

FOCUSED FEASIBILITY STUDY WORK PLAN

POTTSTOWN FACILITY

Prepared For:

MILLER SPRINGS REMEDIATION MANAGEMENT, INC.

JUNE 2006

REF. NO. 09904 (20)

This report is printed on recycled paper.

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1.0 INTRODUCTION

This Work Plan describes the scope and procedures for a Focused Feasibility Study (FFS) for the Earthen Lagoons at the Occidental Chemical Corporation (OxyChem) Pottstown facility. The Work Plan was prepared in response to a formal notification from EPA that a FFS is required for Operable Unit 2 (OU-2) - the Earthen Lagoons. Occidental Chemical Corporation executed an Administrative Order on Consent (AOC) with the U.S. Environmental Protection Agency signed on September 29 and effective October 7, 2005 (Docket No. CERC-03-2005-0090DC). OU-2 consists of four inactive unlined Earthen Lagoons that contain approximately 32,000 cubic yards of polyvinyl chloride ("PVC") material generated from PVC plastic resin manufacturing at the Pottstown facility up until 1974 when their use was discontinued.

Specifically, the AOC states (Section II - Statement of Purpose, paragraph A, page 2): *"The FFS shall determine and evaluate (based on treatability testing, where appropriate) alternatives for remedial action to prevent, mitigate or otherwise respond to or remedy the release or threatened release of hazardous substances, pollutants, or contaminants at or from the Site consistent with the risk assessment performed by EPA (including any adverse impacts to human health or the environment that may result from the activities associated with remediation). The alternatives evaluated must include, but shall not be limited to, the range of alternatives described in the National Oil and Hazardous Substances Pollution Contingency Plan ["NCP"], 40 C.F.R. Part 300, and shall include remedial actions that utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable. In evaluating the alternatives, the Respondent shall address the factors required to be taken into account by section 121 of CERCLA, 42 U.S.C. § 9621, and section 300.400(e) of the NCP, 40 C.F.R. § 300.400(e)."*

This Work Plan complies with the general requirements of the AOC, and specifically addresses the following:

- Section 2.0 Site location, background, and summary of previous studies;
- Section 3.0 Comprehensive summary of known Site conditions;
- Section 4.0 Discussion of data gaps;
- Section 5.0 Methodology, logistics, and data quality objectives for obtaining information to meet the objectives of the FFS;
- Section 6.0 Treatability studies;
- Section 7.0 Evaluation of Remedial Alternatives including preliminary applicable and relevant and appropriate requirements (ARARs) other advisories, criteria, and guidance to be considered (TBCs) and a plan for

refinement of ARARs and TBCs throughout the FFS process including cleanup goals; and

Section 8.0 Schedule for completion of the FFS.

Miller Springs Remediation Management Inc. (MSRMI) has developed this Work Plan to describe the nature of OU-2, summarize past evaluations and testing, outline potential remedies to be evaluated, detail a process to identify ARARs and TBCs, and describe the methodology for conducting treatability studies for solidification and chemical destruction technologies.

In order to address known data gaps, MSRMI recently (July 2005) collected additional samples of the PVC Material for laboratory analysis, primarily to assess the moisture content of the material in the lagoons. Prior to this sampling, MSRMI contacted several waste recyclers and disposal sites to confirm analyses of interest. MSRMI prepared two composite samples for Toxicity Characteristic Leaching Procedure (TCLP) volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and metals analyses to update information on these characteristics. The two composite samples were also analyzed for total VOCs, SVOCs, metals, and RCRA characteristics. A total of one-hundred seventy-two (172) samples were collected specifically for moisture content and bulk density. These data provide a comprehensive database regarding current moisture content of the PVC material, and critical information that will be supplied to potential waste recyclers and disposal sites. The sampling and results are discussed in Section 3.1 of this Work Plan. As needed, additional samples will be provided to waste recyclers and disposal sites for testing.

2.0 SITE HISTORY

2.1 SITE LOCATION AND BACKGROUND

EPA has defined the OxyChem Superfund Site as the approximately 257 acres parcel surrounded on 3 sides by the Schuylkill River and located ½-mile southeast of the borough of Pottstown, Montgomery County, Pennsylvania. Figure 2.1 presents a Site location map depicting the site boundary as shown in the ROD and designating the portion owned by OxyChem and the portion owned by others. The Site formerly contained an active PVC manufacturing plant (the facility). The facility consisted of manufacturing, office and outdoor storage areas as well as inactive manufacturing/storage building space. Paved parking areas, roadways, and open land are also present at the Site. The Site also contains landfills closed under state regulations and areas where trichloroethylene (TCE) was formerly stored and used. The AOC specifically addresses OU-2, which are four inactive unlined Earthen Lagoons.

The Site was owned and operated by Jacobs Aircraft Engine Company ("JAEC") during the Second World War, during which JAEC manufactured aircraft engines. The Defense Plant Corporation (DPC) purchased the Site from JAEC in 1942. JAEC continued to operate and manufacture aircraft engines for DPC until late 1944. In 1945, DPC leased the Site to Firestone Tire and Rubber (FTR). FTR through corporate mergers and/or reorganization became Bridgestone/Firestone Inc. FTR purchased the Site in 1950 and manufactured tires and PVC resins at the Site. FTR sold the Site to Hooker Chemicals and Plastics Corporation (Hooker) in 1980. Hooker, who continued to manufacture PVC at the Site, later became the Occidental Chemical Corporation (OxyChem). Until December 2004, OxyChem continued to manufacture PVC plastics resins at the Site, but has not manufactured tires.

As noted above, the subject of this FFS is OU-2. Figures 2.2 and 2.3 present aerial photographs of the four Earthen Lagoons showing their location and current configuration, respectively. When the lagoons were in use, wastewater from the PVC manufacturing process was first directed to the former concrete holding basins located at the rear of the wastewater treatment plant prior to being sent to the lagoons. Unpolymerized PVC solids from this wastewater treatment process settled to the bottom of the holding basins and the supernatant water was skimmed off and sent directly to the Pottstown publicly owned treatment works. When the PVC solids accumulated to the basin capacity, the PVC solids were diverted to the northern most lagoon, with rotation of flow as solids accumulated in the lagoons. The lagoons were used for the storage of PVC sludge until 1974 when the Pennsylvania Department of Environmental Protection (PADEP, then PADER) ordered FTR to discontinue their use. The Earthen

Lagoons were never formally decommissioned; however, the lagoons have not been used since 1974. A current description of the lagoons is provided in Section 3.5.

2.2 SUMMARY OF PREVIOUS STUDIES

2.2.1 REMEDIAL INVESTIGATION

On June 24, 1988, pursuant to Section 105 of CERCLA, 42 U.S.C. § 9605, EPA proposed to place the Site on the National Priorities List ("NPL"), set forth at 40 C.F.R- Part 300, Appendix B (53 Fed. Reg. 23987). The Site was placed on the NPL on September 29, 1989. OxyChem completed a Remedial Investigation/Feasibility Study (RI/FS) in accordance with the December 1989 Consent Order (Docket No. III-89-20-DC) signed between EPA and OxyChem. The Earthen Lagoons were an area investigated during the RI/FS conducted at the Site in the early-1990s. The Final RI report was submitted in March 1992.

Figure 2.4 presents the locations of borings completed during the RI. Table 2.1 presents the maximum chemical concentrations detected in the PVC material. Sampling conducted during the RI detected the presence of VOCs and SVOCs in the material contained in the four inactive Earthen Lagoons. The following provides a summary of the RI results.

- Each lagoon is generally composed of three layers; a white, wet material, a gray to black wet material and a coal fines layer. The white and gray materials are products of the PVC manufacturing process.
- In the area of Lagoon #1 which lacks the bottom coal fine layer, soil sampling reveals contaminants are present in the soils directly beneath the lagoons. The contaminants present in the soils are those that are present in the lagoon material (Record of Decision (ROD), June 30, 1993). At Lagoons 2, 3, and 4 (southwest, southeast, and northeast, respectively), it appears that the coal fine material has served as a collection/adsorption layer for the chemicals. It is believed that the soil beneath the coal fine layer of Lagoons 2, 3, and 4 has not been affected.
- The chemicals present are the result of the PVC manufacturing process. The Earthen Lagoons material contains VOCs and SVOCs as a result of past PVC manufacturing processes at the Site conducted by FTR. VOCs detected in the Earthen Lagoons include TCE, trans-1,2-DCE, vinyl chloride monomer (VCM), 1,2-dichloroethane (1,2-DCA), styrene, and ethylbenzene.

- The SVOCs detected were those associated with the process of making PVC. Benzoic acid and bis(2-ethylhexyl)phthalate were the two SVOCs present. The concentration of benzoic acid detected in the samples ranged from 1.6 mg/kg to a maximum of 31 mg/kg. The concentration of bis(2-ethylhexyl)phthalate ranged from 1.1 mg/kg to a maximum of 280 mg/kg.
- The soil underlying the lagoons consisted of floodplain deposits, including a naturally occurring coal fine layer present beneath most of the lagoon area. Some chemicals found in the lagoon material were also found, generally at lower concentrations, in the underlying soil. The metal concentrations are not notably different in the lagoon material than they are in the underlying soils.

2.2.2 RECORD OF DECISION

A Record of Decision (ROD) was issued for the Site on June 30, 1993. The selected remedial action for the Earthen Lagoons described in the ROD included:

- excavation of PVC Material, coal fines layer and contaminated soil at the Earthen Lagoons;
- on-Site drying of PVC Material to reduce levels below RCRA Waste Characteristics prior to recycling, and landfilling of coal fines layer at the Earthen Lagoons
- restoration of the earthen lagoon area to original grade.

The ROD requirement of drying the PVC material so that the material no longer exhibits RCRA Waste characteristics for VOCs has not been reliably attainable in pilot testing to date, and thus forestalled the implementation of the ROD-specified remedy. Detailed information about recycling processes under consideration will be assessed to determine the need for application of this standard to the recycling of this material. The impact of this provision is discussed further in Section 7.2. Evaluation of recycling options will include detailed information about the recycling company, end product use, end product characteristics, raw material components (and composition) regularly used by the company to make the end product, the recycling process and specific recycling company requirements.

With respect to the soil underlying the lagoons, a reference to meeting background concentrations was included in the ROD to meet the state ARAR at that time. The ROD states that the soil underlying the lagoons will be remediated to background levels as specified in Table 3 of the ROD.

An unacceptable level of non-carcinogenic risk is presented by the Earthen Lagoon soil/sediments in a future land use scenario involving a child residing on the lagoon who would ingest PVC with contaminants. It should be noted that EPA has subsequently performed a supplemental Human Health Risk Assessment (see Section 2.2.3.10) and calculated unacceptable risks from leaving the material in place and using the lagoons and PVC as a site for residential purposes.

2.2.3 SUBSEQUENT STUDIES

On June 23, 1994, EPA issued an Unilateral Administrative Order for Remedial Design and Remedial Action to OxyChem and Bridgestone/Firestone to implement the remedy in the ROD. Subsequent to the publishing of EPA's ROD, OxyChem and MSRMI have conducted a number of additional investigations to characterize the nature and extent of PVC material and pilot studies related to the final treatment of the PVC Material. The primary focus of these investigations and studies were to determine an appropriate method to reduce levels below RCRA Waste Characteristics by reducing moisture content. The following summarizes those efforts and results.

2.2.3.1 LOW TEMPERATURE THERMAL ABSORPTION - 1997

One of the initial pilot studies conducted was the Low Temperature Thermal Absorption (LTTA) technology study, which was implemented starting in November 1996 in accordance with the LTTA Performance Test Plan (August 1996). This treatment involved the use of an oven to heat the solids to drive off moisture, and used bag houses to filter solids from the air discharge. In March 1997, after three bag house fires and numerous operating problems, this pilot test was terminated. Although it was concluded that this technology might be effective for treating the PVC Material, a decision was made to not continue with the LTTA technology due to the bag house fires and operating problems.

2.2.3.2 ALTERNATE TECHNOLOGY EVALUATION FOR EARTHEN LAGOONS - 1997

Following the conclusion of LTTA testing, an evaluation of alternative technologies was completed to evaluate drying/dewatering technologies that may have the potential to reduce VCM and TCE concentrations below RCRA waste characteristics. This

evaluation was presented in the report entitled "Alternative Technology Evaluation for Earthen Lagoons - Occidental Chemical Corporation Lower Pottsgrove Township Plant - EPA Unilateral Order No. III-94-26-DC", Smith Technology Corporation. This document was submitted to USEPA on May 21, 1997. The results of this technology evaluation identified Mechanical Aeration and Radiant Heat (MA/RH) as a technology that warranted further investigation through a field pilot study.

2.2.3.3 MECHANICAL AERATION AND RADIANT HEAT PILOT - 1998

A pilot study was conducted in two phases between August and October 1998 to evaluate MA/RH for reducing VCM and TCE concentrations. The process involved the mixing and movement of piles of PVC solids on a concrete pad under a sprung structure with treatment of the off gas through vapor phase carbon. During the turnover of the PVC piles in this structure, radiant heat was used to enhance the drying process. The results of the MA/RH pilot study were presented in the document entitled, "Results of Mechanical Aeration and Radiant Heat Pilot Test for Earthen Lagoon PVC Material, Occidental Chemical Corporation, Lower Pottstown Township Plant, Pottsgrove, Pennsylvania, EPA Unilateral Order No. II-94-26-C, Conestoga-Rovers & Associates, December 1998.

Table 2.2 presents a summary of the MA/RH pilot test analytical results. The results of this pilot test showed that MA/RH drying of the PVC Material, although effective at reducing moisture content to levels suitable for recycling, would be labor intensive, relatively slow (estimated duration of 2 to 2.5 years), and very expensive. Drying the PVC Material using this technology would require excessive handling of the material by Site personnel. Processing to this level would pose a risk of significant air emissions should the air control provisions fail. In addition, further measures such as dehumidification would be needed to make this technology effective. In an April 14, 1999 letter to EPA, OxyChem stated that the MA/RH pilot test had been successful, but that "both the declining price of PVC resin and the necessity to add de-humidification to the treatment process have adversely impacted the feasibility" of the MA/RH process. In summary, it was concluded that it was not a feasible option at that time, but it could be a useful technology in the future. For this reason, it will be considered in the FFS.

2.2.3.4 REQUEST FOR EXPLANATION OF SIGNIFICANT DIFFERENCE - 1999

On February 5, 1999, OxyChem requested that EPA issue an Explanation of Significant Difference (ESD) to revise the clean-up criteria that were selected in the ROD for the soil

underlying the Earthen Lagoons. This request was based on 1) the adoption by the Pennsylvania DEP of constituent-specific cleanup standards under the Act 2 Land Recycling program, and 2) the determination that arsenic is present in the underlying soil and coal fine materials at local/regional background levels.

2.2.3.5 ADDITIONAL SAMPLING - 2001

As a result of MSRMI's request for an ESD and OxyChem's concerns regarding the process for drying the PVC sludge, and the origin of arsenic (related to background and not to the PVC sludge), EPA determined that it was necessary to conduct additional sampling in the Earthen Lagoons. In August 2001, this sampling was conducted by MSRMI in accordance with a November 30, 2000 Sampling and Analysis (SAP) prepared by EPA. Specifically, three borings were completed in the northwest and southwest lagoons (empty lagoons), and two borings were completed in the northeast and southeast lagoons (full lagoons). Multiple depth discreet samples from each borehole were submitted for laboratory analysis for VOCs, SVOCs, and metals. Surface sampling was completed by dividing each lagoon into four quadrants, and taking six composites consisting of material from each quadrant. The six composite samples per lagoon were then submitted for laboratory analysis for SVOCs and metals. Background soil and groundwater samples were also collected as part of the sampling program. The results of the sampling program were submitted to EPA as part of a revised ESD for the Earthen Lagoons (see next section). Figures 2.5 and 2.6 present the location of samples completed during the additional sampling program completed in 2001 as per the EPA SAP dated June 19, 2000 and revised November 30, 2000.

Table 2.3 provides a summary of the 2001 analytical results for the PVC material. The data were validated. The data validation reports and other assessments provided show a high level of data usability from the sample analyses. The results indicated that the PVC material contained elevated concentrations of VOCs (2001 average vinyl chloride = ~80 mg/kg) and SVOCs (2001 average bis(2-Ethylhexyl)phthalate = ~354 mg/kg). Other VOCs present at elevated concentrations in the PVC material included the remaining chemicals of concern (TCE, 1,2-DCE, styrene, and toluene). Although these same chemicals were detected during the RI, the analytical results from the 2001 investigation, as well as analytical results obtained from the MA/RH pilot test, were higher than the analytical results obtained during the RI. Results of the additional sampling are discussed further in Section 3.2.

2.2.3.6 REVISED REQUEST FOR ESD - 2001

On October 31, 2001, MSRMI submitted a revised proposal for an ESD for the Earthen Lagoons. The revised ESD considered the results of the 2001 SAP that was performed in response to OxyChem's original request for an ESD submitted to EPA on February 5, 1999. Based on the results of the 2001 sampling - and considering the potential soil-to-groundwater pathway - MSRMI proposed the clean-up levels for soil underlying the lagoons. The proposed clean-up levels were calculated following the EPA's Soil Screening Guidance procedures. MSRMI noted that the ESD was justified based on the post-ROD ARARs (Pennsylvania's Act 2 Program and EPA Soil Screening Guidance). Adoption of these ARARs through the ESD will allow a reasonable assessment of any impacts to the underlying soil and completion of the overall earthen lagoon remediation.

2.2.3.7 DIOXIN AND DIBENZOFURAN SAMPLING - 2003

In a letter dated November 30, 2002, EPA informed OxyChem that they believed that dioxin may be present in the earthen lagoon material as a result of the three fires that occurred during OxyChem's implementation of the LTTA pilot system. In a letter dated May 20, 2003, EPA informed OxyChem that they were going to conduct the dioxin sampling in the northeast and southeast lagoons at the Site.

EPA conducted the dioxin sampling at the Site on December 12 and 13, 2003 in accordance with addendum 2 to the Sampling and Analysis Plan, dated June 27, 2003. OxyChem collected split samples during EPA's sampling program. Specifically, eight composite samples were collected from each of the two full lagoons (northeast and southeast). The samples were collected by compositing four discreet samples (one from each quadrant of the given lagoon) into one sample. Four shallow (0-6 inches) and deep (6 to 24 inches) samples were collected, and submitted for laboratory analysis for dioxin/furan congeners and moisture content.

Table 2.4 presents the results of the split samples collected by OxyChem. In summary the dioxin concentrations in the OxyChem split sample results ranged from 101 to 448 picograms per gram (pg/g) with a mean of 297 pg/g (equivalent to parts per trillion) of Toxic Equivalency Quotient (TEQ) to 2,3,7,8-tetrachlorodibenzo-p-dioxin. The TEQ results from the EPA samples ranged from 80.5 to 900 with a mean of 204 pg/g. The species present are primarily heavily chlorinated dioxins/furans. These constituents being the more heavily chlorinated species are therefore much less toxic, bioavailable, and soluble than 2,3,7,8-TCDD. Appendix A provides a copy of the analytical results from the samples collected by EPA.

In a letter dated May 7, 2004, EPA stated that upon review of the results for the dioxin samples that they collected from Earthen Lagoons the dioxin levels are below the current preliminary remediation goal for dioxin of 1,000 pg/g for residential areas and 5,000 to 20,000 pg/g for industrial areas established by EPA in 1998 (OSWER Directive 9200.4.4-26). In addition, the evaluation included the calculated cancer risk for the levels of dioxin detected for an industrial exposure scenario and a residential exposure scenario. The calculated cancer risk for an industrial exposure scenario was 5×10^{-5} and for a residential exposure scenario was 2×10^{-4} . These levels are within the Superfund acceptable cancer risk range of 10^{-6} to 10^{-4} for an industrial area and at the higher end of the range for a residential area when compared to the residential risk-based concentration of 430 pg/g at 10^{-4} .

2.2.3.8 HUMAN HEALTH RISK ASSESSMENT- 2004

The results of the sampling were used by EPA to determine the levels of contaminants of concern and to conduct a Human Health Risk Assessment (HHRA) regarding the risk presented by arsenic and other contaminants detected in the sampling. EPA's HHRA calculated health risks associated with exposure to the chemicals detected in the Earthen Lagoons under current and potential future land use conditions. A copy of the HHRA risk summary tables and risk characterization summary are presented in Appendix B.

The following specific risks were evaluated:

- The health risk for each individual earthen lagoon at the Site.
- The risk associated with intermittent water accumulated in two empty lagoons prior to removal and treatment was also evaluated in the HHRA.
- As part of the HHRA, a soil-to-groundwater evaluation was also conducted. The soil-to-groundwater pathway evaluated the potential for the migration of contaminants from PVC material and adjacent solids to groundwater beneath the Earthen Lagoons.

Based on the HHRA results, the EPA concluded the following:

- The lagoons showed a carcinogenic risk and/or non-carcinogenic risk to potential future residents (either child and adult or adult/child) if exposed to the contaminants in the lagoons. The primary route of exposure for risk was ingestion of PVC solids from the lagoons. The risk and the risk drivers varied in

each lagoon but the main risk drivers were vinyl chloride, bis(2-ethylhexyl)phthalate, TCE, thallium, and cadmium.

- The results of the PVC solid-to-groundwater pathway showed a list of twenty nine contaminants in the lagoons that can migrate to the groundwater. The five contaminants of concern selected in the 1994 ROD (ethyl benzene, styrene, trans-1,2-DCE, vinyl chloride, and TCE) were also in this list.

EPA's assessment of risks in the HHRA was based on a number of assumptions, including:

- Underlying soil permeabilities
- Use of groundwater from under lagoons for drinking water by residents
- Construction of homes on tops of the lagoons without cover, but with grading and mixture of the PVC solids to homogenize them
- Wading by trespassers in the empty lagoons where bulk PVC was removed but where storm water periodically accumulates following rainfall.

Based on the HHRA conclusions, EPA stated that a Focused Feasibility Study was necessary to re-evaluate options for remediation of this Operable Unit.

3.0 SUMMARY OF KNOWN SITE CONDITIONS

This section provides a summary of known Site conditions. The data collected during the investigations and studies detailed in Section 2 were reviewed, and key data was evaluated to define the current known Site conditions. During both the 1993 and 2001 investigations, samples were collected from the PVC material, the coal fines layer beneath the PVC material (where present), the underlying soil, and background locations. During the various pilot studies moisture content and other data were analyzed from samples collected from the PVC material. As mentioned in Section 1, in 2005 MSRMI collected some information on moisture content and bulk density and total and TCLP analysis of the PVC material. These data were collected to provide current data and fill data gaps with regard to evaluation of potential remedies. MSRMI believes that, based on the comprehensive database compiled over the years combined with the recent 2005 data, there are no data gaps with regard to characterization of the Earthen Lagoons. An overview of the 2005 sampling and sample results is provided in Section 3.1. As the 2005 data are believed to be the most accurate representation of current physical properties (e.g., moisture content, density, etc.) of the PVC Material in the lagoons, they are included in the evaluation presented later in this section. A conceptual model for OU-2 based on current known conditions is presented in Section 3.6.

3.1 JULY 2005 DATA

MSRMI identified some minor data gaps with regard to the evaluation of potential remedies, which are to be more fully evaluated under the upcoming FFS at OU-2. Specifically, these data gaps were related to whether an off Site landfill or recycler can accept the PVC material as is or whether some pre-treatment/pre-stabilization is first required. To address these data gaps, MSRMI completed additional sampling and testing of the material in July 2005 as proposed in a work plan letter to EPA dated July 5, 2005. As described at a June 16, 2005 meeting, the objectives of the sampling were to collect samples of the PVC solids from the Earthen Lagoons to allow a current general description of the material and determine some fundamental properties of the material.

On July 27 and 28, 2005, MSRMI collected samples from ten borings using a Geoprobe unit. The sampling was performed in the northeast and southeast lagoons (five borings from each), in which the majority of PVC material has resided since 1998. Continuous sample cores (2-inch diameter, 4 feet long) were collected. Upon retrieval, the cores were logged to describe the material and scanned with a Photoionization Detector (PID). Discrete samples at different depths from each borehole were collected and analyzed by H2M for bulk density (method: Valdosta State University) and moisture content

(method: ASTM method D2216). In addition, penetrometer measurements were collected using a pocket penetrometer (Canada Resistance Penetration Test methodology). Specifically, the penetrometer test includes slowly pushing the penetrometer piston into the soil sample (collected in a macrocore) until the prescribed indentation was achieved. The unconfined compressive strength reading (measured in penetrometer units equivalent to 125 pounds per square foot) was immediately recorded from the penetrometer gauge. One-hundred and eighty-eight (188) samples were collected. Two representative composite samples were also collected and analyzed for Target Compound List (TCL) VOCs, TCL SVOCs, Target Analyte List (TAL) metals, RCRA characteristics (cyanide, ignitability, reactivity, corrosivity), TCLP VOCs, TCLP SVOCs, TCLP metals, total organic carbon, and the paint filter test. Samples for analytical testing were composited from discrete samples. The first composite (LAG-9904-107) consists of discrete samples collected at each one-foot interval from borings BH-1 through BH-5 and the second composite (LAG-9904-192) consists of discrete samples collected at each one-foot interval from boreholes BH-6 through BH-10. Tables 3.1 through 3.3 present the moisture content and bulk density results, total results, and TCLP results, respectively.

Figures 3.1 through 3.3 present the penetrometer measurements, moisture content, and bulk density, respectively, versus depth for the borings completed. The approximate locations of the soil borings is shown at the bottom of these figures. As shown on Figure 3.1, there appear to be 3 relatively distinct layers - 0 to 8 feet, 8 to 17 feet, and >17 feet. In layer two (8 to 17 feet), penetrometer measurements are almost zero pounds per square inch. Penetrometer results are greater in the 0 to 8 foot interval and > 17 feet. The moisture content results show a similar, yet not as distinct layering. In general, the shallow PVC material (0 to 8 feet) has moisture content in the 20 to 30 percent range, while the deeper PVC material (8 to 17 feet) has moisture content in the high 30 and 40 and 50 percent range. A layer below the PVC material has a moisture content in the 20 percent range. The bulk density results show no apparent layering; however, the underlying soils typically have a bulk density greater than 1.0.

Results of the chemical analyses are summarized in the next section.

3.2 DISTRIBUTION OF CHEMICALS AND TRENDS

Chemical analysis of samples was completed during Site investigations in 1993, 2001, and 2005. In addition, samples have been collected and analyzed for specific parameters during several pilot tests.

Table 3.4 presents the maximum concentrations of chemicals detected in the PVC material from the 1993, 2001, and 2005 data. Fourteen samples were collected during the 1993 investigation, 40 samples were collected during the 2001 investigation, and 2 samples were collected during the 2005 investigation. Although concentrations vary between sampling events, the maximum sample results for each event reveal elevated concentrations of VCM, TCE, and bis-2(ethylhexylphthalate). A trend analysis is not applicable due to one or more of the following: different sampling techniques, different laboratories, heterogeneity of the material, and differences in the quantity of samples collected. Furthermore, trend analysis is not critical as the current state of the PVC material is the primary factor to be considered in the FFS.

Figure 3.4 presents a graph of the TCE, VCM, and bis-2(ethylhexylphthalate) concentrations versus depth. All samples are considered to be PVC material; however, some of the shallow and deeper samples may have minor amounts of soil mixed in with the material. At all depths, elevated concentrations (1 to 1,000 mg/kg) of TCE, VCM and bis-2(ethylhexylphthalate) are present in the PVC material. Bis-2(ethylhexylphthalate) concentrations were typically > 10 mg/kg.

3.2.1 STATUS OF ARSENIC

Arsenic was previously identified as a chemical of concern. Based on the historical data and the 2001 SAP results, arsenic is not a COC. The arsenic concentration in the PVC Material ranged from 1.1 mg/kg to 4.7 mg/kg with an average of 2.1 mg/kg. The arsenic concentration in the underlying soil beneath the Earthen Lagoons ranged from 0.96 mg/kg to 17.5 mg/kg with an average of 3.81 mg/kg. The arsenic concentration in the background samples ranged from 2.0 mg/kg to 18.8 mg/kg with an average of 8.08 mg/kg. These data correlate with the fact that arsenic was not used in the PVC process. Furthermore, arsenic was an analyte in the TCLP tests performed on the PVC material during the RI and was not detected; this lack of detection further supports that the arsenic is naturally occurring and has not leached from the lagoon material.

The majority of the elevated arsenic concentrations in the samples collected from the underlying soil and the background locations occurred when coal fines were present in the samples. The occurrence of the coal fines can be related to the depositional history and geomorphology of the floodplain in general. The presence of the coal fines is typically attributed to extensive coal mining upriver of Pottstown earlier in the 20th century. Coal dust, which accumulated on the river surface, and heavier coal particles suspended in the river load, would periodically be deposited in the floodplain of the Schuylkill River during flood events. The volume and distribution of coal fines

deposited by any single flooding event would be dependent on the extent of the flood event and the given volume of coal fines in the river at the time of flooding. Thus, the coal fines present in the floodplain are the result of several different flood events throughout the 20th century.

In a July 28, 2005 letter, EPA concurred with MSRMI that arsenic is present in the lagoons at background levels, and not a COC.

3.3 TCLP RESULTS

TCLP analysis of samples has been completed during the 1993 RI and the 2005 additional data collection. Table 3.3 presents the TCLP data for the two samples analyzed from the 2005 additional data collection event. The maximum TCLP data for VCM and TCE are 3,100 µg/L and 9 µg/L, respectively. TCLP was also performed extensively during the MA/RH pilot test. These results are discussed in the next section - Section 3.4.

3.4 RESULTS OF MOISTURE CONTENT ANALYSES

Moisture content has been evaluated as part of Site investigations and pilot testing. Specifically, moisture content was evaluated as part of the 2001 and 2005 investigations and the MA/RH pilot tests. The additional testing conducted by MSRMI on the PVC material following issuance of the ROD indicates that the moisture content of the PVC material typically needs to be 20 percent or less to meet the ROD stipulation that PVC not exhibit RCRA Waste Characteristics prior to recycling.

Figure 3.5 presents a graph of moisture content versus depth for all samples collected during the 2001 and 2005 investigations. Thirty-three (33) samples were collected during the 2001 investigation and 188 samples were collected during the 2005 investigation. The graph shows that a wide distribution of moisture content ranging from 6 to 59 percent, with an average of 36 percent. The following table provides a breakdown by depth interval of the minimum, maximum and average percent moisture. Although the 0 to 1 foot and 1 to 5 foot intervals have lower percent moisture concentrations in general, the average is still about 30 percent. The average moisture content of the PVC material from 5 to 20 feet is close to 40 percent. The average moisture content drops below 30 percent at depths greater than 20 feet.

Table 3.5 - Summary of Percent Moisture Results versus Depth

Depth Interval (ft bgs)	Percent Moisture		
	minimum	maximum	average
All depths	6	59	36
0 - 1	24	37	30
1 - 5	6	42	31
5 - 20	9	59	38
> 20	12	35	27

Table 2.2 presents the results of the MA/RH pilot test. The table provides data for the 8 piles of PVC solids tested including total and TCLP results for VCM and TCE, and moisture content. Figure 3.6 present a graph of moisture content and VCM for all samples. As shown on this graph, as the moisture content is reduced to below 20 percent, the concentration of VCM is reduced to below waste regulatory limits. Figure 3.7 presents a representative graph of total VCM and moisture content over time. This graph shows that the moisture content is reduced to less than 30 percent in approximately 5 days and less than 20 percent in 8 days. The results were similar for other piles of PVC solids.

Based on the above data, it appears that the moisture content of the PVC material typically needs to be 20 percent or less to meet the current ROD stipulation that PVC not exhibit RCRA Waste Characteristics prior to recycling. However, it is not clear whether active or passive drying can achieve this reduction in a reasonable time period and at a reasonable processing rate for an acceptable process at the facility.

3.5 CURRENT PHYSICAL CONDITIONS

OU-2 consists of four unlined Earthen Lagoons located on the southeastern side of the property in the floodplain of the Schuylkill River. The Earthen Lagoons were constructed by creating earthen dikes on top of the native material in the floodplain, which has an approximate elevation of 120 feet above mean sea level [but bottom elevation assumed to be 116 MSL]. The dikes are approximately 10 feet high with an approximate 2x1 slope. The top of the dikes have an approximate elevation of 130 feet above mean sea level. The dikes form a grid pattern, creating four separate lagoons that are typically referred to as the northeast, northwest, southeast, and southwest (see figure 2.2). Table 3.6 presents a calculation of the approximate land area of the Earthen Lagoons.

Table 3.6 - Approximate Land Area of the Earthen Lagoons

Earthen Lagoon	Area of Lagoons (square feet)	Area of Lagoons (acres)
Northeast	24,433	0.56
Southeast	25,681	0.59
Southwest	24,713	0.57
Northwest	26,804	0.62
Total (without dikes)	101,631	2.34
Total (with dikes)	125,921	2.89

The lagoons were used for the storage of PVC sludge until 1974 and, although never formally decommissioned, they have not been used since that time. The majority of the material in the earth lagoons was moved during the MA/RH pilot test. Consequently, since 1998 the majority of the PVC material currently resides in the southeast and northeast lagoons. Table 3.7 presents a current estimate of the PVC material in the Earthen Lagoons.

Table 3.7 - Current Estimate of the PVC Material in the Earthen Lagoons

Lagoon	Volume of PVC Material (cubic yards)	Weight of PVC Material (pounds)	Weight of PVC Material (tons)
Northeast	14,185	15,287,500	7,644
Southeast	11,995	12,927,287	6,464
Southwest	4,150	4,472,550	2,236
Northwest	1,957	2,109,104	1,055
Total	32,287	34,796,441	17,398

Notes:

- Bottom elevation assumed to be 116 feet mean sea level.
- Top elevation based on 1-foot contours from Drawing 1- Existing Conditions, RD/RA Work Plan, 2001.
- PVC Material average bulk density = 0.64 g/cm³ = 488,763 g/yd³ = 1,078 pounds/yd³.

3.6 CONCEPTUAL MODEL OF OU-2

OU-2 consists of four unlined Earthen Lagoons used for the management of wastewater generated from the PVC plastic resin manufacturing until 1974. Figure 3.8 presents a conceptual model schematic of OU-2 for the FFS. The Earthen Lagoons are bounded on all sides by earthen berms, which were constructed over the native material and rise approximately 10 feet above the floodplain. The PVC material is predominantly located

in the southeast and northeast lagoons as a result of consolidation during the 1998 MA/RH pilot test. When placed in the southeast and northeast lagoons, the material was mounded somewhat above the elevation of the berms in the center of the lagoons, with a depression in the fill material surface along the inside of the berm to prevent runoff loss of the PVC material.

The approximate land area of the Earthen Lagoons covers a total 2.89 acres including the berms. The interior footprint of each lagoon is approximately 0.58 acres in size. Based on topographic data collected in 2001 and historical data, the total estimated volume of PVC material is 32,287 cubic yard. At an average bulk density of 0.64 g/cm³, this correlates to a total weight of 34,796,441 pounds or 17,398 tons. Currently, approximately 81 percent of this material resides in the southeast and northeast lagoons. Most of the remainder of the material resides in the southwest lagoon. There are soil materials in the surrounding berms (approximately 20 feet at base) and beneath the PVC materials (2 to 5 feet under the lagoons). Based on sampling performed in 2001, some of these soil materials were impacted with site related constituents as a result of contact with the PVC solids.

Based on penetrometer measurements, moisture content, and bulk density from sampling completed in July 2005, there appear to be 3 relatively distinct layers in the two full lagoons (southeast and northeast) - 0 to 8 feet, 8 to 17 feet, and >17 feet. In layer two (8 to 17 feet), penetrometer measurements are almost zero pounds per square with a moisture content in the 40 percent range. Chemical analysis of PVC material reveals elevated concentrations of VCM, TCE, and bis-2(ethylhexylphthalate). TCLP chemical analysis of the PVC material reveals elevated levels of VCM and TCE.

Several previously completed pilot tests reveal that a reduction in moisture content to less than 20 percent typically reduces VCM and TCE to below regulatory limits. Percent moisture versus bis-2(ethylhexylphthalate) concentrations is not available, but it is unlikely that bis-2(ethylhexylphthalate) is as directly related to moisture content due to the less mobile nature of the constituent.

4.0 DATA GAPS

Based on the comprehensive sampling event in 2001 and recent completed sampling and analysis in July 2005, MSRMI believes that there are currently no data gaps with regard to characterization of the PVC Material. Additional data may be collected during the FFS related to the completion of treatability studies as discussed in Section 5.0.

Although some previous data exists regarding the soils surrounding the PVC material (i.e., underlying soils and earthen berms), it is not clear that the samples are representative of the soils that will remain after removal of the PVC material. Previous sampling of the underlying soils was performed through over 20 feet of overlying PVC material. The soils surrounding the PVC material will be excavated to appropriate action levels identified in the FFS, and will either be disposed of off Site (as non-hazardous or hazardous) or via engineered on-Site closure. Data collected following removal of the PVC material, will be used to determine the final disposition of this material (see Section 7.2).

5.0 METHODOLOGY AND DATA QUALITY OBJECTIVES

5.1 METHODOLOGY

Previous studies at the Site, literature, and other sources of data will be used to obtain information relevant to successful completion of the FFS. As mentioned in the last section, MSRMI believes that there are no data gaps with regard to characterization of PVC solids in the Earthen Lagoons. The methodology and process for conducting treatability studies are discussed in Section 6. Initial contact with potential off Site landfills and recyclers reveals that it is likely they will request samples for their own evaluation(s). As these entities are permitted facilities and the project is no longer in the characterization phase, MSRMI does not believe that testing provided by these entities falls under the methodology and data quality objectives of this section.

As requested by potential off Site landfills and recyclers, samples of the PVC material will be provided to potential landfills/recyclers for their evaluation. MSRMI plans to collect samples from borings using a Geoprobe, hollow stem auger drill rig, or other appropriate method. This sampling will be performed in the northeast and southeast lagoons, in which the majority of PVC material has resided since 1998. Samples will be collected at the shallow (0 to 5 feet) and deep (8 to 12 feet) intervals to provide representative PVC material for submittal to potential landfills/recyclers. Upon retrieval, the samples will be logged to describe the material description and scanned with a Photoionization Detector (PID). Composite samples consisting of one to five gallon samples will be created from the material, and shipped off Site as per standard shipment methods with documented chain-of-custody forms. As the FFS progresses, larger amounts of PVC material (one ton or more) may also be provided to select potential landfills/recyclers for additional evaluation. Along with the samples, MSRMI will also provide existing analytical data to all potential vendors so that they are aware of the basic constituents and properties of the material. It should be noted that these potential entities are not EPA contract laboratory program facilities. Their laboratories are presumed adequate to achieve the DQOs necessary to achieve the regulations governing their activities. These regulatory requirements and DQOs will be identified and compliance with them verified with EPA.

5.2 DATA QUALITY OBJECTIVES

Should any sampling and analysis for chemical properties be completed by MSRMI as part of this Work Plan, it will be conducted following all applicable quality assurance, quality control, and chain of custody procedures. Specifically, MSRMI will prepare a

FFS Quality Assurance Project Plan (QAPP) as a stand-alone document. It will be based on the previously completed QAPP by TetraTech on behalf of EPA Region III (QAPP Rev. 3 November 2000 - Remedial Action Oversight). MSRMI will also consider the following in preparation of the QAPP:

- 1) "Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA" (OSWER Directive No. 9355.3-01 (1988));
- 2) "EPA Requirements for Quality Assurance Project Plans for Environmental Data Operations" March 2001 (EPA QA/R-5);
- 3) "Guidance for Quality Assurance Project Plans" December 2002 (EPA QA/G-5);
- 4) "A Compendium of Superfund Field Operations Methods" (OSWER Directive No. 9355-0-14 (December 1987));
- 5) "Guidance for Data Quality Objectives Process for Hazardous Waste Sites" January 2001(QA/G-4HW); and
- 6) Technical direction received from EPA at the meeting(s) described in Section.

Data generated by others for treatability testing or material characterization will be determined prior to analysis, and agreed to with EPA. As noted in the previous section, testing performed by others will be presumed adequate to achieve the DQOs necessary to achieve the regulations governing their activities. These regulatory requirements and DQOs will be identified and compliance with them verified with EPA.

MSRMI proposes that any analytical testing completed by MSRMI that will be used to make remedy decisions will be confirmed through submittal of samples to H2M Laboratories (H2M) for analysis. H2M is the current EPA-approved analytical laboratory for the CERCLA project, and participates in the CLP program. Confirmation samples will be submitted at a rate of 20% of the actual samples being used for a specific treatability test or material characterization. Laboratory results will be provided to EPA as electronic data deliverables in EQulS database format.

For all confirmation samples, H2M will produce and submit a Level III Package, which will provide sufficient information to enable data validation to be completed (using EPA Region III's Innovative Approaches guidance and levels IM1 and IM2). All analyses performed by H2M for the FFS will undergo full data validation.

MSRM will also prepare a FFS Health & Safety Plan (HASP) for field activities.

6.0 TREATABILITY STUDIES

Treatability studies will be conducted as part of the FFS, if deemed necessary. They would focus on pre-treatment technologies that may be required to facilitate on Site disposal, recycling or off Site disposal of the PVC sludge. Pre-treatment technologies that are may be tested include solidification/stabilization and dewatering. Possible other pre-treatment technologies that may also be tested include chemical and biological treatments to reduce VOC and SVOC concentrations to acceptable levels.

- Solidification/stabilization studies would determine the types and amounts of inert materials required produce a material with a lower bulk water content such that the PVC solids are suitable for transport and disposal (should such stabilization be necessary);
- Dewatering studies would examine methods to reduce the moisture content of the PVC sludge (either passively or mechanically) to reduce transportation weight and volatile organic compound concentrations (if necessary); and
- Chemical and biological studies would test the ability of these enhancements to reduce the VOC and SVOC present in the sludge matrix without impacting the PVC (if such reductions are needed for remediation).

For the reasons described in Section 2, at this time MSRMI does not proposed to perform additional thermal dewatering treatability studies. Sufficient data is available from previous studies to understand the treatability of this technology.

The major components of the treatability studies section of the FFS will include determination of the need for and scope of studies, the design of the studies, and the completion of the studies. Treatability testing will be conducted by MSRMI, its primary consultant (CRA), other consultants or potential landfills/recyclers.

Although not considered treatability testing, some testing may be performed by potential recyclers to test the end use of the product. For example, a small quantity of PVC material may be test cleaned with bleach to evaluate the ability to lighten the color for use in blends with other PVC resins. Various types of bleaches may be used for whitening of the PVC, which could oxidize the vinyl chloride associated with the moisture in the solids. Under some conditions, chlorine gas could be generated which could react with organic compounds to produce dioxins, but these could only be produced at combustion temperatures in the range of 200 to 700°C (See Appendix C - Evans and Dellinger (2005); Brent and Rogers (2002); and Yasuhara et al. (2001)). It is anticipated that processing of the PVC Material for recycling would be performed at

temperatures below 70°C and therefore below the temperature required to produce dioxins. MSRMI will evaluate the need to monitor for potential dioxin emissions that could result from testing and/or processing of the PVC material. MSRMI will provide recommendations for monitoring in the Treatability Testing Work Plan.

A portion of the lagoon PVC may be tested to determine if the material will produce an acceptable extrusion, and thus meet the end-users needs. End-use testing will be communicated to EPA prior to completion. MSRMI is aware of the sensitivity regarding the end-use of the material, and this will be considered during completion of the FFS (see Section 7.2).

Requests for samples from treatment, recycling, and disposal facilities will be submitted to EPA for review. EPA will be notified in advance for oversight or split sampling, if EPA deems it necessary. Also, analytical data, including the 2001 data and dioxin data, will be provided to treatment, recycling, and disposal facilities.

The following deliverables will be provided as requested in the AOC with regard to the completion of treatability studies:

- a) Identification of Candidate Technologies Memorandum identifying candidate remedial technologies and whether these technologies require testing of the treatment process to support selection or rejection of the alternative.
- b) Treatability Testing Statement of Work describing the treatability testing to be completed.
- c) Treatability Testing Work Plan (assuming treatability testing is required) including a schedule, sampling and analysis plan, and a health and safety plan.
- d) Treatability Study Evaluation Report detailing the treatability study methodology and results.

7.0 EVALUATION OF REMEDIAL ALTERNATIVES

This Focused Feasibility Study will evaluate a limited set of potential remedies for Operable Unit 2, so as to quickly resolve the appropriate remedy and facilitate subsequent remediation. The general process for evaluation of alternatives, as described in "Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA" (OSWER Directive No. 9355.3-01 (1988)) will be followed, and is outlined in Section 7.1. A set of preliminary remedial alternatives for the PVC solids are identified in Section 7.2.

7.1 SCREENING OF POTENTIAL TECHNOLOGIES

Based on the ARARs/TBCs and a screening of potential technologies, final potential remedial alternatives will be selected for further evaluation. For each potential alternative, an evaluation will be completed including the following: a detailed description, schedule, costs, treatability study scope of work (if warranted), and screening following the NCP criteria evaluation protocol. With regard to the NCP criteria evaluation, each alternative will be evaluated under the nine evaluation criteria set forth in the NCP at 40 C.F.R. 300.430(e)(9). These criteria are organized according to the following categories listed in 40 C.F.R. 300.430(f)(1):

Threshold Criteria

- Overall protection of human health and the environment
- Compliance with ARARs

Primary Balancing Criteria

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Cost

Modifying Criteria

- Community acceptance
- Regulatory acceptance

Threshold criteria must be satisfied in order for an alternative to be eligible for selection. Primary balancing criteria are used to weigh the strengths and weaknesses of the alternatives and to identify the alternative which provides the best balance of the criteria. State and community acceptance are modifying criteria which are taken into account after public comment is received on the Proposed Plan. Descriptions of the individual criteria follow:

Overall Protection of Human Health and Environment. Overall protection of human health and the environment addresses whether each alternative provides adequate protection of human health and environment and describes how risks posed through each exposure pathway are eliminated, reduced, or controlled, through treatment/engineering controls and/or institutional controls.

Compliance with Applicable or Relevant and Appropriate Requirements. Compliance with ARARs addresses whether a remedy will meet all of the applicable or relevant and appropriate requirements of other federal and state environmental statutes for any hazardous substances left on Site or whether it provides a basis for invoking a waiver.

Long-Term Effectiveness and Performance. Long-term effectiveness and performance refers to expected residual risk and the ability of a remedy to maintain its effectiveness over time. It includes the consideration of residual risk and the adequacy and reliability of controls.

Reduction of Toxicity, Mobility, and Volume. Reduction of toxicity, mobility, or volume through treatment refers to the anticipated performance of the treatment technologies a remedy may employ.

Short-Term, Effectiveness. Short-term effectiveness refers to the period of time needed to complete the remedy and any adverse impacts on human health and the environment that may be posed during the construction and implementation of the remedy until cleanup levels are achieved.

Implementability. Implementability refers to the technical and administrative feasibility of a remedy, including the availability of materials and services needed to implement that remedy.

Cost. Cost includes estimated capital, operation and maintenance, and net present worth cost.

Community Acceptance. Community acceptance addresses whether or not the public agrees with the Preferred Remedial Alternative. This is assessed in the Record of Decision following a review of the public comments received on the Administrative Record and the Proposed Plan.

State Acceptance. State acceptance addresses whether the State concurs with, opposes, or has no comment on the Preferred Remedial Alternative.

7.2 **PRELIMINARY REMEDIAL ACTION OBJECTIVES**

The remedial action objectives (RAOs) for OU-2 will be defined in the FFS so that the appropriate technologies can be compared and assessed. Preliminary RAOs are presented herein based on the results of the EPA's HHRA, and NCP Section 300.430 (e)(2)(i).

Figure 3.8 presents a conceptual model of OU-2. The black box on this figure outlines the environmental media of concern, which are the PVC material, the soil surrounding the lagoons (i.e., underlying soils and earthen berms), and shallow (overburden) and deep (bedrock) groundwater. EPA's HHRA identified current exposure pathways as the PVC material and surface water that occasionally is present in the northwest and southwest lagoons. However, there are provisions in place to prevent current exposure to both workers and trespassers. EPA's HHRA identified the lagoons as a carcinogenic risk and/or non-carcinogenic risk to potential future residents if exposed to the chemicals in the lagoons.

The FFS will address potential risks identified by the HHRA as required by the Order. RAOs will be defined to address these risks by establishing protective media-specific remediation goals. The RAOs and remediation goals will be refined through completion of the FFS to provide a consistent basis for comparison and assessment of the remedial alternatives. The following section provides an overview of the preliminary review of potential remedial alternatives.

7.3 **PRELIMINARY IDENTIFICATION OF REMEDIAL ALTERNATIVES**

As noted previously, the current ROD requires that the PVC material be dried so that VOCs are below RCRA Waste Characteristics prior to recycling.. Previous pilot tests focused on meeting this ROD requirement. The results of some of these pilot tests showed promising results, but each had significant problems with regard to full scale

implementation (e.g., health & safety of workers, extensive time and material handling to complete). Detailed information about recycling processes under consideration will be assessed to determine the need for application of this standard to the recycling of this material. Evaluation of recycling options will include detailed information about the recycling company, end product use, end product characteristics, raw material components (and composition) regularly used by the company to make the end product, the recycling process and specific recycling company requirements. MSRMI has prepared this FFS Work Plan with a focus on viable remedial options without limiting potential alternatives to those that can meet this current ROD requirement. Recycling technologies and operations will be evaluated as will end-uses of recycled materials to determine ARARs.

Various remedial options will be evaluated as part of the FFS. This evaluation will consider whether a given remedy will meet some or all of the current requirements of the ROD. As stated above, other potential remedial alternatives will be considered that may be viable and practical solutions. If selected, these remedial alternatives may require a revised ROD or ESD.

MSRMI envisions that the screening of alternatives will result in identification of three major remedial options:

- 1) On Site Disposal,
- 2) Off Site Recycling, and
- 3) Off Site Disposal.

Table 7.1, which summarizes an initial review of these options, reveals the following chemical and physical constraints:

Table 7.1 - Potential Remedial Options and Constraints

Option	Chemical Constraints	Physical Constraints
Off Site Recycling	None.*	May need to be bleached to brighten color and dried.
Off Site Disposal (Canada)	None.*	Must be stable.
Off Site Disposal (US)	Must meet UTS.**	May need to be stabilized or solidified.
On Site Disposal		May need to be stabilized or solidified.

Notes:

* - Although not required for remedial option, the ROD requires treatment to below RCRA Waste Characteristics prior to off Site transport. The TCLP criteria for VCM and TCE are 500 µg/L and 200 µg/L, respectively. Comparison to TCLP criteria reveals that the PVC material, if treated as waste, would be considered hazardous due to elevated VCM.

** - The universal treatment standard (UTS) for bis(2-ethylhexyl) phthalate is 28 mg/kg. The average concentration of bis(2-ethylhexyl) phthalate was 354 mg/kg in the sampling conducted in 2001.

All potential remedies will require some work on Site including excavation, transport, and loading out of the material. For off Site options, the material would be loaded into trucks or railcars. Some alternatives may require additional preparation of the material (pre-treatment) prior to load out or off Site prior to final disposition.

As described in the Section 6.0, potential pre-treatment technologies that may be pilot tested as part of the FFS include solidification/stabilization and dewatering. Solidification/stabilization may be beneficial to produce a material with lower bulk water content such that the PVC solids are suitable for transport and disposal or recycling. Solidification/stabilization may also be beneficial as a pre-treatment for on Site disposal. Dewatering is appropriate prior to recycling but addition of stabilizing compounds may destroy the usefulness of the material for recycling. Dewatering may be useful in reducing the moisture content of the PVC sludge (either passively or actively) to reduce transportation weight and chemical concentrations. Dewatering will consider technologies such as MA/RH, filter presses, and other possible technologies. Chemical or biological treatability tests may also be conducted. Chemical treatments (e.g., chemical oxidation) may be beneficial in reducing chemical concentrations.

The following provides a brief description of the three major remedial options.

On Site Disposal - MSMRI will evaluate the option of on site disposal of the PVC material. This option will consider construction of one or more secure containment cells for placement of the PVC material and final closure on site. The containment cells could be located either within the existing footprint of the lagoons or in adjacent portions of the upland Site property. The FFS will consider engineering controls as necessary to address issues of concern (such as isolation flood waters from the 'footprint' area). Such an on Site closure will be evaluated as a final remedy rather than as an interim step in further processing. This could include either closure in its current state or after reducing moisture content.

With regard to surrounding soils, EPA has identified concern with contamination of these soils. This will be handled by scraping soils down to bedrock, placing on a clean

liner. Assessment will be performed on the soil surrounding the lagoons. As the in-place closure unit is constructed, any soils exceeding remedial action goals will be staged for closure within the unit or treatment and off site disposal as appropriate. Following this construction activity, follow up sampling will be performed on shallow groundwater in the vicinity of the lagoons to identify if further remedial action is needed on the groundwater media.

Off Site Recycling - Off Site recycling is the remedial alternative selected in the ROD. The other main advantage to this option is that the material will be re-used as opposed to contained at the Site or off Site at a landfill. MSRMI will evaluate this alternative during the FFS. Key considerations in evaluating this remedy will include the current recycling market for the PVC material, what the material will be used for (end use) and what, if any, pre-treatment may be required. MSRMI does not consider dioxins/furans a significant issue with regard to potential remedies; nonetheless the recycling option will consider the end use of the PVC material and an evaluation of whether such use is compatible with those detections. Some processing of the material might also be performed by a recycling operation to be located on the facility property adjacent to the lagoons. The evaluation of recycling will also consider previous recycling efforts (i.e., results of previous pilot studies preparation methods and goals) and recycling efforts conducted as part of closure of the RCRA lagoons, which contained similar material and were located adjacent to the Earthen Lagoons. The practices employed for any on site processing will be evaluated to identify potential constituents that could be emitted to air or water during site work and what controls if any might be appropriate on those emissions.

Off Site Disposal - MSRMI will evaluate the option of off Site disposal of the PVC material. Other pre-treatment options would likely need to be considered. One option would be stabilization/solidification prior to acceptance by the landfill. There are two choices: either send it to a solidification facility or solidify it on Site prior to shipping it directly to a landfill. Solidification on Site prior to transport has the advantage of improving the handling characteristics of the material for shipment. It is unlikely that the low levels of dioxins would be a concern to treatment and disposal facilities.

Soils Surrounding the PVC Material - MSRMI will evaluate ARARs for the soils surrounding the PVC Material (i.e., underlying soils and earthen berms). At this time, and as previously proposed in the ESD and revised ESD, MSRMI believes that the Pennsylvania Department of Environmental Protection (PADEP) Land Recycling Act (Act 2) is the most appropriate ARAR for the surrounding soils.

The remedies evaluated in the FFS for the surrounding soils will include excavation to appropriate cleanup standards, and either on Site closure or off Site disposal as hazardous and/or non-hazardous material. Samples of the underlying soils and earthen berms will be collected after removal of the PVC material to characterize these materials for final disposition. The final FFS will describe how the soils will be evaluated: what action levels should be used, and how delineation and remediation would be performed, under each scenario.

7.4 PRELIMINARY ARARS AND TBCS

A preliminary listing and discussion of applicable and relevant and appropriate requirements (ARARs); other advisories, criteria, and guidance to be considered pursuant to section 300.400(g)(3) of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), 40 C.F.R. § 300.400(g)(3) (TBCs) will be completed. Also, a plan for refinement of ARARs and TBCs throughout the FFS process, including proposed clean-up levels will be proposed in the FFS. The ARARs and TBCs will initially be presented in the draft FFS, and used to screen potential technologies, which will be further evaluated. The ARARs and TBCs will be refined throughout the FFS. Therefore, the final evaluation of potential technologies using the refined ARARs/TBCs will be used for preparation of the final FFS.

ARARs and TBCs were identified during the FS completed in 1993 and again in 1997 during the Alternate Technology Evaluation. The ARARs/TBCs identified during these previous studies will be used as the starting point for the FFS. The following is a list of those ARARS identified during the 1997 Alternate Technology Evaluation.

- Pennsylvania Solid Waste Management Act, which would pertain to the on Site closure of the PVC solids at the Site;
- Pennsylvania Clean Streams Law, which would pertain to the closure of waste disposal facilities on floodplains;
- Wetlands Protection Act, which would pertain to the closure of waste disposal facilities on or adjacent to wetlands;
- EPA/Pennsylvania Air Pollution Control Regulations, which would pertain to certain dewatering processes for the PVC solids on Site;
- Federal Clean Air Act;
- Pennsylvania Erosion Control Regulations;
- Pennsylvania Storm Water Management Act;

- Occupational Safety and Health Act Requirements, which would pertain to the handling of the PVC solids and other construction-related activities;
- DOT/Pennsylvania Regulations for Hazardous Material Transport, which would pertain to the shipment of the solids as waste for disposal and/or treatment off Site;
- Pennsylvania Land Recycling Act (Act 2), which will pertain to cleanup of underlying soils after removal of the PVC solids;
- Comprehensive Environmental Response, Compensation, and Liability Act (Superfund);
- Resource Conservation and Recovery Act (RCRA); and
- Canadian Regulations.

8.0 SCHEDULE AND SUBMITTALS

8.1 SCHEDULE

Figure 8.1 presents an anticipated schedule for completion of the FFS. This schedule is dependant upon EPA review and approval times. In addition, the schedule is subject to modification based on the schedule in the Treatability Testing Work Plan.

8.2 SUBMITTALS

Various submittals will be provided to EPA during the FFS process. Specifically, the following deliverables will be submitted to EPA for review.

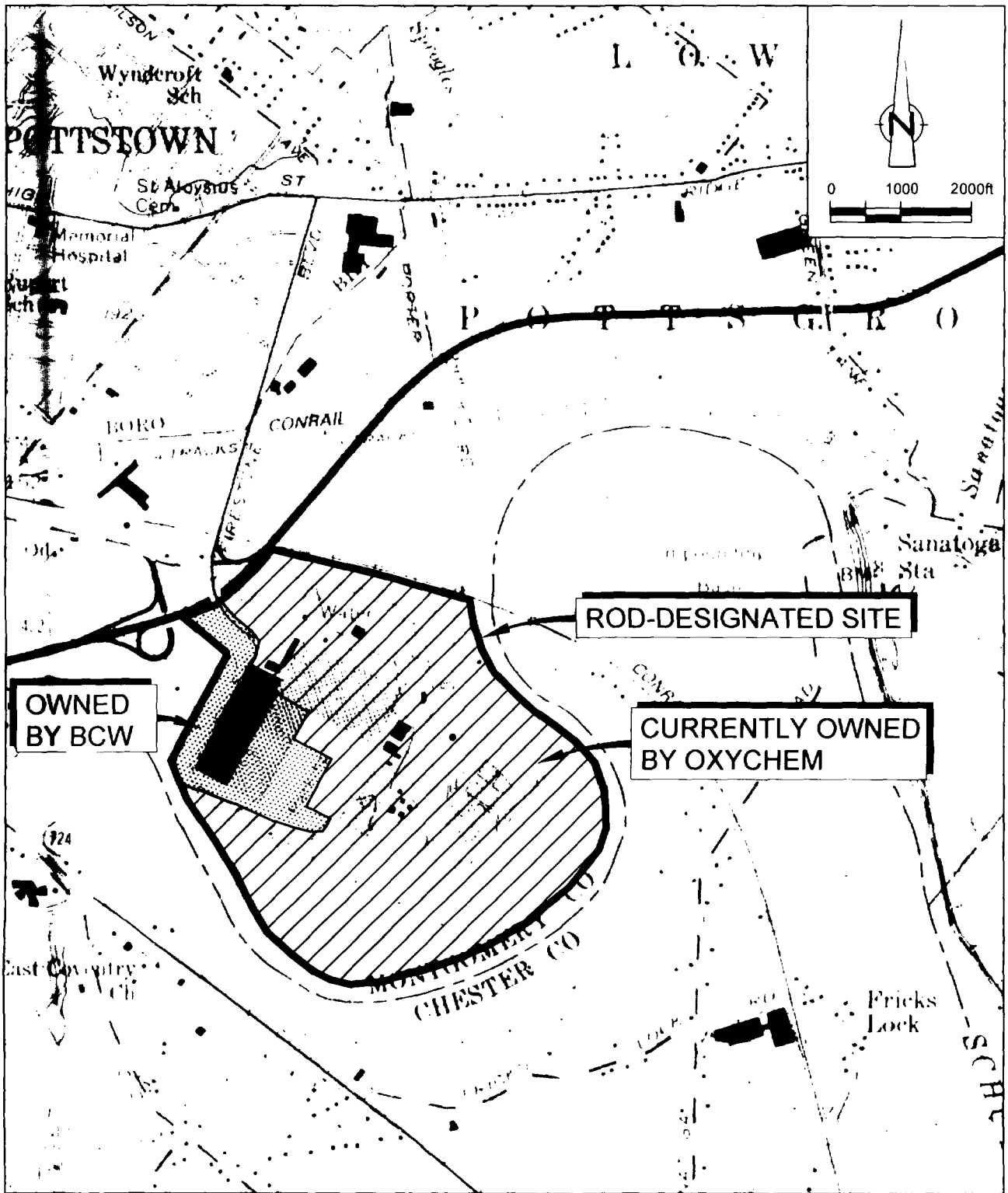
- Identification of Candidate Technologies Memorandum,
- Treatability Testing Statement of Work,
- Treatability Testing Work Plan (if required),
- Treatability Study Evaluation Report,
- Draft Focused Feasibility Study, and
- Final Focused Feasibility Study.

In addition to the above, Monthly Progress Reports regarding the FFS will be submitted to EPA beginning thirty (30) calendar days subsequent to the date on which the Work Plan is approved by EPA. The FFS Monthly Progress Reports (including a schedule of activities) will be submitted as a section of the CERCLA Monthly Progress Reports.

At a minimum, these progress reports shall include:

- 1) a description of the actions that have been taken toward achieving compliance with this Consent Order and the tasks set forth in the approved Work Plan;
- 2) all results of sampling, tests, analytical data (whether or not it has undergone Quality Assurance/Quality Control review and interpretations) and all other information received by the Respondent;
- 3) a description of all data anticipated and activities scheduled for the next thirty (30) calendar day period; and
- 4) a description of any problems encountered, any actions taken or to be taken to remedy or mitigate such problems, and a schedule of when such actions will be taken.

FIGURES



SOURCE: USGS QUADRANGLE MAP, PHOENIXVILLE, 1955, REVISED 1983



figure 2.1
 SITE LOCATION MAP
 OCCIDENTAL CHEMICAL CORPORATION
Pottstown, Pennsylvania

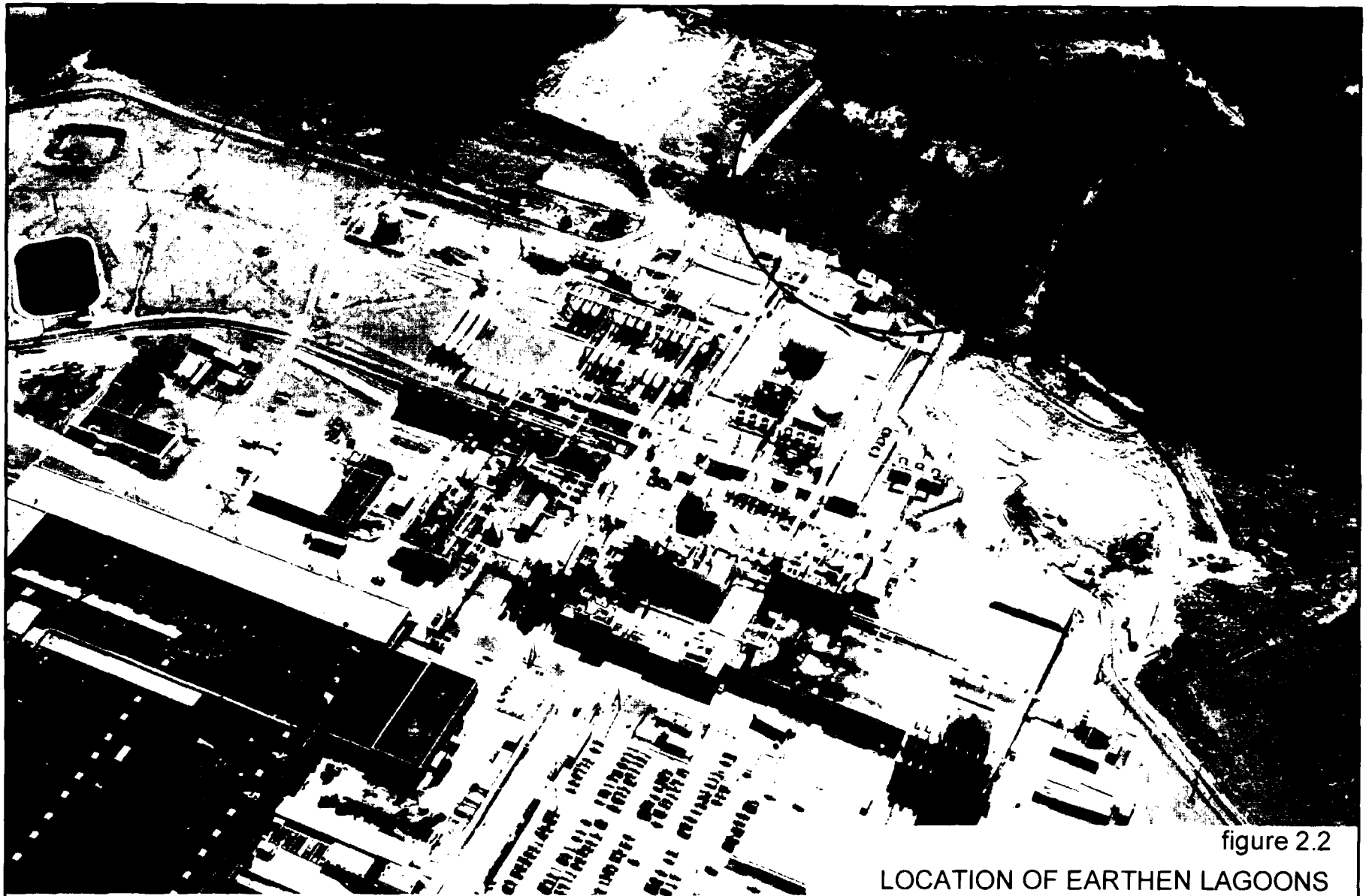


figure 2.2

LOCATION OF EARTHEN LAGOONS
OCCIDENTAL CHEMICAL CORPORATION
Pottstown, Pennsylvania



NOTES:
AERIAL PHOTOGRAPH - AUGUST 23, 1994.
PHOTOGRAPH IS NOT REFLECTIVE OF CURRENT CONDITIONS.



figure 2.3

CONFIGURATION OF EARTHEN LAGOONS
OCCIDENTAL CHEMICAL CORPORATION
Pottstown, Pennsylvania

NOTES:
AERIAL PHOTOGRAPH - CIRCA 2003.
IN GENERAL, PHOTOGRAPH IS REFLECTIVE OF CURRENT CONDITIONS; HOWEVER,
THERE IS CURRENTLY MINIMAL SURFACE WATER IN THE LAGOONS AS THIS IS
PUMPED AND TREATED AT THE ON SITE GROUNDWATER TREATMENT SYSTEM.



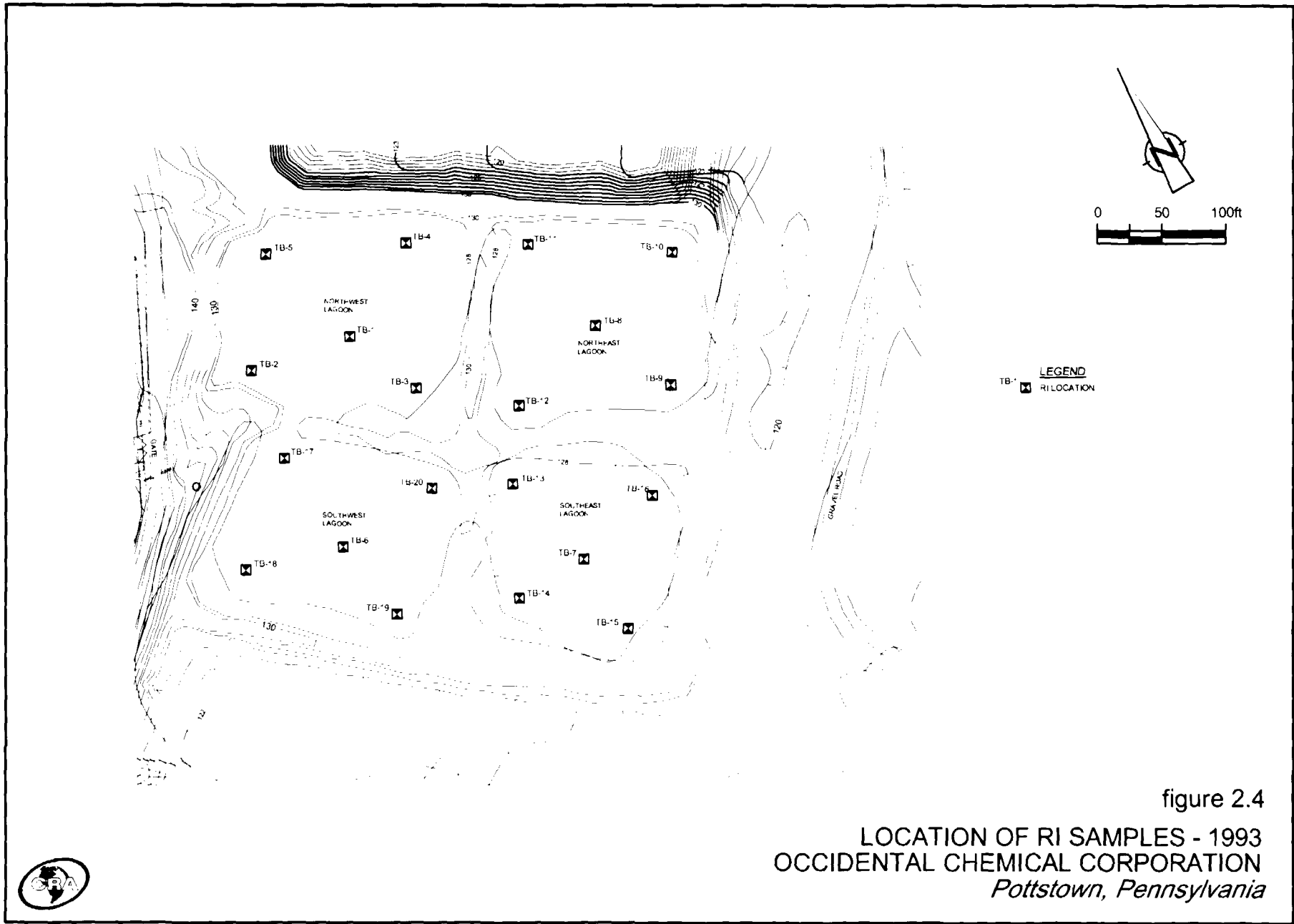


figure 2.4
 LOCATION OF RI SAMPLES - 1993
 OCCIDENTAL CHEMICAL CORPORATION
 Pottstown, Pennsylvania



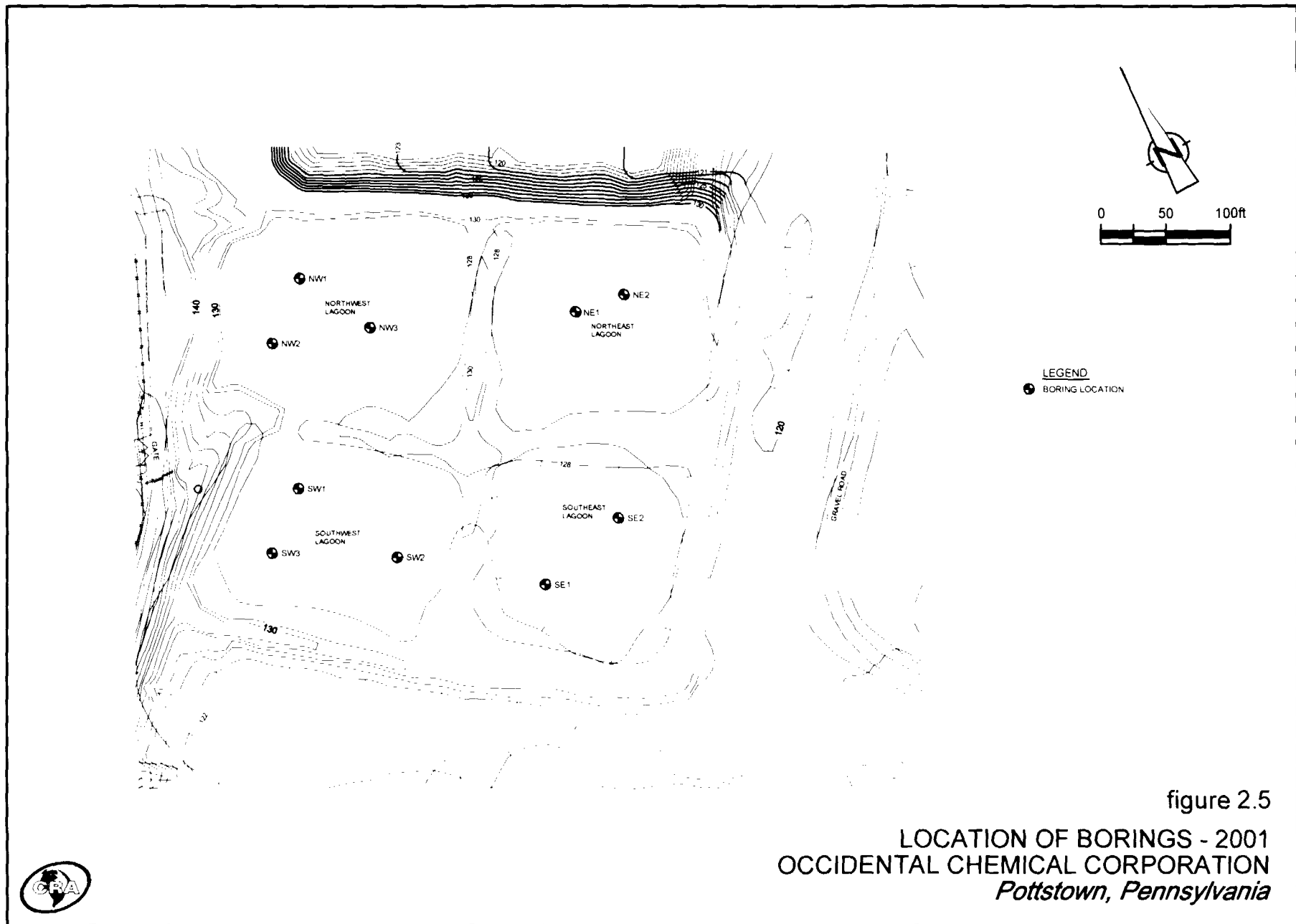
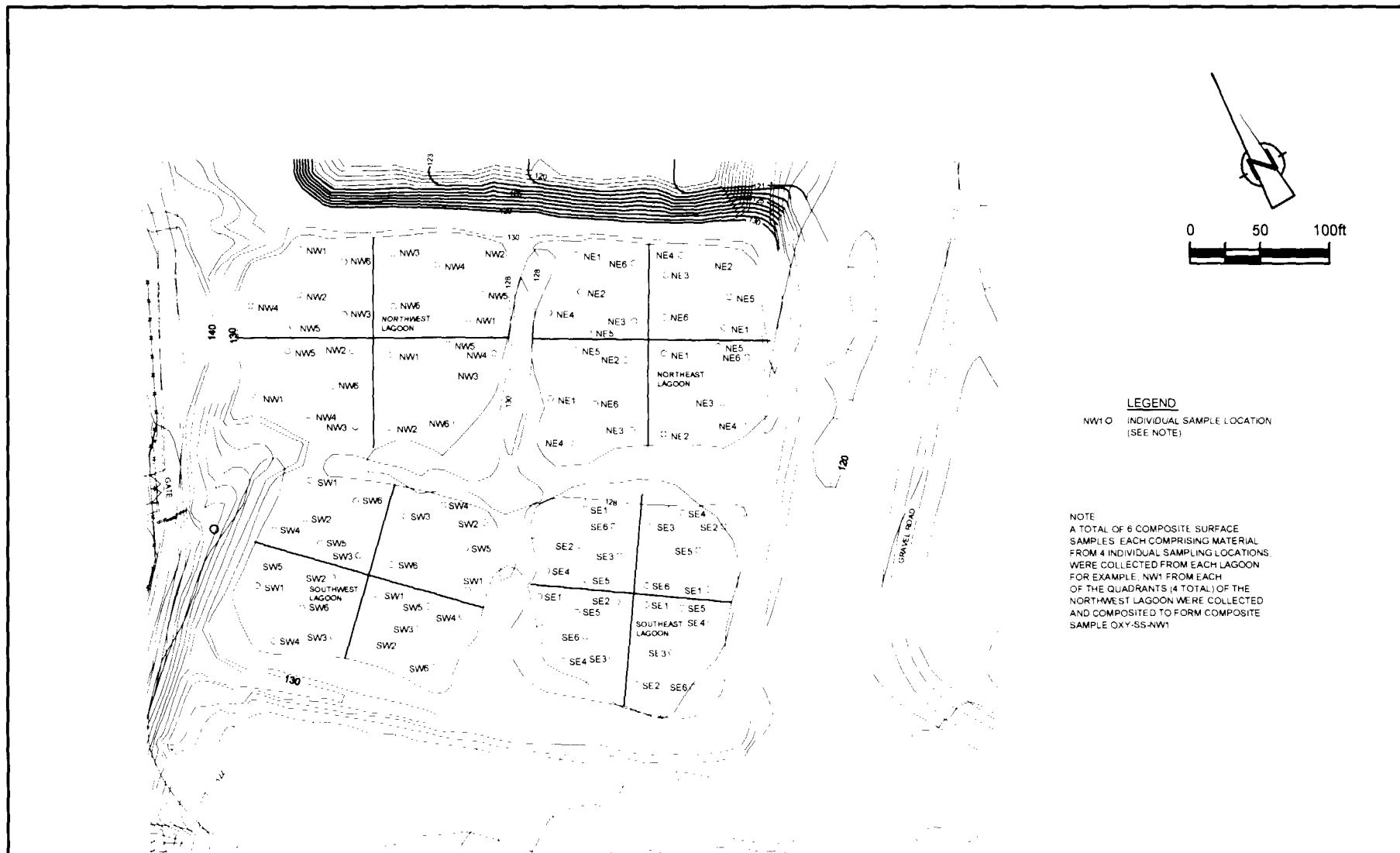


figure 2.5
 LOCATION OF BORINGS - 2001
 OCCIDENTAL CHEMICAL CORPORATION
Pottstown, Pennsylvania





LEGEND
 NW1 O INDIVIDUAL SAMPLE LOCATION
 (SEE NOTE)

NOTE
 A TOTAL OF 6 COMPOSITE SURFACE
 SAMPLES, EACH COMPRISING MATERIAL
 FROM 4 INDIVIDUAL SAMPLING LOCATIONS,
 WERE COLLECTED FROM EACH LAGOON.
 FOR EXAMPLE, NW1 FROM EACH
 OF THE QUADRANTS (4 TOTAL) OF THE
 NORTH-WEST LAGOON WERE COLLECTED
 AND COMPOSITED TO FORM COMPOSITE
 SAMPLE OXY-SS-NW1

figure 2.6
 LOCATION OF SURFACE SAMPLES -2001
 OCCIDENTAL CHEMICAL CORPORATION
 Pottstown, Pennsylvania



Depth		Bore Hole No.									
From	To	1	2	3	4	5	6	7	8	9	10
0	1										
1	2										
2	3										
3	4							3			
4	5										
5	6										
6	7							1	2	3	3
7	8							0	2	0	0
8	9		0		3	3	0	0	0	0	0
9	10	3	0	0	2	0	0	0	0	0	0
10	11	2	0	0	0	0	0	0	0	0	0
11	12	0	0	0	3	3	0	0	0	0	3
12	13	0	2	0	0	0	0	0	0	0	0
13	14	0	0	0	0	0	0		0	0	3
14	15	0	0	0	0	0			0	0	
15	16	0	0	0	0	0			0	0	
16	17		0		0				0	0	
17	18	0	2	3		0			0	0	
18	19	0		0					0		
19	20			0	3	0					
20	21	0			0						
21	20				0						
22	21										
23	22					3					

LEGEND

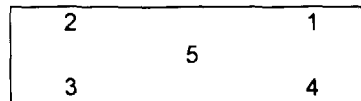
Failure - 2.0 Units

PASSES  > 3.0 Units

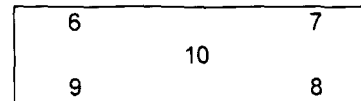
POTENTIALLY FAILS  1.0 to 3.0 Units

DEFINITELY FAILS 0.0 Units

No Sample



River



Plant

NOTES:

(1) ONE PENETROMETER UNIT = ~125 POUNDS PER SQUARE FOOT.

(2) PENETROMETER READINGS MEASURED USING STANDARD PENETROMETER METHODS.

(3) THE PURPOSE OF THE TESTING WAS TO DETERMINE IF THE MATERIAL MET THE REQUIREMENTS FOR DISPOSAL AT SARNIA LANDFILL IN CANADA.


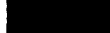



figure 3.1

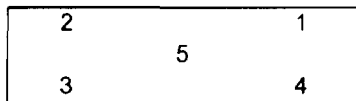
PENETROMETER MEASUREMENTS VERSUS DEPTH - 2005
OCCIDENTAL CHEMICAL CORPORATION
Pottstown, Pennsylvania



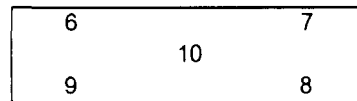
Depth		Percent Moisture									
From	To	1	2	3	4	5	6	7	8	9	10
0	1		32		31		31		35	31	37
1	2	33	33		34	32	34	31	37		37
2	3	32	32	35	37	32	33	38	39	34	38
3	4	32	33	36	33	33	36	39	39		39
4	5	38	35	39	35	35	33			36	39
5	6	32	36	40	36	35	34	30		39	39
6	7	35	35								
7	8		39		38	36					
8	9	35	39		39	31		50			
9	10	31	37			37	50	53			
10	11					35					
11	12	37	38	40		36	53	50		51	50
12	13	39		37			56				50
13	14						52		51	52	56
14	15										
15	16		36						51		
16	17	50	34	36		31			49	52	
17	18	38							59	33	
18	19					39					
19	20	42			32						
20	21					31.3					
21	22				32	34					
22	23				30						
23	24										

LEGEND

-  < 20 %
-  20 - 29 %
-  30 - 39 %
-  40 - 49 %
-  ≥ 50 %
- No Sample



River



Plant







figure 3.2

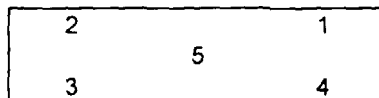
MOISTURE CONTENT VERSUS DEPTH - 2005
 OCCIDENTAL CHEMICAL CORPORATION
Pottstown, Pennsylvania



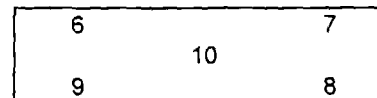
Depth		Bulk Density									
From	To	1	2	3	4	5	6	7	8	9	10
0	1		0.66	0.61	0.67	0.64	0.62	0.79	0.67	0.63	
1	2	0.64			0.65		0.61	0.74	0.70	0.71	0.61
2	3	0.65	0.62		0.68		0.64		0.72	0.65	0.60
3	4	0.65	0.69		0.78			0.76	0.69		0.64
4	5	0.60	0.72	0.46			0.62	0.70	0.67	0.61	0.66
5	6	0.78	0.67		0.77	0.48	0.62		0.66		0.68
6	7	0.66	0.74		0.75			0.63	0.60		
7	8		0.64	0.48	0.73	0.66	0.47	0.61	0.65		
8	9	0.66	0.66							0.64	
9	10	0.79	0.82		0.69	0.69	0.45		0.67	0.49	
10	11	0.69	0.61		0.71	0.69	0.60	0.62	0.68		0.49
11	12	0.75	0.67	0.63	0.65		0.46		0.64	0.49	0.47
12	13	0.66		0.64	0.66		0.38		0.66	0.60	
13	14	0.63			0.63	0.48					
14	15	0.63	0.64		0.58				0.60		
15	16		0.73		0.65	0.60					
16	17			0.74	0.72				0.60	0.47	
17	18	0.76			0.65				0.47		
18	19			0.72	0.24						
19	20	0.75									
20	21	0.64				0.61					
21	22					0.67					
22	23										
23	24										

LEGEND

-  < 0.50
-  0.50 - 0.59
-  0.60 - 0.69
-  0.70 - 0.79
-  ≥ 0.80
-  No Sample



River



Plant

figure 3.3

BULK DENSITY VERSUS DEPTH - 2005
 OCCIDENTAL CHEMICAL CORPORATION
Pottstown, Pennsylvania



NOTES:

- (1) BULK DENSITY UNITS = GRAMS PER CUBIC CENTIMETER.
- (2) BULK DENSITY DETERMINED USING STANDARD METHODS.
 (REFERENCE : VALDOSTA STATE UNIVERSITY)

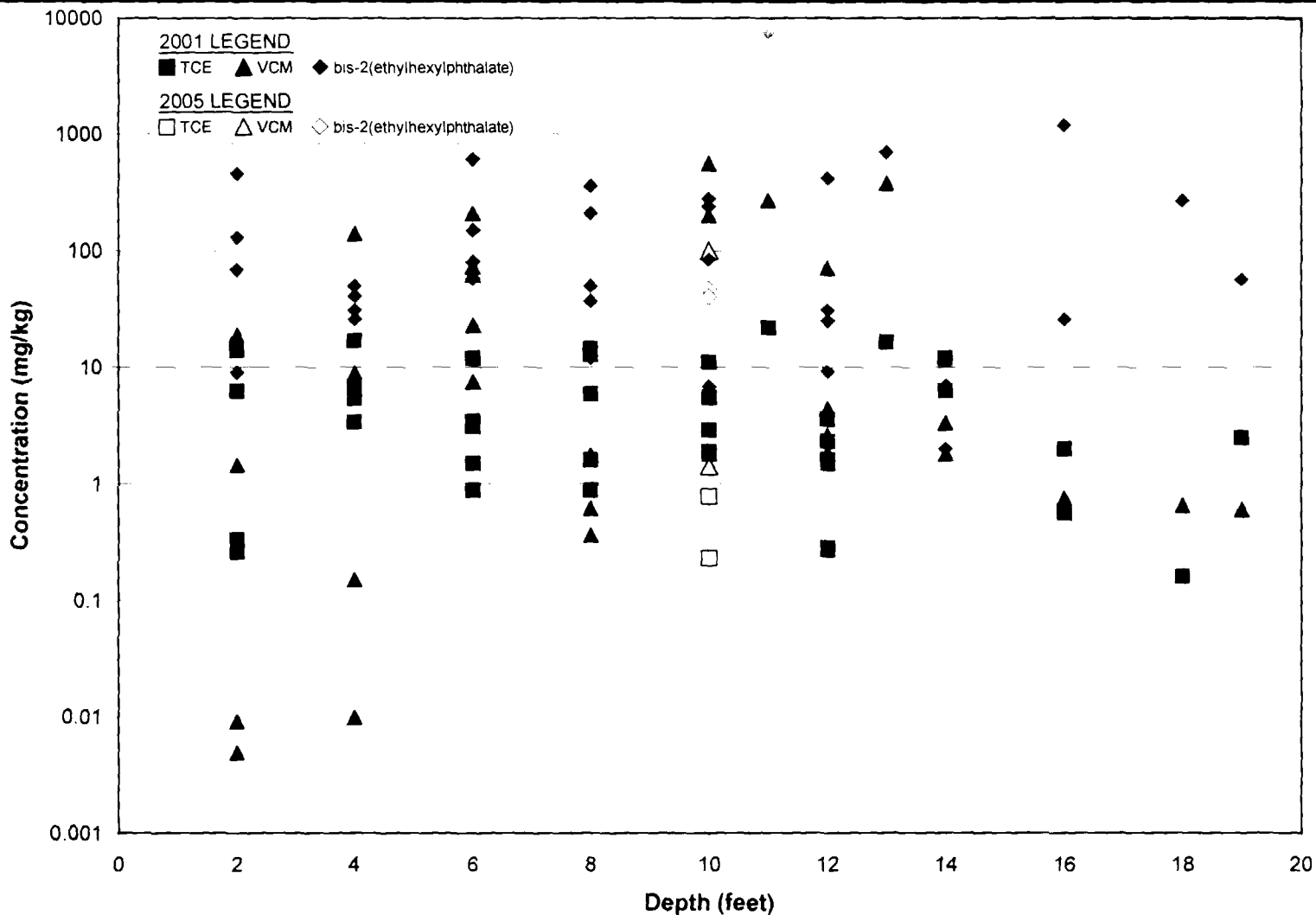


figure 3.4

CONCENTRATIONS IN PVC MATERIAL VERSUS DEPTH - 2001
 OCCIDENTAL CHEMICAL CORPORATION
Pottstown, Pennsylvania



NOTE:
 DATA BASED ON 2001 SAMPLES EXCEPT FOR TWO SAMPLES
 COLLECTED IN 2005.

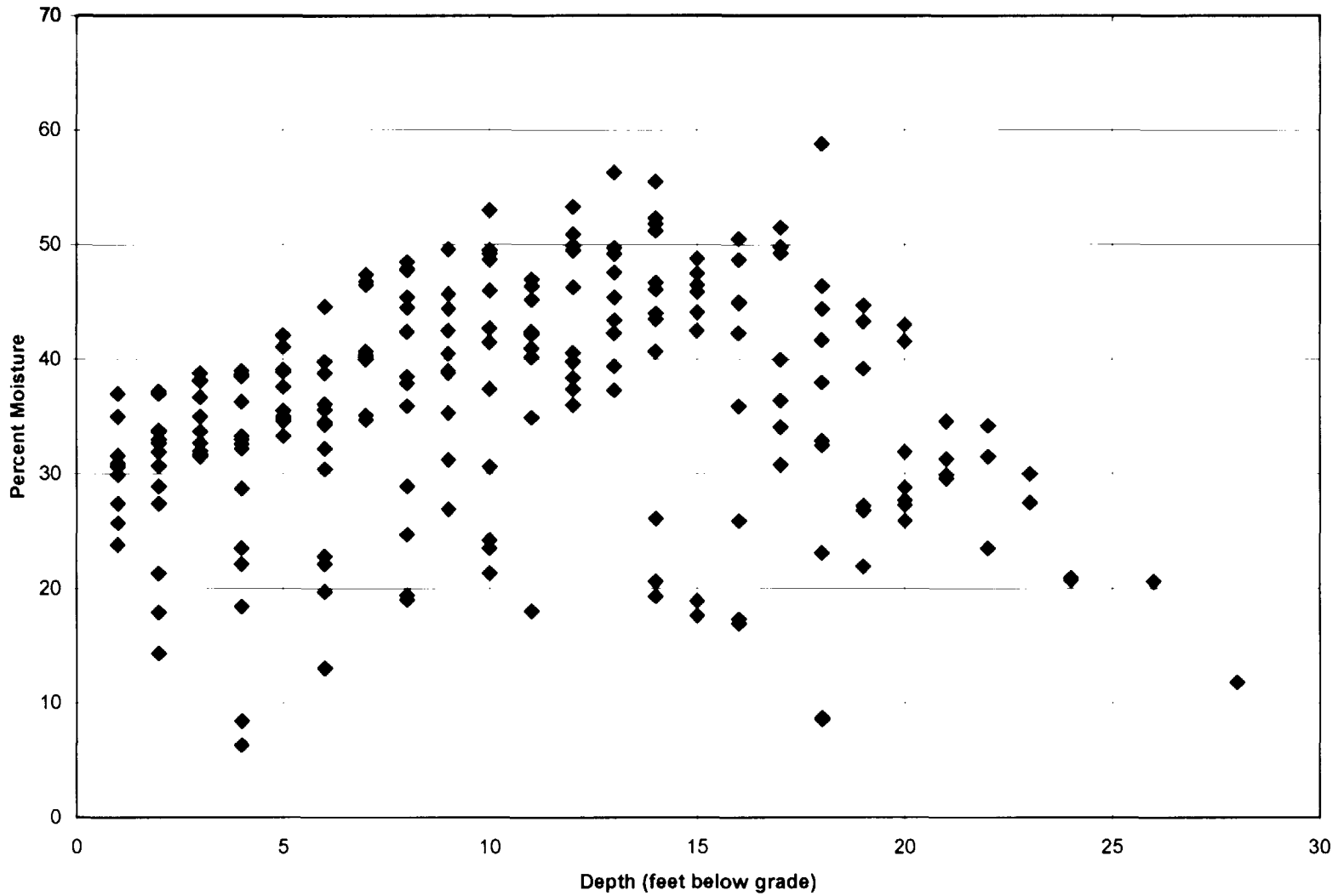


figure 3.5

PERCENT MOISTURE VERSUS DEPTH FOR PVC MATERIAL - 2001 AND 2005
 OCCIDENTAL CHEMICAL CORPORATION
Pottstown, Pennsylvania



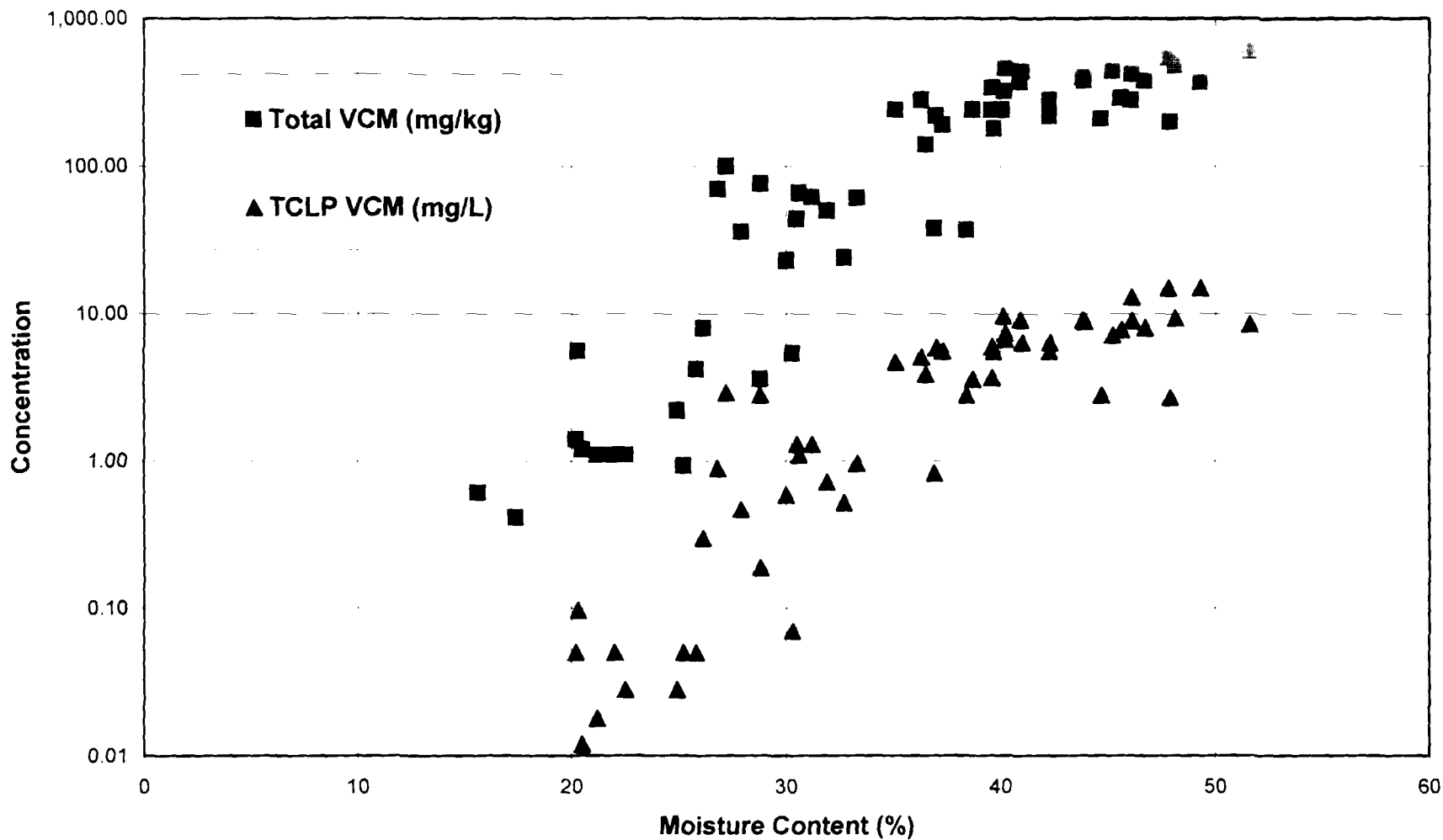


figure 3.6

PERCENT MOISTURE VERSUS VCM AND TCE - MA/RH PILOT TEST - 1998
 OCCIDENTAL CHEMICAL CORPORATION
Pottstown, Pennsylvania



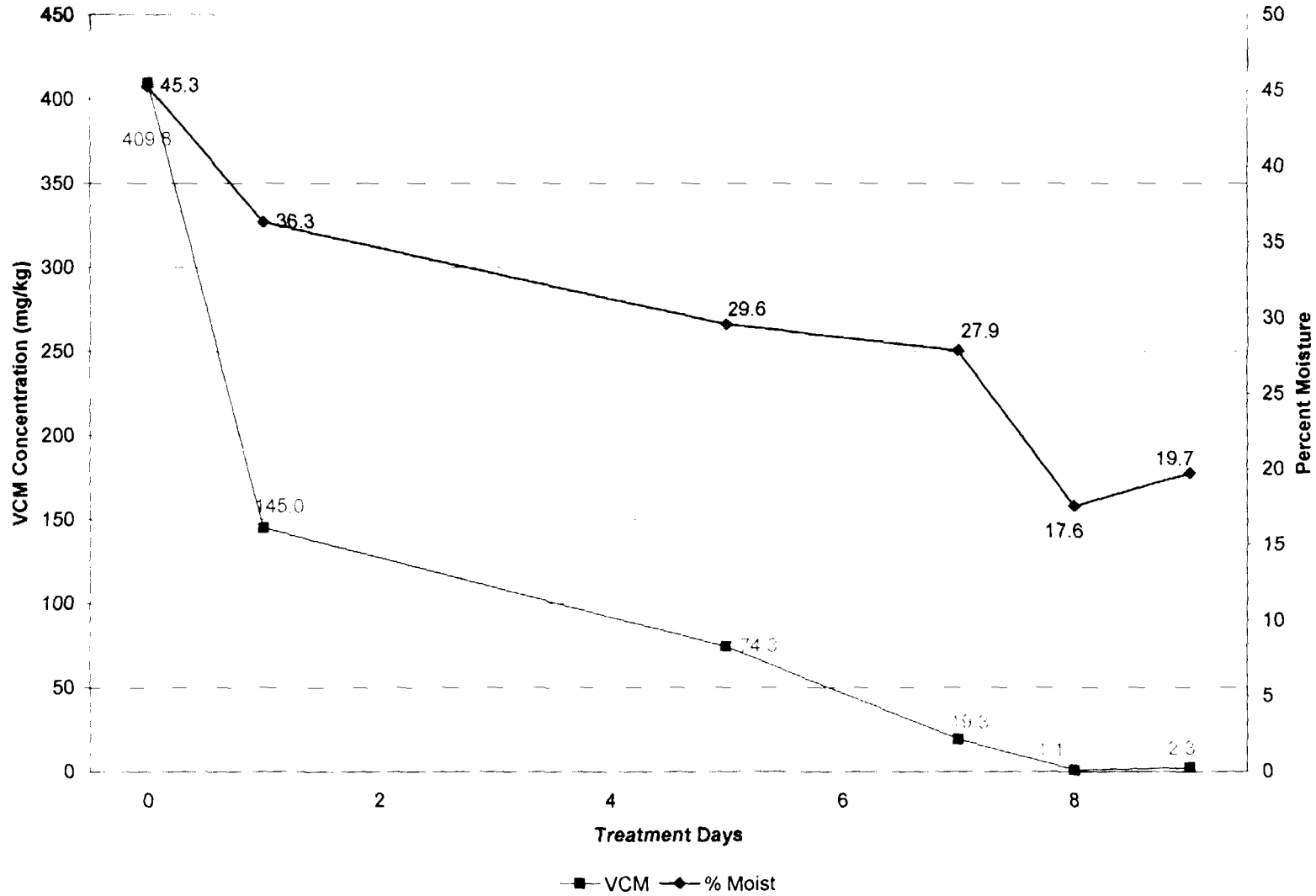
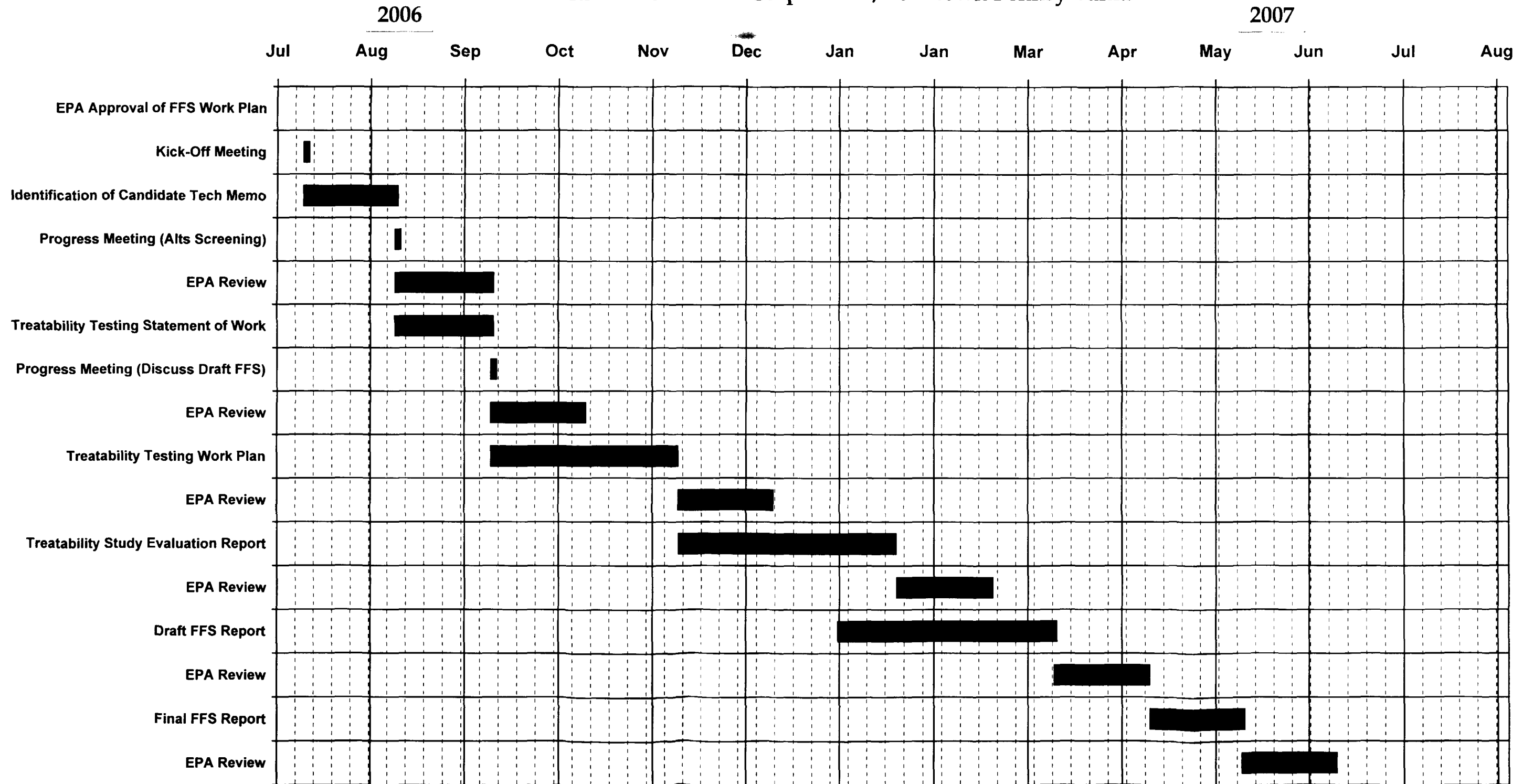


figure 3.7

PERCENT MOISTURE VERSUS VCM AND TCE - MA/RH PILOT TEST - 1998
 OCCIDENTAL CHEMICAL CORPORATION
Pottstown, Pennsylvania



Table 8.1
Anticipated Schedule - Focused Feasibility Study - Earthen Lagoons
Occidental Chemical Corporation, Pottstown Pennsylvania



Notes: 1. Schedule is based on calendar days. 2. Schedule considers EPA review & approval is completed in 30 days. 3. Schedule is subject to modification per final EPA approval of Treatability Testing Statement of Work.

TABLES

TABLE 2.1
 SUMMARY OF RI ANALYTICAL RESULTS 1993
 (Table 3 from the record of decision)

IDENTIFICATION OF CHEMICALS OF POTENTIAL CONCERN: EARTHEN LAGOON SEDIMENT

OCCIDENTAL CHEMICAL CORPORATION SITE REMEDIAL INVESTIGATION
 POTTSTOWN, PENNSYLVANIA

Detected Compounds	Risk-Based Concentrations (Industrial)	Maximum Background Concentration	Sample Location	Maximum Sample Concentration	Sample Location
VOLATILE ORGANICS (ug/kg)					
1,2-Dichloroethane	31000	ND		320 D	TB1-8
1,2-Dichloroethene (total)	920000	ND		4800 DE	TB1-8
2-Butanone	5100000	ND		27	TB6-10
Acetone	10000000	ND		1200 D	TB1-8
Benzene	90000	ND		200 D	TB1-8
Carbon Disulfide	10000000	ND		2300 D	TB1-8
Methylene Chloride	380000	ND		1100 D	TB1-8
Styrene	95000	ND		2100 D	TB1-8
Tetrachloroethene	55000	ND		850 D	TB1-8
Toluene	1800000	2	OS-3S	1800 D	TB1-8
Total Xylenes	20000000	ND		7000 DE	TB1-8
Trichloroethene	280000	ND		940 D	TB1-8
Vinyl Chloride	1500	ND		1700 D	TB1-8
SEMIVOLATILE ORGANICS (ug/kg)					
Benzoic Acid	41000000	100	PBG-1A	31000 D	TB7-4OL
2-Methylnaphthalene	NA	16	OS-2-S	88	TB6-8
Acenaphthylene	6100000	ND		100	TB6-9.5
Benzo[a]anthracene	2700	200	OS-1-S	270	TB6-9.5
Benzo[a]pyrene	390	220	OS-1-S	220	TB6-9.5
Benzo[b]fluoranthene	3200	230	OS-1-S	230	TB6-9.5
Benzo[k]fluoranthene	7400	230	OS-1-S	130	TB6-9.5
Bis(2-ethylhexyl)phthalate	200000	630	OS-1-S	280000 DE	TB6-4
Chrysene	NA	280	OS-1-S	380	TB6-9.5
Di-n-butyl phthalate	10000000	39	OS-2-S	1800 D	TB7-4OL
Diethyl phthalate	23000000	ND		92	TB6-8
Fluoranthene	4100000	450	OS-1-S	230	TB6-9.5
Naphthalene	4100000	ND		3800 D	TB7-4OL
Phenanthrene	3000000	220	OS-1-S	700 D	TB7-4OL
Pyrene	3100000	440	OS-1-S	330	TB6-9.5
PESTICIDES/PCBs (ug/kg)					
4,4'-DDE	8400	ND		6.7	TB1-8
Aldrin	170	ND		150	TB1-8
alpha-BHC	480	ND		39	TB1-8

TABLE 2.1 (cont.)
 SUMMARY OF RI ANALYTICAL RESULTS 1993
 (Table 3 from the record of decision)

IDENTIFICATION OF CHEMICALS OF POTENTIAL CONCERN: EARTHEN LAGOON SEDIMENT
 OCCIDENTAL CHEMICAL CORPORATION SITE REMEDIAL INVESTIGATION
 POTTSTOWN, PENNSYLVANIA

Detected Compounds	Risk-Based Concentrations (Industrial)	Maximum Background Concentration	Sample Location	Maximum Sample Concentration	Sample Location
INORGANICS (mg/kg)					
Aluminum [Ⓢ]	30000	30000	OS-1-S	34000	TB6-13A
Antimony	41	ND		30	TB6-13
Arsenic	1.6	9.3	FBG-1-S	27	TB6-13, TB6-8, TB6-10
Barium	7200	230	OS-2-S	430	TB6-13A
Beryllium [Ⓢ]	0.67	3.4	OS-3-S	2.2	TB6-10
Cadmium	51	11	OS-1-S	3.3	TB6-8
Calcium [Ⓢ]	NA	5800	OS-2-S	23000	TB6-3
Chromium	510	77	OS-1-S	130	TB1-8
Cobalt	NA	80	OS-2-S	36	TB6-13A
Copper	3800	180	OS-3-S	61	TB6-9.5
Iron [Ⓢ]	NA	48000	OS-3-S	48000	TB7-12
Lead	NA	270	OS-3-S	120	TB6-8
Magnesium	NA	4800	OS-1-S	3800 k	TB7-10
Manganese	10000	2900	OS-2-S	2800	TB6-13A
Mercury	31	0.84	OS-1-S	0.59	TB6-9.5
Nickel	2000	96	OS-1-S	39	TB6-10
Potassium	NA	3800	OS-1-S	3200	TB1-14
Selenium	510	1.6	OS-3-S	0.96	TB6-9.5
Silver	510	ND		1.1	TB6-13A
Sodium	NA	430	FBG-1-S	400	TB6-8
Vanadium	720	50	OS-3-S	49	TB6-13
Zinc	31000	470	OS-2-S	170	TB6-9.5, TB6-10

Notes:

Results are rounded to two significant figures.

Shading indicates chemicals of potential concern.

* = Additional Chemical of Potential Concern if Risk Based Concentrations are used to Describe COPCs.

Ⓢ = Not considered a chemical of potential concern due to absence of EPA-verified toxicity values as of March 1992.

NA = Not Available

ND = Not Detected

B = Found in associated blank.

J = Indicates an estimated value.

O = Compounds identified during reanalysis of a diluted sample.

E = For inorganics, indicates an estimate due to interference; for organics, indicates an estimate above calibration range.

b = Values qualified due to presence of analyte in the sample at less than five times the amount in the associated blank.

(Values qualified with b are not considered chemicals of potential concern)

| = Indicates an estimated value due to expected quality control criteria and/or value less than the Contract Required Detection Limit.

Contract Required Quantitation Limit.

k = Value biased high.

l = Value biased low.

| = Value between Instrument Detection Limit and Contract Required Quantitation or Detection Limit.

TABLE 2.2
SUMMARY OF ANALYTICAL RESULTS
MECHANICAL AERATION AND RADIANT HEAT PILOT TEST
OxyChem Pottstown, Pennsylvania Facility

Pile No.	Sample ID	Trichloroethene			Vinyl Chloride			% Moisture
		Total (ug/kg)	Total (mg/kg)	TCLP (mg/L)	Total (ug/kg)	Total (mg/kg)	TCLP (mg/L)	
P1	P1-825-001	4,800	4.8	ND 0.5	540,000	540	15.0	48
P1	P1-826-001	6,400	6.4	ND 0.25	380,000	380	8.1	47
P1	P1-831-001	9,000	9.0	ND 0.25	240,000	240	9.7	40
P1	P1-903-001	11,000	11.0	ND 0.25	460,000	460	6.7	40
P1	P1-909-001	5,506	5.5	ND 0.25	223,170	220	5.9	37
P1	P1-915-001	16,000	16.0	0.025	51,000	61	0.96	33
P1	P1-925-001	8,200	8.2	nd 0.05	1,200	1.2	0.012	21
P2	P2-825-002	5,800	5.8	ND 0.25	600,000	600	8.5	52
P2	P2-826-002	3,600	3.6	ND 0.5	370,000	370	15.0	49
P2	P2-831-002	17,000	17.0	ND 0.25	400,000	400	9.1	44
P2	P2-903-002	16,000	16.0	ND 0.25	440,000	440	6.4	41
P2	P2-909-002	7,928	7.9	0.039	235,069	240	4.7	35
P2	P2-915-002	16,000	16.0	0.027	50,000	50	0.72	32
P2	P2-925-002	8,600	8.6	nd 0.05	1,400	1.4	ND 0.05	20
P3	P3-825-003	15,000	15.0	ND 0.25	440,000	440	7.2	45
P3	P3-826-003	42,000	42.0	ND 0.25	480,000	480	9.4	48
P3	P3-831-003	35,000	35.0	ND 0.25	380,000	380	8.9	44
P3	P3-903-003	23,000	23.0	0.076	320,000	320	7.4	40
P3	P3-909-003	12,039	12.0	ND 0.25	277,244	280	5.1	36
P3	P3-915-003	23,000	23.0	0.029	38,000	38	0.83	37
P3	P3-925-003	10,000	10.0	0.018	2,200	2.2	0.028	25
P4	P4-825-004	63,000	63.0	0.14	290,000	290	7.8	46
P4	P4-826-004	46,000	46.0	0.11	280,000	280	6.4	42
P4	P4-831-004	40,000	40.0	0.088	370,000	370	9.1	41
P4	P4-903-004	22,000	22.0	ND 0.25	340,000	340	6.0	40
P4	P4-909-004	14,708	15.0	0.072	185,717	190	5.6	37
P4	P4-915-004	24,000	24.0	0.036	44,000	44	1.3	31
P4	P4-925-004	13,000	13.0	0.015	1,100	1.1	0.028	23
P5	P5-825-005	7,800	7.8	0.022	37,000	37	2.8	38
P5	P5-826-005	11,000	11.0	0.013	70,000	70	0.89	27
P5	P5-831-005	24,000	24.0	0.029	76,000	76	2.8	29
P5	P5-903-005	14,000	14.0	0.014	66,000	66	1.1	31
P5	P5-909-005	3,652	3.7	0.024	3,591	3.6	0.19	29
P5	P5-915-005	13,000	13.0	0.014	5,400	5.4	0.07	30
P5	P5-925-005	7,900	7.9	--	610	0.61	--	16
P6	P6-825-006	12,000	12.0	0.025	930	0.93	ND 0.05	25
P6	P6-826-006	17,000	17.0	0.02	4,200	4.2	ND 0.05	26
P6	P6-831-006	12,000	12.0	0.017	36,000	36	0.47	28
P6	P6-903-006	15,000	15.0	0.02	62,000	62	1.3	31
P6	P6-909-006	4,900	4.9	0.02	2,414	8	0.3	26
P6	P6-915-006	14,000	14.0	0.01	5,600	5.6	0.097	20
P6	P6-925-006	8,100	8.1	--	410	0.41	--	17
P7	P7-825-007	23,000	23.0	ND 0.1	200,000	200	2.7	48
P7	P7-826-007	13,000	13.0	ND 0.12	210,000	210	2.8	45
P7	P7-831-007	15,000	15.0	0.052	180,000	180	5.6	40
P7	P7-903-007	19,000	19.0	0.029	240,000	240	3.7	40
P7	P7-909-007	7,159	7.2	0.054	137,712	140	3.9	37
P7	P7-915-007	19,000	19.0	0.021	24,000	24	0.52	33
P7	P7-925-007	11,000	11.0	nd 0.05	1,100	1.1	0.018	21
P8	P8-825-008	15,000	15.0	ND 0.5	420,000	420	13.0	46
P8	P8-826-008	20,000	20.0	0.062	280,000	280	9.0	46
P8	P8-831-008	19,000	19.0	0.053	220,000	220	5.6	42
P8	P8-903-008	20,000	20.0	0.028	240,000	240	3.6	39
P8	P8-909-008	5,553	5.6	0.052	100,158	100	2.9	27
P8	P8-915-008	18,000	18.0	0.022	23,000	23	0.59	30
P8	P8-925-008	8,600	8.6	nd 0.05	1,100	1.1	ND 0.05	22

TABLE 2.3
SUMMARY OF PVC MATERIAL ANALYTICAL RESULTS - 2001
OxyChem Pottstown, Pennsylvania

<i>Sample Location:</i>		<i>SE1</i>	<i>SE1</i>	<i>SE1</i>	<i>SE1</i>	<i>SE1</i>	<i>SE2</i>	<i>SE2</i>	<i>SE2</i>	<i>SE2</i>	<i>SE2</i>	<i>SE2</i>
<i>Depth</i>		<i>(4-6) ft</i>	<i>(6-8) ft</i>	<i>(6-8) ft</i>	<i>(8-10) ft</i>	<i>(10-12) ft</i>	<i>(0-2) ft</i>	<i>(2-4) ft</i>	<i>(4-6) ft</i>	<i>(6-8) ft</i>	<i>(8-10) ft</i>	<i>(10-11) ft</i>
<i>Sample Date:</i>		<i>5/24/2001</i>	<i>5/24/2001</i>	<i>5/24/2001</i>	<i>5/24/2001</i>	<i>5/24/2001</i>	<i>5/25/2001</i>	<i>5/25/2001</i>	<i>5/25/2001</i>	<i>5/25/2001</i>	<i>5/25/2001</i>	<i>5/25/2001</i>
<i>Parameter</i>	<i>Unit</i>			<i>Duplicate</i>								
Volatiles												
1,2-Dichloroethane	ug/kg	2,500	230	190	250	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloroethene (total)	ug/kg	241,900	1,220	2,160	4,100	830	89,000	99,000	8,200	54,000	220,000	14,000
2-Butanone	ug/kg	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acetone	ug/kg	ND	390	380	390	ND	ND	ND	ND	ND	ND	ND
Benzene	ug/kg	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Carbon disulfide	ug/kg	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methylene chloride	ug/kg	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Styrene	ug/kg	34,000	ND	190	250	ND	3,700	ND	1,300	ND	9,000	ND
Tetrachloroethene	ug/kg	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Toluene	ug/kg	4,000	ND	ND	ND	ND	2,500	1,500	1,100	ND	ND	9,500
Total Xylene	ug/kg	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Trichloroethene	ug/kg	3,100	880	1,600	1,900	270	14,000	ND	1,500	5,900	11,000	ND
Vinyl chloride	ug/kg	210,000	360	610	1,800	1,500	19,000	140,000	23,000	ND	560,000	270,000
Semi-Volatiles												
2-Methyl naphthalene	ug/Kg	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND
Acenaphthylene	ug/Kg	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND
Benzo(a)anthracene	ug/Kg	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND
Benzo(a)pyrene	ug/Kg	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND
Benzo(b)fluoranthene	ug/Kg	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND
Benzo(k)fluoranthene	ug/Kg	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND
bis(2-Ethylhexyl)phthalate	ug/Kg	81,000	50,000	37,000	280,000	-	130,000	50,000	58,000	12,000	6,800	7,500,000
Chrysene	ug/Kg	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND
Di-n-butylphthalate	ug/Kg	ND	ND	ND	ND	-	2,700	ND	ND	ND	ND	ND
Diethyl phthalate	ug/Kg	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND
Fluoranthene	ug/Kg	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND
Naphthalene	ug/Kg	ND	ND	ND	ND	-	ND	ND	2,500	2,000	ND	ND
Phenanthrene	ug/Kg	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND
Pyrene	ug/Kg	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND

TABLE 2.3
SUMMARY OF PVC MATERIAL ANALYTICAL RESULTS - 2001
OxyChem Pottstown, Pennsylvania

Sample Location:		SE2	SE2	SW1	SW1	SW2	SW3	SW3	SW3
Depth		<i>(11-12) ft</i>	<i>(12-13) ft</i>	<i>(0-2) ft</i>	<i>(2-4) ft</i>	<i>(0-2) ft</i>	<i>(0-2) ft</i>	<i>(2-4) ft</i>	<i>(2-4) ft</i>
Sample Date:		<i>5/25/2001</i>	<i>5/25/2001</i>	<i>7/25/2001</i>	<i>7/25/2001</i>	<i>7/25/2001</i>	<i>7/26/2001</i>	<i>7/26/2001</i>	<i>7/26/2001</i>
Parameter	Unit								<i>Duplicate</i>
Volatiles									
1,2-Dichloroethane	ug/kg	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloroethene (total)	ug/kg	250	81,000	ND	ND	ND	ND	ND	ND
2-Butanone	ug/kg	ND	ND	ND	ND	ND	ND	ND	ND
Acetone	ug/kg	ND	ND	1,700	6	6	ND	ND	14
Benzene	ug/kg	ND	ND	ND	ND	ND	ND	ND	ND
Carbon disulfide	ug/kg	ND	ND	ND	ND	ND	ND	ND	ND
Methylene chloride	ug/kg	ND	ND	ND	4	ND	ND	ND	ND
Styrene	ug/kg	ND	ND	1,900	ND	ND	10,000	ND	ND
Tetrachloroethene	ug/kg	ND	ND	ND	ND	ND	ND	ND	ND
Toluene	ug/kg	170	5,400	3,000	ND	ND	19,000	130,000	94
Total Xylene	ug/kg	ND	ND	ND	ND	ND	ND	ND	ND
Trichloroethene	ug/kg	ND	ND	ND	ND	ND	ND	ND	ND
Vinyl chloride	ug/kg	2,600	380,000	22,000	ND	ND	ND	ND	ND
Semi-Volatiles									
2-Methyl naphthalene	ug/Kg	ND	ND	7,900	9,500	ND	15,000	38,000	ND
Acenaphthylene	ug/Kg	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(a)anthracene	ug/Kg	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(a)pyrene	ug/Kg	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(b)fluoranthene	ug/Kg	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(k)fluoranthene	ug/Kg	ND	ND	ND	ND	ND	ND	ND	ND
bis(2-Ethylhexyl)phthalate	ug/Kg	9,200	700,000	91,000	31,000	17,000	60,000	28,000	ND
Chrysene	ug/Kg	ND	ND	ND	ND	ND	ND	ND	ND
Di-n-butylphthalate	ug/Kg	ND	ND	37,000	48,000	ND	7,300	4,200	ND
Diethyl phthalate	ug/Kg	ND	ND	ND	ND	ND	ND	ND	ND
Fluoranthene	ug/Kg	ND	ND	ND	ND	ND	ND	ND	ND
Naphthalene	ug/Kg	ND	ND	ND	ND	ND	9,400	17,000	ND
Phenanthrene	ug/Kg	ND	ND	ND	6,500	ND	ND	ND	ND
Pyrene	ug/Kg	ND	ND	ND	ND	ND	ND	ND	ND

NOTES:

ND - NON DETECT

TABLE 2.4
ANALYTICAL RESULTS SUMMARY - VALIDATED LAB RESULTS
DIOXINS/FURANS TESTING
POTTSTOWN, PENNSYLVANIA
DECEMBER 2003

Sample Location:				NE7	NE7	SE10	SE10
Sample ID:				SS-990405-RAM-001	SB-990405-RAM-009	SS-990405-RAM-008	SB-990405-RAM-016
Sample Date:				12/8/2003	12/9/2003	12/9/2003	12/9/2003
				0-6"	6-24"	0-6"	6-24"
Parameters	Units	1989 I-TEF	WHO 1998				
Dioxins/Furans							
1,2,3,4,6,7,8,9-Octachlorodibenzofuran (OCDF)	pg/g	0.001	0.0001	1020	1520 J3	658	253 J2
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin (OCDD)	pg/g	0.001	0.0001	145000 J3	201000 J3	133000 J3	38800 J2 J3
1,2,3,4,6,7,8-Heptachlorodibenzofuran (HpCDF)	pg/g	0.01	0.01	399 J4	543	245	107
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin (HpCDD)	pg/g	0.01	0.01	14400 J3	18000 J3	12600 J3	4280
1,2,3,4,7,8-Heptachlorodibenzofuran (HpCDF)	pg/g	0.01	0.01	42.9	53.1	23.7 J1	10.6 J1
1,2,3,4,7,8-Hexachlorodibenzofuran (HxCDF)	pg/g	0.1	0.1	29.4 J4	28.3 J2	15.5 J1	7.5 J1
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin (HxCDD)	pg/g	0.1	0.1	28.7	R	25.1 J1	9.98 J1
1,2,3,6,7,8-Hexachlorodibenzofuran (HxCDF)	pg/g	0.1	0.1	13.6 J1	18.5 J1	8.43 J1	5.02 J1
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin (HxCDD)	pg/g	0.10	0.10	178	210	131	55.3
1,2,3,7,8,9-Hexachlorodibenzofuran (HxCDF)	pg/g	0.1	0.1	5.78 J1	6.28 J1	2.11 U	1.68 U
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin (HxCDD)	pg/g	0.1	0.1	67.9	75.1	58.7	24 J1
1,2,3,7,8-Pentachlorodibenzofuran (PeCDF)	pg/g	0.05	0.05	4.64 U	5.61 J1	2.93 U	1.57 J1
1,2,3,7,8-Pentachlorodibenzo-p-dioxin (PeCDD)	pg/g	0.5	1	R	16.3 J1	12.1 J1	5.84 J1
2,3,4,6,7,8-Hexachlorodibenzofuran (HxCDF)	pg/g	0.1	0.1	19.9 J1	24.8 J1	15.5 J1	6.39 J1
2,3,4,7,8-Pentachlorodibenzofuran (PeCDF)	pg/g	0.5	0.5	R	7.69 J1	4.56 J1	2.27 J1
2,3,7,8-Tetrachlorodibenzofuran (TCDF)	pg/g	0.1	0.1	3.36 U	2.14 J1	3.58 U	R
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)	pg/g	1	1	9.88	10.9	6.95	2.8 J1
Total Heptachlorodibenzofuran (HpCDF)	pg/g			1620 J	2280 J	932 J	360 J
Total Heptachlorodibenzo-p-dioxin (HpCDD)	pg/g			28500 J	38300 J	25800 J	8330 J
Total Hexachlorodibenzofuran (HxCDF)	pg/g			432 J	632 J	332 J	150 J
Total Hexachlorodibenzo-p-dioxin (HxCDD)	pg/g			2130 J	2380 J	1460 J	578 J
Total Pentachlorodibenzofuran (PeCDF)	pg/g			103 J	90.4 J	32.1 J1	35.9 J1
Total Pentachlorodibenzo-p-dioxin (PeCDD)	pg/g			67.7 J	150 J	105 J	44.2 J1
Total Tetrachlorodibenzofuran (TCDF)	pg/g			7.94 J	52.4 J	8.36 J	12.9 J1
Total Tetrachlorodibenzo-p-dioxin (TCDD)	pg/g			58.1 J	60.3 J	27.1 J1	15.7 J1
Toxic Equivalency Quotient (TEQ)	pg/g	TEQ 1989 I-TEF		338.65 J	448.17 J	303.05 J	100.78 J
Toxic Equivalency Quotient (TEQ)	pg/g		TEQ WHO 1998	207.23 J	274.05 J	188.81 J	68.55 J

Notes:

U - Non-detect at the associated value.

J- Total homolog results are considered estimated.

J1- The amount detected is below the Lower Calibration Limit of the instrument and considered estimated.

J2- The amount reported is the maximum possible concentration due to possible chlorinated diphenylether interference.

J3- The amount detected is above the Upper Calibration Limit of the instrument and is considered estimated.

J4 - Estimated results due to low internal standard recoveries.

R - Rejected (did not meet ion abundance criteria for identification).

TABLE 3.1
BULK DENSITY AND MOISTURE CONTENT RESULTS - JULY 2005
OxyChem Pottstown, Pennsylvania

Sample Location:	EARTHEN LAGOONS							
Boring No:	B-1	B-1	B-1	B-1	B-1	B-1	B-1	
Sample Depth:	0-1'	1-2'	2-3'	3-4'	4-5'	6-6'	6-7'	
Sample ID:	LAG-9904-001	LAG-9904-002	LAG-9904-003	LAG-9904-004	LAG-9904-005	LAG-9904-006	LAG-9904-007	
Sample Date:	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	
General Chemistry	Units							
Bulk Density	g/cm ³	0.55	0.64	0.65	0.65	0.60	0.78	0.66
Percent Moisture	%	23.8	33.0	31.7	32.2	37.6	32.2	35.1
Sample Location:	EARTHEN LAGOONS							
Boring No:	B-1	B-1	B-1	B-1	B-1	B-1	B-1	
Sample Depth:	7-8'	8-9'	9-10'	10-11'	11-12'	12-13'	13-14'	
Sample ID:	LAG-9904-008	LAG-9904-009	LAG-9904-010	LAG-9904-011	LAG-9904-012	LAG-9904-013	LAG-9904-014	
Sample Date:	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	
General Chemistry	Units							
Bulk Density	g/cm ³	0.86	0.66	0.79	0.69	0.75	0.66	0.63
Percent Moisture	%	28.9	35.3	30.6	40.2	37.4	39.4	40.7
Sample Location:	EARTHEN LAGOONS							
Boring No:	B-1	B-1	B-1	B-1	B-1	B-1	B-2	
Sample Depth:	14-15'	15-16'	16-17'	18-19'	19-20'	20-21'	0-1'	
Sample ID:	LAG-9904-015	LAG-9904-016	LAG-9904-017	LAG-9904-019	LAG-9904-020	LAG-9904-021	LAG-9904-022	
Sample Date:	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	
General Chemistry	Units							
Bulk Density	g/cm ³	0.63	0.51	0.53	0.76	1.2	0.75	0.64
Percent Moisture	%	42.5	48.7	49.8	38.0	21.9	41.6	29.6
Sample Location:	EARTHEN LAGOONS							
Boring No:	B-2	B-2	B-2	B-2	B-2	B-2	B-2	
Sample Depth:	1-2'	2-3'	3-4'	4-5'	5-6'	6-7'	7-8'	
Sample ID:	LAG-9904-023	LAG-9904-024	LAG-9904-025	LAG-9904-026	LAG-9904-027	LAG-9904-028	LAG-9904-029	
Sample Date:	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	
General Chemistry	Units							
Bulk Density	g/cm ³	0.66	0.57	0.62	0.69	0.72	0.67	0.74
Percent Moisture	%	31.6	32.7	31.5	32.6	34.6	35.6	34.7
Sample Location:	EARTHEN LAGOONS							
Boring No:	B-2	B-2	B-2	B-2	B-2	B-2	B-2	
Sample Depth:	8-9'	9-10'	10-11'	11-12'	12-13'	13-14'	14-15'	
Sample ID:	LAG-9904-030	LAG-9904-031	LAG-9904-032	LAG-9904-033	LAG-9904-034	LAG-9904-035	LAG-9904-036	
Sample Date:	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	
General Chemistry	Units							
Bulk Density	g/cm ³	0.64	0.66	0.82	0.61	0.67	0.57	0.55
Percent Moisture	%	38.5	39.0	37.4	42.2	38.4	47.6	46.7
Sample Location:	EARTHEN LAGOONS							
Boring No:	B-2	B-2	B-2	B-2	B-3	B-3	B-3	
Sample Depth:	15-16'	16-17'	17-18'	18-19'	0-1'	1-2'	2-3'	
Sample ID:	LAG-9904-037	LAG-9904-038	LAG-9904-039	LAG-9904-040	LAG-9904-041	LAG-9904-042	LAG-9904-043	
Sample Date:	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	
General Chemistry	Units							
Bulk Density	g/cm ³	0.64	0.73	1.0	1.1	0.61	0.53	0.50
Percent Moisture	%	45.9	35.9	34.1	23.1	25.7	27.4	35.0

TABLE 3.1
BULK DENSITY AND MOISTURE CONTENT RESULTS - JULY 2005
OxyChem Pottstown, Pennsylvania

Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS
Boring No:		B-3	B-3	B-3	B-3	B-3	B-3	B-3
Sample Depth:		3-4'	4-5'	5-6'	6-7'	7-8'	8-9'	9-10'
Sample ID:		LAG-9904-044	LAG-9904-045	LAG-9904-046	LAG-9904-047	LAG-9904-048	LAG-9904-049	LAG-9904-050
Sample Date:		7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005
General Chemistry	Units							
Bulk Density	g/cm3	0.52	0.46	0.52	0.56	0.48	0.52	0.56
Percent Moisture	%	36.3	38.9	39.8	40.4	42.4	42.5	46.0
Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS
Boring No:		B-3	B-3	B-3	B-3	B-3	B-3	B-3
Sample Depth:		10-11'	11-12'	12-13'	13-14'	14-15'	15-16'	16-17'
Sample ID:		LAG-9904-051	LAG-9904-052	LAG-9904-053	LAG-9904-054	LAG-9904-055	LAG-9904-056	LAG-9904-057
Sample Date:		7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005
General Chemistry	Units							
Bulk Density	g/cm3	0.58	0.63	0.64	0.55	0.58	0.57	0.74
Percent Moisture	%	45.2	39.8	37.3	43.5	44.1	42.3	36.4
Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS
Boring No:		B-3	B-3	B-3	B-4	B-4	B-4	B-4
Sample Depth:		17-18'	18-19'	19-20'	0-1'	1-2'	2-3'	3-4'
Sample ID:		LAG-9904-058	LAG-9904-059	LAG-9904-060	LAG-9904-061	LAG-9904-062	LAG-9904-063	LAG-9904-064
Sample Date:		7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005
General Chemistry	Units							
Bulk Density	g/cm3	0.57	0.72	0.84	0.67	0.65	0.68	0.78
Percent Moisture	%	46.4	44.7	25.9	30.9	33.8	36.7	33.0
Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS
Boring No:		B-4	B-4	B-4	B-4	B-4	B-4	B-4
Sample Depth:		4-5'	5-6'	6-7'	7-8'	8-9'	9-10'	10-11'
Sample ID:		LAG-9904-065	LAG-9904-066	LAG-9904-067	LAG-9904-068	LAG-9904-069	LAG-9904-070	LAG-9904-071
Sample Date:		7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005
General Chemistry	Units							
Bulk Density	g/cm3	0.80	0.77	0.75	0.73	0.80	0.69	0.71
Percent Moisture	%	34.8	36.1	40.2	37.9	38.8	41.5	41.0
Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS
Boring No:		B-4	B-4	B-4	B-4	B-4	B-4	B-4
Sample Depth:		11-12'	12-13'	13-14'	14-15'	15-16'	16-17'	17-18'
Sample ID:		LAG-9904-072	LAG-9904-073	LAG-9904-074	LAG-9904-075	LAG-9904-076	LAG-9904-077	LAG-9904-078
Sample Date:		7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005
General Chemistry	Units							
Bulk Density	g/cm3	0.65	0.66	0.63	0.58	0.65	0.72	0.65
Percent Moisture	%	40.6	42.3	46.1	48.8	44.9	40.0	44.4
Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS
Boring No:		B-4	B-4	B-4	B-4	B-4	B-5	B-5
Sample Depth:		18-19'	19-20'	20-21'	21-22'	22-23'	0-1'	1-2'
Sample ID:		LAG-9904-079	LAG-9904-080	LAG-9904-081	LAG-9904-082	LAG-9904-083	LAG-9904-084	LAG-9904-085
Sample Date:		7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005
General Chemistry	Units							
Bulk Density	g/cm3	0.24	0.98	1.0	1.1	1.1	0.64	0.58
Percent Moisture	%	43.3	31.9	29.9	31.5	30.0	27.4	31.9

TABLE 3.1
BULK DENSITY AND MOISTURE CONTENT RESULTS - JULY 2005
OxyChem Pottstown, Pennsylvania

Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS
Boring No:		B-5	B-5	B-5	B-5	B-5	B-5	B-5
Sample Depth:		2-3'	3-4'	4-5'	5-6'	6-7'	7-8'	8-9'
Sample ID:		LAG-9904-086	LAG-9904-087	LAG-9904-088	LAG-9904-089	LAG-9904-090	LAG-9904-091	LAG-9904-092
Sample Date:		7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005
General Chemistry	Units							
Bulk Density	g/cm ³	0.55	0.52	0.58	0.48	0.57	0.66	0.55
Percent Moisture	%	32.0	33.3	35.0	34.5	40.2	35.9	31.2
Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS
Boring No:		B-5	B-5	B-5	B-5	B-5	B-5	B-5
Sample Depth:		9-10'	10-11'	11-12'	12-13'	13-14'	14-15'	15-16'
Sample ID:		LAG-9904-093	LAG-9904-094	LAG-9904-095	LAG-9904-096	LAG-9904-097	LAG-9904-098	LAG-9904-099
Sample Date:		7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005
General Chemistry	Units							
Bulk Density	g/cm ³	0.69	0.69	0.59	0.55	0.48	0.57	0.60
Percent Moisture	%	37.4	34.9	36.0	43.4	44.0	46.5	45.0
Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS
Boring No:		B-5	B-5	B-5	B-5	B-5	B-5	B-5
Sample Depth:		16-17'	17-18'	18-19'	19-20'	20-21'	21-22'	22-23'
Sample ID:		LAG-9904-100	LAG-9904-101	LAG-9904-102	LAG-9904-103	LAG-9904-104	LAG-9904-105	LAG-9904-106
Sample Date:		7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005	7/26/2005
General Chemistry	Units							
Bulk Density	g/cm ³	0.58	0.59	0.56	0.59	0.61	0.67	1.0
Percent Moisture	%	30.8	41.7	39.2	43.0	31.3	34.2	27.5
Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS
Boring No:		B-6	B-6	B-6	B-6	B-6	B-6	B-6
Sample Depth:		0-1'	1-2'	2-3'	3-4'	4-5'	5-6'	6-7'
Sample ID:		LAG-9904-108	LAG-9904-109	LAG-9904-110	LAG-9904-111	LAG-9904-112	LAG-9904-113	LAG-9904-114
Sample Date:		7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005
General Chemistry	Units							
Bulk Density	g/cm ³	0.62	0.61	0.64	0.52	0.62	0.62	0.56
Percent Moisture	%	30.7	33.7	32.7	36.3	33.3	34.3	40.7
Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS
Boring No:		B-6	B-6	B-6	B-6	B-6	B-6	B-6
Sample Depth:		7-8'	8-9'	9-10'	10-11'	11-12'	12-13'	14-15'
Sample ID:		LAG-9904-115	LAG-9904-116	LAG-9904-117	LAG-9904-118	LAG-9904-119	LAG-9904-120	LAG-9904-121
Sample Date:		7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005
General Chemistry	Units							
Bulk Density	g/cm ³	0.47	0.51	0.45	0.60	0.46	0.38	0.55
Percent Moisture	%	47.9	40.5	49.5	42.3	53.3	56.3	52.3
Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS
Boring No:		B-6	B-7	B-7	B-7	B-7	B-7	B-7
Sample Depth:		15-16'	0-1'	1-2'	2-3'	3-4'	4-5'	5-6'
Sample ID:		LAG-9904-122	LAG-9904-123	LAG-9904-124	LAG-9904-125	LAG-9904-126	LAG-9904-127	LAG-9904-128
Sample Date:		7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005
General Chemistry	Units							
Bulk Density	g/cm ³	1.5	0.79	0.74	0.80	0.76	0.70	0.97
Percent Moisture	%	18.9	29.9	30.7	38.1	38.7	42.1	30.4

TABLE 3.1
BULK DENSITY AND MOISTURE CONTENT RESULTS - JULY 2005
OxyChem Pottstown, Pennsylvania

Sample Location:	EARTHEN LAGOONS						
Boring No:	B-7	B-7	B-7	B-7	B-7	B-7	B-7
Sample Depth:	6-7'	7-8'	8-9'	9-10'	10-11'	11-12'	12-13'
Sample ID:	LAG-9904-129	LAG-9904-130	LAG-9904-131	LAG-9904-132	LAG-9904-133	LAG-9904-134	LAG-9904-135
Sample Date:	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005
General Chemistry	Units						
Bulk Density	g/cm ³	0.63	0.61	0.59	0.55	0.62	0.58
Percent Moisture	%	46.8	47.8	49.6	53.0	47.0	49.2
Sample Location:	EARTHEN LAGOONS						
Boring No:	B-8	B-8	B-8	B-8	B-8	B-8	B-8
Sample Depth:	13-14'	0-1'	1-2'	2-3'	3-4'	4-5'	5-6'
Sample ID:	LAG-9904-136	LAG-9904-137	LAG-9904-138	LAG-9904-139	LAG-9904-140	LAG-9904-141	LAG-9904-142
Sample Date:	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005
General Chemistry	Units						
Bulk Density	g/cm ³	1.5	0.67	0.70	0.72	0.69	0.67
Percent Moisture	%	20.6	35.0	37.2	38.8	38.5	41.1
Sample Location:	EARTHEN LAGOONS						
Boring No:	B-8	B-8	B-8	B-8	B-8	B-8	B-8
Sample Depth:	6-7'	7-8'	8-9'	9-10'	10-11'	11-12'	12-13'
Sample ID:	LAG-9904-143	LAG-9904-144	LAG-9904-145	LAG-9904-146	LAG-9904-147	LAG-9904-148	LAG-9904-149
Sample Date:	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005
General Chemistry	Units						
Bulk Density	g/cm ³	0.60	0.65	1.3	0.67	0.68	0.64
Percent Moisture	%	46.5	44.5	26.9	42.7	42.4	46.3
Sample Location:	EARTHEN LAGOONS						
Boring No:	B-8	B-8	B-8	B-8	B-8	B-8	B-8
Sample Depth:	13-14'	14-15'	15-16'	16-17'	17-18'	18-19'	19-20'
Sample ID:	LAG-9904-150	LAG-9904-151	LAG-9904-152	LAG-9904-153	LAG-9904-154	LAG-9904-155	LAG-9904-156
Sample Date:	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005
General Chemistry	Units						
Bulk Density	g/cm ³	0.56	0.60	0.57	0.60	0.47	1.1
Percent Moisture	%	51.2	47.5	50.5	49.3	58.8	26.8
Sample Location:	EARTHEN LAGOONS						
Boring No:	B-9	B-9	B-9	B-9	B-9	B-9	B-9
Sample Depth:	0-1'	1-2'	2-3'	3-4'	4-5'	5-6'	6-7'
Sample ID:	LAG-9904-157	LAG-9904-158	LAG-9904-159	LAG-9904-160	LAG-9904-161	LAG-9904-162	LAG-9904-163
Sample Date:	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005
General Chemistry	Units						
Bulk Density	g/cm ³	0.63	0.71	0.65	1.1	0.61	0.57
Percent Moisture	%	30.6	28.9	33.7	28.7	35.5	38.8
Sample Location:	EARTHEN LAGOONS						
Boring No:	B-9	B-9	B-9	B-9	B-9	B-9	B-9
Sample Depth:	7-8'	8-9'	9-10'	10-11'	11-12'	12-13'	13-14'
Sample ID:	LAG-9904-164	LAG-9904-165	LAG-9904-166	LAG-9904-167	LAG-9904-168	LAG-9904-169	LAG-9904-170
Sample Date:	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005
General Chemistry	Units						
Bulk Density	g/cm ³	0.57	0.64	0.49	1.3	0.49	0.60
Percent Moisture	%	45.4	44.4	48.7	18.0	50.9	45.4

**TABLE 3.1
BULK DENSITY AND MOISTURE CONTENT RESULTS - JULY 2005
OxyChem Pottstown, Pennsylvania**

Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS
Boring No:		B-9	B-9	B-9	B-9	B-9	B-9	B-10
Sample Depth:		14-15'	15-16'	16-17'	17-18'	18-19'	19-20'	0-1'
Sample ID:		LAG-9904-171	LAG-9904-172	LAG-9904-173	LAG-9904-174	LAG-9904-175	LAG-9904-176	LAG-9904-177
Sample Date:		7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005
General Chemistry	Units							
Bulk Density	g/cm3	1.3	1.2	0.47	1.1	1.2	1.1	0.59
Percent Moisture	%	17.6	25.9	51.5	32.5	27.2	28.8	37.0
Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS
Boring No:		B-10	B-10	B-10	B-10	B-10	B-10	B-10
Sample Depth:		1-2'	2-3'	3-4'	4-5'	5-6'	6-7'	7-8'
Sample ID:		LAG-9904-178	LAG-9904-179	LAG-9904-180	LAG-9904-181	LAG-9904-182	LAG-9904-183	LAG-9904-184
Sample Date:		7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005
General Chemistry	Units							
Bulk Density	g/cm3	0.61	0.60	0.64	0.66	0.68	0.50	0.50
Percent Moisture	%	37.0	38.2	39.0	39.1	38.8	47.4	48.5
Sample Location:		EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	EARTHEN LAGOONS	
Boring No:		B-10	B-10	B-10	B-10	B-10	B-10	
Sample Depth:		8-9'	9-10'	10-11'	12-13'	13-14'	14-15'	
Sample ID:		LAG-9904-185	LAG-9904-186	LAG-9904-188	LAG-9904-189	LAG-9904-190	LAG-9904-191	
Sample Date:		7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	7/27/2005	
General Chemistry	Units							
Bulk Density	g/cm3	0.57	0.50	0.49	0.47	0.52	0.52	
Percent Moisture	%	45.7	49.2	46.4	49.9	49.7	55.5	
Sample Location:								
Boring No:								
Sample Depth:								
Sample ID:								
Sample Date:								
General Chemistry	Units							
Bulk Density	g/cm3							
Percent Moisture	%							
Sample Location:								
Boring No:								
Sample Depth:								
Sample ID:								
Sample Date:								
General Chemistry	Units							
Bulk Density	g/cm3							
Percent Moisture	%							
Sample Location:								
Boring No:								
Sample Depth:								
Sample ID:								
Sample Date:								
General Chemistry	Units							
Bulk Density	g/cm3							
Percent Moisture	%							

TABLE 3.2
ANALYTICAL RESULTS SUMMARY - JULY 2005
OxyChem Pottstown, Pennsylvania

Sample Location: Sample ID: Sample Date:		EARTHEN LAGOONS LAG-9904-107 7/26/2005	EARTHEN LAGOONS LAG-9904-192 7/27/2005
Parameters	Units		
Volatile Organic Compounds			
1,1,1-Trichloroethane	mg/kg	0.17 U	0.18 U
1,1,2,2-Tetrachloroethane	mg/kg	0.17 U	0.18 U
1,1,2-Trichloroethane	mg/kg	0.17 U	0.18 U
1,1-Dichloroethane	mg/kg	0.17 U	0.18 U
1,1-Dichloroethene	mg/kg	0.17 U	0.18 U
1,2,4-Trichlorobenzene	mg/kg	0.17 U	0.18 U
1,2-Dibromo-3-chloropropane (DBCP)	mg/kg	0.17 U	0.18 U
1,2-Dibromoethane (Ethylene Dibromide)	mg/kg	0.17 U	0.18 U
1,2-Dichlorobenzene	mg/kg	0.17 U	0.18 U
1,2-Dichloroethane	mg/kg	0.17 U	0.046 J
1,2-Dichloropropane	mg/kg	0.17 U	0.18 U
1,3-Dichlorobenzene	mg/kg	0.17 U	0.18 U
1,4-Dichlorobenzene	mg/kg	0.17 U	0.18 U
2-Butanone (Methyl Ethyl Ketone)	mg/kg	0.17 U	0.18 U
2-Hexanone	mg/kg	0.17 U	0.18 U
4-Methyl-2-Pentanone (Methyl Isobutyl Ketone)	mg/kg	0.17 U	0.18 U
Acetone	mg/kg	0.17 U	0.18 U
Benzene	mg/kg	0.17 U	0.18 U
Bromodichloromethane	mg/kg	0.17 U	0.18 U
Bromoform	mg/kg	0.17 U	0.18 U
Bromomethane (Methyl Bromide)	mg/kg	0.17 U	0.18 U
Carbon disulfide	mg/kg	0.17 U	0.056 J
Carbon tetrachloride	mg/kg	0.17 U	0.18 U
Chlorobenzene	mg/kg	0.17 U	0.18 U
Chloroethane	mg/kg	0.17 U	0.18 U
Chloroform (Trichloromethane)	mg/kg	0.17 U	0.18 U
Chloromethane (Methyl Chloride)	mg/kg	0.17 U	0.18 U
cis-1,2-Dichloroethene	mg/kg	1.4	180 D
cis-1,3-Dichloropropene	mg/kg	0.17 U	0.18 U
Cyclohexane	mg/kg	0.17 U	0.18 U
Dibromochloromethane	mg/kg	0.17 U	0.18 U
Dichlorodifluoromethane (CFC-12)	mg/kg	0.17 U	0.18 U
Ethylbenzene	mg/kg	0.54	0.55
Isopropylbenzene	mg/kg	0.17 U	0.18 U
Methyl acetate	mg/kg	0.17 U	0.18 U
Methyl cyclohexane	mg/kg	0.17 U	0.18 U
Methyl Tert Butyl Ether	mg/kg	0.17 U	0.18 U
Methylene chloride	mg/kg	0.2 B	0.21 B
Styrene	mg/kg	0.17 U	0.28
Tetrachloroethene	mg/kg	0.17 U	0.18 U
Toluene	mg/kg	0.068 J	0.078 J
trans-1,2-Dichloroethene	mg/kg	0.14 J	0.32
trans-1,3-Dichloropropene	mg/kg	0.17 U	0.18 U
Trichloroethene	mg/kg	0.23	0.78
Trichlorofluoromethane (CFC-11)	mg/kg	0.17 U	0.18 U
Trifluorotrchloroethane (Freon 113)	mg/kg	0.17 U	0.18 U
Vinyl chloride	mg/kg	1.4	99 D
Xylene (total)	mg/kg	0.17 U	0.18 U

TABLE 3.2
ANALYTICAL RESULTS SUMMARY - JULY 2005
OxyChem Pottstown, Pennsylvania

Sample Location: Sample ID: Sample Date:		EARTHEN LAGOONS LAG-9904-107 7/26/2005	EARTHEN LAGOONS LAG-9904-192 7/27/2005
Parameters	Units		
Semi-volatile Organic Compounds			
2,2'-oxybis(1-Chloropropane) (bis(2-chloroiso	mg/kg	5.5 U	2.9 U
2,4,5-Trichlorophenol	mg/kg	14 U	7.4 U
2,4,6-Trichlorophenol	mg/kg	5.5 U	2.9 U
2,4-Dichlorophenol	mg/kg	5.5 U	2.9 U
2,4-Dimethylphenol	mg/kg	5.5 U	2.9 U
2,4-Dinitrophenol	mg/kg	14 U	7.4 U
2,4-Dinitrotoluene	mg/kg	5.5 U	2.9 U
2,6-Dinitrotoluene	mg/kg	5.5 U	2.9 U
2-Chloronaphthalene	mg/kg	5.5 U	2.9 U
2-Chlorophenol	mg/kg	5.5 U	2.9 U
2-Methylnaphthalene	mg/kg	5.5 U	2.9 U
2-Methylphenol	mg/kg	5.5 U	2.9 U
2-Nitroaniline	mg/kg	14 U	7.4 U
2-Nitrophenol	mg/kg	5.5 U	2.9 U
3,3'-Dichlorobenzidine	mg/kg	5.5 U	2.9 U
3-Nitroaniline	mg/kg	14 U	7.4 U
4,6-Dinitro-2-methylphenol	mg/kg	14 U	7.4 U
4-Bromophenyl phenyl ether	mg/kg	5.5 U	2.9 U
4-Chloro-3-methylphenol	mg/kg	5.5 U	2.9 U
4-Chloroaniline	mg/kg	5.5 U	2.9 U
4-Chlorophenyl phenyl ether	mg/kg	5.5 U	2.9 U
4-Methylphenol	mg/kg	5.5 U	2.9 U
4-Nitroaniline	mg/kg	14 U	7.4 U
4-Nitrophenol	mg/kg	14 U	7.4 U
Acenaphthene	mg/kg	5.5 U	2.9 U
Acenaphthylene	mg/kg	5.5 U	2.9 U
Acetophenone	mg/kg	10	2.9 U
Anthracene	mg/kg	5.5 U	2.9 U
Atrazine	mg/kg	5.5 U	2.9 U
Benzaldehyde	mg/kg	5.5 U	2.9 U
Benzo(a)anthracene	mg/kg	5.5 U	2.9 U
Benzo(a)pyrene	mg/kg	5.5 U	2.9 U
Benzo(b)fluoranthene	mg/kg	5.5 U	2.9 U
Benzo(g,h,i)perylene	mg/kg	5.5 U	2.9 U
Benzo(k)fluoranthene	mg/kg	5.5 U	2.9 U
Biphenyl	mg/kg	5.5 U	2.9 U
bis(2-Chloroethoxy)methane	mg/kg	5.5 U	2.9 U
bis(2-Chloroethyl)ether	mg/kg	5.5 U	2.9 U
bis(2-Ethylhexyl)phthalate	mg/kg	40	47 D
Butyl benzylphthalate	mg/kg	5.5 U	2.9 U
Caprolactam	mg/kg	5.5 U	2.9 U
Carbazole	mg/kg	5.5 U	2.9 U
Chrysene	mg/kg	5.5 U	2.9 U
Dibenz(a,h)anthracene	mg/kg	5.5 U	2.9 U
Dibenzofuran	mg/kg	5.5 U	2.9 U
Diethyl phthalate	mg/kg	5.5 U	2.9 U
Dimethyl phthalate	mg/kg	5.5 U	2.9 U
Di-n-butylphthalate	mg/kg	5.5 U	0.81 J
Di-n-octyl phthalate	mg/kg	5.5 U	2.9 U
Fluoranthene	mg/kg	5.5 U	2.9 U
Fluorene	mg/kg	5.5 U	2.9 U
Hexachlorobenzene	mg/kg	5.5 U	2.9 U
Hexachlorobutadiene	mg/kg	5.5 U	2.9 U
Hexachlorocyclopentadiene	mg/kg	5.5 U	2.9 U
Hexachloroethane	mg/kg	5.5 U	2.9 U
Indeno(1,2,3-cd)pyrene	mg/kg	5.5 U	2.9 U
Isophorone	mg/kg	5.5 U	2.9 U
Naphthalene	mg/kg	5.5 U	2.9 U
Nitrobenzene	mg/kg	5.5 U	2.9 U
N-Nitrosodi-n-propylamine	mg/kg	5.5 U	2.9 U
N-Nitrosodiphenylamine	mg/kg	5.5 U	2.9 U
Pentachlorophenol	mg/kg	14 U	7.4 U
Phenanthrene	mg/kg	5.5 U	2.9 U
Phenol	mg/kg	5.5 U	2.9 U
Pyrene	mg/kg	5.5 U	2.9 U

TABLE 3.2
ANALYTICAL RESULTS SUMMARY - JULY 2005
OxyChem Pottstown, Pennsylvania

Sample Location: Sample ID: Sample Date:		EARTHEN LAGOONS LAG-9904-107 7/26/2005	EARTHEN LAGOONS LAG-9904-192 7/27/2005
Parameters	Units		
Metals			
Aluminum	mg/kg	3470 E	9140 E
Antimony	mg/kg	0.55 UN	0.58 UN
Arsenic	mg/kg	0.94 U	1.0 U
Barium	mg/kg	13.9 BE	32.3 BE
Beryllium	mg/kg	2.8 U	3.0 U
Cadmium	mg/kg	0.34 B	1.9
Calcium	mg/kg	8490 E	15400 E
Chromium Total	mg/kg	54.9 E	54.9 E
Cobalt	mg/kg	2.3 B	3.7 B
Copper	mg/kg	14.1 E	12.5 E
Iron	mg/kg	6430 E	10200 E
Lead	mg/kg	10.3 E	55.4 E
Magnesium	mg/kg	1350 E	2110 E
Manganese	mg/kg	107 E	114 E
Mercury	mg/kg	0.11	0.21
Nickel	mg/kg	4.3 B	7.5
Potassium	mg/kg	73.0 BE	289 BE
Selenium	mg/kg	0.89 U	0.95 U
Silver	mg/kg	0.60 U	0.64 U
Sodium	mg/kg	53.5 B	76.4 B
Thallium	mg/kg	0.83 U	0.89 U
Vanadium	mg/kg	4.3 B	9.2
Zinc	mg/kg	45.2 E	49.2 E
General Chemistry			
Free Liquid	mL	0.1 U	0.1 U
Ignitability	Deg C	60 U	60 U
Percent Moisture	%	40.0	43.7
pH (water)	pH Units	7.6	7.7
Reactive Cyanide	mg/kg	100 U	100 U
Reactive Sulfide	mg/kg	100 U	1580
Total Organic Carbon (TOC)	mg/kg	360000	316000

Notes:

- B - Analyte was found in associated blank.
- B - (Metals) Reported value is less than the CRD limit but greater than the IDL.
- BE - (Metals) Reported value is less than the CRD limit but greater than the IDL.
- Estimated due to the presence of interference.
- D - Compounds at secondary dilution factor.
- E - Estimated due to the presence of interference
- J - Estimated value.
- U - Analyte was analyzed but not detected.
- UN - Analyte was analyzed but not detected.
- Sample recovery not within control limits.

TABLE 3.3
TCLP ANALYTICAL RESULTS SUMMARY - JULY 2005
OxyChem Pottstown, Pennsylvania

<i>Sample Location:</i>	EARTHEN LAGOONS		EARTHEN LAGOONS
<i>Sample ID:</i>	LAG-9904-107		LAG-9904-192
<i>Sample Date:</i>	7/26/2005		7/27/2005
Parameters	Units		
Volatile Organic Compounds TCLP			
1,1-Dichloroethene	ug/L	10 U	10 U
1,2-Dichloroethane	ug/L	5 J	2 J
2-Butanone (Methyl Ethyl Ketone)	ug/L	10 U	4 J
Benzene	ug/L	10 U	10 U
Carbon tetrachloride	ug/L	10 U	10 U
Chlorobenzene	ug/L	10 U	10 U
Chloroform (Trichloromethane)	ug/L	10 U	10 U
Tetrachloroethene	ug/L	10 U	10 U
Trichloroethene	ug/L	6 J	9 J
Vinyl chloride	ug/L	41	3100 D
Semi-volatile Organic Compounds TCLP			
1,4-Dichlorobenzene	ug/L	10 U	10 U
2,4,5-Trichlorophenol	ug/L	25 U	25 U
2,4,6-Trichlorophenol	ug/L	10 U	10 U
2,4-Dinitrotoluene	ug/L	10 U	10 U
2-Methylphenol	ug/L	10 U	10 U
3&4-Methylphenol	ug/L	10 U	10 U
Hexachlorobenzene	ug/L	10 U	10 U
Hexachlorobutadiene	ug/L	10 U	10 U
Hexachloroethane	ug/L	10 U	10 U
Nitrobenzene	ug/L	10 U	10 U
Pentachlorophenol	ug/L	25 U	25 U
Pyridine	ug/L	10 U	10 U
Metals TCLP			
Arsenic	ug/L	10.6	12.9
Barium	ug/L	460	386
Cadmium	ug/L	4.2 B	0.37 U
Chromium Total	ug/L	14.7	6.4 B
Lead	ug/L	10.2	2.4 B
Mercury	ug/L	0.10 U	0.10 U
Selenium	ug/L	9.5	10.1
Silver	ug/L	10.7 UN	10.7 UN
Notes:			
B - Reported value is less than the CRD limit but greater than the IDL.			
D - Compounds at secondary dilution factors.			
J - Estimated value.			
U - Analyte was analyzed but not detected.			
UN - Analyte was analyzed but not detected. Sample recovery not within control limits.			

TABLE 3.4
SUMMARY OF MAXIMUM PVC MATERIAL CONCENTRATIONS
OxyChem Pottstown, Pennsylvania

Parameter	Units	Maximum PVC Material Concentration 1993	Maximum PVC Material Concentration 2001	Maximum PVC Material Concentration 2005
Volatiles				
1,2-Dichloroethane	mg/Kg	0.32	2.5	0.046 J
1,2-Dichloroethene (total)	mg/Kg	4.8 J	241.9	180.32
2-Butanone	mg/Kg	0.027 J	ND	ND
Acetone	mg/Kg	1.2 J	12	ND
Benzene	mg/Kg	0.2 J	ND	ND
Carbon disulfide	mg/Kg	2.3	ND	0.056 J
Methylene chloride	mg/Kg	1.1	0.004	0.21 B
Styrene	mg/Kg	2.1 J	34	0.28
Tetrachloroethene	mg/Kg	0.85	0.19	ND
Toluene	mg/Kg	1.6 J	130	0.78 J
Total Xylene	mg/Kg	7 J	0.16	ND
Trichloroethene	mg/Kg	0.94 J	17	0.78
Vinyl chloride	mg/Kg	1.7	560	99
Semi-Volatiles				
Benzoic Acid*	mg/Kg	31 J	31	ND
2-Methyl naphthalene	mg/Kg	0.088 J	38	ND
Acenaphthylene	mg/Kg	0.10 J	ND	ND
Benzo(a)anthracene	mg/Kg	0.27 J	ND	ND
Benzo(a)pyrene	mg/Kg	0.22 J	ND	ND
Benzo(b)fluoranthene	mg/Kg	0.23 J	ND	ND
Benzo(k)fluoranthene	mg/Kg	0.13 J	ND	ND
bis(2-Ethylhexyl)phthalate	mg/Kg	280 J	7,500	47
Chrysene	mg/Kg	0.36 J	ND	ND
Di-n-butylphthalate	mg/Kg	1.6 J	48	0.81 J
Diethyl phthalate	mg/Kg	0.092 J	ND	ND
Fluoranthene	mg/Kg	0.23 J	ND	ND
Naphthalene	mg/Kg	3.8 J	17	ND
Phenanthrene	mg/Kg	0.70 J	6.5	ND
Pyrene	mg/Kg	0.33 J	ND	ND
Metals				
Aluminum	mg/Kg	34,000	831	9,140
Antimony	mg/Kg	30	2	0.58
Arsenic	mg/Kg	27	1.1	ND
Barium	mg/Kg	430 J	4	32.3 B
Beryllium	mg/Kg	2.2	0.1	ND
Cadmium	mg/Kg	3.3	0	1.9
Calcium	mg/Kg	23,000	1,020	15,400
Chromium	mg/Kg	130 J	20	54.9
Cobalt	mg/Kg	36 J	1.0	3.7 B
Copper	mg/Kg	61	6	12.5
Iron	mg/Kg	49,000	1,030	10,200
Lead	mg/Kg	120	2	55.4
Magnesium	mg/Kg	3,900	362	2,110
Manganese	mg/Kg	2,800 J	16	114
Mercury	mg/Kg	0.59	0.1	0.21
Nickel	mg/Kg	39	2	7.5
Potassium	mg/Kg	3,200	21	289
Selenium	mg/Kg	0.95	1.1	ND
Silver	mg/Kg	1.1	-	ND
Sodium	mg/Kg	400	22	76.4 B
Vanadium	mg/Kg	49	1.3	9.2
Zinc	mg/Kg	170	15	49.2

NOTES:

ND- Non detect.

B - Not detected substantially above the level reported in the laboratory or field blanks.

J - Estimated.

APPENDICES

APPENDIX A

DIOXIN RESULTS FROM
EPA SAMPLES - EPA LETTER DATED MAY 7, 2004



**UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029**

May 07, 2004

David P. Steele
Director, Operations
2480 Fortune Dr., Ste 300
Lexington, KY 40509

Dear Mr. Steele:

Enclosed please find the results of the dioxin sampling conducted in the PVC sludge in the lagoons at the Occidental Chemical Superfund Site on December 8 & 9, 2003. The data is submitted in 2,378-Toxicity Equivalents (TEQs). The data is presented in two sets, one which calculated the TEQs using the 1989 Interim Scheme and the other one using the latest WHO 1999 Scheme. Results show that levels of dioxin ranged from 121 to 900 parts per trillion (ppt) using the 1989 Interim Scheme and from 81 to 534 ppt using the WHO 1999 Scheme.

I submitted these data to the EPA toxicologist for an evaluation to determine if the results represented a risk. According to her evaluation, these levels are below the current preliminary remediation goal for dioxin of 1,000 ppt for residential areas and 5,000 to 20,000 ppt for industrial areas established by EPA in 1998 (OSWER Directive 9200.4.4-26). In addition, the evaluation included the calculated cancer risk for the levels of dioxin detected for an industrial exposure scenario and a residential exposure scenario. The calculated cancer risk for an industrial exposure scenario was 5E-05 and for a residential exposure scenario was 2E-04. These levels are within the Superfund acceptable cancer risk range of 1E-06 to 1E-04 for an industrial area and at the higher end of the range for a residential area when compared to the residential risk-based concentration of 430 ppt at 1E-04.

If you have any questions about the data or the toxicologist assessment, please call me at 215-814-3199 or e-mail me at garcia.maria@epa.gov.



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Customer Service Hotline: 1-800-438-2474*

Sincerely,



Maria de los A. Garcia
Remedial Project Manager

cc: Anthony Dappolone, EPA
Dave Minsker, PADEP
Wendy Jastremski, EPA
Nancy Rios-Jafolla, EPA
Robert Hasson, EPA

DATA SUMMARY FORM: PCDDs & PCDFs
Water Samples (pg/L)

Case #: R31737

SDG R3173701

Number of Water Samples: 2

Site: Occidental Chemical Corporation/Firestone Tire and Rubber

Lab: SWRI

Sample Number	Sampling Location: Prefix of OXY- Field QC	Date Sampled	Time Sampled	Dilution Factor	Analyte / TEF	R3173701			R3173702								
						CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q
						EQ01-1203	FB01-1203										
						Rinse Blank	Field Blank										
						12/9/03	12/9/03										
						09:25	15:20										
						1.0	1.0										
						CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q
2378-TCDD (1.0)		4					0			0			0				0
12378-PeCDD (1.0)		10					0			0			0				0
123478-HxCDD (0.10)		10					0			0			0				0
123678-HxCDD (0.10)		10				0.47	0.047	J		0			0				0
123789-HxCDD (0.10)		10					0			0			0				0
1234678-HpCDD (0.01)		10				4.48	0.045	J		0			0				0
12346789-OCDD (0.0001)		20				47.8	0.000	B	2.72	0	B		0				0
2378-TCDF (0.1)		4					0		0.13	0	B		0				0
12378-PeCDF (0.05)		10					0			0			0				0
23478-PeCDF (0.50)		10					0			0			0				0
123478-HxCDF (0.10)		10					0			0			0				0
123678-HxCDF (0.10)		10					0			0			0				0
123789-HxCDF (0.10)		10					0			0			0				0
234678-HxCDF (0.10)		10					0			0			0				0
1234678-HpCDF (0.01)		10					0		0.40	0.0040			0				0
1234789-HpCDF (0.01)		10					0			0			0				0
12346789-OCDF (0.0001)		20					0			0			0				0
Other TCDD																	
Other PeCDD																	
Other HxCDD																	
Other HpCDD																	
Other TCDF																	
Other PeCDF																	
Other HxCDF																	
Other HpCDF																	
TOTAL TEQ							0.092			0.0040			0		0		0

TEQs are based on I-TEF/EF Scheme

DATA SUMMARY FORM: PCDDs & PCDFs
Soil Samples (pg/g)

Case #: R31737 SDG R3173701
Site: Occidental Chemical Corporation/Firestone Tire and Rubber

Number of Soil Samples 16
Lab: SWRI

Sample Number		R3173703			R3173704			R3173705			R3173706			R3173707		
Sampling Location: Prefix of OXY-		SB-NE10(6-24)			SB-NE7(6-24)			SB-NE8(6-24)			SB-NE9(6-24)			SB-SE10(6-24)		
Field QC																
Date Sampled		12/9/03			12/9/03			12/9/03			12/9/03			12/9/03		
Time Sampled		13:45			10:45			11:15			13:10			16:15		
% Solids		83.7			83.4			78.4			81.6			77.0		
Dilution Factor		1.98/19.8			1.98/19.8			1.98/19.8			1.97/19.7			1.97/19.7		
Analyte / TEF	QL	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q
2378-TCDD (1.0)	0.8	9.81	9.81	J	13.1	13.1	J	5.68	5.68	J	6.75	6.75	J	7.39	7.39	J
12378-PeCDD (1.0)	2	22.0	22.0		22.2	22.2		17.0	17.0	J	18.7	18.7	J	12.7	12.7	J
123478-HxCDD (0.10)	2	33.5	3.35		38.5	3.85		35.6	3.56	J	28.1	2.81	J	22.8	2.28	J
123678-HxCDD (0.10)	2	233	23.3		272	27.2		205	20.5	J	171	17.1	J	137	13.7	J
123789-HxCDD (0.10)	2	99.3	9.93		84.8	8.48		82.3	8.23	J	78.3	7.83	J	50.8	5.08	J
1234878-HpCDD (0.01)	2	3600	36.0	+	9540	95.4	+	11300	113	J+	9480	94.8	+	9400	94.0	J+
12348789-OCDD (0.0001)	4	40500	4.05	J+	113000	11.3	J+	145000	14.5	J+	127000	12.7	J+	105000	10.5	J+
2378-TCDF (0.1)	0.8		0	UJ	3.08	0.31	J	3.29	0.33	J	2.27	0.23	J		0	UJ
12378-PeCDF (0.05)	2		0		5.43	0.27		2.93	0.15	J	8.27	0.31			0	UJ
23478-PeCDF (0.50)	2	5.10	2.56		6.31	3.16		4.53	2.27	J	7.00	3.50			0	UJ
123478-HxCDF (0.10)	2	27.9	2.79		34.8	3.48		41.1	4.11	J	28.7	2.87		18.8	1.88	J
123678-HxCDF (0.10)	2	18.4	1.84		17.5	1.75		17.7	1.77	J	19.8	1.98		8.78	0.88	J
123789-HxCDF (0.10)	2		0			0			0	UJ	0.96	0.096	J		0	UJ
234678-HxCDF (0.10)	2	17.4	1.74		44.7	4.47		21.3	2.13	J	13.8	1.38		5.28	0.53	J
1234878-HpCDF (0.01)	2	500	5.00		542	5.42		488	4.88	J	435	4.35		282	2.82	J
1234789-HpCDF (0.01)	2	118	1.18		132	1.32		90.3	0.90	J	83.2	0.83		48.7	0.49	J
12348789-OCDF (0.0001)	4	1150	0.12		1470	0.15		1100	0.11	J	1130	0.11		684	0.068	J
Other TCDD																
Other PeCDD																
Other HxCDD																
Other HpCDD																
Other TCDF																
Other PeCDF																
Other HxCDF																
Other HpCDF																
TOTAL TEQ			123.8			203.0			198.9			176.3			152.2	

- = Result Reported from diluted analysis.
TEQs are based on 1-TEF/89 Scheme.

DATA SUMMARY FORM: PCDDs & PCDFs
Soil Samples (pg/g)

Case #: R31737

SDG: R3173701

Number of Soil Samples: 18

Site: Occidental Chemical Corporation/Pirestone Tire and Rubber

Lab: SWRI

Sample Number	R3173708			R3173709			R3173710			R3173711			R3173712			
Sampling Location - Prefix of OXY- Field QC	SB-SE7(6-24)			SB-SE8(6-24)			SB-SE9(6-24)			SS-NE10(0-8)			SS-NE7(0-8)			
Date Sampled	12/9/03			12/9/03			12/9/03			12/8/03			12/8/03			
Time Sampled	14:25			15:00			15:40			14:35			14:10			
%Solids	73.8			77.1			79.3			76.1			82.7			
Dilution Factor	1.98/19.8			1.98/19.8			1.98/19.8			1.98/39.2			1.98/19.9			
Analysis / TEF	QL	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q
2378-TCDD (1.0)	0.8	7.79	7.79		7.74	7.74		5.55	5.55	J	19.7	19.7	J	8.45	8.45	J
12378-PeCDD (1.0)	2	14.0	14.0		12.8	12.8		10.1	10.1		28.7	28.7		10.3	10.3	J
123478-HxCDD (0.10)	2	21.8	2.18		23.3	2.33		26.9	2.69		54.4	5.44		25.9	2.59	J
123678-HxCDD (0.10)	2	142	14.2		147	14.7		138	13.8		331	33.1		160	16.0	J
123789-HxCDD (0.10)	2	58.7	5.87		58.8	5.88		62.6	6.26		126	12.6		58.8	5.88	J
1234878-HpCDD (0.01)	2	5500	55.0	+	10100	101	+	10800	108	+	36600	366	+	11800	118	J+
12348789-OCDD (0.0001)	4	83800	8.38	J+	111000	11.1	J+	78900	7.89	J+	421000	42.1	J+	85900	8.59	J+
2378-TCDF (0.1)	0.8	2.20	0.22	J		0			0	UJ	2.20	0.22	J		0	UJ
12378-PeCDF (0.05)	2	2.09	0.10	J		0			0		5.03	0.25	J	1.85	0.10	J
23478-PeCDF (0.50)	2	4.19	2.10	J	3.42	1.71	J		0		7.38	3.69			0	UJ
123478-HxCDF (0.10)	2	26.8	2.68		25.5	2.55		18.3	1.83		65.2	6.52		30.7	3.07	J
123678-HxCDF (0.10)	2	12.5	1.25		12.4	1.24			0		30.4	3.04		10.5	1.05	J
123789-HxCDF (0.10)	2	0.88	0.09	J		0			0			0			0	UJ
234878-HxCDF (0.10)	2	33.7	3.37		8.86	0.99		8.07	0.61		23.0	2.30		10.6	1.06	J
1234878-HpCDF (0.01)	2	287	2.97		382	3.82		275	2.75		804	8.04		321	3.21	J
1234789-HpCDF (0.01)	2	50.4	0.50		70.7	0.71		45.9	0.46		183	1.83		55.8	0.56	J
12348789-OCDF (0.0001)	4	863	0.086		1310	0.13		928	0.093		2310	0.23		1070	0.11	J
Other TCDD																
Other PeCDD																
Other HxCDD																
Other HpCDD																
Other TCDF																
Other PeCDF																
Other HxCDF																
Other HpCDF																
TOTAL TEQ			118.5			165.1			158.1			533.8			179.1	

+ = Result Reported from diluted analysis.
 TEQs are based on I-TEF/89 Scheme

DATA SUMMARY FORM: PCDDs & PCDFs
Soil Samples (pg/g)

Case #: R31737

SDG: R3173701

Number of Soil Samples: 18

Site: Occidental Chemical Corporation/Firestone Tire and Rubber

Lab: SWRI

Sample Number	R3173713			R3173714			R3173715			R3173716			R3173717			
	SS-NE8(0-8)			SS-NE8(0-6)			SS-SE10(0-6)	Dup. of R3173717		SS-SE11(0-6)	Dup. of R3173720		SS-SE12(0-6)	Dup. of R3173715		
Sampling Location: Prefix of OXY-Field QC																
Date Sampled:	12/8/03			12/8/03			12/8/03			12/8/03			12/8/03			
Time Sampled:	14:15			14:30			10:00			11:00			11:15			
%Solids	76.6			79.0			72.1			73.7			72.9			
Dilution Factor	1.96/19.6			1.97/19.7			1.97/19.7			1.97/19.7			1.99/19.9			
Analysis / TEF	QL	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q
2378-TCDD (1.0)	0.8	6.81	6.81		9.28	9.28		5.49	5.49		0	UJ		2.18	2.18	J
12378-PeCDD (1.0)	2	12.6	12.6		11.6	11.6		8.07	8.07		10.8	10.6		8.85	8.85	
123478-HxCDD (0.10)	2	21.2	2.12		21.1	2.11		22.0	2.20		20.0	2.00		20.8	2.08	
123678-HxCDD (0.10)	2	14.9	14.9		13.7	13.7		11.5	11.5		10.1	10.1		10.1	10.1	
123789-HxCDD (0.10)	2	55.7	5.57		60.2	6.02		55.6	5.56		52.3	5.23		36.8	3.68	
1234678-HpCDD (0.01)	2	7160	71.6	+	7830	78.3	+	5530	55.3	+	6260	62.6	+	7290	72.9	+
12346789-OCDD (0.0001)	4	77400	7.74	J+	88000	8.80	J+	55700	5.57	J+	65000	6.50	J+	68700	6.87	J+
2378-TCDF (0.1)	0.8	3.37	0.34		2.78	0.28	J	1.29	0.13	J						J
12378-PeCDF (0.05)	2	4.30	0.22	J		0			0		0.95	0.048	J		0	
23478-PeCDF (0.50)	2	5.50	2.75			0		2.40	1.20	J		0		1.90	0.95	J
123478-HxCDF (0.10)	2	33.7	3.37		25.0	2.50		11.6	1.16		10.8	1.08		10.4	1.04	
123678-HxCDF (0.10)	2	12.0	1.20		11.0	1.10		8.58	0.86		8.87	0.89		5.89	0.59	
123789-HxCDF (0.10)	2		0			0		0.62	0.062	J	1.00	0.10	J		0	
234678-HxCDF (0.10)	2	9.82	0.98		8.88	0.89		7.58	0.76			0			0	
1234678-HpCDF (0.01)	2	295	2.95		361	3.61		171	1.71		185	1.85		177	1.77	
1234789-HpCDF (0.01)	2	59.8	0.60		65.2	0.65		32.6	0.33		33.2	0.33		27.0	0.27	
12346789-OCDF (0.0001)	4	768	0.077		997	0.10		421	0.042		606	0.051		406	0.041	
Other TCDD																
Other PeCDD																
Other HxCDD																
Other HpCDD																
Other TCDF																
Other PeCDF																
Other HxCDF																
Other HpCDF																
TOTAL TEQ																
			133.6			138.1			99.9			121.7			111.5	

+ = Result Reported from diluted analysis.
 TEQs are based on I-TEF/89 Scheme.

DATA SUMMARY FORM: PCDDs & PCDFs
Soil Samples (pg/g)

Case #: R31737

SDG R3173701

Number of Soil Samples: 18

Site: Occidental Chemical Corporation/Firestone Tire and Rubber

Lab: SWRI

Sample Number	R3173718	R3173719	R3173720													
Sampling Location: Prefix of OXY-	SS-SE7(0-8)	SS-SE8(0-6)	SS-SE9(0-6)													
Field QC			Dup. of R3173718													
Date Sampled	12/8/03	12/8/03	12/8/03													
Time Sampled	14:50	15:00	09:50													
%Solids	74.3	70.8	72.9													
Dilution Factor	1.98/19.8	1.98/19.8	1.98/19.8													
Analysis / TEF	QL	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q
2378-TCDD (1.0)	0.8		0		5.07	5.07		3.43	3.43	J		0			0	
12378-PeCDD (1.0)	2	8.06	8.06		10.2	10.2		6.76	6.76			0			0	
123478-HxCDD (0.10)	2	25.6	2.56		28.7	2.87		17.7	1.77			0			0	
123678-HxCDD (0.10)	2	155	15.5		132	13.2		88.6	8.66			0			0	
123789-HxCDD (0.10)	2	57.6	5.76		82.6	8.26		34.4	3.44			0			0	
1234878-HpCDD (0.01)	2	4480	44.8	+	7120	71.2	+	4710	47.1	-		0			0	
12346789-OCDD (0.0001)	4	41000	4.10	J+	69300	6.93	J+	50500	5.05	J+		0			0	
2378-TCDF (0.1)	0.8		0	UJ		0			0	UJ		0			0	
12378-PeCDF (0.05)	2	1.45	0.07	J	2.17	0.11	J	1.45	0.07	J		0			0	
23478-PeCDF (0.50)	2	2.80	1.30	J	2.88	1.44	J		0			0			0	
123478-HxCDF (0.10)	2	13.4	1.34		14.8	1.48		13.2	1.32	J		0			0	
123678-HxCDF (0.10)	2	8.57	0.86		7.27	0.73		6.83	0.66			0			0	
123789-HxCDF (0.10)	2	0.34	0.034	J		0			0			0			0	
234678-HxCDF (0.10)	2	6.23	0.62		9.58	0.96		3.49	0.35	J		0			0	
1234878-HpCDF (0.01)	2	248	2.48		193	1.93		182	1.82			0			0	
1234789-HpCDF (0.01)	2	44.9	0.45		45.5	0.46		29.8	0.30			0			0	
12346789-OCDF (0.0001)	4	579	0.058		598	0.060		443	0.044			0			0	
Other TCDD																
Other PeCDD																
Other HxCDD																
Other HpCDD																
Other TCDF																
Other PeCDF																
Other HxCDF																
Other HpCDF																
TOTAL TEQ			88.0			122.9			80.6			0			0	

* = Result Reported from diluted analysis.
TEQs are based on I-TEF/89 Scheme

DATA SUMMARY FORM: PCDDs & PCDFs
Water Samples (pg/L)

Case #: R31737

SDG: R3173701

Number of Water Samples: 2

Site: Occidental Chemical Corporation/Firestone Tire and Rubber

Lab: SWRI

Sample Number:	R3173701			R3173702													
	QL	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	
Sample Number:																	
Sampling Location: Prefix of OXY-Field QC																	
Date Sampled																	
Time Sampled																	
Dilution Factor																	
Analys / TEF																	
2378-TCDD (1.0)	4		0			0			0			0			0		0
12378-PeCDD (0.50)	10		0			0			0			0			0		0
123478-HxCDD (0.10)	10		0			0			0			0			0		0
123678-HxCDD (0.10)	10	0.47	0.047	J		0			0			0			0		0
123789-HxCDD (0.10)	10		0			0			0			0			0		0
1234678-HpCDD (0.01)	10	4.46	0.045	J		0			0			0			0		0
12346789-OCDD (0.001)	20	47.8	0.000	B	2.72	0	B		0			0			0		0
2378-TCDF (0.1)	4		0		0.13	0	B		0			0			0		0
12378-PeCDF (0.05)	10		0			0			0			0			0		0
23478-PeCDF (0.50)	10		0			0			0			0			0		0
123478-HxCDF (0.10)	10		0			0			0			0			0		0
123678-HxCDF (0.10)	10		0			0			0			0			0		0
123789-HxCDF (0.10)	10		0			0			0			0			0		0
234678-HxCDF (0.10)	10		0			0			0			0			0		0
1234678-HpCDF (0.01)	10		0		0.40	0.0040			0			0			0		0
1234789-HpCDF (0.01)	10		0			0			0			0			0		0
12346789-OCDF (0.001)	20		0			0			0			0			0		0
Other TCDD																	
Other PeCDD																	
Other HxCDD																	
Other HpCDD																	
Other TCDF																	
Other PeCDF																	
Other HxCDF																	
Other HpCDF																	
TOTAL TEQ			0.092			0.0040			0			0			0		0

TECs are based on I-TEF/89 Scheme.

DATA SUMMARY FORM: PCDDs & PCDFs
Soil Samples (pg/g)

Case # R31737 SDG R3173701
 Site Occidental Chemical Corporation/Firestone Tire and Rubber

Number of Soil Samples: 18
 Lab: SWRI

Sample Number:	R3173703				R3173704				R3173705				R3173706				R3173707			
Sampling Location Prefix of OXY-Field OC	SB-NE10(6-24)				SB-NE7(6-24)				SB-NE8(6-24)				SB-NE9(6-24)				SB-SE10(6-24)			
Date Sampled:	12/9/03				12/9/03				12/9/03				12/9/03				12/9/03			
Time Sampled	13:45				10:45				11:15				13:10				16:15			
%Solids	83.7				83.4				79.4				81.6				77.0			
Dilution Factor:	1.98/19.8				1.98/19.8				1.98/19.8				1.97/19.7				1.97/19.7			
Analysis / TEF	QL	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q				
2378-TCDD (1.0)	0.8	9.91	9.91	J	13.1	13.1	J	5.68	5.68	J	6.75	6.75	J	7.39	7.39	J				
12378-PeCDD (0.50)	2	22.0	11.0		22.2	11.1		17.0	8.50	J	18.7	9.35	J	12.7	6.35	J				
123478-HxCDD (0.10)	2	33.5	3.35		39.5	3.95		35.8	3.58	J	28.1	2.81	J	22.6	2.26	J				
123678-HxCDD (0.10)	2	233	23.3		272	27.2		205	20.5	J	171	17.1	J	137	13.7	J				
123789-HxCDD (0.10)	2	89.3	8.93		94.9	9.49		82.3	8.23	J	78.3	7.83	J	50.5	5.05	J				
1234678-HpCDD (0.01)	2	3600	36.0	+	9540	95.4	+	11300	113	J+	9480	94.8	+	9400	94.0	J+				
12346789-OCDD (0.001)	4	40500	40.5	J+	113000	113	J+	145000	145	J+	127000	127	J+	105000	105	J+				
2378-TCDF (0.1)	0.8		0	UJ	3.08	0.31	J	3.29	0.33	J	2.27	0.23	J		0	UJ				
12378-PeCDF (0.05)	2		0		5.43	0.27		2.93	0.15	J	8.27	0.31			0	UJ				
23478-PeCDF (0.50)	2	5.10	2.55		6.31	3.16		4.53	2.27	J	7.00	3.50			0	UJ				
123478-HxCDF (0.10)	2	27.9	2.79		34.8	3.49		41.1	4.11	J	28.7	2.87		16.8	1.68	J				
123678-HxCDF (0.10)	2	18.4	1.84		17.5	1.75		17.7	1.77	J	19.6	1.96		8.76	0.88	J				
123789-HxCDF (0.10)	2		0			0			0	UJ	0.98	0.098	J		0	UJ				
234678-HxCDF (0.10)	2	17.4	1.74		44.7	4.47		21.3	2.13	J	13.8	1.38		8.28	0.83	J				
1234678-HpCDF (0.01)	2	500	5.00		542	5.42		488	4.88	J	435	4.35		282	2.82	J				
1234789-HpCDF (0.01)	2	118	1.18		132	1.32		90.3	0.90	J	83.2	0.83		48.7	0.49	J				
12346789-OCDF (0.001)	4	1150	1.15		1470	1.47		1100	1.10	J	1130	1.13		664	0.66	J				
Other TCDD																				
Other PeCDD																				
Other HxCDD																				
Other HpCDD																				
Other TCDF																				
Other PeCDF																				
Other HxCDF																				
Other HpCDF																				
TOTAL TEQ					150.2			294.9			321.9			282.3		240.9				

+ = Result Reported from diluted analysis.
 TEQs are based on 1-TEF/88 Scheme.

DATA SUMMARY FORM: PCDDs & PCDFs
Soil Samples (pg/g)

Case #: R31737

SDG: R3173701

Number of Soil Samples: 18

Site: Occidental Chemical Corporation/Firestone Tire and Rubber

Lab: SWRI

Sample Number	R3173708	R3173709	R3173710	R3173711	R3173712											
Sampling Location Prefix of OXY- Field QC	SB-SE7(6-24)	SB-SE8(6-24)	SB-SE9(6-24)	SS-NE10(0-6)	SS-NE7(0-6)											
Date Sampled	12/9/03	12/9/03	12/9/03	12/8/03	12/5/03											
Time Sampled	14:25	15:00	15:40	14:35	14:10											
%Solids	73.6	77.1	79.3	76.1	82.7											
Dilution Factor	1.98/19.8	1.88/19.8	1.98/19.8	1.96/39.2	1.98/19.8											
Analyte / TEF	QL	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q
2378-TCDD (1.0)	0.8	7.79	7.79		7.74	7.74		5.55	5.55	J	19.7	19.7	J	8.45	8.45	J
12378-PeCDD (0.50)	2	14.0	7.00		12.8	6.30		10.1	5.05		28.7	14.4		10.3	5.15	J
123478-HxCDD (0.10)	2	21.6	2.16		23.3	2.33		26.9	2.69		64.4	5.44		25.9	2.59	J
123678-HxCDD (0.10)	2	142	14.2		147	14.7		138	13.8		331	33.1		160	16.0	J
123789-HxCDD (0.10)	2	56.7	5.67		56.6	5.66		62.6	6.26		128	12.8		59.8	5.98	J
1234678-HpCDD (0.01)	2	5500	55.0	+	10100	101	+	10800	108	+	36600	366	+	11800	118	J+
12346789-OCDD (0.001)	4	63600	63.6	J+	111000	111	J+	78900	78.9	J+	421000	421	J+	85900	85.9	J+
2378-TCDF (0.1)	0.8	2.20	0.22	J		0		0	0	UJ	2.20	0.22	J		0	UJ
12378-PeCDF (0.05)	2	2.09	0.10	J		0		0	0		5.03	0.25	J	1.95	0.10	J
23478-PeCDF (0.50)	2	4.18	2.10	J	3.42	1.71	J	0	0		7.38	3.69		0	0	UJ
123478-HxCDF (0.10)	2	26.6	2.66		25.5	2.55		19.3	1.93		65.2	6.52		30.7	3.07	J
123678-HxCDF (0.10)	2	12.5	1.25		12.4	1.24		0	0		30.4	3.04		10.5	1.05	J
123789-HxCDF (0.10)	2	0.86	0.09	J		0		0	0		0	0		0	0	UJ
234678-HxCDF (0.10)	2	33.7	3.37		9.88	0.99		6.07	0.61		23.0	2.30		10.6	1.05	J
1234678-HpCDF (0.01)	2	297	2.97		362	3.62		275	2.75		804	8.04		321	3.21	J
1234789-HpCDF (0.01)	2	50.4	0.50		70.7	0.71		45.9	0.46		183	1.83		55.8	0.56	J
12346789-OCDF (0.001)	4	583	0.86		1310	1.31		926	0.93		2310	2.31		1070	1.07	J
Other TCDD																
Other PeCDD																
Other HxCDD																
Other HpCDD																
Other TCDF																
Other PeCDF																
Other HxCDF																
Other HpCDF																
TOTAL TEQ			189.7			260.9			224.9			900.4			252.2	

- = Result Reported from diluted analysis.

TEQs are based on I-TEF/88 Scheme.

DATA SUMMARY FORM: PCDDs & PCDFs
Soil Samples (pg/g)

Case #: R31737

SDG R3173701

Number of Soil Samples: 18

Site: Occidental Chemical Corporation/Firestone Tire and Rubber

Lab: SWRI

Sample Number	R3173713			R3173714			R3173715			R3173718			R3173717			
Sampling Location: Prefix of OXY-Field QC	SS-NE8(0-6)			SS-NE9(0-6)			SS-SE10(0-6)			SS-SE11(0-6)			SS-SE12(0-6)			
Date Sampled	12/8/03			12/8/03			12/9/03			12/9/03			12/9/03			
Time Sampled	14:15			14:30			10:00			11:00			11:15			
% Solids	76.8			79.0			72.1			73.7			72.9			
Dilution Factor:	1.96/19.0			1.97/19.7			1.97/19.7			1.97/19.7			1.96/19.9			
Analysis / TEQ	QL	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q
2378-TCDD (1.0)	0.8	6.61	6.61		9.26	9.26		5.49	5.49		0	0	UJ	2.18	2.18	J
12378-PeCDD (0.50)	2	12.6	6.30		11.6	5.80		8.07	4.04		10.6	5.30		8.65	4.43	
123478-HxCDD (0.10)	2	21.2	2.12		21.1	2.11		22.0	2.20		20.0	2.00		20.8	2.08	
123678-HxCDD (0.10)	2	14.9	14.9		137	13.7		115	11.5		101	10.1		101	10.1	
123789-HxCDD (0.10)	2	55.7	5.57		60.2	6.02		55.5	5.56		52.3	5.23		38.8	3.88	
1234678-HpCDD (0.01)	2	7160	71.6	*	7630	76.3	*	5520	56.3	*	6280	62.8	*	7290	72.9	*
12346789-OCDD (0.001)	4	77400	77.4	J*	98000	98	J*	56700	56.7	J*	85000	85.0	J*	86700	86.7	J*
2378-TCDF (0.1)	0.8	3.37	0.34		2.76	0.28	J	1.29	0.13	J		0	UJ		0	UJ
12378-PeCDF (0.05)	2	4.30	0.22	J		0			0		0.85	0.048	J		0	
23478-PeCDF (0.50)	2	5.50	2.75			0		2.40	1.20	J		0		1.90	0.95	J
123478-HxCDF (0.10)	2	33.7	3.37		25.0	2.50		11.8	1.18		10.8	1.08		10.4	1.04	
123678-HxCDF (0.10)	2	12.0	1.20		11.0	1.10		8.68	0.86		8.87	0.89		5.89	0.59	
123789-HxCDF (0.10)	2		0			0		0.62	0.062	J	1.00	0.10	J		0	
234678-HxCDF (0.10)	2	9.62	0.96		8.66	0.86		7.58	0.76			0			0	
1234678-HpCDF (0.01)	2	286	2.86		361	3.61		171	1.71		185	1.85		177	1.77	
1234789-HpCDF (0.01)	2	59.6	0.60		85.2	0.85		32.6	0.33		33.2	0.33		27.0	0.27	
12346789-OCDF (0.001)	4	766	0.77		997	1.00		421	0.42		506	0.51		406	0.41	
Other TCDD																
Other PeCDD																
Other HxCDD																
Other HpCDD																
Other TCDF																
Other PeCDF																
Other HxCDF																
Other HpCDF																
TOTAL TEQ			197.8			221.4			146.4			175.3			189.3	

* = Result Reported from diluted analysis.
 TEQs are based on I-TEF/89 Scheme.

DATA SUMMARY FORM: PCDDs & PCDFs
Soil Samples (pg/g)

Case # R31737

SDG R3173701

Number of Soil Samples: 18

Site: Occidental Chemical Corporation/Firestone Tire and Rubber

Lab: SWRI

Sample Number	R3173718				R3173719				R3173720							
	SS-SE7(0-6)				SS-SE8(0-6)				SS-SE9(0-8)				Dup. of R3173716			
Sampling Location: Prefix of OXY-Field QC																
Date Sampled:	12/8/03				12/8/03				12/8/03							
Time Sampled:	14:50				15:00				09:50							
% Solids	74.3				70.8				72.8							
Dilution Factor	1.98/19.8				1.99/19.9				1.98/19.8							
Analysis / TEF	QL	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q	CONC	TEQ	Q
2378-TCDD (1.0)	0.8		0		5.07	5.07		3.43	3.43	J		0			0	
12378-PeCDD (0.50)	2	8.08	4.03		10.2	5.10		6.78	3.38			0			0	
123478-HxCDD (0.10)	2	25.6	2.58		28.7	2.87		17.7	1.77			0			0	
123678-HxCDD (0.10)	2	155	15.5		132	13.2		86.8	8.68			0			0	
123789-HxCDD (0.10)	2	57.8	5.78		62.8	6.28		34.4	3.44			0			0	
1234678-HpCDD (0.01)	2	4480	44.8	+	7120	71.2	+	4710	47.1	+		0			0	
12346789-OCDD (0.001)	4	41000	41	J+	89300	89.3	J+	50500	50.5	J+		0			0	
2378-TCDF (0.1)	0.8		0	UJ		0			0	UJ		0			0	
12378-PeCDF (0.05)	2	1.45	0.07	J	2.17	0.11	J	1.45	0.07	J		0			0	
23478-PeCDF (0.50)	2	2.60	1.30	J	2.88	1.44	J		0			0			0	
123478-HxCDF (0.10)	2	13.4	1.34		14.8	1.48		13.2	1.32	J		0			0	
123678-HxCDF (0.10)	2	8.57	0.86		7.27	0.73		6.63	0.66			0			0	
123789-HxCDF (0.10)	2	0.34	0.034	J		0			0			0			0	
234678-HxCDF (0.10)	2	6.23	0.82		9.59	0.96		3.49	0.35	J		0			0	
1234678-HpCDF (0.01)	2	248	2.48		193	1.93		162	1.62			0			0	
1234789-HpCDF (0.01)	2	44.9	0.45		45.5	0.45		29.8	0.30			0			0	
12346789-OCDF (0.001)	4	579	0.58		598	0.60		443	0.44			0			0	
Other TCDD																
Other PeCDD																
Other HxCDD																
Other HpCDD																
Other TCDF																
Other PeCDF																
Other HxCDF																
Other HpCDF																
TOTAL TEQ			121.4			180.7			123.0			0			0	

+ = Result Reported from diluted analysis.
 TEQs are based on I-TEF/88 Scheme.

APPENDIX B
RISK SUMMARY TABLES AND RISK
CHARACTERIZATION SUMMARY FROM THE HHRA

6.0 RISK CHARACTERIZATION

The objective of the risk characterization is to integrate the information developed in the exposure assessment (Section 4.0) and the toxicity assessment (Section 5.0) to estimate the potential current and future health risks associated with exposure to the COPCs at the Occidental Chemical Superfund Site.

Risk characterization is presented in two separate sections – carcinogenic and noncarcinogenic – because of the differences in toxicological endpoints, relevant exposure averaging times, and risk characterization methods. In general, the evaluation of carcinogenic effects is limited only to those COPCs that EPA categorizes as carcinogens (EPA 1989). However, all COPCs (including those identified as carcinogens) are evaluated for noncarcinogenic health effects, although not all chemicals may produce noncancer effects.

Cancer risk probabilities are expressed as unitless values in scientific notation. For example, a cancer risk of 1×10^{-4} is expressed as "1E-04," which denotes one excess cancer case in a population of 10,000 individuals over a lifetime. Cumulative exposure route- or media-specific cancer risk probabilities are also represented as a unitless value in scientific notation.

Noncancer hazards are expressed as a unitless ratio of calculated intake to acceptable daily intake (i.e., HQ). Cumulative exposure route- or target organ-specific noncarcinogenic hazards represent the sum of individual HQs and are presented as hazard indices (HI).

6.1 APPROACHES TO EVALUATING RISK

Approaches to evaluating cancer risk probabilities and noncancer hazards are presented in the following subsections.

6.1.1 Cancer Risk Probability

Cancer risk probability is calculated by multiplying the estimated daily intake (I) or dose of a compound that is averaged over a lifetime by an exposure route-specific (oral, dermal, or inhalation) CSF. The calculation of cancer risk probability for a specific chemical via a specific exposure pathway, assuming a low dose, linear relationship, is illustrated by the following equation:

$$\text{Cancer risk} = I \cdot SF$$

where

I	=	Intake (averaged over a 70-year lifetime) for a specific exposure pathway (mg/kg-day) according to the equations described and parameters given in Tables 4.1 through 4.24 of Appendix A.
SF	=	Chemical- and route-specific cancer slope factor $([\text{mg}/\text{kg}\cdot\text{day}]^{-1})$

The linear equation is valid only at low risk levels (i.e., below estimated risks of 1E-02). The combined potential upper-bound cancer risk for a particular exposure pathway (e.g., soil ingestion) is then estimated by summing the risk estimates for all COPCs for that pathway. This approach is in accordance with EPA guidelines on chemical mixtures in which risks associated with carcinogens are considered additive (EPA 1986). This approach assumes independent actions by the chemicals (i.e., that there are no synergistic or antagonistic interactions), and that all of the chemicals have an identical toxicological endpoint (i.e., cancer). The total potential upper-bound lifetime cancer risk probability to an individual in a specified population (e.g., adult worker) is estimated by summing the combined cancer risk probabilities for all chemicals from all relevant exposure pathways.

In assessing cancer risk probabilities posed by potential exposure to chemicals at a site, the NCP establishes an excess cumulative cancer risk of 1E-06 as a "point of departure" for establishing remediation goals

(EPA 1994). Excess cumulative cancer risks lower than 1E-06 are not addressed by the NCP. EPA clarified its position on risk management decisions and the role of the baseline risk assessment as follows:

“Where the cumulative carcinogenic site risk to an individual based on reasonable maximum exposure for both current and future land use is less than 1E-04, and the noncarcinogenic HI is less than 1, action generally is not warranted unless there are adverse environmental impacts” (EPA 1991).

Therefore, it is EPA’s general policy to consider cancer risk probabilities up to 1E-04 as acceptable. However, it is important to note that according to the NCP, excess cumulative cancer risks in the range of 1E-06 to 1E-04 may or may not be considered acceptable, depending on site-specific factors such as the potential for exposure, technical limitations of remediation, and data uncertainties. That is, EPA has considered lifetime cumulative cancer risks of greater than 1E-06, and up to 1E-04, as acceptable either because of cost, feasibility, or the size of the exposed population. The aforementioned target cancer risk levels are based on cumulative risks and not on risks posed by individual chemicals. Exposure scenarios that generate cumulative cancer risks in excess of 1E-05 and up to 1E-04 will generally have cancer risks from individual chemicals that exceed 1E-06. For example, it would take 100 chemicals with a 1E-06 cancer risk to generate a cumulative cancer risk of 1E-04.

6.1.2 Noncancer Health Hazard

Noncancer health hazards are evaluated by calculating HQs and HIs. This is accomplished by comparing the estimated daily intakes of COPCs, which are averaged over the period of exposure, to chemical- and route-specific RfDs. RfDs represent the daily intake of a chemical to which a person can be exposed over a given length of time without any reasonable expectation of adverse noncancer health hazards. The HQ for a particular chemical is the ratio of the estimated daily intake through a given exposure pathway to the applicable RfD. The HQ-RfD relationship is illustrated by the following equation:

$$HQ = \frac{I}{RfD}$$

where:

HQ	=	Hazard quotient
I	=	Intake (averaged over the exposure period) (mg/kg-day)
RfD	=	Chemical- and route-specific reference dose (mg/kg-day)

The HQs determined for each COPC by exposure pathway are summed within an exposure scenario to obtain a total HI. The HI expresses the additivity of noncancer health hazards from all exposure routes and pathways for a given age group within an exposed population. The principle of additivity conservatively assumes that for a given age group and scenario, all COPCs have the same toxic endpoint. This is conservative (health-protective) because there may be a broad range of toxic endpoints at the critical doses for each COPC, and therefore they may not be truly additive. For this reason, EPA requires a separate evaluation of the target organs for each COPC to determine which COPC noncancer health hazard may be expected to be additive. Following RAGS Part A, this evaluation gives a more accurate picture of cumulative noncancer health hazards (EPA 1989). For Occidental Chemical Superfund Site COPCs, target organs are listed in Tables 5.1 and 5.2 of Appendix A, and HIs were summed for those COPC groups that were likely to act additively via the same mechanism or on the same target organ.

The methodology used to evaluate noncancer health hazards, unlike the methodology used to evaluate cancer risk probabilities, is not a quantitative measure of risk; i.e., it does not result in a probability for potential occurrence of adverse noncancer health effects. The HQ or HI is not a mathematical prediction of the

incidence of severity of those effects (EPA 1989). If an HQ or HI exceeds unity (one), noncancer health effects could potentially occur under the defined exposure conditions. Note, however, that the determination of an individual RfD assumes a margin of safety (refer to Section 5.0 for a description of safety factors used in determining RfDs), and the range of RfDs for a series of chemicals in an exposure scenario can potentially represent a number of individual toxic endpoints (as discussed above). Therefore, an HQ or HI greater than one does not necessarily indicate that an adverse noncancer health effect is likely to occur, since the derivation of the "safe" RfD includes a UF of 10 to 10,000. Furthermore, an HI less than or equal to one indicates that it is unlikely for even sensitive populations to experience adverse noncancer health effects.

For the purposes of this risk assessment, an HI greater than 1.4 will be considered an exceedance of unity for discussion purposes. Technically, an HI up to 1.4 is considered to be the same as an HI of 1, since remediation decisions are based on HI values of one significant digit only. Note however that HIs are presented as two significant digits throughout the text/tables to provide more information regarding uncertainty in the hazard.

6.2 SUMMARY OF RESULTS

The risk characterization combines the exposure assessment (and intake calculations) and toxicity evaluation, resulting in the final cancer risks and noncancer HI values for each receptor and pathway. The following provides a reference to the summary of the findings of the risk characterization:

- Noncancer health hazards are discussed in Section 6.2.1;
- Cancer risk probabilities are discussed in Section 6.2.2;
- Tables 9.1 through 9.9 of Appendix A for each lagoon present combined summaries of cancer risks and noncancer hazards for each receptor and exposure pathway across all media;
- Tables 10.1 through 10.9 of Appendix A for each lagoon present combined summaries of cancer risks and noncancer hazards for the main risk and hazard drivers for the site, and include a summary of both those risks and hazards that are acceptable (i.e., no action required) and those that may trigger the need for remedial actions (i.e., HI > 1 or risk > 1E-4), based on final risk management decisions. These tables also identify COPCs which are present at concentrations that are similar to background for evaluation purposes.

It should be noted that while both RME and CT scenarios are evaluated in a typical Superfund HHRA, EPA has had a long-standing policy of placing more weight on RME scenario results when making risk management decisions. Therefore, the discussion of results presented below focuses on the RME scenario calculations presented in Appendix A. CT results are presented on the corresponding tables in Appendix B for comparison only. However, in scenarios where there are cancer risk or HI value that exceeds the threshold (1.0E-04 for cancer risk and 1 for HI), the CT results are also discussed for completeness.

For ease of discussion, grey shaded cells in the tables presented in the following sections indicate exceedances of the risk (1.0E-04) or HI (1) thresholds.

6.2.1 Non-Cancer Health Hazards

Note that target organ information is presented in detail on Tables 5.1 and 5.2 of Appendix A. Where total HIs for all COPCs exceeded the threshold, then a discussion of target-organ specific HIs follows for each scenario in the following sections.

6.2.1.1 Current/Future Industrial Worker Noncancer Health Hazard

The Occidental Chemical Superfund Site is an industrial facility, and noncancer health hazards were evaluated quantitatively for current/future industrial worker exposures to surface soil, subsurface soil, and surface water (see Table 1 of Appendix A). Current industrial worker exposures to groundwater potentially impacted by the site's soil contamination was not evaluated quantitatively in this risk assessment. Groundwater risks were addressed in the Record of Decision for the site.

Surface Soil Exposures for Industrial Workers

Based on conditions at the Occidental Chemical Superfund Site, reasonable potential surface soil exposure pathways for industrial workers include direct ingestion and dermal contact with soil during outdoor activities across the site (see Table 1 of Appendix A). In addition to this exposure pathway, inhalation of particulates from surface soil during outdoor activities was also evaluated. Noncancer HQ and HI values for surface soil exposure for the industrial worker are presented separately for each lagoon on Tables 7.1 and 7.8 of Appendix A. The Table 6 below summarizes the noncancer hazard indices for industrial worker exposure to surface soil for each lagoon:

Table 6					
Current/Future Industrial Worker - Surface Soil Exposure Summary - Noncancer Hazard Indices					
Industrial Worker Exposure to Surface Soil	Ingestion HI	Dermal HI	Inhalation HI	Total HI	Table Reference
NE Lagoon	0.038	0.1	0.0013	0.014	7.1 and 7.8
NW Lagoon	0.011	0.18	0.004	0.3	7.1 and 7.8
SE Lagoon	0.044	0.1	0.0013	0.16	7.1 and 7.8
SW Lagoon	0.2	0.42	0.002	0.6	7.1 and 7.8

The current/future industrial worker noncancer HI for each of the individual and combined surface soil exposure routes for each lagoon did not exceed the HI threshold.

Subsurface Soil Exposures for Industrial Workers

Based on conditions at the Occidental Chemical Superfund Site, reasonable potential subsurface soil exposure pathways for industrial workers include inhalation of vapors in the air from the soil during outdoor activities. (see Table 1 of Appendix A). Noncancer HQ and HI values for exposure to vapors from the subsurface soil for the industrial worker are presented separately for each lagoon on Table 7.15 of Appendix A. Table 7 summarizes the noncancer HIs for industrial worker exposure to subsurface soil:

The current/future industrial worker noncancer HI for each of the individual and combined subsurface soil exposure routes for each lagoon did not exceed the HI threshold.

Industrial Worker Exposure to Subsurface Soil	Ingestion HI	Dermal HI	Inhalation HI	Total HI	Table Reference
NE Lagoon	N/A	N/A	0.0026	0.0026	7.15
NW Lagoon	N/A	N/A	0.0000001	0.0000001	7.15
SE Lagoon	N/A	N/A	0.0075	0.0075	7.15
SW Lagoon	N/A	N/A	0.0007	0.0007	7.15

N/A - not applicable. This route was not evaluated for subsurface soil exposure.

Surface Water Exposures for Industrial Workers

Based on conditions at the Occidental Chemical Superfund Site, reasonable potential surface water exposure pathways for industrial workers include ingestion and dermal contact with surface water during outdoor activities. Noncancer HQ and HI values for exposure to surface water for industrial workers are shown separately for each lagoon on Table 7.20 of Appendix A. Only two of the lagoons have the potential for retaining surface water. The NW and SW lagoons were evaluated for potential exposure to surface water. Table 8 summarizes the noncancer HIs for industrial worker exposure to surface water. Grey shaded cells indicate the HI threshold was exceeded.

Industrial Worker Exposure to Surface water	Ingestion HI	Dermal HI	Inhalation HI	Total HI	Table Reference
NW Lagoon	0.026	0.25	N/A	0.3	7.20
SW Lagoon	0.15	1.3	N/A	1.5	7.20

N/A - not applicable. This route was not evaluated for surface water exposure.

For the SW lagoon industrial worker, the target organ specific HI value that exceeded the HI threshold and/or contributed to the total HI is shown on Table 9:

Lagoon	Target Organ ^a	Target Organ HI	COPC Contributors ^b
SW	Kidney	1.44	Cadmium
	Central Nervous System	0.06	Manganese

^a The primary target organ for this exposure route is listed first.
^b Lists the COPCs for the target organs that were the primary targets for noncancer effects.

The CT calculations for the SW lagoon are similar to the RME calculations, with a total HI of 1.4 for the surface water exposure pathway (see Table 7.20 CT).

Combined Exposure for Industrial Workers

The total HIs (including all target organs) across all media and exposure routes for the current/future industrial worker at the Occidental Chemical Superfund Site are summarized in Table 10 for each lagoon (see Tables 9.1 of Appendix A for each lagoon).

Lagoon	Total HI Industrial Worker
NE	0.14
NW	0.6
SE	0.17
SW	1.6

The total HI (including all target organs) across all media for the average exposure conditions CT scenario for the SW lagoon is 1.6 (see Table 9.1 CT), which is also in excess of the HI threshold. The HI exceedance for the SW lagoon is due to cadmium in surface water which is intermittent.

6.2.1.2 Current/Future Visitor/Trespasser

Noncancer health hazards were evaluated quantitatively for current/future visitors and trespasser combined. These populations are exposed to surface soil, subsurface soil, and surface water (See Table 1 of Appendix A) at the Occidental Chemical Superfund Site. Noncancer health hazards to surface soil are presented on Tables 7.2 and 7.9 of Appendix A. Subsurface soil exposure for the visitor/trespasser are presented separately for each lagoon on Table 7.16, and surface water exposure is presented on Table 7.21 of Appendix A.

Surface Soil Exposure for Current/Future Visitor/Trespasser Noncancer Health Hazard

Surface soil exposure for current/future visitor/trespasser is presented on Table 7.2. The ingestion and dermal contact and inhalation of particulates from surface soil exposure routes were evaluated for this pathway. Table 11 presents a summary of the HI for each lagoon:

Visitor/Trespasser Exposure to Surface Soil	Ingestion HI	Dermal HI	Inhalation HI	Total HI	Table Reference
NE Lagoon	0.002	0.05	0.000052	0.052	7.2, 7.9
NW Lagoon	0.006	0.09	0.0002	0.09	7.2, 7.9
SE Lagoon	0.0022	0.056	0.000055	0.058	7.2, 7.9
SW Lagoon	0.01	0.21	0.000085	0.22	7.2, 7.9

The current/future visitor/trespasser noncancer HI for each of the individual and combined surface soil exposure routes for each lagoon did not exceed the HI threshold.

Subsurface Soil Exposure for Current/Future Visitor/Trespasser and Noncancer Health Hazard

Current and future visitors, trespassers were evaluated for exposure to vapors in the air from the soil. The visitor/trespasser scenario is evaluated on Table 7.16 of Appendix A for inhalation of vapors from subsurface soil. Table 12 presents the HIs for each lagoon:

Table 12
Current/Future Visitor/Trespasser - Subsurface Soil Exposure Summary - Noncancer Hazard Indices

Visitor/Trespasser Exposure to Subsurface Soil	Ingestion HI	Dermal HI	Inhalation HI	Total HI	Table Reference
NE Lagoon	N/A	N/A	0.00011	0.00011	7.16
NW Lagoon	N/A	N/A	0.000000005	0.000000005	7.16
SE Lagoon	N/A	N/A	0.00031	0.00031	7.16
SW Lagoon	N/A	N/A	0.00003	0.00003	7.16

N/A not applicable. The exposure route was not evaluated.

The current/future visitor/trespasser noncancer HI for each of the individual and combined subsurface soil exposure routes for each lagoon did not exceed the HI threshold.

Surface Water Exposure for Current/Future Visitor/Trespasser

Surface water exposure was evaluated for the two lagoons that intermittently retain water. The NW and SW lagoons were evaluated for receptor population exposure to surface water while wading or during outdoor activities. Tables 7.21 of Appendix A evaluate this pathway for each lagoon. Table 13 summarizes the noncancer HIs for visitor/trespasser exposure to surface water. Grey shaded cells indicate the HI threshold was exceeded.

Table 13
Current/Future Visitor/Trespasser - Surface Water Exposure Summary - Noncancer Hazard Indices

Visitor/Trespasser Exposure to Surface water	Ingestion HI	Dermal HI	Inhalation HI	Total HI	Table Reference
NW Lagoon	0.1	0.71	N/A	0.8	7.21
SW Lagoon	0.57	3.8	N/A	4.37	7.21

N/A - not applicable. This route was not evaluated for surface water exposure.

The current/future visitor/trespasser noncancer HI for each of the individual and combined surface water exposure route for the NW lagoon did not exceed the HI threshold.

For the SW lagoon visitor/trespasser, the target organ specific HI value that exceeded the HI threshold and/or contributes to the total HI is shown on Table 14:

Table 14 Current/Future Visitor/Trespasser - Surface Water Exposure Summary - Target Organ Specific Hazard Indices			
Lagoon	Target Organ ^a	Target Organ HI	COPC Contributors ^b
SW	Kidney	4.15	Cadmium
	Central Nervous System	0.18	Manganese
<p>^a The primary target organ for this exposure route is listed first. ^b Lists the COPCs for the target organs that were the primary targets for noncancer effects.</p>			

The CT calculations for the SW lagoon are substantially less than the RME calculations, with a total HI of 1.07 for the surface water exposure pathway (see Table 7.21 CT), which is essentially equal to the HI threshold.

Combined Exposure for Visitor/Trespasser

The total HIs (including all target organs) across all media and exposure routes for the combined visitor and trespasser for each lagoon at the Occidental Chemical Superfund Site is shown on Table 15 below.

Table 15 Current/Future Visitor/Trespasser - Summary of Total Hazard Indices - All Media and Exposure Routes	
Lagoon	Visitor/Trespasser HI
NE	0.05
NW	0.9
SE	0.058
SW	4.6

The total HI (including all target organs) across all media for the average exposure conditions CT scenario for the SW lagoon is only 1.09 (see Table 9.2 CT), which is essentially equal to the HI threshold.

6.2.1.3 Current/Future "Other" Receptor Noncancer Health Hazard

The 'other' exposure population is defined as an adult on-site visitor. These populations are exposed to surface soil, subsurface soil, and surface water (see Table 1 of Appendix A) at the Occidental Chemical Superfund Site. Noncancer health hazards to surface soil are presented on Tables 7.3 and 7.9 for this receptor population. Subsurface soil exposure for the adult on-site visitor is presented separately for each lagoon on Table 7.17 and surface water exposure is presented separately for each lagoon on Table 7.22 of Appendix A.

Surface Soil Exposure for "Other" Noncancer Health Hazard

Surface soil exposure for the adult visitor is presented on Table 7.3 and 7.10 of Appendix A. Ingestion, dermal contact, and inhalation of particulates from surface soil exposure routes were evaluated for this pathway. Table 16 presents a summary of the HI for each lagoon:

"Other" Exposure to Surface Soil	Ingestion HI	Dermal HI	Inhalation HI	Total HI	Table Reference
NE Lagoon	0.00016	0.0028	0.0000081	0.003	7.3, 7.10
NW Lagoon	0.00045	0.0049	0.00003	0.005	7.3, 7.10
SE Lagoon	0.00018	0.0031	0.0000086	0.0033	7.3, 7.10
SW Lagoon	0.00083	0.012	0.000013	0.013	7.3, 7.10

The current/future "other" noncancer HI for each of the individual and combined surface soil exposure route for all lagoons did not exceed the HI threshold.

Subsurface Soil Exposure for Current/Future "Other" Noncancer Health Hazard

Current and future adult visitors ("other") were evaluated for exposure to vapors in the air from the soil. The other scenario is evaluated on Table 7.17 of Appendix A for inhalation of vapors from subsurface soil. Table 17 presents the HIs for each lagoon:

"Other" Exposure to Subsurface Soil	Ingestion HI	Dermal HI	Inhalation HI	Total HI	Table Reference
NE Lagoon	N/A	N/A	0.000017	0.000017	7.17
NW Lagoon	N/A	N/A	0.000000007	0.000000007	7.17
SE Lagoon	N/A	N/A	0.000049	0.000049	7.17
SW Lagoon	N/A	N/A	0.0000047	0.0000047	7.17

N/A - not applicable. This route was not evaluated for subsurface soil exposure.

The current/future "other" noncancer HI for each of the individual and combined subsurface soil exposure route for all lagoons did not exceed the HI threshold.

Surface Water Exposure for Current/Future "Other"

Surface water exposure was evaluated for the two lagoons that intermittently retain water. The NW and SW lagoons were evaluated for receptor population exposure to surface water while wading or during outdoor activities. Tables 7.22 of Appendix A evaluate this pathway for each lagoon. Table 18 summarizes the noncancer HIs for "other" exposure to surface water:

"Other" Exposure to Surface water	Ingestion HI	Dermal HI	Inhalation HI	Total HI	Table Reference
NW Lagoon	0.016	0.15	N/A	0.2	7.22
SW Lagoon	0.088	0.8	N/A	0.9	7.22

N/A - not applicable. This route was not evaluated for surface water exposure.

The current/future "other" noncancer HI for each of the individual and combined surface water exposure route for both lagoons did not exceed the HI threshold.

Combined Exposure for "Other"

The total HIs (including all target organs) across all media and exposure routes for the "other" scenario for each lagoon at the Occidental Chemical Superfund Site is shown on Table 19. None of the HIs exceeded the threshold of HI>1.

Lagoon	"Other" HI
NE	0.003
NW	0.2
SE	0.0034
SW	0.90

6.2.1.4 Current/Future Resident Noncancer Health Hazard at the Fence Line

Based on RME assumptions, the most reasonable exposure pathways for current/future residents is inhalation of particulate and vapor from both surface and subsurface soil at the fence line. Noncancer health hazards were evaluated quantitatively for future adult and child residential exposures to a surface and subsurface soil. (see Table 1 of Appendix A).

Surface and Subsurface Soil Exposures for Current/Future Residents

For ease of presentation, inhalation of particulates from surface soil and the inhalation of vapors from subsurface soil have been combined and presented on Table 20 (adult) and Table 21 (child). Tables 7.12 and 7.19 for the adult and 7.11 and 7.18 for the child of Appendix A present this information in detail.

Current/Future Adult Exposure to Surface and Subsurface Soil	Ingestion HI	Dermal HI	Inhalation HI particulate/vapor		Total HI	Table Reference
NE	N/A	N/A	0.00026	0.00053	0.00079	7.12, 7.19
NW	N/A	N/A	0.0008	1.9E-08	0.0008	7.12, 7.19
SE	N/A	N/A	0.0003	0.0017	0.002	7.12, 7.19
SW	N/A	N/A	0.0004	0.0001	0.0005	7.12, 7.19
N/A - not applicable. These routes were not evaluated for the current/future resident at the fenceline.						

Current/Future Child Exposure to Surface and Subsurface Soil	Ingestion HI	Dermal HI	Inhalation HI particulate/vapor		Total HI	Table Reference
NE	N/A	N/A	0.00082	0.002	0.002	7.11, 7.18
NW	N/A	N/A	0.003	6.2E-08	0.003	7.11, 7.18
SE	N/A	N/A	0.00098	0.0056	0.00658	7.11, 7.18
SW	N/A	N/A	0.001	0.0005	0.0015	7.11, 7.18
N/A - not applicable. These routes were not evaluated for the current/future resident at the fenceline.						

The current/future residents (adult/child) noncancer HI for each of the individual and combined surface soil exposure route for all lagoons did not exceed the HI threshold.

6.2.1.5 Future Resident Noncancer Health Hazard

Based on RME assumptions, the most reasonable exposure pathways for future residents are direct ingestion, inhalation, and dermal contact with soil that could be potentially mixed during construction activities and is therefore a combination of surface and subsurface soil ("soil"), and incidental ingestion and dermal contact with surface water. Noncancer health hazards were evaluated quantitatively for future adult and child residential exposures to soil and surface water (see Table 1 of Appendix A).

Soil Exposures for Future Residents

The most reasonable soil exposure pathways for future residents are the direct ingestion of (1) surface soils during future outdoor activities or (2) subsurface soil (due to soil mixing) during possible future development (see Table 1 of Appendix A). The data used in this evaluation is a combination of the samples collected at land surface and the samples collected at depth from the soil borings in the lagoons. Noncancer HQ and HI values for soil exposures for future residents are presented in Tables 7.4, 7.5, 7.6, 7.7, 7.13 and 7.14 for each lagoon in Appendix A. All three exposure routes were calculated. Inhalation of particulates and vapor are presented on Table 7.6, 7.7, 7.13 and 7.14 for each lagoon in Appendix A. The inhalation pathway exposure concentration was calculated using air modeling presented in Appendix H. Table 22 summarizes the HIs for adult residents. Grey shaded cells indicate the HI threshold was exceeded.

Future Adult Exposure to Soil	Ingestion HI	Dermal HI	Inhalation HI particulate/vapor		Total HI	Table Reference
NE Lagoon	0.39	0.11	0.0027	0.0059	0.51	7.4, 7.7, 7.14
NW Lagoon	0.42	0.21	0.02	2.5E-07	0.7	7.4, 7.7, 7.14
SE Lagoon	1.1	0.29	0.004	0.017	1.4	7.4, 7.7, 7.14
SW Lagoon	5.1	1.1	0.01	0.002	6.21	7.4, 7.7, 7.14

The future adult resident noncancer HI for the NE and NW lagoons did not exceed the hazard threshold. However, the threshold was exceeded for the SW lagoon, and the SE lagoon was essentially equivalent to the HI. Table 23 details the target organ HIs that exceed the HI threshold and/or contributes to the total HI.

Table 23
Future Resident Adult - Soil Exposure Summary - Target Organ Specific Hazard Indices

Lagoon	Target Organ ^a	Target Organ HI	COPC Contributors ^b
SE	Liver	1.21	BEHP (0.73), vinyl chloride (0.26), and iron (0.09)
	Kidney	0.09	trichloroethene
	Fetus	0.09	trichloroethene
SW	Kidney	5.32	Cadmium
	None Reported	0.52	Chromium

^a The primary target organ for this exposure route is listed first.
^b Lists the COPCs for the target organs that were the primary targets for noncancer effects. Additional target organs are listed on Table 9.4 of Appendix A.

The CT calculations for the SE and SW lagoons were less than the RME calculations, with a total HI of 0.6 and 2.67, respectively, for the adult soil exposure pathway (see Tables 7.4 CT, 7.7 CT, and 7.14 CT).

Table 24 summarizes the HI for child residents. Grey shaded cells indicate the HI threshold was exceeded.

Table 24
Future Resident Child - Soil Exposure Summary - Noncancer Hazard Indices

Future Child Exposure to Soil	Ingestion HI	Dermal HI	Inhalation HI particulate/vapor		Total HI	Table Reference
NE Lagoon	3.4	0.64	0.0087	0.019	4.04	7.5, 7.6, 7.13
NW Lagoon	3.6	1.2	0.07	7.9E-07	4.9	7.5, 7.6, 7.13
SE Lagoon	9.4	1.7	0.013	0.055	11.2	7.5, 7.6, 7.13
SW Lagoon	43	6.5	0.05	0.005	49.6	7.5, 7.6, 7.13

The total HIs for the resident child were all greater than HI threshold in all lagoons. Table 25 details the primary target organs HIs for each lagoon.

Table 25
Future Resident Child - Soil Exposure Summary - Target Organ Specific Hazard Indices

Lagoon	Target Organ ^a	Target Organ HI	COPC Contributors ^b
NE	Liver	3.0	BEHP (0.91), vinyl chloride (0.80), iron (0.59), trichloroethene (0.52)
NW	Central Nervous System	3.0	Manganese (2.5),
	Liver	1.5	Iron
SE	Liver	9.7	BEHP (5.7), vinyl chloride (2.2), iron (0.80), trichloroethene (0.73); thallium (0.2)
SW	Kidney	43	Cadmium
	None Reported	4	Chromium
	Liver	1.4	Iron; thallium; BEHP; vinyl chloride
	Central Nervous System	0.6	Manganese

^a The primary target organ for this exposure route is listed first.
^b Lists the COPCs for the target organs that were the primary targets for noncancer effects. Additional target organs are listed on Table 9.5 of Appendix A.

The CT calculations for the NE, NW, SE, and SW lagoon were 1.8, 2.1, 5.0, and 22.4, respectively, for the soil exposure pathway (see Tables 7.5 CT, 7.6 CT, 7.13 CT). All lagoons exceed the hazard threshold for the average exposure scenario.

Surface Water Exposures for Future Residents

Potential surface water exposure pathways for future residents include direct ingestion and dermal contact during outdoor activities in the lagoons (see Table 1 of Appendix A). Noncancer HQ and HI values for surface water exposures for future residents are presented in Tables 7.23 and 7.24 of Appendix A for both the SW and NW lagoons. Table 26 summarizes the adult resident exposure to surface water. Grey shaded cells indicate the HI threshold was exceeded.

Adult Exposure to Surface water	Ingestion HI	Dermal HI	Inhalation HI	Total HI	Table Reference
NW Lagoon	0.063	0.6	N/A	0.7	7.23
SW Lagoon	0.36	3.2	N/A	3.6	7.23
N/A - not applicable. This route was not evaluated for surface water exposure.					

The future adult resident noncancer HI for each individual and combined surface water exposure route for the NW lagoon did not exceed the HI threshold. However, the threshold was exceeded for the SW lagoon. Table 27 details the target organs HIs that exceed the HI threshold.

Lagoon	Target Organ ^a	Target Organ HI	COPC Contributors ^b
SW	Kidney	3.4	Cadmium
a The primary target organ for this exposure route is listed first. b Lists the COPCs for the target organs that were the primary targets for noncancer effects. Additional target organs are listed on Table 9.4 of Appendix A.			

The CT calculations for the SW lagoon are substantially less than the RME calculations, with a total HI of 0.89 for the surface water exposure pathway (see Table 7.23 CT), which does not exceed the HI threshold.

Table 28 summarizes the child resident exposure to surface water. Grey shaded cells indicate the HI threshold was exceeded.

Child Exposure to Surface water	Ingestion HI	Dermal HI	Inhalation HI	Total HI	Table Reference
NW Lagoon	1.3	1	N/A	2	7.24
SW Lagoon	7.4	5.5	N/A	13	7.24
N/A - not applicable. This route was not evaluated for surface water exposure.					

The total HIs for the resident child were all greater than HI threshold in both lagoons. Table 29 details the primary target organs HIs for each lagoon.

Lagoon	Target Organ ^a	Target Organ HI	COPC Contributors ^b
NW	Kidney	2.0	Cadmium
	Central Nervous System	0.7	Manganese
SW	Kidney	12.3	Cadmium

a The primary target organ for this exposure route is listed first.
b Lists the COPCs for the target organs that were the primary targets for noncancer effects. Additional target organs are listed on Table 9.5 of Appendix A.

The CT calculations for the NW and SW lagoon were 0.6 and 3.25, respectively, for the surface water pathway (see Table 7.24 CT). The SW lagoon exceeds the hazard threshold for the average future resident child exposure scenario for surface water.

Combined Exposure for Future Residents

The total HIs (including all target organs) across all media and exposure routes for the future child and adult residents at the Occidental Chemical Superfund Site were calculated on Table 9.4 and 9.5 of Appendix A for both child and adult residents (for each lagoon), and are summarized on Table 30. Surface water exposure was included for the NW and the SW lagoons. Section 6.2.1.6 presents a summary of the health hazards.

Lagoon	Resident (Child)	Resident (Adult)
NE	1.8	0.51
NW	2.7	1.3
SE	5.0	1.4
SW	25.6	3.56

The total HI (including all target organs) across all media for the average resident child exposure CT scenario for the NE, NW, SE, and SW lagoons is 1.8, 2.7, 5.0, and 25.6, respectively. All the lagoons exceed the hazard threshold for future resident child. The total HI for the average resident adult exposure CT scenario for the SW lagoon is 3.56, which also exceeds the HI threshold.

6.2.1.6 Noncancer Risk Summary

Tables 31 through 34 present the RME noncancer HI values for (1) all receptors scenarios in all media evaluated quantitatively at the Occidental Chemical Superfund Site, and (2) COPCs that had HQs greater than the threshold. These summaries are based on the Table 10's of Appendix A developed for each scenario for each lagoon. Each lagoon is presented separately,

Note that where the HI exceeds 1, the CT value is also presented in parenthesis for comparison purposes.

Table 31 Noncancer Risk Summary - NE Lagoon			
Receptor(NE)	Exposure Pathways	Noncancer HI (a)	COPC with HQ > 1 (b)
Current/Future Industrial Worker (Adult)	Surface Soil	0.14	None
	Subsurface Soil	0.0026	None
	Total (all media, all routes)	0.14	
Current/Future Visitor/Trespasser (Pre-Adolescent/ Adolescent)	Surface Soil	0.053	None
	Subsurface Soil	0.00011	None
	Total (all media, all routes)	0.05	
Current/Future Other (c) (Adult)	Surface Soil	0.003	None
	Subsurface Soil	0.000017	None
	Total (all media, all routes)	0.003	
Future Resident (Adult)	Soil(d)	0.51	None
Future Resident (Child)	Soil(d)	3.03(e) (1.4)	None
Current/Future Resident (Adult)	Surface Soil	0.00026	None
	Subsurface Soil	0.00053	None
	Total (all media, all routes)	0.00079	
Current/Future Resident (Child)	Surface Soil	0.00082	None
	Subsurface Soil	0.0017	None
	Total (all media, all routes)	0.0025	

Notes:

- a A hazard index (HI) greater than 1 is considered an excess risk for noncarcinogenic health effects. All HI values are based on the RME assumption, and where applicable, the CT assumption values are presented in (parenthesis)
- b Constituents of potential concern (COPC) with an individual HQ greater than 1 in the medium of concern for the RME exposure.
- c Includes any visitor on-site, not a trespasser.
- d The lagoon's soil is assumed to be mixed during construction and is evaluated as a mixture of surface and subsurface soil.
- e See Table 25 for COPCs contributing to the total target organ for HI>1.

Table 32 Noncancer Risk Summary - NW Lagoon			
Receptor(NW)	Exposure Pathways	Noncancer HI (a)	COPC with HQ > 1 (b)
Current/Future Industrial Worker (Adult)	Surface Soil	0.3	None
	Subsurface Soil	0.0000001	None
	Surface Water (g)	0.3	None
	Total (all media, all routes)	0.6	
Current/Future Visitor/Trespasser (Pre-Adolescent/ Adolescent)	Surface Soil	0.09	None
	Subsurface Soil	5.0E-09	None
	Surface Water (g)	0.8	None
	Total (all media, all routes)	0.9	
Current/Future Other (c) (Adult)	Surface Soil	0.005	None
	Subsurface Soil	7E-10	None
	Surface Water (g)	0.2	None
	Total (all media, all routes)	0.2	
Future Resident (Adult)	Soil(d)	0.7	None
	Surface Water (g)	0.7	None
	Total (all media, all routes)	1.4 (0.4)	
Future Resident (Child)	Soil(d)	4.5 (1.9)(f)	Iron (e), Manganese(e), Cadmium
	Surface Water (g)	2.3 (0.6)	
	Total (all media, all routes)	6.8 (2.5)	
Current/Future Resident (Adult)	Surface Soil	0.0008	None
	Subsurface Soil	2E-08	None
	Total (all media, all routes)	0.0008	
Current/Future Resident (Child)	Surface Soil	0.003	None
	Subsurface Soil	6E-08	None
	Total (all media, all routes)	0.003	

Notes:

- a A hazard index (HI) greater than 1 is considered an excess risk for noncarcinogenic health effects. All HI values are based on the RME assumption, and where applicable, the CT assumption values are presented in parenthesis
- b Constituents of potential concern (COPC) with an individual HQ greater than 1 in the medium of concern for the RME exposure.
- c Includes any visitor on-site, not a trespasser.
- d The lagoon's soil is assumed to be mixed during construction and is evaluated as a mixture of surface and subsurface soil.
- e Background analysis (see Appendix J and Section 7.2.2 for additional discussion) indicates no significant difference in the average or median concentration of these COPCs in the NW lagoon and background.
- f See Table 25 for COPCs contributing to the total target organ for HI>1.
- g Lagoon surface water is intermittent. Water is pumped to the facility for treatment.

Table 33 Noncancer Risk Summary - SE Lagoon			
Receptor (SE)	Exposure Pathways	Noncancer HI (a)	COPC with HQ > 1 (b)
Current/Future Industrial Worker (Adult)	Surface Soil	0.16	None
	Subsurface Soil	0.0075	None
	Total (all media, all routes)	0.17	
Current/Future Visitor/Trespasser (Pre-Adolescent/Adolescent)	Surface Soil	0.058	None
	Subsurface Soil	0.00031	None
	Total (all media, all routes)	0.058	
Current/Future Other (c) (Adult)	Surface Soil	0.003	None
	Subsurface Soil	0.000049	None
	Total (all media, all routes)	0.0034	
Future Resident (Adult)	Soil(d)	1.3 (0.5)	None
	Total (all media, all routes)		
Future Resident (Child)	Soil(d)	10.1 (4.6)(e)	bis(2-ethylhexyl) phthalate vinyl chloride
	Total (all media, all routes)		
Current/Future Resident (Adult)	Surface Soil	0.0003	None
	Subsurface Soil	0.0017	None
	Total (all media, all routes)	0.002	
Current/Future Resident (Child)	Surface Soil	0.00098	None
	Subsurface Soil	0.0056	None
	Total (all media, all routes)	0.0066	

Notes:

- a A hazard index (HI) greater than 1 is considered an excess risk for noncarcinogenic health effects. All HI values are based on the RME assumption, and where applicable, the CT assumption values are presented in (parenthesis)
- b Constituents of potential concern (COPC) with an individual HQ greater than 1 in the medium of concern for the RME exposure.
- c Includes any visitor on-site, not a trespasser.
- d The lagoon's soil is assumed to be mixed during construction and is evaluated as a mixture of surface and subsurface soil.
- e See Table 25 for COPCs contributing to the total target organ for HI>1.

Table 34 Noncancer Risk Summary - SW Lagoon			
Receptor (SW)	Exposure Pathways	Noncancer HI (a)	COPC with HQ > 1 (b)
Current/Future Industrial Worker (Adult)	Surface Soil	0.624	None None Cadmium
	Subsurface Soil	0.00072	
	Surface Water (g)	1.44 (1.3)	
	Total (all media, all routes)	2.06 (1.6)	
Current/Future Visitor/Trespasser (Pre-Adolescent/ Adolescent)	Surface Soil	0.21	None None Cadmium
	Subsurface Soil	0.00003	
	Surface Water (g)	4.15 (1.02)	
	Total (all media, all routes)	4.4 (1.03)	
Current/Future Other (c) (Adult)	Surface Soil	0.012	None None None
	Subsurface Soil	0.0000047	
	Surface Water (g)	0.89	
	Total (all media, all routes)	0.90	
Future Resident (Adult)	Soil(d)	5.36 (2.33)	Cadmium Cadmium
	Surface Water (g)	3.4 (0.85)	
	Total (all media, all routes)	8.8 (3.17)	
Future Resident (Child)	Soil(d)	49.1 (22.1)(f)	Cadmium, chromium, iron (e) Cadmium
	Surface Water (g)	12.9 (3.24)	
	Total (all media, all routes)	62.0 (25.3)	
Current/Future Resident (Adult)	Surface Soil	0.0004	None None
	Subsurface Soil	0.00014	
	Total (all media, all routes)	0.00054	
Current/Future Resident (Child)	Surface Soil	0.0013	None None
	Subsurface Soil	0.00045	
	Total (all media, all routes)	0.0017	

Notes:

- a A hazard index (HI) greater than 1 is considered an excess risk for noncarcinogenic health effects. All HI values are based on the RME assumption, and where applicable, the CT assumption values are presented in (parenthesis)
- b Constituents of potential concern (COPC) with an individual HQ greater than 1 in the medium of concern for the RME exposure.
- c Includes any visitor on-site, not a trespasser.
- d The lagoon's soil is assumed to be mixed during construction and is evaluated as a mixture of surface and subsurface soil.
- e Background analysis (see Appendix J and Section 7.2.2 for additional discussion) indicates no significant difference in the average or median concentration of this COPCs in the SW lagoon and background.
- f See Table 25 for COPCs contributing to the total target organ for HI>1.
- g Lagoon surface water is intermittent. Water is pumped to the facility for treatment.

6.2.2 Cancer Risk Probabilities

Cancer risk probabilities were calculated for all carcinogenic COPCs, media, receptors, and exposure pathways identified in Table 1 of Appendix A. As stated previously, the discussion of results presented below focuses on the RME scenario calculations presented in Appendix A. CT results are presented on the corresponding tables in Appendix B for comparison only. However, in scenarios where there are cancer risk exceeds the threshold ($1.0E-04$), the CT results are also discussed for completeness. For ease of discussion, grey shaded cells in the tables presented in the following sections indicate exceedances of the risk threshold. Tables 8, 9, and 10's, which are included in Appendix A (or Appendix B for the CT scenario), are key references to this discussion.

6.2.2.1 Current/Future Industrial Worker Cancer Risk Probabilities

Soil Cancer Risk Probabilities for Current/Future Industrial Worker

Current/Future industrial worker incidental ingestion, dermal contact, and inhalation of particulate from surface soil and inhalation of vapors from subsurface soil were evaluated as the most reasonable exposure pathways. These were evaluated for each lagoon. The following tables detail the cancer risk probabilities for surface soil and subsurface soil. Tables 35 and 36 present the total cancer risk probabilities for each receptor across all media and all exposure routes.

Current/Future Industrial Worker Exposure to Surface Soil	Ingestion Risk	Dermal Risk	Inhalation Risk (particulate)	Total Risk	Table Reference (Appendix A)
NE	5E-07	4.5E-07	8E-08	1E-06	8.1, 8.8
NW	1E-06	4.2E-07	7E-08	2E-06	8.1, 8.8
SE	9E-07	8.6E-07	8E-08	1.9E-06	8.1, 8.8
SW	1.2E-06	5.1E-07	3E-07	2E-06	8.1, 8.8

Current/Future Industrial Worker Exposure to Subsurface Soil	Ingestion Risk	Dermal Risk	Inhalation Risk Vapors	Total Risk	Table Reference
NE	N/A	N/A	6E-07	6E-07	8.15
NW	N/A	N/A	3E-11	3E-11	8.15
SE	N/A	N/A	1E-06	1E-06	8.15
SW	N/A	N/A	2E-08	2E-08	8.15

N/A - not applicable. These routes were not evaluated for the current/future industrial worker.

The cancer risk probabilities for current/future industrial worker incidental ingestion of surface soil, dermal contact with surface soil, inhalation of particulate from surface soil, and the inhalation of vapors from subsurface soil, for each lagoon, are within or slightly above the lower end of the incremental risk range of $1.0E-04$ to $1.0E-06$.

Surface Water Cancer Risk Probabilities for Current/Future Industrial Worker

Surface water was evaluated for the two lagoons that intermittently receive storm water. The NW and SW surface water data are summarized on the tables below. Total risk across all media and all exposures is calculated on Table 37 for each lagoon (see Section 6.2.2.6).

Table 37					
Current/Future Industrial Worker - Surface Water Exposure Summary - Cancer Risk					
Current/Future Industrial Worker Exposure to Surface Water	Ingestion Risk	Dermal Risk	Inhalation Risk	Total Risk	Table Reference
NW	2.3E-08	1E-08	N/A	3E-08	8.20
SW	2.8E-08	1E-08	N/A	4E-08	8.20
N/A - not applicable. This route was not evaluated for the current/future industrial worker.					

The cancer risk probabilities for industrial worker incidental ingestion of surface water and dermal contact with surface water are below the lower end of the incremental risk range of 1.0E-04 to 1.0E-06.

6.2.2.2 Current/Future Visitor/Trespasser Cancer Risk Probabilities

Soil Cancer Risk Probabilities for Current/Future Visitor/Trespasser

Cancer probability risks were evaluated quantitatively for a visitor or trespasser to the Occidental Chemical Superfund Site. Incidental ingestion, dermal contact, and inhalation of particulate from surface soil and inhalation of vapors from subsurface soil were evaluated as the most reasonable exposure pathways (See Table 1 of Appendix A). Tables 38 and 39 detail the cancer risk probabilities for surface soil and subsurface soil.

Table 38					
Current/Future Visitor/Trespasser - Surface Soil Exposure Summary - Cancer Risk					
Current/Future Visitor/Trespasser Exposure to Surface Soil	Ingestion Risk	Dermal Risk	Inhalation Risk (particulate)	Total Risk	Table Reference
NE	1.3E-08	1.1E-07	2E-09	1E-07	8.2, 8.9
NW	1.3E-08	1E-07	1E-09	1E-07	8.2, 8.9
SE	2.3E-08	2.1E-07	2E-09	2E-07	8.2, 8.9
SW	3.2E-08	1.2E-07	6.7E-09	1.6E-07	8.2, 8.9

Table 39					
Current/Future Visitor/Trespasser - Subsurface Soil Exposure Summary - Cancer Risk					
Current/Future Visitor/Trespasser Exposure to Subsurface Soil	Ingestion Risk	Dermal Risk	Inhalation Risk Vapors	Total Risk	Table Reference
NE	N/A	N/A	1E-08	1E-08	8.16
NW	N/A	N/A	6E-13	6E-13	8.16
SE	N/A	N/A	3E-08	3E-08	8.16
SW	N/A	N/A	5E-10	5E-10	8.16
N/A - not applicable. These routes were not evaluated for the current/future visitor/trespasser.					

The cancer risk probabilities for current/future visitor/trespasser incidental ingestion of surface soil, dermal contact with surface soil, inhalation of particulate from surface soil, and the inhalation of vapors from subsurface soil, for each lagoon, are below the lower end of the incremental risk range of 1.0E-04 to 1.0E-06.

Surface Water Cancer Risk Probabilities for Current/Future Visitor/Trespasser

Surface water was evaluated for the two lagoons that intermittently receive stormwater. The NW and SW surface water risks for the current/future visitor/trespasser are summarized on the Table 40.

Current/Future Visitor/Trespasser Exposure to Surface Water	Ingestion Risk	Dermal Risk	Inhalation Risk	Total Risk	Table Reference
NW	4E-08	1.4E-08	N/A	5E-08	8.21
SW	5E-08	1.7E-08	N/A	7E-08	8.21
N/A - not applicable. This route was not evaluated for the current/future visitor/trespasser.					

The cancer risk probabilities for current/future visitor/trespasser incidental ingestion of surface water and dermal contact with surface water, for the NW and SW lagoons, are below the lower end of the incremental risk range of 1.0E-04 to 1.0E-06.

6.2.2.3 Current/Future "Other" Cancer Risk Probabilities

Soil Cancer Risk Probabilities for Current/Future "Other"

The "other" exposure population is defined as an adult visitor to the site and not a trespasser (See Table 1 of Appendix A). This population was evaluated similarly to the visitor/trespasser and industrial worker. Incidental ingestion, dermal contact, and inhalation of particulate from surface soil and inhalation of vapors from subsurface soil were evaluated as the most reasonable exposure pathways (See Table 1 of Appendix A). Tables 41 and 42 present the surface and subsurface soil cancer risk probabilities.

Current/Future "Other" Exposure to Surface Soil	Ingestion Risk	Dermal Risk	Inhalation Risk vapors	Total Risk	Table Reference
NE	2E-09	1.2E-08	5E-10	1E-08	8.3, 8.10
NW	4.1E-09	1.1E-08	4E-10	2E-08	8.3, 8.10
SE	3.6E-09	2.3E-08	5E-10	3E-08	8.3, 8.10
SW	4.9E-09	1.4E-08	2E-09	2E-08	8.3, 8.10

Table 42 Current/Future "Other"- Subsurface Soil Exposure Summary - Cancer Risk					
Current/Future "Other" Exposure to Subsurface Soil	Ingestion Risk	Dermal Risk	Inhalation Risk Vapors	Total Risk	Table Reference
NE	N/A	N/A	4E-09	4E-09	8.17
NW	N/A	N/A	2E-13	2E-13	8.17
SE	N/A	N/A	8E-09	8E-09	8.17
SW	N/A	N/A	1.5E-010	1.5E-010	8.17
N/A - not applicable. These routes were not evaluated for the current/future "other."					

The cancer risk probabilities for "other" incidental ingestion of surface soil, dermal contact with surface soil, inhalation of particulate from surface soil, and the inhalation of vapors from subsurface soil, for each lagoon, are below the lower end of the incremental risk range of 1.0E-04 to 1.0E-06.

Surface Water Cancer Risk Probabilities for Current/Future "Other"

The NW and SW surface water risks for the current/future "Other" are summarized on the Table 43.

Table 43 Current/Future "Other"- Surface Water Exposure Summary - Cancer Risk					
Current/Future "Other" Exposure to Surface Water	Ingestion Risk	Dermal Risk	Inhalation Risk	Total Risk	Table Reference
NW	1.3E-08	5.7E-09	N/A	2E-08	8.22
SW	1.6E-08	6.9E-09	N/A	2E-08	8.22
N/A - not applicable. This route was not evaluated for the current/future "other."					

The cancer risk probabilities for "other" incidental ingestion of surface water and dermal contact with surface water, for the NW and SW lagoons, are below the lower end of the incremental risk range of 1.0E-04 to 1.0E-06 for the "other" receptor.

6.2.2.4 Current/Future Resident Cancer Risk Probabilities at the Fenceline

Soil Cancer Risk Probabilities for Current/Future Resident at the Fenceline

Cancer risks were evaluated for the current/future adult and child residents at the Occidental Chemical Superfund Site. Surface and subsurface soil were evaluated for inhalation of particulates and vapors for the current/future resident at the fenceline. The Tables 44 (adult) and 45 (child) summarize the risks for each lagoon. The tables show the inhalation cancer risk for both the inhalation of particulates from surface soil and the inhalation of vapors from subsurface soil.

Table 44 Current/Future Resident Adult at the Fenceline - Surface and Subsurface Soil Exposure Summary - Cancer Risk						
Current/Future Adult Resident Exposure to Surface Soil and Subsurface Soil	Ingestion Risk	Dermal Risk	Inhalation Risk Particulate/Vapors		Total Risk	Table Reference
NE	N/A	N/A	2E-08	1E-07	1E-07	8.12, 8.19
NW	N/A	N/A	1E-08	5E-12	1E-08	8.12, 8.19
SE	N/A	N/A	1.9E-08	3E-07	3E-07	8.12, 8.19
SW	N/A	N/A	6.3E-08	5E-09	6.7E-08	8.12, 8.19
N/A - not applicable. These routes were not evaluated for the current/future adult resident.						

Table 45 Current/Future Resident Child at the Fenceline - Surface and Subsurface Soil Exposure Summary - Cancer Risk						
Current/Future Child Resident Exposure to Surface Soil and Subsurface Soil	Ingestion Risk	Dermal Risk	Inhalation Risk Particulate/Vapors		Total Risk	Table Reference
NE	N/A	N/A	1E-08	7E-07	7.5E-07	8.11, 8.18
NW	N/A	N/A	1E-08	1E-11	1E-08	8.11, 8.18
SE	N/A	N/A	2E-08	2E-06	2E-06	8.11, 8.18
SW	N/A	N/A	4.9E-08	4.8E-08	9.6E-08	8.11, 8.18
N/A - not applicable. These routes were not evaluated for the current/future child resident.						

Cancer risk was calculated for the current/future adult and child residents for inhalation of particulates from the surface soil and inhalation of vapors from the subsurface soil. The risks across all exposure pathways for the adult residents at each lagoon are below the lower end of the incremental risk range of 1.0E-04 to 1.0E-06. The risk across all pathways for child residents were also below the lower end of the risk range for the NE, NW, and SW lagoons, and slightly within the range for SE lagoon (2E-06).

6.2.2.5 Future Resident Cancer Risk Probabilities

Soil Cancer Risk Probabilities for Future Residents

Cancer risks were evaluated quantitatively for future adult and child residents for exposure to a mixture of surface and subsurface soil (referred to as soil, see Table 1 of Appendix A) and surface water where it is applicable. Direct ingestion, dermal contact, and inhalation of particulates and vapors exposures to soil were evaluated for the resident. Ingestion and dermal contact with surface water were also evaluated, where applicable for the future residents. Tables 46 (adult) and 47 (child) summarize the risk to the future residents. Gray shaded cells indicate an exceedance of the threshold value (1.0E-04).

Table 46 Future Resident Adult - Soil Exposure Summary - Cancer Risk						
Future Adult Exposure to Soil	Ingestion Risk	Dermal Risk	Inhalation Risk Particulate/Vapors		Total Risk	Table Reference
NE	8E-05	3.8E-06	1E-07	1E-06	9E-05	8.4, 8.7, 8.14
NW	3.7E-06	4.4E-07	5E-08	7E-11	4E-06	8.4, 8.7, 8.14
SE	9E-04	2.1E-05	1E-07	3E-06	9E-04	8.4, 8.7, 8.14
SW	7.5E-06	4E-07	1.5E-06	5E-08	9.4E-06	8.4, 8.7, 8.14

Table 47 Future Resident Child - Soil Exposure Summary - Cancer Risk						
Future Child Exposure to Subsurface Soil	Ingestion Risk	Dermal Risk	Inhalation Risk Particulate/Vapors		Total Risk	Table Reference
NE	9E-03	8.1E-06	9E-08	8E-06	2.5E-03	8.5, 8.6, 8.13
NW	7.7E-06	6E-07	4E-08	2E-10	8E-06	8.5, 8.6, 8.13
SE	9E-03	3.8E-05	8E-08	2E-05	5E-03	8.5, 8.6, 8.13
SW	9E-03	7.6E-07	1E-06	5E-07	1.4E-04	8.5, 8.6, 8.13

Cancer risk was calculated for the future adult resident for ingestion of soil, dermal contact with soil, inhalation of particulates from soil, and inhalation of vapors. Total exposure to the adult resident across all exposure pathways is within the incremental risk range of 1.0E-04 to 1.0E-06 for all the lagoons except the SE lagoon, which exceeds the risk threshold (3E-04).

Cancer risks were also calculated for the child resident for ingestion of soil, dermal contact with soil, inhalation of particulates from soil, and inhalation of vapors. Total exposure to the child resident across all exposure pathways exceeds the incremental risk range of 1.0E-04 to 1.0E-06 for the NE, SE, and SW lagoons. Note that the risk in the SW lagoon (1.4E-04) only slightly exceeds the risk threshold.

The risk across all soil media for the average resident adult exposure CT scenario for the SE lagoon is 5E-05. The risk across all soil media for the average resident child exposure CT scenario for the NE, SE, and SW lagoons is 9E-04, 2.5E-03, and 6.4E-05, respectively.

Note that the total cancer risks for the child and adult resident are additive (e.g., lifetime risks). Therefore, the total lifetime cancer risks for the NE, SE, and SW lagoons are greater than that presented in the preceding tables, although the child resident risk is the driver of the combined risks in NE, SE and SW lagoons. The total lifetime risks are discussed in more detail in Section 6.2.2.6., and presented on Tables 50 through 53. CT scenario risks as also discussed further in Section 6.2.2.6.

Surface Water Cancer Risk Probabilities for Future Residents

Cancer risk probabilities were calculated for the NW and SW lagoons. Incidental ingestion and dermal contact with surface water risks are presented on Tables 48 (adult) and 49 (child).

Table 48 Future Resident Adult - Surface Water Exposure Summary - Cancer Risk					
Future Adult Resident Exposure to Surface Water	Ingestion Risk	Dermal Risk	Inhalation Risk	Total Risk	Table Reference
NW	5.3E-08	2.3E-08	N/A	7.6E-08	8.23
SW	6.4E-08	2.9E-08	N/A	9.3E-08	8.23
N/A - not applicable. This route was not evaluated for the future adult resident.					

Table 49 Future Resident Child - Surface Water Exposure Summary - Cancer Risk					
Future Child Resident Exposure to Surface Water	Ingestion Risk	Dermal Risk	Inhalation Risk	Total Risk	Table Reference
NW	2.8E-07	1E-08	N/A	2.9E-07	8.24
SW	3.4E-07	1.2E-08	N/A	3.5E-07	8.24
N/A - not applicable. This route was not evaluated for the future child resident.					

The cancer risk probabilities for incidental ingestion of surface water and dermal contact with surface water, for the NW and SW lagoons, are below the lower end of the incremental risk range of 1.0E-04 to 1.0E-06 for the future adult and child receptors.

6.2.2.6 Cancer Risk Probability Summary

Tables 50 through 53 present (1) receptor- and media-specific cancer risk probabilities for RME scenarios, and (2) COPCs with cancer risk probabilities greater than the higher end and the lower end of the acceptable risk range. Each lagoon is presented separately.

These summaries are based on the Table 10's of Appendix A developed for each scenario for each lagoon. The Table 10's of Appendix A summarize the primary risk drivers for the site, and also identify the inorganics that are considered background (see Section 7.2.2 for additional discussion of the background study, including a summary of which inorganics were considered background).

For each lagoon, the future resident risk is presented as the combined adult/child risk, as the total lifetime resident cancer risk is the sum of both the adult and child residential risks in all pathways. Note that where the lifetime risk exceeds 1.0E-4, the CT value is also presented in parenthesis for comparison purposes. The CT value represents an average exposure scenario, and combined with the RME value, provides a range of the potential risks for the exposure pathway.

Table 50 NE Lagoon - Cancer Risk Probability Summary				
Receptor (NE)	Exposure Pathways	Cancer Risk^a	COPC^b with Risk > 10⁻⁴	COPC with Risk > 10⁻⁴
Current/Future Industrial Worker (Adult)	Surface Soil	1.03E-06	None	None
	Subsurface Soil	6.0E-07	None	None
	Total (all media, all routes)	2E-06		
Current/Future Visitor/Trespasser (Pre-Adolescent/Adolescent)	Surface Soil	1E-07	None	None
	Subsurface Soil	1E-08	None	None
	Total (all media, all routes)	1E-07		
Current/Future "Other" (Adult)	Surface Soil	1E-08	None	None
	Subsurface Soil	4E-09	None	None
	Total (all media, all routes)	2E-08		
Future Resident (Adult)	Soil ^d		bis (2-ethylhexyl) phthalate TCE Vinyl chloride	None
	Total (all media, all routes)	8E-05		
Future Resident (Child)	Soil ^d		Vinyl Chloride bis(2-ethylhexyl)phthalate TCE	Vinyl Chloride
	Total (all media, all routes)	2E-03 (9E-04)		
Future Resident Adult/Child ^e	Soil ^d		Vinyl Chloride bis(2-ethylhexyl)phthalate TCE	Vinyl Chloride
	Total (all media, all routes)	2E-03 (9E-04)		
Current/Future Resident At the Fenceline (Adult)	Surface Soil	2E-08	None	None
	Subsurface Soil	1E-07	None	
	Total (all media, all routes)	1.3E-07		
Current/Future Resident At the Fenceline (Child)	Surface Soil	1E-08	None	None
	Subsurface Soil	7.4E-07	None	
	Total (all media, all routes)	7.5E-07		
Current/Future Resident At the Fenceline Adult/Child ^e	Surface Soil	3E-08	None	None
	Subsurface Soil	8.5E-07	None	
	Total (all media, all routes)	9E-07		
<p>^a Cancer risk probabilities above 1x10⁻⁴ are generally considered unacceptable.</p> <p>^b Constituents of potential concern with a combined medium exposure (ingestion, dermal and inhalation) cancer risk probability greater than 10x⁻⁴.</p> <p>^c COPCs with a combined medium exposure (ingestion, dermal and inhalation) cancer risk probability greater than 1x10⁻⁴.</p> <p>^d Combined surface soil and subsurface soil.</p> <p>^e Total lifetime residential cancer risk is the sum of both the adult and child residential risks.</p>				

Table 51				
NW Lagoon - Cancer Risk Probability Summary				
Receptor (NW)	Exposure Pathways	Cancer Risk^a	COPC^b with Risk > 10⁻⁴	COPC with Risk > 10⁻⁴
Current/Future Industrial Worker (Adult)	Surface Soil	2E-06	Arsenic	None
	Subsurface Soil	3E-011	None	
	Surface Water	3E-08	None	
	Total (all media, all routes)	2E-06		
Current/Future Visitor/Trespasser (Pre-Adolescent/Adolescent)	Surface Soil	1E-07	None	None
	Subsurface Soil	6E-013	None	
	Surface Water	5E-08	None	
	Total (all media, all routes)	2E-07		
Current/Future "Other" (Adult)	Surface Soil	2E-08	None	None
	Subsurface Soil	2E-013	None	
	Surface Water	2E-08	None	
	Total (all media, all routes)	3E-08		
Future Resident (Adult)	Soil ^d	4E-06	Arsenic	None
	Surface Water	8E-08	None	
	Total (all media, all routes)	4E-06		
Future Resident (Child)	Soil ^d	8E-06	Arsenic	None
	Surface Water	3E-07	None	
	Total (all media, all routes)	9E-06		
Future Resident Adult/Child ^e	Soil ^d	1E-05	Arsenic	None
	Surface Water	3E-07	None	
	Total (all media, all routes)	1E-05		
Current/Future Resident At the Fenceline (Adult)	Surface Soil	1E-08	None	None
	Subsurface Soil	5E-12	None	
	Total (all media, all routes)	1E-08		
Current/Future Resident At the Fenceline (Child)	Surface Soil	1E-08	None	None
	Subsurface Soil	1E-11	None	
	Total (all media, all routes)	1E-08		
Current/Future Resident At the Fenceline Adult/Child ^e	Surface Soil	2E-08	None	None
	Subsurface Soil	2E-11	None	
	Total (all media, all routes)	2E-08		

a Cancer risk probabilities above 1×10^{-4} are generally considered unacceptable.
b Constituents of potential concern with a combined medium exposure (ingestion, dermal and inhalation) cancer risk probability greater than 10×10^{-6} .
c COPCs with a combined medium exposure (ingestion, dermal and inhalation) cancer risk probability greater than 1×10^{-4} .
d Combined surface and subsurface soil.
e Total lifetime residential cancer risk is the sum of both the adult and child residential risks.

Table 52 SE Lagoon - Cancer Risk Probability Summary				
Receptor (SE)	Exposure Pathways	Cancer Risk ^a	COPC ^b with Risk > 10 ⁻⁴	COPC with Risk > 10 ⁻⁴
Current/Future Industrial Worker (Adult)	Surface Soil	1.9E-06	bis (2-ethylhexyl)phthalate None	None
	Subsurface Soil Total (all media, all routes)	1E-06 3E-06		
Current/Future Visitor/Trespasser (Pre-Adolescent/Adolescent)	Surface Soil	2E-07	None None	None
	Subsurface Soil Total (all media, all routes)	3E-08 3E-07		
Current/Future "Other" (Adult)	Surface Soil	3E-08	None None	None
	Subsurface Soil Total (all media, all routes)	8E-09 4E-08		
Future Resident (Adult)	Soil ^d	3E-04 (5E-05)	bis (2-ethylhexyl)phthalate Vinyl Chloride TCE	Vinyl Chloride
	Total (all media, all routes)			
Future Resident (Child)	Soil ^d	5E-03 (2.5E-03)	bis (2-ethylhexyl)phthalate Vinyl Chloride TCE	bis (2-ethylhexyl)phthalate Vinyl Chloride
	Total (all media, all routes)			
Future Resident Adult/Child ^e	Soil ^d	5.7E-03 (3E-03)	bis (2-ethylhexyl)phthalate Vinyl Chloride TCE	bis (2-ethylhexyl)phthalate Vinyl Chloride
	Total (all media, all routes)			
Current/Future Resident At the Fenceline (Adult)	Surface Soil	2E-08	None None	None
	Subsurface Soil Total (all media, all routes)	3E-07 3E-07		
Current/Future Resident At the Fenceline (Child)	Surface Soil	2E-08	None Vinyl Chloride	None
	Subsurface Soil Total (all media, all routes)	2E-06 2E-06		
Current/Future Resident At the Fenceline Adult/Child ^e	Surface Soil	3.47E-08	None Vinyl Chloride	None
	Subsurface Soil Total (all media, all routes)	2.64E-06 2.67E-06		

a Cancer risk probabilities above 1x10⁻⁴ are generally considered unacceptable.
 b Constituents of potential concern with a combined medium exposure (ingestion, dermal and inhalation) cancer risk probability greater than 10x-6.
 c COPCs with a combined medium exposure (ingestion, dermal and inhalation) cancer risk probability greater than 1x10⁻⁴.
 d Combined surface and subsurface soil
 e Total lifetime residential cancer risk is the sum of both the adult and child residential risks.

Receptor (SW)	Exposure Pathways	Cancer Risk ^a	COPC ^b with Risk > 10 ⁻⁴	COPC with Risk > 10 ⁻⁴
Current/Future Industrial Worker (Adult)	Surface Soil Subsurface Soil Surface Water Total (all media, all routes)	2E-06 2E-08 4E-08 2.4E-06	Arsenic None None	None
Current/Future Visitor/Trespasser (Pre-Adolescent/Adolescent)	Surface Soil Subsurface Soil Surface Water Total (all media, all routes)	1.6E-07 4.9E-10 6.7E-08 2.3E-07	None None None	None
Current/Future "Other" (Adult)	Surface Soil Subsurface Soil Surface Water Total (all media, all routes)	2.1E-08 1.5E-10 2.3E-08 4.4E-08	None None None	None
Future Resident (Adult)	Soil ^d Surface Water Total (all media, all routes)	9.4E-06 9.3E-08 9.5E-06	Arsenic Vinyl Chloride None	None
Future Resident (Child)	Soil ^d Surface Water Total (all media, all routes)	1.4E-04 3.5E-07 1.4E-04 (6.4E-05)	Arsenic Vinyl Chloride None	Vinyl Chloride
Future Resident Adult/Child ^e	Soil ^d Surface Water Total (all media, all routes)	1.4E-04 4.5E-07 1.4E-04 (6.6E-05)	Arsenic Cadmium Chromium Vinyl Chloride None	Vinyl Chloride
Current/Future Resident At the Fenceline (Adult)	Surface Soil Subsurface Soil Total (all media, all routes)	6.3E-08 5.0E-09 6.7E-08	None None	None
Current/Future Resident At the Fenceline (Child)	Surface Soil Subsurface Soil Total (all media, all routes)	4.9E-08 4.8E-08 9.6E-08	None None	None
Current/Future Resident At the Fenceline Adult/Child ^e	Surface Soil Subsurface Soil Total (all media, all routes)	1.1E-07 5E-08 1.6E-07	None None	None
<p>a Cancer risk probabilities above 1x10⁻⁴ are generally considered unacceptable.</p> <p>b Constituents of potential concern with a combined medium exposure (ingestion, dermal and inhalation) cancer risk probability greater than 10x-6.</p> <p>c COPCs with a combined medium exposure (ingestion, dermal and inhalation) cancer risk probability greater than 1x10⁻⁴.</p> <p>d Combined surface and subsurface soil.</p> <p>e Total lifetime residential cancer risk is the sum of both the adult and child residential risks.</p>				

6.2.2.7 Lead Toxicity

6.2.2.7.1 Child Lead Toxicity Evaluation

Although there is a great deal of information on its health effects, there is not an EPA slope factor (SF) or reference dose (RfD) for lead. It appears that some health effects, particularly changes in the levels of certain blood enzymes and in aspects of children's neurobehavioral development, may occur at blood lead levels so low as to be essentially without a threshold. Therefore, EPA considers it inappropriate to develop an RfD for inorganic lead (EPA, 2001). Quantifying lead's cancer risk involves many uncertainties, some of which may be unique to lead. Age, health, nutritional state, body burden, and exposure duration influence the absorption, release, and excretion of lead. In addition, current knowledge of lead pharmacokinetics indicates that an estimate derived by standard procedures would not truly describe the potential risk. Thus, EPA's Carcinogen Assessment Group recommends that a numerical estimate not be used (EPA, 2001).

In the absence of lead health criteria, the Integrated Exposure Uptake Biokinetics (IEUBK) Model (IEUBKwin 32 Model 1.0) was the approach used to predict the mean lead blood levels in children exposed to lead at the Occidental Chemical Superfund Site.

IEUBK Model

Blood levels of lead in the age group ranging from 0 to 7 years of age can be predicted with the IEUBK Model. EPA Region 3 recommended its use to provide an estimation of chronic blood lead concentrations in children based, as much as possible, on site-specific data. Such data can assist in the risk management decision regarding cleanup of lead at hazardous waste sites. The IEUBK model was used to evaluate hypothetical risks from exposure to lead at the Occidental Chemical Superfund Site.

Neurotoxic effects of chronic low-level lead exposure in children may occur at lead blood levels as low as 10 ug/dL. Therefore, a blood-lead level of 10 ug/dL is utilized as a standard for this analysis and the site is considered to be of concern for lead if the model predicts that more than 5 percent of a population will exceed this level.

The model allows the input of specific lead exposure parameters associated with the site, where available. Where site-specific information is not available, standard default factors are substituted. The information that was available for inputs included the concentrations of lead detected in surface soil and air. In accordance with Region 3 guidance, the average detected lead concentrations were input into the model.

For the current/future resident at the fenceline scenarios, it is assumed that residents may be exposed to contaminants in air that originate from the soil (particulates). Therefore, the average lead concentration in air for each lagoon (NW, NE, SE, and SW) was input into the model to derive predicted blood lead levels for children who may be exposed to contaminants in air at the Occidental Chemical Superfund Site. Model defaults were used for the soil and water parameters.

The mean blood level and the percentage of measurements above 10 ug/dL for the 0-7 year old child hypothetically exposed to air in the NW, NE, SE, and SW lagoons at the site are presented on Figures 1 through 8 of Appendix L. The Child Lead Model Worksheets summarize the results and are located in Appendix L.

For the future resident scenarios, it is assumed that residents may be exposed to contaminants in both soil and air. Therefore, the average lead concentrations in soil and air for each lagoon (NW, NE, SE, and SW) was input into the model to derive predicted blood lead levels for children who may be exposed to lead in both soil and air at the Occidental Chemical Superfund Site. The average lead concentrations in soil and air

for the future scenarios are presented in Appendix L Table 1. Soil boring data were used to determine average lead concentrations.

The geometric mean blood level and the percentage of measurements above 10 ug/dL for the 0-7 year old child hypothetically exposed to soil and air in the NW, NE, SE, and SW lagoons at the site are presented on Figures 1 through 8 of Appendix L. The Child Lead Model Worksheets summarize the model inputs and are located in Appendix L.

The mean blood levels of children for the current scenarios in the NW, NE, SE, and SW lagoons ranged from 1.66 ug/dL to 3.33 ug/dL. These levels are below EPA's current health-based level of concern of 10 ug/dL.

The mean blood levels of children for the future scenarios in the NW, NE, SE, and SW lagoons ranged from 1.66 ug/dL to 25.2 ug/dL. With the exception of the SW lagoon, the levels in all lagoons were below EPA's health-based level of concern. The mean blood level of 25.2 ug/dl (2.47E-02 ug/m³ [air concentration] and 4481 mg/kg (soil concentration)) in the SW lagoon soil is above EPA's current health-based level of concern 10ug/dL. Under the future scenario, 97 percent of the children exposed to contaminants in the SW lagoon could develop blood-lead levels above the target level 10 ug/dL.

Child Lead Toxicity Conclusions

There is scientific but controversial evidence that subtle neurobehavioral effects in children such as lowered IQ scores, learning disabilities, and attention deficits may occur at chronic blood levels between 10 and 15 ug/dL. These blood lead levels may also be associated with decreased hemoglobin production in the red blood cells with resultant anemia. This is potentially applicable to the SW lagoon exposure scenario.

EPA has established a National Ambient Air Quality Standard (NAAQS) for lead of 1.5 ug/m³ (quarterly average). The air concentrations in all lagoons at the Occidental Chemical Superfund Site were below the NAAQS.

Soil lead concentrations greater than 400 mg/kg in residential areas should be considered a potential health threat. The degree of threat depends on the bioavailability of the lead. The lead model applies default assumptions in estimating the bioavailability of lead; however, the bioavailability of lead at the Occidental Chemical Superfund Site was not measured. Exposure to lead in the SW lagoon may present a significant risk to receptors if incidental ingestion and inhalation of dust occurs, due to the concentrations of lead in soil.

6.2.2.7.2 Adult Lead Toxicity Evaluation

The adult lead model (Recommendations of the Technical Review Workgroup for Lead for an Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil, December 1996) is used to assess risk associated with non-residential adult exposure to lead in soil. In this case the model was used to address risk to an industrial worker at the Occidental Chemical Superfund Site. The results of the model are presented in Appendix L. The default model values were used except for the exposure frequency value. The exposure frequency was set at 250 days/year as opposed to the model default value of 219 days/year.

Surface soil C_{max} values were used as the soil concentrations in the model since the C_{max} is a reasonable estimate of the average concentration in the surface soil. The surface soil samples were collected as composite samples across each lagoon. The adult lead model was used to estimate risk for each lagoon individually. The following values were used in the model for each lagoon:

NE lagoon	164 mg/kg	SE lagoon	282 mg/kg
NW lagoon	49.9 mg/kg	SW lagoon	5920 mg/kg

Two equations are presented in the lead model. The first equation uses the default value of 0.05 g/day as the daily soil ingestion rate (I_r). By using the single I_{rs} parameter to describe all sources of ingested soil, the methodology is consistent with all of the Superfund program and their implementation for risk assessment. Equation 2 provides an alternative approach to addressing the daily soil ingestion rate. The equation calculates separate estimates of lead intake from the direct ingestion of outdoor soil and from the ingestion of indoor dust. (EPA, 2003).

Results of the Model

The lead model uses the geometric mean blood level concentration and geometric standard deviation for adults to calculate the adult blood concentration. The model also shows the 95th percentile blood lead concentration among fetuses born to women having exposures to the site specific soil lead concentrations. The model shows the target blood lead level of 10 ug/dL, and then shows the probability of the site derived blood lead level to be greater than the target blood level.

The results of the model indicate that lead at the C_{max} concentration of 5,920 mg/kg at the SW lagoon would result in adult blood levels to be in excess of the target blood lead level of 10 ug/dL. At this concentration, the probability that a fetus is born to a woman exposed at the site would have blood lead levels in excess of the target level is approximately 50 percent. The concentration of lead in the surface soil in the SW lagoon exceeds the preliminary remedial goals (PRG) as well. The other lagoons do not have lead in excess of the PRGs. See Appendix L for model results.

6.2.3 Qualitative Risk Evaluation

Table 1 of Appendix A identifies two scenarios for a qualitative risk evaluation (1) future soil-to-groundwater for a potential residential population or future industrial workers, visitors, and trespassers; and (2) future surface water to air for a potential residential population along with current/future surface water to air exposure for an industrial worker, visitor/trespasser, and other population. The surface water pathway applies only to the NW and SW lagoons.

6.2.3.1 Soil-to-Groundwater Pathway

Purpose

The soil-to-groundwater pathway is evaluated to assess the potential for soil contamination at the site to impact groundwater quality. The groundwater originating below the lagoons could potentially be impacted by the lagoon soil as rain water flows through the contaminated soil and percolates into groundwater. Future residents, as well as future industrial workers, visitors, and trespassers may be exposed to this groundwater from a private potable well at the site through ingestion by drinking tap water, and by inhalation and dermal exposure during showering or bathing.

This pathway is qualitatively evaluated by comparing soil concentrations to site specific soil-to-groundwater screening levels (SSLs - as described previously in Section 3.1.4), based on USEPA Soil Screening Guidance (July 1996). This evaluation is qualitative because multiple lines of evidence and assumptions are used to calculate the SSLs, which are indicators of potential impacts to groundwater. Therefore, given the variety of complex conditions and processes that can affect the migration of contaminants in the soil to the groundwater, there is some uncertainty about the adequacy of the assumptions used in the calculation. Consequently, a qualitative assessment is more appropriate to address the risk uncertainties associated with the soil to groundwater calculation assumptions and results.

Methodology

SSLs were used to screen for COPCs in the soil for each detected chemical for each lagoon. This screening is presented on Table 2.1 of Appendix A for each lagoon. The concentrations used for screening are included in Appendix M. The concentrations were based on the Soil Screening Guidance, and are discussed in the appendix. The concentration used for screening is the average concentration from the individual boring with the highest concentration. Discussion on the use of non-detected data is also included in Appendix M.

The chemicals of potential concern are presented on Table 3.1 of Appendix A. These are the chemicals which exceeded the site specific SSLs and are retained for this qualitative assessment.

Findings

Tables 54 through 57 presents all the COPCS from each lagoon, respectively, that exceeded the SSLs. The tables also indicate:

- The COPCs that are the human health risk drivers based on the quantitative risk assessment (i.e., $HQ > 1$ or risk $> 1E-6$), and also provides the receptor affected;
- An order of magnitude for each chemical in terms of how it exceeded the SSL. For example concentrations of antimony in the NE lagoon exceed the SSL by 2.7 times; and
- The COPCs for which there was no significant difference in the average or median concentrations detected in the subsurface soil in the lagoon and background locations (i.e., those COPCs that appear to be background and attributable to natural or anthropogenic contributions rather than site-related - see Section 7.2.2 and Appendix J for additional background discussion).

Note that many chemicals were infrequently detected but retained for screening. Chemicals were retained as COPCs even if they were only detected in a single sample. For the purposes of this discussion, chemicals that were detected in less than 10 to 15% of the total number of subsurface samples collected at each lagoon are shaded grey in the following tables. Infrequent detections should be carefully considered during the risk management evaluation of the soil-to-groundwater pathway.

All of the COPCs listed on Tables 54 through 57 could potentially pose a risk for the soil-to-groundwater pathway.

Table 54 NE Lagoon - Soil-to-Groundwater Pathway Summary		
COPCs Soil-to-Groundwater NE lagoon	Potential Risk Drivers for HHRA (marked with ✓)	Number of times the concentration used for screening exceeds the SSL ^a
Antimony ^b		2.7
Arsenic ^b		46
Barium ^b		1.3
Cadmium ^b		1.2
Chromium		53
Iron ^b		73
Manganese ^b		5.4
Acetophenone		140000
Acetone		5
1,1 Dichloroethene		6
1,2 Dichloroethane		340
cis 1,2 Dichloroethene		187
Ethyl Benzene		1.6
Toluene		3.8
trans 1,2-Dichloroethene		3.3
Trichloroethene	✓ (future resident)	38
Tetrachloroethene		273
Vinyl Chloride	✓ (future resident)	1159
Carbon Disulfide		2.6
4-Methyl 2-pentanone		16
<p>a This was calculated by dividing the concentration used for screening by the SSL.</p> <p>b Background analysis (see Appendix J and Section 7.2.2 for additional discussion) indicates no significant difference in the average or median concentration of this COPC in the lagoon and background.</p> <p>Grey fill distinguishes the chemicals that were infrequently detected (i.e. detected in less than 10-15% of the total number of samples from this lagoon).</p>		

Table 55		
NW Lagoon - Soil-to-Groundwater Pathway Summary		
COPCs Soil-to-Groundwater NW lagoon	Potential Risk Drivers for HHRA (marked with ✓)	Number of times the concentration used for screening exceeds the SSL ^a
Antimony ^b		4
Arsenic ^b	✓ (current/future industrial worker; future resident)	106
Barium ^b		3
Chromium ^b		16
Cobalt ^b		2
Iron ^b	✓ (future resident child)	242
Manganese ^b	✓ (future resident child)	103
Nickel		2
<p>a This was calculated by dividing the concentration used for screening by the SSL.</p> <p>b Background analysis (see Appendix J and Section 7.2.2 for additional discussion) indicates no significant difference in the average or median concentration of this COPC in the lagoon and background.</p> <p>Grey fill distinguishes the chemicals that were infrequently detected (i.e. detected in less than 10-15% of the total number of samples from this lagoon).</p>		

Table 56		
SE Lagoon - Soil-to-Groundwater Pathway Summary		
COPCs Soil-to-Groundwater SE lagoon	Potential Risk Drivers for HHRA (marked with ✓)	Number of times the concentration used for screening exceeds the SSL ^a
Antimony ^b		4
Arsenic ^b		40
Cadmium ^b		2
Chromium		50
Iron ^b		74
Manganese ^b		10
Benzaldehyde		3
Benzene		2144
Naphthalene		30
1,2 Dichloroethane		770
Chloromethane		73
cis 1,2 Dichloroethene		926
Ethyl Benzene		3
Toluene		2.5
trans 1,2-Dichloroethene		7
Trichloroethene	✓ (future resident)	75
Vinyl Chloride	✓ (future resident; current/future resident at fence line)	5728
Carbon Disulfide		7
4-Methyl 2-pentanone		9
<p>a This was calculated by dividing the concentration used for screening by the SSL.</p> <p>b Background analysis (see Appendix J and Section 7.2.2 for additional discussion) indicates no significant difference in the average or median concentration of this COPC in the lagoon and background.</p> <p>Grey fill distinguishes the chemicals that were infrequently detected (i.e. detected in less than 10-15% of the total number of samples from this lagoon).</p>		

Table S7
SW Lagoon - Soil-to-Groundwater Pathway Summary

COPCs Soil-to-Groundwater SW lagoon	Potential Risk Drivers for HHRA (marked with ✓)	Number of times the concentration used for screening exceeds the SSL ^a
Arsenic ^b	✓ (current/future industrial worker, future resident)	80
Barium		4
Cadmium	✓ (current/future industrial worker/visitor/trespasser; future resident)	1069
Chromium	✓ (future resident child)	540
Iron ^b	✓ (future resident child)	170
Lead		180
Manganese ^b		21
Mercury ^b		12
Nickel ^b		3.5
Benzene		160
Naphthalene		77.6
1,2 Dichloroethane		355
cis 1,2 Dichloroethene		9
Toluene		13
Trichloroethene		1.5
Vinyl Chloride	✓ (future resident)	200
2-Methyl naphthalene		7.5
Dibenzofuran		4
2,4 Dimethylphenol		10.7
Phenanthrene		40
4-Methylphenol		53
Methylene Chloride		9

a This was calculated by dividing the concentration used for screening by the SSL.
 b Background analysis (see Appendix J and Section 7.2.2 for additional discussion) indicates no significant difference in the average or median concentration of this COPC in the lagoon and background.

Grey fill distinguishes the chemicals that were infrequently detected (i.e. detected in less than 10-15% of the total number of samples from this lagoon).

6.2.3.2 Surface Water Air Pathway

Table 1 of Appendix A indicated that qualitative review of the surface water to air pathway is to be completed. Based on the review of the semivolatile and volatile organic data, there are no substantial detections of compounds that exceed the screening criteria, and consequently, no quantitative evaluation is necessary. Table 58 summarizes the semivolatile and volatile organic compounds detected in the NW and SW lagoons at the Occidental Chemical Superfund Site. Therefore, this pathway is insignificant for future residents or current/future industrial workers, visitors, or trespassers.

Table 58		
Surface Water Air Pathway - Summary of Organic Compound Detections		
Chemical Name	Concentration & Qualifier Code ^a	Lagoon
2-Butanone	1 J	One detection in each lagoon
Acetone	5 detections from 8 to 13 J	NW and SW
Diethyl phthalate	2 J	SW
^a J is defined as an Analyte present. Reported value may not be accurate or precise.		

8.0 RISK ASSESSMENT SUMMARY

The following is a summary of the results of the risk assessment for each exposure scenario for each lagoon at the site. This discussion includes: 1) a summary of carcinogenic and noncarcinogenic risks for each exposure pathway (presented on a summary table derived from Tables 10.1 through 10.9 of Appendix A), for both the reasonable maximum exposure (RME) and central tendency (CT) exposure scenarios (as necessary if the RME values exceed the threshold for action to show the range of potential risks at the site); 2) a summary of lead toxicity; 3) a summary of soil-to-groundwater pathway qualitative assessment; and 4) a discussion of background (if necessary).

8.1 NORTHEAST LAGOON RISK SUMMARY

A summary of the risks for each exposure scenario for the NE lagoon is presented in Table 60. Highlighted areas on the table indicate risks above acceptable levels (cancer risk > 1E-04 or HI > 1). Note that there is no surface water exposure in the NE lagoon.

Time Frame	Population	Total Carcinogenic Risk Across All Media and All Exposure Routes	Total Hazard Index Across All Media and All Exposure Routes
Current/Future	Industrial Worker	2E-06	0.14
Current/Future	Visitor/Trespasser	1E-07	0.05
Current/Future	Other	2E-08	0.003
Future	Adult	8E-05	0.51
Future	Child	2E-03 (9E-04)	3.03 (1.4)
Future	Adult/Child	2E-03 (9E-04)	n/a
Current/Future	Adult at Fence line	1.3E-07	0.00079
Current/Future	Child at Fence line	7.5E-07	0.0025
Current/Future	Adult/Child at Fence line	9E-07	n/a

The following are the primary conclusions about the risks assessed for the NE lagoon:

- The off-site air risks for the exposure of current/future residents at the fence line are 3 orders of magnitude below the acceptable risk levels for the NE lagoon.
- The risks to current/future visitor/trespassers, and "Others" are several orders of magnitude below the acceptable risk levels for the NE lagoon.
- The carcinogenic risk to current/future industrial workers is slightly above the 1E-06 "point of departure," but still below the acceptable risk levels for the NE lagoon. The noncarcinogenic risk for this receptor is well below the HI threshold of 1.
- The cumulative carcinogenic risk to future onsite residents (adult/child) is above the acceptable risk level for the NE lagoon for both the RME (2E-03) and CT (9E-04) scenarios. Future onsite resident child

ingestion of soil is the primary route of exposure for this risk, and vinyl chloride is the primary risk driver.

- The noncarcinogenic risk to future onsite resident children is **above** the acceptable risk level for the NE lagoon for the RME scenario (3.03), and nearly equivalent to the acceptable risk level for the CT scenario (1.4). Ingestion is the primary route of exposure for this risk, and the target organ is the liver. Bis 2-ethylhexyl phthalate, vinyl chloride, iron, thallium, and TCE are the primary risk drivers. Although iron is considered to be attributable to "background" in the NE lagoon, its contribution to the HI is not substantial, and the RME risk scenario would still be above the acceptable risk level if iron was eliminated from the risk calculation.
- The noncarcinogenic risk to future onsite resident adults is below the acceptable risk level for the NE lagoon.
- The results of the IEUBK model indicate that the level of lead in the NE lagoon is below EPA's current health-based level of concern for both children and adults. Results of the adult lead model protect the pregnant woman's fetus in the workplace. Refer to Appendix L for the adult and child lead modeling.

8.2 NORTHWEST LAGOON RISK SUMMARY

A summary of the risks for each exposure scenario for the NW lagoon is presented in Table 61. Highlighted areas on the table indicate risks above acceptable levels (cancer risk >1E-04 or HI>1). Note that surface water exposure is included in the NW lagoon assessment.

Time Frame	Population	Total Carcinogenic Risk Across All Media and All Exposure Routes	Total Hazard Index Across All Media and All Exposure Routes
Current/Future	Industrial Worker	2E-06	0.6
Current/Future	Visitor/Trespasser	2E-07	0.9
Current/Future	Other	3E-08	0.2
Future	Adult	4E-06	1.4 (0.4)
Future	Child	9E-06	6.8 (2.5)
Future	Adult/Child	1E-05	n/a
Current/Future	Adult at Fence line	1E-08	0.0008
Current/Future	Child at Fence line	1E-08	0.003
Current/Future	Adult/Child at Fence line	2E-08	n/a

The following are the primary conclusions about the risks assessed for the NW lagoon:

- The off-site air risks for the exposure of current/future residents at the fence line are at least 3 orders of magnitude below the acceptable risk levels for the NW lagoon.
- The risks to current/future visitor/trespassers, and "Others" are below the acceptable risk levels for the NW lagoon.

- The carcinogenic risk to current/future industrial workers is slightly **above** the 1E-06 “point of departure,” but still **below** the acceptable risk level for the NW lagoon. The noncarcinogenic risk for this receptor is well **below** the HI threshold of 1.
- The cumulative carcinogenic risk to future residents (adult/child) for the NW lagoon is **above** the 1E-06 “point of departure,” but is still one order of magnitude **below** the acceptable risk level.
- The noncarcinogenic risk to future resident children is **above** the acceptable risk level for the NW lagoon for the RME scenario (6.8) and CT scenario (2.5). Ingestion of soil (primary route), as well as ingestion of and dermal exposure to surface water (secondary route) are the major routes of exposure for this risk. The primary target organs are the kidney, liver and central nervous system. Manganese and iron are the primary risk drivers in the soil, and cadmium is the primary risk driver in the surface water.

Although manganese and iron are considered to be attributable to “background” in the NW lagoon soil, the RME risk scenario (but not the CT scenario) would still be above the acceptable risk level if the “background” COPCs were eliminated from the risk calculation because of the surface water exposure. However, it should be noted that the presence of surface water in the NW lagoon is intermittent, and its presence is related to precipitation. The surface water is currently being pumped to the facility for treatment. This should be considered as part of any risk management decision related to the NW lagoon.

- The noncarcinogenic risk RME to future resident adults is equivalent to the acceptable risk level for the NW lagoon (1.3), but is **below** the acceptable risk level (e.g., HI=1) for the CT scenario (0.4).
- The results of the IEUBK model indicate that the level of lead in the NW lagoon is **below** EPA’s current health-based level of concern for both children and adults. Results of the adult lead model protect the pregnant woman’s fetus in the workplace. Refer to Appendix L for the adult and child lead modeling.

8.3 SOUTHEAST LAGOON RISK SUMMARY

A summary of the risks for each exposure scenario for the SE lagoon is presented in Table 62. Highlighted areas on the table indicate risks above acceptable levels (cancer risk >1E-04 or HI>1). Note that there is no surface water exposure in the SE lagoon.

Time Frame	Population	Total Carcinogenic Risk Across All Media and All Exposure Routes	Total Hazard Index Across All Media and All Exposure Routes
Current/Future	Industrial Worker	3E-06	0.17
Current/Future	Visitor/Trespasser	3E-07	0.058
Current/Future	Other	4E-08	0.0034
Future	Adult	3E-04 (5E-05)	1.3 (0.5)
Future	Child	5E-03 (2.5E-03)	10.1 (4.6)
Future	Adult/Child	5.7E-03 (3E-03)	n/a
Current/Future	Adult at Fence line	3E-07	0.002
Current/Future	Child at Fence line	2E-06	0.016
Current/Future	Adult/Child at Fence line	3E-06	n/a

The following are the primary conclusions about the risks assessed for the SE lagoon:

- The cumulative carcinogenic risks for the exposure of current/future resident at the fence line is slightly above the $1E-06$ "point" of departure," but still below the acceptable risk level for the SE lagoon. The noncarcinogenic risk for the current/future resident adult and child are both well below the HI threshold of 1.
- The risks to current/future visitor/trespassers, and "Others" are well below the acceptable risk levels for the SE lagoon.
- The carcinogenic risk to current/future industrial workers is slightly above the $1E-06$ "point of departure," but still below the acceptable risk level for the SE lagoon. The noncarcinogenic risk for this receptor is well below the HI threshold of 1.
- The cumulative carcinogenic risk to future residents (adult/child) is above the acceptable risk level for the SE lagoon for both the RME ($5.7E-03$) and CT ($3E-03$) scenarios. Future resident adult and child ingestion of soil is the primary route of exposure for this risk, and bis2-ethylhexyl phthalate, vinyl chloride, and TCE are the primary carcinogenic risk drivers.
- The noncarcinogenic risk to future resident children is above the acceptable risk level for the SE lagoon for both the RME scenario (10.1) and CT scenario (4.6). Ingestion of soil is the primary route of exposure for this risk, and the target organ is the liver. Bis 2-ethylhexyl phthalate and vinyl chloride are the primary noncarcinogenic risk drivers.
- The noncarcinogenic risk to future resident adults is equivalent to the acceptable risk level of $HI=1$ for the SE lagoon for the RME scenario (1.3), but is below the acceptable risk level for the CT scenario (0.5).
- The results of the IEUBK model indicate that the level of lead in the SE lagoon is below EPA's current health-based level of concern for both children and adults. Results of the adult lead model protect the pregnant woman's fetus in the workplace. Refer to Appendix L for the adult and child lead modeling.

8.4 SOUTHWEST LAGOON RISK SUMMARY

A summary of the risks for each exposure scenario for the SW lagoon is presented in Table 63. Highlighted areas on the table indicate risks above acceptable levels (cancer risk $>1E-04$ or $HI>1$). Note that surface water exposure is included in the SW lagoon assessment.

Time Frame	Population	Total Carcinogenic Risk Across All Media and All Exposure Routes	Total Hazard Index Across All Media and All Exposure Routes
Current/Future	Industrial Worker	2.4E-06	2.06 (1.6)
Current/Future	Visitor/Trespasser	2.3E-07	4.4 (1.03)
Current/Future	Other ^a	4.4E-08	0.90
Future	Adult	9.5E-06	8.8 (3.19)
Future	Child	1.4E-04 (6.6E-05)	62.0 (25.3)
Future	Adult/Child	1.4E-04 (6.6E-05)	n/a
Current/Future	Adult at Fence line	6.7E-08	0.00054
Current/Future	Child at Fence line	9.6E-08	0.0017
Current/Future	Adult/Child at Fence line	1.6E-07	n/a

The following are the primary conclusions about the risks assessed for the SW lagoon:

- The off-site air risks for the exposure of current/future residents at the fence line are at least 2 orders of magnitude below the acceptable risk levels for the SW lagoon.
- The risks to current/future "Others" are well below the acceptable risk levels for the SE lagoon.
- The carcinogenic risk to current/future industrial workers is slightly **above** the 1E-06 "point of departure," but still below the acceptable risk level for the SW lagoon. However, the noncarcinogenic risk for this receptor is slightly **above** the acceptable risk level for the SW lagoon for both the RME (2.02) and CT (1.6) scenarios. Dermal contact with the surface water is the primary route of exposure for this risk, and the target organ is the kidney. Cadmium is the primary noncarcinogenic risk driver.
- The carcinogenic risk to current/future visitors/trespassers is below the acceptable risk level for the SW lagoon. However, the noncarcinogenic risk for this receptor is slightly **above** the acceptable risk level for the SW lagoon for the RME scenario (4.4), and equivalent to the acceptable risk level for the CT scenario (1.03). Dermal contact with the surface water is the primary route of exposure for this risk, and the target organ is the kidney. Cadmium is the primary noncarcinogenic risk driver.
- The cumulative carcinogenic risk to future residents (adult/child) is slightly **above** the acceptable risk level for the SW lagoon for the RME scenario (1.4E-04), but slightly below the acceptable risk level for the CT (6.6E-05) scenario. Future resident child ingestion of soil is the primary route of exposure for this risk and vinyl chloride is the primary carcinogenic risk driver.
- The noncarcinogenic risk to future resident children is **above** the acceptable risk level for the SE lagoon for both the RME (62) and CT (25.3) scenarios. Soil ingestion (primary) and ingestion and dermal contact with surface water (secondary) are the routes of exposure for this risk, and the target organs are the kidney and liver. Cadmium, chromium, and iron are the primary noncarcinogenic risk drivers for the soil, and cadmium is the primary driver for the surface water.

Although iron is considered to be attributable to "background" in the SW lagoon soil, the RME and CT scenario risk values would still be above the acceptable risk level if this "background" COPC was eliminated from the risk calculation because of the other COPCs and the surface water exposure.

It should be noted that the presence of surface water in the SW lagoon is intermittent, and its presence is related to precipitation. This should be considered as part of any risk management decision related to the SW lagoon. However, the RME and CT scenario risk values would still be above the acceptable risk level if the surface water was eliminated from the risk calculation.

- The noncarcinogenic risk to future resident adults is also above the acceptable risk level for the SW lagoon for both the RME (8.8) and CT (3.17) scenarios. Soil ingestion (primary) and dermal contact with surface water (secondary) are the routes of exposure for this risk, and the target organ is the kidney. Cadmium is the primary noncarcinogenic risk driver for the soil and the surface water.

It should be noted that the presence of surface water in the SW lagoon is intermittent, and its presence is related to precipitation. The surface water is currently being pumped to the facility for treatment. This should be considered as part of any risk management decision related to the SW lagoon. However, the RME and CT scenario risk values would still be above the acceptable risk level if the surface water was eliminated from the risk calculation.

- The results of the IEUBK model indicate that the level of lead in the soil of the SW lagoon is above EPA's current health-based level of concern for both children and adults for the residential exposure scenario. Soil ingestion is the primary exposure route for this potential risk. Blood lead levels were also exceeded for the industrial work. Results of the adult lead model protect the pregnant woman's fetus in the workplace. Refer to Appendix L for the adult and child lead modeling.

8.5 SUMMARY OF SOIL-TO-GROUNDWATER PATHWAY SUMMARY

The following is a summary of the soil-to-groundwater pathway for each earthen lagoon.

The earthen lagoons are located in the 100-year floodplain of the Schuylkill River. Most of the lagoons are composed of white and gray materials (sludge) which are products of the PVC manufacturing process. The underlying soil beneath the sludge consists generally of a coal fine layer, clay and bedrock. The stratigraphy logs revealed the absence of sludge in the North West (NW) lagoon, and only 0 to 4 feet of sludge in South West (SW) lagoon. The coal fine layer is completely absence in the North West Lagoon.

The average soil concentration for each contaminant in each lagoon was used as the screening concentration and then compared to the SSL for that contaminant to determine if it would likely leach to groundwater at a concentration greater than the RBCs and/or MCLs. A table with the concentrations used for screening and the SSLs are included in appendix M.

The following is a summary of the soil-to-groundwater pathway for each earthen lagoon.

NORTHEAST LAGOON

- Sludge is currently present from 16 to 19 feet below land surface.
- Sixteen (16) VOCs were detected in this lagoon (see Appendix M).
- The screening concentration of twelve of the detected VOCs were above the Soil Screening Levels (SSLs). These were: 1, 1-Dichloroethene, 1, 2-Dichloroethane, 4-Methyl-2-pentanone, Acetone, Carbon Disulfide, cis-1, 2-Dichloroethene, Ethyl benzene, Tetrachloroethene (TCA), Toluene, trans-1, 2-Dichloroethene, Trichloroethene (TCE), and Vinyl Chloride. All of these VOCs were detected in the soil beneath the sludge, except for 1, 1-Dichloroethene, 1, 2-Dichloroethane, Acetone, and TCA.

- Four (4) SOVs were detected in the northeast lagoon. Of those, only Acetophenone was above the SSL.
- Seven metals: antimony, arsenic, barium, cadmium, chromium, iron, and manganese, were above the SSLs.

NORTH WEST LAGOON

- Sludge is not present in this lagoon.
- Four (4) VOCs were detected in the southwest lagoon (see Appendix M).
- None of the concentration of the detected VOCs was above the SSLs
- No SVOCs were detected in the Northwest lagoon..
- Eight metals: antimony, arsenic, barium, chromium, cobalt, manganese, and nickel, were above the SSLs

SOUTH EAST LAGOON

- Sludge is currently present from 10 to 13 feet below land surface.
- Fifteen (15) VOCs were detected in the southeast lagoon (see appendix M).
- The concentration of eleven (11) of the detected VOCs were above the SSLs. These were: 1, 2-Dichloroethane, 4-Methyl-2-pentanone, Benzene, Carbon Disulfide, Chloromethane, cis-1, 2-Dichloroethene, Ethyl benzene, Toluene, trans-1, 2-Dichloroethene, TCE, and Vinyl Chloride. Eleven of these VOCs were detected in the soil beneath the sludge except for 1, 2-Dichloroethane, and Chloromethane.
- Five (5) SOVs were detected in the southeast lagoon. Of those, only Benzaldehyde and Naphthalene were above the SSLs.
- Six metals: antimony, arsenic, cadmium, chromium, iron, and manganese, were above the SSLs.

SOUTH WEST LAGOON

- Sludge is currently present from 0 to 4 feet below land surface.
- Twelve (12) VOCs were detected in the southwest lagoon (see appendix M).
- The concentration of seven (7) of the detected VOCs were above the SSLs. These were: 1, 2-Dichloroethane, Benzene, cis-1, 2-Dichloroethene, Methylene Chloride, Toluene, TCE, and Vinyl Chloride. All of the VOCs were detected in the soil beneath the sludge.
- Ten (10) SVOCs were detected in the northeast lagoon. The concentration of seven SVOCs (2,4-Dimethylphenol, 2-Methyl naphthalene, 4-Methylphenol, Benzaldehyde, Dibenzofuran, Naphthalene, Phenanthrene) were above the SSL.
- Nine metals (arsenic, Barium, cadmium, chromium, iron, lead, manganese, Mercury and Nickel) were above the SSLs.

8.6 SUMMARY OF MEDIA/EXPOSURE POINTS THAT MAY TRIGGER REMEDIAL ACTION

A summary of the media/exposure points identified in the quantitative risk assessment that may trigger remedial action at the Occidental Chemical Superfund site are presented in Table 64. All of these exposure pathways exceed a cancer risk $>1E-04$ or a noncarcinogenic risk $HI>1$. Both RME and CT (in parenthesis) values are provided in the table. In addition, potential soil-to-groundwater risks that may trigger remedial action are presented on Table 65. See Section 7.2.2 and Appendix J for a detailed discussion regarding contaminants attributable to background.

Table 64 Summary of Media/Exposure Points that May Trigger Remedial Action Occidental Chemical Site			
Receptor Population	Cumulative Carcinogenic Risk >10E-4	Total Hazard Index >1	Main Risk Drivers ^a
NE Lagoon			
Future Resident Child (risks driven by soil ingestion)	2E-03 (9E-04)	3.03 (1.4)	vinyl chloride; bis 2-ethylhexyl phthalate; TCE thallium; [iron]
Future Resident Adult/Child (carcinogenic risk driven by soil ingestion)	2E-03 (9E-04)	n/a	
NW Lagoon			
Future Resident Child ^b (noncarcinogenic risk driven by soil ingestion [primary risk driver] and ingestion of and dermal contact with surface water [secondary risk driver])	No Cumulative Risk >10E-4	6.8 (2.5)	Soil - {manganese; iron} Surface water - cadmium
SE Lagoon			
Future Resident Adult (risks driven by soil ingestion)	3E-04 (5E-05)	No Commutative Hazard > 1	bis-2 ethylhexyl phthalate; vinyl chloride; TCE
Future Resident Child (risks driven by soil ingestion)	5E-03 (2.5E-03)	10.1 (4.6)	
Future Resident Adult/Child (carcinogenic risk driven by soil ingestion)	5.7E-03 (3E-03)	n/a	
SW Lagoon			
Current/Future Industrial Worker (noncarcinogenic risk driven by dermal contact with surface water) ^c	No Cumulative Risk >10E-4	2.06 (1.6)	Cadmium
Current/Future Visitor/Trespasser (noncarcinogenic risk driven by dermal contact with surface water) ^c	No Cumulative Risk >10E-4	4.4 (1.03)	Cadmium
Future Resident Adult (noncarcinogenic risk driven by soil ingestion [primary risk driver] and dermal contact with surface water [secondary risk driver ^c]). Soil lead exposure also exceeds target levels for this receptor.	No Cumulative Risk >10E-4	8.8 (3.17)	Soil and Surface Water - cadmium
Future Resident Child (carcinogenic risk driven by soil ingestion and noncarcinogenic risk driven by soil ingestion [primary risk driver] and ingestion of and dermal contact with surface water [secondary risk driver ^c]). Soil lead exposure also exceeds target levels for this receptor.	1.4E-04 (6.4E-05)	62.0 (25.3)	Soil - vinyl chloride; cadmium; chromium; [iron] Surface Water - cadmium
Future Resident Adult/Child (carcinogenic risk driven by soil ingestion)	1.4E-04 (6.6E-05)	n/a	vinyl chloride

Table 64			
Summary of Media/Exposure Points that May Trigger Remedial Action			
Occidental Chemical Site			
Receptor Population	Cumulative Carcinogenic Risk >10E-4	Total Hazard Index >1	Main Risk Drivers ^a
<p>Central Tendency Exposure Value presented in parenthesis.</p> <p>a - These are the chemicals that are the main risk drivers for the exposure pathway that are attributable to site contamination. Any main risk drivers attributable to background are presented in brackets.</p> <p>b - Noncarcinogenic risk for this pathway is related to soil COPCs which are considered to be attributable to background. Elimination of background COPCs from the risk calculations would reduce the CT value to below the acceptable risk level, but the RME value would remain above the acceptable risk level because of surface water exposure. However, surface water is intermittent in the lagoon and pumped to the facility for treatment, so this risk is probably overestimated given that the exposure assumptions would probably not be satisfied. This should be carefully considered as part of any risk management decision.</p> <p>c - Surface water is intermittent in the lagoons and is currently collected and pumped to the facility for treatment. Therefore, any surface water risk is probably overestimated given that the exposure assumptions would probably not be satisfied. This should be carefully considered as part of any risk management decision.</p>			

The lead content in the SW lagoon surface and subsurface soil (which is in excess of the EPA residential preliminary remedial goal of 400 mg/kg) may also trigger remedial action for the current/future industrial worker and future resident.

Based on the soil to groundwater analysis, the following COPCs were identified for each of the lagoons. These COPCs may trigger remedial action for groundwater in the earthen lagoons (see Table 65).

None of the concentration of the detected VOCs and SVOCs are above the SSLs at the NW lagoon. All the metals detected at the NW lagoon, except nickel, are below background. Based on the soil to groundwater analysis, the NW lagoon may not trigger any remedial action.

The analysis shows that vertical migration of leachate into bedrock is occurring. With the exemption of the NW Lagoon contaminants are present in the soils directly underlying the sludge. These contaminants detected in the underlying soils are those that are present in the sludge inside the lagoons.

The 1994 Record of Decision (ROD) for Occidental Chemical Corporation Site states that the coal fine material has served as a collection/adsorption for the chemicals and that the soil beneath the coal fine material of the earthen lagoons has not been affected. However, this soil to groundwater pathway analysis shows that this is not the case at this time, where the soil underlying the sludge and the coal fine material has been impacted by the contaminants. The high concentrations of several contaminants in the underlying soils show that the coal fine material is no longer preventing the vertical migration of the contamination.

The five volatile organic compounds identified as chemicals of concerns (COCs) in the 1994 ROD for the groundwater were detected in the earthen lagoons. These compounds are ethyl benzene, styrene, trans-1, 2-Dichloroethene (trans-1, 2-DCE), Vinyl Chloride, trichloroethylene (TCE). All of these COCs were detected in the sludge and in the underlying soils. The migration of these chemicals represents a continuous source of contamination for the groundwater.

Table 65 Summary of Soil-to-Groundwater Pathway Contaminants that May Trigger Remedial Action Occidental Chemical Site				
Chemical	NE Lagoon	NW Lagoon	SE Lagoon	SW Lagoon
1-1 dichloroethene	X			
1-2 dichloroethene	X		X	X
4-methyl-2 acetone	X		X	
acetone	X			
benzene			X	X
carbon disulfide	X		X	
cis, 1-2 dichloroethene	X		X	X
methylene chloride				X
ethyl benzene	X		X	
trichloroethene	X		X	X
tetrachloroethene	X			
toluene	X		X	X
trans 1,2 - dichloroethene	X		X	
vinyl chloride	X		X	X
chloromethane			X	
acetophenone	B			
benzaldehyde			X	
dibenzofuran				X
naphthalene			X	X
phenanthrene				X
2-4 dimethylphenol				X
2-methylnaphthalene				X
4-methylphenol				X
arsenic	B	B	B	B
antimony	B	B	B	
barium	B	B		X
cadmium	B		B	X
chromium	X	B	X	X
colbalt		B		
iron	X	B	B	B
lead				X
manganesc	X	B	B	B
mercury				B
nickel		X		B

X = Contaminant present at concentration in excess of SSLs.
B = Contaminant present, but background analysis indicates no significant difference between the average or median concentration of this COPC in the lagoon and background locations.

It should be noted that there are various uncertainties associated with this risk assessment. Most uncertainties identified will result in the potential for overestimation of risk for both the RME and CT scenarios (i.e., the combination of several upper-bound assumptions for most exposure scenarios). These uncertainties should be considered as part of any risk management decision about the site.

APPENDIX C
REFERENCES REGARDING DIOXIN FORMATION

TECHNICAL PAPER

ISSN 1047-3289 J. Air & Waste Manage. Assoc. 52:811-821

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Establishing the Propensity for Dioxin Formation Using a Plume Temperature Model for Medical Waste Incinerator Emissions in Developing Countries

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ABSTRACT

Air pollution control devices (APCDs) are not compulsory for medical waste incinerators (MWIs) in developing countries. In South Africa, combustion gases are usually vented directly to the atmosphere at temperatures greater than the formation temperature of dioxin. The possibility of dioxin formation outside the incinerator stack has been hypothesized. A plume model has been developed and tested in the wind tunnel with a scale model of an incinerator stack. The plume temperature and trajectory predictions of the plume model were verified within a $\pm 3\%$ experimental accuracy. Using South African data, the plume model predicts that the residence time of gases in the temperature range of 150–450 °C in a plume is 1.3 sec on average for 5% of a year (18 days) at meteorological conditions resulting in wind speeds of less than 1 m/sec. Two published dioxin formation models were used to assess the probability of dioxin formation in the plume. The formation models predict that the average polychlorinated

dibenzodioxins/furans (PCDD/Fs) formed in the plume will exceed the stack emission regulations in South Africa of 0.2 ng/Nm³ toxic equivalent quotient (TEQ) by between 2 and 40 times. The calculated concentrations do not include additional gaseous PCDD/F compounds that may be formed at high-temperature post-combustion zones through pyrosynthesis mechanisms.

INTRODUCTION

Regulatory guidelines¹ for the incineration of medical waste are not strictly enforced by the South African authorities, because of ongoing changes in the current legislation and national waste management strategies.² Air pollution control devices (APCD) are not compulsory, and combustion gases may be emitted directly to atmosphere at high temperatures. For some incineration processes in South Africa, temperatures as high as 900 °C have been recorded.³ Although dioxins are formed at temperatures lower than this, there is no measurement data to indicate the amounts formed in the plumes from incinerator stack tips.

A survey of the literature has shown that no calculations are available to estimate dioxins formed within the first section of the plume. Measurements of dioxins present in stacks have been correlated with the concentrations of particulates, inorganic chlorides, metallic species, and organic precursors,^{4,9} and with the residence time of the gases within the temperature ranges of 150–450 °C^{7,8} and 250–450 °C.⁷ To determine whether these conditions exist for significant periods, a model for plume behavior close to the tip of the stack is required.

The plume region prior to the establishment of horizontal flow has been described using fluid dynamic principles¹⁰ and by the classical empirical equations derived by Briggs.¹¹ At the exit of the stack tip, the plume is assumed

IMPLICATIONS

At present, waste managers in developing countries assume that direct venting to the atmosphere acts as an adequate quenching process to prevent the formation of dioxin compounds in the plumes of MWIs. The results indicate that the temperatures and residence times in plumes above an incinerator can be similar to those in the post-combustion zone of incinerators where dioxin compounds have been measured. When these temperatures and residence times are used in the most recent dioxin formation models, the predicted amounts of dioxins exceed the emission concentration guidelines of the South African government.

to be a round, perpendicular jet issuing into a horizontal flow of ambient air. The physical conditions of the plume are described by dividing the plume¹² into a zone of laminar flow [i.e., the zone of flow establishment (ZFE)], and a zone of cyclonic flow [i.e., the zone of established flow (ZEF)]. The ZFE has the characteristic parameters of a jet.¹⁰ It has been found that inside the ZFE, the flow distribution does not follow a Gaussian profile because of eddy exchange coefficients.¹³ The ZEF takes into account the conditions above the jet caused by turbulence of both the jet and the ambient flowing medium, where the plume bends over and a Gaussian profile occurs.¹⁴

Studies on a medical waste incinerator (MWI) in South Africa^{15,16} indicate that the temperature range of 150–450 °C, where dioxins may be formed, occurs in the transition from the ZFE to the ZEF after the gases have left the stack tip. The MWI is a simple retort-type multiple-chamber design¹⁷ without APCD, and is a semi-batch operation.^{15,16} The importance of dioxin formation was emphasized as the result of work carried out by the CSIR for a multi-pathway health risk assessment (MPHRA) of this MWI¹⁵ during which conditions in the stack of the incinerator were extensively measured.¹⁶ However, dioxins and furans could not be sampled, because the gas temperature in the stack is greater than the 450 °C temperature during normal operation.¹⁶ Because dioxin was the key risk driver in the MPHRA, a scientific basis for obtaining an upper estimate of the dioxin emissions was required.

A two-stage model (PlumeDIOX) was developed by the CSIR to provide estimates of the concentration of dioxin compounds formed in the MWI plume. PlumeDIOX combines a hot plume model, describing the physical characteristics of the plume during the cool-down to ambient temperatures, with published dioxin formation models.⁷⁻⁹

DEVELOPMENT OF A HOT PLUME MODEL

Empirical equations derived by Briggs¹¹ are applicable only to determine the final plume height and cannot be used to estimate the plume characteristics close to the stack exit. In addition, the Lagrangian velocity correlation coefficient indicates that a Gaussian model is not applicable very close to the source, where diffusion is rapid.¹⁸ A similarity or Gaussian model can, however, be used when the plume is in the established flow region.

In the ZFE, the necessary equations were derived from the properties of a deflected turbulent jet.^{10,11,14,19} In the ZEF, the physical characteristics of the plume were determined from the conservation of mass, momentum, and energy.^{12,13,20,21} Appendix A summarizes the equations used to describe these two zones of the hot plume.

Assumptions Used in the Development of the Plume Model

The following assumptions simplify the mathematical description of the model:

- The ZFE corresponds to calculations of a deflected jet,¹⁰ and viscous effects can be neglected. However, some corrections are made for the density and velocity changes caused by buoyancy.¹⁹ The bend-over of the plume that does occur in this zone is calculated from a modification to the Briggs equation for a bent-over buoyant plume;¹¹
- In the ZEF, the mean flow velocity perpendicular to the main flow along the length of the plume is small in comparison with the main flow velocity. The secondary flows perpendicular to the plume axis caused by bend-over of the plume are consequently ignored;
- In the ZEF, the turbulence is uniform, giving a Gaussian concentration distribution profile;²²
- Molecular transports are considered negligible in comparison with turbulent transports;
- Once released into the atmosphere, the plume is an isobaric system;²³
- Aerodynamic effects such as down-wash of the plume caused by surrounding structures are neglected;
- Linear mixing occurs after the stack exit (i.e., the density of the mixture is a volume-weighted average of the densities of the components);²¹
- The molecular weight and specific heat of the exit gases are approximately the same as those of the surrounding air; and
- The model is formulated as a steady-state model in which time derivatives are set equal to zero.

Plume Coordinates Used in the Model Calculations

The equations are based on the system illustrated¹² in Figure 1. The system can briefly be described as follows:

- The ambient wind velocity is uniform and horizontal over the whole height of the plume and is given by the term U ;
- The first part of the plume is already known as the ZFE. Its length is given by the term δ . The characteristics of the plume at the end of this zone will describe the origin of the coordinate system for the ZEF;
- The ZEF is treated as an axis-symmetric turbulent plume with a temperature gradient only in the vertical direction. Consequently, only a two-dimensional coordinate system is considered, with y being the distance above the origin and x the approximate distance from the origin; and

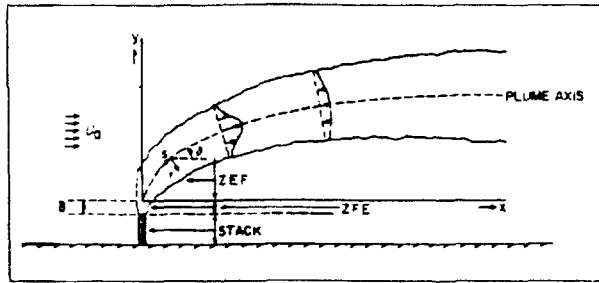


Figure 1. Plume coordinates used for mathematical formulation.

- s , r , and ϕ are taken as the plume coordinates in the ZEF, as shown in Figure 1.

Hot Plume Model Verification

An experimental study was conducted at the wind tunnel facilities of the Division of Aeronautical Science and Technology (Aerotek) of the CSIR, South Africa.²⁴ The experimental design consisted of a hot plume ejected into a steady horizontal cross flow. The stack was 0.2 m in diameter and 1.2 m high, and was insulated to prevent excess heat loss. Cyclonic flow in the stack was prevented by a flow distributor system at the bottom of the stack. The stack was placed close (~0.5 m) to the inlet of the wind tunnel. The total flow height of the tunnel is 1.5 m, with 1 m above ground level. The stack therefore extended into the horizontal flow region by 0.2 m. An average cross flow of between 1.3 and 1.6 m/sec was maintained in the wind tunnel. Further stability could not be attained because of the influence of ambient conditions outside the inlet and outlet of the tunnel at these low velocities.

A liquid petroleum gas (LPG) burner, operating at an LPG-to-air ratio slightly higher than the stoichiometric requirement, was used to generate the hot plume from the stack. Dilution air was injected at the bottom of the experimental stack to obtain an adequate exit flow rate and also consumed the remaining excess LPG. The LPG gas and burner airflow rates were controlled using calibrated rotameters. The total airflow (burner and dilution) was controlled using a 28-mm orifice plate and water u-tube manometer.²⁴ The exit velocity of the stack gas was calculated from a mass balance over the burner/stack system and the measured exit temperature. The ambient cross-flow velocity was measured with a hot wire anemometer.

The temperatures along the plume trajectory were measured using five thermocouples, placed in line with the cross wind as indicated in Figure 2. The central thermocouple at the stack exit was taken as the zero reference point in space. The five thermocouples were mounted on a computerized xyz table. The linear movement of the plume toward the tunnel exit was confirmed by a smoke releaser. The thermocouples were therefore moved only in the xy direction. Random incremental steps were taken

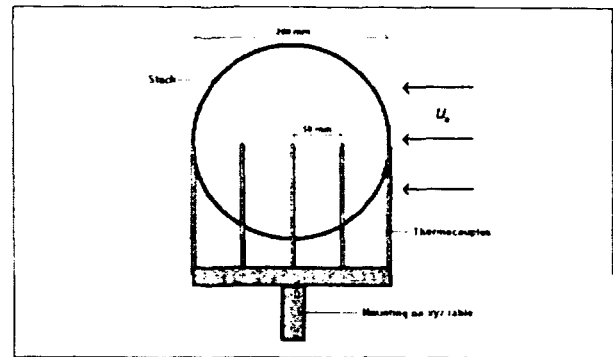


Figure 2. Thermocouple positioning at the stack exit.

until the highest temperature was observed between the five thermocouples. The position of the thermocouples was maintained at this location for ~5 min to reach temperature stability. A third-order polynomial curve was fitted to the data at each measurement location to determine the plume center location and temperature (Figure 3).

Table 1 summarizes the conditions of the exit plume and the ambient conditions generated inside the wind tunnel. In Table 1, the experimental values are compared with those of an industrial incinerator, which the experimental stack simulates. For an accurate simulation, the Reynolds number of the exiting plume and the velocity ratio (U/U_0) should be similar²⁵ for both the scaled-down stack and the industrial process. The values given for the industrial process in the table are typical of conditions that have been measured at some plants in South Africa.²⁶ The results of one measurement cycle are compared with the model predictions in Figures 4 and 5.

Verification Discussion. The accuracy of the model was estimated from the correlation coefficient between the measured values and the values predicted by the model. This coefficient measures the relationship between two data sets independent of the unit of measurement. The population correlation calculation returns the covariance

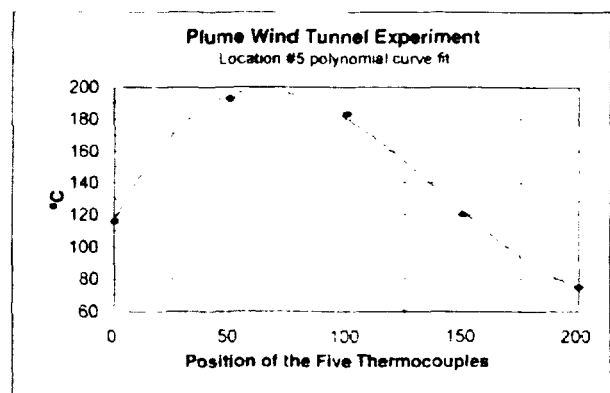


Figure 3. Polynomial curve fitted to the fifth measurement location's data.

Table 1. Conditions of the CSIR wind tunnel experiment.

Property	Units	Experiment	Industrial Process
Temperature	°C	286	900
Velocity	m/sec	1.49	5
Diameter	m	0.2	0.2
Density	kg/m ³	0.56	0.27
Viscosity	kg/m sec	0.29	0.47
Wind velocity	m/sec	1.42	5
Reynolds number		5740	5731
Velocity ratio		1.05	1.00

of two data sets divided by the root product of their standard deviations^{2b}

$$v = \frac{Cov(\xi, \eta)}{\sqrt{Var\xi \cdot Var\eta}} \quad (1)$$

where v is the correlation coefficient, η is the model data set, and ξ is the measured data set. The data set of the CSIR wind tunnel experiment consisted of two independent sets of 11 values each, on which a correlation calculation could be carried out with eq 1. The results are given in Table 2.

Conclusions from the Model Verification. The temperature prediction along the plume trajectory is accurate within 3%, with a correlation coefficient of more than 99%. This discrepancy tends toward an overprediction, which leads to a slight overestimate of the residence time within a temperature range. Additional verifications will have to be made at real stack locations to substantiate these conclusions.

APPLICATION OF THE PROPOSED PLUME MODEL

The model was applied to a high-temperature plume from the stack of a medical waste incinerator (MWI) in South Africa. This incinerator underwent intensive evaluation by the CSIR over a two-year period.^{1b} The meteorological conditions for the region are often relatively warm and

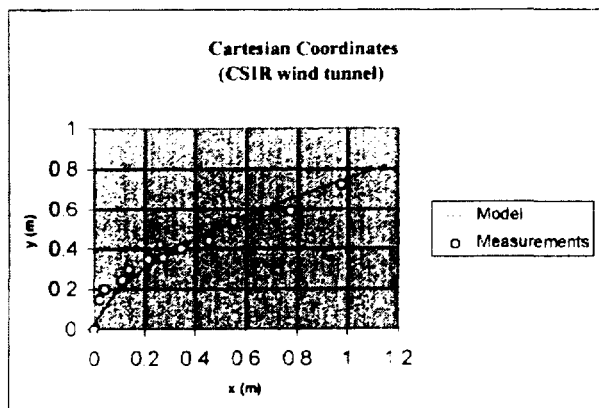


Figure 4. Plume path results of the CSIR measurement campaign.

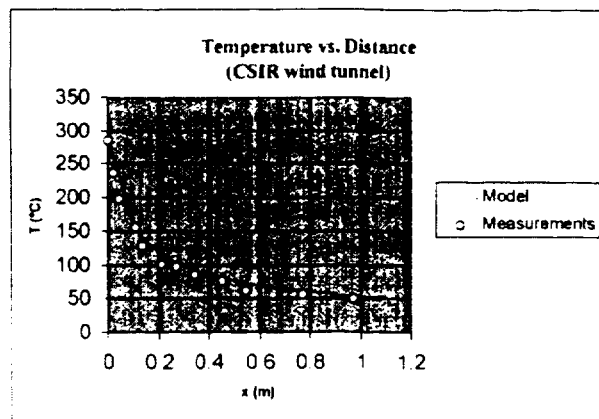


Figure 5. Temperature results of the CSIR measurement campaign.

calm. It is known that dioxin compounds are formed in the post-combustion gases of MWIs when the gases are cooled.⁴ The highest amount of dioxins are formed when

- The combustion efficiency is low (<99%);
- Chlorinated plastics are present in the feed (e.g., PVC); and
- High concentrations of metallic species are present on the emission particulates (i.e., Fe and Cu).

The latter two conditions are true for the MWI in South Africa, and it is hypothesized that dioxins are formed in the plume.

Mechanisms for Dioxin Compound Formation

The dioxin group of compounds includes polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF). Four possible pathways have been proposed for the observed presence of the dioxin group of compounds in the flue gases from combustion processes,^{4,27} although the contributions of different mechanisms are still under debate.²⁷

- The presence of PCDD and PCDF in the waste that is burnt;
- Pyrosynthesis (i.e., high-temperature gas-phase formation);
- Formation by way of reactions between chemically related compounds (precursors), such as chlorophenols, condensed on the fly ash; and
- Formation via de novo synthesis from chemically unrelated compounds and chlorine donors on the fly ash between temperatures of 250 and 450 °C.

Table 2. Correlation coefficient for the measurement campaign at the CSIR.

Parameter		Correlation	
Height above stack at x	r	99.05	%
Temperature at x	r	99.19	%

It is assumed, from available evidence,²⁶ that medical waste contains no dioxins. The pyrosynthesis pathway is considered less important at the lower temperatures in the plume.²⁷ However, formation of PCDD/Fs through this mechanism²⁹ could take place in the high-temperature post-combustion zones before the stack tip. The reaction of condensed precursors and de novo synthesis pathways are considered as possible post-combustion formation mechanisms²⁷ in the plume. Metallic species, especially Fe and Cu,³⁰ have also been shown to catalyze these formation mechanisms.⁷ A large concentration of metallic species, especially Fe, Cr, Cu, and Mn, has been measured at the MWI considered here.² This emphasizes the importance of these two mechanisms for the potential risk of PCDD/F formation in the plume.

Condensed Precursor Pathway of PCDD/F Formation. This heterogeneous model^{7,8} for the formation of dioxins between temperatures of 150 and 450 °C follows a gas-fly ash reaction mechanism for the formation of the dioxin group of compounds. The fly ash from the incineration process is a catalyst for surface reactions. The total concentration of dioxins in the solid phase can be calculated from the actual residence time t of the gas and particulate mixture and the average particulate concentration M_p in a temperature range T , using the equations summarized in Appendix B. The equations also calculate the desorbed dioxin. These, however, do not include all the dioxin in the gaseous phase.

De Novo Synthesis Pathway of PCDD/F Formation. The proposed empirical model⁹ for de novo synthesis on incinerator fly ash between 450 and 225 °C assumes that the reaction of Cl from HCl with carbon on the fly ash results in PCDD/F formation. All reactions, therefore, take place on the surface of the fly ash, where metals act as catalyst. Empirical eq 34 in appendix C can be numerically integrated assuming a linear cooling rate and an initial dioxin concentration from the combustion process.⁹ Again, the calculated concentration does not include the gaseous phase because formation in the high-temperature post-combustion stages is not considered and desorption is ignored in the model.

Case Study Incinerator Conditions

The initial conditions at the stack tip of the case study MWI are summarized in Table 3. For a conservative assessment, calm atmosphere conditions were considered, because it is not expected that the residence time of the plume within the required temperature range will be significant at higher wind speeds. The wind speed for extremely calm conditions was taken to be less than

Table 3. Initial conditions at the stack tip of the case study incinerator

Parameter		Value	
Mean wind velocity	U_a	0.5	m/sec
Ambient temperature	T_a	19.7	°C
Ambient density	ρ_a	1.002	kg/m ³
Emission exit velocity	U_0	4.62	m/sec
Emission exit temperature	T_0	460	°C
Emission exit density	ρ_0	0.402	kg/m ³
Initial plume angle	φ_0	1.571	rad
Stack diameter	D	0.915	m

1 m/sec. An average ambient velocity of 0.5 m/sec was chosen for the model calculations because of wind fluctuations.

Plume Model Predictions

ZFE. Following the proposed plume model, the relevant parameters were calculated at the end of the ZFE. These values are summarized in Table 4. Figure 6 is a graphical representation of the calculated plume path over the whole temperature range. The transition from the ZFE to the ZEF is indicated by the arrow.

ZEF. For the ZEF, the parameters were calculated over the additional section of the plume trajectory until the target temperature was reached. The results of the calculations are plotted in Figures 6 and 7. A comparison of the two figures indicates the distance along the plume trajectory to the target cool-down temperature. The calculated values of the other plume characteristics are summarized in Table 5.

Estimation of Dioxin Formation with the Precursor Condensation Model

Using the results obtained from the plume model and specifically the residence time in the temperature range 450–150 °C, the potential for the formation of dioxin in the plume can be estimated using the precursor condensation pathway. The particle concentration at the target cool-down temperature of 150 °C is calculated from the ratios of the plume cross-sectional areas.

Table 4. Plume conditions at the end of the ZFE

Parameter		Value	
Path length of the ZFE	δ	4.575	m
Plume velocity	u_1	5.1	m/sec
Characteristic plume width	b	0.647	m
Plume density	ρ_1	0.562	kg/m ³
Plume temperature	T_1	249.1	°C
Plume angle	ω_1	1.488	rad
Residence time	t_1	0.938	sec

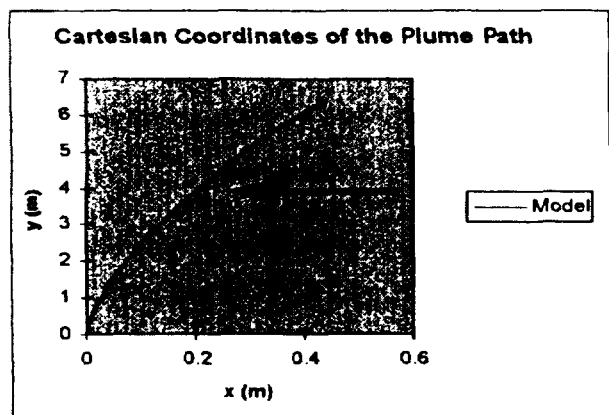


Figure 6. Plume Cartesian coordinates over the whole plume trajectory.

$$C_{\text{target}} = C_0 \cdot \frac{A_0}{A_{\text{target}}} \quad (2)$$

with $C_0 = 0.22 \times 10^{-6} \text{ g/cm}^3$ (3)

$$A_0 = \frac{\pi}{4} \cdot D^2 = 0.66 \quad (4)$$

$$A_{\text{target}} = \frac{\pi}{4} \cdot (h_{\text{target}})^2 = 3.38 \quad (5)$$

The following parameters are used in the model with the assumptions and equations of Appendix B:

- An average particulate concentration of 73.2 mg/Am³;
- A residence time of the plume of 1.3 sec between 450 and 150 °C; and
- An average temperature of 300 °C, which is also the temperature of maximum dioxin formation.¹¹

Assuming that tetrachlorinated dioxins are formed with a molecular mass of 321 g/mol, the total solid-phase dioxins are calculated to be 6.97 ng/Nm³. The desorbed concentration is insignificantly small. The results are shown in Table 6.

Sensitivity of the Condensed Precursor Model. A change in the particulate concentration has a very small influence on the PCDD/F solid-phase formation calculation with

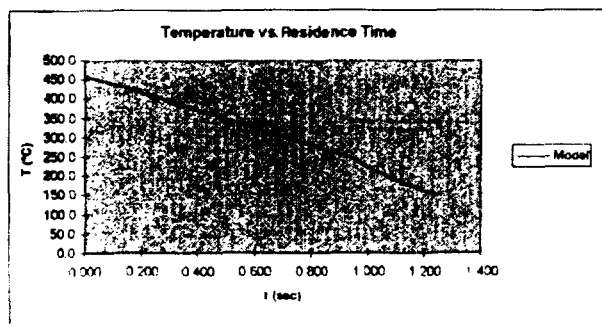


Figure 7. Cool-down rate over the trajectory of the case study plume.

Table 5. Parameter values at the target temperature after cool-down of the plume

Parameter		Value	
Target temperature	T_{target}	150	°C
Reference density	ρ_{ref}	3.694	g/m ³
Density difference	ρ_{diff}	-0.308	g/m ³
Plume width	D_{plume}	2.075	m
Height above the stack	z_{stack}	6.277	m
Distance from the stack	x_{ZEF}	0.428	m
Distance along trajectory	S_{plume}	6.325	m
Plume velocity	$U^*(S_{\text{plume}})$	5.7	m/sec
Residence time in ZEF	t_{ZEF}	1.252	sec

the precursor condensation model. The calculation is linear with residence time (i.e., a fluctuation of 10% in the total residence time results in a similar change in PCDD/F concentration prediction). The average plume temperature, however, has a significant influence on the overall concentration, with a 10% higher temperature resulting in a factor 2 increase in concentration. This is shown in Figure 8.

Estimation of Dioxin Formation with the De Novo Synthesis Model

Similar to the precursor formation model, the average particulate concentration required for the de novo synthesis model can then be calculated using eq 3. The following parameters are used together with the equations of Appendix C:

- An average particulate concentration of 78.8 mg/Am³;
- A residence time of the plume of 0.98 sec between 450 and 225 °C; and
- An average temperature of 337.5 °C.

The results are shown in Table 7. The total PCDD/F calculation is higher than the calculation estimate of the precursor condensation model by a factor of 16.

Sensitivity of the De Novo Synthesis Model. The PCDD/F solid-phase formation calculation is linear with particulate concentration (i.e., a fluctuation of 10% in the average

Table 6. Solid-phase PCDD/F calculations using the precursor condensation model

Parameter	Precursor Condensation Model	
Applicable temperature range	450-150	°C
Residence time range	1.252	sec
Total predicted dioxins and furans	7.0	ng/Nm ³
TEQ estimated as 1/15th of the total concentration	0.46	ng/Nm ³

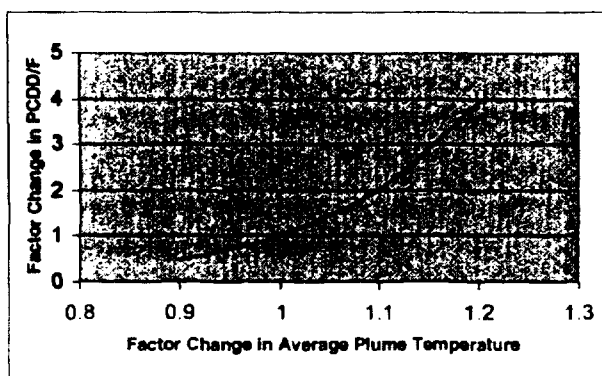


Figure 8. Sensitivity analysis of the precursor condensat on model with temperature.

particulate concentration results in a similar change in PCDD/F concentration prediction). The residence time and average plume temperature do not have a significant influence on the de novo synthesis model.

Discussion on the Dioxin Formation in an Incinerator Plume

Dioxin formation in plumes from MWIs can be reduced by a rapid decrease in the stack temperature and the precursor and metallic emission concentrations from the stack.

Exit Temperature. A rapid quench in the stack with a consequent exit temperature of 250 °C would reduce the amount of dioxins formed through both formation mechanisms. The PlumeDIOX model predicts a reduction in the residence time by up to 16% at an average temperature of 200 °C (precursor mechanism) and up to 66% at an average temperature of 237.5 °C (de novo mechanism). A total absorbed dioxin concentration of 0.28 ng/Nm³ is calculated through the precursor condensation mechanism (i.e., a factor of 25 lower than 7 ng/Nm³), while the PCDD/F formation through the de novo synthesis mechanism is insignificant.

Precursor Concentrations. The PlumeDIOX model predicts that reducing the precursor concentration of polychlorinated phenol to 150 µg/m³ by increasing the combustion efficiency of the incinerator would lower the total amount

Table 7. Solid-phase PCDD/F calculations using the de novo synthesis model.

Parameter	De Novo Synthesis Model	
Applicable temperature range	450–225	°C
Residence time in range	0.977	sec
Total predicted dioxins and furans	110.1	ng/Nm ³
TEQ estimated as 1/15th of the total concentration	7.34	ng/Nm ³

of dioxins formed by a factor of 2 (i.e., to 3.45 ng/Nm³). If the toxic equivalent quotient (TEQ) of dioxin is further estimated at one-fifteenth of the total concentration,¹⁵ the emission of dioxins is 0.23 ng/Nm³ TEQ, which is approximately equal to the South African and United States regulations.

Metal Emissions. A reduction in the concentration of metallic species, especially Cu and Fe, in the stack emissions would reduce the catalysis of the formation reactions. As an example,⁶ lowering the Fe concentration by a factor of 2 could reduce the concentration of absorbed dioxins on incineration ash by a factor of 2.4.

CONCLUSIONS

A plume model (PlumeDIOX) has been developed to describe the cool-down of a hot plume to ambient temperature. A verification of the model against temperature measurements along the plume trajectory reveals the model to agree within an experimental accuracy of ±3%. The model was incorporated into a computer program that can be used to determine the residence time, together with other characteristics, of a hot plume within a certain temperature range in a calm atmosphere.

The model was used to estimate the formation of the dioxin group of compounds by previously published mechanisms of condensed precursor reactions and de novo synthesis. The calculated values are summarized in Tables 6 and 7. The current regulation of South Africa¹ for dioxin emissions from hazardous waste incinerators, similar to that of the U.S. Environmental Protection Agency¹² in 1996, is 0.2 ng/Nm³ TEQ. Using the proposed PCDD/F formation mechanisms, and assuming a TEQ fraction of one-fifteenth of the total dioxins,¹⁵ this model calculates the PCDD/F formed in the plume to be above the current regulations for calm weather conditions by a factor of 2–40.

The compiled plume model (PlumeDIOX) can, therefore, be used to indicate possible PCDD/F formation in the plume from high-temperature processes. This does not include the gaseous formation of these compounds at high-temperature post-combustion zones through possible pyrosynthesis mechanisms. The inaccuracies of PlumeDIOX in terms of overall PCDD/F concentrations in the plume need to be verified further. However, PlumeDIOX does indicate that atmospheric quenching of incinerator plumes may not be adequate to prevent the formation of dioxins.

NOMENCLATURE FOR THE HOT PLUME MODEL

- $b(s)$ Local characteristic width of the plume, or radial length scale (m)
 C_d Drag coefficient

D	Stack diameter	(m)	δ	Length of the zone of flow establishment	(m)
F_D	Densimetric Froude number		ϵ	Eddy energy dissipation	(m ² /m ³)
g	Gravitational acceleration	(m/sec ²)	If not stated otherwise, the subscripts		
l	Characteristic length	(m)	• "0" refer to conditions at the stack exit,		
P	Pressure of the ambient atmosphere	(kg/m.sec ²)	• "1" refer to the conditions where the flow changes from one zone to the other, and		
r	Radial distance of a point inside the plume to the plume axis	(m)	• "target" or "2" refer to the target temperature and density to which the plume gases must cool down.		
R	Radius of the plume	(m)			
s	Distance along the plume axis from the origin of the zone of established flow	(m)			
t	Residence time for cool down	(sec)			
T	Temperature of the plume	(°C)			
T_a	Ambient temperature	(°C)			
T_{target}	Target temperature for the cool-down evaluation of the plume	(°C)			
$u(s,r,\phi)$	Plume velocity at a point in the plume along the direction of the tangent to the plume axis	(m/sec)			
$w(s,r,\phi)$	Plume velocity, perpendicular to the plume axis	(m/sec)			
$u'(s)$	The maximum plume velocity at a certain point on the plume axis, relative to the surrounding atmosphere, in the direction of the tangent to the plume axis	(m/sec)			
u'	Entrainment velocity caused by atmospheric turbulence	(m/sec)			
U_0	Exit velocity from the stack	(m/sec)			
U_a	Mean wind velocity	(m/sec)			
x	Cartesian coordinate	(m)			
y	Cartesian coordinate	(m)			
z	Cartesian coordinate	(m)			
α_1	Entrainment coefficient of a free jet				
α_2	Entrainment coefficient of a line thermal				
α_3	Entrainment coefficient caused by atmospheric turbulence				
λ^2	Turbulent Schmidt number				
$\rho(s,r,\phi)$	Plume density at a point inside the plume	(kg/m ³)			
ρ_a	Density of the atmosphere	(kg/m ³)			
ρ_{a0}	Density of the ambient at the stack exit	(kg/m ³)			
$\rho^*(s)$	Density difference between the plume axis and the ambient	(kg/m ³)			
ρ^*_0	Density difference between the plume and the ambient at the stack exit	(kg/m ³)			
ϕ	Angle between the plume axis and the horizontal				
β	Temperature coefficient	(K ⁻¹)			
NOMENCLATURE FOR CONDENSATION REACTION CALCULATIONS					
ξ_0	Gas-phase precursor number density	(molec/cm ³)			
k_1	Rate constant for dioxin formation	(sec ⁻¹)			
k_2	Rate constant for dioxin desorption	(sec ⁻¹)			
N_p	Fly ash number density	(particles/cm ³)			
M_p	Fly ash concentration	(g/cm ³)			
P	Equation variable				
Q	Equation variable				
r_p	Radius of a fly ash particle	(cm)			
R	Universal gas constant	(J/mol/K)			
t	Residence time for cool down to the reference temperature	(sec)			
T	Absolute temperature of the plume	(K)			
ρ_p	Density of the fly ash	(g/cm ³)			
σ_x	Effective precursor radius	(cm)			
σ_p	Effective fly ash radius	(cm)			
θ_x	Fractional coverage of fly ash by precursor molecules				
NOMENCLATURE FOR DE NOVO SYNTHESIS CALCULATIONS					
A_s	Surface area available for reaction	(m ² /g)			
d	Surface mean diameter	(m)			
M	Molecular mass of HCl	(g/mol)			
m_p	Concentration of PCDD/F	(g/g)			
R	Universal gas constant	(J/mol/K)			
r_{ads}	Rate of adsorption	(mol/m ² /sec)			
r_{det}	Rate of thermal destruction	(sec ⁻¹)			
T	Absolute temperature of the plume	(K)			
t	Residence time for cool down	(sec)			
X_p	Moles of PCDD/F	(mol)			
α	Fraction of gaseous molecules partaking in the reaction				
β	Rate of cooling	(K/sec)			
ρ	Density of the fly ash	(kg/m ³)			
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APPENDIX A: MATHEMATICAL EQUATIONS OF THE HOT PLUME MODEL

ZFE

A deflected jet approximates the first part of the trajectory path. However, in the case of a plume with a high temperature, buoyancy will play an important role in the

rise of the plume. As has been shown,¹⁴ the ratio of velocity to the initial exit velocity will have its maximum at the end of this zone

$$\frac{u}{U_0} = f_w(F_{D0}) \quad (6)$$

where

$$f_w(F_{D0}) = \begin{cases} 1.66 & F_{D0}^2 < 8 \\ 1.99 - 0.24 \times \ln(F_{D0}^2 + 2), & 8 < F_{D0}^2 < 128 \\ 1.00 & F_{D0}^2 > 128 \end{cases} \quad (7)$$

and

$$F_{D0}^2 = \frac{U_0^2}{R_0 \times (\rho_a - \rho)_0} \quad (8)$$

with

$$R_0 = \frac{D}{2} \quad (9)$$

R_0 represents the radius of the stack as shown in eq 10, and replaces the Gaussian radial length of the plume at the source. The local Gaussian characteristic radial width of the plume at the origin of the ZEF is defined as

$$b_1 = \sqrt{2} \times R_0 \quad (10)$$

The radial width is defined^{12,9} as the "e folding distance" [i.e., the point along radial plume cross-section where the velocity is that of u_{max} (center of plume) divided by the transient number e]

The density can be determined from

$$(\rho_a - \rho)_1 = \frac{1 + \lambda^2}{2 \times \lambda^2 \times f_w(F_{D0})} \times (\rho_a - \rho)_0 \quad (11)$$

with

$$\lambda = 1.257 - 1.606 / F_{D0}^2 \quad (12)$$

and

$$F_{D1}^2 = \infty \quad (13)$$

Equation 14 is taken for a jet region¹⁴ as assumed by this model. The temperature can subsequently be calculated from $P = \rho R_g T$. The length is defined from published studies of turbulent deflected jets in a cross flow,⁹ where the maximum turbulence intensity has been noted (i.e., the uniform core of the jet has been totally eroded)

$$\delta = 5 \times D \quad (14)$$

The length of this zone will be overestimated slightly because of the buoyancy characteristics in the first part of the plume. This length is only true for exit-velocity to

wind-velocity ratios (U_s/U_a) of more than 4. Because of the volumetric difference of stack plumes as opposed to experimental jets, the path of the jet is not taken to be vertical in the ZEF, as expressed in eq 15. Instead, the path is taken to follow a slight modification of the Briggs equation for bent-over buoyant plumes¹¹

$$y = 3.2 \times \left(g \cdot U_0 \cdot \left(\frac{D}{2} \right)^2 \cdot \frac{T_s - T_a}{T_s} \right)^{\frac{1}{3}} \times x^{\frac{2}{3}} \times U_a^{-1} \quad (15)$$

The angle (ϕ) and the path length of the plume at the end of this zone is determined by differentiating eq 17 at small increment steps of x over the path trajectory until the length δ is reached.

ZEF

For the ZEF, changes of the plume properties with time have been modeled through the conservation of mass, momentum, and energy. Through these conservation fundamentals, the entrainment properties of a plume,^{12,14,20} and the Gaussian similarity profile assumed in the ZEF,^{12,19,21} the conservation equations can be expressed as

The Equation of Conservation of Mass

$$\frac{d}{ds} \left(\int_0^{b,2} \rho u 2\pi r \cdot dr \right) = 2\pi b \rho_a \left\{ \alpha_1 |u^*(s)| + \alpha_2 U_a |\sin \phi| \cos \phi \right\} \quad (16)$$

The Equation of Conservation of Momentum in the x Direction

$$\frac{d}{ds} \left(\int_0^{b,2} \rho u^2 2\pi r \cos \phi \cdot dr \right) = 2\pi b \rho_a U_a \left\{ \alpha_1 |u^*(s)| + \alpha_2 U_a |\sin \phi| \cos \phi \right\} + C_d \pi b \rho_a U_a^2 |\sin^3 \phi| \quad (17)$$

The Equation of Conservation of Momentum in the y Direction

$$\frac{d}{ds} \left(\int_0^{b,2} \rho u^2 2\pi r \sin \phi \cdot dr \right) = \int_0^{b,2} g(\rho_a - \rho) 2\pi r \cdot dr \pm C_d \pi b \rho_a U_a^2 \sin^2 \phi \cos \phi \quad (18)$$

with plus sign for $-\pi/2 \leq \phi < 0$
 minus sign for $0 \leq \phi \leq \pi/2$

The Equation of Conservation of Energy

$$\frac{d}{ds} \left(\int_0^{b,2} \rho u \left(\frac{1}{\rho} - \frac{1}{\rho_a} \right) 2\pi r \cdot dr \right) = 0 \quad (19)$$

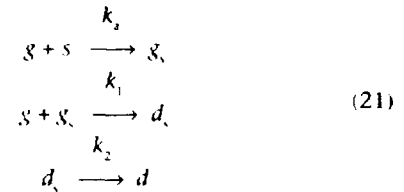
Equation 20 implies that the layer of atmosphere through

which the plume rises is neutrally stratified

$$\rho_a = \rho_{a0} \quad (20)$$

APPENDIX B: MATHEMATICAL EQUATIONS FOR THE CONDENSATION REACTION MECHANISM FOR PCDD/F FORMATION

The reaction mechanism of the precursor condensation formation of dioxins can be summarized as follows:²²



where g is the gaseous precursors (e.g., polychlorinated phenol), s is the solid fly ash particles, g_s is the absorbed precursors, d_s is the absorbed dioxin, and d is the desorbed gaseous dioxin.

The assumptions for the model are⁸

- The post-combustion zone (after the secondary combustion chamber) of the incineration process is characterized by an average temperature of 700 °C;
- Gas-phase polychlorinated phenols are present at concentrations of ~300 µg/m³;
- The average diameter of the fly ash particles is 10 µm, and the particles have the same composition;
- The particles are spherical solids;
- Fly ash has the same density as silica (i.e., 2.5 g/cm³);
- The number of adsorption sites on the fly ash is 3×10^{14} sites/cm² of surface area;
- The molar ratio of polychlorinated phenols to other molecules capable of undergoing adsorption is 10⁻²:1; and
- Molecular species that compete with polychlorinated phenols for adsorption sites on the fly ash have adsorption and desorption rates approximately the same as those of polychlorinated phenols.

The following mathematical relations have been derived²³ for the condensation reaction mechanism of eq 2:

$$d_s = \left(\frac{Q}{P} \right) \times \left[1 - e^{(-Pr)} \right] \quad (\text{molec/cm}^2) \quad (22)$$

$$d = \left(\frac{k_2 Q r}{P} \right) - \left(\frac{k_2 Q}{P^2} \right) \times \left[1 - e^{(-Pr)} \right] \quad (\text{molec/cm}^3) \quad (23)$$

with

$$Q = k_1 g_0 \theta_g \quad (\text{molec/cm}^3/\text{sec}) \quad (24)$$

$$P = \left[\frac{k_1 g_0}{2 \cdot N_p} \left(\frac{\sigma_g}{\sigma_p} \right)^2 \right] + k_2 \quad (\text{sec}^{-1}) \quad (25)$$

and

$$\theta_g = 0.01 \quad (\text{molec/cm}^3) \quad (26)$$

$$\sigma_p = 5 \times 10^{-4} \quad (\text{cm}) \quad (27)$$

$$\sigma_g = 3 \times 10^{-8} \quad (\text{cm}) \quad (28)$$

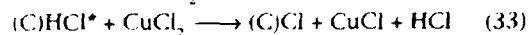
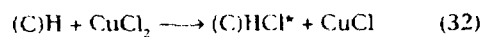
$$k_1 = 275 \sqrt{\frac{T}{973}} \cdot e^{\left(\frac{-14,850}{RT} \right)} \quad (\text{sec}^{-1}) \quad (29)$$

$$k_2 = 10^{13} \cdot e^{\left(\frac{-45,740}{RT} \right)} \quad (\text{sec}^{-1}) \quad (30)$$

$$N_p = \frac{M_p}{\left(\frac{4}{3} \right) \cdot \pi \cdot r_p^3 \cdot \rho_p} \quad (\text{particles/cm}^3) \quad (31)$$

APPENDIX C: MATHEMATICAL EQUATIONS FOR THE DE NOVO SYNTHESIS MECHANISM FOR PCDD/F FORMATION

The model assumes the halogenation of the carbon-containing surface of fly ash, either directly from gaseous HCl or from metallic chlorides already absorbed on the surface



where (C) denotes a carbon atom in the edge of graphitic layers or in aromatic compounds. Because the carbon is comparatively prevalent, the Cl supply for the reaction mechanism is taken as limiting. The average Cl atoms per

molecule of PCDD/F is taken as six, and the rate of PCDD/F formation is, therefore, one-sixth of the Cl absorption rate. The change in concentration of PCDD/F is then calculated from the difference in formation ($r_{\text{ads}}/6$) and thermal destruction rates (r_{dest})⁹

$$\frac{dm_p}{dt} = 380 \cdot \frac{A_s}{\beta} \left[\frac{r_{\text{ads}}}{6} - r_{\text{dest}} \cdot X_p \right] \quad (\text{PCDD/F g/g/sec}) \quad (34)$$

with

$$r_{\text{ads}} = \frac{\alpha P}{\sqrt{2\pi MRT}} \quad (\text{mol of HCl/m}^2/\text{sec}) \quad (35)$$

$$r_{\text{dest}} = 6.3 \times 10^{12} \exp\left(-\frac{167,000}{RT} \right) \quad (\text{sec}^{-1}) \quad (36)$$

and

$$A_s = \frac{6}{1000 \cdot \rho \cdot d} \quad (\text{m}^2/\text{g}) \quad (37)$$

About the Authors

Alan Brent (corresponding author; e-mail: abrent@eng.up.ac.za) has been involved with emissions and process measurements for five years. Further expertise has been directed toward the optimization of large incinerators and the design of small-scale incinerators for rural applications. This work is the result of a master's degree thesis partially conducted at Chalmers University of Technology, Sweden, and the CSIR, South Africa. Alan Brent now fills the Chair in Life Cycle Engineering at the University of Pretoria, whose aims are to develop a competency in life cycle engineering in South Africa. Dave Rogers has been involved in environmental, materials, and process-related measurements for more than 20 years, and incineration for five years. He is currently working on health care waste management projects for developing countries and has been appointed as a temporary advisor to the World Health Organization (WHO) in this field.

Mechanisms of Dioxin Formation from the High-Temperature Oxidation of 2-Bromophenol

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The homogeneous, gas-phase oxidative thermal degradation of 2-bromophenol was studied in a 1 cm i.d., fused silica flow reactor at a concentration of 88 ppm, reaction time of 2.0 s, over a temperature range from 300 to 1000 °C. Observed products in order of yield were dibenzo-*p*-dioxin (DD) > 4,6-dibromodibenzofuran (4,6-DBDF) > 4-monobromodibenzofuran (4-MCDF), dibenzofuran (DF), 1-monobromodibenzo-*p*-dioxin (1-MBDD), naphthalene, bromonaphthalene, 2,4-dibromophenol, 2,6-dibromophenol, phenol, bromobenzene, and benzene. This result is in contrast to the oxidation of 2-chlorophenol, where the major product is 4,6-dichlorodibenzofuran (4,6-DCDF). 4,6-DBDF was observed in high yields in contrast to our previous results for the pyrolysis of 2-bromophenol, where 4,6-DBDF was not detected. The increase in 4,6-DBDF yields is attributed to hydroxyl radical being the major chain carrier under oxidative conditions, which favors hydrogen-abstraction reactions that lead to formation of 4,6-DBDF. However, DD is still the highest yield product under oxidative conditions because of the relative ease of displacement of Br• in the ring-closure reaction.

Introduction

Over the past decade there has been an increase in concern over the risk of environmental exposure to brominated flame-retardant-containing materials (1, 2). Many of these materials, such as electronic or "E-wastes", find their way to waste-treatment facilities where they are burned (3–7). They are also subject to thermal degradation during accidental fires (8). Because of their chemical composition and combustion inhibition properties, they are prone to forming products of incomplete combustion, including polybrominated dibenzo-*p*-dioxins and dibenzofurans (PBDD/Fs).

Previous research has indicated that the presence of bromine during the combustion of hazardous wastes increases the production of PBDD/Fs and well as polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs) and mixtures of brominated and chlorinated dibenzo-*p*-dioxins and dibenzofurans (PXDD/Fs) (2, 9). It has also been established that brominated phenols and brominated flame retardants, e.g., polybrominated biphenyl ethers (PBDEs), are known precursors to PBDD/Fs (2, 3, 10–12). More importantly, some studies have shown that brominated phenols form more PBDD/Fs than the analogous chlorinated phenols form PCDD/Fs (10, 13, 14). With this knowledge, it is important to note that the toxicity of the PBDD/Fs has been shown to be similar to the analogous PCDD/Fs (15, 16).

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Previous works on the oxidation of chlorinated phenols under "slow combustion conditions" (i.e., $T = 300\text{--}600\text{ °C}$, reaction times between 10 s and 10 min) have reported the formation of PCDFs as the major products (17–20). However, in our recently reported studies on the high-temperature pyrolysis of both 2-chlorophenol and 2-bromophenol we reported the formation of PCDDs (dibenzo-*p*-dioxin (DD) and 1-monochlorodibenzo-*p*-dioxin (1-MCDD) or 1-monobromodibenzo-*p*-dioxin (1-MBDD)) was favored over the formation of PCDFs (4,6-dichlorodibenzofuran (4,6-DCDF) or 4,6-dibromodibenzofuran (4,6-DBDF)) (14, 21). There is an apparent contradiction that suggests that molecular oxygen is playing a large role in the product distribution and PCDD/F ratio.

In this paper, the thermal degradation of 2-bromophenol under oxidative conditions is reported for a reaction time of 2.0 s over the temperature range from 300 to 1000 °C and we compare these results to the results from previous studies of the pyrolysis of 2-bromophenol (14) as well as oxidation and pyrolysis of 2-chlorophenol (22).

Experimental Section

All experiments were performed using a high-temperature flow reactor system referred to in the archival literature as the System for Thermal Diagnostic Studies (STDS). The detailed design has been published elsewhere (23). In short, the STDS consists of a high-temperature, 1 cm i.d., fused silica flow reactor equipped with an in-line Varian Saturn 2000 GC/MS. The flow reactor is housed inside a furnace located inside a Varian GC, where the temperatures surrounding the reactor are controlled. Pressure inside the reactor is also maintained at 1.00 ± 0.15 atm. Gas-phase products are cryogenically trapped at the head of the GC column in preparation for chemical analysis.

To maintain a constant concentration of 88 ppm, 2-monobromophenol (2-MBP) (Aldrich) was injected into a 20% O₂ in helium gas stream by a syringe pump through a vaporizer maintained at 280 °C. Gas-phase samples of 2-MBP then were swept by the 20% O₂ in helium flow through heated transfer lines (300 °C) into a 35 cm long, 1.0 cm i.d., fused silica tubular flow reactor where the temperature was maintained between 300 and 1000 °C in individual experiments. The 20% O₂ in helium flow rate was varied with temperature, so that the residence time within the reactor was held at 2.0 s. The unreacted 2-MBP and thermal degradation products were then swept through a heated transfer line to another Varian GC, where they were cryogenically trapped at the head of a CP-Sil 8 phase capillary column (30 m, 0.25 mm i.d., 0.25 μm film thickness). To separate the individual reaction products the column was temperature programmed from –60 to 300 °C at 15 °C/min. Detection and quantification of the products were obtained using a Varian Saturn Mass Spectrometer which was operated in the full-scan mode (40–650 amu) for the duration of the GC run. The length of each experimental run was approximately 45 min.

Product concentrations were calculated based on the calibrations with standards of the products (Aldrich and Cambridge Isotope Lab) and the peak area counts from the chromatogram. The yields of the products were calculated using the expression

$$\text{yield} = \left\{ \frac{[\text{product}]}{[2\text{-MBP}]_0} \right\} \times 100$$

where [product] is the concentration of the particular product formed (in moles) and [2-MBP]₀ is the initial concentration

TABLE 1. Percent Yield of Products of Gas-Phase Oxidation of 2-Bromophenol^a

product	temp (°C)											
	350	400	450	500	550	600	650	700	750	800	850	900
2-bromophenol	99.2	74.7	69.3	66.9	54.7	36.2	16.7	4.07	1.90	1.09	0.22	0.06
dibenzo- <i>p</i> -dioxin		1.36	3.27	12.6	22.2	17.0	16.6	8.01	3.30	0.18	0.12	
1-bromodibenzo- <i>p</i> -dioxin		0.04	0.08	0.13	0.15	0.12	0.07	0.06	0.03	0.02		
dibenzofuran					0.02	0.16	0.90	0.64	0.11	0.05		
4-bromodibenzofuran			0.06	0.22	0.52	0.58	0.82	0.46	0.17	0.10	0.005	
4,6-dibromodibenzofuran			0.46	1.14	1.69	1.89	2.40	1.25	0.22	0.11		
naphthalene		0.04	0.07	0.08	0.06	0.04	0.08	0.06	0.03	0.02	0.02	0.02
1-bromonaphthalene						0.04	0.10	0.06				
phenol						0.37	0.61					
2,4-dibromophenol		0.008	0.04	0.06	0.07	0.04	0.03	0.03	0.03	0.03	0.01	0.006
2,6-dibromophenol		0.03	0.11	0.10	0.17	0.04	0.03	0.01	0.007	0.005		
benzene						0.002	0.02	0.02				
bromobenzene						0.005	0.02	0.02	0.005	0.004	0.03	0.06
phenylethyne							0.007	0.005				

^a Percent yield = $\{(\text{product}/[2\text{-MBP}]_0) \times 100$.

of 2-MBP (in moles) injected into the reactor. Multiple runs were performed for each temperature to ensure the repeatability of the experiments. Once the experimental procedure was fully developed, the repeatability of the experiments was within 10%.

Products (other than PBDD/Fs) were identified based on the NIST mass spectral library as well as the GC retention times and mass spectra of the standards for each product. Product concentrations were calculated based on the calibrations with standards of the products (Aldrich and Cambridge Isotope Lab) and the peak area counts from the chromatogram.

Standards for PBDD/Fs with less than four bromines were not available. Concentrations of observed PBDD/Fs are reported based on calibrations for the analogous PCDD/F. This is a reasonably accurate approach as the peak area counts for various chlorinated and brominated aromatics and PCDD/Fs and PBDD/Fs were compared, and it was found that the difference in calibration factors for brominated aromatic hydrocarbons and chlorinated aromatic hydrocarbons varied less than 10%.

Only three chromatographic peaks were observed that were tentatively identified as PBDD/F based on their mass spectra: 1-bromodibenzo-*p*-dioxin, 4,6-dibromodibenzofuran, and 4-bromodibenzofuran. The mass spectral library match qualities for each of these species were 264, 326, and, 248, respectively. These products are the same three PBDD/Fs that were anticipated based on the predicted pathways from previous research on formation of PCDD/F from the analogous 2-chlorophenol (22). In the 2-chlorophenol study the PCDD/F standards were available to confirm the identifications based on GC retention time and mass spectral pattern. Although standards were not available to confirm the identifications of PBDD/F, we are confident in the assignments based on the following: combination of mechanistically anticipated product formation; comparison of GC retention times, mass spectral response, and mass spectral patterns of chlorinated and brominated hydrocarbons; and previous studies of the formation of PCDD/F from 2-chlorophenol (22).

The heats of reaction, ΔH_{rxn} , for key steps in product formation pathways were calculated using AM1, semiempirical molecular orbital formalism. The calculations were performed using the MOPAC computation program that is contained within the ChemBats3D Pro computer application (24). Without experimental benchmarks the calculated ΔH_{rxn} cannot be considered to be completely accurate. They are shown to assess the likelihood of potential parallel pathways.

Pseudo-equilibrium calculations were performed to estimate the concentrations of reactive species such as $\cdot\text{OH}$,

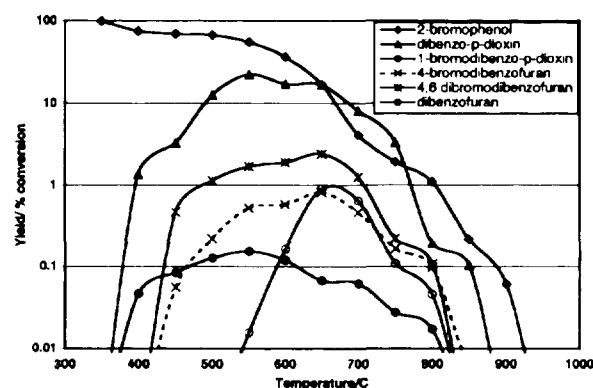


FIGURE 1. "Dioxin" products from the gas-phase oxidation of 2-MBP. [2-MBP]₀ = 88 ppm in helium. Gas-phase reaction time of 2.0 s.

$\cdot\text{O}$, H^{\cdot} , and Br^{\cdot} . The Chemkin Equil code was used to calculate the concentrations of these species over a range of reaction temperature from 300 to 1000 °C (25). The initial inputs for the calculations were the same as the experimental runs in that the initial 2-MBP concentration was held at 88 ppm and the initial O_2 concentration was held at 20%. Over this temperature range the major molecular species are CO_2 , H_2O , HBr , and Br_2 . Other species of interest included in the calculation were $\cdot\text{OH}$, O^{\cdot} , H^{\cdot} , Br^{\cdot} , HO_2 , H_2 , and CO .

Results

The temperature dependence of the oxidative thermal degradation of 2-MBP and the yield of "dioxin" products are presented in Figure 1 and Table 1 for a reaction time of 2.0 s. The non-dioxin products are presented in Figure 2 and Table 1. Figures 1 and 2 are presented on a semilogarithmic scale in which the percent yields of products (or percent yield of unconverted 2-MBP) are presented on a logarithmic scale versus temperature. The thermal degradation of 2-MBP initially increased gradually from 350 to 600 °C, achieving 99% destruction at 800 °C.

The predicted PBDD/F products, dibenzo-*p*-dioxin (DD), 1-bromodibenzo-*p*-dioxin (1-MBDD), and 4,6-dibromodibenzofuran (4,6-DBDF), were all observed for the oxidation of 2-MBP (cf. Figure 1 and Table 1). Other detected PBDD/F products were 4-bromodibenzofuran (4-MBDF) and dibenzofuran (DF). The two PBDD products, DD and 1-MBDD, were observed between 400 and 850 °C, reaching maximum yields of 22.2% and 0.15% at 550 °C, respectively. 4,6-DBDF and 4-MBDF were detected between 450 and 850 °C, reaching maximum yields at 650 °C of 2.40% and 0.82%, respectively.

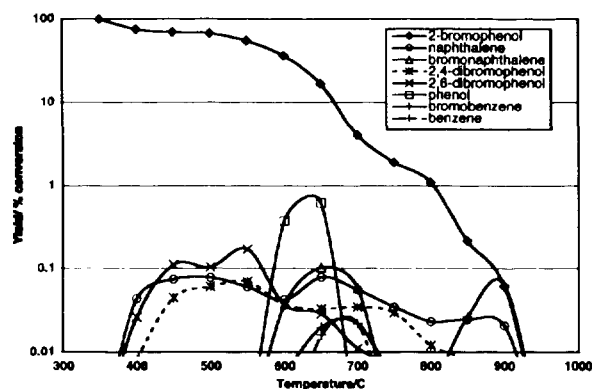


FIGURE 2. "Non-dioxin" products from the gas-phase oxidation of 2-MBP. [2-MBP]₀ = 88 ppm in helium. Gas-phase reaction time of 2.0 s.

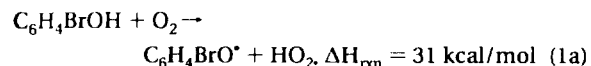
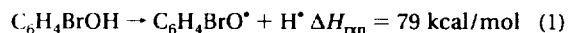
The final product, DF, was not detected until 550 °C and achieved a maximum yield of 0.90% at 650 °C. No brominated dioxin products were detected above 900 °C.

Non-PBDD/F products were also detected for the oxidation of 2-MBP (cf. Figure 2 and Table 1). Initially, at 400 °C 2,4-dibromophenol, 2,6-dibromophenol, and naphthalene were observed. 2,4-Dibromophenol and 2,6-dibromophenol achieved maximum yields of 0.07% and 0.17% at 550 °C, respectively. Naphthalene remained at a relatively constant yield from 400 to 700 °C and then decreased in yield at 900 °C, where it was no longer detected. Phenol, benzene, and phenylethyne were detected between 550 and 750 °C, achieving their respective maximum yields of 0.61%, 0.02%, and 0.007% at 650 °C. Bromobenzene was observed between 550 and 750 and 825–925 °C with local maximum yields of 0.02% at 650 °C and 0.06% at 900 °C.

Discussion

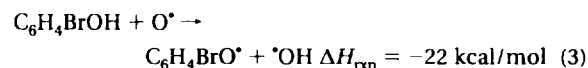
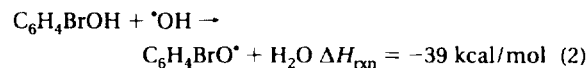
The formation of dioxin products (DD, 1-MBDD, and 4,6-DBDF) indicates that stable phenoxy radicals are formed in significant yields through loss of the hydroxyl hydrogen. The formation of aromatics (phenol, bromobenzene, and benzene) indicates that simple substitution reactions are occurring. The formation of 2,4-dibromophenol and 2,6-dibromophenol indicate evidence of bromination of 2-MBP. The formation of larger aromatic molecules at low temperatures (naphthalene and bromonaphthalene) is the result of reactions involving the release of CO from the phenoxy and bromophenoxy radicals that will then recombine to form naphthalene and bromonaphthalene.

2-MBP Decomposition. The addition of oxidative destruction pathways with the addition of molecular oxygen results in the decomposition of 2-MBP initiating at 600 °C rather than 650 °C, the temperature observed under pyrolytic conditions (14). The decomposition of 2-MBP can, in principle, be initiated by loss of the phenoxy hydrogen by unimolecular, bimolecular, or possibly other low-energy pathways (including heterogeneous reactions). Unimolecular decomposition of the oxygen–hydrogen bond (eq 1) is rapid with a reported rate coefficient for phenol of $k_1(430\text{--}930\text{ °C}) = 3.2 \times 10^{15} \exp(-86\,500/RT) \text{ s}^{-1}$ (26, 27). The direct bimolecular reaction with O₂ via reaction 1a is endothermic by 28 kcal/mol and viable only as minor initiation reaction



Bimolecular propagation reactions under oxidative conditions include attack by H[•], Br[•], [•]OH, and O[•]. In our previous

paper on the thermal degradation of 2-MBP under pyrolytic condition, ΔH_{rxn} for reactions with H[•] and Br[•] was discussed (14). It was determined that the most favorable reactions for generating the bromophenoxy radical were the abstraction of hydrogen by H[•] or Br[•]. With the addition of O₂ one can easily generate [•]OH and O[•] that can also abstract hydrogen via highly exothermic reactions (eqs 2 and 3)



Rate coefficients based on analogous reactions with phenol for eqs 2 and 3 are $k_2(1000\text{--}1150 \text{ K}) = 6.0 \times 10^{12} \text{ cm}^3/\text{mol/s}$ (28) and $k_3(340\text{--}870 \text{ K}) = 1.28 \times 10^{13} \exp(-2900/RT) \text{ cm}^3/\text{mol/s}$ (28). We used equilibrium calculations and other formalisms from the literature to estimate the [•]OH and O[•] concentration in our system (26, 28). Using these concentrations and the rate expressions given above (using $E_a(\text{eq } 1) = \Delta H_{\text{rxn}} = 79 \text{ kcal/mol}$), the rate of eq 2 is ~200× faster than eq 3 and a factor of 30 faster than eq 1. Thus, eq 2 is the dominant source of phenoxy radical under oxidative conditions.

Formation of Phenol, Bromobenzene, Benzene, 2,4-Dibromophenol, and 2,6-Dibromophenol. The formation of phenol is likely due to the exothermic displacement of bromine by H[•] ($\Delta H_{\text{rxn}} = -29 \text{ kcal/mol}$). The temperature range at which phenol is detected is much lower than for previous results of 2-MBP under pyrolytic conditions (14). This is due to the early onset of reaction of 2-MBP under oxidative conditions and the oxidation of phenol at higher temperatures.

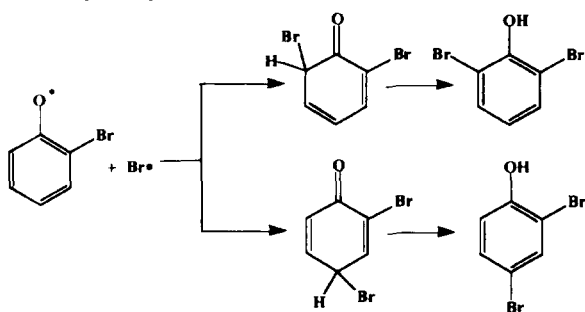
This result is very similar to that observed for pyrolysis and oxidation of 2-MCP (17, 22). The yield of phenol for the oxidation of 2-MBP is slightly higher than the yield for 2-MCP, which reflects the relative ease of bromine displacement compared to chlorine displacement due to the 15.5 kcal/mol lower carbon–bromine bond energy (29).

Bromobenzene and benzene are formed with much lower yields than phenol. These lower yields are due to the slightly endothermic displacements of hydroxyl by H[•] to form bromobenzene ($\Delta H_{\text{rxn}} = 2 \text{ kcal/mol}$) and hydroxyl from phenol by H[•] to form benzene ($\Delta H_{\text{rxn}} = 4 \text{ kcal/mol}$). However, bromobenzene reaches a maximum at 650 and 900 °C. The lower temperature maximum is due to the displacement of hydroxyl from 2-MBP by H[•]. The higher temperature maximum of bromobenzene is due to well-documented molecular growth pathways resulting from fragmentation of 2-MBP into C₂ species (30–32).

2,4-Dibromophenol and 2,6-dibromophenol are produced from bromination of the 2-MBP. Since displacement of hydrogen by Br[•] is endothermic, the direct reaction of Br[•] with 2-MBP is unlikely. The formation of dibromophenol is instead due to recombination of phenoxy radicals and Br[•]. Scheme 1 depicts the formation of 2,4-dibromophenol and 2,6-dibromophenol by Br[•] attack at the resonance-stabilized, *ortho*- or *para*-carbon sites of the bromophenoxy radicals ($\Delta H_{\text{rxn}} = -29 \text{ kcal/mol}$). Subsequent tautomerization results in the formation of the respective dibromophenols ($\Delta H_{\text{rxn}} = -17 \text{ kcal/mol}$) (33). The dibromophenols were also detected in our previous study of 2-MBP under pyrolytic conditions (14). However, they were observed over a narrower temperature range and lower yields (14).

On the basis of our pseudo-equilibrium calculations at 700 °C, the concentrations of Br₂ ($9.4 \times 10^{-6} \text{ mol}$) and Br[•] ($9.6 \times 10^{-7} \text{ mol}$) are, respectively, 3 and 1 orders of magnitude higher than the concentration of HBr ($5.4 \times 10^{-8} \text{ mol}$). This

SCHEME 1. Reaction Mechanism for the Formation of 2,4-Dibromophenol and 2,6-Dibromophenol from 2-Bromophenoxy Radical



is in contrast to the results for 2-MCP, where the concentration of HCl (1.7×10^{-5} mol) was greater than that of Cl₂ (1.3×10^{-6} mol) and Cl[•] (1.5×10^{-7} mol) (22) and our calculations for the pyrolysis of 2-MBP for which the HBr, Br₂, and Br[•] concentrations were 4.2×10^{-7} , 2.0×10^{-12} , and 2.7×10^{-10} mol, respectively. The addition of oxygen creates [•]OH, which converts HBr into water and Br[•], the latter being in equilibrium with Br₂ (28). The increased yield of brominated products under oxidative conditions is likely due to the release of strong brominating agents, Br[•], as well as the increase in bromophenoxy radical concentration.

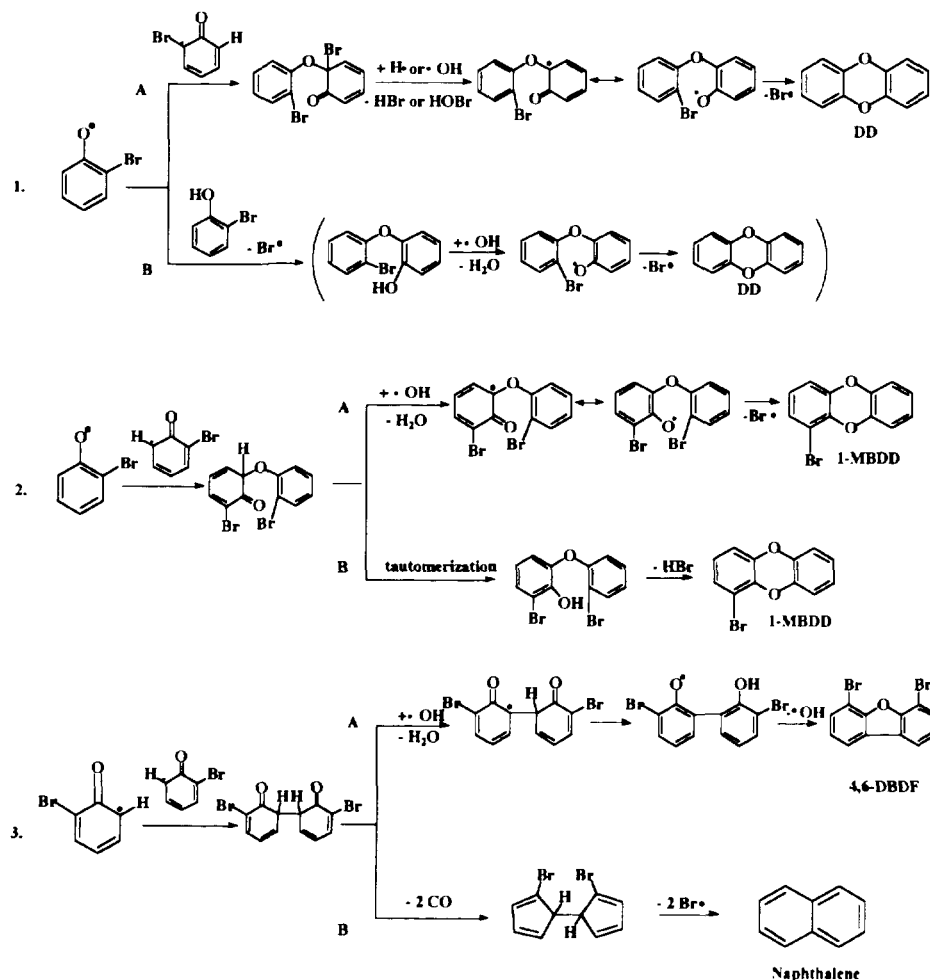
Formation of Naphthalene and Bromonaphthalene.

Formation of polycyclics such as naphthalene and bro-

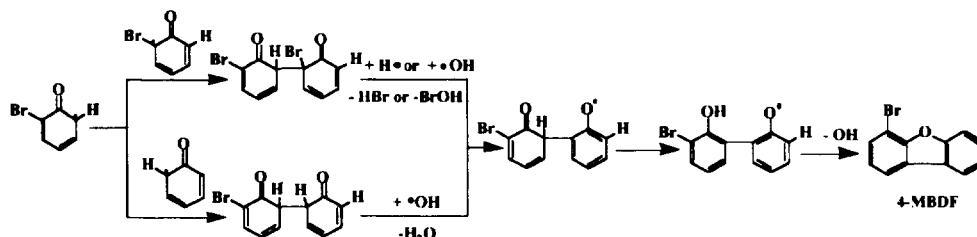
monaphthalene has been traditionally ascribed to molecular growth pathways involving largely C₂ fragments (30–32). However, the low-temperature onset of formation of naphthalene (400 °C) suggests a pathway that does not require the complete fragmentation of 2-MBP. In our previous work on the pyrolysis of 2-MBP we presented a reasonable pathway for the formation of naphthalene from the 2-bromophenoxy radical through elimination of CO to form a cyclopentadienyl radical (14). The recombination of two cyclopentadienyl radicals has been previously shown to be a favorable pathway for formation of naphthalene (34, 35). A similar low-temperature route to the formation of naphthalene from the recombination of bromophenoxy radicals is described in Scheme 2 (vide infra) as a competitive pathway to the formation of 4,6-DBDF. This formation of naphthalene is based on a previously proposed pathway of the recombination of two chlorophenoxy radicals to form naphthalene (36).

The yields of naphthalene and bromonaphthalene are significantly lower under oxidative than pyrolytic conditions, most probably due to the more rapid rate of oxidation of the cyclopentadienyl radical (14). Also, with the increase in the concentration of brominated phenoxy radicals, the rate of PBDD/F formation will increase in competition with elimination of CO. The oxidation rate of naphthalene is also increased. Thus, the concentration of naphthalene is dramatically lowered and never becomes a major product as it did under pyrolytic conditions.

SCHEME 2. Pathways for Formation of DD, 1-MBDD, and 4,6-DBDF



SCHEME 3. Pathways for the Formation of 4-MBDF



The formation of naphthalene for the oxidation of both 2-MCP and 2-MBP occurred over a similar temperature range. However, higher yields of naphthalene were observed for the oxidation of 2-MCP than for 2-MBP (22). This may be due to the higher concentration of bromophenoxy than chlorophenoxy radicals, leading to an increased rate of formation of PBDD/F by radical recombination processes at the expense of CO elimination, leading to naphthalene formation.

Formation of Dibenzo-*p*-dioxin, 1-Bromodibenzo-*p*-dioxin, 4,6-Dibromodibenzofuran, 4-Bromodibenzofuran, and Dibenzofuran. Scheme 2 summarizes previously identified reaction pathways to DD, 1-MBDD, and 4,6-DBDF from reaction of the different mesomers of 2-bromophenoxy radical.

Pathway 1a in Scheme 2 depicts the mechanism for DD formation; the oxygen-centered radical mesomer recombines with the carbon- (bromine substituted) centered radical mesomer to form a keto-ether. Following abstraction of bromine by H[•] or [•]OH, DD is formed by intra-annular elimination of Br[•]. Another possible pathway for the formation of DD is through a radical-molecule reaction, pathways 1b, shown in parentheses below the radical-radical pathway in Scheme 2. This reaction depicts the oxygen-centered radical mesomer reacting with 2-MBP via Br[•] displacement to form a bromohydroxy diphenyl ether (HDE) followed by abstraction of hydrogen by [•]OH. Finally, DD is formed by intra-annular displacement of Br[•]. It has been previously suggested that this radical-molecule reaction is too slow to account for the observed yields of the DD (37-39).

Formation of 1-MBDD, shown as pathway 2a in Scheme 2, is initiated by recombination of the oxygen-centered radical mesomer and the carbon (hydrogen)-centered radical mesomer to form a keto-ether. Following loss of hydrogen to form the phenoxyl phenyl ether (PPE), ring closure to form 1-MBDD occurs through intra-annular displacement of Br[•]. Pathway 2b depicts an alternate unimolecular pathway for the formation of 1-MBDD.

Pathway 3a depicts a possible pathway to 4,6-DBDF formation. Initially, for both pathways 3a and 3b two carbon-hydrogen-centered radical mesomers react to give the diketo dimer. The dimer can follow the upper pathway, 3a, by abstraction of hydrogen by [•]OH and then undergo tautomerization followed by displacement of [•]OH to form 4,6-DBDF. Pathway 3b is the alternative pathway to formation of naphthalene through CO and Br[•] elimination (36).

We believe that DF is simply a recombination of unbrominated phenoxy radical formed from decomposition of phenol (40). The reaction proceeds by mechanisms analogous to those shown for formation of 4,6-DBDF in Scheme 2.

Scheme 3 depicts proposed pathways for the formation of 4-MBDF. Two pathways are depicted: (1) the carbon (hydrogen)-centered radical mesomer recombines with the carbon (bromine)-centered radical mesomer or (2) the carbon (hydrogen)-centered radical mesomer recombines with an unbrominated carbon-centered phenoxy radical to form a diketo dimer. For the first pathway H[•] abstracts bromine, and in the second [•]OH abstracts another hydrogen. Both

pathways then undergo tautomerization followed by displacement of hydroxyl to form 4-MBDF. Under oxidative conditions the latter pathway is more favorable, while under pyrolytic conditions the former is dominant.

Oxidation versus Pyrolysis of 2-MBP. DD is the major product of both pyrolysis and oxidation of 2-MBP. However, the yield of DD is 4 times greater for oxidation than for pyrolysis (14). This is primarily due to the increase in bromophenoxy radicals at lower temperatures for oxidative conditions, which react to form PBDD/Fs. Under pyrolytic conditions bromophenoxy radicals form at higher temperatures, where their rate of decomposition is greater and yields of PBDD/F are reduced. The yield of 1-MBDD is 5× greater under oxidative conditions than pyrolytic conditions. Its formation is again facilitated by the increase in bromophenoxy radicals. However, the presence of [•]OH facilitates hydrogen abstraction in pathway 2a, which further promotes formation of 1-MBDD.

Detection of 1-MBDD is also observed as low as 400 °C. This is a dramatically lower than the 650 °C formation temperature observed under pyrolytic conditions (14). This suggests another pathway is involved in the low-temperature formation. In our previous study of the oxidation of 2-MCP similar results were observed where 1-MCDD was detected as low as 400 °C (22). We suggested that at lower temperatures 1-MCDD can be formed by a unimolecular pathway following the formation of the keto-ether intermediate via radical-radical recombination. An analogous pathway is proposed for formation of 1-MBDD (cf. pathway 2a in Scheme 2). Alternately to the abstraction of hydrogen by [•]OH in pathway 2a in Scheme 2, a simple, intra-ring, single-proton tautomerization results in the formation of a hydroxyl-diphenyl ether intermediate that can then form 1-MBDD by inter-ring elimination of HBr. This proposed mechanism is based on the similar observation of naphthalene at temperatures as low as 400 °C. Previous work has proposed that after recombination of chlorinated phenoxy radicals to form the diketo intermediate, the formation of naphthalene shown in pathway 3b in Scheme 2 is unimolecular (39). Following recombination the resulting intermediate eliminates two CO moieties, resulting in the formation of bicyclopentadienyl. On the basis of their similarity to the chlorophenoxy radicals, naphthalene can be formed by the bromophenoxy radicals in a similar manner. Naphthalene is then formed by the rearrangement pathways previously proposed in the literature (14, 34, 35). Once the diketo intermediate is formed, the entire process is unimolecular. This can explain the high yields at low temperatures before the radical pool has developed. However, above 500 °C the radical pool increases rapidly and bimolecular pathways involving H[•] and Br[•] abstraction begin to dominate the formation of 1-MBDD and other PBDD/F products. The formation of DD and 4-MBDF at 400-450 °C is attributed to the lower temperature formation of the bromophenoxy radical precursor.

One product not observed under pyrolytic conditions, 4,6-DBDF, was detected in high yields under oxidative conditions (14). This behavior is similar to that observed for 2-MCP (22). With the addition of oxygen, [•]OH becomes the

major carrier over H[•]. Hydroxyl radical facilitates highly exothermic hydrogen-abstraction reactions in pathways 2a (-46 kcal/mol) and 3a (-47 kcal/mol), resulting in the formation of 1-MBDD and 4,6-DBDF, respectively. However, the abstraction of bromine by [•]OH is 40 kcal/mol endothermic and not favorable. Thus, the increase in [•]OH concentration increases the rate of 1-MBDD and 4,6-DBDF formation but does not increase the rate of DD formation, which requires abstraction of bromine.

However, 4,6-DBDF is not the major PBDD/F product like 4,6-DCDF is for the analogous oxidation of 2-MCP (22). In the competing pathway to formation of DD from 2-MBP or 2-MCP, the final ring closure involves elimination of Br or Cl[•], respectively. For 2-MBP this step is 12 kcal/mol exothermic, while it is 12 kcal/mol endothermic for 2-MCP. The addition of [•]OH to the system increases the rates of formation of both 4,6-DBDF and 4,6-DCDF by promoting hydrogen abstraction in pathway 3a. However, this increase is insufficient to dominate over the exothermic formation of DD from 2-MBP, whereas it is sufficient to compete with the endothermic formation of DD from 2-MCP (14). Therefore, DD remains the dominant PBDD/F product for 2-MBP.

The yields of 4,6-DBDF and 1-MBDD are ~5× less than the yields of 4,6-DCDF and 1-MCDD. This may be due to the more exothermic abstraction of hydrogen by [•]OH by 12 kcal/mol for the chlorinated reaction intermediates than the corresponding brominated intermediates as well as the 28 kcal/mol more exothermic abstraction of hydrogen by Cl[•] than hydrogen by Br[•]. On the basis of our pseudo-equilibrium calculations for 2-MBP and similar calculation for the 2-MCP system, the addition of oxygen to the system increases the concentrations of [•]OH and Br[•]. However, the hydrogen-abstraction reactions necessary for formation of 4,6-DBDF and 1-MBDD from 2-MBP are not as favored by this increase as in the 2-MCP system.

The maximum yield of 4-MBDF is 16 times higher under oxidative conditions than pyrolysis (14). This can be explained in the same way as the formation of 4,6-DBDF is explained. With the addition of oxygen, the lower pathway in Scheme 3 is the more favorable pathway in that the addition of [•]OH will lower ΔH_{rxn} for the abstraction of hydrogen (-47 kcal/mol) by 17 kcal/mol over the abstraction of hydrogen by H[•]. The upper pathway in Scheme 3, the abstraction of bromine by [•]OH, is endothermic by 35 kcal/mol. Thus, the upper pathway is not affected by the addition of oxygen other than with the increase in bromophenoxy radicals.

In summary, we proposed reasonable mechanisms for the formation of each observed product of the oxidation of 2-MBP. We also identified mechanistic rationales for the differences in product distribution and PBDD to PBDF branching ratios for oxidative versus pyrolytic conditions. Comparison of oxidation and pyrolysis results has also identified possible lower temperature, primarily unimolecular routes to formation of naphthalene and 1-MBDD that can occur before the radical pool increases significantly at 600 °C. On the basis of a comparison of the oxidation of 2-MBP and 2-MCP, there is a 20× greater yield of DD formation for 2-MBP (22). This indicates the increased propensity for dioxin formation from brominated precursors. Thus, the presence of brominated flame retardants in incinerators and energy-recovery devices as well as accidental fires suggests that additional attention should be paid to PBDD/F formation from combustion of brominated chemicals and materials.

Acknowledgments

We gratefully acknowledge the assistance of our colleagues, Dr. Lavrent Khachatryan and Alexander Burcat, in evaluation of the thermochemistry presented in this manuscript as well as helpful discussions concerning the mechanisms of dioxin formation. We acknowledge the partial support of this work

under EPA Contract 9C-R369-NAEX, EPA Grant R828166, and the Patrick F. Taylor Chair foundation.

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Received for review September 29, 2004. Revised manuscript received December 28, 2004. Accepted January 11, 2005.

ES048461Y

Formation of Dioxins during the Combustion of Newspapers in the Presence of Sodium Chloride and Poly(vinyl chloride)

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Exhaust gases from the combustion of newspaper alone, from branches of London plane tree alone, and from newspapers mixed with sodium chloride (NaCl), polyethylene, or poly(vinyl chloride) (PVC) were collected. The samples were analyzed for dioxins by gas chromatography/mass spectrometry. Total amounts of dioxins found in the samples were 0.186 ng/g from newspapers alone, 1.42 ng/g from the branches of London plane, 102 ng/g from newspapers impregnated with sodium chloride (Cl wt % = 3.1), 101 ng/g from newspapers impregnated with sodium chloride mixed with PVC (Cl wt % = 2.6), and 146 ng/g from newspapers mixed with PVC (Cl wt % = 5.1). Samples with a higher chloride content produced more dioxins, and there is a clear correlation between dioxin formation and chloride content. The amount of dioxins formed in the samples according to the number of chlorides was $Cl_5 > Cl_4 > Cl_6 > Cl_7 > Cl_8$ in PCDD isomers and $Cl_4 > Cl_5 > Cl_6 > Cl_7 > Cl_8$ in PCDF isomers, except in the case of newspapers alone. Benzofurans composed 78–92% of the total dioxins formed in the exhaust gases. The higher the number of the chlorides, the lower the production of benzofuran observed. NaCl vaporized at the temperature of the flame used for combustion of the samples (760–1080 °C). The results indicate that NaCl and PVC contribute significantly to dioxin formation from waste materials combusted in incinerators.

Introduction

Major sources of dioxins in the environment are the combustion of waste materials as well as many other high-

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temperature processes commonly used in industrial settings (1, 2). For example, dioxins are formed from natural woods and waste woods by combustion (3, 4). They are also formed from sodium chloride (NaCl)-impregnated woods (3) and a mixture of wood and plastic wastes (5) upon combustion.

There have been many studies on the formation of dioxins under various conditions (6–9). However, formation mechanisms of these dioxins are not yet completely understood because many complex reaction pathways seem to be involved in the process. There are some reports on hypothesized formation pathways in dioxin formation (1, 2). For example, dioxins form from precursors via organic chemical reactions, such as the condensation reaction of two molecules of chlorophenols and the cyclization reaction of polychlorinated biphenyls (10). They are formed from the reaction involving a radical reaction between simple carbon radicals and chloride radicals (11, 12). They are released from polymers with dioxin moieties (13). In addition to these major pathways, dioxins form via many complex combustion processes (14). The chemical reactions involved in dioxin formation are extremely complex and heterogeneous (12); therefore, it is quite difficult to know all the formation mechanisms of dioxins in a combustion chamber. These as yet not fully understood formation mechanisms are no doubt the main reasons why dioxin formation varies within different combustion chambers.

It is important to determine how much dioxins form from various materials in high-temperature processes in order to reduce their role in environmental contamination. Many hypotheses about dioxin formation in combustion systems have been advanced, but most of them are based on results obtained from dioxins collected from the recombustion of exhaust gas or from the exhaust gas that has already passed through a device for exhaust gas treatment. However, it is important to collect dioxins before treatment of exhaust gas in order to investigate their formation mechanisms.

The source of chloride has been one of the major concerns in studies of dioxin formation in incinerators. It appears that both organic and inorganic chlorides can be a precursor of dioxins in incinerators. There are two hypotheses about the role of chloride percentages in dioxin formation upon combustion. One is that the percentage of chloride plays an important role in dioxin formation (15–17). The other is that the percentage of chloride is independent of dioxin formation during combustion (18, 19). However, there are still many unknown formation mechanisms of dioxins in high-temperature processes. More experiments and theoretical studies to elucidate the details of dioxin formation in combustion are a pressing need.

In the present study, exhaust gas was collected at the outlet of a small-scale incinerator in which newspaper alone, branches of London plane tree alone, and newspapers mixed with NaCl, polyethylene, or poly(vinyl chloride) (PVC) were combusted. Samples collected were analyzed for dioxins by gas chromatography/mass spectrometry (GC/MS) in order to investigate the factors influencing dioxin formation.

Experimental Section

Chemicals. Isotope-labeled dioxins for internal standards (10 pg/mL *n*-nonane) were purchased from Cambridge Isotope Laboratories, Inc. (Andover, MS). For the solution of the sampling-spike recovery test, a 1-mL *n*-nonane solution containing 0.0005 ng/ μ L each of [¹³C₁₂]-1,2,3,4-T₄CDD, 1,2,3,4,7,8-H₆CDF, and 1,2,3,4,7,8,9-H₇CDF solution was prepared. For the solution of the cleanup-spike recovery test,

a 100- μ L *n*-nonane solution containing 0.005 ng/ μ L each of [$^{13}\text{C}_{12}$]-2,3,7,8-T₄CDD, 1,2,3,7,8-P₅CDD, 1,2,3,6,7,8-H₆CDD, 1,2,3,4,6,7,8-H₇CDD, 1,2,3,4,6,7,8,9-O₈CDD, [$^{13}\text{C}_{12}$]-2,3,7,8-T₄CDF, 1,2,3,7,8-P₅CDF, 1,2,3,4,7,8-H₆CDF, 1,2,3,4,6,7,8-H₇CDF, and 1,2,3,4,6,7,8,9-O₈CDF was prepared. For the solution of the internal standards, a 2- μ L *n*-nonane solution containing 0.25 ng/ μ L each of [$^{13}\text{C}_{12}$]-1,3,6,8-T₄CDD and 1,2,3,7,8,9-H₆CDD was prepared. *n*-Nonane for dioxin analyses was bought from Kanto Chemical Co., Inc. (Tokyo, Japan).

Instruments. The chloride content in the samples was measured by a TOX-100 total organic halogen analyzer (Dia Instruments Co., Ltd., Chigasaki, Japan). Metal contents in the samples were measured by an IRIS-AP IPC mass spectrometer (Jarrellash Co., Ltd., Franklin, MA). Combustion chamber and flame temperatures were measured by a LK-1200 thermocouple conductor interfaced to a CT-1310 digital thermometer (Custom Co., Ltd., Tokyo, Japan). Pretreatment for water removal from exhaust gas was conducted by PS-200SCR (Horiba, Ltd., Kyoto, Japan). Continuous measurement of carbon monoxide, carbon dioxide, and oxygen in samples was performed by a Horiba PG-230 gas analyzer (Horiba, Ltd., Kyoto, Japan). Hydrogen chloride concentration in exhaust gas was measured by a Yokogawa IC-7000S ion chromatograph (Yokogawa Analytical Systems Inc., Tokyo, Japan).

A Hewlett-Packard (HP) model 5890 gas chromatograph (GC) interfaced to Micromass double-focus MS (Auto Spec ULTIMA, England) and equipped with a 60 m \times 0.25 mm i.d. (df = 0.2 μ m) SP-2331 bonded-phase fused-silica capillary column (Supelco, Bellefonte, PA) for Cl₄₋₆ dioxins or a 30 m \times 0.25 mm i.d. (df = 0.25 μ m) DB-5 bonded-phase fused-silica capillary column (J & W Scientific, Folsom, CA) for Cl_{7,8} dioxins was used. Gas chromatographic oven temperatures were programmed from 130 to 190 $^{\circ}\text{C}$ at 20 $^{\circ}\text{C}/\text{min}$ and then to 250 $^{\circ}\text{C}$ at 2 $^{\circ}\text{C}/\text{min}$ for the SP-2331 column and programmed from 130 to 280 $^{\circ}\text{C}$ at 10 $^{\circ}\text{C}/\text{min}$ for the DB-5 column. The linear velocity of the helium carrier gas was 30 cm/s. The injector temperatures were 250 $^{\circ}\text{C}$ for the SP-2331 column and 280 $^{\circ}\text{C}$ for the DB-5 column. MS ion source temperatures were 250 $^{\circ}\text{C}$ for the SP-2331 column and 289 $^{\circ}\text{C}$ for the DB-5 column. MS ionization voltage was 35 eV.

Materials for Combustion Experiments. Newspapers (top circulation in Japan) purchased from a local store were soaked in a 3% NaCl solution for 20 min. The newspapers were dried in an electric dryer at 120 $^{\circ}\text{C}$ prior to use in the experiment. The percentage of impregnated chloride was 3.1% (w/w).

A polyethylene sheet (0.3 mm thickness), of which the chloride content was less than 0.005% (w/w), was purchased from Shinkobe Electric Co., Ltd. (Tokyo, Japan). A PVC sheet, of which the chloride content was 35.7% (w/w), was bought from Hiroshima Kasei Co., Ltd. (Fukuyama, Japan). Branches of London plane (*Platanus hispanica* Muenchh), of which the chloride content was 0.028% (w/w), were collected from a local tree planted along the main street in the city of Gifu, Japan (population 400 000).

Fuel for the subsidiary combustion burner was low-sulfur-content heavy oil A (density = 0.8748) containing 0.0036% (w/w) chloride, 0.25% (w/w) sulfur, and 0.02% (w/w) nitrogen.

Combustion of Samples. Six different samples were combusted in an incinerator used in a previous study (16). The volume of the firebrick combustion chamber was 0.89 m³, and the area of the grate was 1.2 m². The incinerator was equipped with a subsidiary combustion burner, which is a rotary burner for heavy oil combustion (30 L/h). Sample I (blank): low-sulfur-content heavy oil A was combusted alone for 4 h at the rate of 15 L/h. Sample II: 5 kg of newspapers was combusted at 25-min intervals for 4 h (total 55 kg). Sample III: 2.5 kg of London plane tree branches was combusted at

10-min intervals for 3 h and 40 min (total 60 kg). Sample IV: 5 kg of NaCl-impregnated newspapers was combusted at 25-min intervals for 3 h and 55 min (total 50 g). Sample V: NaCl-impregnated newspapers (3.17 kg each) were combusted with 0.8 kg of polyethylene (PE) at 25-min intervals for 3 h and 20 min (total 31.78 kg). Sample VI: 3 kg of newspapers was combusted with 0.5 kg of PVC at 25-min intervals for 3 h and 20 min (total 28 kg).

Sample Collections for Carbon Monoxide (CO), Carbon Dioxide (CO₂), and Hydrogen Chloride (HCl) in Exhaust Gas. Gas samples were collected at the sampling port located between the combustion chamber and the cyclone. Sample collection for analysis of CO and CO₂ in the exhaust gas was conducted continuously throughout combustion. Sample collection for HCl analysis in the exhaust gas was performed by drawing exhaust gas for 20 min twice.

Sample Collections for Dioxin Analysis in Exhaust Gas. The exhaust gas samples for dioxin analysis were collected using the apparatus previously reported (20). Dust in the exhaust gas was trapped in an in-line silica fiber thimble filter. The exhaust gas was next drawn into three 1-L impingers connected in series. The first impinger contained 150 mL of hexane-washed distilled water. Dioxin standards were added here to the first impinger for sampling-spike recovery tests. The first impinger was connected to the second impinger, which contained 300 mL of hexane-washed distilled water, and then interfaced to the third empty impinger. The empty impinger was further connected to a column packed with 40 g of XAD-2 resin, which was interfaced to a 1-L impinger containing 250 mL diethylene glycol and an empty impinger connected in series. The impingers were kept at 5 $^{\circ}\text{C}$ in an ice-cooled water bath during sample collections. The exhaust gas was drawn using a diaphragm vacuum pump with the flow rate the same as that of the exhaust gas in the duct (21–23 L/min).

Dioxin Analysis in Samples. Analysis of dioxins in the collected exhaust gas was conducted according to the official method of the Japan Ministry of Health and Welfare using a GC/MS (17). The dust trapped in the silica fiber thimble filter (approximately 1 g) was washed with a 2 mol/L hydrochloric acid solution (20 mL) and combined with the XAD-2 resin. The resin was extracted for 16 h with toluene (200 mL) using a Soxhlet extractor. The water (500 mL) and diethylene glycol (250 mL) in the impingers as well as the water trapped (trace) in the empty impingers were combined and extracted with toluene (500 mL). Dioxin standards were added here for cleanup recovery tests. After extraction, each extract was condensed by distillation using a rotary flash evaporator, and the combined samples were cleaned with multilayer silica gel chromatography (21). The sample was further cleaned with a 120-mL hexane/dichloromethane (1/1) solution using alumina column chromatography. Each sample was condensed using a rotary flash evaporator, and the condensed sample was subsequently dissolved into a minimal amount of *n*-nonane. After 0.5 ng each of [$^{13}\text{C}_{12}$]-1,3,6,8-T₄CDD and 1,2,3,7,8,9-H₆CDD was added to each sample as internal standards for the quantitative analysis of dioxins, the volume of the samples was adjusted to exactly 50 μ L with *n*-nonane. The samples were analyzed by GC/MS for dioxins.

Determination for Rate of Vaporization of NaCl. High-purity NaCl (2 g) was placed in a boat-shaped quartz container and heated with a Bunsen burner (air and propane gas) for 10 min. The temperature of the flame at the sample container was measured by a thermocouple conductor. The same container containing 1 g of the same NaCl was placed in an electric furnace and heated for 15 min. The furnace was heated to the specific temperature prior to introducing the sample. Residual NaCl was weighed to determine the rate of vaporization.

TABLE 1. Conditions and Contents of Incinerator and Concentrations of CO₂, CO, and HCl in the Exhaust Gases

	sample I heavy oil A	sample II newspaper	sample III London plane	sample IV newspaper + NaCl	sample V newspaper + NaCl & PE	sample VI newspaper + PVC
chamber temp (°C)						
range	407–492	560–907	403–525	445–703	350–630	38–542
av	457	653	456	510	473	456
av exhaust gas temp (°C)	378	526	435	415	434	416
av amt of dry exhaust gas (m ³ /h)	898	918	907	995	1020	967
oxygen concn (%)						
range	18.6–19.0	14.2–17.9	14.5–17.3	13.2–17.7	12.3–18.5	15.0–18.5
av	18.8	17.2	16.5	16.7	17.2	17.4
av CO ₂ concn (%)	1.3	2.4	3.7	3.4	3.2	3.0
av CO concn (ppm) ^a	87	1000	1090	1200	990	1500
av HCl concn (mg/m ³) ^a	nd ^b	nd		23	59	640

^a Relative to 12% oxygen. ^b nd, not detected.

Results and Discussion

The recovery efficiencies of standard dioxins with sampling-spike were 89% for [¹³C₁₂]-1,2,3,4-T₁CDD, 82% for 1,2,3,4,7,8-H₆CDF, and 91% for 1,2,3,4,7,8,9-H₇CDF. The recovery efficiencies of standard dioxins with cleanup-spike were 83% for [¹³C₁₂]-2,3,7,8-T₄CDD, 82% for 1,2,3,7,8-P₅CDD, 88% for 1,2,3,6,7,8-H₆CDD, 92% for 1,2,3,4,6,7,8-H₇CDD, 95% for 1,2,3,4,6,7,8,9-O₈CDD, 84% for [¹³C₁₂]-2,3,7,8-T₄CDF, 84% for 1,2,3,7,8-P₅CDF, 92% for 1,2,3,4,7,8-H₆CDF, 94% for 1,2,3,4,6,7,8-H₇CDF, and 89% for 1,2,3,4,6,7,8,9-O₈CDF in the present study. Values are the averages of six experiments. The results indicate that the recovery of dioxins throughout the experiments was satisfactory.

The total heat generation of low-sulfur-content heavy oil A was 10 800 kcal/kg. The total heat generations of the samples were 4420 kcal/kg from newspaper, 11 200 kcal/kg from PE, and 6240 kcal/kg from PVC.

Table 1 shows the conditions and contents of the incinerators during the experiments and the results of carbon monoxide (CO) and hydrogen chloride (HCl) analyses in exhaust gas. The average temperatures in the combustion chamber ranged from 460 to 650 °C during combustion. The CO contents in the exhaust gases were consistent among the samples. When newspapers were combusted without NaCl, HCl was not detected in the exhaust gas. On the other hand, when NaCl-impregnated newspapers were combusted, 23 mg/m³ HCl was found.

Table 2 shows the results of dioxin analyses of the exhaust gas samples obtained from the incinerator. There were no significant differences in dioxin composition among the different samples. The amount of dioxins formed in the samples according to the number of chlorides was Cl₅ > Cl₄ > Cl₆ > Cl₇ > Cl₈ in PCDD isomers and Cl₄ > Cl₅ > Cl₆ > Cl₇ > Cl₈ in PCDF isomers, except in the case of newspapers alone. PCDFs composed 78–92% of the total dioxin formed in the exhaust gases. The higher the number of chlorides, the less PCDF was produced. Formation of total PCDFs was considerably higher than that of total PCDDs in all six samples. For example, total PCDFs was 11.4-fold total PCDD in sample III (London plane). The total PCDF/total PCDD ranged from 3.04 (sample IV) to 11.4 (sample III). These results were consistent with the results obtained from municipal solid waste combustion (7). Also the composition of dioxins with different numbers of chlorides found in the present study was consistent with that found in exhaust gas from combustion of woods containing NaCl (3). TEQ values ranged from 10 (sample I, heavy oil A alone) to 4250 (sample VI, newspaper + PVC).

When newspapers alone (sample II) and London plane tree branches alone (sample III) were combusted, the total amounts of dioxin formed were 0.18 and 1.4 ng/g (the amount

formed from fuel was subtracted), respectively. These values are quite low as compared with those of samples with chloride. They are similar to those reported in the combustion of woods (4, 5). When newspapers were impregnated with 3% NaCl as an inorganic chloride source (sample IV), formation of dioxins increased 100-fold, suggesting that NaCl is a possible chloride source for dioxin formation. In fact, some food products containing NaCl have reportedly produced dioxins upon combustion (22). When newspapers were combusted with PVC (sample VI), of which the chloride content was 5.1%, 147 ng of dioxin was formed.

The chloride contents of the samples were 0.0064% for newspapers alone, 0.028% for London plane tree branches, 3.1% for NaCl-impregnated newspapers, less than 0.005% for PE, and 35.7% for PVC. It is obvious that the samples with a higher percentage of chloride content produced more dioxins when burned with newspapers and that there is a clear correlation between dioxin formation and chloride content (23). For example, London plane tree branches (sample III) produced a higher percentage of dioxins than newspapers alone (sample II) did because of differences in their chloride percentages. The addition of PE (sample V) did not result in appreciable changes in dioxin formation, suggesting that PE does not significantly contribute to dioxin formation. Samples with inorganic chloride (NaCl) or with organic chloride (PVC) produced significantly higher amounts of dioxins as compared with newspapers alone.

In the present study, both organic and inorganic chloride were shown to be a source of chloride for dioxin formation. There are many reports on dioxin formations from the combustion of various waste materials with organic chloride. In particular, PVC produced dioxins in high amounts via combustion or thermal degradation (24). It is reported that chloride sources in municipal wastes are 50% from NaCl and 45% from PVC (6). However, there have been only a few reports on the possible formation of dioxins from a reaction of inorganic chloride, such as NaCl and HCl, with waste materials during combustion. When HCl was injected in gaseous combustion gases—including methane, propane, and ethylene—production of dioxins was observed (25). It is hypothesized that HCl is formed at first from NaCl or PVC by high temperature and that dioxins are produced subsequently (26). Dioxins were formed under electrostatic precipitation conditions in the presence of HCl and/or CuCl₂ (10). Organic chloride (tetrachloroethylene) with a catalyst such as iron(III), tin(II), and copper(II) promoted the formation of particle-bound dioxins in combustion experiments. On the other hand, inorganic chloride (NaCl) promoted the formation of dioxins more effectively in the gas phase than in the particle phase (27).

TABLE 2. Dioxin Analyses of Exhaust Gases of Incinerated Substances

dioxin	amt of dioxins (pg/g of sample)*						dioxin	sample I	sample II	sample III	sample IV	sample V	sample VI
	sample I	sample II	sample III	sample IV	sample V	sample VI							
T₄CDD													
1,3,6,8-	5.75	7.49	13.7	506	474	430	1,2,3,4- + 1,2,4,6-	1.01	3.72	9.29	935	918	1270
1,3,7,9-	2.84	4.26	7.07	311	327	421	+ 1,2,4,9- + 1,2,3,8-						
1,3,7,8-	1.99	2.73	7.1	766	887	1090	1,2,3,6- + 1,2,7,9-	0.754	3.32	5.63	677	727	841
1,3,6,9- + 1,2,4,7-	1.48	5.2	9.09	788	573	745	1,4,6,9-	0.0007	0.357	5.59	654	840	933
+ 1,2,4,8-							1,2,7,8-	0.0008	0.357	0.307	16.3	32.3	28.5
1,2,6,8-	0.0008	1.49	3.4	370	363	412	1,2,3,9-	0.0019	0.687	1.68	249	277	393
1,4,7,8-	0.0011	0.96	1.3	127	149	227	1,2,6,9-	0.0015	0.455	1.28	139	164	249
2,3,7,8-	0.669	1.48	3.9	332	475	524	1,2,6,7-	0.0025	0.236	1.6	169	202	261
1,2,3,7-	1.01	3.72	2.88	451	411	762		0.0015	0.0005	1.43	210	269	285
total	15.5	36.5	75.2	6700	7090	8870							
P₃CDD													
1,2,4,6,8-	6.27	7.52	10.6	1230	971	1430	1,2,3,7,8-	0.947	1.8	2.93	929	978	1380
+ 1,2,4,7,9-							1,2,3,6,9-	0.44	1.76	1.26	213	218	480
1,2,3,6,8-	3.99	5.92	7.64	825	698	1020	1,2,4,6,7-	0.407	1.46	1.68	448	462	639
1,2,4,7,8-	1.36	1.37	2.78	741	760	1130	1,2,4,8,9-	0.677	1.49	2.11	522	452	680
1,2,3,7,9-	2.5	3.95	4.98	660	625	882	1,2,3,4,6-	0.0007	1.63	1.58	209	200	438
1,2,4,6,9-	1.43	5.43	4.65	550	494	968	1,2,3,6,7-	0.001	1.73	1.8	539	493	835
+ 1,2,3,4,7-							1,2,3,8,9-	0.001	1.29	1.87	644	593	996
total	18.0	35.4	43.9	7510	6940	10900							
H₄CDD													
1,2,3,4,6,8-	8.04	17.4	13	1760	974	1770	1,2,3,4,7,8-	0.398	1.44	1.46	494	238	525
+ 1,2,4,6,7,9-							1,2,3,6,7,8-	0.621	2.82	1.25	500	272	508
+ 1,2,4,6,8,9-							1,2,3,4,6,9-	0.001	2.07	0.749	120	63.2	218
1,2,3,6,7,9-	4.26	7.33	6.72	1830	930	2020	1,2,3,7,8,9-	0.0006	1.17	1.6	505	293	641
+ 1,2,3,6,8,9-							1,2,3,4,6,7-	0.0012	2.78	1.73	732	307	729
total	13.3	35.0	26.5	5940	3080	6410							
H₇CDD													
1,2,3,4,6,7,9-	10.9	12.1	9.83	1840	577	1410	1,2,3,4,6,7,8-	15.9	12.4	8.54	2100	678	1650
total	26.8	24.5	18.4	3940	1260	3060							
O₈CDD													
1,2,3,4,6,7,8,9-	21.3	17.5	9.85	1370	298	721	PCDD total	94.9	149	174	25600	18700	30000
T₄CDF													
1,3,6,8-	14.2	18.3	44.9	686	944	565	1,2,7,8-	2.98	31.3	106	2040	3310	2880
1,3,7,8- + 1,3,7,9-	22.3	25.2	83.4	1680	2780	2040	1,2,6,7- + 1,2,7,9-	21.4	21.4	69.4	1710	2420	2120
1,3,4,7-	11.5	12.7	34.1	623	846	718	1,4,6,9-	2.61	2.54	3.17	70.2	126	71.3
1,4,6,8-	9.19	11.3	28.9	456	574	447	1,2,4,9-	11.3	14.8	7.13	236	288	272
1,2,4,7-	12.9	14.1	46.6	1010	1110	1010	2,3,6,8-	11.3	14.8	77.4	1540	2260	2470
1,3,6,7-	14	14.6	40.7	756	1310	899	2,4,6,7-	19.3	22.8	57	1640	2020	2220
1,3,4,8-	10.4	11.7	31.9	643	860	772	1,2,3,9-	8.66	9.4	6.23	279	357	470
1,3,4,6- + 1,2,4,8-	24.9	27.7	78.3	1380	1670	1420	2,3,4,7-	8.66	9.4	38	1170	1610	2150
1,2,4,6- + 1,2,6,8-	40.2	48.8	105	1690	2280	1470	1,2,6,9-	1.76	2.58	4.96	193	227	298
1,4,7,8- + 1,3,6,9-	30.1	33.8	100	1730	2130	2270	2,3,7,8-	18.4	20.3	67.7	1550	2440	2270
+ 1,2,3,7-							2,3,4,8-	12.9	15.6	37.4	783	1290	1940
1,6,7,8- + 1,2,3,4-	39.3	32.5	89.8	2250	2040	1990	2,3,4,8-	12.9	15.6	37.4	783	1290	1940
2,4,6,8-	10.6	12.8	35	919	1180	1280	2,3,4,6-	15.8	18	45.5	1700	1890	1870
1,2,3,8- + 1,4,6,7-	31.6	45.4	99.5	1890	2540	2760	2,3,6,7-	23.6	26.3	84	2590	3600	3580
+ 1,2,3,6-							3,4,6,7-	11.6	13.1	36.2	1790	2120	1770
1,3,4,9-	4.76	4.5	10.5	331	409	273	1,2,8,9-	0.36	1.62	4.04	187	230	303
total	447	537	1470	33500	44900	42600							
P₃CDF													
1,3,4,6,8-	6.17	7.31	16.7	956	914	1370	1,2,3,4,6-	6.07	6.07	15	828	691	1080
1,2,4,6,8-	9.19	9.09	21.8	1000	1020	1460	1,2,3,7,9-	0.907	1.5	2.57	226	274	335
1,3,6,7,8-	4.15	6.05	12.6	926	1100	1720	1,2,3,6,7-	6.01	6.62	16.4	1239	1406	1904
1,3,4,7,9-	1.21	1.54	3.07	294	355	423	1,2,4,6,9-	9.3	10.3	26.7	1680	1660	2380
1,2,3,6,8-	11.4	13.3	34.2	2220	2680	3670	+ 1,2,6,7,8-						
+ 1,3,4,7,8-							1,2,6,7,9-	1.44	1.69	3.72	341	345	645
1,2,4,7,8-	8.55	10.1	25.9	1470	1820	2280	1,2,3,6,9-	0.667	0.903	1.6	162	171	320
1,2,4,7,9-	7.56	8.89	21.3	1410	1430	2180	2,3,4,6,8-	7.8	9.44	20.9	1220	1030	2090
+ 1,3,4,6,7-							1,2,3,4,9-	1.57	1.32	3.07	225	166	437
1,2,4,6,7-	8.44	9.75	23.1	1340	1420	1910	1,2,4,8,9-	1.38	1.34	2.85	252	231	371
1,4,6,7,8-	4.69	5.04	9.62	457	571	1310	2,3,4,7,8-	8.3	9.17	25.1	1810	1770	2940
1,2,3,4,7-	4.69	5.04	14.1	746	707	1410	1,2,3,8,9-	0.851	0.919	2.33	244	228	329
P₃CDF													
1,3,4,6,9-	1.76	1.66	3.41	332	296	403	2,3,4,6,7-	9.92	11.9	27.1	2330	1800	2700
1,2,3,4,8-	10.8	12.3	30.1	1970	2380	3420							
+ 1,2,3,7,8-													
total	133	151	363	23700	24500	37100							

TABLE 2 (Continued)

dioxin	amt of dioxins (pg/g of sample) ^a						dioxin	sample I	sample II	sample III	sample IV	sample V	sample VI
	sample I	sample II	sample III	sample IV	sample V	sample VI							
H₆CDF													
1,2,3,4,6,8-	5.66	6.52	13.1	1184	890	2460	1,2,4,6,8,9-	0.87	1.34	1.3	209	139	330
1,3,4,6,7,8-	7.93	8.48	20.3	2510	2070	4590	1,2,3,4,6,7-	5.44	7.62	17.5	2010	1380	3150
+ 1,3,4,6,7,9-							1,2,3,6,7,9-	0.828	0.956	1.79	422	371	663
1,2,4,6,7,8-	8.03	9.53	22.1	2240	1740	3760	1,2,3,4,6,9-	2.22	1.92	2.91	527	386	887
1,2,4,6,7,9-	1.58	2	2.98	505	388	820	+ 1,2,3,6,8,9-						
1,2,3,4,7,8-	5.57	6.76	12.7	1770	1480	3770	1,2,3,7,8,9-	0.001	0.26	1.13	332	191	470
+ 1,2,3,4,7,9-							1,2,3,4,8,9-	0.775	1.29	1.22	285	153	481
1,2,3,6,7,8-	5.64	5.91	8.63	1370	1390	3260	2,3,4,6,7,8-	4.13	5.66	15	1190	855	2050
total	48.7	58.2	121	14600	11400	26700							
H₇CDF													
1,2,3,4,6,7,8-	13.1	19.8	26.4	2820	1390	5590	1,2,3,4,6,8,9-	2.53	3.77	3.29	571	215	895
1,2,3,4,6,7,9-	2.89	4.16	3.89	890	325	1580	1,2,3,4,7,8,9-	1.31	1.97	1.73	679	201	1140
total	19.8	29.7	35.3	4960	2130	9200							
O₂CDF													
1,2,3,4,6,7,8,9-	2.36	7.14	3.65	1080	220	1690							
PCDF total	651	783	1990	77800	83200	117000							
grand total	746	932	2170	103000	102000	147000							
PCDF/PCDD	6.84	5.26	11.4	3.04	4.45	3.0							
total TEQ ^b	10	13	30	2650	2700	4250							

^a Samples as defined in Table 1. ^b pg TEQ/g.

TABLE 3. Results of Experiments on Rate of NaCl Vaporization

heat source	temp (°C)	time (min)	NaCl (mg)	amt reduced (mg)	% of vaporization
gas burner	750	10	1991.1	1.2	0.06
	800	10	1989.9	2.3	0.12
	850	10	1987.6	37.0	1.9
	900	10	1950.6	40.8	2.1
electric furnace	750	15	941.0	0.5	0.05
	800	15	942.0	0.6	0.06
	850	15	997.7	56.0	5.6

Metal contents in the newspapers used in the present study were 0.33 µg/g Cr, 2.7 µg/g Mn, 33 µg/g Fe, 0.23 µg/g Ni, 8.6 µg/g Cu, 2.3 µg/g Zn, 0.01 µg/g Cd., and 0.75 µg/g Pd. As (arsenic) was not detected. The calculated amounts of Cu and Fe present in the incinerator during combustion of 50 kg of newspapers were 0.43 and 1.65 g, respectively, suggesting that the low concentrations of these metals did not significantly contribute to dioxin formation.

Table 3 shows the rate of NaCl vaporization at various temperatures. The results indicate that NaCl vaporizes slightly at temperatures above 850 °C. Temperatures of a flame at the outlet of the subsidiary combustion burner and the tip of the flame were above 1200 and 1076 °C, respectively. Therefore, it is hypothesized that NaCl was vaporized and that vapor-phase chlorides subsequently reacted with carbons in the newspapers to form dioxins.

No significant differences in the composition of dioxin isomers were observed between the samples obtained from the newspapers combusted with inorganic chloride (NaCl) and those combusted with organic chloride (PVC). Formation of dioxin isomers from different samples is quite complex and difficult to rationalize for a specific pattern of dioxin compositions. When heavy oil A was combusted alone, the 1,3,6,8-isomer composed over 35% of the total isomers of T₄CDD formed. Generally, 1,3,6,8-, 1,3,7,8-, and 1,4,6,9-isomers formed in high concentrations among T₄CDDs formed. Formation of the 2,3,7,8-isomer—which is the most toxic dioxin/furan congener—also increased with the addition of chloride sources. Newspapers with PVC produced 0.5 ppb

of this particular dioxin. It seems that the higher the chloride concentration, the higher the dioxin formation. It is obvious that increases of chloride concentrations at temperatures under 450–650 °C increased dioxin formation. However, as mentioned above, the exact role of chloride concentration in dioxin formation is not well understood. Further investigation of the role of chloride in PCDD/F formation is in order.

Acknowledgments

We thank T. Miyazaki, R. Watanabe, T. Saito, Y. Tanaka, J. Hatanaka, and Y. Hashimoto for their outstanding technical assistance.

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Received for review April 26, 2000. Revised manuscript received January 2, 2001. Accepted January 8, 2001.

ES001210E

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