be present in the following remediation units (RU) or areas of the FMC Operable Unit:

- RU 1 – Furnace building, secondary condenser, and loading dock due to leaks and spills from production processes and waste management;
- RU 2 – Slag pit due to leaks and spills from production processes and waste management;
- RU 13 – Pond 8S recovery process area and metal scrap preparation area due to management of waste materials in the adjacent old pond area;
- RU 19c – Railcars containing P4 sludge buried in the slag pile (RU 19);
- RU 22b – Old pond area due to management and disposal of P4-containing wastes;
- RU 22c – Railroad swale, due to phossy water spills entering stormwater sewers and discharging to the stormwater retention pond;
- Areas containing underground piping or sewer lines that carried phossy water, precipitator slurry, or CO gas, and therefore potentially could contain residual P4, or which may have leaked P4 (RUs 1, 2, 3, 8, 12, 13, 22b, and 24); and
- P4 in the capillary fringe above groundwater in RUs 3 and 7.

P4 where present in soil at the site could be encountered at concentrations ranging from just above the analytical detection limit to nearly pure P4. Since P4 oxidizes almost instantaneously on exposure to air, red phosphorus and in some cases compounds containing phosphorus will also be present. However, industrial processes (for example, the pipelines used to convey CO gas from the electric arc furnaces to the calciner) could contain nearly pure P4, especially if the P4 in the pipelines has not been exposed to air. The buried rail cars located in RU 22c could also contain nearly pure P4. Elemental phosphorus in various forms from these product and waste handling practices may have impacted native soil at the site which can include: silt, sandy silt, sand, gravel, gravelly silt and cobbles.

Production processes and waste handling practices have changed over time. Some of the surface impoundments used to handle the phossy water and the precipitator slurry were defined as hazardous waste management units under the Resource Conservation and Recovery Act (RCRA) and were closed under EPA-approved RCRA closure plans. The rotary kilns were replaced with traveling grate calciners in 1968. Off-gas from the kilns and calciners was treated with wet scrubbers. Scrubber liquor blowdown was managed in both lined and unlined surface impoundments, some of which were de-constructed and placed in the RCRA units. In addition, slag handling practices have changed over time.

Independent Review of Excavation and Treatment Technologies

In September 2012, the EPA issued an Interim Amendment to the Record of Decision for the FMC Operable Unit at the Eastern Michaud Flats Superfund site in Pocatello, Idaho (hereafter: "Interim Amendment (EPA 2012"). In the initial and supplemental Remedial Investigation/Feasibility Study (RI/FS), a review of technologies that could be implemented to address the elemental phosphorous in soil (the principal threat waste) was conducted. Based on that review and using CERCLA's nine evaluation criteria, EPA determined that capping was the preferred approach. However, the Shoshone-Bannock Tribes (Tribes) favor the permanent removal of and/or treatment of contaminants. The Tribes have expressed concerns regarding the previous review conducted on potential treatment technologies. The Tribes and EPA agreed to have Argonne perform an Independent Review as described in a Work Order Interagency Agreement EPA DW-89-92291201 / Proposal P-08125 Argonne National Laboratory, Environmental Science Division (*7/1/2014).*

To address the Tribes' concerns, Argonne will assemble an expert review team to perform an Independent Review of excavation and treatment technologies (ETT) for soils contaminated with elemental phosphorous to supplement the assessment of potential ETT. The Independent Review of ETT will be conducted in one or possibly two phases. This Technical Proposal is in response to the 7/1/2014 Work Order and addresses the performance of Phase 1. Phase 1 will entail researching, reviewing and evaluating, and reporting on ETT for the FMC OU pursuant to the criteria listed below. In order to perform Phase 1, Argonne has made the following assumptions:

Assumption 1: For the purposes of Phase 1, "elemental phosphorus" as referred to in the Work Order means elemental phosphorus with the chemical formula P_4 (CAS Registry Number 12185-10-3). The review will encompass elemental phosphorus, its chemical reactions and byproducts in the soil at the FMC OU. The review will focus on remediation of elemental phosphorus, but will consider other known contaminants as well, particularly with regard to the effect that potential ETTs for phosphorus and related compounds may have on other known contaminants.

Assumption 2: For the purposes of Phase 1, soil will be defined as unconsolidated earth material composing the superficial geologic strata (material overlying bedrock), consisting of clay, silt, sand, or gravel size particles as classified by the U.S. Natural Resources Conservation Service, or a mixture of such materials with liquids, sludges, or solids which is inseparable by simple mechanical removal processes and is made up primarily of soil by volume based on visual inspection (40 CFR 268. 2 (G));

Assumption 3: Debris will be defined as: solid material exceeding a 60 mm particle size that is: a manufactured object; or plant or animal matter; or natural geologic material. However, the following materials are not debris: any material for which a specific treatment standard is provided in Subpart D, Part 268, such as process residuals like smelter slag and residues from the treatment of waste, wastewater, sludges, or air emission residues; A mixture of debris that has not been treated to the standards provided by §268.45 and other material is subject to regulation as debris if the mixture is comprised primarily of debris, by volume, based on visual inspection (40 CFR 268.2 (K)).

Assumption 4: Excavating and treating soil contaminated with elemental phosphorus may involve the excavation of soil, debris and materials such as smelter slag and residues from the treatment of waste, wastewater, sludges or emission residues for which a specific treatment standard is provided in Subpart D of 40 CFR 268 (Land Disposal Restrictions). The evaluation of ETT will need to consider soil and the non-soil residuals described in Assumptions 3 above that could be excavated along with the soil and may need to consider other chemical and radiological contamination in addition to elemental phosphorus contamination. The potential for the triggering of LDRs will in no way limit the review of ETT technologies.

Assumption 5:Since the background information provided to ANL indicates that elemental phosphorus contamination could be present at depths in excess of 80' below ground surface (BGS), the review committee can consider in-situ remediation technologies. Technologies that may involve excavation below the practical excavation will be noted as part of the review

Assumption 6: As part of the scope described in the Work Order, the review committee has been asked to address the FMC Operable Unit. The portion of the FMC Operable Unit to be considered by the review committee includes the RU boundaries as depicted in Figure 1-2 of the Supplemental Feasibility Study Report for the FMC Plant Operable Unit (July 2010). However, Ponds 8S, 11S, 12S, 13S, 14S, 15S, 16S, 17S, 18A, 8E, and 9E which were closed and capped under EPA-approved RCRA closure plans (designated as RU 22a) are not subject to evaluation by the review committee. These ponds, also known as "RCRA Ponds" and their geographic relationship to the approximate Remediation Area boundaries described in the Interim Amendment (EPA 2012), are depicted in Figure 5 of the Interim Amendment (EPA 2012) and are attached to this response to the request for a technical proposal Furthermore, the Western and Southern Undeveloped Areas as depicted in Figure 1-3 of the Supplemental Feasibility Study Report for the FMC Plant Operable Unit (July 2010) are not subject to evaluation by the review committee. Nonetheless, the Review committee will consider all relevant information on ETT for the FMC OU, including information related to other NPL, military or RCRA sites, including the RCRA ponds.

Phase 1 will involve the following tasks:

Task 1 Establishment of an Expert Review Team and Conflict of Interest Plan

Argonne has identified the members of the Expert Review Team. The team will consist of four Argonne staff members who are subject matter experts (SMEs) and two additional SMEs that have been given, or that will be given Special Term Appointments with Argonne. The team members and their related expertise are as follows:

Mr. Louis Martino, Environmental Systems Engineer, Argonne. Mr. Martino is a SME in the investigation and remediation of chemical warfare agent and military munitions-related sites having functioned as the project manager, health and safety officer and field team manager for the remedial investigation and feasibility study and for the collection of samples associated with the ecological risk assessment for the White Phosphorus Pits at Aberdeen Proving Ground. Mr. Martino was the ANL project manager for the Final Independent Design Review: Simplot Site Eastern Michaud Flats Superfund Site Pocatello, Idaho (EPA-542-R-09-006) August 2009. Mr. Martino is a SME in the performance of feasibility studies and cost estimation for the implementation of remediation technologies. Mr. Martino is also a SME in key regulatory frameworks likely to have an impact on the feasibility and implementability of ETT including the RCRA Land Disposal Restrictions.

John Quinn, PhD, PE, Environmental Systems Engineer, Argonne. Dr. Quinn has expertise in hydrogeology, data visualization, and remediation technology, and has prior experience working on the Final Independent Design Review: Simplot Site Eastern Michaud Flats Superfund Site Pocatello, Idaho (EPA-542-R-09-006) August 2009. Dr. Quinn also participated in the review of a Remedial Systems Evaluation of the Homestake Mine (New Mexico), and a data gap analysis of the Dover Gas Light Company, Delaware site.

Jim Cunnane, PhD, Special Term Appointee, Argonne. Dr. Cunnane has expertise in geochemistry, fate and transport of inorganic chemicals in the environment and has prior experience working on Final Independent Design Review: Simplot Site Eastern Michaud Flats Superfund Site Pocatello, Idaho (EPA-542-R-09-006) August 2009. He is a former Group Leader in the Chemical Sciences and Engineering Division at Argonne.

James Jerden, PhD, Senior Scientist, Argonne, Dr. Jerden is a geochemist. Dr. Jerden has expertise in the reactive transport of contaminants and environmental mineralogy. He has over a decade of experience in the characterization and modeling of processes by which radionuclides and other metals are transported into the biosphere. His recent work has focused on the speciation and mineralogy of actinides and phosphorous in the environment.

Mr. Todd Kimmell, Senior Scientist, Argonne. Mr. Kimmell has participated in a number of National Research Council (NRC) committees involved in chemical weapons demilitarization, including several that have dealt with determining appropriate actions for chemical weapons disposed at various sites across the U.S. He has also supported several cleanups under RCRA and CERCLA at military sites within the U.S., and has been involved at a national level with guidance and training programs involving remediation of hazardous waste sites. Mr. Kimmell is a SME in key regulatory frameworks likely to have an impact on the feasibility and implementability of CERCLA removal and remedial actions. He is also expert in areas of hazardous waste characterization under RCRA and the RCRA Land Disposal Restrictions.

Mr. Ira May, BP Environmental Services, has been offered a position as a Special Term Appointee with Argonne. Mr. May worked with the U.S. Army Environmental Center and its predecessor agency United States Army Toxic and Hazardous Materials Agency for 25 years as the head of tis Geology and Chemistry Branch. While working in the USAEC/ USATHAMA organization Mr. May was involved in multiple projects involving the excavation of ignitable and reactive elemental phosphorus and in projects involving both *insitu* and *exsitu* treatment of elemental phosphorus. Projects included: Fort Wingate, NM, Ft Richardson, AK, and Aberdeen Proving Ground, MD. He was involved with cleanup projects at over 40 U.S. Army bases in the U.S. and around the world.

Each member of the team has completed, or before the initiation of this project will complete, an Argonne-required conflict of interest form that will identify affiliations or activities that would constitute any conflicts of interested related to participation on the Review Team. No member of the team has worked for FMC or currently works for FMC.

Other than serving as report authors, the roles of the team members are as follows:

Louis Martino: Team lead, preparation of ETT Review Parameters, review of ex situ technologies, cost engineering.

Dr. John Quinn: Review of ETT in particular technologies to address the presence of elemental phosphorus in the capillary fringe of the vadose zone.

Dr. Jim Jerden and Dr. James Cunnane, Review of potentially applicable insitu technologies and an assessment of the treatability of wastes using technologies under review.

Todd Kimmell and Ira P. May: Preparation of ETT Review Parameters. Review of potential excavation technologies and *exsitu* treatment technologies including worker health and safety-related issues.

Task 2 Review of Existing Site Characterization Information – Existing information regarding site-specific conditions, such as site contamination profiles and the evolving Conceptual Site Model (CSM), will be reviewed by the team or will be provided to the Review Team if needed information is not otherwise accessible via the internet. No additional sampling will be commissioned or undertaken to support this review. The focus of the review will be those aspects of the CSM that relate specifically to elemental phosphorus, its chemical reactions and byproducts in the soil at the FMC OU and those aspects that could impact implementation of an ETT at the site. Impacted soil that could be encountered at the site includes silt, sand, gravel, cobbles, sandy silt and gravelly silt. Other contaminants or media will be evaluated as needed because the presence of radiological and chemical constituents of concern, RCRA reactivity characteristics, and myriad non-soil media present throughout the site such as plant infrastructure (concrete foundations, asphalt, underground piping, sumps, storm drains, sumps), slag, metal scrap, pollution control sludge etc. will likely have a profound impact on the efficacy of an ETT. This task is envisioned to include a site visit and walk-over, and review of historical site information.

Task 3 Review of Technologies – The review will identify technologies from existing literature, applied research, bench-scale, pilot and/or operational situations that are relevant to the conditions found at the FMC OU. This review will include technologies evaluated previously at the FMC site and will include exploring opportunities of combining ETTs or using one or more ETTs in different locations at the FMC site.

Task 4 Applicability – For those ETT identified, the review will evaluate applicability to the conditions found throughout the FMC OU. The site may be divided into areas based on horizontal, vertical, or other factors depending on the applicability of various ETTs.

- Review parameters - The Expert Review Team will propose the parameters to be used to evaluate ETT. The Expert Review Team will prepare Draft and Final versions of the parameters hereafter referred to as "ETT Review Parameters".
  – As a starting point, the list below contains the ETT review parameters EPA and the Tribes have identified. Note that due to schedule constraints, the review of potential ETTs will be initiated following submission of the draft review parameters.
    - Efficacy and Feasibility (Technical merits)
      - Advantages
      - Disadvantages
      - Limitations
      - Time to implement
      - Effectiveness of removing and/or treating elemental phosphorus
      - Health and Safety

The Expert Review Team anticipates comments on the Draft version of the ETT Review Parameters and finalization of the ETT Review Parameters pursuant to the Schedule described below.

As specified in the 7/1/2014 Work Order from EPA and the Tribes, the review will not contain an evaluation of ETT against the set of nine CERCLA criteria. However it should be noted that in evaluating the "Technical Merits" called out above, Argonne may need to consider specific criterion that could be considered similar to aspects of the nine CERCLA criteria.

Task 5 Findings – Argonne will prepare a Draft Report, Final Report and a Response to Comments on the Draft Report as described in Task 6 below. Argonne will also prepare and present (via a webinar or face-to-face meeting) a powerpoint presentation report to summarize key conclusions of the Draft Report. The Draft and Final Report will be structured as follows:

- Summary;
- ETTs examined;
- Identification of other sites where ETTs has been performed both domestically and internationally;
- Summarize the use and applicability of ETT at those sites to the FMC OU;
- ETTs that warrant further consideration; and,
- For the ETTs examined, data gaps will be identified for all applicable technologies in order to implement the ETT at the site. In the case of ETTs that did not warrant a detailed examination because of the existence of data gaps, the Expert Review Team will identify any further studies that would be needed to fill those gaps.

These deliverables will be transmitted electronically (email) to a contact list, which will be provided by the EPA Project Officer (PO) and which will include both the Tribes and other parties as directed by EPA. (However, discussions and reports about cost, effort, and general administration of the Interagency Agreement (IA) shall take place only between ANL/DOE and the EPA PO.)

Status Reports

As part of the monthly IA reporting, Argonne will provide a brief status update of the effort, such as the general stage of the review, the percentage completed, and any changes in the schedule. This status will be shared with the EPA team members and the Shoshone-Bannock Tribes. The Status Report is not to contain any cost or invoice information. The EPA PO will approve invoices based on the reported progress and address any issues associated with costs and level of effort (costs and LOE reported in standard IA-wide, regular monthly reports to the PO).

Proposed Schedule

Date	Action or Deliverable
July to	Argonne submits draft technical proposal for review by EPA and the Tribes

Date	Action or Deliverable
September 2014	EPA PO provides comments on the draft technical proposal Argonne submits a draft final technical proposal for review by EPA and the Tribes A subset of the Expert Review Team conducts a site visit EPA PO approves draft final technical proposal after concurrence from the Tribes Argonne prepares final technical proposal Proposal accepted*
October 2014	Argonne Expert Review Team begins to conducts review
October 22 2014	Argonne submits Draft version of ETT Review Parameters
November 5, 2015	Argonne submits Final ETT Review Parameters after concurrence from the Tribes and EPA*
March 23, 2015	Argonne delivers Draft Report to EPA and Tribes jointly
April 7, 2015	Argonne gives presentation summarizing draft report (e.g. webinar) jointly to EPA and Tribes, including the Fort Hall Business Council.*
April 14, 2015	EPA and Tribes transmit comments on the Draft Report to Argonne and to each other.*
May 20, 2015	May 20, 2015 Argonne prepares and issues final *Report* and *Response to Comments* to EPA and Tribes jointly.

***If these dates are not met, follow-on deadlines may slip accordingly**

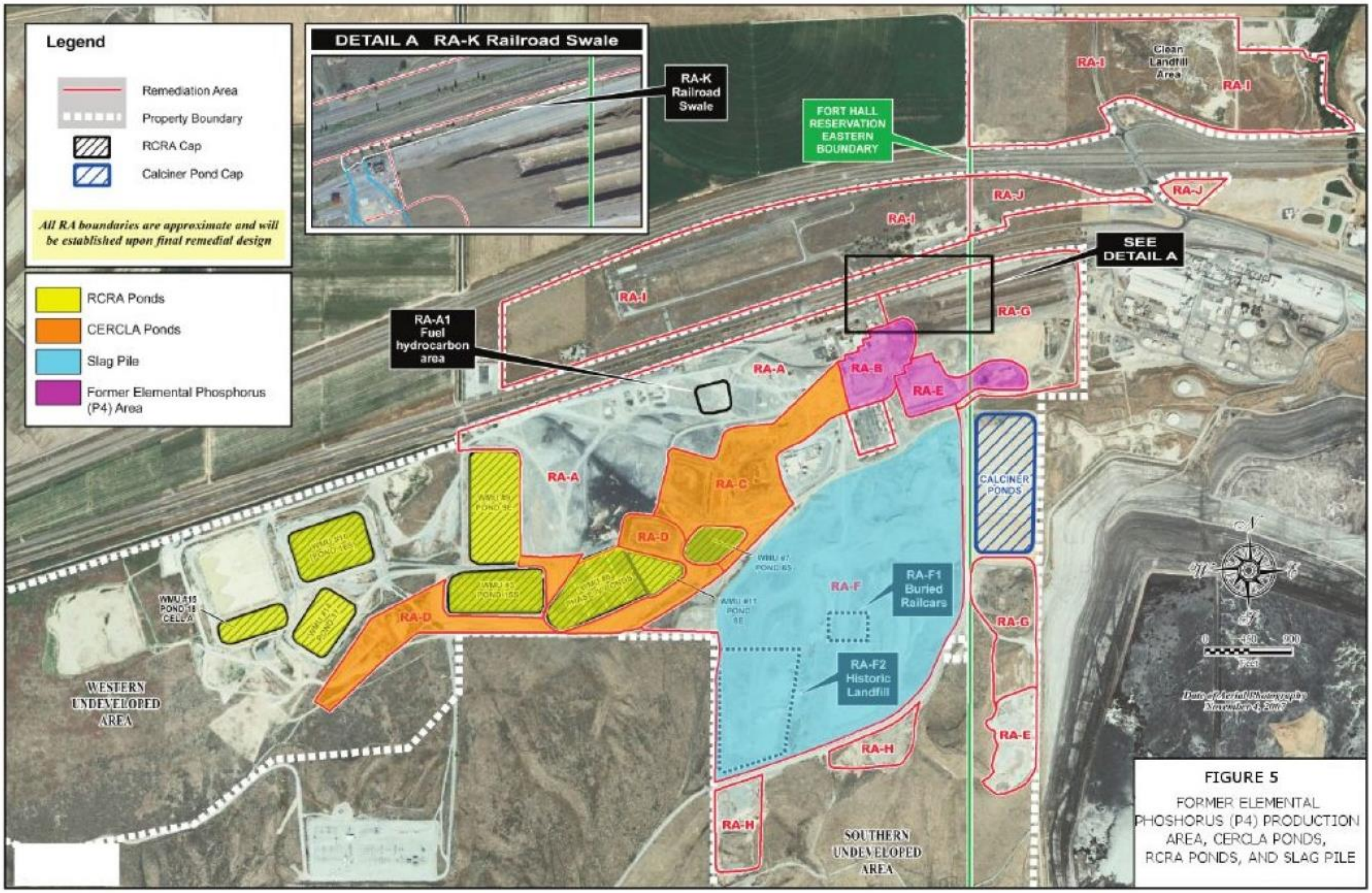

FIGURE 5

FORMER ELEMENTAL PHOSHORUS (P4) PRODUCTION AREA, CERCLA PONDS, RCRA PONDS, AND SLAG PILE

APPENDIX C:

PRESENTATION FROM SHOSHONE-BANNOCK TRIBES

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Shoshone Bannock Tribes Presentation to EPA and ANL

February 6, 2015

Objectives of Presentation

- Provide Brief History of Issues at EMF Superfund Site and the FMC site
- Facts, Pictures and Point to Documents that show almost 50 years of site use without regard to human and ecological health
- Demonstrate how FMC has consistently mis-stated reality
- Show Technologies Used at the Site and the Positives and Negatives of Each

Why an Independent Study?

- A Non-biased group of scientists, engineers and other professionals to identify possible treatment technologies for elemental phosphorus in soil .

- Which technologies can remediate the site versus existing / IRODA planned activities? Are there other possibilities?

Picture looking north

American Falls Reservoir and Fort Hall Indian Reservation located north of plants

Continued impacts to bottoms

FMC Operable Unit


Slag Pile
22 Rail cars
Fort Hall Reservation
Furnace Area

IMPACTS FROM AIR CONTAMINATION- DEPOSITION

Historical Perspective

- Placed on the NPL list in 1990
- Commonly known as the Eastern Michaud Flats Superfund Site
- FMC Operated from 1949 through December 2001
- FMC became subject to RCRA in March 1990 due to removal of Bevill Exemption from mineral processing wastes.
- History of non-compliance with Environmental Laws- RCRA- Consent Decree

Historical Perspective(Cont.)

- 1999 DOJ RCRA Consent Decree negotiated agreement – allow ignitable waste to be put in ponds-FMC agrees to treat the material or remove the waste
- Tribes allow FMC to cap ONLY pond 18a- after the RCRA Consent Decree- agreement to treat material going into the pond
- Superfund Remedy- presumptive remedy- Tribes believe because of agreement through RCRA to cap.
- No treatability studies completed

CAPPING

- FMC/EPA caps for the CERCLA Area are based on uncontrolled reactions occurring within the soils
- Barometric pressure- storm fronts allowing air pressure to push down on soils and allow any gas generated to move within the soils
- Changes from RCRA closure
- Capping/ closure of the RCRA ponds did not work
- TMPs alert system in closure plan (failure)


6 2'99


6 2'99


9 25 '96

List

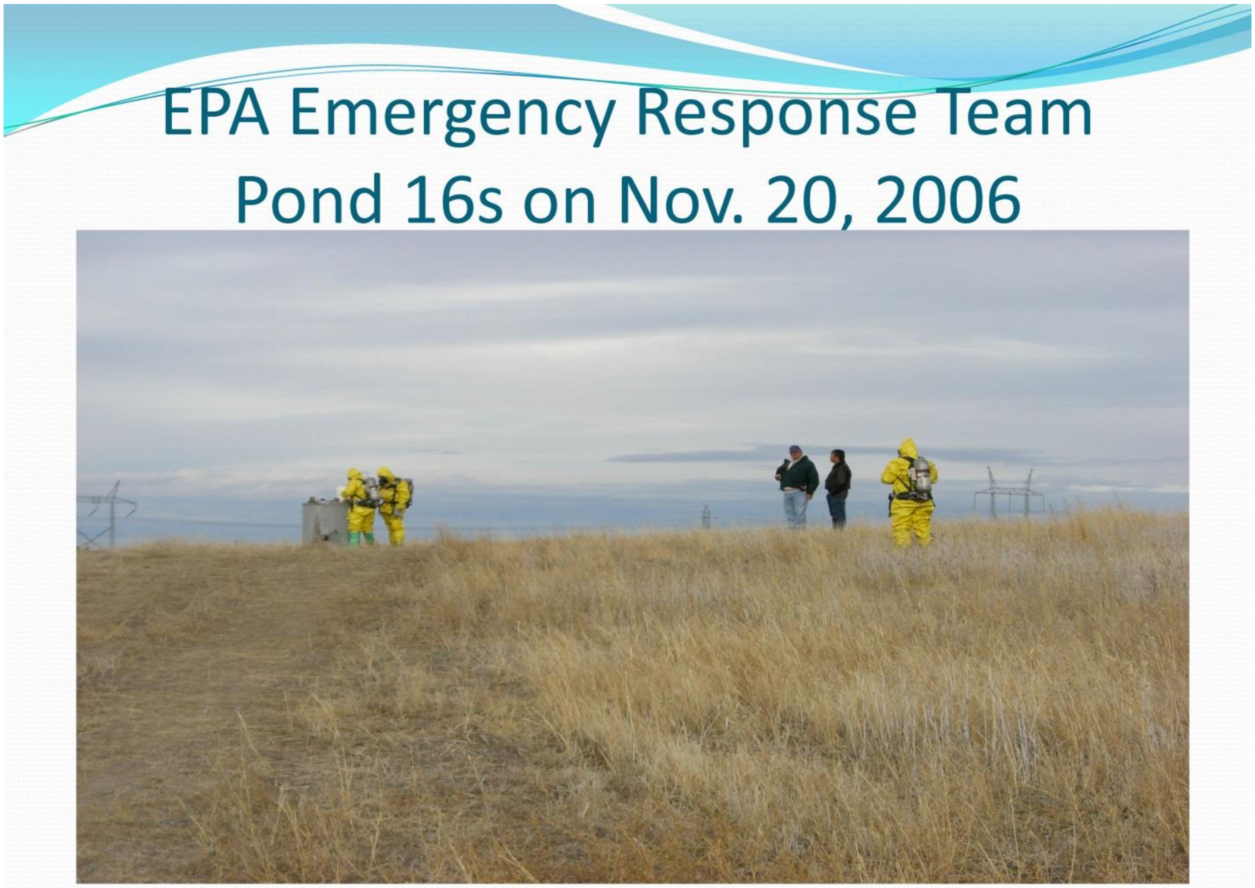
- Provided ANL a large list of documents

- UAO & AOC actions started with Pond 16S phosphine, HCN, H2S (gases) escaping from TMPs.

- FMC has reported through calculations (not direct measurement) that between 1 to 10 pounds of phosphine are released daily.

Pond 16S Venting

TMP P_2O_5 Leaking


EPA Emergency Response Team
Pond 16s on Nov. 20, 2006

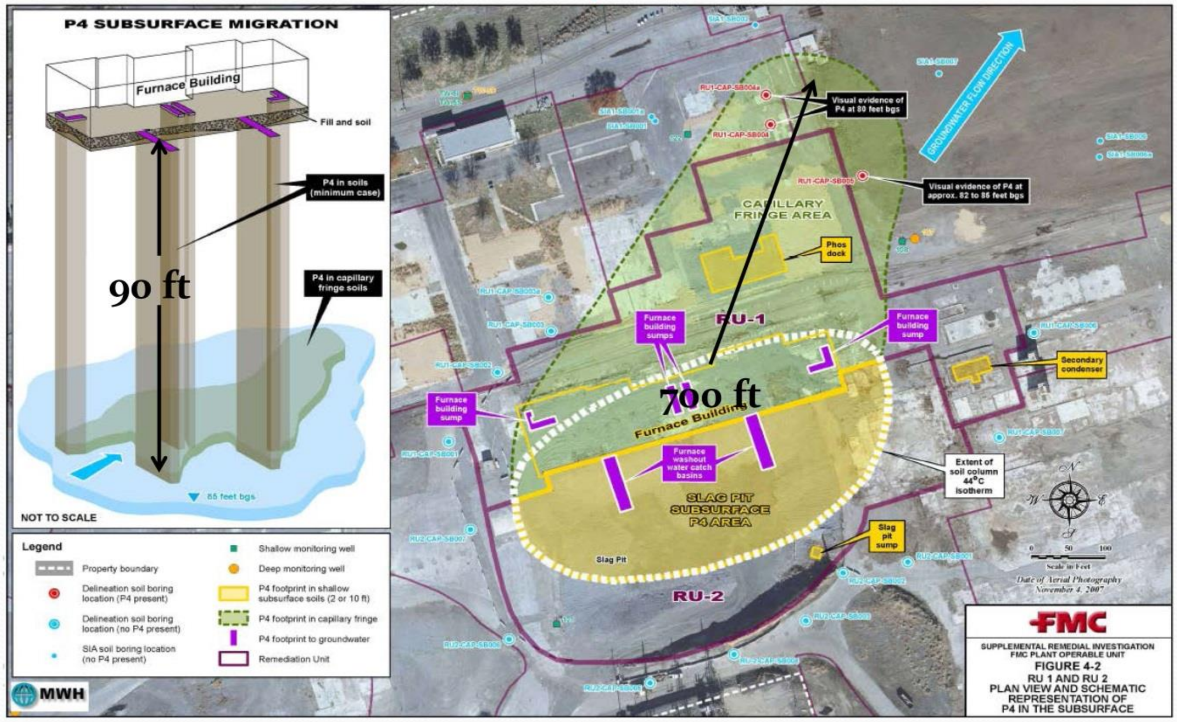
Non-Containment

- Containment of waste at FMC is not working
- Uncontrolled chemical reactions are generating and releasing hazardous constituents
- No adequate soil gas monitoring in place to characterize releases of phosphine or other gases within the soil
- Pond 8s has been generating both phosphine and hydrogen cyanide since its closure in 1999. The approved EPA Closure Plans requires FMC to monitor but not report

CONCERN

- Capping as a technology is feasible if the waste is treated… not ignitable and reactive.
- ELEMENTAL PHOSPHORUS IS NOT BEING MANAGED – UNCONTROLLED REACTIONS

Furnace Area P_4 contamination



FMC Dump on Tribal Fee Lands

Technologies Used at FMC Site

- Capping
- Gas Extraction (GES and GETS) plus Carbon Treatment
- O & M Issues and Power Issues
- “Containment”
- Waste Removal (“Spent” Carbon)

Technology: Cap

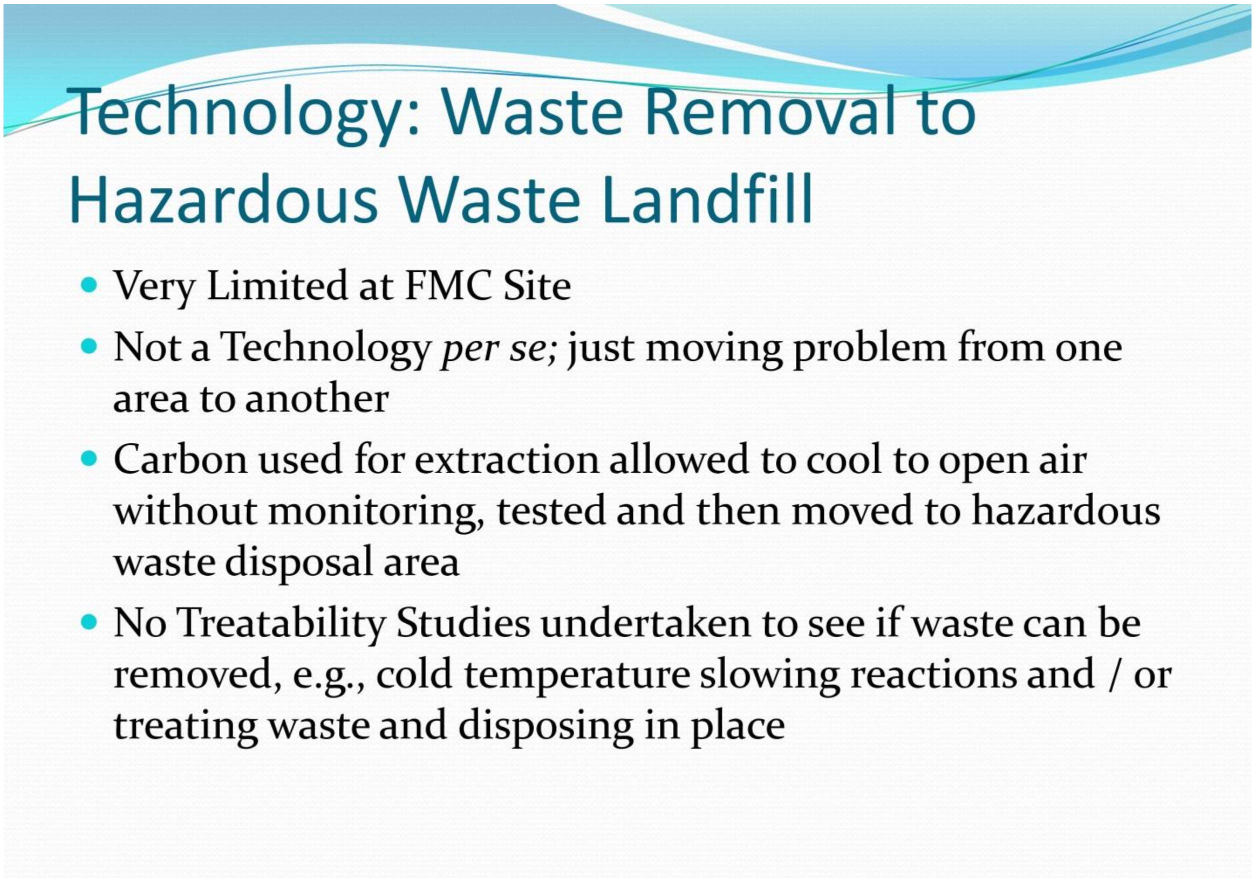
- Capping Used as Part of RCRA Closure Plans; Arid Region & EPA Research Very Limited
- Non-reactive waste in "ponds" separated by dike
- Liners and Anchor Trenches (Gaps)
- TMP Alert System for "Gas Build-up" (Failure)
- Monitoring Difficult & Limited
- Burrowing Animals & Wind Erosion plus Grass Growth Impaired. Cap Cracking with Large Crevices and Cracks; Thin Cap Will Not Work
- Waste Reacting Under Cap & Gasses Escaping

Technology: Gas Extraction with Carbon Treatment – Small and Large

- GES (Gas Extraction Treatment System)- portable, exothermic reaction
- GETS fixed: Issues Leaks, clogging, crystals, uses TMPs not designed as extraction wells, auto-ignitions, carbon bed fires, etc.
- Band-aid approach: Treating Problem Product but not remediating waste (Theory of Elimination: Allow waste to react until no more waste)
- O & M Constant; Gas still escaping underground, emissions

Technology: Containment

- Liners are Nearing “End of life” High Temperature may have Breached Liners (ex: thermally-destroyed PVC perimeter pipe Pond 15)
- Evidence of Reactive Gas Escaping from Ponds Exists; Fails Containment Mobility Requirement
- Not a Remediation Solution as Waste Still Exists (No Treatment was Done before Disposal)
- EPA Containment Guidance Does Not Exist


Technology: Waste Removal to Hazardous Waste Landfill
Very Limited at FMC Site
Not a Technology *per se;* just moving problem from one area to another
Carbon used for extraction allowed to cool to open air without monitoring, tested and then moved to hazardous waste disposal area
No Treatability Studies undertaken to see if waste can be removed, e.g., cold temperature slowing reactions and / or treating waste and disposing in place

Technology Associated Issues

- Current Monitoring using measuring devices not approved or tested for environmental monitoring (mostly occupational devices)
- Soil gas monitoring has been very limited so extent of gas escaping ponds, furnace and process areas, hotspots, rail cars/slag is basically unknown
- No real time phosphine numbers, concentrations too high for equipment.!

Cultural Impacts from FMC

- Contamination Spreading to Cultural Sites

Conclusions & Discussion Areas

- Limited "Views" of Alternative Technologies at Site
- Walsh (ACoE), Madalinski (EPA)
- Abandoned Technology by FMC and Why?
- Lack of Testing of Waste for Possible Remediation due to Danger and Economics
- Better Alert System Using Knowledge Gained no Matter What Technology is Used to Prevent Exposure

QUESTIONS

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APPENDIX D:

ARGONNE'S QUESTIONS TO FMC

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Argonne National Laboratory- 4/21/2015

Dear FMC:

As you know, Argonne is working with EPA and the Tribes to evaluate technologies that may be used to treat and otherwise manage waste containing P4 at the FMC location outside Pocatello. We thank FMC for the informative site visit provided to John Quinn, Jim Jerden and myself in September of 2014. Since that time we have continued to investigate planned actions (e.g., caps, covers, groundwater monitoring), and potential P4 recovery, treatment and waste handling practices at a number of domestic elemental phosphorus manufacturing facilities in the US. We have a few additional questions regarding the Pocatello Plant. We are on a relatively tight schedule for continuing our work on the project and we would appreciate a response to these queries by May 8th 2015.

Railroad car–related questions

What physical state would you expect that the material within the buried railroad cars would be? Solid? Liquid? Semisolid? Combination?

What physical state would you expect the railroad cars to be in? Corroded? Leaking? Intact?

Piping –related questions

During our site visit, we learned that some of the underground piping had been removed as part of the plant demolition. Is there any remaining underground piping? If there is underground piping present, what physical state would you expect material in any buried piping to be? Solid? Liquid? Semisolid? Combination?

If there is underground piping remaining at the site, what physical state would you expect the buried piping to be in? Corroded? Leaking? Intact?

Land Disposal Restriction Treatment Plant-Related Questions

FMC submitted several documents related to the construction of a Land Disposal Restriction (LDR) treatment plant. A subsample of the documents prepared includes:

- Land Disposal Restriction Treatment System Demonstration, Report Supporting Technology Selection for FMC Pocatello LDR Treatment Plant, FMC Corporation, Phosphorus Chemicals Division, October 1999; and,
- LDR Waste Treatment System, FMC Corporation, Phosphorus Chemical Division, March 2001.

The LDR waste treatment system is described in the March 2001 volumes as being capable of treating several production-related waste streams and Pond 18 sediments. Treatment was to involve clarification and a high temperature/high pressure anoxic treatment system. The March 2001 volumes appear to include a 20% engineering design. However, it appears that design engineering had advanced beyond the 20% stage since during our site visit it was reported that a full-scale LDR plant was constructed.

Are we correct in our assumption that a full-scale LDR waste treatment system was constructed at the Pocatello Plant but that the system was not operated because the plant was closed? Also, can you tell us more about why the LDR plant was closed? For example, were there operational or waste processing issues? Were there issues with meeting LDR standards or meeting criteria for underlying hazardous constituents? Were there issues with back-end stabilization?

High Temperature Dust Filtration (HTDF)-related questions

In a Federal Register Notice (Federal Register Volume 66, Number 79 (Tuesday, April 24, 2001) EPA notes that, at the time, FMC/Astaris informed EPA that they were considering an entirely different technology, referred to as High Temperature Dust filtration (HTDF) to address generation of the waste streams and supplant the LDR Treatment Plant. If the plant switched to the HTDF technology what treatment system was FMC going to use to treat waste streams that the LDR Treatment Plant would have been designed to treat, such as Pond 18 waste?

Wastewater Pond Dredging-related questions

With respect to references to Pond 18 in the March 2001 document, Pond 18 was to be dredged using a remotely operated dredge. Based upon a review of archival documents, we note that FMC had used dredging systems or processes in the past to: recover P 4 in wastewater pond sediment; aid in constructing new ponds; or to aid in refurbishing existing ponds.

Can FMC provide more information regarding how the dredge system described in the LDR Treatment Plant volumes (March 2001) was expected to function and how dredging of the wastewater ponds, in general was performed in the past? Please describe the process for dredging, touching on the physical/mechanical process and the means by which materials were to be kept from exposure to air, thus minimizing the potential for oxidation.

Cover/Cap Questions

The latest remediation plan involves emplacement of various types of caps and covers over part of the facility, as a means of minimizing migration of COCs into the environment. Please provide details of how these caps/covers will be monitored to ensure physical integrity, including escape of possible gasses (e.g, phosphine) into the atmosphere.

The possibility exists to manage wastes remaining on site under the requirements of a RCRA Corrective Action Management Unit (CAMU). Please provide information on if/how cover/cap materials may be different than that planned under current remediation plans (e.g., 2012 IRODA).

Historical Surface Impoundment Area (RUs 13 and 22b)

The 2010 Supplemental Feasibility Study describes plant landfills in RU-18 and RU-19b as receiving filter media, kiln scrubber solids, furnace dig-out material, carbon from PH3 gas extraction system. With respect to the noted RUs, the Supplemental Feasibility Study mentions that in the 1980s a process to recover P_4 from historical impoundment pond 8S was “developed, built, and tested” and then closed and removed in 1993.

Can FMC describe the P 4 recovery process that was developed, built and tested? During FMC’s efforts to recover P4 from pond 8s and based upon any other experience with the historical ponds, could FMC determine whether or not the material in the historical ponds was homogeneous or stratified (with respect to P 4 concentration)?

Does FMC have an estimate for the mass of P4 (if any) in the plant landfills in RU-18 and RU-19b?

Is spent carbon from gas extraction system a possible source of PH3 emission?

Thanks in advance for your assistance.

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APPENDIX E:

FMC RESPONSES TO EPA INDEPENDENT PANEL CONTRACTOR'S QUESTIONS AND REQUEST FOR ADDITIONAL INFORMATION DATED APRIL 21, 2015

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FMC Responses to EPA Independent Panel Contractor's Questions and Request for Additional Information dated April 21, 2015
May 18, 2015

In order to differentiate the Argonne National Laboratory (ANL) questions from the, in some cases, lengthy FMC answers and supporting documentation, the ANL questions have been re-printed in **bold** and numbered, followed by FMC's responses. For the FMC responses that reference an existing document(s) that provides the requested information, the response includes both a reference to the source document and a reprint of the relevant section(s) of the source document. The reprinted text section(s) are demarked with heavy line borders before and after the reprinted text.

Dear FMC:

As you know, Argonne is working with EPA and the Tribes to evaluate technologies that may be used to treat and otherwise manage waste containing P4 at the FMC location outside Pocatello. We thank FMC for the informative site visit provided to John Quinn, Jim Jerden and myself in September of 2014. Since that time we have continued to investigate planned actions (e.g., caps, covers, groundwater monitoring), and potential P4 recovery, treatment and waste handling practices at a number of domestic elemental phosphorus manufacturing facilities in the US. We have a few additional questions regarding the Pocatello Plant. We are on a relatively tight schedule for continuing our work on the project and we would appreciate a response to these queries by May 8th 2015.

1. Railroad car–related questions

What physical state would you expect that the material within the buried railroad cars would be? Solid? Liquid? Semisolid? Combination?

What physical state would you expect the railroad cars to be in? Corroded? Leaking? Intact?

FMC Response to Question 1:

The Technology Screening Memorandum, Buried Railcar Evaluations for the FMC Plant Operable Unit, May 2009 (Appendix B in the Supplemental Feasibility Study (SFS) Report for the FMC Plant OU, July 2010), Section 2.2 contains the best available information in response to these questions. The relevant subsections within section 2.2 are reprinted below:

2.2 UNKNOWNS CONCERNING THE BURIED RAILCARS

The depth and location of the railcars within the slag pile can be estimated to within a few feet, based upon the original vs. current surface elevations and historical aerial photographs.

However, there are several unknowns concerning the buried railcars that significantly hinder potential remedial actions. These unknowns are discussed in the following subsections.

2.2.1 Condition of the Railcars

The physical condition of the railcars is unknown. Their condition is important in determining whether or not the railcars could be handled whole once excavated. If the railcars have deteriorated through corrosion, any attempt at removing the entire railcar in one piece is likely to result in exposure of the P4 sludge to air and a P4 fire. It is presumed that the railcars were in good physical working condition at the time of the burial in 1964. However, the level of deterioration due to corrosion is unknown.

Based upon experience with mild steel underground piping at the plant site, the soil conditions do not result in significant corrosion on the outside of the piping. However, corrosion from the inside of mild steel equipment in phossy water service was observed due to oxidizing P4 which creates phosphoric acid. The phosphoric acid could cause significant corrosion from the inside, weakening the railcar. This could make exhuming the railcars in one piece impracticable. As discussed in the next subsection, the amount of phosphoric acid formed within the railcars, and therefore, the amount of internal corrosion since burial, is impossible to estimate. The worst case, i.e., that the railcars are greatly weakened by corrosion, would have to be assumed in evaluating the "excavate and treat" alternative. The remedial action evaluation thus must address potential methods for decontaminating and dismantling the railcars in place.

2.2.2 Contents of the Railcars

As described in Section 1.0, it is expected that the railcars contain about 10 to 25% of their total capacity as P4 sludge. However, it is not known if the railcars were filled with water or nitrogen prior to transportation to the slag pile area for burial. Nitrogen would have been a logical choice, given that it was present at the phos dock and used in railcar shipments. However, water may have also been used. The use of water would increase the likelihood that phosphoric acid would be formed, resulting in an increased rate of internal corrosion. The presence of water would also increase the amount of material to manage once the railcars were exhumed under an "excavate and treat" alternative. The worst case, i.e., that the railcars are filled with water, would have to be assumed in evaluating the "excavate and treat" alternative.

2.2.3 Whether the Railcars Have Already Leaked

The P4 sludge in the railcars would have been, and has remained, at subsurface soil temperatures since burial. These temperatures are below the melting point of P4. If P4 has leaked into soils at ambient temperatures, it would be assumed to have migrated no more than a foot from the point of the release and may have oxidized. However, upon removal of the railcar, any P4 that has accumulated in the soil outside the tank that has not oxidized would catch fire and burn. P4 can burn during most ambient conditions, including cold winter weather. The worst case, i.e., that the railcars have leaked and P4 is present in the soils near them, would have to be assumed in evaluating the "excavate and treat" alternative.

2. Piping –related questions

During our site visit, we learned that some of the underground piping had been removed as part of the plant demolition. Is there any remaining underground piping? If there is underground piping present, what physical state would you expect material in any buried piping to be? Solid? Liquid? Semisolid? Combination?

If there is underground piping remaining at the site, what physical state would you expect the buried piping to be in? Corroded? Leaking? Intact?

FMC Response to Question 2:

During the plant demolition, the aboveground piping was removed. Only minor sections of underground piping were removed as needed at limited locations where the aboveground pipe transitioned to underground pipe. The remaining underground utilities (pipe and power) are well documented and information responsive to ANL's questions are contained in the Supplemental Remedial Investigation Report for the FMC Plant Operable Unit (SRI Report, May 2009) in Section 4.26.3.2, which is reprinted below:

4.26.3.2 Underground Piping, Sumps and Structures Inventory

Although most of the operational records generated throughout the plant operation no longer exist, the underground piping/sump/structure inventory was created utilizing the following sources of information:

- Historical plant drawings
- Historical and current aerial photos and maps
- Field observations and surveys
- Interviews with personnel knowledgeable about the historical plant operations

The inventory of active and abandoned piping/sumps/structures on a site-wide and RU by RU basis is provided in Table 4-51. It is noted that pipes and conduit less than three-inches in diameter would not have carried process materials, and therefore, were not included in the inventory. Appendix I provides additional information supporting the underground piping and structures inventory including Figures I1 through I6 showing underground piping and structures on an RU-by-RU basis and a series of drawings which plot the location of all identified piping/sumps/structures (Drawing Sheets 0 to 11). Most of the remaining underground piping consists of inert materials that do not pose a future threat of release of COCs into subsurface soils. These include:

- Well/fire/process (makeup water) water lines

- Drinking water lines
- Natural gas lines
- Condensate return lines
- LDR lines never put into service
- Electrical conduit
- Sanitary sewer lines

However, some underground piping potentially could contain materials that could pose a threat of release of COCs as result of the materials conveyed. These include:

- Phossy water lines (includes ICW lines)
- Precipitator slurry lines
- Slag pit dewatering lines
- CO lines (containing condensed P4)
- Some non-contact cooling water drain lines (IWW drain lines)

These underground piping runs are shown on Figure 4-34 with the exception of the IWW drain lines. The IWW drain and return lines are shown in the inventory and drawings included in Appendix I. Based on operational use, the IWW drain lines would not be suspected to contain process related COCs. However, based on observations of the condition of the IWW drain line manholes (accumulation of solids, potentially from surface run-in) and piping (corrosion and potential for unintended cross-contamination from other sources) within RU 1, the IWW drain lines have been included on the list for consideration during the SFS.

4.26.4 Contamination Assessment

Any leaks of residual P4 from underground pipe lines historically used to transport CO, precipitator slurry and phossy water across the FMC Plant Site would represent a potentially unacceptable acute hazard to future receptors exposed to subsurface materials adjacent to these lines. Receptors located downwind of these pipelines could also potentially be exposed to phosphoric acid aerosols, associated with P4 combustion, at concentrations of acute health concern if the subsurface materials were to become exposed to air.

In addition to acute P4 hazards, receptors exposed to subsurface leaks from precipitator slurry lines, i.e. utility workers, could also be sub-chronically exposed to P4 and other COCs/ROCs associated with precipitator solids. As shown in Table 4-52, the Supplemental HHRA determined that risks to utility workers from exposure to precipitator solids associated with underground pipelines used to transport precipitator slurry are below the 1E-04 RAO specified in the 1998 ROD for potential future workers. Incremental non-cancer risks via the soil ingestion pathway, which are driven by the assumed presence of non-smoking P4 at a concentration of 3,000 mg/kg, exceed the 1.0 hazard index ROD RAO for utility workers. Incremental noncancer risks for all other COCs/ROCs and exposure pathways are below the 1.0 hazard index RAO specified in the 1998 ROD.

With respect to leaks from phossy water underground lines, receptors could be exposed to phossy solids in addition to P4. As shown in Table 4-53, the Supplemental HHRA determined that incremental non-cancer risks via the soil ingestion pathway, which are driven by the assumed presence of non-smoking P4 at a concentration of 3,000 mg/kg, exceed the 1.0 hazard index ROD RAO for utility workers. Risks to utility workers from exposure to other COCs/ROCs associated with leaks from underground phossy water pipelines are below the 1E-04 and the 1.0 hazard index RAOs specified in the 1998 ROD.

A comprehensive discussion of the methods and assumptions that were used to perform the Supplemental HHRA is provided in Appendix J.

Although specific sampling to determine releases of COCs/ROCs from piping/sumps/structures to subsurface soils was not performed as part of the SRI, the inventory created will be valuable in performing the SFS. The following presumptions will be applied during the SFS at each RU where piping/sumps/structures are identified:

- For abandoned underground piping, sumps, storm drains or structures that contained or were in contact with process streams (e.g., elemental phosphorus, phossy water, precipitator slurry), the presumption will be that the piping or sump has released the process material (and associated COCs/ROCs) into the surrounding subsurface soils and has the potential to act as a conduit of COCs/ROCs from one location to another into the surrounding subsurface soils.
- For abandoned underground piping that contained well/fire/process (makeup water), drinking water, condensate water, or natural gas, the presumption will be that the piping and pipeline corridor may act as a conduit for water to infiltrate from one location to another, but would not have been a source of historical release into the surrounding subsurface soils.
- For abandoned underground electrical conduit, the presumption will be that the piping and pipeline corridor may act as a conduit for water to infiltrate from one location to another, but would not have been a source of historical release into the surrounding subsurface soils.

- For abandoned building and equipment foundations, the presumption will be that the foundation will remain in place and will be incorporated into the remedial alternative design, as appropriate.
- For abandoned open access tunnels, the presumption will be that the access tunnel will remain in place or be filled-in depending on the remedial alternative design, as appropriate.
- For active pipelines, sewer lines, water lines, and electrical conduit, the presumption will be that these will remain in place and active.
- For active pipelines/utilities subject to easements (e.g., Chevron and El Paso Gas pipelines), these lines will remain in place pursuant to the respective easement agreements.

Estimation of P4 Volume in Underground Piping:

The underground pipe inventory presented in Appendix I was utilized to develop an estimate of the volume of residual P4 potentially present in underground pipelines at the plant site. The underground pipes that may potentially contain residual P4 are:

- Phossy water lines;
- Precipitator slurry lines;
- Phosphorus (P4) lines;
- CO line; and,
- Stormwater piping from the Phosphorus Dock Area to the Railroad Swale (RUs 1, 3, 7, 24)

Based on plant operational knowledge regarding the use of these lines and the observed conditions during historic maintenance and removal of aboveground segments of phossy water/precipitator slurry lines and CO lines, a volume estimate was developed for 1) Phossy water, precipitator slurry and P4 lines collectively, 2) CO line, and 3) Stormwater piping from the Phosphorus Dock Area to the Railroad Swale. The basis for the estimated volume is provided below:

<u>Phossy water, precipitator slurry and P4 lines</u>

The P4 volume was estimated for these pipes collectively due to general proximity of these lines within the furnace building and slag pit (RUs 1 and 2) and leading out to the phossy ponds area (RU 22b). A void volume within the pipelines was calculated using the diameter and total length of each pipe identified in Appendix I. Although some of these pipes were probably abandoned due to plugging that could not be cleared, plant experience (again, based on removal of aboveground segments of phossy water/precipitator slurry lines) that plugs typically occurred in low points and/or angles (turns) in the pipelines, not uniformly within the entire pipeline. The plugs typically included a mixture of phossy/precipitator solids and agglomerated P4. However, to provide a conservative estimate, half the volume of the pipes was assumed full of phossy solids or precipitator slurry and the P4 concentration in the residual phossy material was assumed to range from 2 to 20 percent P4. The estimated residual P4 volume in all identified underground phossy water, precipitator slurry and P4 lines ranged between 2.8 and 28 tons. This estimate does not include the weight of the residual non-P4 solids or the weight of the pipe. The P4 volume estimate does not include potential leakage or loss at pipeline cleanouts (from maintenance) that likely occurred but are not quantifiable.

CO line

The void volume within the CO line was calculated using the diameter and total length identified in Appendix I. The use and operation of the old underground CO line would be similar to the aboveground CO line that was in operation until plant shutdown and removed during the plant decommissioning. P4 was encountered as a thin layer in the invert of the CO line and, similar to the phossy/precipitator slurry lines, tended to be encountered at low points and turns in the pipeline; however, the CO lines never plugged with P4 because of gas velocity and typical gas temperature above the freezing point of P4. Therefore, a range of 1 to 10 percent of the pipe volume is reasonable. In the CO line, any residual material would be high concentration P4 with minor particulate solids and the residual was assumed to be essentially 100% P4. The residual P4 volume in the CO line was estimated to range between 0.2 and 1.8 tons.

Stormwater piping from the Phosphorus Dock Area to the Railroad Swale (RUs 1, 3, 7, 24)

The void volume within the of the stormwater piping in the Phosphorus Dock area leading to the railroad swale was calculated using the diameter and total length identified in Appendix I. These pipes primarily conveyed stormwater, but were also known to have intercepted spilled phossy water from the phosphorus dock operations and transported that phossy water and entrained P4 to the railroad swale. There is no operational or historical knowledge that these pipes plugged, but some segments of the pipe may have accumulated dirt, and possibly phossy solids and particulate P4 from historic dock spills. Assuming that the entire length of pipe is 20 percent full with dirt / solids and the P4 concentration in the dirt ranges from 1 to 5 percent, the residual P4 volume in the stormwater piping was estimated to range between 0.13 and 0.6 tons. This estimate does not include the weight of the residual non-P4 solids or the weight of the pipe.

3. Land Disposal Restriction Treatment Plant-Related Questions

FMC submitted several documents related to the construction of a Land Disposal Restriction (LDR) treatment plant. A subsample of the documents prepared includes:

- **Land Disposal Restriction Treatment System Demonstration, Report Supporting Technology Selection for FMC Pocatello LDR Treatment Plant, FMC Corporation, Phosphorus Chemicals Division, October 1999; and,**
- **LDR Waste Treatment System, FMC Corporation, Phosphorus Chemical Division, March 2001.**

The LDR waste treatment system is described in the March 2001 volumes as being capable of treating several production-related waste streams and Pond 18 sediments. Treatment was to involve clarification and a high temperature/high pressure anoxic treatment system. The March 2001 volumes appear to include a 20% engineering design. However, it appears that design engineering had advanced beyond the 20% stage since during our site visit it was reported that a full-scale LDR plant was constructed.

Are we correct in our assumption that a full-scale LDR waste treatment system was constructed at the Pocatello Plant but that the system was not operated because the plant was closed? Also, can you tell us more about why the LDR plant was closed? For example, were there operational or waste processing issues? Were there issues with meeting LDR standards or meeting criteria for underlying hazardous constituents? Were there issues with back-end stabilization?

FMC Response to Question 3:

A full-scale LDR treatment process was partially constructed at the FMC plant, but the construction was not completed prior to the announcement of the plant shutdown in October 2001. The LDR plant was not "closed." In fact, construction of the LDR treatment process was not completed. The process did not proceed through commissioning and startup and did not receive or treat any process wastes; therefore, there were no operational or processing issues. The single-purpose function of the LDR treatment process for the intended treatment of on-going phosphorus production wastes (the RCRA consent decree was amended with EPA and Tribal approval in 2001 to eliminate the requirement to remove Pond 18 wastes and treat those at the LDR plant) and limitations on using that process for potentially treating non-production P4-contaminated materials are described in the Identification and Evaluation of P4 Treatment Technologies, January 2009 (Appendix A in the SFS Report), Section 3.3.4. That section is reprinted below:

3.3.4 Caustic Hydrolysis Treatment Performance and Limitations

Given the engineering challenges and issues associated with ex-situ caustic hydrolysis, the following limitations, advantages, and potential applications are identified for P4- contaminated soils at the FMC Plant Site:

Limitations:

- Generally not applicable for soil depth over 15 feet for ex-situ application due to limitations of construction excavation equipment.
- Extremely complex complete treatment sequence including all the ancillary treatment processes (feed preparation, reactant preparation, waste slurry management, air emissions management).
- Difficult to supply consistent (size and concentration) P4 feed stream and therefore control P4 reactions.
- Significant variation in soil particle size and P4 concentration, as found in most P4-containing RUs, would make the handling process extremely complex and difficult to operate and maintain.
- Requires additional treatment for radionuclides at a minimum, but possibly the metal oxides and hydroxides as well.

Advantages:

- Converts heavy metals in process feed material to metal oxides and hydroxides that may not require additional treatment. Bench scale testing of treatment sludges would be necessary to evaluate if additional treatment is necessary for metal and radionuclides present in process sludges.

Potential Applicability:

- Shallow soils with low concentration P4 (< 10,000 ppm).
- Shallow soils with consistent material sizing and concentration of P4.

3.3.5 By-Products and Residuals

In any treatment process, the by-products and residuals must be addressed in the feasibility evaluation including the cost analysis. The following by-products and residuals would be expected from the caustic hydrolysis treatment process:

- Slurry/solid residue in the hydrolysis reactor bottoms stream, consisting primarily of inert dirt, un-reacted lime, and insoluble calcium phosphite ($CaHPO_3$) would require further stabilization;

- The wastewater generated from the caustic hydrolysis treatments would contain suspended solids and soluble calcium hypophosphite that would require treatment and disposal;

- Gases produced during hydrolysis include phosphine (PH_3), hydrogen (H_2), and water; and

- Air pollution control system sludges.

3.3.6 History of Use

A full-scale caustic hydrolysis system has been in operation since 2000 at the GSHI facility in Columbia, Tennessee to treat a low concentration P4 furnace production process waste stream (Rhodia, 2007).

Beginning in the mid-1990s, FMC began using lime treatment of precipitator slurry in the furnace precipitator dust "slurry pots" principally to increase the pH of the precipitator slurry and decease the solubility of metals within the precipitator solids. The lime treatment was termed Non-hazardous Slurry Assurance Project or "NOSAP." The lime addition also catalyzed hydrolysis of P4 within the precipitator solids causing generation of PH3 from the lime-treated precipitator slurry. Under the RCRA Consent Decree, certain operating criteria, including volume of lime addition, temperature, final pH and retention time, were established that constituted "on-specification" NOSAP precipitator slurry. However, the RCRA Consent Decree required the development and implementation of a more rigorous treatment process for the precipitator slurry and phossy water/solids from the plant due, in part, to EPA's position that the NOSAP process did not meet EPA's treatment objectives. EPA's conclusion that additional treatment was required led to the RCRA Consent Decree requirement that FMC design, construct and operate what was referred to as the LDR Treatment Plant to more thoroughly treat the plant process wastes. Although the LDR Treatment System was not completed or ever operated, the LDR system was intended to replace and improve upon the NOSAP process for the treatment of precipitator slurry from ongoing P4 production.

The main objective of the LDR treatment system was to treat the waste stream slurries from the furnace production process containing low levels of elemental phosphorus (less than 2% P4 and particle size less than U.S. Standard Sieve Mesh # 60) to reduce the P4 concentration. The treated, filtered and dewatered waste solids then would have undergone cement stabilization to stabilize metals and meet RCRA LDR requirements prior to disposal in an on-site landfill. As stated in Section 4.2, the LDR treatment system would have had narrow operational parameters (e.g., injection rates, particle size cutoffs, and P4 feed concentrations). It also would have involved numerous operational steps. These would have included the following: slurry feed processing in a ball mill to achieve less than 60 mesh particle size; collection and piping of the considerable amount of off-gas the caustic hydrolysis process would have generated; lime reactant preparation; chemical hydrolysis in reactor columns; reacted solids dewatering and stabilization; treatment of the off-gas management in a thermal oxidizer unit; oxidizer emissions scrubbing; and scrubber water treatment. The process was developed based on bench and pilot testing. It was never operated or demonstrated to be successful at full-scale even on the specific type of waste for which it was designed. A major process engineering review and design effort would be required in any to attempt to modify and expand that process to treat varying soil matrices that contain varying levels of P4.

4. High Temperature Dust Filtration (HTDF)-related questions

In a Federal Register Notice (Federal Register Volume 66, Number 79 (Tuesday, April 24, 2001) EPA notes that, at the time, FMC/Astaris informed EPA that they were considering an entirely different technology, referred to as High Temperature Dust filtration (HTDF) to address generation of the waste streams and supplant the LDR Treatment Plant. If the plant switched to the HTDF technology what treatment system was FMC going to use to treat waste streams that the LDR Treatment Plant would have been designed to treat, such as Pond 18 waste?

FMC Response to Question 4:

The high-temperature dust filtration (HTDF) technology proposed by FMC in 2001 was a process change that would have replaced the electrostatic precipitators that captured dust (blow-over) from the furnaces. HTDF was proposed as a step-change in the process that had the potential to replace the electrostatic precipitators and thus eliminate the precipitator slurry wet (slurry pot) handling system that was the major, by volume, waste stream that the LDR treatment system was designed to treat. As a replacement to the furnace process systems (electrostatic precipitators), HTDF was not a treatment process whatsoever. It was not in any way capable of treating the wet-dredged sediments from Pond 18, other pond wastes, or the precipitator slurry and phossy water otherwise planned to be directed to the LDR plant.

5. Wastewater Pond Dredging-related questions

5a. With respect to references to Pond 18 in the March 2001 document, Pond 18 was to be dredged using a remotely operated dredge. Based upon a review of archival documents, we note that FMC had used dredging systems or processes in the past to: recover P4 in wastewater pond sediment; aid in constructing new ponds; or to aid in refurbishing existing ponds.

FMC Factual Correction to Items Noted in Question 5a:

Dredging for P4 recovery was only performed at Pond 8S to provide feed material to the Pond 8S Recovery Process. Additional information on the Pond 8S Recovery Process is provided in FMC's response presented below to the questions under "7. Historical Surface Impoundment Area (RUs 13 and 22b)." Dredging was neither used nor needed for the construction of new ponds. New ponds did not contain water upon which to float a dredge, nor did they contain any pond sediments to dredge. New ponds were constructed using conventional heavy (earthmoving) equipment. Lastly, dredging was not used to "refurbish" existing ponds. The sediments from Ponds 8E and 9E were dredged to the extent practicable and the dredged sediment slurry was routed to Pond 16S. This was done with the intent to convert Ponds 8E and 9E to service as non-hazardous disposal units. The upper two to three feet of sediments in Pond 15S were dredged only for the purpose of redistributing (or "leveling") the sediments to facilitate the closure of that pond.

5b. Can FMC provide more information regarding how the dredge system described in the LDR Treatment Plant volumes (March 2001) was expected to function and how dredging of the wastewater ponds, in general was performed in the past? Please describe the process for dredging, touching on the physical/mechanical process and the means by which materials were to be kept from exposure to air, thus minimizing the potential for oxidation.

FMC Response to Question 5b:

The dredging of Pond 18 sediments would have been performed using the same floating dredge system used by FMC for the pond dredging described in the factual correction for Question 5a above. The dredge floated on pontoons that required 2 to 3 feet of free-water (freeboard) and utilized a hydraulically-operated horizontal auger cutting-head suction dredge. The cutting head could be lowered to about 5 feet below the bottom of the pontoons. Information responsive to ANL's questions are contained in the FMC document "Supplemental Information Requested by EPA Regarding Treatment of Phosphorus-Containing Pond Solids at FMC," December 8, 1997. Relevant text from that document is reprinted below:

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2. Ex-situ lime treatment (caustic hydrolysis)

The discussions relating to lime treatment, wet oxidation, and steam distillation are, in part, based on extrapolations of data and observations made during technology evaluation and development efforts and limited or no data was available for elemental phosphorus removal below a 1,000 ppm residual elemental phosphorus. The lime treatment, wet oxidation and steam distillation technologies were evaluated on the basis that the processes would be used to treat a clarifier underflow stream that has been concentrated to about 20% total suspended solids (TSS) and 3% total dissolved solids (TDS).

Effectiveness: The lime treatment process is carried out at 65-degrees Celsius (C) at a pH of 12.0. Due to the nature of pond solids, high shear mixing will probably be necessary to break the stable P4/dirt/water emulsions that exist in the pond solids. The reaction rate that was determined in the laboratory for this first order reaction was 3 per hour. From a practical point of view, 3 reactors are required in a process with approximately 2 hours of residence time to reduce phossy waste underflow containing up to 3% P4 to 1,000 ppm.

Obviously a higher pH, higher temperature, and higher energy agitation will all impact the reaction rate, but for this discussion the above-defined conditions are maintained. A best estimate from data generated in the CHD development process assuming 3% maximum P4 in the feed is that 3 hours of residence time will be required to get to less than 500 ppm and that 5 hours of residence time would be required to ensure less than 50 ppm. A graph showing P4 reduction versus residence time at various tested temperatures and lime addition rates is attached (Figure 2). No additional processing to deal with cyanide or UTS metals is included in this process.

Implementability: FMC has experienced a number of difficulties during dredging and processing (8S recovery process) of pond solids that would be encountered with any ex situ treatment option.

Health and Safety concerns primarily due to potential burning hazard (thermal burns) to workers from elemental phosphorus exposed to air while disturbing pond solids; and potential exposure to PH3 and P205 while disturbing pond solids. Additional potential exposures to workers on dredge and within treatment process plant area. As experienced during operation of the 8S recovery process, management of water level and exposed pond bank sediments during operation was difficult. In order to reach deeper pond sediments, the water level had to be lowered, exposing pond bank solids to air which resulted in oxidation of phosphorus in the solids until soil could be applied to cover exposed solids. A long-reach excavator was used to cover bank solids, but bank slope conditions (wet, loose soil inside the pond embankment) made access with the excavator difficult and dangerous.

Air emissions of PH3 increase when pond water/solids are agitated and potential P205 from smoking/burning solids exposed during disturbance of pond solids. Dredging creates additional agitation and increases PH3 emissions. Removal of the final 1.5 to 2 feet of solids cannot be accomplished by dredging so conventional equipment would have to be used; therefore, some open oxidation of solids would be inevitable. Treatment process plant will also have some level of air emissions.

Any ex-situ treatment would be expected to experience similar difficulties as the 8S recovery process. The process was operation and maintenance intensive. Often 2 to 4 hours were required for start up of the system prior to processing pond sediments (time to position the dredge, pump solids to the system, process warm up, etc.). In addition, solids had to be flushed out and the system drained each time the system was shut down to avoid plugging lines and process units. During 1989, the 8S recovery process had an on- stream efficiency under 40-percent (e.g., for every 10 hours of system operation, less than 4 hours were spent processing pond solids for P_4 recovery).

As experienced with the 8S recovery process, slurried pond sediments were highly variable with respect to phosphorus content, making control of the process difficult. Extensive training of operations personnel was required before the operators could run the system effectively. Although each unit in the process system may have operated at high efficiency, if one process step experienced an upset, the entire process had to be shut down. The overall reliability of the process system was poor.

Lowest 1.5 to 2 feet of solids cannot be dredged (solids are not "confined" and are displaced laterally rather than collected by the dredge). A total solids pump may be able to recover some of the remaining solids, but would not handle agglomerations or debris.

Access for the pond dredge and support equipment is problematic. Pond 15S and Pond 11S are currently too full of solids to float a dredge or barge, and there is insufficient capacity to add additional water without raising the water level above the 2-foot minimum freeboard. The pond solids are far too soft to support conventional heavy equipment (dozer, loader, etc.).

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6. Cover/Cap Questions

6a. The latest remediation plan involves emplacement of various types of caps and covers over part of the facility, as a means of minimizing migration of COCs into the environment. Please provide details of how these caps/covers will be monitored to ensure physical integrity, including escape of possible gasses (e.g, phosphine) into the atmosphere.

FMC Response to Question 6a:
The EPA-selected remedial action for the FMC OU is set forth in EPA's 2012 Interim Amendment to the Record of Decision (IRODA) for the EMF Superfund Site - FMC Operable Unit - Pocatello, Idaho, September 27, 2012 and was made enforceable by the Unilateral Administrative Order for Remedial Design and Remedial Action (RD/RA UAO), EPA Docket No. CERCLA-10-2013-0116, issued on June 10, 2013. FMC is implementing the EPA-selected remedy in accordance with the RD/RA UAO. Caps are a required element of the selected remedy but FMC has not yet commenced constructing them. Post-construction cap monitoring and maintenance is described in the EPA-approved Remedial Design Work Plan (RDWP) for the FMC OU, December 2013, which FMC developed as required under the UAO. The Soil Remedy Monitoring Elements set forth in Section 4.2 of the RDWP are reprinted below:

4.2 SOIL REMEDY MONITORING ELEMENTS

4.2.1 Institutional Controls Program

FMC will implement legally enforceable institutional controls with respect to all or part of the FMC Plant OU, as appropriate for the needed control, that will include any or all of the following in addition to those institutional controls already in place:

a. Prevent any future ingestion of or exposure to contaminated groundwater (i.e., deed restrictions or restrictive covenants including prohibitions on extraction and consumption of impacted groundwater).
b. Restrictions on the types of activities and/or development (e.g., limited to commercial or industrial);
c. Prohibition of intrusive activities, construction and/or excavation at RAs designated for gamma or ET caps; and,

d. A soil/fill management plan that would be incorporated into deed restrictions to ensure that disturbance, management, and/or disposition of site-impacted soil/fill is controlled.

Objective: In conjunction with the Soil and Groundwater Remedial Action elements, the objectives of the institutional controls program are to 1) prevent exposure via all viable pathways (external gamma radiation, incidental soil ingestion, dermal absorption, and fugitive dust inhalation) to soils and solids contaminated with COCs that would result in an unacceptable risk to human health assuming current or reasonably anticipated future land use, 2) prevent the direct exposure to elemental phosphorus under conditions that may cause it to spontaneously combust, posing a fire hazard or resultant air emissions that represent a significant risk to human health and the environment, and 3) prevent potential ingestion of groundwater containing COCs having concentrations exceeding RBCs or MCLs (chemical-specific ARARs), or site-specific background concentrations if those are higher.

Performance Standard: The performance standard for this element of work is implementation of the Institutional Controls Implementation and Assurance Plan (ICIAP) that will include the elements described above.

4.2.2 Gas Monitoring Program

A phosphine monitoring program will be implemented at RAs B, C, D, F1 and K, where elemental phosphorus is present in the subsurface, to identify any phosphine releases to ambient air or soil chemistry disturbances.

Objective: The objectives of the gas monitoring program are to 1) identify potential phosphine releases to ambient air through the caps and 2) identify potential changes in the basic soil properties (physical and chemical) within the cap materials that would threaten the cap integrity or vegetative cover.

Performance Standard: Specific performance standards for the gas monitoring program will be finalized and documented in the Performance Standards Verification Plan.

4.2.3 Operation, Monitoring and Maintenance Program

The cap operation and maintenance element of work includes visual observation and measurements at the capped RAs, maintenance of the caps as necessary, and evaluation and reporting of the results of the monitoring and any maintenance.

Objective: The objective of the cap monitoring and maintenance of the capped RAs is to assure the caps continue to perform as designed and installed.

Performance Standard: Specific performance standards for the cap monitoring program depend on the nature of the fill / soil beneath the cap and the type of cap (gamma or ET) and the final design for each of those caps / RAs. The performance standard for cap monitoring and maintenance will be finalized and documented in the Remedial Action Work Plan. The cap monitoring will include, as appropriate, the following:

- Vegetation monitoring on the surface of the capped areas;
- Erosion monitoring (periodic and after certain storm events);
- Stormwater / precipitation drainage system monitoring;
- Security monitoring (fences, signage, etc.); and
- Settlement monitoring.

Continuation of FMC response to Question 6a:

Pursuant to the UAO, FMC submitted to EPA in January 2015 a Draft Institutional Control Implementation and Assurance Plan (ICIAP) and a Draft Operation, Monitoring and Maintenance Plan (OM&M Plan) as required components of the Pre-Final Remedial Design (RD) for the soil remedy. Those plans include the details of the cap monitoring and maintenance elements and the means and methods to perform that work. The monitoring and maintenance will ensure that the caps meet, both initially and for the duration of the remedial action, the required performance standards. Those draft plans are still under review by EPA and, pending receipt of EPA comments, will be finalized for EPA approval.

6b. The possibility exists to manage wastes remaining on site under the requirements of a RCRA Corrective Action Management Unit (CAMU). Please provide information on if/how cover/cap materials may be different than that planned under current remediation plans (e.g., 2012 IRODA).

FMC Response to Question 6b:

The suggestion that RCRA CAMUs could possibly be used to manage site wastes is inconsistent with the CERCLA Remedial Design and Remedial Action (RD/RA) that is being performed pursuant to EPA's 2012 IRODA and 2013 RD/RA UAO, because the EPA selected remedy addresses both CERCLA remedial action and RCRA corrective action requirements at the FMC OU. Use of CAMUs also is unnecessary for the RCRA Waste Management Units at the facility, consisting of capped RCRA ponds and the slag pit sump, since those have all been closed and they are in post-closure.

The SFS Report documents the evaluation of several soil covers (caps) designs including the preliminary designs for the soil cover (gamma cap) and evapotranspirative (ET) caps. As described in Section 5.2.3.1 of the SFS Report, the preliminary design for the gamma cap was based on 12-inches of native soil (consisting of on-site derived silt). As described in the Comparison of Conventional and Alternative Capping Systems for Use at the FMC Plant OU, June 2009 (Appendix D in the SFS Report), the preliminary design for the ET caps was based on 24-inches of native soil (on-site derived silt) over a 12-inch layer of capillary break material (consisting of slag). Both of these cap designs were incorporated in soil remedial alternative 3 in the SFS Report. SFS soil remedial alternative 3 was presented in EPA's Proposed Plan for an Interim Amendment to the Record of Decision for the EMF Superfund Site FMC Operable Unit, September 2011, and its capping elements were included in EPA's preferred soil remedial action alternative presented in that document. The soil remedial action selected in the IRODA included these capping elements. As stated in the IRODA at Section 1.2, entitled "Detailed Description of the Selected Interim Amended Remedy:"

> "No significant changes to the remedy, as originally identified in the Proposed Plan, were deemed necessary or appropriate."

Thus, as a starting point for the RD/RA, the preliminary RD for the gamma cap was 12-inches of native soil and for the ET cap was 24-inches of native soil over a 12-inch layer of capillary break material (slag) consistent with the preliminary designs presented in the SFS Report.

As presented in the Pre-Final RD Report submitted in January 2015, the design of the gamma cap has remained a 12-inch native soil layer subject to confirmation of the design basis. A Gamma Cap Addendum field study completed during April 2015 was directed at developing this confirmation. As recently communicated to EPA in the Gamma Cap Addendum Test Cap - Data Report, May 6, 2015:

> …the average pre-excavation (baseline) exposure rate (HPIC) at the test pad was 13.3 μR /hr and the average exposure rate on the 12-inch depth of the test gamma cap was 14.8 μR /hr which is a difference of 1.5 μR /hr (unadjusted for the daily reference HPIC measurement). The 1.5 μR /hr exposure rate difference is well below the RAO exposure rate of 2.8 μR/hr increment above background which, consistent with prior modeling, indicates that a 12-inch gamma cap will meet the RAO.

The current pre-final design of the ET cap is presented in Appendix B-2, Draft ET Cover Modeling Report, contained in the Pre-Final RD Report. Sections 2.1 and 3 of that report are reprinted below:

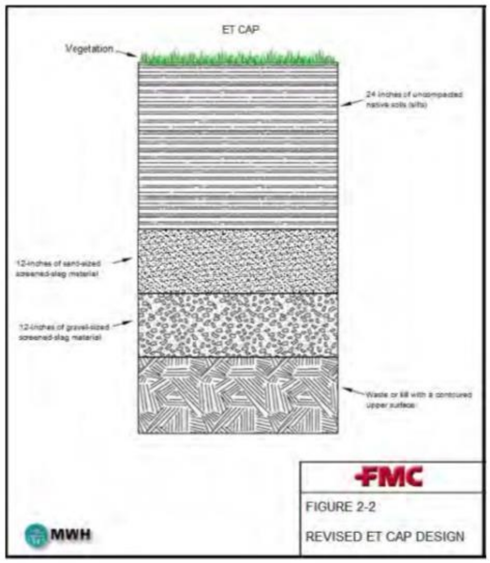
2.1. ET Cover Design

The proposed cover system consists of the following layers:

• 60.96-cm of silty soil,
• 30.48-cm of sand-sized screened-slag, and
• 30.48-cm of gravel-sized screened-slag

The proposed cover system is presented in **Figure 2-1**. Outputs from the Hydrus 1-D model for this ET Cover included annual: surface infiltration, surface evaporation, root water uptake, changes in soil water storage, flux from the bottom of the soil profile, and peak snowpack. In addition to modeling the flux from the bottom of the 60.96-cm soil system, variable soil thickness depths of 71.12-, 76.20-, 78.74-, and 91.44-cm were investigated to determine changes to the bottom flux rate to evaluate the sensitivity to different cover thicknesses (28-, 30-, 31-, and 36-in, respectively). For these alternative cover thickness comparisons, the sand-sized screened slag and gravel-sized screened-slag sub-layers were included to provide consistent results.

Figure 2-1: Proposed ET Cover Design



3. CONCLUSION

The recommended design meets all of the RAOs stipulated in the IRODA and list in Section 1.0, specifically with respect to reducing the release of COCs to groundwater by significantly reducing the amount of water percolating through the waste. The proposed ET cover results in significantly lower percolation rates when compared to the performance standards of a compacted clay liner of 1x10-7 cm/sec. Although uncertainties exist surrounding the spatial performance of the cover design, modeled results indicate that even in conservative conditions, the cover reduces percolation to less than 0.1 cm/cm of average annual precipitation, even in wet years.

It should be noted that these results are only for the ET cover itself and do not take into account the reduction in infiltration as a result of the topsoil layer (not pictured in Figure 2-1). Based on soil loss calculations (presented in Appendix C of the Remedial Design Report), an additional 6-inches of soil will be placed over the cover as an erosion control layer to account for soil losses associated with wind and water erosion based on a 500-year performance period.

Continuation of FMC Response to Question 6b:

In summary, the gamma cap and ET cap designs are consistent with, or in the case of the ET cap more robust than, the cap designs identified in the SFS Report, and proposed by and selected by EPA, as documented in the IRODA.

7. Historical Surface Impoundment Area (RUs 13 and 22b)

7a. The 2010 Supplemental Feasibility Study describes plant landfills in RU-18 and RU-19b as receiving filter media, kiln scrubber solids, furnace dig-out material, carbon from PH3 gas extraction system. With respect to the noted RUs, the Supplemental Feasibility Study mentions that in the 1980s a process to recover P_4 from historical impoundment pond 8S was "developed, built, and tested" and then closed and removed in 1993.

Can FMC describe the P4 recovery process that was developed, built and tested? During FMC's efforts to recover P4 from pond 8S and based upon any other experience with the historical ponds, could FMC determine whether or not the material in the historical ponds was homogeneous or stratified (with respect to P4 concentration)?

FMC Response to Question 7a:

The following section from FMC's "Information Responding to EPA and Tribal Comments on Pond 8S Closure Plan" (August 5, 1997) regarding the Pond 8S Recovery Process provides information responsive to this question:

FMC developed a process for recovering elemental phosphorus from the pond solids stored in Pond 8S. This process system, which started initial operation in fall 1982, involved a number of individual processes (screens, hydroclones, centrifuges, heaters, chillers, tanks, etc.) in a complex series. During the early stages of the operation of this process system, a number of factors emerged which made the continued operation of this system impractical. Major factors that led to closing the process were:

> The process was operation and maintenance intensive. Often 2 to 4 hours were required for start up of the system prior to processing pond sediments (time to position the dredge, pump solids to the system, process warm up, etc.). In addition, solids had to be flushed out and the system drained each time the system was shut down to avoid plugging lines and process units. During 1989, the system had an onstream efficiency under 40-percent (e.g., for every 10 hours of system operation, less than 4 hours were spent processing pond solids for P4 recovery).
>
> Slurried sediments were highly variable with respect to phosphorus content, making control of the process difficult. Extensive training of operations personnel was required before the operators could run the system effectively. Although each unit in the process system may have operated at high efficiency, if one process step experienced an upset, the entire process had to be shut down. The overall reliability of the process system was poor. In

addition, the P4 recovery of the system was highly variable. The design maximum P4 recovery efficiency was 85-percent; however, during 1990 the P4 recovery efficiency varied between 25 and 90-percent. Regardless of the recovery efficiency, the process solids returned to the pond (Pond 8S) still contained P4 concentrations above 1,000 milligrams per kilograms (the approximate level at which P4 in the solids will oxidize when exposed to air).

Management of water level and exposed pond bank sediments was difficult. In order to reach deeper sediment, the water level had to be lowered, exposing pond bank solids to air which resulted in oxidation of phosphorus in the solids until soil could be applied to cover the exposed solids. A long-reach excavator was used to cover bank solids, but bank slope conditions (wet, loose soil inside the pond embankment) made access with the excavator difficult and dangerous.

After a number of attempts to improve the efficiency of the 8S recovery operation, the process was finally abandoned, and the 8S recovery process was closed in 1993. Ex-situ treatment of pond solids would involve similar handling (dredging and pumping slurry), management of water level and bank sediment, and variability of elemental phosphorus content. Therefore, difficulties experienced with the 8S recovery process would also be expected with ex-situ treatment alternatives for P4-containing sediments.

7b. Does FMC have an estimate for the mass of P4 (if any) in the plant landfills in RU-18 and RU-19b?

FMC Response to Question 7b:

The available information regarding the types and estimated mass of wastes placed in landfill RUs 18 and 19b at the FMC OU is contained in Table 5-2 of the SRI Report. However, EPA did not request and FMC did not estimate the mass of P4 associated with the "P4-bearing wastes" disposed in RU-19b (the historic slag pile landfill).

7c. Is spent carbon from gas extraction system a possible source of PH3 emission?

FMC Response to Question 7c:

No.

Thanks in advance for your assistance.

Glossary

hydroclone

A device used to classify, separate or sort particles in a liquid suspension based on the density of liquids or solids in the liquid suspension or particle size of solids in the liquid suspension.

phos dock

The facility at the FMC Pocatello plant that was used to store product grade P4 produced from the furnaces and to transfer that product into P4 railcars (tanker cars) for shipment to the P4 product receiving plants. In later years, the phos dock also reprocessed off-spec P4 and P4 sludge for reintroduction into the furnaces to enhance overall P4 recovery from the process and P4 railcars.

phossy water

Water at the FMC Pocatello plant that came into contact with elemental phosphorus and typically contained small amounts of P4, ore, coke and silica dust, and P4 reaction products. Examples include water cover on P4 product storage tanks, water used to displace P4 during pumping / transfer to P4 railcars, and water used to slurry precipitator dust..

precipitator slurry

The P4 produced in the furnaces came off as a vapor in the gas stream exiting the furnaces. As a process step, electrostatic precipitators were used to remove blow-over dust from the furnaces prior to condensing the gas stream to below the melting point of phosphorus to collect the product-grade P4 in water covered sumps or tanks. The dust and some P4 collected in the electrostatic precipitators dropped to the bottom of the precipitators continuously and, due to the presence of P4, was collected in water filled slurry pots to prevent P4 oxidation. The content of the slurry pots (precipitator slurry) was periodically pumped through pipelines to water-covered waste ponds.

slag pit

The area on the south side of the Pocatello plant furnace building where molten slag from the furnaces flowed into slag-bermed pits (there were 8 cooling pits within the slag pit area), allowed to cool and solidify, and then dug out using front-end loaders and loaded into slag haul trucks.

sludge

P4 sludge was a semi-solid, non-product grade mixture of P4, dirt and water that would build up over time in the bottom of P4 railcars and P4 storage sumps / tanks. Air pollution control sludge from a wet scrubber air pollution control system consists of particulate and/or aerosols removed from the gas stream and water.

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APPENDIX F

SHOSONE-BANNOCK TRIBES' RESPONSES TO ARGONNE'S QUESTIONS AND COMMENTS ON FMC'S RESPONSES

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Shoshone-Bannock Tribes' Comments on FMC's May 18, 2015 Responses to ANL's Questions of April 21, 2015

June 17, 2015

The Shoshone-Bannock Tribes (SBT) has reviewed and is commenting on FMC's May 18, 2015 responses to the questions posed by independent contractor Argonne National Laboratory (ANL) on April 21, 2015. On May 20, 2015, SBT received from EPA a copy of FMC's responses, as edited by ANL. SBT briefly reviewed the responses and, based on its initial review, expressed to EPA its concern that many of the responses were inaccurate. EPA and SBT agreed that SBT would document its observations of inaccuracies and other issues in writing and provide them directly to Argonne via email, with a copy to EPA Headquarters' team. SBT has now reviewed FMC's responses more thoroughly and is providing the following comments on the responses.

SBT finds that in many instances the responses omit important facts, are misleading, and contain irrelevant information. FMC insinuates that certain treatment alternatives are not feasible due to health and safety issues surrounding P4 when those health and safety issues do not in fact exist or can be managed, as is currently occurring as FMC re-grades the entire FMC site.

SBT's comments highlight FMC's responses, which ANL should not consider when conducting its independent study, due to FMC's omission and outright misstatement of relevant facts. SBT requests EPA to instruct ANL to omit these statements from the review and use only relevant information that is supported by facts, so as to avoid any attempts to unfairly influence ANL's independent, in-depth study of treatment alternatives for the Pocatello site.

IN-DEPTH COMMENTS ON SPECIFIC QUESTIONS / RESPONSES

1. Railcars:

   Page 2, Section 2.2.1. 2nd paragraph – "This could make exhuming the railcars in one piece impracticable. ...to railcars in place." These 4 sentences are speculation. There are many examples in the literature where railcars have been moved, or emptied and treated in place. ANL asked FMC about the condition of the railcars and of the materials inside them, and not FMC's opinion about exhuming or treating the material. These sentences should not be included in ANL's evaluation.

   Section 2.2.2 Contents of the Railcars

   During a recent court trial, FMC acknowledged and provided documentation from maintenance personnel present during the furnace upset that led to the railroad cars being filled with material and taken to the slag pile. There was no indication of water or nitrogen being added to the railroad cars.

Section 2.2.3 Whether the Railcars Have Already Leaked

FMC's response assumes the P4 has not leaked due to subsurface soil temperatures since burial and that, if P4 has leaked into soils at ambient temperatures, it would be assumed to have migrated no more than a foot from the point of the release and may have oxidized. Leakage of P4 from these tanks is a likely scenario. Whether leakage has occurred further down than 1 foot is important for volumes within the railcars but for treatment scenarios it seems reasonable to assume P4 material is throughout the slag pile. FMCs assumptions and EPA decisions based upon the Supplemental Feasibility Study (SFS) have proven inaccurate. P4 has been found throughout the entire slag pile that has been excavated to date.

FMC is excavating the slag pile as part of the remedial design. FMC has excavated slag from the pile bringing the elevation down approximately 25 feet. FMC is excavating and moving the slag throughout the entire FMC facility to re-grade and contour the site. Daily, FMC contract workers dig into P4 material contained within the slag pile. FMC calls these events Undocumented Subsurface Conditions (USCs). This material is either allowed to burn until no P2O5 smoke is visible or sand is brought in to cover the material until stabilization occurs. The material is then taken to a staging area where it still remains.

The USCs as documented do not fully disclose the nature and extent of the number of events. Multiple burning incidents may make up one reported USC, depending on where the material is placed. SBT is providing this information to ANL in an effort to disclose FMC's daily work with this material, their experience excavating material that contains P4, and their management practices.

FMC moved 1,314, 509 cubic yards in 2014 and as of May 5, 2015 had moved 756,073 cubic yards. If ANL is interested in knowing the locations where this material was moved, the information can be provided by EPA Region 10 personnel per Remedial Action Area.

Appendix A is a figure showing USC events and a table identifying P4 material volumes and disposition.

2. Piping

FMC's response to question 2 refers ANL to the Supplemental Remedial Investigation Report for the FMC Plant Operable Unit (May, 2009) and neglects to provide updated information based on the remedial work taking place at the site. FMC most recently contracted to have videos taken of the inside of piping. Those videos are available should ANL wish to review. FMC has learned many of the pipes are filled with cobble material and one section of piping contains P4 material.

Piping in the railroad swale area was discovered to be eroded. FMC has used hydro blasting to clean sections of piping in an effort wash out any P4 material that may be present and has requested and been granted permission by EPA Region 10 to grout and backfill sections of piping running between Remedial Units. This updated information is available from FMC should ANL find it useful. The Tribes are attaching the most recent map and information provided to them, labeled as Appendix B.

It should be noted the information FMC referred ANL to in the Supplemental Remedial Investigation (SRI) from 2009 is not only outdated concerning the piping but also contains information irrelevant to the treatment technology assessment, i.e., risk assessment assumptions and P4 volumes in the underground piping

FMC provided information from the SRI in 2009 but omitted information on pipes surrounding the RCRA ponds, concentration of phosphine gas within this piping, thermal destruction of piping due to conditions within the ponds, and documented plugging of temperature and monitoring piping (TMPs) at the RCRA ponds. This information may directly respond to ANL question, "… What physical state would you expect the buried piping to be in?" and may impact CERCLA treatability work. It has clearly been demonstrated that underground piping contained reactive components that caused engineering issues.

3. Land Disposal Restriction Treatment Plant-Related Questions

FMC largely answers ANL questions surrounding the LDR by referring to the SFS report of January 2009, including Section 3.3.4 - Limitations section. SBT disagrees with the limitations FMC asserts regarding the caustic hydrolysis treatment process. The limitation of 15 feet due to construction excavation equipment is inaccurate. FMC has been excavating much deeper in the slag pile during the current Remedial Design/Remedial Actions in 2015. There are many examples on the Portland Cement Association site of excavation and auguring treatments and stabilization greater than 15 feet. Additionally while treatment for the radionuclides and metals may be a secondary and tertiary requirement, caustic hydrolysis can treat the ignitability and reactivity component of P4.

The LDR plant was intended to treat multiple waste streams. See ASTARIS RCRA Part B Permit Application for the LDR plant, submitted March 31, 2001, detailing the waste streams.

Section 3.3.6 History of Use

FMC concludes, "A major process engineering review and design effort would be required…" The Tribes agree any treatment would require a process engineering review and design efforts to accommodate the specific situations. Caustic hydrolysis can be effective but may require additional treatments. Work plan efforts during planning and implementation of the LDR plant were fully expected to treat the waste streams for compliance with LDR requirements.

5. Dredging

Very little of the information in this section pertains to the questions that ANL asks. Almost the entire section on pages 12 and 13 pertains to a treatment alternative entitled ex-situ lime treatment, not the dredging process, and SBT does not understand why it is included. For example, the first paragraph on page 13 relates to health and safety concerns regarding exposure to PH3 and P2O5, followed by a discussion of excavation rather than dredging. The second paragraph refers mainly to air emissions. In paragraphs 3 and 6 FMC states that the lowest 1.5 to 2 feet of solids cannot be dredged but does not provide any support for this statement. The EPA Office of Research and Development has provided dredging project advice over the years yet none of the information from that office was used to respond to this question. For example, modified excavators with adequate reach could be used across the width of these ponds to lower the waste levels to where water could be added to support dredging equipment. The water would also act to cover the waste to prevent oxidation reactions, a process FMC has used in the past and even discussed earlier in its responses when it presented information on the railcars. FMC also had a substantial aboveground nitrogen tank volume required for safe waste processing during the Pond 16S UAO. Much of this relevant information has not been provided to ANL.

FMC practiced dredging on a regular basis during plant operation. FMC retrofitted plant operations to accommodate changing conditions: one example was the center dike FMC used during closure of ponds to accommodate heavy construction, placement of materials, and changing conditions.

6. Cover/Cap Questions (including questions on monitoring)

Emplacement of a cap is not true remediation, but is instead a risk management and health risk and exposure reduction process, since no waste is actually removed or treated and the cap only minimizes migration of the COCs vertically. However, SBT has already offered extensive comments on EPA's remediation plan and will not repeat its issues in this document because they are available elsewhere for ANL to review, including in SBT's comments on the 2012 Proposed Plan and IRODA.

The available monitoring devices are not supported for ambient monitoring by the manufacturer, Draeger, but instead were developed for occupational monitoring (http://www.dragersafetyusa.com/c-1-gas-monitors.aspx). Neither FMC nor EPA has ever validated their use for ambient monitoring. Moreover, the procedure for modifying the monitors for use at the RCRA ponds was not referenced in FMC's response. (FMC has strapped Draegar monitors on a bar to be swept in a sideward motion 12 inches above RCRA caps to measure PH3 gas concentrations). Since proper monitoring begins with the device, its use and calibration, there are immediate inherent limitations on any monitoring program that FMC develops, which should be stated upfront.

Soil gas monitoring has been minimal to date and there are no studies or data showing vertical and lateral migration patterns or soil movement velocity.

Pond 16s UAO documentation details the history of monitoring at that pond and shows that physical integrity was lacking. Grass growth on this cap was very limited, and burrowing animal holes were present when several inspections took place. An improper road was designed and built without discussing or informing the Tribes or EPA of its existence. These are examples of the past and present failure to monitor existing caps. Currently questions remain regarding the appropriate thickness and the Gamma Cap Work plan has yet to be approved by EPA.

6b. CAMU Issue

CAMU is but one regulatory program that may be part of the final remedy. P4 material, by-products of the treatment process and other material with Contaminants of Concern could be managed in a CAMU if CERCLA waste streams were treated. While it may be currently inconsistent with the CERCLA Remedial Design and Remedial Action (RD/RA) at the site, amendments to the existing IRODA may be made based on new information. The Tribes believe new information surrounding the widespread P4 found in the slag pile and the placement of this material throughout the site are but one justification for an amended plan.

7a. Historical Surface Impoundment Area (RUs 13 and 22b)

The P4 recovery system described by FMC is but one example that may be useful for future treatment. FMC now has an additional 20 to 25 years experience of working with these conditions.

Conclusion

The SBT has presented the preceding information to EPA and ANL to clarify and to supplement some of the responses submitted by FMC in response to ANL questions. The Tribes appreciate the work ANL is doing and wants to see a thorough independent study on treatment issues completed at this site. Should ANL have any need for further clarification on any of the above issues, please contact the EPA project officer and the Shoshone-Bannock Tribes will provide information quickly.

The Tribes are attaching the following:

A map depicting USCs to date (areas where P4 has ignited generating P2O5 during remediation work), a table with specific information surrounding the USCs, a map and supporting information of piping at the FMC OU, sampling results from water used to hydro blast through the pipes and pictures of USCs and excavation at the site.

FMC Pocatello Undocumented Subsurface Conditions

Date/Time (MST) Event Discovered	Event ID	Date/Time (MST) Event area released	Event Quantity in CY **(not including sand)**	Event Details
10/01/14 (09:30)	USC-1	10/03/14 (08:30)	1.000	09:30 (MST) USC-1, occurred at NW Corner of RA-F in vicinity of Crusher Pad. KW responded and chased area until limits of USC where identified, KW collected approximately 1 CY (not including cover sand) of material and staged it in the vicinity of USC covered it with sand and monitored. USC has been relocated to Coke Settling Basin-2.
10/03/14 (12:00)	USC-2	10/09/14 (17:30)	0.750	12:00 (MST) USC-2 occurred at NE corner of RA-F (adjacent to access road that runs between RA-F and Calciner Ponds). KW responded and chased limits and collected approximately 0.75 CY of material and is stabilized in area of USC. USC has been relocated to Coke Settling Basin-2.
10/6/14 (11:10)	USC-3	10/09/14 (17:30)	0.007	11:10 (MST) USC-3 occurred, material was loaded in off road end dump at RA-F and truck deposited load into RA-C where it was to be graded in as fill. It was when it was deposited into RA-C that USC was made. KW was notified and coned off area.. USC has been relocated to Coke Settling Basin-2.
10/6/14 (11:52)	USC-4	10/09/14 (17:30)	0.500	11:52 (MST) USC-4 occurred at SW Corner of RA-F (on top of slag pile). KW was notified and responded to the scene. This event did not burn out on its own, KW put it out with sand at 12:15 MST. Area of event is coned off. USC has been relocated to Coke Settling Basin-2.
10/7/14 (10:46)	USC-5	10/09/14 (17:30)	0.000	10:46 (MST) USC-5 occurred, material was loaded in off road end dump at RA-F and truck deposited load into RA-C just east of where USC-3 was deposited on 10/6/14. . It was when it was deposited into RA-C that USC was made. I was in area when this occurred, USC burned itself out in 1 minute.KW was notified and has arrived on the scene. USC has been relocated to Coke Settling Basin-2.
10/7/14 (12:04)	USC-6	10/09/14 (17:30)	0.500	At 12:04 (MST) USC-6 occurred, material was loaded in off road end dump at RA-F and truck deposited load into RA-C, SE of where USC-5 was deposited today. It was when it was deposited into RA-C that USC was made. USC has been relocated to Coke Settling Basin-2.
10/7/14 (15:10)	USC-7	10/09/14 (17:30)	0.250	15:10 (MST) USC-7 occurred at SW Corner of RA-F (on top of slag pile, 40' south of USC-4). KW has responded to the scene and placed sand on USC to put out. USC has been relocated to Coke Settling Basin-2.
10/8/2014 (14:23)	USC-8	10/09/14 (17:30)	0.250	14:23 (MST) USC-8 occurred, material was loaded in off road end dump at RA-F and truck deposited load into RA-C just west of where USC-3 was deposited on 10/6/14. It was when it was deposited into RA-C that USC was made. The USC (a 2' x 2' carbon hearth block) stopped smoking by the time KW arrived on the scene. KW consolidated USC-8 with USC-5 and released area back to CB&I. USC has been relocated to Coke Settling Basin-2.
10/8/14 (18:25)	USC-9	10/09/14 (17:30)	0.007	18:25 (MST) USC-9 occurred. USC-9 is located in RA-F (East side top of pile SW of where USC-2 occurred). USC-9 Stopped smoking by the time KW arrived on the scene USC has been relocated to Coke Settling Basin-2.
10/9/14 (10:04)	USC-10	10/09/14 (17:30)	0.250	10:04 (MST) USC-10 occurred. USC-10 is located in RA-F (West side top of slope). KW responded to the scene and relocated material to Coke Settling Basin-2.
10/9/14 (10:27)	USC-11	10/09/14 (17:30)	2.000	10:27 (MST) USC-11 occurred. USC-11 is located in the valley of RA-F. KW responded to the scene and relocated material to Coke Settling Basin-2.
10/9/14 (11:01)	USC-12	10/09/14 (17:30)	0.250	11:01 (MST) USC-12 occurred. USC-12 is located in the valley of RA-F (at entrance on South end). KW responded to the scene and relocated material to Coke Settling Basin-2.
10/9/14 (11:55)	USC-13	10/18/14 (16:10)	0.250	11:55 (MST) USC-13 occurred. USC-13 is located in RA-F (Top of slag pile, West Side in an area that requires 23' cut to meet grade) . USC-13 is what KW is referring to as a "Tiger Pit Material" and is the source of USC-11 and USC-12. KW will delineate area. CB&I has relocated load out operations 50' south of USC-13.
10/10/14 (10:45)	USC-14	10/11/14 (12:00)	1.000	10:45 (MST) USC-14 occurred. USC-14 is located RA-G-South-1-Spent Carbon Rod Pile. KW responded to the scene and relocated material to Coke Settling Basin-2.
10/14/14 (15:25)	USC-15	10/14/14 (16:20)	0.007	15:25 (MST) USC-15 occurred. USC-15 is located RA-H-East. KW delineated the scene and identified (1) "briquette" of material and released area back to CB&I control @ 16:20 on 10/14.14.
10/17/14 (16:04)	USC-16	10/17/14 (17:00)	0.007	At 16:04 (MST), USC-16 occurred. USC-16 is located RA-F West (East slope of valley on North end). KW has been notified and is responding to the scene.
10/20/14 (14:50)	USC-17	10/21/14 (10:00)	0.007	14:50 (MST), USC-17 occurred. USC-17 is located RA-F West (East slope of valley on North end) and consists of (3) smokers in a 20' area approximately 30' up from toe of slope. KW is currently responding to the scene.
10/20/14 (16:30)	USC-18	10/21/14 (15:00)	1.000	KW has identified and area on top slope RA-F West (east side slope north end), which could be possibly be the source for USC-17 and USC-16. KW is delineating area and for tracking purposes this area will be identified as USC-18 (instead of continuation of the other events).
10/22/14 (11:00)	USC-19	10/22/14 (11:31)	0.007	11:00 (MST),USC-19 occurred (event was quick and out in seconds). USC-19 is located RA-F West-top of slag pile (event was quick and out in seconds). KW responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-19, Cliff was onsite giving a tour with Tribal Environmental and Air Quality Reps at the time.
10/22/14 (11:50)	USC-20	10/22/14 (14:30)	0.007	11:50 (MST), USC-20 occurred (this event was quick one also). USC-20 is located RA-F West-top of slag pile, approximately 10' North of USC-19 (event was quick and out in seconds). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-20, Cliff Merrill and Tribal Environmental and Air Quality Reps were still onsite when this event occurred.
10/23/14 (11:05)	USC-21	10/23/14 (14:15)	0.500	11:05 (MST), USC-21 occurred. USC-21 is located RA-G South 1. KW is responding to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-21 by phone.
10/24/14 (13:25)	USC-22	10/24/14 (17:30)	0.750	13:25 (MST), USC-22 occurred in RA-C , material being placed in RA-C is coming out of RA-F. KW is responding to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-22 by phone.
10/24/14 (14:00)	USC-23	10/25/14 (10:20)	0.300	14:00 (MST),USC-23 occurred in RA-F West (Top of Slag Pile). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-23 by phone.
10/24/14 (15:15)	USC-24	10/24/14 (16:15)	1.000	15:15 (MST), USC-24 occurred in RA-F West (Top of Slag Pile). KW responded to the scene and delineated the area. Cliff Merrill (onsite EPA Rep) was notified of USC-24 by phone.
10/25/14 (16:10)	USC-25	10/25/14 (16:10)	0.250	14:45 (MST), on 10/25/14, USC-25 occurred in RA-F West (Top of Slag Pile). KW has responded to the scene and delineated the area. Cliff Merrill (onsite EPA Rep) was notified of USC-25 by phone.
10/27/14 (09:10)	USC-26	10/27/14 (09:40)	0.250	09:10 (MST), USC-26 occurred in RA-F (North end of the valley). KW has responded to the scene and delineated the area. Cliff Merrill (onsite EPA Rep) was onsite when this occurred and was notified of USC-26.
10/27/14 (13:42)	USC-27	10/27/14 (16:15)	0.037	13:42 (MST), USC-27 occurred (2) smokers in RA-F, (North end of valley). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-27 by phone.
10/27/14 (14:45)	USC-28	10/28/14 (12:15)	1.500	14:45 (MST), USC-28 occurred in RA-F West, (Top of slag pile). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-28 by phone.
10/27/14 (15:20)	USC-29	10/28/14 (13:30)	0.037	15:20 (MST), USC-29 occurred in RA-F West, (Top of slag pile-North end). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-29 by phone.

10/27/14 (15:49)	USC-30	10/27/14 (17:35)	0.037	15:49 (MST), USC-30 occurred in RA-F West, (Top of slag pile-North end) approximately 20' North of USC-29. KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-30 by phone.
10/27/14 (16:50)	USC-31	10/27/14 (17:50)	0.055	16:50 (MST), USC-31 occurred in RA-F West, (North end of the valley). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-31 by phone.
10/27/14 (16:51)	USC-32	10/27/14 (18:00)	0.037	16:51 (MST), USC-32 occurred in RA-F West, (South end of the valley). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-32 by phone.
10/28/14 (14:10)	USC-33	10/28/14 (18:10)	0.019	14:10 (MST),USC-33 occurred in RA-F West, (top of slag pile). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-33 by phone.
10/28/14 (17:00)	USC-34	10/28/14 (17:25)	0.007	17:00 (MST), USC-34 occurred in RA-C. KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-34 by phone.
10/28/14 (17:50)	USC-35	10/28/14 (18:10)	0.007	17:50 (MST), USC-35 occurred in RA-C. KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-35 by phone.
10/30/14 (13:40)	USC-36	10/30/14 (15:00)	0.037	13:40 (MST),USC-36 occurred in RA-G South 1. KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-36 by phone.
10/30/14 (14:10)	USC-37	10/30/14 (15:20)	0.007	14:10 (MST), USC-37 occurred in RA-G South 1 (approximately 75' SE of USC-36). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-37.
10/30/14 (15:25)	USC-38	10/30/14 (16:00)	0.007	15:25 (MST), USC-38 occurred in RA-F West (top of slag pile). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-38
10/31/14 (08:25)	USC-39	11/01/14 (11:57)	4.000	08:25 (MST) USC-39 occurred in RA-F West (top of slag pile). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-39. KW will continue with delineation on 11/1/14. KW removed approximately 11.9 CY (including stabilization sand)of material from this area.
10/31/14 (09:28)	USC-40	10/31/14 (14:50)	0.004	09:28 (MST),USC-40 occurred in RA-F West (top of slag pile). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-40.
10/31/14 (13:50)	USC-41	11/01/14 (08:45)	0.500	13:50 (MST), USC-41 occurred in RA-G South 1. KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-41. KW will continue with delineation on 11/1/14.
11/01/14 (12:44)	USC-42	11/01/14 (17:57)	0.500	12:44 (MST),USC-42 occurred in RA-F (top of slag pile, consisting of 3 smokers). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-42.
11/01/14 (15:15)	USC-43	11/01/14 (15:40)	0.007	15:15 (MST),USC-43 occurred in RA-F-Valley. KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-43.
11/03/14 (08:12)	USC-44	11/03/14 (08:45)	0.004	08:12 (MST), on 11/03/14, USC-44 occurred in RA-F-Valley (South end). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-44.
11/03/14 (14:20)	USC-45	11/03/14 (14:45)	0.037	14:20 (MST), USC-45 occurred in RA-F-Valley (mid valley). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-45.
11/03/14 (15:45)	USC-46	11/04/14 (08:30)	0.007	15:45 (MST), USC-46 occurred in RA-F-Valley (North end). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-46. KW did not find any USC material after delineating area.
11/04/14 (13:45)	USC-47	11/04/14 (14:15)	0.000	13:45 (MST), USC-47 occurred in RA-F-Valley (mid-valley). KW has been notified and is responding to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-47. **KW unable to find source of USC event after delineating area.**
11/04/14 (13:45)	USC-48	11/04/14 (14:15)	0.007	13:46 (MST), USC-48 occurred in RA-F-West (top of pile). KW has been notified and is responding to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-48.
11/04/14 (16:25)	USC-49	11/04/14 (16:45)	0.007	16:25 (MST), USC-49 occurred in RA-F-Valley (North End). KW has been notified and is responding to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-49.
11/05/14 (10:50)	USC-50	11/05/14 (13:30)	0.055	10:50 (MST), USC-50 occurred in RA-B, material being placed in RA-B is coming from RA-F West (top of pile). KW has responded to RA-B and investigated source area in RA-F. KW released areas at 13:25.Cliff Merrill (onsite EPA Rep) was notified of USC 50.
11/05/14 (15:50)	USC-51	11/05/14 (16:05)	0.000	15:50 (MST), USC-51 occurred in RA-F West (top of pile). KW is responding to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC 51. **KW unable to find source of USC event after delineating area.**
11/05/14 (16:35)	USC-52	11/06/14 (09:05)	1.000	16:35 (MST), USC-52 occurred in RA-F West (top of pile). KW has responded to the scene and stabilized the area, KW will delineate on 11/6/14. Cliff Merrill (onsite EPA Rep) was notified of USC 52.
11/06/14 (10:40)	USC-53	11/06/14 (16:45)	12.000	10:40 (MST), USC-53 occurred in RA-F Valley. KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC 53.
11/06/14 (10:42)	USC-54	11/21/14 (17:00)	84.000	10:42 (MST), USC-54 occurred in RA-F West (top of pile). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC 54. KW worked on delineating area through out the day on 11/7/14 and did not complete, KW will resume delineation on 11/8/14. Delineation of USC-54 was not completed on 11/8/14, to date approximately 30-35 CY of material was removed from event area, KW will resume with delineation on 11/10/14.
11/06/14 (11:40)	USC-55	11/06/14 (13:10)	0.037	11:40 (MST), USC-55 occurred in RA-C (material came out of an End Dump which was loaded in RA-F). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC 55.
11/07/14 (10:50)	USC-56	11/07/14 (11:30)	0.007	10:50 (MST),USC-56 occurred in RA-F West -South side on access ramp. The event when called in was reported as (1) smoker, when KW arrived on scene smoker was out. Cliff Merrill (onsite EPA Rep) was notified of USC 56.
11/08/14 (13:09)	USC-57	11/08/14 (13:40)	0.007	13:09 (MST), on 11/8/14, USC-57 occurred in RA-F Valley-North end. KW responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC 57. Tim Whiteus informed the CM that he collected (2) nuggets slightly larger than a softball each from this event.
11/10/14 (08:48)	USC-58	12/10/14 (12:00)	105.000	08:48 (MST), USC-58 occurred in RA-F East (top of slag pile). KW responded to the scene and stabilized the area. Cliff Merrill (onsite EPA Rep) was notified of USC 58. Tim Whiteus stated that on initial assessment of area USC-58 is a larger area than USC-54 which is still being delineated. **Delineation of this event was completed on 12/10/14.**
11/11/14 (10:29)	USC-59	11/11/14 (11:30)	0.007	10:29 (MST), USC-59 occurred in RA-F Valley (North end). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC 59.
11/11/14 (14:59)	USC-60	11/11/14 (16:15)	0.000	14:59 (MST), USC-60 occurred in RA-F Valley (North end, material came from top of RA-F East). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-60. **KW unable to find source of USC event after delineating area.**
11/13/14 (16:00)	USC-61	11/14/14 (08:30)	0.037	16:00 (MST), USC-61 occurred in RA-F West (top of slag pile) KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-61.
11/18/14 (16:00)	USC-62	11/19/14 (11:40)	0.500	16:00 (MST), USC-62 occurred in RA-F West (top of slag pile, North end) KW has responded to the scene and stabilized the area. Cliff Merrill (onsite EPA Rep) was notified of USC-62. KW will delineate USC-62 on 11/19/14.
11/18/14 (16:34)	USC-63	11/20/14 (16:00)	10.000	16:34 (MST), USC-63 occurred in RA-F West, top of slag pile, North end approximately 50 yards SW of USC-62. KW has responded to the scene and stabilized the area. Cliff Merrill (onsite EPA Rep) was notified of USC-63. KW will delineate USC-63 on 11/19/14.
11/19/14 (08:19)	USC-64	11/19/14 (11:40)	0.500	08:19 (MST), USC-64 occurred in RA-F West, top of slag pile, North end. KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-64.

11/19/14 (15:02)	USC-65	11/19/14 (15:25)	0.007	15:02 (MST), USC-65 occurred in RA-F West, top of slag pile, North end. KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-65.
11/19/14 (16:05)	USC-66	11/19/14 (16:40)	0.007	16:05 (MST),USC-66 occurred in RA-F West, top of slag pile, North end. KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-66.
11/20/14 (07:45)	USC-67	11/20/14 (10:30)	0.037	07:45 (MST), USC-67 occurred in RA-F West, top of slag pile, just north of USC-63, North end. KW was notified and responded to the scene and stabilized. Cliff Merrill (onsite EPA Rep) was notified of USC-67.
11/21/14 (13:52)	USC-68	11/21/14 (14:20)	0.007	13:52(MST), USC-68 occurred in RA-F Valley (north end) KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-68.
11/22/14 (08:21)	USC-69	11/22/14 (08:50)	0.037	08:21 (MST), USC-69 occurred in RA-F Valley (north end) KW has responded to the scene and stabilized. Cliff Merrill (onsite EPA Rep) was notified of USC-69.
11/22/14 (11:50)	USC-70	11/22/14 (12:10)	0.037	11:50 (MST), USC-70 occurred in RA-F Valley (north end) KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-70.
11/22/14 (15:35)	USC-71	11/26/14 (08:30)	18.000	15:35 (MST), USC-71 occurred in RA-F West ,top of slag pile, in vicinity of where USC-54 was located. KW is responding to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-71. KW released USC-71 0n 11/26/14.
11/25/14 (16:20)	USC-72	11/25/14 (16:40)	0.019	16:20 (MST), USC-72 occurred in RA-F West ,top of slag pile NW corner. KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-72.
11/26/14 (10:29)	USC-73	11/26/14 (12:00)	0.037	10:29 (MST), USC-73 occurred in RA-F West ,top of slag pile. KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-73.
12/01/14 (10:29)	USC-74	12/01/14 (17:00)	0.111	14:30 (MST), USC-74 occurred in RA-F (west side of the valley approximately 10' from toe of slope), dozer was pushing material from the top of RA-F West . KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-74.
12/02/14 (08:00)	USC-75	12/02/14 (08:30)	0.007	08:00 (MST), USC-75 occurred in RA-F (west side of the valley approximately 100' south of north end and 20' from toe of slope), dozer was pushing material from the top of RA-F West . KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-75.
12/02/14 (13:20)	USC-76	12/02/14 (16:50)	0.007	13:20 (MST), USC-76 occurred in RA-F West (top of slag pile) . KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-76.
12/04/14 (14:54)	USC-77	12/04/14 (15:30)	0.007	14:54(MST), USC-77 occurred in RA-F West (top of slag pile) . KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-77.
12/09/14 (15:20)	USC-78	12/10/14 (08:30)	0.007	15:20 (MST), USC-78 Occurred in RA-F West. KW has responded and removed a 4"x4"x3" piece. KW will delineate and search for more material. Cliff Merrill (onsite EPA Rep) was notified of USC-78.
12/10/14 (10:19)	USC-79	12/15/14 (15:45)	170.000	10:19 (MST), on 12/10/14, USC-79 occurred in RA-F West (top of slag pile, top of west slope in vicinity of where USC-78 occurred). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-79.
12/12/14 (08:20)	USC-80	12/12/14 (08:35)	0.007	08:20 (MST),USC-80 occurred in RA-F East (top of slag pile, in the area where USC-58 occurred). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-80.
12/12/14 (08:55)	USC-81	12/12/14 (09:00)	0.007	08:55 (MST),USC-81 occurred in RA-F West Slope of Valley (material dozer pushed from top of RA-F). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-81.
12/12/14 (09:03)	USC-82	12/12/14 (09:20)	0.007	09:03 (MST), USC-82 occurred in RA-F Valley North end. KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-82.
12/12/14 (11:20)	USC-83	12/12/14 (11:30)	0.000	11:20 (MST), USC-83 occurred in RA-B (material being placed is from top of slag pile RA-F East). KW has responded to the scene Cliff Merrill (onsite EPA Rep) was notified of USC-83. **KW reported that they could not locate any material to recover from this event.**
12/12/14 (13:40)	USC-84	12/12/14 (14:15)	0.007	13:40 (MST), USC-84 occurred in RA-F East (top of slag pile in vicinity of USC-80). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-84.
12/13/14 (08:19)	USC-85	12/13/14 (10:30)	0.045	08:19 (MST), USC-85 occurred in RA-B (material that is being placed is coming from RA-F East top of slag pile). KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-85.
12/13/14 (11:34)	USC-86	12/13/14 (12:00)	0.007	11:34 (MST), USC-86 occurred in RA-F East, top of slag pile in NW corner where dozers are pushing. KW has responded to the scene. Cliff Merrill (onsite EPA Rep) was notified of USC-86.
12/19/14 (07:30)	USC-87	12/19/14 (16:00)	0.000	07:30 (MST), USC-87 -RA-C requires a cut to meet grade, within the cut is an abandoned Phossy Water Line. KW was on scene throughout the day to respond to and investigate any other pipe exposed during grading operations. Cliff Merrill (onsite EPA Rep) was notified of USC-87. CB&I exposed Phossy water line intact. The grading plan for this area of RA-C was modified (as submitted to EPA January 21, 2015) to eliminate cut and the exposed line will be re-covered with fill.
3/11/15 (12:00)	USC-88	3/13/15 (15:00)	0.007	12:00 (MST), USC-88 occurred in RA-F, (North end in the area where CB&I is expanding crusher pad). KW has responded to the scene and stabilized. No EPA rep available to notify on this event.
3/12/15 (14:58)	USC-89	3/13/15 (15:30)	100.000	14:58 (MST), USC-89 occurred in RA-F West , top of slag pile mid-way, top of west slope. KW has responded to the scene and stabilized.
3/16/15 (15:10)	USC-90	3/16/15 (15:30)	0.007	15:10 (MST), USC-90 occurred in RA-F-North end in haul road between RA-F East and RA-F West,(South of crusher pad area). KW has responded to the scene and stabilized. Cliff Merrill EPA rep was notified.
3/17/15 (09:43)	USC-91	3/20/15 (11:30)	65.100	09:43 (MST), USC-91 occurred in RA-F western slope. KW has responded to the scene and stabilized. Cliff Merrill EPA rep was notified.
3/17/15 (10:27)	USC-92	3/17/15 (10:50)	0.007	10:27 (MST), USC-92 occurred in RA-B/C fill area. KW has responded to the scene. Cliff Merrill EPA rep was notified.
3/17/15 (11:07)	USC-93	3/21/15 (17:45)	0.207	11:07 (MST), USC-93 occurred in RA-B/C fill area. KW has responded to the scene. Cliff Merrill EPA rep was notified.
3/18/15 (09:55)	USC-94	3/18/15 (10:40)	0.007	09:55 (MST), USC-94 occurred in RA G-North. KW has responded to the scene. Cliff Merrill EPA rep was notified.
3/20/15 (12:10)	USC-95	5/9/15 (17:00)	36.800	12:10 (MST), USC-95 occurred in RA C near power lattice tower in NW corner. KW was notified and responded to the scene and began delineation . Cliff Merrill EPA rep was notified. **Area was closed on 5/9/15.**
3/23/15 (14:56)	USC-96	3/28/15 (17:45)	5.090	14:56 (MST), USC-96 occurred in RA B. KW has been notified and is responding to the scene. Cliff Merrill EPA rep was notified.
3/23/15 (15:05)	USC-97	3/23/15 (17:00)	0.074	15:05 (MST),USC-97 occurred in RA C (approx 100 yards east of USC-95) . KW has responded to the scene. Cliff Merrill EPA rep was notified.
3/23/15 (15:36)	USC-98	3/28/15 (17:45)	3.620	15:36 (MST), USC-98 occurred in RA C (east side) . KW has responded to the scene. Cliff Merrill EPA rep was notified.
3/30/15 (09:15)	USC-99	3/30/15 (09:40)	0.001	09:15 (MST), USC-99 occurred in RA G North . KW has been notified and is responding to the scene. Cliff Merrill EPA rep was notified.
3/30/15 (10:15)	USC-100	3/30/15 (10:40)	0.001	10:18 (MST), USC-100 occurred in RA-F (Crusher Pad Area) . KW was notified and has responded to the scene. Cliff Merrill EPA rep was notified.
3/31/15 (16:56)	USC-101	3/31/15 (17:30)	0.003	16:56 (MST), USC-101 occurred in RA-North (South Side) . KW was notified and has responded to the scene. Cliff Merrill EPA rep was notified.

4/1/15 (11:45)	USC-102	4/1/15 (16:15)	2.500	11:45 (MST), 04/01/15, USC-102 occurred in RA-F West-top of west slope . KW was notified and has responded to the scene. Cliff Merrill EPA rep was notified.
4/6/15 (09:40)	USC-103	4/6/15 (09:55)	0.003	09:40 (MST), USC-103 occurred in RA-G North. KW has been notified and is responding to the scene. Cliff Merrill EPA rep was notified.
4/6/15 (12:04)	USC-104	4/6/15 (14:40)	1.500	12:04 (MST),USC-104 occurred in RA-F East (North end; toe of East slope). KW has been notified and is responding to the scene. Cliff Merrill EPA rep was notified.
4/6/15 (13:34)	USC-105	4/6/15 (14:45)	0.003	13:34 (MST), USC-105 occurred in RA-B. KW was notified and responded to the scene. Cliff Merrill EPA rep was notified.
4/6/15 (14:30)	USC-106	4/6/15 (15:15)	0.003	14:30 (MST), USC-106 occurred in RA-B (East end). KW was notified and responded to the scene. Cliff Merrill EPA rep was notified.
4/7/15 (08:55)	USC-107	4/7/15 (16:40)	0.003	08:55 USC-107 occurred in RA-B (west end). KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
4/8/15 (08:10)	USC-108	4/8/15 (10:30)	1.750	08:10 (MST), USC-108 occurred in RA-B (center of pad). KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
4/8/15 (11:48)	USC-109	4/8/15 (17:30)	14.000	11:48 (MST), USC-109 occurred in RA-F East (toe of east slope). KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
4/8/15 (12:15)	USC-110	4/8/15 (13:15)	0.007	12:15 (MST), USC-110 occurred in RA-G North (east end). KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
4/9/15 (07:50)	USC-111	4/9/15 (17:30)	0.007	07:50 (MST), USC-111 occurred in RA-B. KW was notified and responded to the scene. Cliff Merrill EPA rep was notified.
4/9/15 (10:15)	USC-112	4/9/15 (14:00)	7.500	10:15 (MST), USC-112 occurred in RA-F East (toe of east slope). KW was notified and responded to the scene. Cliff Merrill EPA rep was notified.
4/10/15 (07:45)	USC-113	4/10/15 (09:30)	0.000	07:55 (MST), USC-113 was opened in RA-F East (toe of east slope) to explore area. KW delineated area and found no material. Darlene McCray EPA rep was notified.
4/10/15 (13:50)	USC-114	4/10/15 (14:55)	0.037	13:50 (MST), USC-114 occurred in RA-F West (top of pile north end, near haul road). KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
4/11/15 (12:16)	USC-115	4/11/15 (17:30)	0.007	12:16 (MST), USC-115 occurred in RA-B. KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
4/11/15 (14:00)	USC-116	4/11/15 (17:30)	0.007	14:00 (MST), USC-116 occurred in RA-E North. KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
4/11/15 (16:45)	USC-117	4/11/15 (17:30)	0.037	16:45 (MST), USC-117 occurred in RA-F (south end of the valley). KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
4/13/15 (15:10)	USC-118	4/13/15 (16:15)	0.000	15:10 (MST), USC-118 occurred in RA-F East (top of slag pile). KW was notified and responded to the scene. Cliff Merrill EPA rep was notified. **KW reported that they could not locate any material to recover from this event.**
4/13/15 (16:15)	USC-119	4/13/15 (17:15)	0.007	16:15 (MST), USC-119 occurred in RA-F East (toe of slope, backside). KW was notified and responded to the scene. Cliff Merrill EPA rep was notified.
4/14/15 (10:12)	USC-120	4/14/15 (17:15)	0.007	10:12 (MST), USC-120 occurred in RA-G North (east end). KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
4/15/15 (13:30)	USC-121	4/15/15 (14:30)	0.007	13:30 (MST), USC-121 occurred in RA-B. KW was notified and responded to the scene. Cliff Merrill EPA rep was notified.
4/16/15 (13:30)	USC-122	4/16/15 (13:30)	0.002	09:14 (MST), USC-122 occurred at crushing operation in RA-F. KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
4/16/15 (13:30)	USC-123	4/16/15 (13:30)	0.000	11:00 (MST), USC-123 occurred in RA-D East, (RA-F material being placed in RA-D East). KW was notified and responded to the scene.. Darlene McCray EPA rep was notified.
4/17/15 (17:00)	USC-124	4/17/15 (17:30)	0.007	17:00 (MST), USC-124 occurred in RA-C. KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
4/18/15 (11:20)	USC-125	4/18/15 (12:00)	0.000	11:20 (MST),USC-125 occurred in RA-F East (top of slag pile). KW was notified and responded to the scene. Darlene McCray EPA rep was notified. **KW reported that they could not locate any material to recover from this event.**
4/24/15 (08:37)	USC-126	4/24/15 (09:00)	0.000	08:37 (MST), USC-126 occurred in RA-B (material being placed came from RA-F East). KW was notified and responded to the scene. Darlene McCray EPA rep was notified.**KW reported that they could not locate any material to recover from this event.**
4/24/15 (15:03)	USC-127	4/24/15 (16:00)	0.074	15:03 (MST), USC-127 occurred in RA-B (material being placed came from RA-F East). KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
4/25/15 (14:03)	USC-128	4/25/15 (15:00)	0.001	14:03 (MST), USC-128 occurred in RA-F East (top of slag pile). KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
4/29/15 (11:32)	USC-129	4/29/15 (11:32)	0.001	11:32 (MST), USC-129 occurred in RA-F East (south side toe of slope). KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
4/30/15 (08:42)	USC-130	4/30/15 (09:45)	0.001	08:42 (MST), USC-130 occurred in RA-F East (top of slag pile). KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
5/2/15 (07:56)	USC-131	5/2/15 (17:30)	0.002	07:56 (MST), USC-131 occurred in RA-G North (East end). KW was notified and responded to the scene. Darlene McCray EPA rep was notified.
5/5/15 (08:15)	USC-132	5/5/15 (08:45)	0.002	08:15 (MST), USC-132 occurred in RA-F Valley (south end). KW has been notified and is responding to the scene. Cliff Merrill EPA rep was notified.
5/6/15 (13:41)	USC-133	5/6/15 (15:15)	0.001	13:41 (MST), USC-133 occurred in RA-F West (North end, feed side of the crusher). KW has been notified and is responding to the scene. Cliff Merrill EPA rep was notified.
5/7/15 (13:30)	USC-134	5/7/15 (14:00)	0.002	13:30 (MST), USC-134 occurred in RA-F West-Crushing Operations. KW has been notified and is responding to the scene. Cliff Merrill EPA rep was notified.
5/8/15 (09:35)	USC-135	5/8/15 (12:00)	0.000	09:35 (MST), USC-135 occurred in RA-G North-East end. KW was notified and responded to the scene.. Cliff Merrill EPA rep was notified. **KW reported that they could not locate any material to recover from this event.**
5/8/15 (13:20)	USC-136	5/8/15 (17:00)	1.000	13:20 (MST), USC-136 occurred in RA-E North. KW was notified and responded to the scene. Cliff Merrill EPA rep was notified.
5/8/15 (15:40)	USC-137	5/8/15 (16:20)	0.005	15:40 (MST), USC-137 occurred in RA-F East (top of slag pile). KW was notified and responded to the scene. Cliff Merrill EPA rep was notified.
5/11/15 (09:27)	USC-138	5/11/15 (11:00)	0.500	09:27 (MST), USC-138 occurred in RA-F East (top of slag pile-NE Corner). KW was notified and responded to the scene. . Cliff Merrill EPA rep was notified.
5/13/15 (07:58)	USC-139	5/13/15 (17:30)	0.500	07:58 (MST), USC-139 occurred in RA-E North-East end. KW was notified and responded to the scene. Cliff Merrill EPA rep was notified.
5/13/15 (13:22)	USC-140	5/13/15 (14:00)	0.001	13:22 (MST), USC-140 occurred in RA-D East. KW was notified and responded to the scene. Cliff Merrill EPA rep was notified.

5/14/15 (11:45)	USC-141	5/14/15 (16:56)	0.000	11:45 (MST), USC-141 occurred in RA-F West (feed end of the crusher). KW was notified and responded to the scene. Tim Norman EPA rep was notified. **KW reported that they could not locate any material to recover from this event.**
5/14/15 (16:08)	USC-142	5/14/15 (16:56)	0.002	16:08 (MST), USC-142 occurred in RA-F East (NE corner). KW was notified and responded to the scene. Tim Norman EPA rep was notified.
5/15/15 (16:07)	USC-143	5/15/15 (17:00)	0.003	16:07 (MST), USC-143 occurred in RA-C. KW was notified and responded to the scene. Tim Norman EPA rep was notified.
5/16/15 (11:10)	USC-144	5/16/15 (12:10)	0.000	11:10 (MST), USC-144 occurred in RA-F West-NW Slope. KW was notified and responded to the scene. Tim Norman EPA rep was notified. **KW reported that they could not locate any material to recover from this event.**
5/18/15 (16:15)	USC-145	5/18/15 (16:50)	0.007	16:15 (MST), USC-145 occurred in RA-C (West end). KW was notified and responded to the scene.. Tim Norman EPA rep was notified.
5/19/15 (12:19)	USC-146	5/19/15 (17:00)	0.035	12:19 (MST), USC-146 occurred in RA-C (West end-South of lattice tower). KW was notified and responded to the scene. Tim Norman EPA rep was notified.
5/20/15 (15:13)	USC-147	5/20/15 (16:30)	0.134	15:13 (MST), USC-147 occurred in RA-F East (NE corner top of pile). KW was notified and responded to the scene. Tim Norman EPA rep was notified.
5/21/15 (07:38)	USC-148	5/21/15 (17:30)	1.500	07:38 (MST), USC-148 occurred in RA-F East (NE corner top of pile). KW was notified and responded to the scene. Cliff Merrill EPA rep was notified.
5/28/15 (15:35)	USC-149	5/28/15 (17:30)	0.074	15:35 (MST), USC-149 occurred in RA-F East (top of slag West side). KW was notified and responded to the scene.. Cliff Merrill EPA rep was notified.
5/30/15 (09:48)	USC-150	5/30/15 (10:50)	0.050	09:48 (MST), USC-150 occurred in RA-F East (top of slag pile). KW was notified and responded to the scene. Cliff Merrill EPA rep was notified.
5/30/15 (11:10)	USC-151	5/30/15 (16:50)	0.074	11:10 (MST), USC-151 occurred in RA-C (West end near lattice tower). KW was notified and responded to the scene. Cliff Merrill EPA rep was notified.
5/30/15 (14:58)	USC-152	**Stabilized/Not Delineated**	0.025	14:58 (MST), USC-152 occurred in RA-C (SW corner). KW was notified and responded to the scene. Cliff Merrill EPA rep was notified. Stabilized/Not Delineated, CY of material recovered to date.
6/02/15 (08:21)	USC-153	6/02/15 (18:00)	0.001	08:21 (MST), USC-153 occurred in RA-F East (East side). KW was notified and responded to the scene. Cliff Merrill EPA rep was notified.
6/05/15 (14:00)	USC-154	6/05/15 (17:15)	0.001	14:00 (MST), USC-154 occurred in RA-F East (top of slag pile in the middle). KW was notified and responded to the scene. Tim Norman EPA rep was notified.
6/06/15 (09:33)	USC-155	6/06/15 (17:30)	1.000	09:33 (MST), USC-155 occurred in RA-F West (North end-South of Crushing Plant). KW was notified and responded to the scene. Tim Norman EPA rep was notified.
6/08/15 (15:15)	USC-156	6/08/15 (17:00)	0.000	15:15 (MST), USC-156 occurred in RA-C. KW has been notified and is responding to the scene. Tim Norman EPA rep was notified. **KW reported that they could not locate any material to recover from this event.**
6/09/15 (07:30)	USC-157	6/09/15 (17:00)	0.001	07:30 (MST), USC-157 occurred in RA-F East (top of slag pile). KW was notified and responded to the scene. Tim Norman EPA rep was notified.
6/09/15 (14:58)	USC-158	6/09/15 (17:00)	0.003	14:58 (MST), USC-158 occurred in RA-F West (South of crushing operation). KW was notified and responded to the scene. Tim Norman EPA rep was notified.
		Total CY not including stabilization sand=	662.83	

Business/ Val Kotter
/ Roto Rooter

Summary of RA-A Storm Water Pipe Cleaning Project

- **Preliminary Work**
  - 4/28/2015 Removed 6 sections of west discharge drain line to facilitate access and solids containment.
  - Set up solids/liquid containment systems.
  - Set up water management systems.
- **5/4/2015** Performed JPSA w/Roto Rooter and support team. Began cleaning at the west drain line.
- **5/11/2015** Roto Rooter completed cleaning lines at 3000 psi pressure.
  - 15 to 20 to passes from West Outfall to AI-4
  - 10 to 12 passes from AI-4 to AI-3
  - 5 to 6 passes from AI-3 to Manhole 1
  - 5 passes from East Outfall to AI-1
- **5/12/2015** KW dug up 8 inch line from AI-4 to AI-2, cleaned, videoed and placed back to original location.
- Week of 5/18/2015 Roto-Rooter completed high pressure cleaning (8000 psi) w/gamma head.
  - 4 to 5 passes with high pressure from West Outfall to Manhole #1
  - Additional 3000 psi cleaning to pull solids out
    - 5 to 6 additional passes from West Outfall to Manhole #1
- **5/21/2015** Val Kotter videoed lines
- **5/27/2015** exposed manhole on section of pipeline that was connected to east discharge drain line. These lines were not identified on plant drawings utilized for the SRI underground utility drawings.

Water volume = Approximately 60,000 gallons

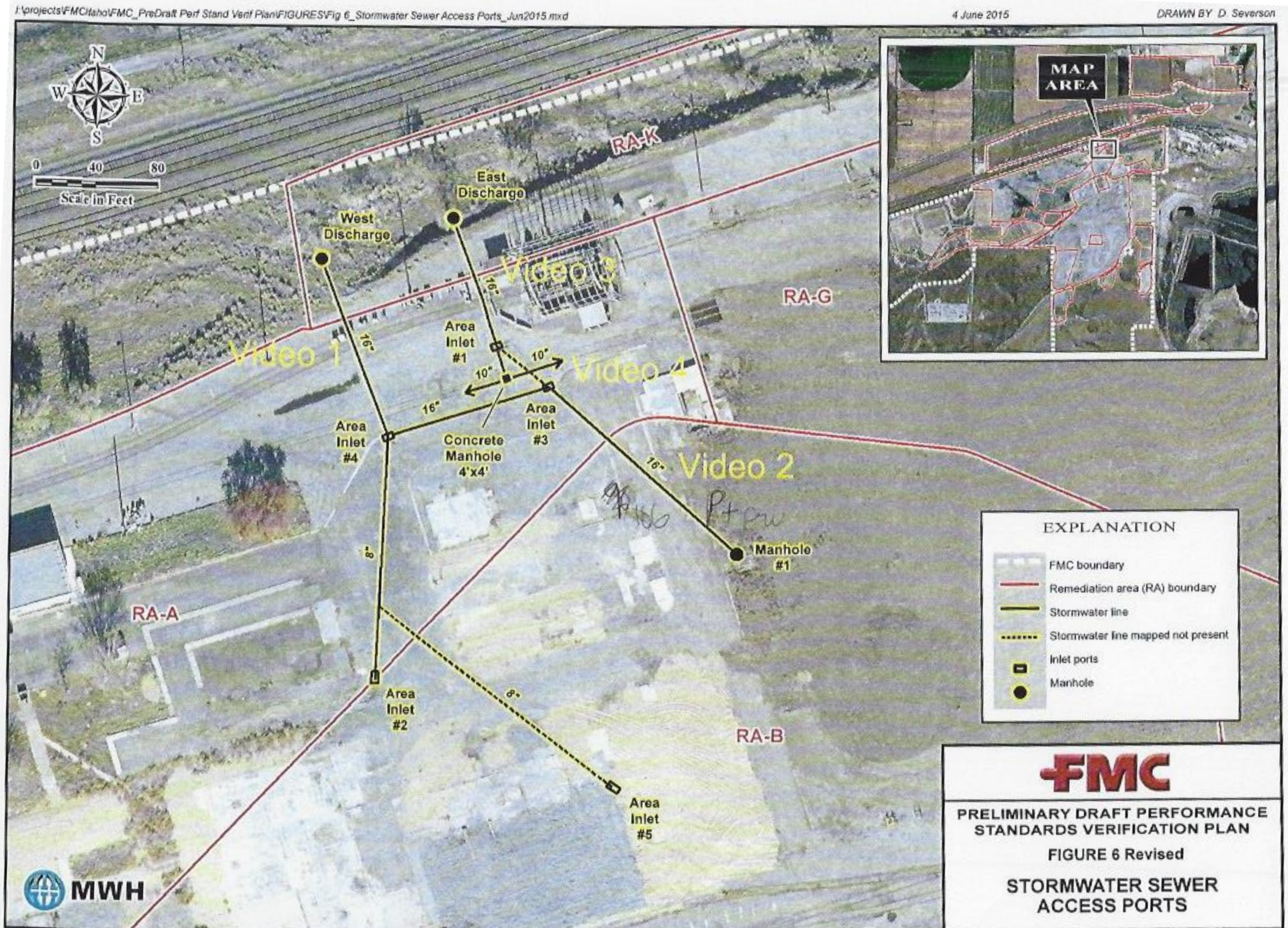
TCLP/pH results non-hazardous

Water disposed on site

Solids removed – Approximately 250 cf solids v estimate 294 cf solids

Solids TCLP non-hazardous, smoke test results all negative for P4

Solids are still on-site.



8" pipe—corrected – 60,000 gallons disposed on-site
– [illegible]

Table 1

Storm Drain Cleaning Water Analysis

FMC Pocatello, Idaho

Sample ID

Storm Drain Cleaning - Water Analysis										
	TCLP Analyte	Arsenic As	Barium Ba	Cadmium Cd	Chromium Cr	Lead Pb	Mercury Hg	Selenium Se	Silver Ag	pH
	Toxicity Limit (mg/L)	5.0	100	1.0	5.0	5.0	0.2	1.0	5.0	
Sample No	Sample Date									
I505013-01	05/04/15	<0.05	0.06	<0.05	<0.05	<0.05	<0.01	<0.05	<0.05	7.2
I505039-01	05/06/15	<0.05	<0.05	<0.05	<0.05	<0.05	<0.01	<0.05	<0.05	7.7
I505047-01	05/07/15	<0.05	<0.05	<0.05	0.11	<0.05	<0.01	<0.05	<0.05	8.2

Notes

TCLP Analysis by USEPA Analysis Method 1311/6020A

Table 2

Storm Drain Cleaning Solids Analysis and P4 Smoke Test

FMC Pocatello, Idaho

Sample ID

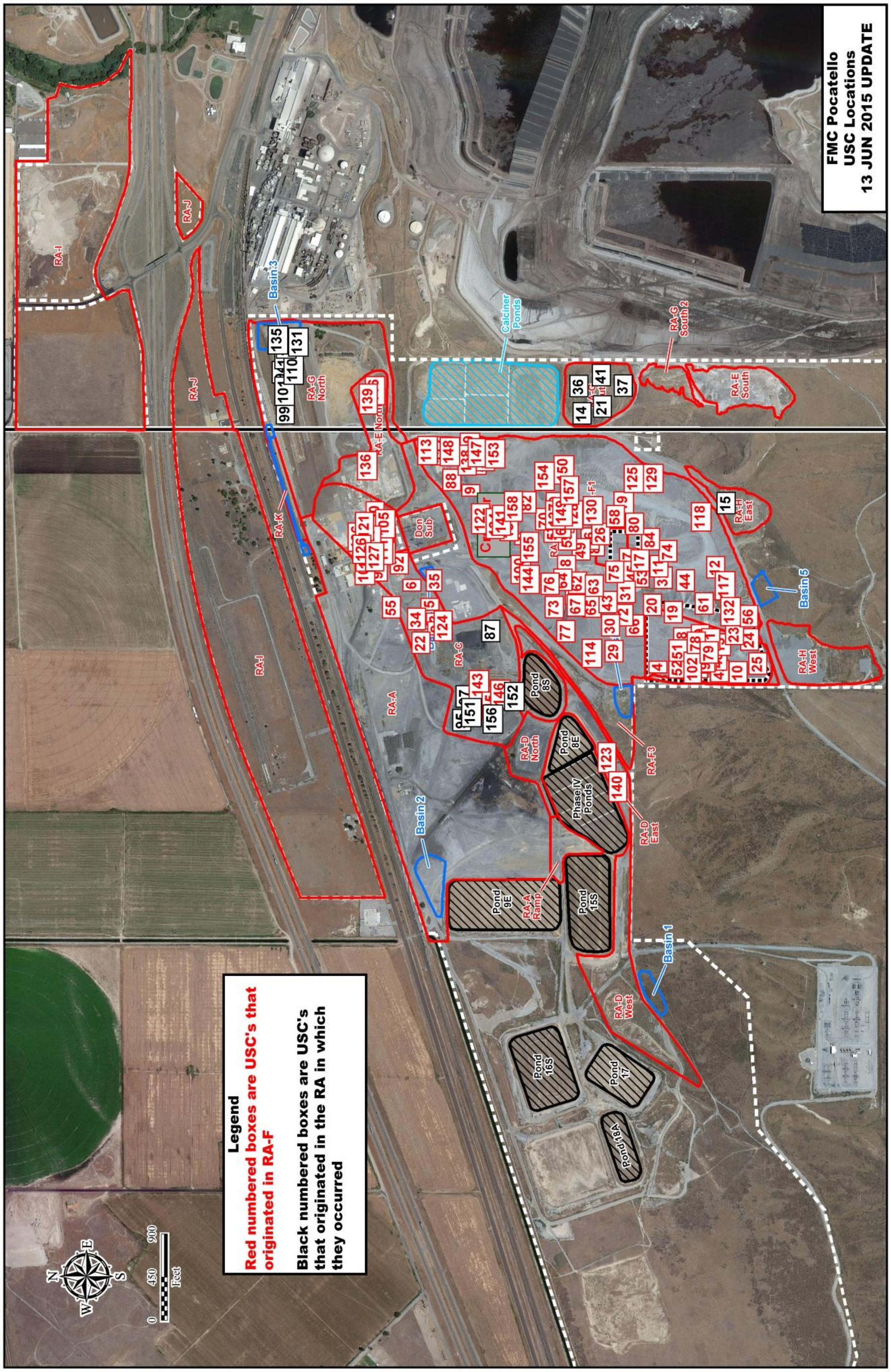
Storm Drain Cleaning - Solids Analysis												
		TCLP Analyte	Arsenic As	Barium Ba	Cadmium Cd	Chromium Cr	Lead Pb	Mercury Hg	Selenium Se	Silver Ag	P4 Smoke
	Toxicity Limit (mg/L)		5.0	100	1.0	5.0	5.0	0.2	1.0	5.0	
KW Sample No	IAS Sample No	Sample Date									
SDS -1	I504139-01	04/28/15	<0.05	0.15	<0.05	<0.05	<0.05	<0.01	<0.05	<0.05	No
SDS -2	I505061-01	05/08/15	<0.05	0.07	<0.05	<0.05	<0.05	<0.01	<0.05	<0.05	No
SDS -3	I505067-01	05/11/15	<0.05	0.09	<0.05	<0.05	0.05	<0.01	<0.05	<0.05	No
SDS -4	I505109-01	05/18/15	<0.05	0.23	<0.05	<0.05	<0.05	<0.01	<0.05	<0.05	No
SDS -5	I505109-02	05/18/15	<0.05	0.11	<0.05	<0.05	<0.05	<0.01	<0.05	<0.05	No
SDS -6		05/18/15									No
SDS -7		05/18/15									No
SDS -8		05/18/15									No

Notes

TCLP Analysis by USEPA Analysis Method 1311/6020A

Stormwater Sample Log

Sample ID	Date sampled	S/L	Analysis	Sample Description
I504139-01 (SDS -1)	4/28/2015	S	TCLP	042815-SDNW / Sample of solids out of west culvert discharge before cleaning commenced
I505013-01	5/4/2015	L	TCLP/PH	Storm Water Decant / Sample of water out of roll off bin
I505039-01	5/6/2015	L	TCLP/PH	050615-SD#2 /Sample of water from roll off bin while cleaning west culvert
I505047-01	5/7/2015	L	TCLP/PH	050715-SD#2 /Sample of water from roll off bin while cleaning west culvert
I505061-01 (SDS- 2)	5/8/2015	S	TCLP	050815-SD /Solids Sample of solids out of collection trough on west culvert from cleaning #1 & 2 sections
I505067-01 (SDS-3)	5/11/2015	S	TCLP	051115-SDS#3/ Sample of solids out of collection trough on west culvert from cleaning #3 section
I505109-01 (SDS-4)	5/18/2015	S	TCLP	051815-ESD/Sample of solids from collection trough from cleaning section #5
I505109-02 (SDS-5)	5/18/2015	S	TCLP	051815-WSD/Sample of solids from collection trough from cleaning sections #1,#2 & #3
SDS-1	4/28/2015	S	P4 Smoke Generation	Composite sample from pipe removed during preliminary work (west culvert)
SDS-2	5/8/2015	S	P4 Smoke Generation	Composite sample of solids from week 1 cleanout of west drain line (section 1 ans 2)
SDS-3	5/11/2015	S	P4 Smoke Generation	Composite sample of solid removed during cleaning of pipe section #3
SDS-4	5/18/2015	S	P4 Smoke Generation	Composite /Sample of solids from collection trough from cleaning section #5
SDS-5	5/18/2015	S	P4 Smoke Generation	Composite sample of solids removed from east drain line during final week of cleaning sections #1,#2 & #3
SDS - 6_051815 #1 RO west 1	5/18/2015	S	P4 Smoke Generation	Composite sample of solids from west roll off bin
SDS - 7_051815 #3 RO East 3	5/18/2015	S	P4 Smoke Generation	Composite sample of solids from east roll off bin
SDS - 8 _051815 #2 RO Center 2	5/18/2015	S	P4 Smoke Generation	Composite sample of solids from center oll off bin


FMC Pocatello
USC Locations
13 JUN 2015 UPDATE
Legend
Red numbered boxes are USC's that originated in RA-F
Black numbered boxes are USC's that originated in the RA in which they occurred
N
E
S
W
0
450
900
Feet
RA-I
RA-J
RA-K
RA-A
RA-C
RA-D North
RA-D East
RA-D West
RA-E South
RA-G North
RA-G South 2
RA-H East
RA-H West
RA-F3
RA-A Ramp
Don Sub
Basin 1
Basin 2
Basin 3
Basin 5
Calciner Ponds
Pond 8S
Pond 8E
Pond 9E
Pond 15S
Pond 16S
Pond 17
Pond 18A
Phase IV Ponds
D:\WAH\FMC\Idaho\FMC_REMEDIAL DESIGN\FIGURES\Fig 1_RA Boundary_BASE_17Apr2015.mxd
9 April 2015
DRAWN BY D. Severson

APPENDIX G:

ARGONNE'S RESPONSE TO COMMENTS RECEIVED FROM SHOSHONE-BANNOCK TRIBES

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APPENDIX G: ARGONNE'S RESPONSE TO COMMENTS RECEIVED FROM SHOSHONE-BANNOCK TRIBES

Appendix G contains the response to the comments received on October 20, 2015, from Shoshone-Bannock Tribes on the Draft Report: *Independent Review of Elemental Phosphorus Remediation at the Eastern Michaud Flats FMC Operable Unit near Pocatello, Idaho*, September 2015. Note that page and line numbers referenced in this appendix refer to an earlier draft of this document. Italicized text indicates changes that were made in response to the comments received from the Tribes.

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SBT Comment Number	Tribes' Comment	Response by Argonne Review Team
1	ANL prepared this report pursuant to an EPA Statement of Work (SOW) which did not request that ANL provide any analyses of costs. Instead, ANL was directed to review excavation and treatment technologies (ETTs) from a technology (science and engineering) perspective. The Shoshone-Bannock Tribes (Tribes) find it to be a major problem with the report that, contrary to the SOW, the costs of implementing ETTs are mentioned throughout the report. All of these references to costs should be deleted.	The Tribes and the U.S. Environmental Protection Agency (EPA) agreed to the inclusion of cost in the content of "Limitations" for the review parameters. In drafting the report, Argonne provided very broad estimates of the cost of each ETT. Argonne did not analyze costs in any detail. Argonne believes that the report is in compliance with the SOW, as a cost "analysis" was not conducted. Argonne believes that it is necessary that costs be considered in determining whether to go forward with any of the ETTs. Hence, Argonne believes that the very broad discussion of cost provided in the Draft report should be carried forward into the Final report. If and when EPA determines to go forward with any of the ETTs, a very detailed analysis of cost will be an important part of the decision-making process.
2	In the beginning of the report, there is only a brief discussion related to chemical and physical parameters that could affect the success or failure of an ETT. These factors should be reviewed more thoroughly, not only for their effects on	*Agreed, the document will be modified. The following will be inserted on Pg. 7, Line 37:* *White phosphorus is acutely toxic and poisonous, with a fatal dose for humans around 50 mg. White phosphorus will spontaneously ignite in air at temperatures greater than* 30^{o}*C (86°F); therefore, in addition to keeping P4 under water whenever possible, another generally applicable safety precaution is to work with P4 only under cold conditions (Rivera et al. 1996). The physical and chemical properties of P4 that could affect the ETTs discussed below include its melting point of 44°C, its densities of 1.828 g/cm*^{3} *(solid) and 1.745 g/cm*^{3} *(liquid at 44.5°C), its vapor pressures of 3.4E-5 atm at 20°C and 1.0E-3 atm at 76.6°C, and its solubility of approximately 4 mg/L at 25°C in water (Rivera et al. 1996).*

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	remediation, but also for their possible effects on worker and community safety and health. For example, as stated by the Tribes at the September 2015 meeting, the effect of cold temperatures during ETT use, such as reducing phosphine gas formation and/or lowering exposure (and therefore risk), should be reviewed in the document.	*Oxidation of P4 results in a number of different gaseous phosphorus species, the most abundant of which is* P_2O_5 *(Rivera et al. 1996). When exposed to water or humid air,* P_2O_5 *is converted to phosphoric acid. This process can occur within human lungs after inhalation of* P_2O_5*, thus causing severe irritation. White phosphorus reacts to form phosphine gas (PH3) in moist, anoxic environments such as subsurface sediments and soils. The rate of this reaction increases dramatically with increasing pH (above 7) (Rivera et al. 1996). Phosphine gas is flammable and highly toxic with an auto-ignition temperature of 38°C and an LD50 (median dose) of 3 mg/kg. As with the oxidation/ignition hazard, the risk of PH3 production can be mitigated by working with P4 at low temperatures (at least below 30°C) (Rivera et al. 1996).* *In addition to the acute inhalation hazard and dermal hazards associated with skin contact, chronic poisoning due to long-term exposure to P4-related vapors and gases poses significant risks that need to be accounted for in assessing site worker safety. Chronic exposure to P4 vapors and associated gases can cause necrosis of the jaw bone (phossy-jaw) and damage to lungs, eyes, bones, and the gastrointestinal tract (Rivera et al. 1996).*
3	LDR treatment as an ETT needs clarification because several technologies can be used. A more detailed discussion of the caustic (alkaline) hydrolysis treatment should be provided as an example or should be discussed as its own technology rather than just being "part" of the LDR treatment. One question: Are there other technologies that could be	This comment requires no change to the text. It appears that FMC was quite thorough in identifying the technology or technologies that could be used to address the land disposal regulation (LDR) treatment standards. The commenter is correct in noting that the LDR waste treatment system (WTS) is not a single ETT, but rather is a suite of technologies used to treat P4 and other hazardous constituents. The technologies associated with the LDR WTS were selected specifically because the technologies *can* meet the LDR requirements; hence, the name "LDR WTS." The assemblage of technologies is described on Pgs. 87 and 88, and the components are summarized in bulleted fashion on Pg. 88. The review team specifically acknowledges that the LDR WTS is a process in that it is a collection of separate technologies.

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	used in an LDR treatment process? It is important to denote that the LDR treatment is probably more of a system or process than an ETT because one ETT alone most likely will not satisfy the LDR requirements.	
4	The report needs stronger language and an explanation pertaining to the weakness of the current Conceptual Site Model (CSM), the lack of subsurface sampling and therefore characterization, and the many data gaps that affected ANL's ability to evaluate the in situ technologies to a greater extent and created some difficulties in analyzing the ex situ technologies also. The Tribes suggest that there be more detailed discussion of these points in the conclusions/recommendations section of the report and in the executive summary	Deficiencies in the CSM have been called out in numerous instances throughout the report. The fact that there is "sparse characterization data" available is noted in the Abstract. The fact that there are uncertainties about the CSM is noted in the Executive Summary. Furthermore, uncertainties about the CSM are discussed, where relevant, in the discussion on a specific ETT. Nevertheless, the Review Team needs to better explain how CSM uncertainties affected the review of technologies. The Review Team will include the following language in the Abstract, Executive Summary, and Summary and Conclusions. Abstract ES-2, Line 4: after "…..and treat P4 wastes, then *the Review Team determined that a number of the ETTs examined warrant further consideration for the treatment of P4 waste that has been characterized (for example, P4 waste present in the historical ponds). Nevertheless, concerns about the health and safety of site investigation workers using then-available investigation approaches prevented the collection of subsurface samples containing P4 from large areas of the site (e.g., the railroad swale, the vadose zone beneath the Furnace Building, and the abandoned railcars), As a result, the contaminant CSM in those particular areas was not refined enough to allow the Review Team to draw conclusions about using some of the ETTs to treat P4 waste in those areas.* Similar language will be added to ES-6, Line 42 and Pg 137, Line 12, *If, despite this risk and these impacts, stakeholders determine there is a need to excavate and treat P4 wastes, then the Review Team concludes that several of the ETTs could be used in combination to treat only a subset of the P4 waste present at the site. Concerns about the*

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	(as discussed several times at the September meeting). The inadequacy of the CSM and the lack of site characterization [were] especially apparent when it came to evaluating ETTs for the [Furnace Building] and the area where the railcars are buried, and these are both areas that the Tribes view as high priorities for cleanup.	*health and safety of investigation site workers using the then-available investigation approaches prevented the collection of subsurface samples containing P4 from large areas of the site, including, for example, the railroad swale, the vadose zone beneath the Furnace Building, and the abandoned railcars. It appears that no attempt was made to experiment with or to use alternative characterization methods (such as modified PPE, nonintrusive techniques, remotely controlled sample collection equipment, cryogenics, etc.) as part of the investigation. As a result, the CSM in those particular areas is not refined enough to allow a full evaluation of ETTs and to allow the Review Team to draw conclusions about the efficacy of the ETTs examined. However, in other areas of the site, for example, the historical ponds, process knowledge (information about the process waste stream discharged to the historical ponds), and the information gathered during both the CERCLA investigations and the RCRA-related investigations, provide the information needed to determine whether or not the ETTs considered warrant further consideration for P4 in those areas.*
5	There needs to be a section of the report on monitoring and measuring because these two parameters are entwined with the ETTs and the CSM. If one cannot monitor/measure phosphine gas while using a technology, then should it be considered or eliminated by ANL? Will it be more difficult to monitor and measure with one technology than another, and should this factor be a part of the evaluation of an ETT? Much, if not all, of	This independent review focused on ETTs that could be used to treat elemental phosphorus and not on measurement and monitoring of phosphine gas and other toxic gasses. The Review Team has noted that FMC and other elemental phosphorus manufacturers have used monitoring technologies and analytical methods. In particular, monitoring for phosphine and other toxic gases seems to have a precedent at the FMC site and at other sites. See the response to comment 39 below.

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	the ambient air an occupational monitor measuring ambient air and using methods that have never been properly validated obtained data used in the FS/SFS. There is no discussion on the possible effect this issue would have on the collected data and its analysis. For example, if any of the ETTs reviewed in the report were used at the FMC site, how could one be sure that phosphine and other toxic gases were not being released? Is the occupational monitoring and measuring protocols adequate for residential risk assessments?	
6	There is no mention of any bioremediation treatment ever being attempted nor was its feasibility considered for remediating phosphorous compounds at the site. Since it does not appear that ANL has a biologist or microbiologist	It appears that this comment requires no change in the text. Argonne's search of applicable technologies included potential bio-remediation tools. Argonne's search included areas where P4 remediation has been considered in the past. Argonne found no cases where bioremediation was used at all and found no suggestion in the literature that bioremediation is a possible ETT worthy of further research. Intuitively, Argonne believes that bioremediation would not be successful, considering the reactive and ignitable properties of P4, even at low concentrations.

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	on their team, did ANL investigate or talk with other experts to see if injection of bacteria could work at the lower levels as an in situ remedial process?	
7	Page 9 (line 21) P4 analytical detection limit is not explained or provided, and did it change over time?	It appears that this comment requires no change in the text. The Review Team is positing that P4, if present, would be present at concentrations ranging from above the analytical detection limit to nearly pure P4.
8	Page 9 The low temperature is an important point but values or ranges were not provided to the reader.	This comment requires no change to the text. The temperature of the isotherm and the melting point of P4 are already called out in the discussion.
9	Page 10 Depth to railcars: is this figure correct or is it misleading, since the railcars are at ground level with material placed over them? In 2015, FMC moved between 20 [and] 40 ft of stag (sic) from the top of the slag pile to other areas at the site. The railcar	Table 2-1 has been modified with a footnote to indicate the following: Since Table 2-1 was published *(in MWH 2010), FMC has removed 20 to 40 ft of slag from the top of the slag pile to other areas at the site.*

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	depths may no longer be 80 ft below surface.	
10	<u>Section 2.2</u> Is the CSM discussion complete? The issue of P4 retention and the experiment would seem to fit in a data gaps section on the CSM (possibly a new section). See Major Comments, above, for additional needs in this section.	Agreed. The discussion on the issue of P4 retention and the suggested bench- and pilot-scale studies (Pg. 9, Lines 32 to 36) will be moved to the discussion on in situ technologies in Section 5.1. Regarding the comment on preparing a new section to discuss the data gaps for the CSM, the Review Team has already discussed CSM data gaps as they relate to implementing ETTs, especially in the case of the in situ technologies. See how the Review Team responded to this comment in Major Comments above.
11	<u>Section 2.4</u> "…Some of the remedial actions that were proposed (in the IRODA) informed the way the Review Team performed the evaluation of the ETTs." This statement is not clear and needs to be more informative, possibly with an example. <u>Section 2.5.2.3</u> It would be beneficial for Argonne to state whether or not the Review Team found	Agreed. Pg. 14, Lines 22, 23, and 24 text will be modified as follows: The *IRODA is summarized here because some of the proposed remedial actions, including the groundwater pump and treat (P&S) system, informed the way the Review Team performed the evaluation of the ETTs.* It appears that this comment requires no change in the text. The purpose of the LDR WTS was to generate a waste that would pass the LDR Universal Treatment Standards. TCLP data for stabilized product produced by the LDR WTS were reported in the multivolume report on the system. The Review Team examined the concentrations reported in, for example, Table 4.1-4, Characteristics of

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	and reviewed any TCLP testing. If so, what were the conclusions? Supposedly, FMC did some TCLP testing. Thus, if the leachate fails TCLP, it should be noted that this is another RCRA issue.	the Stabilized Product in Volume I. The LDR WTS documentation relates to treating both waste generated by active processes at the former FMC plant and sludge extracted from Pond 8S. Were a version of the LDR WTS to be used to address P4 wastes under a remediation scenario, there would be different waste acceptance criteria for the LDR WTS, and the TCLP would probably have to be repeated.
12	Section 2.5.4 The discussion of RCRA compared to CERCLA, including CAMUs, is interesting. Since the site is in EPA Region 10, does Region 10 have any guidance on this issue?	Comment noted.
13	Section 2.5.5 - RSLs (Remedial/Regional Screening Levels) ANL may be using RSLs improperly here because they are screening levels and not necessarily remediation concentrations. The RSLs are generally based on human health numbers for screening purposes only, and not necessarily remediation	It appears that this comment requires no change in the text. The Review Team has included this discussion to discuss cleanup levels in a relative sense, the thought being that in treating P4, one may need to do more than to remove the "reactivity" characteristic. The Review Team indicates that these levels "may" be applicable if and when one decides to actually implement a given ETT.

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	levels for soil concentrations of a chemical, e.g., P4. Also, Region 10 does not have to recognize the Region 3 or 9 concentrations as an ARAR because they are not necessarily applicable to the site. Mostly, clarification is needed in this section.	
14	Section 2.5.5.1 - SBT Soil Remediation Levels ANL quotes a portion of the IRODA that states that the Tribes' Soil Cleanup Standards (SCS) "require . . . excavation and/or treatment of all buried elemental phosphorus on the Fort Hall Reservation. Among the Tribes' stated goals in promulgating the SCS is restoring all land within the Reservation to its original state prior to the contamination that the standards are designed to address." ANL concludes from this statement [that]	The text will be modified as follows (Pg. 24, Line 33): It is clear that in some cases the Shoshone-Bannock Tribes*' cleanup standard for P4 in soil would entail complete removal, which typically is interpreted to entail removal to the extent that no contaminant that is detectable when using validated and approved analytical techniques. However, the SCS specifically provides in §1.1 that "The Tribes recognize, however, that there are situations where use of Commercial/Industrial Cleanup Standards rather than Unrestricted Use standards may be appropriate, or where attainment of the Cleanup Standards may be technically impracticable." The Tribes also specify, however, that "The SCS do require soils that exhibit the characteristics of ignitability or reactivity to be treated to eliminate those characteristics, or else the soils must be removed from the site (Part 4)." Hence, it appears that the Tribes' SCS would permit application of a cleanup standard other than complete removal of P4, as long as the remaining media would no longer exhibit the RCRA characteristics of ignitability and reactivity. This would entail developing a set of criteria that would establish a de facto definition of RCRA ignitability and reactivity, specifically due to P4 content, as well as an alternate numerical cleanup standard for media that contains P4 below RCRA ignitability and reactivity characteristic levels.*

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	"It is clear that the Shoshone-Bannock Tribes cleanup standard for P4 in soil would entail complete removal." However, EPA's description of the SCS is inaccurate and incomplete, and ANL's conclusion about the SCS is incorrect. The SCS specifically provide[s] in § 1.1 that "The Tribes recognize, however, that there are situations where use of Commercial/Industrial Cleanup Standards rather than Unrestricted Use standards may be appropriate, or where attainment of the Cleanup Standards may be technically impracticable. The Cleanup Standards provide alternatives for these situations, as discussed further in Part 3 below." SCS § 3.1 authorizes a facility owner or operator to petition to	

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	use the commercial/industrial cleanup standards in lieu of the standards for unrestricted use. Notably, the numerical SCS (Tables A-D) contain values for both residential and commercial/industrial use. Therefore, treatment to industrial standards may satisfy the SCS. The SCS also provide for alternative standards to be applied if the unrestricted use or commercial/industrial standards cannot be achieved due to technical impracticability (§ 3.2). In addition, and when appropriate, site-specific standards may be developed for some or all portions of the site (Part 4), and in a policy statement issued in February 2011 the Tribes' Environmental Waste Management Program ("EWMP")	

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	explained the general procedures and bases for developing site-specific standards ("EWMP Policy for Setting Site-Specific Cleanup Standards under the Shoshone-Bannock Waste Management Act"). The SCS do require soils that exhibit the characteristics of ignitability or reactivity to be treated to eliminate those characteristics, or else the soils must be removed from the site (Part 4). The ANL Report discusses ETTs that would provide for such treatment or removal.	

15	<u>Section 5.1.1</u> - Thermal Treatment and Recovery. Thermal Conduction and/or Electrical Resistance Heating. 80 feet. It is very difficult to evaluate this ETT without detailed data as to where the P4 is located. This ETT also is not likely to remove other constituents (metals). Another big unknown is where the P4 would go besides along the hydraulic gradient, and the amount of P4 that would be removed versus the amount that would stay. The removal efficiency is unknown without testing. And again, this only accounts for the P4 and not the other contaminants that would not be removed by the process unless trapped or associated with the P4. Finally, even if the "original" P4 is removed after testing, the area will more than likely rebound (be replenished) with more P4 after the original removal. This issue has been demonstrated and	Regarding the difficulty in evaluating this ETT without detailed data as to where the P4 is located, see the comment response on the CSM above. The July 1, 2014, Work Order bounded the review parameters as follows: • Extent of Review – The review will encompass ETT for elemental phosphorus, its chemical reactions, and byproducts in the soil at the FMC OU. Other contaminants or media will not be evaluated unless it is determined that they impact the efficacy of an ETT. As a result, the Review Team focused on technologies that could address P4. To address this comment, a sentence will be added on Pg. 36, Line 27 as follows: *Inorganic hazardous constituents present would be brought to the surface along with the P4 mobilized by the heating method.* A sentence will be added on Pg. 38, Line 7: *Inorganic hazardous constituents present in the P4 that could not be mobilized by the heating method would remain in the subsurface.*

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	documented several times under the CERCLA order for Ponds 16S and 15 (and others).	
16	<u>Table 5.1</u> - Thermal Treatment The Tribes appreciate ANL doing a technology evaluation table for each ETT, and it adds to the evaluation and readability of the report. There should be a statement as to the purity of P4 that might be recovered and possibly sold, although the sale probably would have only a small impact on the overall cost. Also, there could be negative impacts if the "now" liquefied P4 moves in many directions without being able to be contained, possibly making the situation worse.	Pg. 39: The discussion on overall advantages and disadvantages will be modified as follows: *The purity of the P4 that would be recovered is unknown*. Table 5-1 already includes a discussion on the need for containment in the section titled "Limitations."

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17	<u>Section 5.1.2</u> Solvent Leaching While the report is primarily about P4, it would be important to mention other COCs which could be a limiting factor in using this technology since most other COCs would not be soluble in oils, etc. Cost and recovery would be high, but bacteria would flourish with some of the oils. Train tracks on site are a big plus for being able to deliver a solvent to the site.	Pg. 38, Line 34: A sentence will be added as follows: Hazardous inorganic constituents present in P4 would be soluble in water but only sparingly soluble in the organic solvents mentioned below. *It is only slightly soluble in alcohol (C_2H_6O), ether, and benzene (C_6H_6).*
18	<u>Section 5.1.3</u> Oxidation (with hydraulic barrier) One limitation missed in the discussion of the ETT (as well as of others, as noted above) is that other COCs were not mentioned and their removal is unlikely. A hydraulic barrier would have its own limitations. This technology is very good for	It appears that this comment requires no change in the text. Of all of the *in situ* technologies discussed, oxidation (with a hydraulic barrier) has the greatest potential to address inorganic hazardous constituents, in that inorganic constituents could be brought to the surface along with any other P4 oxidative reaction products.

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	removal at groundwater depth, but some Remedial Units at the FMC site are not amenable to this technology (meaning this ETT would have to be used in conjunction with another ETT). Another limitation would be getting a hot material (solvent) to 80 feet bgs.	
19	Section 5.1.4 - Containment Technologies Three examples of containment technologies are provided in the report. EPA Region 3 has led EPA in building barrier and slurry walls, some 50-80 feet bgs. No mention is made of the possible effects of a containment wall i.e., stopping groundwater flow, backing it up so to speak. Also, buried piping and material would be an issue for containment in these areas, but see ex situ for facing those issues.	Containment technologies are discussed in the context of being coupled with other ETTs in order to treat and remove P4 from the subsurface, not just contain it in the subsurface. The following changes will be made to Pg. 48, Line 21: ... containment system to isolate the treatment area, preventing both the solvent and the target compound from *escaping and blocking groundwater flow into the treatment zone.*

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20	<u>Section 5.2.2</u> Mechanical Excavation Technologies Page 54 cites Figures 5-3 and 5-5 but they do not follow page 54. There is no information discussing ambient temperature below 44 degrees C and its effect on the excavation. If the excavation were done at cold temperatures, would the hazards and exposure be minimized?	Pg. 54, Line 1: A phrase will be added to the sentence as follows: … *performing the excavation when ambient temperatures are below 30°C (or by controlling temperature in a temporary structure erected over the excavation site) and/or by keeping the white-phosphorus-bearing materials covered and saturated with water, while the off-gas from the excavation site could be captured and treated.* Pg. 54, Line 4: The sentence will be modified to include a reference to the use of a temporary structure over the excavation site: The pyrophoric hazard could be mitigated by performing the excavat*ion when ambient temperatures are below 30°C (or by controlling temperature in a temporary structure erected over the excavation site) and/or by keeping the white-phosphorus-bearing materials…*
21	<u>Section 5.2.3</u> Cutter Suction Dredging This ETT appears feasible, but it captures the material without treatment. Most likely it would still be necessary to do some long-reach excavator process.	It appears that this comment requires no change in the text. Section 5.2 is titled "*Ex Si*tu Excavation Technologies." Discussion is included to the effect that in order for P4 waste to be treated by an ex situ technology, the waste would have to be excavated, stored, sampled, sized, and blended first. The Review Team has explicitly stated that the ETT in this case captures the material without treatment.
22	<u>Section 5.2.4</u> Thermal-Hydraulic Dredging Again, dredging is a technology for removing the waste but not treating it, as noted in the report and is true for many of these technologies.	It appears that this comment requires no change in the text. Section 5.2.4 is within Section 5.2, "*Ex Situ* Excavation Technologies," so the response provided above is applicable.

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23	Section 5.2.5 Excavation Methods Summary There is some speculation in the beginning of this section that could be lessened if the appropriate testing were conducted. It would be necessary to remove (move) the slag to view the railcars and the material below the railcars, which may have leaked from the cars over time.	Comment noted.
24	Section 5.3 Ex situ incineration is feasible. The difficulty at this site most likely would be the feed system, and how to accomplish it with minimal exposures. ANL calls it preprocessing. There is not a comparison between mobile and stationary incinerator systems. It is likely the mobile system would create fewer issues, but either could function well at this site. One problem may be	It appears that this comment requires no change in the text. There is a comparison of on-site vs off-site incineration on Lines 32 to 46 on Pg. 125 and Lines 1 to 31 on Pg. 126. The time to implement and treat waste is stated as requiring more than 10 years.

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	the amount of CO_2 released. The time to implement and treat waste is stated to take 10 years. This value seems overly conservative and data are not provided to understand this value (i.e., feed rate of incinerator, treatment per day, depth of excavation, etc.).	
25	<u>Section 5.3.2</u> Drying/Mechanical Mixing Units of measurement need correction and clarification for the reader. Note 12,000 gal is not 40,000 liters. The numbers in this section do not make it very understandable. Pounds of water on a railcar? For example, how many pounds of water can a railcar hold? Most railcars hold about 200,000 pounds or 100 tons, but older railcars may not hold that amount. In this instance weight is not as important as volume.	Pg. 74, Line 13: The text will be modified as follows: …a railroad tank car containing 12,000 gal of liquid P4 (*approximately* 40,000 L, 170,000–175,000 lb)… The Review Team is repeating the information from the cited reference. Absent information to the contrary, the Review Team would like to retain the existing quantities and units of measure.

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	Page 78 Line 33 citing EPA RSL of 23 mg/kg which MAY be a target concentration. Since it is not a Region 10 value, it is probably wiser not to use it in this evaluation or to cite (clarify) it as a Region 9 value when ANL uses it, even if that fact was stated previously.	The Review Team will cite Region 9 as being the source of the RSL.
26	Section 5.3.3 - A & W Page 8, top. P4 treatment done; is it possible to remove the metals with a lime precipitation process? Not stated. Answer yes. May be beneficial to state this aspect, as it is an advantage over a technology that does not remove or bind the metals. Page 84, 3rd paragraph. "...soils and residuals excavated from the FMC site…might make the mud still not be effective" is speculation because tests have not been done at the	It appears that this comment requires no change in the text. The Review Team has noted in Section 5.3.3.1 that residuals solids might contain heavy metals and that residuals solids would require additional treatment to meet RCRA LDR requirements, or on-site disposal in a RCRA CAMU (Pg. 82, Lines 8 to 16). It appears that this comment requires no change in the text. The Review Team is noting that low concentrations of P4 might impact the efficiency of the A&W mud still, which is reasonable given that the unit was tested at P4 concentrations of 20%.

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	Silver Bow site or at the FMC site. Unless you can show scientifically why, then it is speculation.	
27	Section 5.3.4 - LDR processes and the Waste Treatment System (WTS). Built but torn down and never used by FMC. See major comment on LDR.	Comment noted. It appears that this comment requires no change in the text.
28	Section 5.3.5 - Wet Air Oxidation This process may be difficult to control at the FMC site. It may be possible in certain areas of the site, but without testing, one can only show by theory. Solvent extraction in a vessel should explicitly state the vessel size would limit the process. Table 5-15 has a contradiction. The first description states that the ETT is "considered	It appears that this comment requires no change in the text. FMC also determined that WAO technology would be difficult to operate at the site. FMC-related research went far beyond the theory stage. The reference to solvent extraction and solvents seems out of context. WAO is not a solvent extraction method. Table 5-15 does not include a contradiction. The Review Team notes that WAO is mature in the waste treatment industry, but that only a pilot-scale version has been assessed for treating P4.

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	mature" but only a pilot-scale treatment has been done. Then the third description states, "lack of maturity of this method." Many of the solvents that could be used have their own drawbacks. Testing with oils may be the first attempt at doing this type of extraction at a phosphorous site. If ANL is aware of other attempts, that should be noted in the report.	
29	<u>Section 5.3.7</u> - Off-site Incineration It is unclear from the report whether there are other types of incineration available besides the rotary kiln referenced in this section.	It appears that this comment requires no change in the text. When FMC performed a nationwide survey in the mid-1990s, incinerators and wastewater treatment facilities were surveyed. The Review Team does not know what types of incinerators were surveyed.
30	<u>Section 5.4</u> - Ex situ Disposal Pages Pg. 99-100 On-site disposal – ANL explains that, although the *IRODA*	The Review Team has discussed disposal that would occur only after treatment to remove P4 to acceptable levels. The text on Pg. 100, Line 5, will be modified as follows: However, on-site disposal of residuals that remain after P4 has been removed *to acceptable levels by treatment* is examined herein. Argonne also disagrees with the Tribes regarding the assertion that "when P4 remains in the soil, due to its reactivity and ignitability, the exposure pathway cannot be minimized or eliminated." Argonne

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	remedy of capping and cover is effective in reducing risks to human health and the environment when the exposure pathway is minimized or eliminated, "only rarely have these types of remedies been approved of for soil and debris that are reactive and ignitable, such as P4." The Tribes comment that when P4 remains in the soil, due to its reactivity and ignitability the exposure pathway cannot be minimized or eliminated. Evidence of this problem abounds at the FMC site, where capped RCRA ponds continue to react and emit toxic phosphine gas and P4 continues to make its way into the groundwater. ANL then states that capping and cover "are not presented in this document for soil and debris containing P4 above the cleanup level of 23 mg/kg,"	maintains that once the reactive component of the P4 waste has been treated, even though some P4 would remain in the waste, a well-designed and cared-for cover can effectively preclude migration of contaminants and can eliminate or at least minimize the exposure pathway.

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	which ANL identified in § 2.5.5 as a soil remediation goal for P4. SBT supports ANL's elimination of capping and cover of untreated waste as an ETT worth further exploration in its report, for the reasons stated above.	
	Solidification/Stabilization is pretty much ignored basically because of the increase in size of the waste to then dispose of in a CAMU-like containment. The alternative should have been more thoroughly investigated regardless of the size or volume. Encapsulation was probably not considered for the same reason, plus it is energy-intensive; is that correct? It seems ANL would agree with this statement because in the first line under Section 5.4.1.2 ANL states: "Disposal of treated waste and soils and debris…in an	The Tribes also imply that stabilization, solidification, and even encapsulation could be used to address the P4-contaminated areas. Argonne disagrees with this implication. First, Argonne is unaware of any stabilization, solidification, or encapsulation technology that would be successful on contaminated media containing high or even moderate concentrations of P4. Noteworthy is the failed experience with in situ stabilization attempted at Tarpon Springs, Florida. One could dilute the P4 with solidification and stabilization media so that the P4 would then be present only at very low concentrations, but Argonne believes that this "dilution is the solution" approach would be unacceptable from a number of different perspectives. More important, Argonne understood that its charge was to evaluate ETTs that would remove the P4 as the principal threat waste. Stabilization and solidification technologies, other than diluting the P4 with massive amounts of stabilization or solidification materials, would be ineffective for addressing anything other than treated materials from which the bulk of the P4 has been removed to acceptable levels. And here also, the purpose of the stabilization or solidification would not be to address the P4, but rather to address heavy metals or radionuclides that may remain within the treated residue.

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	on-site CAMU or CERCLA on site land disposal unit is applicable to FMC (the site)." Without treatability studies, it is difficult to know the approximate increase in volume with stabilization processes. Solidification would probably at least double the waste material for containment on-site.	
	<u>Section 5.4.2</u> Off-site disposal Creating a new off-site disposal facility has been done at other sites for large amounts of waste with reactive, radioactive issues and metal issues (e.g., Oak Ridge, TN). Saving money through on-site disposal could, in turn, accelerate the cleanup work at Oak Ridge National Laboratory and Y-12 National Security	The citation referenced by the reviewer appears to be describing an on-site disposal facility not an off-site disposal facility. The Review Team evaluated disposal (whether on or off site) assuming that the waste to be disposed of would first be treated to remove the P4-related hazards. Off-site disposal would be needed only to address any heavy metals or radionuclides that remain in the treated media.

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	Complex, said Laura Wilkerson, federal project director for the Y-12 National Security Complex in the Oak Ridge Office of Environmental Management. The new landfill, the Environmental Management Disposal Facility, would be built on Bear Creek Road west of the Y-12 National Security Complex near another landfill that is already in use and has been operating since 2002. The earlier 43-acre, six-cell landfill is known as the Environmental Management Waste Management Facility. It has a capacity of 2.18 million cubic yards—about	The third bullet for the Overall Discussion of advantages and disadvantages in Table 5-20 will be replaced with the following language: *The cost of transporting treated P4 waste to an off-site disposal facility would be high relative to the cost of on-site disposal of treated P4 waste.*

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	872,000 pickup truck loads—and it is roughly 66 percent full. It's expected to be filled by the remaining cleanup work at the East Tennessee Technology Park, also known as the former K-25 site, sometime around 2023. (DOE) ANL states that this option would not be considered because of the high cost and other aspects. Those types of statements should have not been placed in this document because of their speculative nature and the fact that costs were not supposed to be considered. Table 5-20 also lists as the first disadvantage that it would take many years; however that same disadvantage was not listed in other long-term remediation options. Thus	

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	an unfounded bias seems to be part of this alternative evaluation. Indeed, a comparison is made to the interim *IRODA*: "The cost would be high relative to the cost of cap and cover options." But ANL did not provide an evaluation of a cap and cover option and so has no independent basis for making this statement; instead ANL is accepting the *IRODA's* value without doing its own analysis. The Tribes disagree with this approach and its use in this report, which is intended to be an independent review.	
31	Section 5.5.1 Piping Section needs more depth to it.	Comment noted.
32	Section 5.5.2 Railcars In May 2009 FMC commissioned MWH to complete the SFS Technology Screening Memorandum for Buried Railcar Evaluations for the FMC Operable. The report stated the buried railcars	The memorandum mentioned in the comment is Appendix B of the *Supplemental FS*, which the Review Team has used as an assumed authoritative source for the following: (1) gathering information about the abandoned railcars and (2) drawing conclusions about the potential applicability of ETTs. The *Supplemental FS* has been cited in the Independent Review as (MWH 2010). To be more specific and address the noted comment, Pg. 110, Lines 41 to 43, will be amended in response to a detailed comment from the EPA about the same topic.

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	contained an estimated range of 200 to 2,000 tons of P4 sludge (depending on the amount of P4 in each railcar, as reported in Section 4.15.4 of the SRI Report). The report cited the need to remove 300,000 cubic yards of material to reach the railcars. FMC has moved over 4 million cubic yards from the slag pile in 2014 and 2015. This report should be cited in the report when railcars are discussed.	
33	Section 5.5.5.5 Applicability to FMC ANL states here (Pg. 113) "At a minimum, a more refined CSM is needed, including a better or complete understanding of the location, configuration, and condition of the railcars." This is one of the instances in which weaknesses in the current CSM affected ANL's analysis, as SBT notes in its	Comment noted. See the response to a General Comment above.

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	general comments on the report.	
34	<u>Section 6.2</u> Evaluations "…Whether the ETT is applicable to the FMC site…": Since this is a site-specific review as designated by the SOW, why did the Review Team state this point?	The Review Team is merely restating language included in the SOW.
35	<u>Section 6.2.1</u> Ex Situ Excavation and Ancillary Technologies The Tribes disagree strongly with the reasoning (excuse) for the site being uncharacterized. Samples can be taken in a safe manner. The PRP has not allowed the Tribe to sample and they have not been forthright in trying to characterize the site. This issue arises in two different contexts in this section. First, on Pg. 119, ANL says, "Due to worker health and safety issues, site investigators have strived	Comment noted.

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	to avoid collecting any samples that contain P4." It is difficult to see how an investigation into applicable technologies for addressing P4 contamination at a site would be viewed as adequate or complete when few or no samples of P4 at the site were collected. Second, on p. 123, ANL states: "Although the in-situ ETTs are potentially applicable to the FMC OU, uncertainties pertaining to both the CSM and the in-situ ETTs suggest that further consideration of these in-situ ETTs is not warranted because the subsurface remediation, no matter the ETT implemented, would be incomplete." It seems that if an adequate CSM were developed the subsurface remediation may not need to be incomplete, at least not in all areas.	

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36	Table 6-1 ETT Report Matrix 11 out of 18 or almost 2/3 of the ANL-reviewed technologies warrant further consideration for use in remediating the site. Also, some of the other 7 ETTs may be considered if the testing and samples are collected and analyzed to develop a more complete CSM.	Comment noted.
37	Section 6.2.2 *Ex situ* Technologies Ex-situ incineration – FMC eliminated this option in the SFS because it involved waste excavation, but the ANL Review Team disagrees. The Review Team stated that excavation has been done in several instances at the FMC site, and furthermore, done without tents. Thus, why eliminate the technology for excavation reasons? The Tribes agree strongly	Comment noted.

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	with ANL's analysis of the issue and the technology, and note that this discussion is an illustration of how the SFS was flawed.	
38	**Chapter 7 " Primary " Recommendations** It is unclear why the word primary is used in the heading of this chapter. Are there other recommendations being made, that are not stated? Overall, this chapter is insufficient. ANL needs to be more critical as this report is supposed to be both a review and an evaluation. ANL has done a great job on a hard task. This chapter should be re-written after the meeting and subject to comments and discussion.	The Review Team will remove the word "*Primary*."
39	**Major Point: Between Table 6-1 and the beginning of the Recommendations chapter, the Review Team has eliminated *in situ***	There is no point in performing bench- and pilot-scale studies if the success of *in situ* treatment methods being tested cannot be measured. If the CSM could be refined to the point that an isolated and defined mass of P4 could be identified, it may be fruitful to perform a pilot-scale study to evaluate if a particular ETT can treat that isolated and defined mass of P4. Before proceeding, such a pilot-scale study would have to be preceded by bench-scale studies to address the uncertainties discussed in Section 6.2.1. Perhaps, by proceeding in such a step-wise fashion, investigators could

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	treatment without further pilot studies. In essence, this consideration has a basis, but there needs to be a caveat stating that if the CSM is revised and if the site is characterized more fully (especially the subsurface), then a re-analysis of *in situ* technologies would be warranted.	determine whether an in situ ETT has merit and, if so, scale up from the pilot scale as the presence/absence of P4 is defined in the remaining areas of the subsurface.
	Use of mature technologies with a proven track record is agreeable to the Tribes. However, for certain parts of the site, some of the lesser-practiced and used technologies may be optimum after testing for remediation. According to the Shoshone Bannock Tribes' Chairman, Blaine Edmo, "I am encouraged that this report does dispute the claims that there are no other technologies out there. In the past we were told that there were no other options.	It appears that there are technologies that can be used to measure and monitor phosphine gas. Phosphine gas measurement is particularly important when fumigating grain with some phosphide grain fumigants. Worker safety for fumigators requires an accurate monitoring device. Tube-type and direct reading electronic-type meters have been assessed in the past (with particular attention paid to monitoring in the IDLH concentration range; 50 ppm); see https://scholar.lib.vt.edu/ejournals/JPSE/v7/JPSEV7_1-9.pdf. Accuracy around dangerous concentration levels appears to be satisfactory. Vendors apparently manufacture equipment that can detect phosphine gas at concentrations well below and up to the IDLH level. For example, the RKI meter SP-205ASC can detect phosphine at concentrations as low as 0.3 ppm; see http://www.rkiinstruments.com/pages/sp205.htm.

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	I think this is encouraging, having at least 12 technologies listed. We want to move quickly to the next step, to talk with EPA about Phase 2."	
	ANL was asked to look at technologies that warrant more considerations. However, the "elephant in the room" is the lack of proper environmental monitoring - weather, temperature swings, wind storms, the dust storms that shut down the highways, air quality monitoring, and the failure to have a proper conceptual model for the site. "We do not have enough information about the site. We need a table of studies that need to be done in Phase 2. We said that whatever is below the furnace it is just a guess."	Draeger, Industrial Scientific, and BW Technologies also manufacture meters that can detect phosphine gas. So apparently, monitoring technologies exist to measure phosphine and provide for the management of phosphine-related risks. The Review Team will specifically note in the report that, in general, technologies do exist that can be used to monitor for phosphine gas. The monitoring technology would need to be matched with the ETT. However, implementation of any given ETT would require adherence to a health and safety plan (HASP). Monitoring is only one part of that plan. The HASP and any remedial action plans would have to address meteorological conditions and the potential for the off-site migration of contaminants. The Review Team focused on evaluating ETTs that can treat elemental phosphorus. It appears that there are technologies for monitoring and measuring phosphine gas should an ETT be implemented.
	Decision tree on ifs and the procedures is	Comment noted. Specificity and completeness are dependent upon what the remediation goals are and what ETTs are selected to achieve the remediation goals. The Review Team feels that this language, although it is generalized and simple, focuses on the key decisions that must be made before selecting remediation with an ETT.

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	oversimplified and was not requested in the SOW. It should either be removed or amended to include specificity and completeness.	
40	Chapter 8 Conclusions Most of the comments on the conclusions have been made elsewhere in the previous pages, including in the Executive Summary.	Comment noted. The conclusions and executive summary are meant to be a summation of the report and thus include information contained throughout the report.

APPENDIX H:

ARGONNE'S RESPONSE TO COMMENTS FROM THE U.S. ENVIRONMENTAL PROTECTION AGENCY

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APPENDIX H: ARGONNE'S RESPONSE TO COMMENTS FROM THE U.S. ENVIRONMENTAL PROTECTION AGENCY

Appendix H contains Argonne National Laboratory's (ANL's) responses to the October 19, 2015, review comments received from the U.S. Environmental Protection Agency (EPA) on the Draft Report: Independent Review of Elemental Phosphorus Remediation at the Eastern Michaud Flats FMC Operable Unit near Pocatello, Idaho, September 2015. Note that page and line numbers referenced in this appendix refer to an earlier draft of this document. Italicized text indicates changes that were made in response to the comments received from the EPA.

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Global 1			1. The Draft report contains several statements pointing out that the Conceptual Site Model (CSM) is not well constrained because few borings have been advanced in areas of subsurface elemental phosphorous. EPA agrees and believes that important contextual information should be included when stating that the nature/extent of subsurface P4 has not been well characterized. The health and safety concerns that have discouraged boring through pyrophoric P4 are genuine, and thus additional characterization efforts would be very challenging. EPA requests that ANL describe specific examples or approaches for how characterization of the subsurface elemental phosphorous mass could be accomplished safely.	Argonne assumes that EPA is requesting the inclusion of input on site characterization in this response, rather than inclusion of an amendment to the independent review report. Since site characterization is outside the scope of this Statement of Work, the Review Team only provides a general response here. The cleanup programs implemented at sites with significant site worker health and safety concerns, such as U.S. Department of Energy (DOE) and U.S. Department of Defense sites, are instructive in this case. At the Aberdeen Proving Ground (APG), the State of Maryland and APG staff are challenged with investigating sites contaminated with elemental phosphorus, chemical warfare agents (with both a dermal and inhalation hazard), unexploded ordinance, volatile organics, biohazards, radioactive components, and inorganic constituents. Over the tenure of the APG Installation Restoration Program, investigation efforts proceeded in phases, with a gradual reduction in risk and hazard management (personnel protective equipment [PPE] levels, hazard monitoring, air monitoring, explosive ordinance avoidance, decontamination requirements, etc.) as more was learned about the hazards associated with site characterization. For example, initial characterization efforts involved modified Level A PPE and may have involved remotely operated drilling equipment (see http://info.ngwa.org/gwol/pdf/880156108.PDF). As more was learned about site hazards, PPE levels were downgraded from Level A to B to C, air monitoring was modified, and the availability and rigor of decontamination teams were relaxed, for example. The DOE cleanup program involved developing an alternative and innovative approach for sampling in the interest of mitigating risks to remediation workers. For example, cryogenic drilling may be a viable approach to use

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				to characterize P4 in the subsurface (see https://frtr.gov/pdf/cryogenicdrilling_2.pdf). Cryogenic drilling could be coupled with flooding the borehole with an inert gas, while exploratory borings could be staged in a water-filled drop tank. The Review Team will acknowledge that the risks to investigator workers are/were genuine, but that, apparently, no attempt was made to refine the CSM using other than routine, intrusive sampling approaches.
Global 2			2. ANL stated plainly during their September 21, 2015, presentation to the Tribes and EPA's Office of Superfund Remediation and Technology Innovation (OSRTI) that it substantially relied on the same data as other parties (i.e., EPA, FMC, and their respective consultants). ANL, however, arrived at different conclusions regarding a key issue: ANL believes P4 in soil can be safely excavated at the FMC Operable Unit (OU). ANL should make sure it clearly communicates that conclusion in the final report.	The Review Team will make clear that a subset of the P4 waste can be safely excavated. Specifically, it appears that P4 waste can be safely removed from the historical ponds, since process knowledge can be used to appraise any risk to site workers, and since FMC has past experience in removing P4 waste from both the historical ponds and the so-called "RCRA ponds." In the case of subsurface P4 present, for example, beneath the Furnace Building and within the abandoned railcars, the Review Team has communicated the fact that additional CSM refinement would be needed to even evaluate excavation and treatment technology (ETTs). The Review Team will include the following language in the Abstract, Executive Summary, and Summary and Conclusions. Abstract ES-2, Line 4: … *was not refined enough to allow the Review Team to draw conclusions about using some of the ETTs to treat P4 waste in those areas. The readiness of an ETT for implementation varies depending on many factors, including stakeholder input, permitting, and remedial action construction*

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				requirements. Technologies that could be ready for use in the near term (within 1 year) include the following: mechanical excavation, containment technologies, off-site incineration, and drying and mechanical mixing under a tent structure. Technologies that could be ready for use in the mid-term (1 to 2 years) include cutter suction dredging, thermal-hydraulic dredging, and underground pipeline cleaning technologies. Technologies requiring a longer lead time (2 to 5 years) include on-site incineration, a land disposal restriction waste treatment system, an Albright & Wilson batch mud still, post-treatment on-site disposal, and post-treatment off-site disposal. Similar language will be added to ES-6, Line 42, and Pg. 137, Line 12: …then the Review Team concludes that several of the *ETTs could be used in combination to treat only a subset of the P4 waste present at the site. Concerns about the health and safety of investigation site workers using the then-available investigation approaches prevented the collection of subsurface samples containing P4 from large areas of the site, including, for example, the railroad swale, the vadose zone beneath the Furnace Building, and the abandoned railcars. It appears that no attempt was made to experiment with or to use alternative characterization methods (such as modified PPE, nonintrusive techniques, remotely controlled sample collection equipment, cryogenics, etc.) as part of the investigation. As a result, the CSM in those particular areas is not refined enough to allow a full evaluation of ETTs and to allow the Review Team to*

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				draw conclusions about the efficacy of the ETTs examined. However, in other areas of the site, for example, the historical ponds, process knowledge (information about the process waste stream discharged to the historical ponds), and the information gathered during both the CERCLA investigations and the RCRA-related investigations, provide the information needed to determine whether or not the ETTs considered warrant further consideration for P4 in those areas. Similar language will be added to ES-6, Line 42, and Pg. 137, Line 12.
Global 3			3. The report provides a list of ETTs for P4 that could be applied at the site. Recognizing that no one technology would be sufficient to … address all P4 in soil, the information would be more usable if ANL more clearly indicated where within the OU specific technologies might be most applicable and implementable. This would focus any follow-on work after Phase 1 on the most viable technologies. Perhaps to illustrate this, ANL could provide one or two examples of a combination of technologies that would substantially address P4 throughout the spatial extent of the OU. This might take the form of a 'compartment' approach where one technology addresses one volumetric waste area and another addresses a different area to best match the waste and site characteristics with the technology's strengths, and for each combination or technology indicate what amount of 'completeness' of excavation and treatment would be expected.	The Review Team was asked to identify ETTs that "warrant further consideration" as stated in the Work Order. As stated in the response to Global Comment 2 above, the Review Team has tried to make clear in the Final independent review report that for a subset of the P4 waste present at the site, a number of ETTs warrant further consideration.

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Global 4			4. EPA appreciates that ANL attempted to address relative cost; however, ANL did not use the most expensive 2011 FFS alternative as its comparison point. Perhaps it would be more informative to use more FFS alternatives as cost reference points to provide a range for the ETTs. That would provide more substance on expected costs rather than considering every ETT being greater than $81 million as is currently presented by ANL.	See the response to General Comment 8.
Global 5			5. ANL attempts to speak to the implications of RCRA throughout the document, including Corrective Action Management Units, Bevill Amendment/Exemption, and Land Disposal Restrictions both for off-site treatment and disposal and on-site treatment and (treatment residuals) disposal. Unfortunately, ANL's discussion on RCRA is generally inaccurate, and some references to RCRA subsections are also incorrect. For example, in a number of places in the document, it indicates that that waste residuals could be treated to meet RCRA LDRs or managed as part of an on-site CERCLA remedy or in a CAMU. If subject to LDR ARAR requirements, short of an ARAR waiver, residuals [cannot] simply be managed in on-site CERCLA landfill without also meeting LDRs or alternatively CAMU treatment ARAR requirements (see for example Post Implementation Impacts summary on Pg. 87, Line 14, and on Pg.. 128). Instead of ANL spending time making voluminous corrections on RCRA throughout the document, EPA recommends that ANL make a simple statement	Argonne acknowledges that EPA may interpret some of the RCRA implications discussed in the Draft report differently than Argonne. Argonne agrees to placing verbiage into the report that addresses RCRA complexity and potentially different RCRA interpretations of regulatory requirements. A paragraph will be added at Pg. 33, Line 36, as follows: *While the FMC OU is a CERCLA cleanup site, the waste that may be produced as a result of active remediation at the site is subject to RCRA regulatory requirements. Wastes exhumed from the site become immediately subject to RCRA's waste management requirements, as do facilities that may be used to treat or otherwise manage these wastes, and also residuals remaining if and when these wastes are treated in some fashion. As RCRA requirements are considered during the CERCLA ARAR process, it is imperative that RCRA requirements are adequately addressed in determining management requirements for wastes that are exhumed from the site and also for waste treatment residuals. In addition, and as allowed by CERCLA, EPA could, with adequate justification, choose to waive certain requirements through one of the statutory ARAR waiver approaches (see http://www2.epa.gov/superfund/applicable-or-relevant-and-*

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			early in the document (perhaps in the Guiding Principles section) saying that RCRA LDRs and requirements for Treatment, Storage and Disposal Facilities may be pertinent to some ETTs. ANL could further state that they assume these requirements could be met, or in the case of activities that occur physically at the Eastern Michaud Flats site EPA could choose to waive certain requirements through one of the statutory ARAR waiver approaches (http://www2.epa.gov/superfund/applicable-or-relevant-and-appropriate-requirements-arars).	*appropriate-requirements-arars). Most notable of the RCRA requirements applicable to wastes that may be exhumed from the site and for treatment residuals are the RCRA LDR requirements, which are discussed frequently in this report. In accordance with these requirements, wastes determined to be hazardous must be treated in accordance with strict requirements before they can be land-disposed. RCRA LDRs and requirements for treatment, storage, and disposal facilities may be pertinent to some of the ETTs discussed in this report, in particular, those designed to remove the RCRA characteristics of ignitability and reactivity from the waste (i.e., address the P4) and also to address heavy metals that may be contained in remediation waste or in treatment residuals.*
Global 6			6. ANL's connection of the IRODA's definition of a CERCLA Principal Threat Waste (P4 exceeding 1,000 mg/kg) has no connection to P4's RCRA characteristic hazardous waste definition. ANL should note that no minimum P4 level in wastes has been established by EPA to define whether or not such wastes would be considered to meet the RCRA reactivity characteristic criteria. However, the RCRA consent decree required FMC to treat the P4 contaminated wastes by "permanently and irreversibly bonding the waste into the molecular structure of a solid product such that the treated waste will not undergo changes that cause it to release toxic gases in concentrations greater than 0.3 ppm phosphine or 10.0 ppm hydrogen cyanide, or leach heavy metals-in concentrations greater than applicable LDR Universal Treatment Standards." ANL may find the RCRA consent	Argonne acknowledges that to date, the EPA has not established a minimum P4 level in wastes to define whether or not such wastes would be considered to meet the RCRA reactivity characteristic criteria. Argonne would observe that this same statement applies equally to the ignitability characteristic, as P4 present in wastes to a significant degree would render that waste both ignitable and reactive per the RCRA definitions of these characteristics. That said, Argonne believes that, should P4-containing soil and debris at the FMC OU be actively remediated, EPA and stakeholders will need to come up with a de facto definition of what would be considered the cutoff for ignitability and reactivity, specifically addressing P4 content. The treatment requirements laid out in the RCRA consent decree alone are insufficient as a definitive cutoff for P4 content and the RCRA characteristics of ignitability and reactivity. We note that simply defining phosphine and hydrogen cyanide emissions is inadequate as a definition for reactivity. These

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			decree requirement useful in identifying potential treatment goals in its assessment. Regardless, EPA asks that ANL include projections for each ETT on the extent/amount of treatment or removal, either qualitatively or quantitatively, based on information available to ANL (i.e., for excavation beneath the furnace building what extent of contaminated soil would reasonably be excavated).	emissions are a function of many different variables, including temperature, atmospheric pressure, and soil moisture content, just to name a few. More important, these criteria also do not address ignitability. A more comprehensive definition is needed, preferably one that is quantitative as well as readily straightforward to implement (a simple analytical method). A simple concentration cut-off of P4 within wastes that may be exhumed is most desirable. This is needed to define what waste exhumed from the site will need to be actively remediated (i.e., treated), as well as to determine whether the LDR "deactivation" treatment requirement is satisfied. Argonne will clarify within the report the connection of the *Interim Record of Decision Amendment*'s (IRODA's) definition of a CERCLA Principal Threat Waste (P4 exceeding 1,000 mg/kg) to P4's RCRA characteristic hazardous waste definition. EPA also asks, however, that Argonne include projections for each ETT on the extent/amount of treatment or removal, either qualitatively or quantitatively, that would be needed. Argonne finds that it is difficult to fulfill this request without having first defined a level within the waste that would cause that waste (or treatment residual) to meet the RCRA definitions of ignitability and reactivity. The changes made in the Draft report are to add a new paragraph at the end of Section 2.5.2.2, as follows: *Argonne notes that EPA has not established a minimum P4 level in wastes to define whether or not such wastes would meet the RCRA ignitability or reactivity characteristic criteria. Argonne's connection of the*

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				IRODA's definition of a CERCLA Principal Threat Waste (a P4 concentration exceeding 1,000 mg/kg) is made in an attempt to establish a concentration for P4 in waste that would define that waste as RCRA ignitable and RCRA reactive. This is necessary because, if the P4 contaminated soil and debris at the FMC OU is to be actively remediated, a de facto definition of what would be considered the cutoff for ignitability and reactivity specifically addressing P4 content is needed. In addition, the RCRA LDRs for these characteristics, which specify a "deactivation" treatment requirement, would need to be satisfied, unless, as indicated above, EPA elects to waive these requirements through one of the statutory applicable or relevant and appropriate requirement (ARAR) waiver approaches. *The RCRA consent decree required FMC to treat the P4-contaminated wastes by "permanently and irreversibly bonding the waste into the molecular structure of a solid product such that the treated waste will not undergo changes that cause it to release toxic gases in concentrations greater than 0.3 ppm phosphine or 10.0 ppm hydrogen cyanide, or leach heavy metals in concentrations greater than applicable LDR Universal Treatment Standards." These treatment requirements, as laid out in the RCRA consent decree, are insufficient as a definitive cutoff for P4 content and the RCRA characteristics of ignitability and reactivity. Simply defining phosphine and hydrogen cyanide emissions is inadequate as a measure of reactivity. These emissions*

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				are a function of many different variables, including temperature, atmospheric pressure, and soil moisture content, just to name a few; more important, however, these properties do not address ignitability. A more definitive definition is needed, preferably one that is quantitative as well as readily straightforward to implement (i.e., a simple analytical method). A simple concentration cutoff of P4 within wastes that may be exhumed is most desirable. Should the FMC OU be actively remediated at some point in the future, Argonne's connection of the IRODA's definition of a CERCLA Principal Threat Waste (a P4 concentration exceeding 1,000 mg/kg) to the RCRA ignitability and reactivity characteristics may be considered an interim starting point in the eventual establishment of a cutoff for P4 content for RCRA ignitability and reactivity (EPA 1999).
Global 7			7. Soil and debris at the FMC OU also contain radionuclides and heavy metals. ANL should clearly indicate metals and gamma radiation co-contaminants co-mingled with P4 would need to be addressed ultimately with final disposition of residual materials. This in particular may add complexity and cost for off-site treatment or disposal even if ETTs address P4.	The Review Team has noted that radionuclides and metals present in the waste would need to be addressed for the off-site disposal option and for the on-site incineration ETT. Not mentioned is the fact that naturally occurring radioactive material (NORM) contamination is also relevant for an off-site incineration ETT. Section 5.3.7.2 will be modified as follows (Pg. 101, Line 17): Performing a waste acceptance survey is outside the scope of this independent review. As indicated in the Case by Case Extension discussed in Section 5.3.7.1, the presence of NORM in the waste stream has, in the past, precluded some off-site facilities from accepting P4 waste. The Review Team has not determined if the NORM content would be an issue for off-site incinerators at the present time. However, the

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				NORM content of the P4 waste may add to the complexity and cost for the treatment of P4 waste and the off-site disposal of incinerator residuals. It is unknown whether waste residuals generated as part of a historical pond remediation program might now be acceptable at an off-site TSD facility. The review parameter overall discussion of advantages and disadvantages, Table 5-18 (Pg. 103), will be modified as follows: After initial treatment, additional treatment might be required to meet WAC at off-site disposal facilities. *Both the initial treatment facility and any final off-site disposal facility may have to accept waste containing NORM. The NORM content of the waste may add to the complexity and cost.*
			General Comments (Gen.)	
1	Gen.		Suggest that ANL include a specific statement that this report is not a Feasibility Study and is not a review/critique [of] the existing RI, FS and EPA's selected remedy in the Interim Record of Decision Amendment.	The abstract, executive summary, Section 1.1, Summary of Issues at the FMC Operable Unit, and Section 8, Summary and Conclusions already summarize the impetus, intent, and the general content of the independent review.
2	Gen.		EPA did not cross reference every citation in the text with the references found in Section 9. EPA asks ANL to ensure thorough citations of factual information throughout the text, and inclusion of those sources in Section 9. Additionally, ANL can assist EPA, the Tribes, and others with potential 'next steps' for the FMC OU by including in its Response to Comments document a full list of references it reviewed or considered in its review, even if those sources were not directly cited in the report. In addition, EPA further requests that any	The main assumptions that ANL has made are included as the guiding principles. Otherwise, the authors explicitly state if an assumption has been made.

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			assumptions ANL makes or uses to make determinations in their report be identified and provided in the report.	
3	Gen.		EPA would benefit from ANL insights regarding whether the focus of the application of ETTs should be on the high mass areas or the whole OU. ANL could then identify key CSM gaps introducing main ETT/combined remedy uncertainties that could be addressed through further characterization and interpretation.	The focus on the application of ETTs is a decision best left up to the stakeholders. The Review Team agrees that there is insufficient information to remediate what is referred to here as “the high mass areas.” The Review Team also agrees that there is sufficient information to remediate P4 in other areas, such as areas where process knowledge can be used to characterize P4 waste and determine site worker hazards indirectly. However, there is a range of opinions among the four members of the Review Team on remediating other portions of the site. One member favors a status quo approach, that is, implementation of the remedy in the *IRODA*. One member feels much of the P4 in the historical ponds and in the RCRA ponds can and should be remediated. One member feels that only Pond 16S, a “RCRA pond,” or any RCRA pond that is actively emitting phosphine or damaging technology control features (liners, covers, piping, leachate recovery, etc.), should be remediated.
4	Gen.		Language in the Executive Summary (ES) and throughout the report states that P4 waste is also present at the former FMC plant in waste disposal units that were permitted to operate under RCRA. This is not an accurate statement. A RCRA permit has not been issued for the FMC waste disposal units. The RCRA Ponds are being managed under RCRA Post-Closure Plans. FMC did file	The text will be modified throughout to indicate that the “RCRA ponds are being managed under RCRA post-closure plans.” Pg. ES-3, Line 32, will be modified as follows: ... *waste disposal units that underwent closure under the Resource Conservation and Recovery Act (RCRA) and*

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			notifications and Part A permit applications to achieve interim status authorization for several hazardous waste TSD units. However, FMC did not obtain interim status for a number of the Waste Ponds subject to RCRA because the Part A applications submitted for those ponds were not timely. Failure to comply with applicable RCRA requirements was the basis for an EPA enforcement action that resulted in a Consent Decree that was entered by the court in 1999 requiring the waste disposal units subject to RCRA to close.	*that are now being managed under RCRA post-closure plans.* Pg. 14, Line 7: Section 2.3 will be modified as follows: … waste disposal units that are being managed under RCRA post-closure plans. P4 waste is also present in portions of the plant that were not regulated under RCRA…
5	Gen.		Language in the ES and throughout report states that that waste units subject to RCRA underwent closure prior to plant shutdown in 2001. This is not accurate. A number of the RCRA ponds were not closed until well after 2001.	The modifications suggested for Global Comment 4 above will address this comment.
6	Gen.		The Draft report contains several statements pointing out that the CSM is not well constrained because few borings have been advanced in areas of subsurface elemental phosphorous. EPA agrees and believes that important contextual information should be included when stating that the nature/extent of subsurface P4 has not been well characterized. The report should affirm that health and safety concerns, which have discouraged boring through pyrophoric P4, are genuine, and thus additional characterization efforts would be very challenging or, alternatively, describe how characterization of the subsurface elemental phosphorous mass could be accomplished safely.	See the Response to Global Comment 2.

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7	Gen.		The "overall discussion of advantages and disadvantages" of each ETT within the assessment tables (e.g., Table 5-3) contains a wealth of useful information. Each of the advantages and disadvantages should be "bulleted" or otherwise clearly delineated to make this information easier for the reader to digest.	The Review Team will modify the noted tables and use bullets as suggested when the information can be summarized in that way.
8	Gen.		Each ETT evaluated appears to have high cost as a disadvantage in the assessment tables. The phrase consistently used is "This ETT would likely exceed the $81.6 million net present value cost for Soil Alternative 4, the most expensive soil alternative evaluated in the Supplemental Feasibility Study (MWH 2010)." This statement neglects to recognize Alternatives 5 through 7, which were developed to varying degrees during and following the Supplemental FS process, are contained in the Administrative Record, and were presented in the September 2010 Proposed Plan. Alternatives 5 through 7 all included varying degrees of excavation and treatment using the most promising excavation and treatment technology, caustic hydrolysis. These alternatives have an estimated net present value cost of $405 million to $950 million, based upon high, medium, and low volume estimate assumptions about the (largely uncharacterized) mass of subsurface P4. ANL may choose to include Soil Alternatives 4–7 as cost comparison points for its ETTs.	In the description of the review and evaluation parameters (Table 3-1), "Limitations," a discussion will be added to the table with the following explanatory note: *The Work Order directed the Review Team to not include CERCLA's nine evaluation criteria, one of which is cost, as evaluation parameters. However, EPA and the Tribes agreed that cost could be included in the content of the review and evaluation parameter referred to as "Limitations."* In the text below Table 3-1, the following is included: *Cost as a limitation factor has been included to allow a rough order of magnitude (OOM) comparison with the ETTs evaluated. The net present value (NPV) cost of Alternatives 5 through 7 in the September 2010 Proposed Plan (which included excavation and treatment) is an estimated $405 million to $950 million, based upon high and low volume estimate assumptions about the (largely uncharacterized) mass of subsurface P4 (EPA 2010). Since some ETTs also involve excavation followed by treatment, the NPV determined for Alternatives 5 through 7 provides a comparable OOM estimate.* The Review Team will remove the noted language about the feasibility study from all discussions of advantages and disadvantages in each ETT table and include this language in

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				the review and evaluation parameters under limitations for each ETT as follows: *The NPV estimate for Alternatives 5 through 7 in the September 2010 Proposed Plan would be a comparable OOM estimate to implement this ETT.*
9	Gen.		Some ETTs include recovery of marketable elemental phosphorous and others do not. This is generally described in the report and assessment tables. EPA suggests that an additional table summarizing relative P4 recovery by ETTs would be helpful.	Recovery rates for P4 waste would be waste-specific and technology-specific. Recovery rates for P4 are unknown, so it would be difficult to create a table summarizing relative P4 recovery by an ETT.
10	Gen.		The Draft report clearly describes the uncertainty surrounding the specific retention (Pg. 13, Line 21) of liquid elemental phosphorous, and methods which could be used to constrain that uncertainty. However, the significance of this uncertainty when assessing different ETTs is not entirely clear. EPA suggests a table be developed which identifies ETTs where a reduction in uncertainty about specific retention would make a significant difference when implementing the ETTs.	A portion of the discussion of specific retention on Pg. 13 (Lines 24 to 46) will be moved to the section on in situ technologies to make it clear that uncertainties surrounding specific retention would only be applicable for the in situ technologies.
11	Gen.		ANL seems to dismiss in situ technologies in its evaluation because the distribution of subsurface P4 is largely unknown for health and safety reasons. The implication is that in situ technologies might hold promise if the distribution of subsurface P4 could be characterized with a higher degree of certainty. Per ANL Table 6-1, there are no known successful in-situ P4 treatment examples of any scale ever successfully demonstrated. If there were any examples, it might better support the need to refine the CSM. This rationale underscores the importance of stating clearly	In Section 6.2.1, the Review Team points out uncertainties about two different things: uncertainties about the CSM and uncertainties about the in situ technologies themselves. The Review Team did not mean to imply that in situ technologies would automatically hold promise if the CSM uncertainties were eliminated. In fact, during the September 21, 2015, presentation of the Draft independent review report, one member of the Fort Hall Tribal Council indicated that a heated injection well located at the west end of the Furnace Building was used to dispose of waste P4. An online database of wells was searched for a possible injection well(s) at the west end of the Furnace Building (Idaho Department of

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			whether or not subsurface P4 waste can reasonably be safely characterized.	Water Resources 2015); however, the data in this source are only as recent as 1992, so the possibility of an older injection well could not be confirmed. The potential presence of a P4 injection well adds to the uncertainty about the contaminant CSM. In addition, on pages 122 and 123, six key in situ technology-specific uncertainties have been highlighted. These uncertainties are based on the best information available. In response to the comment about successful in situ P4 treatment examples: Table 5-1: Process maturity will be modified as follows: *Mature for remediation of some waste. The potential application of the technology for P4 waste is conceptual only*. Table 5-3: Process maturity will be modified as follows: *Mature for broadly defined solvent leaching. Immature for use of food oils. Application of the technology to address P4 waste is conceptual only*. Table 5-6: Process maturity will be modified as follows*: Mature, but the technology has never been applied to P4 waste*. The CSM suggests that P4 beneath the former Furnace Building exists as almost a single large mass. That contaminant CSM may or may not be true. The contaminant CSM is a key first step in even conceptualizing, let alone evaluating, in situ technologies. The Review Team will include the following language on Pg. 122, Line 3, after “best guess”:

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				The inferred contaminant CSM may or may not be true. The P4 may also have behaved like a dense nonaqueous phase liquid (DNAPL) and be present as DNAPL-like "ganglia"; blobs; and smear zones in a more widespread, dispersed contaminant mass than is depicted. Such a dispersed contaminant distribution may be more amendable to treatment using in situ ETTs. However, since there have been only limited attempts to characterize subsurface P4 because of investigation worker health and safety concerns, it is difficult to identify and evaluate in situ ETTs.
12	Gen.		A Glenn Springs (Occidental Petroleum) site is described and used as an example (e.g., Table 6-1) in more than one part of the report, but its location is not provided. The location of each P4 cleanup site described or used as comparisons should be included.	Pg. 29, Line 20, will be modified to reference *Ducktown, Tennessee.* The locations of other P4 sites are included in this summary.
13	Gen.		The summary and conclusions state that "The Tribes favor the permanent removal and/or treatment of contaminants." Yet information in the Draft report suggests that none of the ETTs will permanently remove or treat all contaminants. The Final report should indicate whether there is the potential to fully remove or treat the P4 to provide clarity on how well a remedy could be responsive to what the Tribes favor.	Because the P4 cleanup level seems to be fluid, the Review Team discussed several potential P4 cleanup levels and/or ways in which the cleanup levels might end up being derived. As a result, the success of a treatment can only be discussed in a general sense. Whether or not a given ETT can fully remove or treat the P4 is included in the review and evaluation parameters. Also discussed in the review and evaluation parameters and in the discussion on each ETT is whether other constituents of concern like metals and radionuclides would need to be addressed post-P4 treatment. In addition, as discussed in the abstract, executive summary and main text, the Review Team believes that ETTs in combination could be used to treat a subset of the P4 waste present at the site, but not all of the P4 waste.

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14	Gen.		ANL stated plainly during their September 21, 2015, presentation to the Tribes and EPA OSRTI that it relied on the same data as other parties (EPA, FMC, their respective consultants); however, ANL arrived at different conclusions regarding a key issue: can P4 in soil be safely excavated? ANL concluded P4 could safely be excavated at the FMC OU. ANL should make sure it clearly communicates that conclusion in the report. It would also be helpful if ANL gave a few specific examples of divergence on the excavation safety issue (e.g., is it practical to use temporary structures to contain and manage combustion gases?).	In Section 4, Lines 10-13, the Review Team states, as a guiding principle: • It appears that technologies to safely excavate, size, create waste feed materials, and temporarily store P4 waste in preparation for treatment in a "downstream" ETT exist (hereinafter, these are called "ancillary technologies"). The following language will be added on Pg. 34, Line 9: *In reference to a key issue — whether P4 can be safety excavated — the Review Team arrived at different conclusions than other parties. On the basis of a review of information, it appears that a subset of the P4 waste present at the site can be safely excavated. There appears to be a history of sludge removal from the ponds at the FMC plant. In the FMC response included in Appendix E of the* independent design review report, *there are several references to excavation. Appendix E describes both dredging and mechanical excavation activities involving Ponds 8s, 8e, and 9e, Pond 15s, and Pond 18. Furthermore, the LDR WTS was designed to treat sludge dredged from Pond 8s. The Pond 8s dredge was designed as a component of the LDR WTS. In an EPA-authored reference, reclamation processes consisting of excavating pond materials is described as having occurred at historical Ponds 1s, 2s, 3s, 9s, 2e, and 4e (EPA 2003).* *The excavation of P4 is also addressed at other P4 plants.* T*he Clarifier Treatability Study Phase 3 Report on the Rhodia/Solvay Site, Silver Bow, Montana (which was not available when the IRODA was prepared)*

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				contains a description of the removal of clarifier sludge from the clarifier by use of a Cat 320 excavator (Franklin Engineering Group 2012). Also of interest is a description of mechanical excavation in the Phase 1 report on the same Rhodia/Solvay clarifier. "Conventional earth working equipment, such as tracked excavators, back hoes, and clam shells, can be used to excavate the solidified sludge and transfer it to a shipping container or processing system. With careful operation, the phosphorus can be transferred with a water cover in the bucket to minimize mass burning" (Franklin Engineering Group 2007).
15	ES-2	4	Timeframes are attached to "readiness" of various technology groups (i.e., within 1 year, 1–2 years, etc.). It is not clear where these numbers came from or what is being referred to as "readiness." While the document acknowledges that "readiness" depends on many factors, including stakeholder input, permitting, and remedial construction requirements, it underestimates the administrative process and time necessary for any of these technologies to be "ready" to implement at the FMC site. Further, the CERCLA permit exemption would apply to CERCLA cleanup activities at the FMC OU and thus should not be included in the "readiness" calculation. In addition to the factors listed, the report indicates that all ETTs will require additional site characterization and engineering designs. The report should provide how these estimates were developed and what impacts the "readiness" estimates have for different technologies. Do some have a longer	The Review Team agrees that the concept of "readiness" needs to be discussed further in the independent review report. The EPA notes that the independent review report underestimates the administrative process and time necessary for these technologies to be ready, while noting that the permit exemption would apply to CERLCA cleanup activities (which would speed up remedy implementation). While it is true that CERLCA permit exemptions apply to CERCLA cleanup activities, given the stakeholder involvement at the site, the administrative component needed to come to an agreement on any remedy different than the IRODA would likely involve a long lead time. In addition, the CERCLA permit exemption would not apply for ETTs with an off-site component. Pg. 136, Line 6, will be amended as follows: After "in Table 7-1": *Readiness in this case is an estimate based on best professional judgment. The timespans noted for*

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			"readiness" time because additional research and development is required? Suggest putting specific duration estimates for major process steps to give a more accurate picture of the full time horizon to implement these various ETTs. For example: • CSM refinement – X to Y years • Treatability/pilot testing (if necessary) – X to Y years • CERCLA remedy evaluation and selection process, including public input – X to Y years • Remedial design – X to Y years • Contract procurement and remedial action work plan development – X to Y years • Remedial action implementation – grouped or listed with "X to Y years" estimates for each ETT	*readiness are most useful when comparing ETTs to each other in that some ETTs probably require more preparation time before implementation than others. The accuracy of the timespan estimate is best for the "near-term" readiness category. For example, the near-term category (within 1 year) is estimated to be correct for technologies with real-world examples that are available currently. By way of example, as noted in the text, P4 waste from FMC and other sites has been mechanically excavated, containerized, and shipped off site for treatment in an off-site incinerator. Accuracy decreases for the mid-term and the long-term readiness category. ETTs that could be readied in the mid-term would require a longer preparation time because the ETTs (dredging or the pipe cleaning technologies) would likely require a water component involving modification and operation of the P&T system (to provide access to a water source) and preparing containment features to allow for the excavation footprint to be flooded. ETTs in the long-term readiness category are assumed to require a longer lead time to address design and approval requirements and waste acceptance criteria.*
16	ES-2	20	The interim ROD Amendment issued in 2012 was for the FMC Operable Unit only, not the Eastern Michaud Flats Superfund site.	The Work Order to ANL included a mention of both Eastern Michaud Flats and the FMC OU. Any reference to the Eastern Michaud Flats Superfund site will be modified to include a mention of the *FMC Operable Unit.*

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17	ES-2	22	The 2010 RI/FS should be identified as the *Supplemental RI/FS* to avoid confusion with the RI/FS completed in 1998.	The text will be changed as follows: *Supplemental Remedial Investigation Feasibility Study – Supplemental RI/FS and/or Supplemental FS*.
18	ES-3	27	In paragraph 2, and in several other places in this report, the statement is made that the buried railcars are suspected to contain nearly pure P4. This is not consistent with documentation available in the administrative record. All documentation that is available on the location and potential disposition of the railcar(s) is summarized in Appendix B of the Supplemental FS and should be referenced. There is no evidence in the administrative record as to the condition or content of the railcars when buried. ANL may choose to identify disagreements between the [administrative record] and other information sources on this topic; however, sources should be cited. In addition, this point was also challenged by the Tribes at the Tribal Business Council meeting by a tribal member who is a former FMC employee.	The Review Team did rely on Appendix B of the *Supplemental FS*. Language in Section 5.5.2.1 will be changed as follows: Twenty-one railroad tank cars are present in RU 19c, which is about 2.7 acres in size and is located in the center of the slag pile (RU 19). The railcars were placed at the then-southern edge of the slag pile in 1964 and were covered with native soil. *The amount and purity of the P4 sludge present in the railcars are uncertain. As reported in Appendix B of the Supplemental FS, the sludge was nearly pure (95% P4), and the capacity of the railcars was 10% to 25%. Here is language from Appendix B of the Supplemental FS:* ***"1.3.3 Description of P4 Sludge Generation and Management*** *P4 was typically very pure, white phosphorus. However, due to a number of process variables, ore, silica and/or coke dust, along with other condensables would pass through the electrostatic precipitator in trace amounts and end up with the liquid P4 product. These insolubles would rise to the top of the liquid P4 as it was stored in a liquid state and eventually concentrate to form what was referred to as P4 sludge. The sludge typically ranged from 75 to 95% P4. The P4 sludge was much more viscous and would not easily pump from the sumps and tanks. Therefore, over time P4 sludge would build up within the storage vessels and railcars."*

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				And as reported in Section 2.2.2 of Appendix B: ***"2.2.2 Contents of the Railcars*** *As described in Section 1.0, it is expected that the railcars contain about 10 to 25% of their total capacity as P4 sludge. However, it is not known if the railcars were filled with water or nitrogen prior to transportation to the slag pile area for burial."* *Ironically, the information in Appendix B of the Supplemental FS conflicts with the information that summarizes the contents of the railcars in the main body of the same Supplemental FS report: The Supplemental FS reports in* ***2.3.3.4 Railroad Cars in Slag Pile (RU 19c) "****that the railcars contain an estimated 10 to 25% P4 sludge." Also included in the main body of the Supplemental FS is the following: "<u>Summary of Pertinent SFS Information for RU 19c:</u> P4 concentrations of the sludge within the railcars range from 10 to 25%"* *It appears that the main text of the Supplemental FS transposed the percentage of capacity and the percentage of purity.* Sludge resulted from both the manufacturing process and from shipping P4 in railcars…. Any reference to pure or nearly pure P4 will be changed to "*concentrated*" or "*potentially highly concentrated.*" Pg. 113, Line 19, will be modified as follows: *The conflict regarding the relative purity of the P4 present in the*

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				railcars (25% vs 95%) is another uncertainty that could be resolved if the abandoned railcar CSM is refined in the future
19	ES-3	28	The document states that "elemental phosphorus in various forms may have affected the native soils at the site." There is direct evidence that P4 has indeed impacted native soils.	"*May*" will be changed to "*has*."
20	ES-3	34	The assumption regarding obtaining all water from the groundwater pump-and-treat system may not be accurate due to treatment volumes and water right issues. The extraction and treatment rate target will be established during Remedial Design; 600 gpm may be a reasonable assumption. ANL should indicate about how much water would be needed for each technology.	The amount of water required for each technology is unknown. The Review Team has inferred that a 600-gpm flow would probably be sufficient to be incorporated into a phased excavation approach, wherein water could be used to flood a portion of a historical pond footprint in order to allow hydraulic dredging to occur, for example.
21	ES-3	35	The statement is made that the review team did not evaluate impact of the RCRA ponds on potential "implementability" of the ETTs. ANL should make sure the Phase 1 Independent Review scope, and the intentional 'exclusion' from the ANL Phase 1 work, is clearly communicated for the reader, preferably in the beginning of the document.	On Pg. ES-3, Lines 35 and 36, the Review Team states that the independent review did not focus on the closed disposal sites that were regulated under RCRA. The reference to the ability to implement is included in the independent review because the Review Team did not evaluate moving, or shoring up, a RCRA pond in order to gain access to a historical pond.
22	ES-4	28	ANL should provide and discuss their rationale for determining that the location, quantity, and concentration of P4 in the soil and fill throughout the OU in 2015 present the same or different hazards than the original manufacturing process where conditions were somewhat controlled. It may be useful if ANL reviews and refers to how this issue was documented in the Supplemental	The Review Team makes this statement because documents examined by the Review Team suggest that during routine P4 manufacturing operations activities somewhat similar to the tasks required for remediation workers were performed. Furthermore, during the presentation given by the Review Team to the Tribes on September 21, 3015, attendees at the meeting who worked at the former FMC plant indicated that some activities performed by plant workers would probably be similar to the activities required for the performance of site

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			FS, particularly if ANL has arrived at different conclusions.	remediation. For example, surface impoundments containing P4 waste were periodically excavated or dredged, and railcars containing P4 and P4 sludge were periodically cleaned out.
23	ES-5	38	Based on the information presented throughout the report, all ETTs would present significant safety and cost issues. Suggest that the report describe in greater detail what makes these issues even more of a concern for in situ technologies.	The language on Pg. ES-5, Line 38, will be altered as follows: *The significant cost and safety issues would primarily be associated with the need to refine the CSM and to perform bench- and pilot-scale studies.*
24	ES-6	1	This last sentence seems to be in conflict with other statements throughout the document that indicate several ETTs warrant further consideration despite the acknowledged uncertainties with the CSM.	The noted sentence is referring to the abandoned railcars.
25	ES-6	9	It seems that all of these ETTs would need to be coupled with other technologies, not just "containment technologies."	Pg. ES-6, Line 7: The phrase "coupled with other technologies" will be removed.
26	ES-6	35	It would be helpful if the report included more specific information about the potential impacts to community health and safety, the environment, schedule, and costs.	The Review Team includes information about potential impacts to community health and safety and the environment in the discussion about each ETT in the tables documenting review and evaluation parameter results.
27	1	10	The ANL report states: "Operating from 1949 until 2001, FMC (or predecessor P4 manufacturers) processed about 1.4 million tons of shale ore per year, about 250 million lb of P4 per year, and more than 26,455 lb per year of ignitable and reactive hazardous waste (Figure 1-1). The FMC plant closed in 2001." This appears to be orders of magnitude lower than the amount cited in some of the reference documents, and even ANL Table 2-1. Is the waste generation rate on Page 1 a typo? Please cite and verify the P4 waste mass generation figure. For example, the EPA 2003 report on	The values in the section came directly from the July 1, 2014, Work Order prepared by EPA and the Tribes (in deference to EPA and the Tribes). These values are somewhat similar to values noted in the FMC Idaho web site, which reports that in a typical year, with all furnaces operating, 1.75 million tons of raw shale/coke and silica were processed into 250 million pounds of elemental phosphorus (see http://fmc-idaho.com/plant-history/). The Review Team will modify this discussion (retaining the 1.4 million ton reference, since this is the amount of shale ore processed, not shale ore/coke and silica) and will make clear that the product P4 was produced at a rate of 250 million lb/year. The Review Team will

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			treatment technologies indicates in Table 1-1 the historical ponds alone contain nearly 108,000 cubic yards of "phossy waste" that was placed 1954-1981. Using an assumed density of 1.4 tons per cubic yard, this would be over 11 million pounds of phossy waste per year. Supplemental RI Report (FMC 2009), Table 4-2 is another good resource and is more comprehensive than the EPA 2003 report. If the waste generation per year was orders of magnitude more than ANL cited, it may be necessary to revise the ETT report to reflect waste volumes requiring excavation or treatment and the corresponding ETT assessments to reflect a much larger waste stream.	remove the reference to 26,455 lb/year of ignitable and reactive waste, as that value cannot be corroborated with a reference. Pg. 1, Lines 9–12, will be replaced with this language: *Operating from 1949 until 2001, FMC (or predecessor P4 manufacturers) processed about 1.4 million tons of shale ore per year, produced 250 million lb of P4 per year, and generated about 1,360,000 tons of hazardous waste per year (FMC 2000) (Figure 1-1). The FMC plant closed in 2001.*
28	2	32	The technical team has experienced professionals with various areas of expertise, including hydrogeology, geochemistry, and warfare agents. The team would have been greatly enhanced with an inorganic chemist or chemical/munitions engineering discipline with specific experience with P4 who could focus strictly on the P4 treatment/neutralization options. If this expertise was missing from ANL's team, it would be useful if ANL indicated whether bringing this expertise forward for potential follow-on activities would be appropriate.	The Review Team includes a PhD geochemist: Dr. Jim Jerden. In addition, as it happens, the Review Team includes Todd Kimmell, Senior Scientist, Argonne. Mr. Kimmell has participated in a number of National Research Council committees (as both a participant and as a chairman) involved in chemical weapons demilitarization. Mr. Kimmell worked on a remedial investigation/feasibility study of a P4 disposal site. The Work Order specifies that there is no commitment by stakeholders for the involvement of ANL in follow-on activities.
29	9	21	"Since P4 oxidizes almost instantaneously upon exposure to air (except at low temperatures), red phosphorus and, in some cases, compounds containing phosphorus are also present." This sentence does not make sense. Suggest revising to clarify the point.	The language in Lines 20–23 will be changed to: *The P4 that is present in the soil at the site could be encountered at various concentrations, ranging from just above the analytical detection limit to its nearly pure state. Since P4 oxidizes almost instantaneously upon exposure to air (except at low temperatures),*

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				oxidation by-products, such as red phosphorus and, in some cases, phosphate minerals, are probably also present.
30	9	26	Location of the buried railcars is RU-19c not 22c. Also, the content of the railcars and how they came to be located in the slag pile should be based on cited references. ANL may also choose to qualify this information, as there may be a different understanding among EPA, the Tribes, and FMC regarding the history and nature of the railcar waste.	The RU designation and the information source will be changed/added for RU 22c as follows: *The buried railcars in RU 19c are reported to contain P4 sludge with concentrations ranging from 75% to 95%, as reported in Appendix B* of *the Supplemental FS, or P4 sludge concentrations ranging from 10% to 25%, as reported in the main text of the* Supplemental FS *(MWH 2010).*
31	10	1	Table 2-1: Please provide a source for all information (mass, concentration, depth) in this table.	The source for Table 2-1 is the following: MWH 2010, Supplemental Feasibility Study Report for the FMC Plant Operable Unit, Vol. 1, Report, for FMC Idaho LLC, Pocatello, Id., July (see http://www.epa.gov/region10/pdf/sites/ emichaud/fmc_sfs_report_july2010.pdf). Pg. 10, Table 2-1, will be modified as follows to provide the t*able source*: *Supplemental FS MWH 2010.* A row will be modified in the table to indicate that the railcar RU is *19c*, the acreage is *2.7* acres, and footnote b will be modified to indicate the following*: Appendix B of the Supplemental FS reports a percent concentration ranging from 75% to 95%.*
32	10	2	Include subtotal of area and volume for groupings of similar wastes, then a grand total. That will help the reader see the quantity of waste against which ETTs are compared. FFS (2010) Pg. 6-7 says 780,122 cy, with 5,050–16,380 tons of P4.	Pg. 9, Line 39, will be amended as follows: *The distribution of the P4 waste present at the site is roughly as follows:* A*bout 10,870 tons of P4 waste with P4 concentrations ranging from 0.25% to 20% are present in about 482,224 yd^3 of fill. The more concentrated P4 waste*

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				present in the capillary fringe, the railcars, and underground piping contains about 7,500 tons of P4 waste with P4 concentrations greater than or equal to 20% present in 2,800,000 yd^3 of fill. A figure depicting this breakdown will be added to the text as well. *Figure 2-2 depicts the mass of P4 present in the historical ponds and railroad swale in relation to the mass of P4 present in the railcars, piping, and capillary fringe.* Existing figures will be renumbered accordingly.
33	13	5	It would be useful to have a better word describing the magnitude of the temperature than "much warmer."	Text on Pg. 13, Lines 4 and 5, will be modified as follows: *Since molten slag was periodically tapped from the electric arc furnaces and drained to a slag pit, any P4 that escaped from the Furnace Building was probably warmer than the melting point of P4 (FMC 2009)*
34	13	8	Do we have a model estimate from previous reports?	The text in Pg. 13, Line 8, will be modified as follows after capillary fringe: *The 44°C isotherm was modeled by investigators (FMC 2009).* Presumably, *the depiction of P4 subsurface presence and migration in Figure 2-4 is based on that model.*
35	14	1	The first two sentences are confusing and misleading. The Bevill amendment/exemption from RCRA regulation process wastes from the beneficiation of minerals and ores. The Bevill exemption for waste generated during the production of P4, except furnace off gas solids, ended on March 1, 1990. The exemption for furnace off gas solids ended on July 23, 1990. Upon the lifting of the Bevill exemption, beneficiation wastes that were hazardous waste were subject to RCRA regulation. Exempt wastes disposed of prior to the lifting of the Bevill exemption would not be subject to RCRA	Argonne agrees that the first two sentences of this paragraph may be misleading in light of the Bevill amendment and exemptions. This section has been rewritten to report that portions of the site are regulated under RCRA post-closure plans, and portions of the site are regulated CERLCA, as amended. A footnote is added at the end of the second sentence as follows: *The former FMC plant is regulated under both RCRA, as amended, and CERCLA, as amended. P4 waste is present at the former FMC plant in waste disposal units that are being managed under RCRA post-closure plans. P4 waste is also present in portions of the plant that*

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			(provided not subsequently managed in a way that triggers RCRA) but can be and are being addressed under CERCLA. Again, no permit was issued for FMC waste disposal units. Failure to comply with applicable RCRA requirements was the basis for EPA enforcement action that resulted in a Consent Decree that was entered by the court in 1999 requiring the waste disposal units subject to RCRA to close.	*were not regulated under RCRA (hereinafter called non-RCRA areas) but that are regulated under CERCLA, as amended. This independent review did not focus on the closed disposal sites that are regulated under RCRA post-closure plans. In some cases, the closed RCRA units are on top of or adjacent to the non-RCRA areas (Figure 2-5). The Review Team did not evaluate whether or not the proximity of the non-RCRA areas to the closed disposal sites regulated under RCRA would affect the ability to implement the ex situ ETTs discussed in this independent review.* *RCRA regulation of process wastes from the beneficiation of minerals and ores is affected by the Bevill amendments and exemptions. The Bevill exemption for waste generated during the production of P4, except furnace off-gas solids, ended on March 1, 1990. The exemption for furnace off-gas solids ended on July 23, 1990. Upon the lifting of the Bevill exemption, beneficiation wastes that were hazardous waste were subject to RCRA regulation. Exempt wastes disposed of prior to the lifting of the Bevill exemption would not be subject to RCRA (provided they are not subsequently managed in a way that triggers RCRA) but can be and are being addressed under CERCLA.* (*See* http://www3.epa.gov/epawaste/nonhaz/industrial/special/http://www3.epa.gov/epawaste/nonhaz/industrial/special/ *for details.*)
36	14	17	In the *IRODA* subsection, or in a new Section 2 subsection, [summarize] what technologies were previously screened by EPA per the documents	Argonne agrees that it would be good to identify other alternatives considered. However, this will add text to the report without changing conclusions or recommendations. A

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			ANL reviewed. This will help contextualize the new work performed by ANL.	sentence is added before the last sentence of this paragraph, on Line 28, as follows: Pg. 16, Line 10 *Additional alternatives previously screened and considered by EPA may be reviewed by examining the IRODA (IRODA; EPA Region 10 2012a).*
37	21	22	Add radionuclides.	Language will be added to reflect the fact that radionuclides are present, but are not regulated under RCRA: …*to address heavy metals and radionuclides (although radionuclides are not regulated under RCRA).*
38	21	42	The statement that FMC site is a CERCLA site, not a RCRA site, is incorrect. It is also a RCRA site. The RCRA ponds are subject to RCRA requirements. The CERCLA FMC OU does not include the RCRA ponds.	The language in Line 42 will be changed as follows: *The FMC site is regulated under both RCRA and CERCLA. The CERCLA FMC OU does not include the portion of the site regulated by RCRA post closure plans, the so-called "RCRA ponds." However, the CAMU-option may be brought in to the CERCLA action through ARARs. Management of remediation waste….*
39	22	19	Regional screening levels are not cleanup levels. At times for site-specific reasons they may be used as the basis for cleanup levels, but they are not in and of themselves cleanup levels. If no regulatory level exists, a site-specific risk assessment would need to be conducted to develop risk-based cleanup levels for various exposure scenarios.	The language in Line 18 will be modified as follows: *EPA Regions 3 and 9 have established regional screening levels that can serve as the basis for the development of cleanup levels.*
40	22	31	Statement that that RSLs are below presumed RCRA characteristic cutoff needs to be revised. See comments above on presumed cutoff level.	The language will be modified as follows: *As can be seen, these human-health-based RSL levels for P4 are probably lower than the levels below which the waste would be considered to meet a RCRA ignitability or reactivity characteristic.*

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41	22	42	The statement that RSL could be considered an ARAR is not accurate, as RSLs are not standards, requirements, criteria, or limitations under federal or state environmental law. Therefore, they are not ARARs.	The language will be modified as follows: *Nevertheless, the RSL would be a "To Be Considered" but not an ARAR under CERCLA, since RSLs are not standards, requirements, criteria, or limitations under federal or state environmental law.*
42	24	44	The document states that health and safety concerns would be no greater than those during original industrial process. ANL should indicate that they have taken into account the unknown location and concentrations of P4 in the environment. A basis or rationale for this assumption or statement should be provided.	Pg. 44, Lines 41 and 42 will be modified as follows: in *Remedial Action (RA) units where hazards are understood (for example, RA units such as the historical ponds where process knowledge can be used to establish site worker risks), concerns for worker exposure during active remediation efforts would be no greater than those for exposure during the original industrial processes for producing, packaging, transporting P4 and for managing soil and debris created as a result. For those RA units where process knowledge is absent and where the CSM is not refined, there would be greater site worker risks. Nevertheless appropriate….* Pg. 44, Line 46, after "OSHA": *Where site worker risks are not well understood (for example, if subsurface samples potentially containing P4 are collected during any future CSM refinement activities), unknown hazards would need to be addressed accordingly with conservatively safe PPE, monitoring, and sampling approaches to comply with OSHA.*
43	27	23	This line appears to contain an extra word ("sources").	The second instance of "sources" will be removed.
44	28	17	The FMC facility closed in 2001, not 2011.	2011 will be changed to *2001*.
45	28	35	Tribal government should be added.	*The Tribal Government* will be added.
46	28	46	The planned capping and gamma cover remedies are not ETTs, so unless capping/containment was contemplated by ANL for off-site disposal, it	Comment noted.

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			would appear out of scope to evaluate cap and cover.	
47	29	20	Should this be Occidental Petroleum/Glenn Springs, Ducktown, TN?	The bullet on Pg. 29, Line 20 is revised to read as follows: *Occidental Petroleum, Glenn Springs, Ducktown, Tennessee.*
48	33	8	Suggest that ANL incorporate discussion of the three key guiding principles (enough water, can safely excavate/handle P4, worker safety issues with ETT are comparable with FMC facility operations safety issues) explicitly with each technology.	The Review Team makes references to the elements that make up the guiding principles, at least implicitly, in the discussion and review and evaluation table content for each ETT.
49	33	22	The design extraction rate for the P&T has not been finalized but is estimated to be around 600 gpm. Are there any ETT scenarios where this flow rate would be insufficient?	Pg. 33, Line 25. A footnote will be added to indicate the following: *Water use would mainly be required to manage the risks associated with excavation (whether by mechanical or by hydraulic means). As a result, the removal of P4 waste and processing by ancillary technologies could proceed in phases dictated by water requirements (should water requirements be a limiting factor).*
50	35	16	Statement is made that soil and debris could be "triaged," and some P4 waste would not require treatment. How would this determination be made? And provide a rationale for this statement.	The Review Team will modify language in this section as follows: Line 8: *ETTs can be "triaged" or categorized in that….* The following will be inserted at Line 17: Waste *P4 that would not require treatment is waste that meets agreed-upon treatment requirements established for the second fraction. Some waste present at the site would presumably already meet such treatment requirements.*
51	35	Gen.	For all technologies: ANL should address throughput rates vs. assumed waste quantities and connect the dots to cleanup durations. Many of the	Argonne agrees that throughput rates are an important consideration in determining which ETTs should be considered further. An equally important consideration is the mass, volume, and concentration of P4 wastes to be treated.

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			identified ETTs seem to have low production rates, which could lead to long remediation timeframes.	Some of the ETTs can be scaled-up as needed. For example, the A&W mud still design could be scaled up, or multiple units could be constructed to obtain a sufficient production rate for treatment. Where information is available, the Review Team reports throughput. For example, the volume of dredged materials treated by a transportable mobile rotary kiln used at the Bayou Bonfouca Superfund Site is included in the text to provide some understanding of the waste treatment capacity of such systems.
52	36	1	On-site disposal in a CAMU or CERCLA unit is not, by definition, an ETT. If on-site land disposal of excavated P4 waste could be possibly coupled with ETTs, ANL should discuss land disposal in that manner to differentiate ETTs from landfilling.	Pg. 36, Line 1, will be modified as follows*: Disposal technologies (considered for P4 waste that has already been treated)*….
53	36	38	In situ thermal remediation vendors use diagonal and horizontal drilling and trenching approaches to install heating units (electrodes, steam injection pipes, etc.) in other-than-vertical configurations. Suggest perusing web sites for several additional vendors in addition to Tersus and TerraTherm: TRS (http://www.thermalrs.com/), Geo (http://www.georemco.com/insitu.php), and McMillan-McGee (http://www.mcmillan-mcgee.com/mcmillan-mcgee/index.php).	The first link did not work. Information in the second link (i.e., http://www.georemco.com/insitu.php) seemed to focus on vertical wells only. The third link provides some information about horizontal wells.
54	37	8	Would steam also involve a potential flux of oxygenated air into the reaction zone? Heat + oxygen + P4?	Not necessarily, in that the gas delivered to the reaction zone in this scenario would likely be steam mixed with an inert gas, such as Ar or N_2.
55	37	11	What is the estimated extraction efficiency?	Extraction efficiency is unknown, which is why, as stated in the report, a pilot-scale study is needed.

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56	37	30	ANL mentioned during the September 21, 2015, presentation that additional characterization using geophysical methods could help fill data gaps and enable an updated CSM. It would be helpful if ANL would provide more details on specific geophysical survey approaches/methods/tools to address data gaps and determine extent of contamination.	We do not have a geophysicist on the Review Team. Presumably, EPA and the Tribes have probably consulted with a geophysicist in the past about CSM refinement. Since all structures have been demolished, there may now be an opportunity to perform geophysics at the site as part of a CSM refinement effort. One technique to consider is resistivity or high-resolution resistivity (HRR). HRR can be used to delineate regions of the vadose zone with anomalous electrical conductivity. However, these methods work best when the results can be validated with borings and sample results in proximity to where the geophysical investigation has occurred.
57	37	31	The fact that there has not yet been a laboratory study, or a field application, to assess whether applying heat to a formation containing P4 would promote effective downward draining of P4, seems like a significant concern potentially leading to screening out this technology from further consideration. Would molten P4, with a specific gravity of 1.8, behave as a DNAPL and flow with gravity and soil porosity vs. hydraulic gradient? The report should articulate why this approach is still considered viable.	All of the in situ technologies examined have been screened out. The Review Team has posed a DNAPL-like contaminant CSM in a comment above.
58	38	9	A statement is made that estimating the amount [of P4] remaining would be difficult to characterize safely because in past site characterizations, a "precedence to avoid drilling into P4 was set." Please clarify what is meant by a "precedence to avoid drilling into P4." Does ANL mean this was an administrative decision or a health and safety decision and provide the basis for this determination? ANL has indicated it arrived at	This statement is actually made on Pg. 11, Line 10. The Review Team examined archival information to draw conclusions. Since EPA staff were present throughout the CERCLA and RCRA closure/post-closure activities, EPA is in the best position to know whether the precedent was an administrative decision or a health and safety decision. The information reviewed suggests that investigators avoided drilling into any area where P4 could be present due to health and safety considerations. As noted in a global response

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			different conclusions regarding the ability to safely characterize, excavate, and treat P4 wastes than other entities. It would be helpful if ANL provided information on how the data gaps could be safely filled given known hazards associated with drilling into P4 waste.	above, the Review Team will acknowledge that there would be investigation worker health risks if conventional investigation techniques were used. The Review Team will also note that alternative investigation methods (remote drilling, drilling with cryogenic fluids, augmented health and safety protocols, and geophysics) were not attempted, and that these alternative methods could have been implemented with manageable site worker risks. The text on Pg. 11, Line 12 will be modified as follows: *Using conventional investigation techniques and routine health and safety protocols, there are obvious…*
59	39	1	Table 5-1: A statement is made that the "formation would wipe them clean." Please explain what this means.	Text in Table 5-1 and Table 5-3 will be changed to: *It is expected that if direct push methods were used, there would be only a minimal amount of P4 on withdrawn drill rod or casing, since they would be rubbed clean on clean, shallow soils. With regard to extracted P4, significant safety and management issues would need to be addressed.*
60	40	1	Cite data sources regarding P4 solubility in food oils.	A citation will be added: *(Marck Index, 2001) Merck Index, 2001, Thirteenth Ed., Merck & Co., Inc., Whitehouse Station, New Jersey.*
61	41	5	Solvent extraction relies on surface chemistry and surface contact, and the waxy P4 solids likely have a low to moderate surface area to mass, meaning it will take longer and a lot of solvent to dissolve and recover the P4. This is a very common issue with solvent extraction remedial technologies. It could be more effective if performed above the P4 melting point, as that would increase its surface area and the resulting rate of dissolution into the solvent. That would also add cost per the thermal	These are appropriate points that are reflective of the uncertainties about the P4 present in the subsurface (at locations away from the historical ponds). The P4 could be present as a single mass of material directly beneath the furnace, for example, or be dispersed throughout the vadose zone in a contaminant distribution somewhat similar to a DNAPL with ganglia, smear zones, stringers, etc. A combined approach of heating and treating may optimize performance, especially for the DNAPL-like contaminant CSM, but optimally one would need to know more about the CSM to combine technologies.

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			treatment discussed above, but perhaps a combined approach would optimize the performance.	
62	41	33	Given that soil auger/oxidant injection equipment can go upward to 50 ft, if one can excavate to 35 ft below ground surface (safe excavation of soil with P4, as well as if the soil formation and storage capacity can support such excavation), this may be an alternative to well injection for oxidant delivery. Recovery/extraction wells may still be needed to ensure waste doesn't migrate.	Agreed. Excavation to 35 ft would be an ex situ method, which the Review Team has included as an ETT. Treatment of P4 with auger/oxidant equipment post-excavation would be an *in situ* method with the same uncertainties already noted for in situ ETTs.
63	41	40	What would the return on investment (ROI) be for a thermal remedy where P4 was heated just at or about 45°C? Would it have to be significantly warmer to be effective, and would the incremental cost and energy to make it warmer be well worth it for performance?	The ROI is unknown to the Review Team.
64	43	1	The IAEA figure indicates the hot water flooding/extraction injection and extraction wells have 100 ft? How does this compare with the pump and treat system installed under the *IRODA*? Would there potentially need to be a closer spacing/greater density to ensure hydrogeologic control?	As noted on Pg. 41, Line 44, the IAEA figure is conceptual and is not meant to imply an actual design. The design of the *IRODA* pump and treat system would be useful information for designing an in situ system. The density of any injection/extraction system would be dictated by the contaminant distribution as well.
65	45	3	It is unclear if ANL evaluated ETTs for areas of known high P4 contamination (ponds and furnace area) or for the whole OU. It would be helpful if ANL clarified what/where they focused their evaluations for the specific P4 in place.	Pg. 45, Line 40. The text indicates that the in situ method is most appropriate for deep subsurface white phosphorus contaminated zones that are not amenable to excavation.
66	45	25	Would it be possible to utilize a slow(er) release oxidant?	That could be evaluated via bench- or pilot-scale testing. It may be found that a slow-release oxidant, such as potassium permanganate in paraffin, would be preferred over a more rapid-release reactant.

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67	47	1	Table 5-5: Impacts to environment during implementation. Would this call for SVE as a safety feature, in the same way ozonating the vadose zone might?	The Review Team suggests enclosing the injection/extraction well site and off-gas treatment on Pg. 47.
68	48	6	"Success" needs to be defined for the purpose of the Phase 1 Independent Review. From ANL's perspective, does success mean complete removal of all P4 such that a cap and institutional controls will no longer be required? Recommend clearly describing the "end state" of the FMC OU following application of each ETT.	Argonne agrees that it would be a good idea to describe the end state, but for active remediation in general, not for each ETT. The following sentence is inserted on Pg. 25 in a new paragraph on Line 33: *The end state of the application of a suite of ETTs for active remediation of the FMC OU would be that all contaminated media no longer exhibit the RCRA characteristics of ignitability and reactivity, that P4 is removed to acceptable cleanup levels, and that RCRA LDRs are satisfied for heavy metals and other constituents, as appropriate. There are two possible exceptions to this suggested end state. First, and as allowed by CERCLA, EPA could, with adequate justification, choose to waive certain requirements through one of the statutory ARAR waiver approaches (http://www2.epa.gov/superfund/applicable-or-relevant-and-appropriate-requirements-arars). This may be especially applicable to RCRA LDRs. Second, and as stated previously, the CSM would have to be improved to permit adequate understanding of heavy deposits of P4, such as that underlying the Furnace Building and that contained within the buried railcars.*

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69	49	12	Some remediation construction companies have successfully trenched to nearly 100 feet bgs at some sites as part of installation of a slurry wall as a vertical engineered barrier. Additionally, in situ solidification/stabilization implementors successfully use auger/mixer equipment to implement ISS to 50 ft bgs. Maximum depth at the FMC OU would need to be determined based on soil stratigraphy and contaminant characteristics, and potentially other design parameters. Please include that the depth of contamination would need to be confirmed.	Comment noted. The discussion on the ETT indicates the importance of determining the extent of contamination in the subsurface. The Review Team identified issues with ISS placement at another elemental phosphorus manufacturing site, Tarpon Springs, Florida, where chemical reactions between the solidification/stabilization material and P4 caused a fire in the test area and where debris present in the test area caused difficulties with the in situ technique (see Appendix F, *Supplemental FS*).
70	49	40	"Cost-prohibitive" needs to be defined. What makes something cost-prohibitive? Recall that for the Phase 1 Independent Review, EPA and the Tribes did not want ANL to rule out potential ETTs solely on cost; thus, the concept of "cost-prohibitive" is not appropriate for this report.	Cost is referred to here in a general sense. See the response to General Comment 8 above regarding the use of cost in the evaluation of technologies.
71	51	1	Table 5-6: This is the first time that contract acquisition is mentioned with respect to "time to implement," but it would be a factor for all ETTs.	Argonne agrees with EPA on this comment. This is the only line in the entire report that refers to contract acquisition. The sentence in Table 5-6 is revised as follows: *Identifying a containment approach could take up to 1 year*.
72	54	1	How would you keep the vadose zone wet on a large scale? Would you look at compartmentalizing the site on a footprint and depth basis to minimize the scale of what has to be kept wet at any one time? Please provide more detail.	The reference relates to wetting P4 waste once it is brought to the surface during excavation and not wetting the entire vadose zone.
73	58	37	Typo: The vs. he.	The text will be changed.
74	70	8	Use of food oils may add substantial BTUs to partially dewatered sediments.	Comment noted.

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75	71	10	Table 5-10 estimates almost 18,000 tons of P4, so this technology with this throughput at 90% uptime would take 9.5 years to incinerate/de-characterize the P4 if the mass/volume is similar to Army waste.	The incinerator at the Crane Army Ammunition Plant was cited as an example of incineration technology. The P4 waste that would be excavated at the FMC site would not be similar to the waste treated at the Crane incineration facility. Some mobile incinerators have a much greater capacity (up to 10 tons/hr); see http://www.environmental-expert.com/services/thermal-treatment-of-hazardous-waste-mobile-incinerators-199705.
76	82	43	This kind of caveat would lead one to serious concerns about scale-up and efficient operation of this unit, or is this typical O&M for an operational still/furnace?	Table 5-13 states that low throughput is a limitation.
77	83	7	Figure 5-13: Appears to be missing some pipes.	Comment noted.
78	84	28	This is a very small batch throughput. Can ANL speak to scalability? 3 cubic feet seems like a bench scale.	The Review Team discussed scalability with investigators that performed the treatability study. A version of the technology, obviously scaled up significantly, is under consideration for treating P4 waste in the clarifier at the Silver Bow, Montana, site.
79	87	Table 5-13	Regarding "Disadvantages" bullet 2: tell us more. How many units and how much bigger? Expected full scale throughout would be _X_?	Limitations on throughput are discussed throughout Section 5.3.3.
80	88	38	There is a statement that the LDR WTS was designed and built specifically to treat P4-containing solids and sediments present in the historical ponds. The LDR WTS was only required to treat waste from Pond 18, and possibly Pond 17, but no other historical ponds.	The Review Team has noted that the treatment of residuals from Pond 18 seems to be directly applicable to the treatment of the waste present in the non-RCRA historical ponds.
81	90	1	Table 5-14: Repeat parenthetical description of LDR description in title as done in text: "(anoxic caustic hydrolysis, metals precipitation, filtration, stabilization)."	The noted change will be made in the title of Table 5-14.

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82	92	9	This is a relative comparison of two ETTs, which is not consistent with the Work Order from EPA OSWER to ANL.	Comment noted. The comparison occurred as part of the FMC investigation into treatment technologies. The results of the comparison speak directly to the overall likelihood of success at FMC.
83	94	2	Suggest revising the order in the table, perhaps from most to least soluble.	Comment noted. The table will not be reorganized.
84	94	2	Table 5-16: Isn't ethanol flammable?	Table 5-16 will be modified to indicate that *ethanol is flammable.*
85	97	18	Technology review, not design.	Line 18 will be changed to indicate the following: *acceptance survey is outside the scope of this independent* review.
86	103	1	500,000–750,000 CY may not overwhelm a permitted RCRA C facility. Did ANL contact the three closest ones to reality check throughput limitations as well as waste acceptance criteria (Laidlaw - Utah, ChemWasteMgmt - Oregon, U.S. Ecology - Idaho)? Provide a rationale for this statement.	Argonne agrees that 500,000–750,000 may not overwhelm a permitted RCRA facility. And no, Argonne did not contact any RCRA TSDFs to determine possible acceptance of a large volume of waste.
87	105	35	Note that the SFS includes a Section 7 figure (Figure 7-2). For what was the *IRODA* selected remedy that indicates pipes suspected (based on process knowledge) to contain P4 that would be cleaned.	Comment noted. The figure used also depicts the RUs where pipelines are suspected to be present.
88	115	15	"Guzzler" could use a reference.	Guzzler™ was referenced in a previous section of the report.
89	122	4	Excavation technologies also have a similar limitation regarding insufficient characterization (i.e., one cannot just start digging up a site without a level of confidence in knowing the state and location of contamination). Ex situ treatment technologies may share in this limitation, noting that incineration may have a greater degree of	This section is discussing in situ treatment technologies that could potentially target areas not accessible with excavation technologies. As it happens, P4 present in the deep subsurface is not characterized at all. In contrast, much more is known about the contents of the historical ponds that could be targeted with excavation technologies. This is due to process knowledge and the fact that some samples have been collected from the historical ponds (EPA 2003).

Comment No.	Pg.	Line Ref.	EPA Comment	ANL Review Team Response
			flexibility for successfully processing P4-related wastes.	
90	123	17	It should be recognized that P4 also exists throughout the OU, as evidenced by the recent grading activities.	Pg. 123, Line 18, will be amended as follows after "FMC Plant": *As noted during the grading operations performed in 2015, P4 exists throughout the materials in the near surface.*
91	124	10	Note that the dry excavation experience as quantified in Appendix C is specifically related to P4 found in the regrading and consolidation of site slag related to implementation of ET cover and soil cover systems for the *IRODA*. The total quantity of P4/slag waste excavated was less than 1,000 cubic yards out of over 2 million cubic yards relocated. It may be useful for ANL to indicate what aspects of the P4/slag experience would be relevant to ETT implementation more broadly in the FMC OU.	Pg. 124, Line 13: The following language will be inserted: *In the event slag needs to be moved to gain access to a P4 excavation area, experience gained when moving slag as part of the regrading project may be useful.*
92	124	12	From a health and safety and environmental protection standpoint, it may not be an acceptable practice to simply uncover P4 and allow it to burn until the smoke is no longer visible. During the grading operations, P4 encountered was immediately quenched with sand. Reference to this as an acceptable excavation technique should be removed. It would be helpful if ANL identified limitations and complications if P4 in soil were to be open burned (i.e., what would be the combustion gas rate of generation, anticipated concentrations compared with worker safety and for off-site fugitive emissions the acute and chronic exposure levels and restrictions). What would be the impact area and potential evacuation zone needed?	The noted language will be changed as follows: *When P4 was uncovered, it was immediately quenched with sand.*

Comment No.	Pg.	Line Ref.	EPA Comment	ANL Review Team Response
93	124	32	Would you expect the site to drain rapidly given the site geology, particularly in the vadose zone? If yes, how would that affect the water usage rate to keep P4 submerged during ETT activities?	It is known that the historical ponds were used to retain waste submerged in water in the past. As a result, for the historical ponds, it seems reasonable to expect that waste in an excavation footprint could be kept submerged.
94	124	39	Are the three identified excavation methods applicable to specific spatial and depth locations in the FMC OU? For example, which ones would be applicable to presumed shallow depths for waste in the CERCLA ponds? What about deeper "candles" of P4 beneath the process facility? What about P4 within the capillary fringe or upper saturated zone, around 85 ft bgs?	The requested information is provided in Table 5-10.
95	125	40	It would help if ANL can speak to excavation, transport respecting off-site management, and incinerator throughput. It would also be useful if ANL can provide more specificity on past FMC industrial safety practices with P4 that would be applicable to excavation during remediation.	Section 5.3.1.2 includes a discussion on the volumes of sediments treated by incineration at the Bayou Bonfouca Superfund Site. Pg. 70, Line 33, will be amended as follows: *…in a rotary kiln incinerator treated at a rate of approximately 25 tons/hr (EPA 2001).* One FMC source that includes specificity on past FMC industrial safety practices is the following: FMC Corporation, Phosphorus Chemicals Division, 1999 RCRA Case-by-Case Extension Application, July. Appendix CC (Pond Management Plan) of that document includes a discussion on the operation of remotely operated surveying equipment to assess sediment depth; the operation of auger and suction dredges; the movement of dredged slurry to a tank; the use of water to control the threat of bank fires; the operation of a vacuum truck to place materials into Pond 16s; and the movement of phossy wastes from containers into ponds.

Comment No.	Pg.	Line Ref.	EPA Comment	ANL Review Team Response
96	126	8	For reference, please indicate what quantity of P4-impacted soil would be transported for off-site incineration. Statements about possibly needing dedicated trucks or railcars may not appear feasible or reasonable if the volume is over 500,000 cubic yards vs. a smaller amount of P4 waste.	The amount of P4 waste to be transported off site would depend on what RUs are actually remediated. The noted language in Line 14 will be modified as follows: *If a large quantity of P4 waste is to be excavated in a short period of time, a large number of trucks (or railcars) may be required.*
97	128	25	*IRODA* Section 8.3.3, page 45, says "The removal of elemental phosphorus from the underground pipes can be done safely because the material is relatively homogeneous, contained in pipes at known locations, and is a relatively small quantity. Removed sludge will be disposed off-site following characterization in an appropriate landfill or be incinerated. The sludge will be removed, so this storm/sewer piping may remain in use." ANL's work in investigating ETTs potentially applicable to underground pipes may be useful to EPA Region 10 and FMC; however, it is not clear that ANL's evaluation and presentation of technologies relevant to piping is responsive to the Phase 1 Independent Review Work Order. Additionally, the *IRODA's* handling of pipelines may not be problematic to the Tribes since EPA selected pipe cleaning and disposal for P4 contained in pipes known or suspected to contain P4 based on process knowledge.	The noted language is a description of elemental phosphorus in the storm sewer piping only. As noted in Table 5-21 of the independent review, other pipes are located throughout the FMC OU that apparently also could contain P4. The Review Team looked at pipelines because they could contain P4 and thus seemed to be consistent with the Work Order to investigate the treatment of P4 at the site.
98	129	6	It is not clear how an enhanced CSM or really anything short of excavation of the railcars themselves will provide the necessary information to evaluate potential ETTs. Nonintrusive characterization work may better identify the railcar locations but how would this speak to the	The Review Team notes that some additional information would be needed to start with the first step: excavation of the railcars.

Comment No.	Pg.	Line Ref.	EPA Comment	ANL Review Team Response
			amount and condition of the contents, or former contents if there have been any leaks or migration?	
99	133	26	It would be helpful if ANL could provide some input or examples on potentially safe(r) characterization approaches that could fill ETT data gaps. For example, are there in situ sensors or indirect measurements that could provide an appropriately high density of data on the presence and relative concentration of P4 in soil throughout the vadose zone as well as shallow saturated zone?	See the response above to a Global Comment.
100	135	4	2012 *IRODA* was for the FMC OU only. Identify 2010 FS as the Supplemental FS to distinguish it from the original site-wide FS.	The noted clarifications will be integrated into the text. Pg. 135, Line 4, will be amended as follows: …*Rod for the FMC OU in Pocatello, Idaho (EPA Region 10 2012a). In the Supplemental FS a review of …*
101	135	22	FMC OU not FMC site.	The text will be changed to *FMC OU.*
102	135	25	Recommend documenting the face-to-face meeting with EPA, the Tribes, and FMC as well as the follow-up separate meeting with the Tribes prior to the Independent Review kick-off.	The language on Pg. 135, Line 14, will be modified as follows: *The Work Order was developed during a face-to-face meeting with EPA and the Tribes and was refined in a follow-up teleconference in the spring and summer of 2014.*
103	135	28	Draft and draft final lists should be included for reference in an appendix. [ANL] should also [give] recognition that the draft and draft final lists of ETTs to be evaluated were for the sole purposes of ANL, and neither EPA nor the Tribes had any input into the final list of ETTs evaluated.	Only the final list will be included in the report.

Comment No.	Pg.	Line Ref.	EPA Comment	ANL Review Team Response
104	136	5	It would be helpful if the general categories of uncertainties for in situ technologies were articulated here (i.e., viability, efficacy, implementability, etc.)	These uncertainties have been detailed in Section 6.2.1 on Pg. 122.
105	136	8	Would in situ technologies pose more significant safety and cost concerns than ex situ and if so, what is that determination based on? How were these factors (safety and cost) compared to ex situ alternatives?	This statement will be augmented. Pg. 136, Line 8, will be modified as follows: …*the health and safety concerns would be caused by the need to perform additional site characterization work.*
106	136	10	It is inferred that this sentence is referring to ex situ ETTs. For clarity, recommend including "Further, the Review Team decided that several ex situ ETTs also did not warrant…."	The ETTs included here are all ex situ ETTs.
107	136	15	It is unclear if this statement is just referring to the railcars or all ETTs.	The statement will be clarified to indicate that the reference to the CSM refinement relates to the abandoned railcars.
108	136	21	Based on how the analysis was conducted (separating excavation and treatment technologies), virtually all ETTs in this list would need to be coupled with other technologies. As stated elsewhere in EPA's comments, it would be useful if ANL more fully developed how a combined remedy approach could be used to successfully remediate P4 in soils at the FMC OU.	The phrase "coupled with other technologies" will be removed.
109	137	1	It would be helpful if there was some discussion of the specific safety risks associated with implementation of the evaluated ETTs. Could include some examples such as uncontrolled reactions causing fires, toxic gas emissions, etc.	Argonne believes that the safety risks associated with P4 remediation are well understood. No changes to report.
110	199	11	Needs space.	A space will be added.

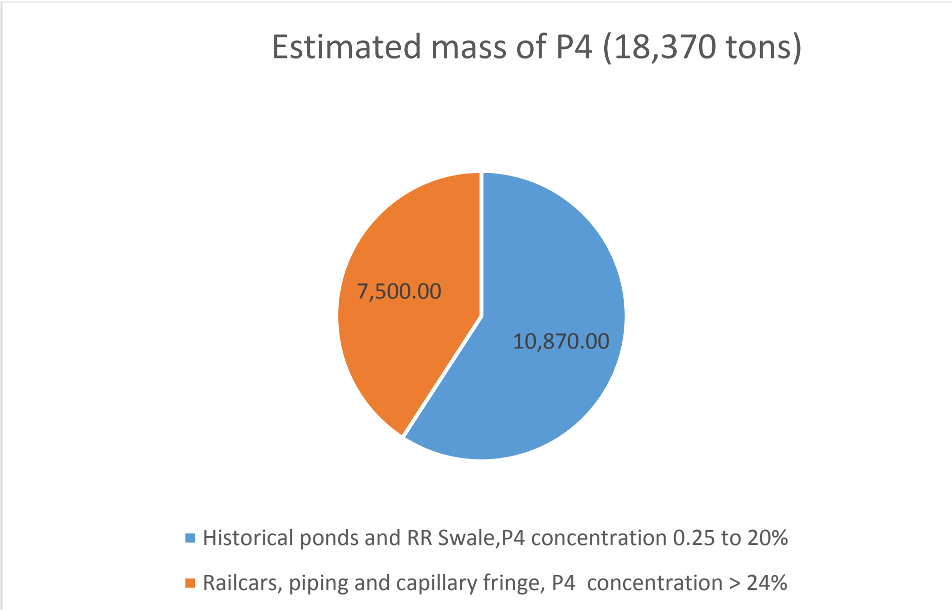

FIGURE 2-2 Estimated mass and concentrations of P4 present

END

APPENDIX I:

ARGONNE'S EDITORIAL CHANGES

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APPENDIX I: ARGONNE'S EDITORIAL CHANGES

In addition to the changes to the Draft version of the document required by responses to comments from the Shoshone-Bannock Tribes (Tribes) and the U.S. Environmental Protection Agency (EPA), changes to the Draft version of the document as noted in Appendix I were required to:

- Add a reference to the meeting in the Tribal Council Chambers;
- Reference the comments from the Tribes and EPA and responses to the comments by the Review Team; and
- Address additional editorial changes results from the required Argonne technical review process.

Pg. 7, Line 42: The bullets will be changed as noted below:

- RU 1 – *Furnace Building, secondary condenser, and loading dock; present possibly due to leaks and spills from production processes and waste management and/or injection of waste or excess P4;*
- RU 19c – *Railcars (also known as "buried railcars" or "abandoned railcars"); present because they were filled with P4 sludge and then buried in the slag pile (RU 19);*

Pg. 9, Line 40: The following will be added: *"The contaminant CSM is somewhat refined for some RUs and is almost hypothetical for other RUs. As discussed below, there are few or no sample results to characterize the presence of P4 in the deep subsurface (e.g., the capillary fringe and the vadose zone beneath the Furnace Building). However, process knowledge can be used to characterize the contents of the waste present in the historical ponds. In addition, borings have been collected adjacent to or within several of the historical ponds, resulting in additional information that contributes greatly to the contaminant CSM for the historical ponds. Investigators have even described soil borings collected from historical ponds within RU 22B as "pure precipitator dust" and "phossy solids" (EPA 2003)."*

Pg. 9, Line 43: This line will be changed as follows: "…the Furnace Building vicinity assumes that warm, liquid P4 migrated downward from the sumps and…."

Pg. 11, Line 5: The following paragraphs will be added:

"A different aspect of the CSM for the deep Furnace Building P4 is the possibility of an injection well(s) used to dispose of impure or excess pure P4. On the basis of discussions at the September 21, 2015, meeting at the Fort Hall Tribal Business Council, the injection well was said to be at the west end of the Furnace Building and was used to dispose of P4 waste near the water table. The piping was warmed by circulating hot water through a double casing to prevent clogging. Some of the P4 was pure but was

excess once the railcars were full. This practice continued until the early 1990s when the well was hidden by a slab of concrete. An online database of wells was searched for a possible injection well(s) at the west end of the Furnace Building (Idaho Department of Water Resources 2015); however, the data in this source are only as recent as 1992, so the existence of an older injection well could not be confirmed."

[Idaho Department of Water Resources, 2015, "*Well Construction*" *search online database http://www.idwr.idaho.gov/Apps/appsWell/WCInfoSearchExternal/. Accessed* on *September 23, 2015.]*

"It is possible that P4 beneath the Furnace Building is present due to both the use of an injection well and the infiltration of P4 leaked from sumps and tanks. The former would explain the deep P4 observed in several boreholes (described below); the latter would explain any P4 in the thick unsaturated zone and also possibly the deep P4."

Pg. 11, Line 9: The following will be inserted after "northeast": *hydraulically.*

Pg. 13, Line 5: "the liquid P4" will be replaced with*:* "*any liquid P4.*"

Pg. 13, Line 12: The following will be inserted after "temperature was above 100°C": "*Alternatively, P4 could have been released near the water table by a heated injection well system. It is possible that both transport mechanisms could have been in effect. In either case, the P4 may have built up as a mass or "blob"…*

Pg. 18, Line 16: …meaning that soil and debris containing *significant amounts of P4 once exhumed, would…*

Pg. 21, Line 31: Disposal of contaminated in the on-site CAMU may be done *under a reduced set of requirements (for example without meeting LDRs)…*

Pg. 30, Line 24: Two new sections (Sections 3.7 and 3.8) will be added to the document:

3.7 Presentation of Findings from the Draft Report,

The Review Team submitted a draft version of the report to the Tribes and the EPA on September 8, 2015. The Review Team presented the results of key findings from the Draft report to the Fort Hall Business Council, in the Fort Hall Council Chambers on September 21, 2015. All members of the Review Team (listed in Chapter 1) participated in the presentation. The presentation was followed by a morning and afternoon question-and-answer session. A follow-up webinar presentation was also provided to representatives of EPA who could not attend the meeting in Fort Hall. The webinar meeting occurred on September 28, 2015. This meeting was attended by all members of the Review Team, representatives of the Tribes, and EPA staff members.

3.8 Response to Comments and the Final Report

On the basis of information presented at the Fort Hall Business Council meeting, the follow-up webinar meeting and the content of the Draft report, the SBT and EPA produced a series of comments. The Review Team responded to the comments by including a discussion and/or the actual language used to address the comments. The Tribes' comments and Review Team responses can be found in Appendix G. The EPA comments and Expert Review Team responses can be found in Appendix H. Also included is a summary of changes required during final editing by Argonne staff (Appendix I). This Final version of the independent review report includes changes in the Draft version needed to address the Tribes' and EPA's comments and to address editorial and technical issues noted in the Draft version.

Pg. 106, Line 26: "*would overwhelm*" will be changed to *"could overwhelm."*

Pg. 107, Line 1: "*would be overwhelmed*" will be changed to "*could be overwhelmed.*"

Pg. 112, Line 30: This line will be modified to reflect the fact that regrading has covered the native soil: Figure 5-16 is a photograph of site visitors standing at or near the level of native soil *(before the 2015 regrading operation).*

Pg. 136, Line 10: ETTs will be modified to*: ex situ ETTs.*

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