

Assessment of Issues Related to the Newport Hydrolysate Treatability Study Conducted at Perma-Fix

A Third-Party Review of the Data and Reports

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Asad T. Amr, Ph. D., P.E.

Michael A. Berger

George O. Bizzigotti, Ph. D.

Salvatore P. Salerno

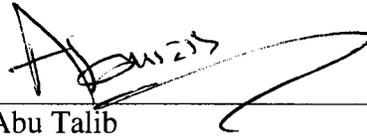
Rebecca E. Watson, Ph. D.

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**Center for Science and Technology
Falls Church, VA**

Mitretek Project Approval:

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Abu Talib
Director, Chemical Demilitarization

Executive Summary

Background

The Army Project Manager for Alternative Technologies and Approaches (PMATA) constructed the Newport Chemical Agent Disposal Facility (NECDF) to destroy the nerve agent VX stored in ton containers at the Newport Chemical Depot in Indiana. The method selected for agent destruction at Newport is caustic hydrolysis; the resulting Newport hydrolysate product is a hazardous waste that requires disposal. The Army's NECDF Systems Contractor, Parsons Infrastructure and Technology Group, originally selected Perma-Fix of Dayton, Inc. (PFD), which discharges liquid effluent from its treatment processes to a local publicly owned treatment works (POTW) in Montgomery County (MC), OH, as the treatment and disposal facility for the hydrolysate. PFD performed a treatability study to demonstrate that they could effectively treat Newport hydrolysate.

The Montgomery County Commission, which controls PFD's operating discharge permit, hired Professor Bruce E. Rittmann of Northwestern University as a consultant to assess the results of the treatability study and to document his findings. Following receipt of Rittmann's report, the Commission announced that it would not support hydrolysate treatment at PFD facilities. Subsequently, Parsons terminated its subcontract with PFD for convenience of the Government, and the Army announced that it would delay the start of chemical agent neutralization operations. The Army also commissioned a report intended to provide further clarification on programmatic issues related to hydrolysate production at NECDF and hydrolysate treatment and disposal at a commercial treatment, storage, and disposal facility (TSDF) that may not have been adequately addressed in Rittmann's assessment.

PMATA tasked Mitretek Systems, a not-for-profit science and technology company working in the public interest, to conduct an independent third-party assessment and evaluation of the hydrolysate treatability study conducted by PFD. The assessment includes a thorough review of all test data generated as well as PFD's confidential test report stemming from the study. Rittmann's report was reviewed, as well as the Government response to that report. As a result of the scope of Rittmann's report, this assessment includes issues such as risks posed by Newport hydrolysate and process effluents that were not covered in the treatability study; Mitretek reviewed information provided by Parsons and by PFD that was relevant to these issues.

Hydrolysate and Risks

NECDF destroys VX by reacting it with aqueous sodium hydroxide. The main reaction cleaves VX into 2-(diisopropylamino)ethanethiol (known as thiolamine) and the sodium salt of ethyl methylphosphonate (NaEMPA). A side reaction cleaves VX into sodium

S-[2-(diisopropylamino)ethyl] methylphosphonothioate (NaEA2192) and ethanol. NaEA2192 in turn hydrolyzes under the reaction conditions into thiolamine and disodium methylphosphonate (Na₂MPA); the chemical hydrolysis effectively destroys VX leaving no detectable traces of either the chemical agent or the NaEA2192 by-product of its destruction in the hydrolysate.

The risks posed by Newport hydrolysate are similar to those posed by common industrial chemicals. The main risk is from dermal contact with the hydrolysate, which is corrosive due to unreacted sodium hydroxide. At ambient temperature, Newport hydrolysate forms two separate layers. At the 8 and 16 percent loadings to be used at NECDF, the upper organic layer should be less than 3 percent of the total hydrolysate and testing indicates that the hydrolysate is not flammable. Newport hydrolysate also has a strong odor. Although the odor is highly objectionable, it does not *per se* present a risk to human health or the environment. It should be noted that workers at TSDFs are trained to handle routinely materials posing similar and greater risks than Newport hydrolysate.

Several authors have raised the potential for the reaction products in Newport hydrolysate to recombine to form VX. However, testing has shown that reformation does not occur in neutralized Newport hydrolysate. Thus, reformation presents no significant risk for Newport hydrolysate under reasonable scenarios for TSDF operations or transportation.

Another perceived risk from Newport hydrolysate is attributed to the presence of unreacted VX or NaEA2192, which is less toxic than VX. However, as indicated earlier, the chemical reactions involved in the hydrolysis process effectively destroy both VX and NaEA2192. The hydrolysate will be closely monitored for any potential presence of detectable quantities of VX or NaEA2192. NECDF will not release Newport hydrolysate for transport if the concentration of VX is detectable at a method detection limit of 20 parts per billion or lower. NECDF will not release Newport hydrolysate for transport if the concentration of NaEA2192 is detectable at a method detection limit of 1 parts per million or lower. Thus the hydrolysate transported from NECDF does not pose risks resulting from the presence of unreacted VX or NaEA2192.

Perma-Fix Process Performance and Impact

PFD is a hazardous waste TSDF permitted under the provisions of Part B of the Resource Conservation and Recovery Act. PFD devised a multi step full-scale process that included several physical, chemical, and biological treatment steps.

PFD conducted a demonstration treatability study for the type of hydrolysate that is produced from the caustic hydrolysis of VX. The treatability study was very similar to the proposed full-scale process but used process units smaller than full-scale for this treatability demonstration. The stated goal of the laboratory study was to “select and demonstrate a treatment process that would allow PFD to meet current POTW permit limits, and a limit of

0.1% for each of the compounds listed on Schedule 2, part B of the CWC that are found in the hydrolysate: thiolamine, MPA [methylphosphonic acid], and EMPA [ethyl methylphosphonic acid].” The treatment process was required to run for a certification period of at least 10 days, during which time the Schedule 2 and permit criteria were to be met. In support of the treatability study, the biotreatment process was run for a total of 139 days. Generally, this period is a more than reasonable period of testing. Future optimization testing was planned.

Mitretek reviewed the quality assurance of the data used in the treatability study. The quality of the data was sufficient to support the conclusions drawn in the study.

Mitretek assessed the level of documentation of the fate of the Schedule 2 compounds at each step of treatment. The treatability study presented data only on the final effluent from the process. However, PFD performed analyses on the concentrations of Schedule 2 compounds in many intermediate streams. Relative volumes of the streams are considered proprietary data by PFD, so no mass balance has been released publicly. Mitretek has reviewed the proprietary data and determined that the Schedule 2 compounds were removed as follows:

- Approximately 90 percent of the total Na₂MPA and NaEMPA initially present in the waste is destroyed or removed in the aggressive oxidation step. Proprietary data were also collected to quantify the amount of Na₂MPA and NaEMPA removed during the solids filtration step.
- No significant degradation of Na₂MPA or NaEMPA occurred in the biotreatment step.
- Na₂MPA and NaEMPA were not removed by carbon filtration.
- Data indicated that thiolamine is converted essentially quantitatively to oxidized species during the mild oxidation step.

The technologies used in the Treatability Study are demonstrated and available technologies, and the individual steps of the PFD process have been used throughout the waste treatment industry. The process developed represents the application of unit processes that are standard parts of PFD’s operations to a new waste stream. Scale-up of bench-scale processes can be challenging, however it is a normal practice to ramp up slowly in stages when moving from small-scale to full-scale. Mitretek found no limitation regarding the treatability study and the full-scale operation with respect to mixing, temperature, and pH control. These are some of the scale-up issues that are normally addressed and optimized during a treatability study and or during ramp up of operations at a TSDF.

In his report, Rittmann reviewed six months of PFD operational data and two years of effluent monitoring data from Montgomery County. As part of this review, Mitretek did not have access to this data and is unable to assess some specific issues concerning PFD's sequencing batch reactor operations. Nevertheless, Mitretek drew several conclusions:

- The odor issue at the PFD site is well documented by the Regional Air Pollution Control agency (RAPCA), and it is apparent that the odor is caused by fugitive emissions and the escape of gases from the operations at PFD. Treating any odorous waste at PFD may increase the issue of odor at the PFD site. However, odor control measures and technologies are available.
- In a full-scale plant, a multimedia filter removes suspended solids before the stream is passed through the carbon filter to avoid clogging the carbon filter. The use of filtration and carbon adsorption to treat industrial wastewater can be operated reliably.
- The concentrations of Na₂MPA, NaEMPA, and NaEA2192 entering MC's Western Regional Wastewater Facility will not lead to adverse effects to workers via dermal or aerosol inhalation and are unlikely to adversely affect the microorganisms in the facility.

Risk to Human Health and the Environment

The potential toxicity of process effluents was discussed at length in Rittmann's assessment of the PFD Treatability Study and in the Army's response. Mitretek reviewed the available toxicity data on compounds discussed in these documents and assessed the risks to human health and the environment posed by treatment effluent. Mitretek agrees with Rittmann's general conclusion that the concentrations of Na₂MPA and NaEMPA will not pose a threat to human health or the environment. However, the positive Ames test result cited by Rittmann was erroneous; no such test on EMPA was reported in the reference he cited or anywhere else. Furthermore, an Ames test performed on a similar compound was negative, indicating that EMPA is nongenotoxic. Hazard quotients were generated by dividing exposure concentrations for relevant exposure pathways by the reference dose. The hazard quotients indicated that concentrations of Na₂MPA and NaEMPA found at various steps of the Newport hydrolysate treatment process will not lead to adverse toxic effects in humans. Na₂MPA and NaEMPA are present in leachate from solids generated in the process, but these solids would have been disposed of in a certified and regulated landfill where the leachate is contained; therefore no exposure pathway is anticipated. Estimated in-stream concentrations of Na₂MPA and NaEMPA resulting from Newport hydrolysate treatment will not pose an unacceptable chronic risk to aquatic organisms.

Assessment of Issues and Recommendations

In his report, Rittmann stated that "... the proposed multi-step process has a sound scientific foundation. Properly implemented and monitored, the multi-step treatment process could eliminate hazardous components in the VXH without causing health risk or odors to neighbors and without disrupting the operation and performance of MC's Western Regional Wastewater Treatment Facility." Mitretek agrees with this statement. However, Rittmann also identifies in his Executive Summary several "important questions" that he asserts have not been answered. In addition, he makes five recommendations concerning disposal of Newport hydrolysate. Mitretek disagrees that these questions have not been adequately answered, and makes several alternative recommendations.

TSDFs routinely apply their unit processes to new wastes with risks similar to those posed by Newport hydrolysate with no more testing than was done by PFD. Thus, although Rittmann's statement that successful full-scale operation has not been proven anywhere is literally true, viewing the treatment of Newport hydrolysate as an experimental method is an overstatement. Mitretek recommends that Newport hydrolysate treatment begin with a phased start up, which is a normal commercial practice; this is also required because operations at NECDF have long included a planned phased start up.

Implementation of appropriate odor control measures should be a normal part of operations at any TSDF. Mitretek recommends that any TSDF selected to treat Newport hydrolysate should have such measures already in place.

Data are available to determine the specific fate of Schedule 2 compounds in the various steps of the PFD process. The proprietary nature of some information prevents public release of a full mass balance for Schedule 2 compounds in the PFD process. Mitretek recommends that any TSDF selected to accept Newport hydrolysate be prepared to publish data to support the fate of Schedule 2 compounds in significant process streams. In addition, any TSDF selected to treat Newport hydrolysate should address, in as transparent a fashion as possible, questions of the degree to which the treatability study is representative of what can be expected at full-scale and whether the effluent from the treatment process would cause ecotoxicity or pose a threat to human health.

Mitretek's assessment is that there is no reason that Schedule 2 compounds need to be reduced to levels below the certification levels. Certification levels are set according to U.S. Government policy designed to ensure that Schedule 2 compounds produced in the destruction of chemical weapons cannot be recovered for potential re-use; this policy is independent of safety or environmental considerations. Hazard quotient estimates of exposure through dermal, oral, and inhalation pathways based on the levels of NaEMPA and Na₂MPA resulting from treatment of Newport hydrolysate indicate that they will not lead to adverse toxic effects in humans, nor will they pose an unacceptable chronic risk to aquatic organisms.

The PFD treatability study was tailored and designed to simulate full-scale operations and was reasonably representative of what can be expected during full scale operations. Some adjustments to the process, *e.g.*, the multi-media filter, were planned to be tested and implemented at full-scale. For full-scale operations, any TSDf accepting Newport hydrolysate should conduct a treatability study to optimize all operating parameters, which is a common industry practice.

In his assessment of the costs and benefits of carrying the first oxidation step at NECDF, Rittmann omitted several major impacts (increased storage risk resulting from the time required to modify environmental permits and to install equipment), and two of his major benefits (prevention of VX reformation and transporting a nonflammable material) do not apply. Mitretek's assessment is that the Parsons determination that there are substantial benefits to performing this step at an off-site TSDf appears reasonable in light of these impacts as well as a realistic consideration of the benefits of the action.

Mitretek believes that any TSDf should, as a normal part of its operations, develop a monitoring scheme that reflects the process being carried out and the wastes being treated. Monitoring should be designed to provide performance indicators that the process is functioning as designed. The specific measurements described in Rittmann's report may or may not be appropriate for the TSDf to be selected to receive Newport hydrolysate because the process will be different from the PFD process. A simple ecotoxicity screening for the survival of selected aquatic and terrestrial plants and animals sensitive to chemical changes with the effluent generated by a treatability study could be useful in confirming the ecotoxicity assessment.

As part of this review, Mitretek also assessed the Government response to Rittmann's report. The bulk of the Army response is accurate. There are several instances where responses are technically correct and provide useful perspective, yet do not fully address the issues raised by Rittmann. Recurring statements about the "polymeric" nature of MPA and EMPA in precipitated solids from the PFD process use the term incorrectly. This provides a misleading impression of the mobility of NaEMPA and Na₂MPA. However, given that the solids will be placed in a certified and regulated landfill where the leachate is contained, this does not significantly misrepresent the risk posed by the leachate.

In addition to the previous recommendations, Mitretek recommends that PMATA continue to correct misinformation concerning Newport hydrolysate in the public domain.

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Section 1

Introduction

The U.S. Army currently stores the nerve agent VX in 1,690 ton containers (TCs) at the Newport Chemical Depot (NECD) in Indiana; this material corresponds to approximately 4 percent of the nation's original chemical agent stockpile. The Army Project Manager for Alternative Technologies and Approaches (PMATA) constructed the Newport Chemical Agent Disposal Facility (NECDF) to destroy this material to comply with Public Law 99-145 and to meet U.S. obligations under the Chemical Weapons Convention (CWC). The method selected for agent destruction at Newport is caustic hydrolysis, also referred to as "neutralization;" the resulting Newport hydrolysate product is a hazardous waste that requires disposal. Following the terrorist attacks of 11 September 2001, the Army sought to accelerate the destruction of the VX stockpile to eliminate the risk of continued storage. The accelerated neutralization program sought to use existing commercial waste disposal facilities to treat the hydrolysate rather than duplicating or developing these capabilities on-site at the NECDF.

The Army and its NECDF Systems Contractor, Parsons Infrastructure and Technology Group, originally selected Perma-Fix of Dayton, Inc. (PFD), as the treatment and disposal facility for hydrolysate produced by NECDF. In 2003, PFD performed a treatability study to demonstrate that they could effectively treat Newport hydrolysate.¹ The study was to confirm whether the proposed process would result in a product that would meet all permitting and discharge requirements required of PFD by state and local regulators and a limit of 0.1 percent for each of the compounds listed on Schedule 2 of the CWC and found in the hydrolysate. PFD discharges liquid effluent from its treatment processes to a local publicly owned treatment works (POTW) in Montgomery County, OH. The Montgomery County Commission, which controls PFD's operating discharge permit, hired Professor Bruce E. Rittmann of Northwestern University as a consultant to assess the results of the treatability study and document his findings.² Following receipt of Rittmann's report, the Commission announced that it would not support hydrolysate treatment at PFD. Subsequently, Parsons terminated its subcontract with PFD for convenience of the Government, and the Army announced that it would delay the start of chemical agent VX neutralization operations, which were planned for January 2004. Since this action, the Army has been working aggressively to reevaluate options for hydrolysate treatment and final disposal, and to determine a path forward that applies the most effective resources and technologies. The Army also commissioned a report intended to provide further clarification on programmatic issues related to hydrolysate production at NECDF and hydrolysate treatment and disposal at a commercial treatment, storage, and disposal facility (TSDF) that may not have been adequately addressed in Rittmann's assessment.³ More information about the history may be obtained from the website of the Program Manager for the Elimination of Chemical Weapons

(<http://www.pmc.d.army.mil>); follow the links to “Indiana” under the current and historical activity locations heading.

PMATA tasked Mitretek Systems, a not-for-profit science and technology company working in the public interest, to conduct an independent third-party assessment and evaluation of the hydrolysate treatability study conducted by PFD. The assessment includes a thorough review of all test data generated, as well as PFD’s confidential test report stemming from the study. Rittmann’s report was reviewed, as well as the Government response to that report. As a result of the scope of Rittmann’s report, this assessment includes issues such as risks posed by Newport hydrolysate and process effluents that were not covered in the treatability study; Mitretek reviewed information provided by Parsons and by PFD that was relevant to these issues. Mitretek staff visited NECDF and interviewed representatives of Parsons and PFD; a list of the individuals consulted is included as the Appendix.

Mitretek has supported the Army’s program to safely dispose of chemical warfare material for over 20 years. Mitretek has gained an in-depth understanding of the properties of chemical agents, the risks they pose to health and environment, the range of technologies to safely neutralize chemical agents and destroy chemical weapons, and the best measures to protect individuals and populations that might be exposed. Mitretek has expertise in areas such as agent handling, chemical analyses, filtration systems, and regulatory issues. Mitretek has world-renowned experts in toxicology and risk assessment that provide expertise on agent toxicology issues. As a public service, Mitretek maintains a website with recent research data on the chemical and physical properties of chemical agents (<http://www.mitretek.org/home.nsf/homelandsecurity/BackChemWarfare>).

Section 2 of this report presents Mitretek’s assessment of the risks posed by Newport hydrolysate. Section 3 assesses the performance of the PFD process. Section 4 discusses the impact of the effluent resulting from PFD treatment of Newport hydrolysate on human health and the environment. Section 5 covers the validity and feasibility of the unanswered questions and recommendations put forward by Rittmann. Section 6 contains an assessment of the Army’s response to the Rittmann report. Section 7 contains a summary and Mitretek’s recommendations. Mitretek’s findings are presented in boxes throughout the report.

Section 2

Risks Posed by Newport Hydrolysate

NECDF destroys VX by reacting it with aqueous sodium hydroxide. This section describes the hazards of the resulting Newport-generated hydrolysate. Section 2.1 discusses the neutralization process used at NECDF, section 2.2 discusses the composition of the hydrolysate, and section 2.3 addresses risks to human health posed by the hydrolysate as it is released from NECDF to a TSDF. Mitretek's major findings in this section are listed below:

- The risks posed by Newport hydrolysate are similar to those posed by common industrial chemicals. Workers at TSDFs are trained in the routine handling of materials posing similar and greater risks than Newport hydrolysate.
- Rittmann's report is inaccurate in its characterization of risks to human health and the environment from Newport hydrolysate. Mitretek finds that:
 - Hydrolysate will not be transported from NECDF with detectable amounts of VX or toxic intermediates produced during hydrolysis.
 - VX reformation presents no significant risk for Newport hydrolysate under reasonable scenarios for TSDF operations or transportation.

2.1 The Newport Hydrolysis Process

The VX destruction process employed at NECDF is based on a chemical reaction called base-promoted hydrolysis. The two reactants are VX and a solution of sodium hydroxide in water. VX is added at a rate of 5 gallons per minute to the caustic solution, and the reaction proceeds at nominally 90°C (194°F) for 150 minutes after completion of agent addition. The main reaction cleaves VX into 2-(diisopropylamino)ethanethiol (known as thiolamine) and the sodium salt of ethyl methylphosphonate (NaEMPA). This reaction accounts for the destruction of 73 to 88 percent of VX^{4,5} under the reaction conditions and is shown in Figure 2-1.

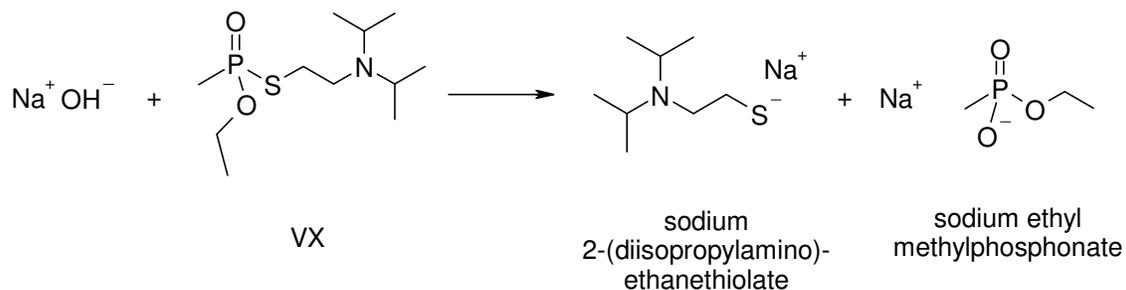


Figure 2-1. Main VX Hydrolysis Reaction Producing “thiolamine” and NaEMPA

A side reaction cleaves VX into sodium *S*-[2-(diisopropylamino)ethyl] methylphosphonothiolate (known as NaEA2192) and ethanol. This reaction accounts for the destruction of 12 to 27 percent of VX^{4,5} under the reaction conditions and is shown in Figure 2-2.

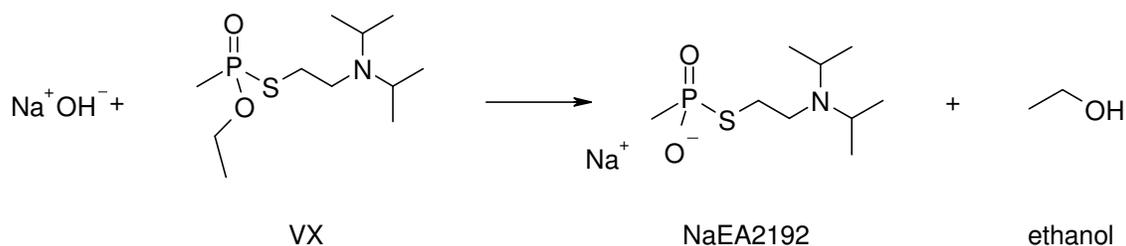


Figure 2-2. Side VX Hydrolysis Reaction Producing NaEA2192 and Ethanol

NaEA2192, in turn, hydrolyzes under the reaction conditions into thiolamine and disodium methylphosphonate (Na₂MPA); at the pH of hydrolysate, these are present as their sodium salts. All detectable NaEA2192 is destroyed in this reaction, which is shown in Figure 2-3.

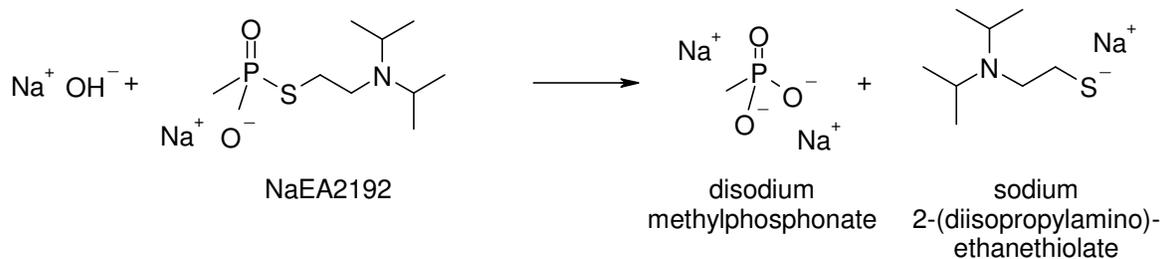


Figure 2-3. NaEA2192 Hydrolysis Reaction

Currently, NECDF plans to begin operations with hydrolysis of the agent from a relatively small number of ton containers, using a loading of 8 percent VX in the aqueous caustic solution. Production is scheduled to be ramped up as shown in Table 2-1. After full operational rates are achieved, the loading of the destruction reaction will be increased, with a goal of processing 16.6 percent VX with a loading of 8.8 percent sodium hydroxide by weight.⁶ This ramp-up is part of NECDF’s pilot testing phase.⁷

Table 2-1. Ramp-up Schedule for VX Hydrolysis⁸

Month	VX Loading	Ton Containers Processed
Month 1	8 percent	3
Month 2	8 percent	7
Month 3	8 percent	7
Month 4	8 percent	11
Month 5	8 percent	22
Month 6	8 percent	36
Month 7	16 percent	80

2.2 Hydrolysate Composition

The composition of Newport hydrolysate is given in Table 2-2. Original plans called for NECDF to process VX at a 33 percent loading using 20 percent sodium hydroxide solution; as a result, there is an extensive body of testing that was conducted on this composition. More recently, NECDF has elected to use lower VX loading in 8.8 percent sodium hydroxide solution, which produces a hydrolysate that is easier to analyze because it contains lower

levels of organic constituents. VX and NaEA2192 were not detected (ND) in hydrolysate at the required method detection limits. The method detection limits reported for NaEA2192 differ because the lower levels of organic constituents in the more dilute hydrolysate make it possible to analyze with a lower method detection limit. The material used in the treatability study was originally generated at the 33 percent loading.

In addition to thiolamine, NaEMPA, Na₂MPA, and ethanol that result from the reactions discussed in Section 2.1, several other components are observed:

- 2-(diisopropylamino)ethyl disulfide results from the oxidation of thiolamine by dissolved oxygen
- Diisopropylamine results from the thermal decomposition of thiolamine

Table 2-2. Composition of Newport Hydrolysate

Component	Concentration from 33 percent VX loading ⁹	Concentration from 16 percent VX loading ¹⁰	Material used in Treatability Study ¹
Water	56%	75%	Not measured
Thiolamine	23%	11%	10%
NaEMPA	15%	7%	8%
Na ₂ MPA	3%	2%	1%
Other components (including ethanol and diisopropylamine)	1%	0.5%	Not measured
Sodium hydroxide	3%	4%	Not measured
2-(diisopropylamino)ethyl disulfide	0-5%	0-4%	Not measured
Stabilizer and stabilizer breakdown products	0-1%	0-1%	Not present
NaEA2192	ND (< 20 mg/L)	ND (< 1 mg/L)	ND (< 20 mg/L)
VX	ND (< 20 µg/L)	ND (< 20 µg/L)	ND (< 20 µg/L)

All percentages reported as weight-to-weight unless otherwise specified.

- The VX stored at Newport is stabilized with either diisopropylcarbodiimide (DICDI) or dicyclohexylcarbodiimide (DCCDI). Stabilizer breakdown products in hydrolysate

are primarily the corresponding diisopropylurea and dicyclohexylurea. VX, as manufactured, contained a number of reactive impurities, including water, alcohols, thiolamine, and ethyl methylphosphonic acid (EMPA). Carbodiimide stabilizers were added to VX because the impurities react with the stabilizers faster than they react with VX and thus prevent VX from degrading. EMPA is of particular concern because it causes VX to decompose via an autocatalytic reaction.¹¹ Under the hydrolysis conditions used at NECDF, water remains in large excess relative to both carbodiimide and VX. Under such conditions, the stabilizer will not affect the extent of VX destruction;¹² hydrolysate from both stabilized and unstabilized material has met the requirement of no detectable VX with a method detection limit of less than or equal to 20 µg/L.^{12,13}

At ambient temperature, Newport hydrolysate forms two separate layers. The lower layer is an aqueous layer; it constitutes 95-99 percent by volume of the hydrolysate and contains the bulk of the water, NaEMPA, Na₂MPA, sodium hydroxide, and ethanol. The upper layer is an organic layer; it constitutes approximately 3 to 5 percent (by volume) of the total hydrolysate at 33 percent loading; at the 8 and 16 percent loadings to be used at NECDF, the upper layer should be 3 percent or less of the total hydrolysate. The upper layer contains the bulk of the 2-(diisopropylamino)ethyl disulfide, unreacted stabilizer, and stabilizer breakdown products. Thiolamine is present in both layers.¹²

2.3 Risks Posed by Hydrolysate as Shipped

Finding: The risks posed by Newport hydrolysate are similar to those posed by common industrial chemicals. Workers at TSDFs are trained in the routine handling of materials posing similar and greater risks than Newport hydrolysate.

The risks posed by hydrolysate are similar to those posed by many common industrial chemicals. The primary risk arises from dermal contact. Newport hydrolysate is classified as corrosive according to Department of Transportation (DOT) regulations. The neutralization uses excess caustic, with the 16 percent Newport hydrolysate containing approximately 4 percent unreacted sodium hydroxide. Experiments on rats and rabbits indicated that Newport hydrolysate is corrosive to skin and, if swallowed, damaging to the gastrointestinal tract, as expected of a sodium hydroxide solution. However, the effects seen were not indicative of nerve agent activity nor were they sufficiently severe to qualify Newport hydrolysate as a DOT poison or toxic material.¹⁴ Accidental exposure of Newport hydrolysate to the eyes or breathing in aerosol droplets of hydrolysate would be expected to produce significant irritation, which would be predominantly related to the concentration of sodium hydroxide.¹⁵

In addition, the Newport hydrolysate generated at 33 percent loading has a flashpoint of 127°F (53°C). This makes this particular formulation of hydrolysate flammable, with a

flashpoint slightly greater than that of glacial acetic acid. However, preliminary testing of Newport hydrolysate generated at 16 percent loading by weight has shown that the flammability is eliminated. Finally, Newport hydrolysate also has a strong odor. Although the odor is highly objectionable, it results from extremely small concentrations of thiolamine in air, which are unlikely to present a significant toxicological risk.

Workers handling the hydrolysate will be equipped with approved safety equipment such as gloves and protective clothing; materials posing similar risks are commonly used in industry and have well-established handling procedures and industrial safety standards. Workers at TSDFs are trained in the routine handling of materials posing similar and greater risk than Newport hydrolysate. When a TSDF is selected, a detailed transportation safety assessment and risk management plan will be prepared as planned. Assessment of specific transportation risks is beyond the scope of this document.

2.3.1 VX Reformation is not Observed

Finding: VX reformation does not occur spontaneously in Newport hydrolysate and presents no significant risk under reasonable scenarios for TSDF operations.

A number of reports concerned with the risks posed by Newport hydrolysate have raised the potential for the reaction products in Newport hydrolysate to recombine to form VX.¹⁶ Extracting hydrolysate components from water at lower pH into an organic solvent is reported to favor reformation of VX in trace amounts.⁴ The individual chemical reactions that could lead to reformation have been observed, including carbodiimide coupling of organophosphates to produce pyrophosphonates¹⁷ and formation of VX from a mixture of EMPA, diethyl dimethylpyrophosphonate, and thiolamine.¹⁸ The carbodiimide stabilizers in VX are somewhat resistant to hydrolysis in aqueous sodium hydroxide; a few percent of the dicyclohexylcarbodiimide originally present is likely to remain in the organic layer.¹⁷ Based on these observations, it appeared prudent to determine whether residual carbodiimide stabilizer in the organic layer of hydrolysate could react with EMPA to form diethyl pyromethylphosphonic acid, which can in turn react with thiolamine to regenerate traces of VX in the hydrolysate organic layer.

The available data from several recent studies addressing the issue directly indicate that there is no detectable VX reformation in hydrolysate. The reference cited on this issue by Rittmann in his report¹⁶ mentioned the potential for VX reformation in neutralization then being tested by the Program Manager for Assembled Chemical Weapons Alternatives (PMACWA) and was published before test results were available. PMACWA's testing was designed to test for "the absence of agent in the effluents" of the VX hydrolysis followed by a biotreatment system; one of the evaluation factors included the question "to what extent will the products or byproducts react to form agents at any stage in the process?" PMACWA's results indicated that no VX was detectable at a level of 16 µg/L in hydrolysate

generated from stabilized VX, both in the hydrolysate prior to treatment and in the effluent after hydrolysate was neutralized and processed through a biotreatment unit.¹⁹ More recently, PMATA has conducted tests to determine whether VX could be detected in Newport hydrolysate from the process to be used at NECDF, also using stabilized VX. Preliminary results indicate no VX was detectable with a method detection limit of 20 µg/L.²⁰ Both tests involved neutralizing the sodium hydroxide in the hydrolysate, so the data indicate that simply lowering the pH of Newport hydrolysate below a threshold value does not cause observable reformation of agent. Thus, in both instances when actual hydrolysate has been tested, VX reformation is not observable.

It should be noted that there are several possible factors that explain why no reformation is observed in hydrolysate:

- In Newport hydrolysate, EMPA exists almost exclusively as its sodium salt ($[\text{NaEMPA}]/[\text{EMPA}] = \text{ca. } 1 \times 10^{12}$ above pH 14, based on reported EMPA pK_a values of 2.00²¹ or 2.76²²). This would drastically slow the rate of the reaction between stabilizer and EMPA because the concentration of the reactive acid is very low in both layers of the hydrolysate. The carbodiimide stabilizers are reactive towards acids, but are unreactive towards bases, which is why some stabilizer persists in hot caustic.
- Water is likely to be present in the upper layer at concentrations that exceed EMPA concentrations, so the stabilizer may react faster with water (a reaction that does not lead to agent reformation) than with EMPA.
- As pH of Newport hydrolysate is lowered, more EMPA exists in the acid form and the rate of the reaction that potentially leads to agent reformation increases, but the reaction of the stabilizer with water becomes more rapid as well. In addition, the thiolamine component becomes less reactive as the pH drops. This could explain why the lowering of pH has little net effect on observable agent reformation, contrary to the assertion in Rittmann's report.

Although it would be theoretically possible to remanufacture VX using the components in Newport hydrolysate, this is a very remote possibility and a rather impractical approach. It would require recovery of NaEMPA, Na₂MPA, and thiolamine from the hydrolysate, followed by the addition of other reagents to remanufacture VX. Recovery of these compounds, which are listed on Schedule 2, Part B of the CWC as precursors for agent manufacture, would require a multi-step process because each is subject to one or more pH-dependent equilibria; therefore precise manipulation of the pH over several stages would be necessary. Recovery and remanufacture would be extraordinarily difficult without a small chemical facility of some sophistication. The impracticality of recovery of Schedule 2, Part B chemical from dilute solution is reflected in the regulations implementing the CWC, which exempt mixtures containing less than 30 percent of these chemicals.²³

In summary, VX reformation does not occur spontaneously in neutralized Newport hydrolysate. Reformation is observed only as an artifact in a specific analytical procedure or after recovery of the constituents from the hydrolysate; this process would not occur by accident. VX reformation presents no significant risk for Newport hydrolysate under reasonable scenarios for TSDF operations or transportation.

2.3.2 Toxic Constituents are not Detected

Finding: Hydrolysate will not be transported from NECDF with detectable amounts of VX or NaEA2192.

Another perceived risk from Newport hydrolysate is attributed to the presence of unreacted VX or NaEA2192, which is itself a nerve agent less toxic than VX (see Section 4.1.3). To minimize this risk, the reaction conditions of the NECDF process (90°C for 150 minutes in 8.8 percent sodium hydroxide solution) are selected to effectively ensure VX destruction. NECDF will not release its hydrolysate for transport if the concentration of VX is detectable with a method detection limit of 20 µg/L (roughly equivalent to 20 parts per billion [ppb]) or lower. Current NECDF policy is to release Newport hydrolysate for transport only if the concentration of NaEA2192 is less than 20 mg/L (roughly equivalent to 20 parts per million [ppm]).²⁴ However, Parsons recently reviewed existing criteria for the concentration of NaEA2192 in hydrolysate, and identified a recommended limit of 1 ppm on the basis of toxicity and the potential for human exposures.²⁵ They have recommended to the Army that NECDF should not release Newport hydrolysate for transport if the concentration of NaEA2192 is detectable with a method detection limit of 1 mg/L (ppm) or lower.²⁶

In summary, hydrolysate transported from NECDF does not pose significant risks resulting from VX and NaEA2192 to those who might come in contact with the waste. Burns from dermal contact are the most significant risk posed by hydrolysate due to the excess sodium hydroxide. The current VX method detection limit was developed at a more protective level than is required for dermal contact or other workplace exposure pathways. The proposed method detection limit for NaEA2192 adequately protects workers potentially exposed to Newport hydrolysate via dermal contact, the most significant workplace exposure pathway.²⁵ The risks to human health and the environment posed by potentially toxic constituents in Newport hydrolysate after treatment and discharge by PFD are discussed in Section 4 of this report.

Section 3

Perma-Fix Process Performance

Mitretek's major findings in this section are listed below:

- PFD's Treatability Study collected sufficient data to adequately address the purpose for which it was intended. Duration of the treatability study was sufficient for scale-up.
- Based on Mitretek's review, the quality of the data was sufficient to support the conclusions drawn in the study.
- Data exist to support fate of Schedule 2 compounds in specific steps.
- The technologies used in the Treatability Study are demonstrated and available, and the individual steps of the PFD process have been used throughout the waste treatment industry. The application of existing technologies to new waste streams is routine.

3.1 Introduction to Wastewater Treatment

Industrial and chemical production processes create a variety of wastewater pollutants, some of which may be difficult to treat. Wastewater characteristics and levels of pollutants vary significantly from one waste stream to another. Discharges from industrial and chemical facilities can be direct or indirect. Direct discharges are made to a waterway or water body, and indirect discharges are usually made to POTWs, where the discharge is treated.

Commercial TSDFs treat wastewater in accordance with appropriate federal, state, and local laws and permits. As appropriate, treated wastewater and effluent may be discharged to POTWs for further treatment or directly to bodies of water, solid waste sent to regulated landfills, and allowable air emissions discharged to the atmosphere.

There are three general treatment methods for industrial wastewaters: physical, chemical, and biological treatment. Physical treatment methods consist of processes such as membrane technologies, carbon adsorption, distillation, filtration, ion exchange, oil and grease skimming, oil/water separation, sedimentation, steam stripping, and solvent extraction. Chemical treatment methods include chemical oxidation, chemical precipitation, coagulation, dissolved air flotation, electrochemical oxidation, flocculation, hydrolysis, and neutralization (pH control). Biological treatment methods include biological nitrogen removal, bioaugmentation, extended aeration, anaerobic processes, rotating biological contactors, sequencing batch reactors, and trickling filters. Many of these biological processes use activated sludge, in which microorganisms in the treatment process break down organic material with aeration and agitation, after which solids settle out.

Activated carbon is used in many applications for the treatment of water and wastewater. In some cases, powdered activated carbon is added to the actual wastewater stream to adsorb contaminants, and then the carbon is removed from the stream and either disposed or regenerated. There are various types of filter beds that are used, such as fixed-bed filters, multiple beds, and pulsed or moving bed systems. Carbon treatment of waste can achieve the desired low levels of contaminants in the stream prior to discharge provided that such contaminants can be adsorbed by carbon. Turnkey mobile and fixed carbon adsorption systems for both gas and liquid-phase are commercially available.

3.2 Perma-Fix of Dayton

PFD is a hazardous waste TSDF permitted under the provisions of Part B of the Resource Conservation and Recovery Act (RCRA). It is a wholly-owned subsidiary of Perma-Fix Environmental Services, Inc; the parent company had \$84.9 million in revenue for 2003. PFD has operated at the current location in Dayton since 1941. It offers many different hazardous waste treatment processes, including the following:

- Biological treatment of a wide range of relatively high strength organic wastewaters (containing high levels of organic contaminants), as well as treating the wastewater currently exiting the wastewater treatment system. Treated wastes include waste from pharmaceutical plants, chemical processing plants, manufacturers of chemical intermediates, petrochemical plants, food processing plants, and agrichemicals. Wastes from other PFD treatment operations may be processed through the biological treatment unit. PFD has two activated sludge process units that operate in parallel as sequencing batch reactors (SBRs).
- Neutralization of corrosive wastes
- Heavy metal removal of both RCRA-regulated and RCRA-non-regulated metals on a continuous or batch basis
- Fuel blending and used oil recycling for energy recovery in asphalt plants and permitted industrial boilers
- Thermal conditioning, liquid/liquid separation via coalescing, and liquid/liquid/solid separation through ultra-filtration of non-hazardous oily wastewater and coolants
- Solidification of sludge and specialty wastes

PFD treats liquid waste using whatever combination of physical, chemical, and biological treatment is most appropriate, based on the components and characteristics of a particular waste stream.

3.3 Description of Perma-Fix Hydrolysate Treatment Process

PFD was contracted by Parsons to treat hydrolysate produced during the destruction of VX stored in ton containers at NECDF. PFD devised a multi step full-scale process that included physical, chemical, and biological treatment:

1. Oxidize thiolamine
2. Reduce the pH by adding acid
3. Add strong oxidant to oxidize EMPA and MPA
4. Remove the solids by filtration
5. Adjust the pH and aerate to strip ammonia
6. Blend the oxidized and filtered hydrolysate with other wastewater being treated at PFD
7. Treat the mixture in two SBRs
8. Filter the biological effluent and then treat with activated carbon, when required (see Section 3.5.2)
9. Discharge the effluent to POTW

Figure 3-1 is a block flow diagram that shows the planned steps for full-scale treatment.

3.4 The Perma-Fix Treatability Study

3.4.1 Treatability Study Goals and Approach

A treatability study is defined as a study in which a hazardous waste is subjected to a treatment process to determine whether the waste is amenable to the treatment process, what pretreatment (if any) is required, the optimal process conditions needed to achieve the desired treatment, the efficiency of a treatment process for a specific waste or wastes, or the characteristics and volumes of residuals from a particular treatment process. PFD conducted a demonstration treatability study (completed in July 2003) for the type of hydrolysate that is produced from the caustic hydrolysis of VX. According to the Final Report,¹ the goal of the laboratory demonstration study was to “select and demonstrate a treatment process that would allow Perma-Fix of Dayton Inc. to meet current POTW permit limits, and a limit of 0.1 percent for each of the Schedule 2 compounds found in the hydrolysate: thiolamine, MPA, and EMPA.” The process was required to run for a certification period of at least 10 days, during which time the Schedule 2 and permit criteria were to be met. Table 3-1 (which is Table 2 of the PFD Treatability Study) lists all of the certification limits.

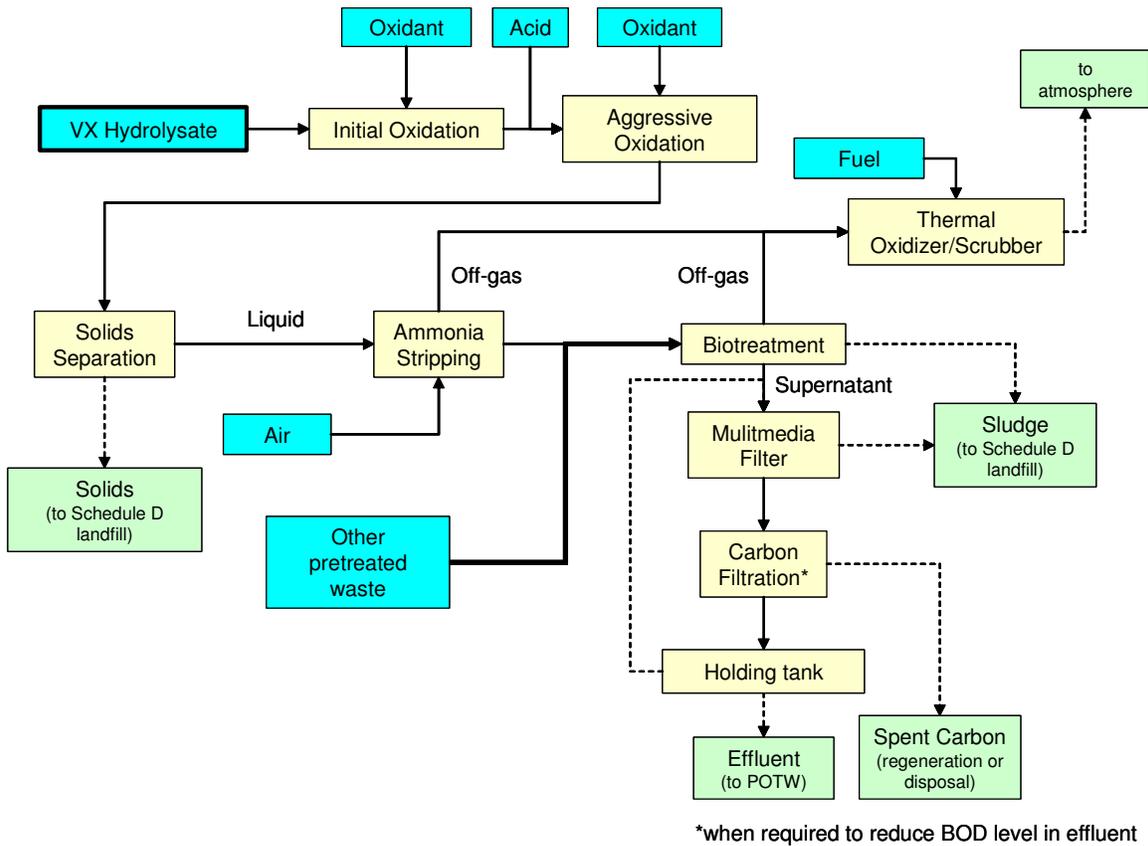


Figure 3-1. Full-Scale Hydrolysis Treatment Process Flow

Hydrolysate was manufactured at the Edgewood Chemical and Biological Center (ECBC) as part of testing of the caustic hydrolysis process and for testing of treatment options. The hydrolysate treated included no VX stabilizer or stabilizer breakdown products because the VX used to generate the hydrolysate did not contain stabilizers (see Section 2.2). Future optimization testing was planned with additional hydrolysate containing stabilizer components and produced by the exact process to be used at NECDF.

Table 3-1. Demonstration Study Limits for the Final Period^a

Discharge Parameter^b	Frequency	Discharge Limitations (One-Day Max)	Discharge Limitations (Max. Monthly Average)^c
Cd, µg/L	Daily	90	40
Cr (total), µg/L	Daily	2,000	2,000
Cu, µg/L	Daily	1,000	500
Cyanide, (free) µg/L	Twice during performance period	500	500
Pb, µg/L	Daily	600	400
Hg, µg/L	Twice during performance period	0.24	0.12 ^d
Ni, µg/L	Daily	2,500	1,300
Ag, µg/L	Daily	600	600
Zn, µg/L	Daily	2,250	2,250
pH, s.u.	Daily	6.0-11.5	-
CBOD ₅ , mg/L	Daily	500	250
Suspended Solids, mg/L	Daily	600	300
Ammonia (as N), mg/L	Daily	100	50
Oil & Grease, mg/L	Twice during performance period	600	300
As, µg/L	Twice during performance period	300	150
Mo, µg/L	Daily	4,000	4,000
Se, µg/L	Twice during performance period	100	100
Total Toxic Organics, µg/L See 2001 edition of Standard Methods, Method 8260 (volatiles) Method 8270 (semi-volatiles)	Once during performance period	N/A	See 2001 edition of Standard Methods, Method 8260 (volatiles) Method 8270 (semi-volatiles)
CWC Treaty Based Limits			
Hydrolysate thiolamine	Daily	0.1 wt. %	0.1 wt. %
EMPA	Daily	0.1 wt. %	0.1 wt. %
MPA	Daily	0.1 wt. %	0.1 wt. %

This is Table 2 of the Treatability Study¹

^a Individual samples must not exceed the One-Day Max discharge values, and the average of all samples collected must not exceed the Max Monthly Average.

^b The methods used to measure the selected compounds will be established EPA Standard Methods or similar.

^c An analytical result of less than method detection limit will be treated as “zero” for purposes of calculating Monthly Averages.

^d Mercury limit of 0.12 µg/L or less than the Reporting Detection Limit (RDL) based on the Best Demonstrated Available Technology (BDAT).

In support of the treatability study, the biotreatment process was run from March 7 through July 24, 2003, for a total of 139 days.

- March 7 through April 30 (54 days): the biotreatment process was run with effluent from the plant (without hydrolysate) to acclimate the reactors to laboratory conditions.
- May 1 through June 9 (40 days): the biotreatment process was acclimated to treated hydrolysate blended with plant wastewater. The volume of hydrolysate added was ramped up to the relative load that would be expected at full scale.
- June 10 through July 7 (28 days): the test bioreactors were fed hydrolysate solely in a manner to simulate full scale. This period included the certification testing.
- From July 8 through July 24 (17 days): the bioreactors were maintained on hydrolysate with the anticipation of further testing with fresh hydrolysate, which did not occur.

For the entire period during which bioreactors were maintained in the laboratory, the reactors were tested for the following parameters to establish that the reactors were functioning properly.

- pH
- Dissolved oxygen (DO)
- Oxygen uptake rates (with and without wastewater spikes)
- Total organic carbon (TOC)
- Total dissolved solids of influent (TDS)
- Mixed liquor suspended solids (MLSS)
- Inorganic nutrients in the influent and effluent (ammonia, nitrate, nitrite, phosphate)
- Sludge volume index (SVI) and
- Temperature

Patterns apparent in these process parameter values were used to modulate the wastewater load. The maintenance of appropriate wastewater loading is a critical aspect of optimizing SBR operation.

In addition to the above parameters, other tests were performed from June 10 through July 7, in accordance with certification test requirements. These additional parameters (see Table 3-1) were measured during the 10-day certification period, as well as during the 18-day period preceding and following the certification test to check compliance with effluent requirements.

3.4.2 Description of the Perma-Fix Treatability Test Process

The treatability process was very similar to the proposed full-scale process but used process units smaller than full-scale for this treatability demonstration. There were nine process steps:

1. Oxidize thiolamine
2. Reduce the pH by adding acid
3. Add strong oxidant to oxidize EMPA and MPA
4. Remove the solids by filtration through a glass-fiber filter
5. Adjust the pH and aerate to strip ammonia
6. Blend the oxidized and filtered hydrolysate with other wastewater being treated at PFD
7. Treat the mixture in two 5.8-L SBRs
8. Mix the biological effluent with activated carbon and filter it through a glass-fiber filter
9. Discharge the effluent to POTW

Figure 3-2 is a block flow diagram that shows the steps of the process demonstrated in the treatability study; operations from the full-scale process that were not performed in the treatability study are marked in gray.

3.4.3 Data Quality

Finding: The quality of the data was sufficient to support the conclusions drawn in the study.

Mitretek reviewed the quality assurance of the data used in the treatability study. The study included a Laboratory Quality Assurance Plan (LQAP) as Appendix D. The LQAP specified the analytical methods to be used and indicated that appropriate quality control was employed. Samples were analyzed using valid methods. Although a complete data audit was beyond the scope of this assessment, the treatability study summarized pertinent measures of precision and accuracy; these measures indicated acceptable laboratory performance.

One analytical method that should be reviewed in detail is the five-day Carbonaceous Biochemical Oxygen Demand (CBOD₅) test method (Standard Method 5210 B). In his review of the PFD treatability study, Rittmann questioned the reliability of the CBOD₅ data set: “I lack confidence in PFD’s CBOD₅ data.” This statement was based on two considerations: the lack of spike recovery data for CBOD₅ analyses and apparent discrepancies between CBOD₅ results reported by PFD and other indicators. Consequently, Mitretek examined each of these considerations in detail.

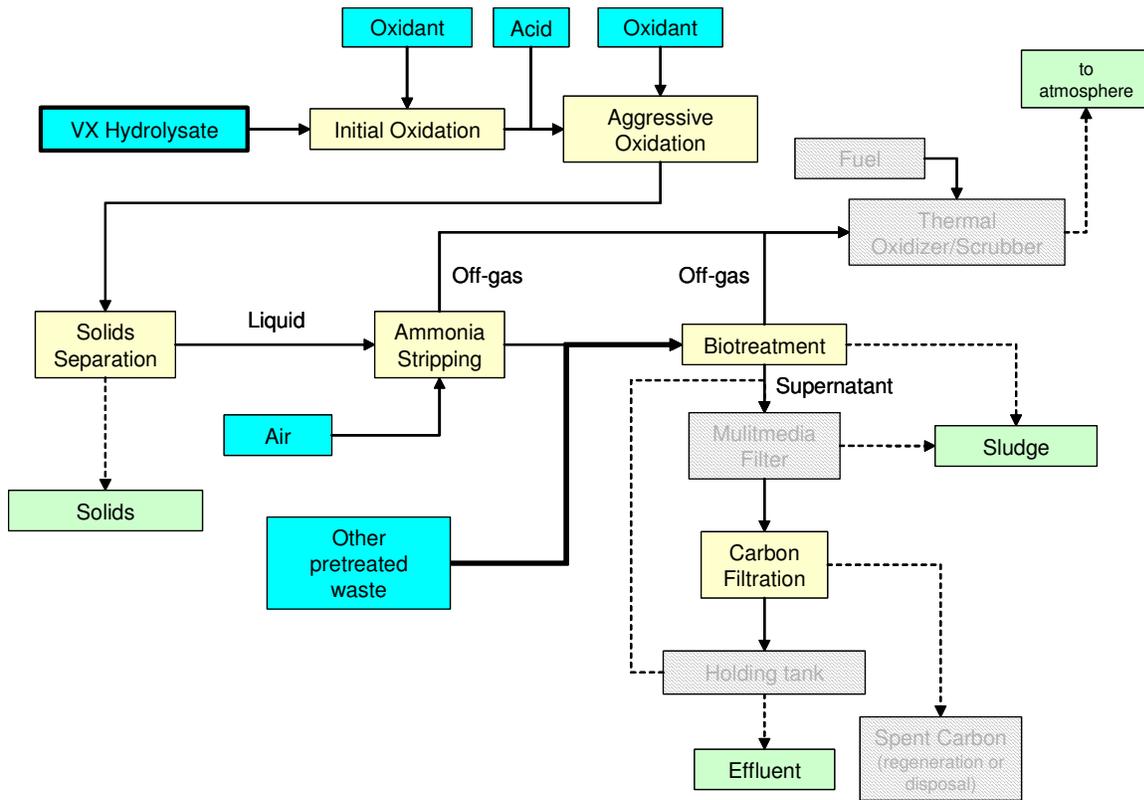


Figure 3-2. Treatability Study Process Flow

The reason that no spike-recovery testing was presented for CBOD₅ is that none was required, either by the standard test method or by the LQAP for the treatability study. CBOD₅ testing in the treatability study was performed in both the PFD laboratory and by Test America of Dayton, OH,²⁷ in accordance with Standard Method 5210. Standard Method 5210 requires four quality control elements: unseeded dilution water, a glucose-glutamic acid standard check solution, a seed control standard, and a duplicate sample; one of each type should be run per each analytical batch of 20 samples or fewer.²⁸ Data sheets filled out by the analysts performing the PFD laboratory CBOD₅ tests indicate that the required quality control samples were analyzed; the results either were in control or were qualified appropriately.²⁹ Data sheets from the analysts were not included with the Test America CBOD₅ data package, which is not unusual for commercial laboratory results. Nevertheless, for one batch, the lab noted that laboratory control samples were outside of the acceptable limits and the results were appropriately qualified as estimated, suggesting that the remaining results were in control.³⁰ Test America is accredited by the American Association of Laboratory Accreditation (effective 1/16/03), and by the National Environmental Laboratory Accreditation Conference (NELAC) through the State of New York (originally effective

8/19/02, currently approved through 4/1/04). The NELAC/New York accreditation specifically includes Standard Method 5210.³¹ Although a complete audit of Test America's data was not performed, there was no indication to suggest that appropriate quality assurance was not performed. The QC element that Rittmann asserts to be lacking is required neither by the project LQAP nor by the standard method; therefore, its absence provides no reason for diminished confidence in the performance of that method.

Rittmann reports apparent "discrepancies" related to the CBOD₅ results. He argues that historical full-scale operational CBOD₅ data reported by PFD appear to be inconsistent with their own soluble Total Organic Carbon (TOC) data and with Montgomery County's CBOD₅ data. However, these discrepancies were not associated with analyses performed by Test America; therefore, they do not impact the quality of the data in the treatability study. Differences between CBOD₅ data reported by PFD and Montgomery County for the existing plant effluent have alternative explanations. PFD indicated that waste streams with certain characteristics are treated chemically but bypass the biotreatment plant. Additionally, the CBOD₅ concentrations of the raw wastewater going to biotreatment vary by an order of magnitude from truck to truck during normal operations. Depending on how the plant is being operated at a given time, the CBOD₅ of the PFD discharge varies over time. It is not unusual for there to be some scatter in the CBOD₅ performance of a biological treatment process, particularly if it treats relatively high-strength industrial wastewater. It therefore appears that these discrepancies could easily have resulted from samples that were taken at different times and resulted from processing different feeds.

Another potential discrepancy refers to apparent inconsistencies between PFD's CBOD₅ data and other measurements of SBR effluent quality. Mitretek did not have access to data for routine PFD plant operations unrelated to the Treatability Study, and so cannot assess whether PFD's CBOD₅ and TOC data are inconsistent. However, this question does not bear on the quality of the data used to evaluate the treatment of Newport hydrolysate because the Treatability Study used data generated by Test America, which is not involved in testing of routine plant operations.

In summary, Mitretek reviewed the quality assurance of the data used in the treatability study. In our judgment, the quality of the data was sufficient to support the conclusions drawn in the study.

3.4.4 Fate of Schedule 2 Compounds

Finding: Data exist to support the fate of Schedule 2 compounds in specific process steps.
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Mitretek assessed the level of documentation of the fate of the Schedule 2 compounds at each step of treatment. The treatability study presented data only on the final effluent from the process. However, PFD performed analyses on the concentrations of Schedule 2

compounds in many intermediate streams.³² These analyses were included in raw data in Appendix E of the treatability study. Concentrations of Schedule 2 compounds and CBOD₅ in the PFD hydrolysate treatment process are provided in Table 3-2.

Table 3-2. Concentrations of Schedule 2 Compounds and CBOD₅ in the Perma-Fix Hydrolysate Treatment Process (in Percent)

Process Stream	MPA	EMPA	Thiolamine	CBOD ₅
Initial	1	8	10	0.8
After mild oxidation	1	8	<0.01	0.8
After pH adjustment	1	8	<0.01	0.8
After strong oxidation	0.4	0.2	<0.01	0.7
After ammonia removal	0.4	0.2	<0.01	0.7
After mixing with plant flow	0.08	0.03	<0.01	0.07
After carbon polishing	0.08	0.03	<0.01	0.01
At discharge point	0.08	0.03	<0.01	0.01

Relative volumes of the streams are considered proprietary data by PFD, so no mass balance has been released publicly. Mitretek has reviewed the proprietary data and determined that the Schedule 2 compounds were removed in the expected steps and to the required degrees:

- Data indicate that thiolamine is converted essentially quantitatively to oxidized species during the mild oxidation step. These oxidation products further react during the aggressive oxidation step to ammonia and a variety of soluble organic species. The amount of ammonia measured in the waste stream represents complete conversion of thiolamine to ammonia.³³
- Mitretek reviewed analyses of NaEMPA and Na₂MPA reported for the feed to the aggressive oxidation step, the suspension produced by the aggressive oxidation step, and the solution remaining after the solids were removed from the suspension. Approximately 90 percent of the Na₂MPA and NaEMPA initially present in the waste is destroyed or otherwise removed in the aggressive oxidation step. NaEMPA represents 83 percent of the phosphonate in the feed to the aggressive oxidation step; 99 percent of NaEMPA is destroyed or removed. The net destruction and removal of Na₂MPA is 50 percent; the destruction of initial Na₂MPA is certainly larger because destruction of NaEMPA produces Na₂MPA.

Data for orthophosphate analysis were also reviewed. The mass balance for the aggressive oxidation was reported by PFD to be confirmed by analyses for orthophosphate anion.³⁴

- Proprietary data were collected to quantify the amount of Na₂MPA and NaEMPA removed during the solids separation step. PFD make no claims for destruction in the solids separation step; based on the chemical properties of these salts, it appears reasonable to assume that the reported quantities of Na₂MPA and NaEMPA remain associated with the solids. Some of this material appears subject to potential leaching in a landfill, but these solids would be disposed of in a regulated Schedule D landfill, which is designed to contain leachate. These landfills have a composite liner consisting of upper component of a minimum 30-mil (0.030-inch) flexible membrane liner (FML) and a lower component consisting of at least of a 2-foot layer of compacted soil. The FML components, consisting of high-density polyethylene (HDPE), are at least 60-mil. These landfills also have a leachate collection system and a contaminants monitoring system.
- No significant degradation of Na₂MPA or NaEMPA occurs in the biotreatment step. The use of Na₂MPA and NaEMPA in hydrolysate by microorganisms as phosphorus sources requires the addition of excess nitrogen and carbon and the absence of orthophosphate;³⁵ considerable variation between different types of bioreactors in levels of biodegradation achieved has been observed.^{36,37} The biotreatment step of the PFD process does not need to degrade Na₂MPA or NaEMPA; rather, it is needed in the process to reduce CBOD₅ resulting from the oxidation of the hydrolysate.
- Na₂MPA and NaEMPA are not removed by carbon filtration; these water-soluble ionic compounds are not significantly adsorbed by the activated carbon.

In summary, data are available to determine the specific fate of Schedule 2 compounds in the various steps of the PFD process. The proprietary nature of some information prevents public release of a full mass balance for the process.

3.4.5 Integration and Scale-Up

Finding: PFD's Treatability Study collected sufficient data to adequately address the purpose for which it was intended. Duration of the treatability study was sufficient for scale-up.

Finding: The technologies used in the Treatability Study are demonstrated and available, and the individual steps of the PFD process have been used throughout the waste treatment industry. The application of existing technologies to new waste streams is routine.

The technologies used in the Treatability Study are demonstrated and available technologies, and the individual steps of the PFD process have been used throughout the waste treatment industry. The process developed represents the application of unit processes that are standard parts of PFD's operations to a new waste stream.

Mitretek found no problem with the testing length because the treatability study was run for a total of 139 days, including the testing period (10 days for certification plus another 18 days of data collection). Generally, this length of time is a more than reasonable period of testing.

For full-scale operations, a further treatability study would be implemented as normal commercial practice to optimize all operating parameters that could enhance the reliability of operations. Scale-up of bench-scale processes can be challenging, however it is a normal practice to ramp up slowly in stages when moving from small-scale to full-scale. Typically, parameters such as mixing, temperature, pH, and oxygen control are monitored and used to optimize the process so that discharges meet relevant requirements.

Mitretek assessed how well key design parameters for the treatability study matched the parameters for the full-scale application. The bioreactor's hydraulic retention time (HRT) is a function of reactor volume and flow rate. For any specific reactor design (and HRT), there will be an appropriate loading rate that results in contaminant removal. Because high removal rates require high microbial populations, which themselves exert BOD, treatment of high BOD wastes is usually most efficient when treatment is followed by clarification and sludge (biomass) removal. Therefore, it is not unusual to have the retention time of 11.6 days for this treatability study (experimental method) and 5.3 days for the full-scale SBR. Furthermore, full-scale optimization would determine the optimal operating conditions, including solids retention time (SRT), influent concentration, and the food/microorganisms ratio (F/M). The difference in hydraulic retention (or detention) times between the bench studies and the full-scale SBRs is only significant if the latter is insufficient to meet the system's performance requirements. The HRT can be adjusted, within limits, to meet the operational requirements of achieving a desired contaminant removal efficiency.

Mitretek found no limitation regarding the treatability study and the full-scale operation with respect to mixing, temperature, and pH control. These are scale-up issues that are normally addressed and optimized during the further treatability study and during ramp up of operations at the designated TSDF. In addition, some scale-up issues are more complex than others; for example, during the treatability study, the operator brought an outside consultant to advise on heat exchange scale-up issues.

3.5 Issues Related to Perma-Fix's Operations

General issues related to PFD's operations that were not solely related to the Treatability Study or to the processing of Newport hydrolysate are addressed in this section. In his report,

Rittmann reviewed 6 months of PFD operational data and 2 years effluent monitoring data from Montgomery County. During this review, Mitretek did not have access to this data and is unable to assess some specific issues concerning PFD's SBR operations.

3.5.1 Process Monitoring, Sampling, and Analysis

Finding: Monitoring required at a biotreatment plant depends on the specific wastes, processes, and discharge and emission criteria for that plant.

Monitoring at biotreatment plants is a function of the waste received, the process used, and the discharge and emission criteria under which the plant operates. Influent and effluent monitoring of analytes and the frequency of monitoring are essential to measure the performance of the process and to make sure that the plant is not violating its operational permits. A monitoring system that can both assess the load of the incoming waste stream and quantify its potential toxicity, such as an on-line respirometry method, will achieve the required results. Liquid samples of feed and treated effluent and samples of system off-gas would be collected and analyzed in accordance with approved and regulated sampling and analysis plans. Monitoring could include measurements for temperature, sludge volume index (SVI), oxygen demand for treatment (BOD, COD), nitrogen species (TKN, NH₄-N, NO₂-N, NO₃-N), pH, total solids (suspended and dissolved), volatile suspended solids (VSS), arsenic, effluent suspended solids (ESS), organics including volatile and semi-volatile organics (VOC, SVOC), as well as total organic carbon (TOC), and oil and grease.

3.5.2 Odor Control

Finding: Treating any odorous waste at PFD may increase and compound the issue of odor at the PFD site. However, odor control measures and technologies are available.

The odor issue at the PFD site is well documented by the Regional Air Pollution Control Agency (RAPCA); it is apparent that the odor is caused by fugitive emissions and the escape of gases from the operations at PFD. Treating any odorous waste at PFD may increase and compound the issue of odor at the PFD site. However, odor control measures and technologies are available. Measures such as capturing fugitive gases, keeping some areas under negative pressure, good housekeeping, sealing doors and openings, monitoring for volatile organics, and thermal oxidation of captured gases can greatly reduce and even eliminate the odor problem.

3.5.3 Activated Carbon Filtration Requirement

Finding: In a full-scale plant, a multimedia particulate filter removes the SS before the stream is passed through the carbon filter to avoid clogging the carbon filter. The use of filtration and carbon adsorption to treat industrial wastewater can be operated reliably.

During the treatability study, carbon adsorption/filtration was used to control CBOD₅ and ESS. The biotreatment reactor did not bring the levels of BOD and ESS to acceptable low

levels; therefore, carbon adsorption was used to bring these levels to acceptable discharge limits. For example, CBOD₅ was reported to be about 450 mg/L (250 mg/L daily certification limit), and ESS was reported to be about 600 mg/L one day maximum (300 mg/L discharge limit monthly maximum average). In a full-scale plant, a multimedia particulate filter removes the SS before the stream is passed through the carbon filter to avoid clogging the carbon filter. Carbon treatment of the resulting liquid filtrate can achieve low levels of contaminants concentrations (including CBOD₅ and SS if needed) prior to discharge, but the main concern here should be activated carbon's ability to effectively remove contaminants of interest. Mobile and fixed adsorption systems for both gas and liquid-phase are commercially available for installation as a complete system ready to operate on a turnkey basis. Again, the treatment of the hydrolysate waste at a full-scale unit would involve a treatability study to determine the optimal operating conditions including carbon replacement/regeneration needs. Activated carbon's affinity for the various organic contaminants would be established through treatability testing.

The use of filtration and carbon adsorption to treat industrial wastewater can be operated reliably. In many applications, activated carbon is routinely used for the treatment of water and wastewater. In some cases, powdered activated carbon is added to the actual wastewater stream to adsorb contaminants, and then the carbon is removed from the stream and discarded or regenerated. As noted in Section 3.1, carbon adsorption systems are both effective and commercially available.

3.5.4 Effect of Newport Hydrolysate on the Western Regional Wastewater Facility

Finding: The concentrations of Na ₂ MPA, NaEMPA, and NaEA2192 entering the Western Regional Wastewater Facility will not lead to adverse affects to workers via dermal or aerosol inhalation and are unlikely to adversely affect the microorganisms in the facility.
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Mitretek assessed the hazard posed by treatment effluent produced from Newport hydrolysate to workers at the Western Regional Wastewater Facility, the Montgomery County POTW. Performance Indicator (PI) values were calculated for accidental dermal exposure of Na₂MPA, NaEMPA and NaEA2192 from the static screens, the point where the effluent from PFD enters the POTW. Values were determined according to guidelines published by the EPA Region IX Preliminary Remediation Goals (PRG) report and parameters specific to the Newport hydrolysate treatment process, as described in a 2001 U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) report.²⁵ The estimated chemical intake (dose) was compared with a reference dose level below which adverse health effects are unlikely, using a ratio called the hazard quotient. Hazard quotients were generated by dividing the concentrations of each component in the static screens by the PI values. Hazard quotients for Na₂MPA, NaEMPA, and NaEA2192 were all well below 1 (0.00005, 0.00013, and 0.0065, respectively), indicating that dermal exposure of these components at the static screens or later in the process would not lead to adverse effects.

Mitretek also estimated the hazard posed by aerosols generated in the Western Regional Wastewater Facility. Exposure parameters for inhalation of aerosols are not standardized, so Mitretek has assumed as an upper bound a typical aerosol concentration produced by a high volume aerosol generator of 100 µg liquid per L of air. This value is then multiplied by the concentrations of Na₂MPA, NaEMPA and NaEA2192 in the effluent at the static screens to give a maximum airborne concentration. Using the equation for vapor-phase inhalation from the U.S. EPA Region IX PRG guidelines and the same exposure parameters used to estimate dermal exposure, the hazard quotient was below 1; 0.18 for Na₂MPA, 0.05 for NaEMPA, and 0.5 for NaEA2192. The actual aerosol concentration in the Western Regional Wastewater Facility should be much lower, leading to much lower hazard quotients for inhalation of aerosols.

In summary, the concentrations of Na₂MPA, NaEMPA, and NaEA2192 at the static screens are unlikely to lead to adverse toxic effects to workers at the Western Regional Wastewater Facility. Ecological studies described in Section 4.2 indicate that Na₂MPA and NaEMPA resulting from Newport hydrolysate treatment would not pose an unacceptable risk to aquatic organisms and therefore appear unlikely to adversely affect the microorganisms in the Western Regional Wastewater Facility.

Section 4

Impact on Human Health and the Environment

The potential toxicity of process effluents was discussed at length in Rittmann's assessment of the PFD Treatability Study and in the Army's response. Therefore, Mitretek has reviewed the available toxicity data on compounds discussed in these documents and assessed the risks to human health and the environment posed by treatment effluent. Mitretek's major findings in this section include the following

- MPA and EMPA are extremely unlikely to be toxic at the concentrations produced in the wastewater following treatment of Newport hydrolysate
- There is no evidence in the literature that EMPA or MPA is mutagenic. A negative Ames test for a closely related compound indicates that they are unlikely to be genotoxic
- EA2192 and VX are undetectable in Newport hydrolysate and in effluents, with method detection limits sufficient to provide protection.
- Sections of Rittman's report inaccurately characterize risks to human health and the environment from the effluent produced by the PFD process.

4.1 Human Health Risks Posed by Treatment Effluent

Mitretek assessed the human health risks posed by constituents of the effluents resulting from PFD treatment of Newport hydrolysate. Mitretek reviewed toxicity values presented in the Rittmann report, as well as the available toxicity data on MPA, EMPA, and EA2192. Mitretek then computed hazard quotients for people exposed to these compounds in drinking water drawn from the Great Miami River at concentrations resulting from PFD treatment of Newport hydrolysate. There are several equivalent ways to compute hazard quotients; in this section, Mitretek compared the reference dose, a numerical estimate of a daily oral exposure to a human population (including sensitive subgroups) that is not likely to cause harmful noncancer effects during a lifetime, with the estimated chemical intake (dose) to compute the hazard quotient. Hazard quotients below 1 indicate that the exposure in question will not lead to adverse effects.

4.1.1 Review of Na₂MPA Toxicity Data

Finding: Concentrations of MPA found at various steps in the Newport hydrolysate treatment process will not lead to adverse toxic effects in humans.
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Na₂MPA is the sodium salt of MPA (methylphosphonic acid, CAS Registry No. 993-13-5); toxicity data applicable to both salt and acid are reported as "MPA," so the latter term will be used in this discussion. Information regarding the toxicity of MPA indicates that it has

minimal toxic effects, particularly at the concentrations encountered during the treatment of Newport hydrolysate. Material safety and data sheets (MSDS) list high concentrations of pure, non-diluted MPA as a skin and eye irritant that may exhibit some toxicity by skin absorption, ingestion, or inhalation. In a study examining neurophysiologic effects of chemical agent hydrolysis products on cortical neurons in tissue culture, MPA failed to affect extracellular action potentials (a measurement of neuronal function) at all concentrations examined.³⁸ MPA is stable in the environment because its non-reactive P-CH₃ bond makes it resistant to hydrolysis, photolysis, and thermal decomposition. MPA has a very low log octanol/water partition coefficient (log *K_{ow}*) value of -2.28, indicating that it is unlikely to bioaccumulate in organisms. Furthermore, MPA is not expected to volatilize from water or moist soils and an estimated vapor pressure of 2×10^{-6} mmHg indicates that MPA would exist only at very small amounts in the particulate matter.³⁹ The acute oral LD₅₀ value is $\geq 5,000$ mg/kg in the mouse and the rat.³⁹ The oral reference dose (RfD) for MPA was estimated using (1) the no observed adverse effect level (NOAEL) value for isopropyl methylphosphonic acid (IMPA) of 279 mg/kg/day and (2) the rat chronic lowest observed adverse effect level (LOAEL) estimated by the toxicology computational package TOPKAT[®] to be 221 mg/kg/day. Using the IMPA NOAEL value, an RfD of 0.020 mg/kg/day⁴⁰ was estimated, and using that estimated RfD value, the estimated reference concentration (RfC) value for continuous inhalation exposure of 0.024 mg/m³ was derived. At environmentally relevant pH values (5-9), MPA will be highly dissociated in water; p*K_a* at 25°C is 2.38.³⁹ Estimates of dermal, oral, and inhalation pathway exposure concentrations were calculated according to guidelines described in the EPA Region IX PRG with parameters specific to the Newport hydrolysate treatment process.²⁵ Hazard quotients were generated by dividing the estimated exposure concentrations by the RfD. The hazard quotients indicated that concentrations of MPA found at various steps of the Newport hydrolysate treatment process will not lead to adverse toxic effects in humans.

4.1.2 Review of NaEMPA Toxicity

Finding: Concentrations of NaEMPA found at various steps in the Newport hydrolysate treatment process will not lead to adverse toxic effects in humans.

NaEMPA is the sodium salt of EMPA (ethyl methylphosphonic acid; CAS Registry No. 1832-53-7); toxicity data applicable to both salt and acid are reported as “EMPA.” It is expected that the toxicity of EMPA is similar to that of MPA.³⁹ EMPA is extremely water-soluble and has a low vapor pressure (3.6×10^{-4} mm Hg). Thus, exposure through inhalation is improbable. A quantitative structure-activity relationship (QSAR)-based estimate of the EMPA oral LD₅₀ is 65 mg/kg,³⁹ and based on the rat subchronic NOAEL of 279 mg/kg/day for IMPA,⁴¹ the RfD for EMPA was estimated to be 0.025 mg/kg/day.³⁹ EMPA has a log *K_{ow}* of -1.15, making it unlikely to bioaccumulate. At environmentally relevant pH values (5-9), EMPA will be highly dissociated in water; p*K_a* at 25°C has been reported at 2.00-2.76.^{21,22} As with MPA, hazard quotient estimates of exposure through

dermal, oral, and inhalation pathways indicate that EMPA will not lead to adverse toxic effects in humans.

4.1.3 Review of NaEA2192 Toxicity

NaEA2192 is the sodium salt of EA2192 (*S*-[2-diisopropylaminoethyl] methylphosphonothioic acid; CAS Registry No. 73207-98-4); toxicity data applicable to both salt and acid are reported as “EA2192.” EA2192 possesses neurotoxic anticholinesterase activity that is lower in magnitude than VX.²⁵ RfD and RfC values are estimated at 6×10^{-7} mg/kg/day and 7×10^{-7} mg/m³, respectively.³⁹ EA2192 is insufficiently volatile to be an inhalation hazard, and rodent studies have indicated that toxicity via dermal exposure is unlikely.³⁹ EA2192 is infinitely water-soluble and stable in water at neutral and alkaline pH.⁴² It is more resistant to hydrolysis than VX. It has a log K_{oc} of 1.9, indicative of a low potential to adsorb to soil, as well as a log K_{ow} value of 0.96, indicative of a low potential to bioaccumulate in organisms.³⁹ Oral and intravenous LD₅₀ values in the rat are 0.63 mg/kg and 0.018 mg/kg, respectively.⁴³ The mouse intravenous LD₅₀ value is 0.050 mg/kg,⁴⁴ and rabbit intravenous values have been reported to be 0.012-0.017 mg/kg.⁴⁵

USACHPPM published a report in 2001 evaluating the risk posed by EA2192 to TSDF workers.²⁵ Using the U.S. EPA Region IX PRG approach, USACHPPM calculated a performance indicator value of 1.128 mg/L to give a hazard quotient of 1 based on dermal exposure that is derived from properties specific to EA2192 (RfD and permeability coefficients), as well as exposure values and times specific to NECDF operations and TSDF facilities. The assumptions include an exposure duration (2.75 years), which is somewhat conservative given NECDF’s current plan to generate hydrolysate for 2.09 years.⁶ In addition, the permeability coefficient is likely to overestimate dermal exposure because the log K_{ow} value used is for the acid form of EA2192; the sodium salt (NaEA2192) will have a lower log K_{ow} value, although to what extent is unknown. Therefore, NaEA2192 will have a smaller permeability coefficient than does EA2192, resulting in a lower hazard quotient for the salt relative to the same amount of the acid.

4.1.4 Risk Posed by Leachate from Process Solids

Finding: Solids produced by the PFD processing of Newport hydrolysate would have been disposed of in a certified and regulated landfill where the leachate is contained; therefore, no exposure pathway is anticipated and no risk results.

Following the oxidation of Newport hydrolysate, the PFD process requires the removal of solids by filtration through a multimedia filter. The treatability study subjected these solids to the U.S. EPA’s Toxicity Characteristic Leaching Procedure (TCLP) test. Na₂MPA and NaEMPA are present in leachate at 0.07 percent (w/v) and 0.05 percent (w/v), respectively. The risks posed by MPA and EMPA at these levels are expected to be minimal. These solids

would have been disposed of in a certified and regulated landfill where the leachate is contained; therefore, no exposure pathway would be anticipated.

Thiolamine was not detected after the mild oxidation; measured thiolamine concentrations in the supernatant after filtration of the solids are below the method detection limit of 0.01 percent (100 mg/L).⁴⁶ The “not measured” notation in the treatability study for thiolamine in leachate from the solid indicates that no analysis was performed. During discussions with Mitretek, PFD indicated that there was no method available to detect thiolamine in the leachate matrix. Given the lack of detection in the feed to the aggressive oxidation or in the filtrate from solids removal, Mitretek believes that the lack of measured thiolamine levels in the leachate does not represent a significant data gap. If it was not present in the liquid feed, there is no compelling reason to speculate it would be in the solids.

The Army document³ evaluating the issues raised in Rittmann’s report contains the statement that MPA and EMPA occur in the precipitated solids in polymeric form. Mitretek disagrees with this statement; MPA and EMPA are present in the solids as ionic salts, not in polymeric form. “Polymeric” typically refers to covalent binding to macromolecules, often an effective form of immobilization. Levels of MPA and EMPA found in TCLP leachate indicate that such salts are not immobilized in the solid material. Furthermore, MPA and EMPA do not have the chemical functional groups necessary to undergo conventional polymerization.

4.1.5 Risk of NaEMPA, Na₂MPA, and NaEA2192 in Effluent from the Western Regional Wastewater Treatment Facility

Finding: Effluent from the Western Regional Wastewater Treatment Facility is unlikely to pose any significant risk to human health as a result of treatment of Newport hydrolysate using the PFD process.

In Rittmann’s assessment, he estimates concentrations for MPA and EMPA in the effluent from the Western Regional Wastewater Treatment Facility of 2.3 mg/L and 1.0 mg/L, respectively.⁴⁷ Using the reference doses reported in Sections 4.1.1 and 4.1.2, one can calculate that the hazard quotient for a 70 kg individual consuming 1.4-2.0 L per day of water containing these concentrations ranges from 2.3 to 3.3 for MPA and from 0.8 to 1.1 for EMPA. However, consumption of drinking water drawn from the Great Miami River below the POTW outfall in Dayton represents the most significant effluent potential exposure pathway for the public. Based on the mean stream flow at Dayton (1,306 ft³/sec, equivalent to 844 million gal/day or 3.19 billion L/day),⁴⁸ the hazard quotients decrease to less than 0.05 after the effluent mixes into the receiving stream. These hazard quotients indicate that the risk of MPA and EMPA contained in drinking water drawn from the Great Miami River would be insignificant; this represents the most significant liquid effluent exposure pathway for the public.

There will be no detectable NaEA2192 in the Newport hydrolysate that would have been sent to PFD. The risk posed by NaEA2192 can be assessed based on the method detection limit (1 ppm) and the increase in the volume as the waste is treated. The method detection limit is set to protect workers dermally exposed directly to Newport hydrolysate.⁴⁹ The increase in volume during treatment at PFD is proprietary, but Mitretek has used the proprietary data to determine that the hazard quotients for a 70 kg individual consuming 1.4 to 2.0 L of water would be less than 10 for the effluent from the Western Regional Wastewater Treatment Facility and less than 0.2 for drinking water from the Great Miami River. Other exposure pathways besides drinking water represent still lower levels of risk.

Rittman's report asserts that "one study on EMPA (in Munro et al., 1999) gave an Ames-test mutagenicity reference concentration of 30 $\mu\text{g}/\text{m}^3$ " Mitretek has reviewed the cited reference,³⁹ and it did not contain Ames information for EMPA. Searching the PubMed database also failed to provide a reference for this value. The 30 $\mu\text{g}/\text{m}^3$ value is suspicious because (1) Ames test results are not expressed in $\mu\text{g}/\text{m}^3$ units and (2) 30 $\mu\text{g}/\text{m}^3$ is the estimated value for the EMPA RfC. Therefore, this value was probably erroneously reported as an Ames test result. The cited reference does report that for IMPA, a compound with a very similar chemical structure to EMPA, "mutagenicity testing with and without metabolic activation in *Salmonella typhimurium* gave negative results,"⁵⁰ indicating that EMPA is unlikely to be genotoxic.

Furthermore, the reference concentration for EMPA has been estimated to be 0.030 mg/m^3 .⁵⁰ However, the reference concentration is the concentration of a substance in air which is considered to be unlikely to cause non-cancer adverse health effects over a lifetime of inhalation exposure and should not be used to assess the risk of oral exposures, as Rittman has done; the correct parameter for assessing risk of oral exposure to substances dissolved in water is the RfD.⁵¹ Converting aqueous oral concentrations to reference inhalation concentrations is inappropriate.

In summary, effluent from the Western Regional Wastewater Treatment Facility is unlikely to pose any significant risk to human health as a result of treatment of Newport hydrolysate using the PFD process.

4.2 Ecological Risks Posed by Treatment Effluent

Finding: Estimated in-stream concentrations of MPA and EMPA resulting from Newport hydrolysate treatment will not pose an unacceptable chronic risk to aquatic organisms.

Ecological screening levels for aquatic organisms exposed to NaEA2192 were established. These levels indicated that no adverse effects were seen at concentrations below 70 ppm,⁴⁹ well above the 1 ppm method detection limit for Newport hydrolysate; this indicates that there is no significant risk to exposed aquatic organisms from NaEA2192 in treatment effluent.

Ecological studies have demonstrated that MPA poses low toxicity to the freshwater protozoan communities and fish species examined, including bluegill fish and fathead minnows.⁵² These species were chosen to represent various trophic levels that might come in contact with MPA.⁵² Acute hazard risk quotients generated using EPA guidelines are well below 0.0007, indicating that MPA poses no acute risk to aquatic organisms.⁵³ Chronic hazard quotients ranged from 0.0004 in green algae to 0.008 for reproductive effects on *Ceriodaphnia dubia*, a freshwater daphnid.⁵³ Ecotoxicity of EMPA is expected to be similar to that of MPA. Ecological risk assessments of MPA and EMPA prepared using the risk assessment approach presented in U.S. EPA guidance⁵⁴ indicate that estimated in-stream concentrations of MPA and EMPA resulting from Newport hydrolysate treatment will not pose an unacceptable chronic risk to aquatic organisms.⁵³

Section 5

Assessment of Unanswered Questions and Recommendations from the Rittmann Report

In his report, Rittmann stated that “the proposed multi-step process has a sound scientific foundation. Properly implemented and monitored, the multi-step treatment process could eliminate hazardous components in the VXH without causing health risk or odors to neighbors and without disrupting the operation and performance of MC’s Western Regional Wastewater Treatment Facility.” Mitretek concurs with this statement. However, Rittmann also identifies in his Executive Summary several “important questions” that he asserts have not been answered. In addition, he makes five recommendations concerning disposal of Newport hydrolysate. In the sections that follow, Mitretek addresses those questions and recommendations.

5.1 Novelty of the Perma-Fix Process

“The multi-step process is new and unique, and its successful full-scale operation has not been proven at PFD or anywhere else. Therefore, MC and PFD should view the treatment of VXH as an ‘experimental method.’”

“Recommendation 5: PFD should implement VXH treatment through a phased start up that has extensive monitoring.”

Mitretek’s assessment is that the process represents the application of unit processes that are standard parts of PFD’s operation to a new waste stream. Although Rittmann’s statement that successful full-scale operation has not been proven anywhere is true, the same could be said of the treatment of any new waste submitted for disposal at a TSDF. TSDFs routinely apply their unit processes to new wastes with risks similar to those posed by Newport hydrolysate with no more testing than was done by PFD. Viewing the treatment of Newport hydrolysate as an experimental method is an overstatement.

Mitretek recommends that Newport hydrolysate treatment begin with a phased start up, which is a normal commercial practice. In addition, Newport hydrolysate will become available in small quantities initially, with the quantities of waste generated rising over a period of several months; as shown in Section 2.1, operations at NECDF have long included a planned phased start-up. Thus, any TSDF that processes Newport hydrolysate will have to begin processing with small quantities using an appropriate degree of monitoring of the process, as discussed in Section 3.5.1. As experience and data are obtained, processing rates will rise as the production rate of Newport hydrolysate at NECDF rises.

5.2 Odor Control Issues

“PFD has not documented complete success with odor control at its site and with operation of its existing biological treatment reactors.”

“Recommendation 2: PFD should solve its current odor problems before it accepts VXH for treatment.”

The odor issue at the PFD site is well documented by the Regional Air Pollution Control Agency (RAPCA); it is apparent that the odor is caused by fugitive emissions and the escape of gases from the operations at PFD. Treating any odorous waste at PFD may increase and compound the issue of odor at the PFD site. However, odor control measures and technologies are available. Measures such as capturing fugitive gases, keeping some areas under negative pressure, good housekeeping, sealing doors and openings, monitoring for volatile organics, and thermal oxidation of captured gases can greatly reduce and even eliminate the odor problem.

Implementation of appropriate odor control measures should be a normal part of operations at any TSDF. Mitretek recommends that any TSDF selected to treat Newport hydrolysate should have such measures already in place.

5.3 Removal of Schedule 2 Compounds

“Were the Schedule 2 compounds (and EA2192, if present) removed in the expected steps and to the expected degrees?”

Mitretek has reviewed the proprietary data and determined that the Schedule 2 compounds were removed in the expected steps and to the required degrees:

- Data indicate that thiolamine is converted essentially quantitatively to oxidized species during the mild oxidation step.
- Approximately 90 percent of the total Na₂MPA and NaEMPA initially present in the waste is destroyed or removed in the aggressive oxidation step. NaEMPA represents 83 percent of the methylphosphonates in the feed to the aggressive oxidation step; 99 percent of NaEMPA is destroyed or removed. The net destruction and removal of Na₂MPA is 50 percent; the destruction of the initial Na₂MPA is certainly larger because destruction of NaEMPA produces Na₂MPA. Proprietary data were collected that quantify the amount of Na₂MPA and NaEMPA removed during the solids filtration step and validate this finding.
- No significant degradation of Na₂MPA or NaEMPA occurs in the biotreatment step.
- Na₂MPA and NaEMPA are not removed by carbon filtration.

In summary, data are available to determine the specific fate of Schedule 2 compounds in the various steps of the PFD process. The proprietary nature of some information prevents

public release of a full mass balance for Schedule 2 compounds in the PFD process. Mitretek recommends that any TSDf selected to accept Newport hydrolysate be prepared to publish data to support the fate of Schedule 2 compounds in all significant process streams.

“Can the concentrations of the Schedule 2 compounds be reduced to far below the certification level by improved chemical treatment, biodegradation, or a combination?”

The treatability results indicate that the oxidation process had been optimized during the treatability study; the relative amounts of NaEMPA, Na₂MPA, and orthophosphate in suspension after the aggressive oxidation were measured at several different quantities of oxidant.⁵⁵ The process was run using the next to highest level oxidant level depicted because it met the certification levels imposed by the U.S. Army. Higher levels of oxidant would have given even higher levels of EMPA/MPA destruction, but at higher cost and increased volume of waste. Thiolamine is destroyed to below the method detection limit in the first, mild oxidation step.

Mitretek’s assessment is that there is no reason that Schedule 2 compounds need to be reduced to levels “far below” the certification levels. As shown in Section 4, the certification levels result in no significant risk to human health and the environment from the Schedule 2 compounds. Certification levels are set according to U.S. Government policy designed to ensure that Schedule 2 compounds produced in the destruction of chemical weapons cannot be recovered; this policy is independent of safety or environmental considerations. NaEMPA, Na₂MPA, and thiolamine are listed on Schedule 2, Part B, of the CWC because they are precursors for the manufacture of chemical weapons, not because of the level of health or safety hazard they pose. Regulations implementing the CWC set a reporting threshold of 1 ton per year for facilities that produce, process, or consume these chemicals; the regulations exempt mixtures containing less than 30 percent of these chemicals.⁵⁶ When used for purposes not prohibited by the CWC, these compounds are not regulated as toxic constituents of hazardous waste.⁵⁷

5.4 Operational Issues

“Was biological treatment representative of what can be expected at full scale?”

Scale-up can sometimes present challenges, making it a pertinent issue. The PFD treatability study was tailored and designed to simulate full-scale operation and was reasonably representative of what can be expected at full-scale operation. Some adjustments to the process, *e.g.*, the multi-media particulate filter, were planned to be tested and implemented at full scale. For full-scale operations, any TSDf accepting Newport hydrolysate should conduct a treatability study, which is a common industry practice that would be required by the Army, to optimize all operating parameters, including carbon replacement/regeneration needs. As discussed in Section 5.1, treatment should ramp up

slowly (as will be done at NECDF) to full scale, with adequate monitoring and controls. Such actions should ensure the reliability of operations.

“Can post-biological adsorption and filtration be operated reliably?”

Rittmann specified his concerns that an activated carbon filter would be prone to clogging and creation of anaerobic conditions. In the full-scale plant, there will be a multimedia particulate filter before the carbon filtration step to remove suspended solids; clogging should not be an issue. If the carbon units do not clog, anaerobic conditions are of much less concern. The use of filtration and carbon adsorption to treat industrial wastewater is routine in industry and can be operated reliably.

“Recommendation 1: Parsons should carry out the first oxidation step in Newport, IN.”

Mitretek disagrees with this recommendation. Rittmann cites four large benefits that would result from this recommendation. Two of the benefits cited do not apply:

- As discussed in Section 2.3.1, VX reformation does not occur spontaneously in Newport hydrolysate. Elimination of the “potential to reform VX” is therefore not a significant benefit.
- As discussed in Section 2.3, testing of Newport hydrolysate generated at 16 percent loading by weight has shown that the flammability is eliminated. Therefore, reduction of the flammability hazard can no longer be considered a significant benefit.

Carrying out the first oxidation step at NECDF would definitely reduce objectionable odors, but it would not improve general process safety. Rittmann acknowledges that the volume of Newport hydrolysate to be transported would increase due to the addition of chemicals for oxidation and lowering the pH, but there are several impacts that are not considered in his assessment. The oxidation process is not covered by NECDF’s environmental permits, so they would require modification to permit an initial, on-site oxidation step. In addition, installation of equipment to perform an initial oxidation would further delay the start of operations at NECDF, thus increasing the risk from continued storage of VX.

Parsons indicates that it has evaluated the implementation of peroxide and acid addition on site. The results of this investigation indicate that substantial testing would be required for implementation that was not justifiable by the schedule or by gains in general process safety.³ There are advantages to using an off-site TSDF with an existing capability and experience. Based on the impacts being more and the benefits being less than those acknowledged by Rittmann, the Parsons determination that there are substantial benefits to performing this step at an off-site TSDF appears reasonable.

5.5 Toxicity

“Will the treated VXH cause receiving-stream ecotoxicity when diluted into the municipal wastewater?”

As discussed in Section 4.2, available information indicates that MPA and EMPA are unlikely to result in untoward ecological effects, particularly at the concentrations found in the wastewater. Studies on the ecotoxicity posed by EMPA originating in hydrolysate would be desirable, but considering the concentrations released into the wastewater, the low potential for bioaccumulation of either MPA or EMPA, and studies of MPA indicating that it did not lead to toxic effects in the aquatic organisms studied using concentrations well above what would be released by PFD, ecotoxicity is unlikely.

5.6 Monitoring and Testing

“Recommendation 3: PFD should upgrade the monitoring and, perhaps, the performance of its SBR biological treatment system before accepting any VXH for treatment.”

If PFD had processed Newport hydrolysate at full-scale, it should have developed an appropriate monitoring scheme to optimize and run its process and meet its discharge requirements. Mitretek believes that any TSDF should, as a normal part of its operations, develop a monitoring scheme that reflects the process being carried out and the wastes being treated. Monitoring should be designed to provide performance indicators that the process is functioning as designed. The specific measurements described in Rittmann’s report may or may not be appropriate for the TSDF to be selected to receive Newport hydrolysate because the process will be different from the PFD process.

“Recommendation 4: PFD should conduct additional laboratory testing to supplement the Demonstration Study so that they can answer the important questions.”

Mitretek believes that any TSDF that accepts Newport hydrolysate would, as part of its normal operations, conduct a treatability study to address process and discharge permit issues. As a result, the study would provide data that addressed many of the issues discussed in this report. Mitretek has recommended that the TSDF be prepared to publish data to support the fate of Schedule 2 compounds in all significant process streams. We further recommend that the TSDF address, in as transparent a fashion as possible, questions of the degree to which the treatability study is representative of what can be expected at full-scale operation and whether the effluent from the treatment process would cause ecotoxicity or pose a threat to human health.

Section 6

Assessment of the Army Response

As part of this review, Mitretek also assessed the Government response to Rittmann's report. The bulk of the Army response is accurate. There are several instances where responses are technically correct and provide useful perspective yet do not fully address the issues raised by Rittmann.

The Army responded that use of a regenerative thermal oxidizer to oxidize odor-causing compounds is common.⁵⁸ This is correct, but the response does not address whether PFD's odor control problems would have been solved before Newport hydrolysate would be processed. Mitretek has listed some additional measures that might be required to capture fugitive gases for odor control in Section 3.5.2. Whether or not such measures would have been effectively implemented for Newport hydrolysate processing cannot be known.

The Army responded that MPA has very low acute oral toxicity based on LD₅₀ values,⁵⁹ but the Government does not determine the actual level of risk posed by MPA in the discharge to the Great Miami River. Although technically correct, the comparison to the toxicity of table salt is an oversimplification that does not take exposure pathways or concentrations into account. Mitretek has assessed the risk posed by MPA, EMPA, and EA2192 for a variety of risk scenarios in Section 3.5.4 and Section 4.

The Army responded that post-biological adsorption and filtration is run reliably at wastewater treatment facilities around the world.⁶⁰ This is correct, but it does not address the specific reservations voiced by Rittmann concerning measurements that in his opinion suggested that the process may be problematic in this implementation. Mitretek has addressed the specific concern about clogging in Section 3.5.3.

The Army responded that the size and the duration of the treatability study were more extensive than studies typically done to test out a new waste stream in a biological treatment facility.⁶¹ Although correct, this assertion does not address potential differences between results obtained at bench scale and the process at full scale. Mitretek addressed additional activities not discussed by Rittmann in Section 3.3, and discussed integration and scale-up issues in Section 3.4.5.

Finally, one statement that occurs several times in the Government response is questionable. The polymeric nature of MPA and EMPA in precipitated solids from the PFD process⁶² is an incorrect use of the term "polymeric." This provides a misleading impression of the mobility of NaEMPA and Na₂MPA. However, given that the solids will be placed in a certified and regulated landfill where the leachate is contained, this usage does not significantly misrepresent the risk posed by the leachate

Section 7

Summary and Mitretek Recommendations

7.1 Summary

Mitretek conducted an independent third-party assessment and evaluation of the data generated during hydrolysate treatability study conducted by PFD, PFD's confidential report of the study, and the review of PFD's report by Rittmann. Mitretek determined that the treatability study collected sufficient data--not all of it in PFD's report--to adequately address the purpose for which it was intended. Unfortunately, the confidential nature of the PFD report inhibited comprehensive discussion of the results. Nevertheless, the data established that the Schedule 2 compounds were removed from Newport hydrolysate in the expected treatment steps and to a degree such that the treatment effluent would present no significant risk to human health or the environment.

Any TSDf accepting Newport hydrolysate should conduct a treatability study using their specific process, which is a common industry practice and would be required by the Army. Newport hydrolysate treatment should undergo a phased start up with sufficient monitoring to ensure that the process operates as expected. Any TSDf should have appropriate odor control measures in place. Any TSDf that accepts Newport hydrolysate should be prepared to publish data to allow the public to confirm the fate of Schedule 2 compounds in the process. It is further recommended that the TSDf address, in as transparent a fashion as possible, questions concerning the degree to which the treatability study is representative of what can be expected at full-scale and whether the effluent from the treatment process would cause ecotoxicity or pose a threat to human health.

Mitretek disagrees with Rittmann's assessment on several points. Our review of PFD data suggests that Rittmann's contention that the study did not answer the question of whether Schedule 2 compounds were removed in the expected steps and to the expected degrees is not accurate. The study report as written may not have directly answered that question, but PFD collected data that do answer the question in the affirmative. Mitretek disagrees with Rittmann on the question of whether an initial oxidation should be carried out at NECDF; Rittmann overstates the benefits and ignores some of the impacts of such a decision. Rittmann also questions whether Schedule 2 compounds need to be reduced to levels far below the certification levels, but, there is no reason identified to support the need; Mitretek's assessment is that further reduction is not required.

Mitretek's assessment is that Rittmann has grossly overestimated the risks posed by the treatment of Newport hydrolysate. Rittmann makes the potential for VX reformation in hydrolysate a significant issue, yet a careful review of the available data indicate that reformation will not occur spontaneously in Newport hydrolysate under any scenario relevant

to waste treatment. Rittmann considers the potential for the toxic byproduct NaEA2192 to be present in hydrolysate; however, no hydrolysate will be released from NECDF with detectable levels of NaEA2192 at a method detection limit of 1 ppm, a level which gives a hazard quotient of 1 or lower for subsequent exposure pathways. Finally, Rittmann asserts that the product NaEMPA is mutagenic and overestimates its toxicity; a review of the literature indicates no evidence for mutagenicity and indicates that effluents should pose no significant hazard to human health or the environment.

7.2 Other Issues

Mitretek has identified no significant unanswered questions concerning the application of the PFD process to Newport hydrolysate that would not have been addressed as part of the normal course of scaling up the operation, as discussed in Section 3 and Section 5.1. There is sufficient information available to assess the hazards of Newport hydrolysate, the treatability of hydrolysate, the feasibility of the PFD process, and the risks to human health and the environment posed by the effluents of that process.

There is minimal data available on the ecotoxicity of EMPA. However, the similarities between EMPA and MPA or IMPA allow reasonable assessments to be made; these substances appear very unlikely to lead to ecotoxicity, particularly at the concentrations involved in hydrolysate treatment. Nevertheless, a simple ecotoxicity screening for the survival of selected aquatic and terrestrial plants and animals with the effluent generated by a treatability study could be useful in confirming the ecotoxicity assessment.

7.3 Recommendations

Mitretek makes the following recommendations to PMATA:

- Any TSDF selected to treat Newport hydrolysate should conduct a treatability study appropriate for their specific process.
- Any TSDF accepting Newport hydrolysate should implement Newport hydrolysate treatment through a phased start-up coordinated with the planned phased start-up of operations at NECDF. The TSDF will have the opportunity to begin processing small quantities with close monitoring of the process. As experience and data are obtained, processing rates should rise as the production rate of Newport hydrolysate at NECDF rises.
- Any TSDF selected to treat Newport hydrolysate should have appropriate odor control measures already in place.
- Any TSDF selected to treat Newport hydrolysate should be prepared to publish data to support the fate of Schedule 2 compounds in all significant process streams.
- Any TSDF selected to treat Newport hydrolysate should address, in as transparent a fashion as possible, questions of the degree to which the treatability study is

representative of what can be expected at full-scale and whether the effluent from the treatment process would cause ecotoxicity or pose a threat to human health.

7.4 Clarification of Misinformation

In addition to the previous recommendations, Mitretek recommends that PMATA continue to correct misinformation concerning Newport hydrolysate in the public domain. For example, the Delaware Clean Air Council recently prepared a resolution for the House of Representatives of the Delaware General Assembly that contained the following misinformation, some of it possibly based on inaccuracies in the Rittmann report:

- The resolution refers to Newport hydrolysate as a “highly toxic nerve gas agent,” “deadly nerve agent,” and “a diluted form of VX nerve gas.” In fact, no detectable VX will be present in hydrolysate cleared for transportation out of NECDF.
- The resolution asserts that Newport hydrolysate could be used to reformulate VX nerve gas. As this assessment shows, the available evidence indicates that this cannot occur spontaneously; sophisticated industrial processes would be required to isolate compounds that could be used to reform the agent; such an approach is impractical.
- The resolution describes EA2192 as a constituent in Newport hydrolysate that would create a significant public health threat in transport, storage, and handling. As this assessment shows, no detectable EA2192 will be present in hydrolysate cleared for transportation out of NECDF, and the limit of detection is set to protect against reasonable exposure scenarios during transport, storage, and handling.
- The resolution states that “U.S. Department of Defense assessments of alternative technologies for the demilitarization of assembled chemical weapons, as reviewed by the Assembled Chemical Weapons Assessment Program, have indicated that biotreatment of organophosphorus compounds found in Newport hydrolysate has shown unsatisfactory or inconclusive results.” However, PMACWA tested a specific type of bioreactor for use in a total technology package and determined that the package was not viable “at this time;” the report was sent to Congress in September 1999. Moreover, it is now understood that biotreatment does not need to destroy organophosphorus compounds in Newport hydrolysate. A treatment process can discharge those compounds at levels determined to be safe, as shown in this assessment, provided that they are effectively unrecoverable.
- The resolution asserts that the failure of a biodegradation system to adequately destroy the organophosphorus compounds found in Newport hydrolysate, including EMPA, will result in toxic and harmful chemicals in trace amounts being dumped into waterways and could result in significant impacts to aquatic life. As shown in this assessment, EMPA and MPA can be discharged at levels that will not result in ecotoxicity or pose a risk to human health.

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Appendix

Sources of Data for Mitretek's Assessment

In addition to the documents cited in the References section, the individuals in Table A-1 were interviewed for information used in this assessment.

Table A-1. Individuals Interviewed

Name	Affiliation	Date of Interview	Location of Interview
Randall B. Marx, Ph. D., P.E.	SBR Technologies (contracted to Perma-Fix)	24-25 February 2004	NECDF
Scott Rowden	Parsons Environmental Manager	23-25 February 2004	NECDF
John T. Stewart, P.E.	Parsons Site Manager	23-25 February 2004	NECDF

Glossary

°C: degrees Celsius

°F: degrees Fahrenheit

Ames-test: A widely used test to detect possible chemical carcinogens based on a substance's ability to induce mutation in the bacterium *Salmonella*

As: arsenic

BOD: Biological oxygen demand, a measure of the quantity of oxygen consumed by microorganisms during the decomposition of organic matter, also used to evaluate the efficiency of biological treatment processes

BDAT: Best Demonstrated Available Technology

CAS: Chemical Abstracts Service, which maintains a registry that uniquely identifies chemical substances

CBOD₅: 5-day carbonaceous biological oxygen demand, a specific type of test for BOD

Ceriodaphnia dubia: a freshwater invertebrate

CFR: The Code of Federal Regulations (www.gpoaccess.gov/cfr)

COD: Chemical oxygen demand, a measure of the quantity of oxygen consumed during chemical decomposition of organic matter, used to assess the strength of discharged waste such as sewage and industrial effluent waters

CWC: Chemical Weapons Convention, formally known as the 1994 *Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction*; the U.S. is a party to the CWC

DCCDI: Dicyclohexylcarbodiimide, CAS registry no. 538-75-0, added as a stabilizer to VX

DICDI: Diisopropylcarbodiimide, CAS registry no. 693-13-0, added as a stabilizer to VX

DO: Dissolved oxygen, the weight of oxygen that is contained in water; wastes high in COD and BOD can cause a decrease in average DO levels in effluent if improperly treated

DOT: Department of Transportation

EA2192: *S*-(2-diisopropylaminoethyl) methylphosphonothioic acid, CAS registry no. 73207-98-4 (see also NaEA2192)

ECBC: Edgewood Chemical and Biological Center

Ecotoxicity: ecological or environmental toxicity

EMPA: Ethyl methylphosphonic acid, CAS registry no. 1832-53-7 (see also NaEMPA)

EPA: U.S. Environmental Protection Agency

ESS: Effluent suspended solids, the concentration of suspended solids in the effluent of a treatment plant

F/M: Food/microorganisms ratio, a measurement of the amount of influent CBOD applied per day divided by the amount of microorganisms in a reaction basin, expressed in **kg BOD/d:kg M**.

FML: Flexible membrane liner, in a contained and regulated landfill

Hazard Quotient: A comparison of an estimated chemical intake (dose) with a reference dose level below which adverse health effects are unlikely. The hazard quotient is expressed as the ratio of the estimated intake to the reference dose. The value is used to evaluate the potential for non-cancer health effects, such as organ damage, from chemical exposures.

HDPE: High density polyethylene, a material such as the one used for flexible membrane liners in landfills

HRT: Hydraulic retention or residence time, the length of time that liquid remains in a treatment basin

IMPA: Isopropyl methylphosphonic acid, CAS registry no. 1832-54-8, a close analog of EMPA.

kg: kilogram

L: liter

LD₅₀: Median lethal dose, the dose of a substance that kills 50 percent of a population of experimental animals exposed through a route other than inhalation

LOAEL: Lowest observed adverse effects level, the lowest dose of a substance in an experiment that produces an observable adverse effect

log K_{ow} : log of the octanol/water partition coefficient, an indicator of a chemical's fate in the environment

LQAP: Laboratory Quality Assurance Plan

m: meter

MC: Montgomery County, Indiana (as used by Rittmann)

MDL: method detection level, the detection level using a specific analytical method

mg/L: milligrams per liter

mil: 1/1,000th of an inch (1 mil = 0.010 inch)

MLSS: Mixed liquor suspended solids, the total suspended solids concentration in the activated sludge basin or tank

MLVSS: Mixed liquor volatile suspended solids, the volatile fraction of MLSS

mM: milli-Moles

MPA: Methylphosphonic acid, CAS registry no. 993-13-5 (see also Na₂MPA)

MSDS: material safety data sheet

Mutagenicity: The capacity of a chemical or physical agent to cause permanent genetic alterations

Na₂MPA: Disodium methylphosphonate, a salt of MPA produced during NaEA2192 hydrolysis

NaEA2192: Sodium S-[2-(diisopropylamino)ethyl] methylphosphonothioate, a toxic salt of EA2192 produced as an intermediate and subsequently destroyed during VX hydrolysis

NaEMPA: Sodium ethyl methylphosphonate, a salt of EMPA produced during VX hydrolysis

NaOH: sodium hydroxide (“caustic”)

ND: non-detect, lack of detection for a specific analyte at a given detection level

NECD: Newport Chemical Depot, Newport, IN

NECDF: Newport Chemical Agent Disposal Facility

NELAC: National Environmental Laboratory Accreditation Conference

Newport: Newport, Indiana, general location of Newport Chemical Depot (NECD) and Newport Chemical Agent Disposal Facility (NECDF)

NO₂-N: Nitrite nitrogen, a parameter used to monitor biological treatment effluent discharges

NOAEL: No observed adverse effects level, an experimentally-determined dose at which there is no statistically or biologically significant indication of the toxic effect of concern, i.e., the highest experimentally determined dose without statistically or biologically significant adverse effects.

Organophosphorus: an organic compound containing phosphorus, usually refers to a pesticide (*e.g.*, Malathion) or nerve agent that acts by inhibiting cholinesterase

Parsons: Parsons Infrastructure and Technology Group, the systems contractor for NECDF.

PFD: Perma-Fix of Dayton, Inc.

pH: The negative logarithm of the hydrogen ion concentration in an aqueous solution, it provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a solution (where 7 is neutral and greater than 7 is acidic and less than 7 is basic)

PI: Performance indicator, a concentration that corresponds to a desired hazard quotient

pK_a: The negative logarithm of the acid dissociation constant, K_a

PMACWA: Program Manager for Assembled Chemical Weapons Alternatives

PMATA: U. S. Army Project Manager for Alternative Technologies and Approaches

POTW: Publicly owned treatment works

ppb: Parts per billion

ppm: Parts per million

PRG: Preliminary Remediation Goals, developed according to guidelines set by USEPA Region IX

PubMed: PubMed Central, the U.S. National Library of Medicine's digital archive of life sciences journal literature (www.pubmedcentral.nih.gov)

QA: Quality assurance

QC: Quality control

QSTR: quantitative structure-toxicity relationship

RAPCA: Regional Air Pollution Control Agency, enforcing state and local air pollution control regulations in a six county area in the Dayton, Ohio area

RCRA: Resource Conservation and Recovery Act

RfC: Reference concentration, an estimate of a continuous inhalation exposure to a human population, including sensitive subgroups, that is not likely to cause harmful noncancer effects during a lifetime.

RfD: Reference dose, a numerical estimate of a daily oral exposure to a human population, including sensitive subgroups, that is not likely to cause harmful noncancer effects during a lifetime.

SBR: Sequencing Batch Reactor, a specific type of biological treatment reactor

Schedule 2: a controlled toxic chemical or a precursor meeting certain criteria of the CWC

SRT: Solids retention time, the length of time that solids remain in a treatment system or it is the ratio of biomass in inventory within the system (M) to the growth rate on new microorganisms (R_g), or $SRT=M/R_g$ in days

SS: suspended solids

SVI: Sludge volume index (mL/g), it relates the weight of the sludge to the volume of the sludge after settling, typically used to monitor settling characteristics of a suspension and pumping rates.

SVOC: Semivolatile organic compounds

TCLP: Toxicity characteristic leaching procedure, a test procedure simulating leaching of substances placed in landfills

TDS: Total dissolved solids

Thiolamine: 2-(diisopropylamino)ethanethiol, CAS registry no. 5842-07-9, produced during VX hydrolysis

TKN: Total Kjeldahl nitrogen, a measurement of the total amount of nitrogen in a sample

TOC: Total organic carbon, a measurement of the amount of carbon in a sample not counting inorganic carbon, i.e., carbon dioxide and carbonates

TOPKAT®: a toxicology computational software package by Health Designs, Inc. Corporation, 183 East Main Street, Rochester, New York 14604 that uses quantitative structure-toxicity relationship (QSTR) to predict various parameters

Trophic: of or relating to nutrition

TSDF: Treatment, storage, and disposal facility permitted under RCRA

USACHPPM: U.S. Army Center for Health Promotion and Preventive Medicine

VOC: Volatile organic compounds

VSS: Volatile suspended solids

VX: Nerve agent, *O*-ethyl *S*-[2-[bis(1-methylethyl)amino]ethyl] ester of methylphosphonothioic acid, CAS registry no. 50782-69-9

VXH: VX Hydrolysate (used by Rittmann)

w/v: weight per volume, designated as a percentage

µg: microgram

µg/L: micrograms per liter