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Re-Evaluation of F2 and F3 Petroleum Hydrocarbon Management Limits

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Table of Contents

List of Tables

List of Appendices

1.0 INTRODUCTION

Management limits for petroleum hydrocarbon (PHC) fractions were established to indicate concentrations where factors other than toxicity, such as aesthetics, mobile free-phase formation and explosion hazards may be of concern. Two sets of management limits for PHC fractions F2 and F3 are currently applicable in Alberta, one set in the Tier 1 guidelines document (AEP, 2022) applicable to all land uses, and one set specific to remote parts of the Green Area (ESRD, 2014).

The existing management limits are based on consideration of a range of factors. This document examines the scientific basis for the management limits assessed for each of these factors, reports on additional research and analysis completed to refine the understanding of these factors and makes recommendations for updated F2 and F3 management limits.

1.1 Objective

The objectives of the current project are to re-examine the scientific basis for the current petroleum hydrocarbon fraction F2 and F3 management limits and, where appropriate, to develop revised management limits with a more robust scientific basis.

1.2 Scope of Work

The scope of work for this project includes the following tasks:

1. Review the background and context for the existing PHC management limits;
2. Re-evaluate the relevant factors to include in calculating PHC management limits in various land uses in Alberta;
3. Clearly summarize the scientific basis of the management limit component associated with each factor considered in the current PHC management limits;
4. Evaluate the scientific defensibility of each management limit component;
5. As required, commission or conduct additional research and analysis to improve the scientific defensibility of each management limit component; and,
6. If appropriate, make recommendations for updated management limits for F2 and F3.

1.3 Funding Acknowledgements

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1.4 Key Source Documents

Three documents are referenced extensively through the current work. These documents are listed below for convenience:

1. CCME (Canadian Council of Ministers of the Environment), 2008. *Canada-Wide Standard for Petroleum Hydrocarbons (PHCs) in Soil: Scientific Rationale*. This document explains how the original PHC management limits were derived by CCME in 2008. The original 2001 version of this document was also consulted for historical details, as well as unpublished documents and communications from the 2008 update of the Canada-Wide Standard.
2. Alberta Environment and Sustainable Resource Development (ESRD), 2014. *Subsoil petroleum hydrocarbon guidelines for remote forested sites in the Green Area*. This document provides updated PHC management limits for F2 and F3 for use in remote parts of the Green Area of Alberta.
3. Petroleum Technology Alliance Canada (PTAC), 2013. *Proposed management limits for F2 and F3 Petroleum Hydrocarbons at Remote Alberta Green Area Sites*. This document provides more details of the new research findings upon which the above document (ESRD, 2014) was based.

2.0 BACKGROUND AND CONTEXT FOR PHC MANAGEMENT LIMITS

The Alberta Tier 1 guideline framework (AEP, 2022) sets soil remediation guidelines based primarily on a range of exposure pathways related to avoiding adverse toxicity-based effects on a range of human and ecological receptors. It is acknowledged that there are other considerations relevant to setting soil remediation guidelines. Within the Tier 1 soil guideline framework, these other considerations are grouped together as a guideline called a management limit. Two documents have developed management limits for PHCs, the CCME (2008) "Canada-Wide Standard for Petroleum Hydrocarbons" and the ESRD (2014) document "Subsoil Petroleum Hydrocarbon Guidelines for Remoted Forested Sites in the Green Area". The management limits developed in these two documents are summarized below.

2.1 Petroleum Hydrocarbon Canada-Wide Standard (2008)

The management limits for petroleum hydrocarbon fractions currently used in the AEP (2022) Tier 1 guidelines were adopted without change from the CCME (2008) Petroleum Hydrocarbon Canada-Wide Standard. CCME (2008) recognized that the potential adverse effects of PHC are not limited to chronic toxicity to human and ecological receptors. CCME (2008) identified six factors that were considered to develop their management limits. Those six factors were as follows:

1. Mobile free phase formation;
2. Exposure of workers in trenches to PHC vapours;

3. Fire and explosion hazard;
4. Effects on buried infrastructure;
5. Aesthetic considerations; and
6. Technological factors.

These factors were evaluated quantitatively, semi-quantitatively or qualitatively as available data permitted. The rationale for setting the existing value for each factor is summarized in Section 4. An assessment of the scientific defensibility of each factor, together with additional research and analysis conducted in relation to each management limit component is provided in Section 5.

The overall PHC management limits that were developed by CCME (2008) were adopted without change in the current Alberta Tier 1 guidelines document (AEP, 2022) and are summarized in Table 1.

Table 1 Existing Overall PHC Management Limits – Alberta Tier 1

PHC Fraction	Management Limit (mg/kg)	
	Fine Soil	Coarse Soil
F1	800	700
F2	1,000	1,000
F3	3,500	2,500
F4	10,000	10,000

2.2 Subsoil Petroleum Hydrocarbon Guidelines for Remote Sites in the Green Area

Alberta (ESRD, 2014) has also published PHC management limits for PHC fractions F2 and F3 that can be applied in subsoils in the Green Area of Alberta when the site meets the following five conditions:

1. The site is within the Green Area;
2. The site is in a forested area and is, or will be reclaimed to a forested ecosystem;
3. The site is remote from existing residences and roads;
4. There is no dugout on site and future construction of a dugout is unlikely; and,
5. The site is stable.

Detailed guidance on how to assess these five conditions is provided in ESRD (2014).

In developing these revised management limits, ESRD (2014) and PTAC (2013) considered the six factors considered by CCME (2008) (Section 2.1 above). Some of these factors were not considered relevant to the remote Green Area setting and were not included. Conversely, some factors not considered by CCME (2008) were included for consideration by ESRD (2014). The factors included for detailed consideration by ESRD (2014) were:

1. Mobile free phase formation;
2. Fire and explosion hazard;
3. Hydrophobicity; and
4. Upwards migration of hydrocarbons into the root zone.

These factors were evaluated quantitatively, in several cases by commissioning new experimental research. The ESRD (2014) rationale for setting the existing value for each factor is summarized in Section 4, while scientific defensibility, both in the context of remote Green Area sites, and more widely in Alberta, is discussed in Section 5.

The overall PHC management limits that were developed by ESRD (2014) for remote Green Area subsoils are summarized in Table 2.

Table 2 Existing Overall PHC Management Limits – Alberta Remote Green Area Subsoil

PHC Fraction	Management Limit (mg/kg)	
	Fine Soil	Coarse Soil
F2	10,000	9,000
F3	14,000	4,000

Note: ESRD (2014) notes that when applying these management limits, the sum of the concentrations of PHC fractions F1 to F4 must not exceed 30,000 mg/kg.

3.0 FACTORS TO BE CONSIDERED IN SETTING MANAGEMENT LIMITS

Existing sources of PHC management limits (Sections 2.1 and 2.2) identified an aggregate of 8 potential factors to be evaluated when developing management limits.

1. Mobile free phase formation;
2. Exposure of workers in trenches to PHC vapours;
3. Fire and explosion hazards;
4. Effects on buried infrastructure;
5. Aesthetic considerations;

6. Technological factors;
7. Hydrophobicity; and,
8. Upwards migration of hydrocarbons into the root zone.

No other relevant factors were identified in the current review, and the above list is considered to be complete. Note that issues related to toxicity are evaluated elsewhere in the Tier 1 guideline framework.

3.1 Relevance of Factors by Land Use

The following factors are assessed as being relevant in all land use designations:

1. Mobile free phase formation;
2. Fire and explosion hazards;
3. Hydrophobicity; and
4. Upwards migration of hydrocarbons into the root zone.

The "Technological Factors" consideration is not retained going forward (see Section 5.6).

Three factors are considered relevant only to land uses outside the remote Green Area, as discussed below.

The remote Green Area is defined (ESRD, 2014) as an area within the Green Area of Alberta and sufficiently remote from human activities that it can be safely assumed that the soil profile will not be disturbed by human activities in the foreseeable future. Under these conditions, the following factors are not considered relevant in this land use:

1. Exposure of workers in trenches to PHC vapours;
2. Effects on buried infrastructure; and,
3. Aesthetic considerations.

The exposure of workers in trenches to PHC vapours and effects on buried infrastructure are not relevant in a remote Green Area setting because the construction or presence of utility lines and trenches is highly unlikely in such remote areas.

Aesthetic considerations are also not relevant in a remote green zone setting as the subsoil profile is unlikely to be disturbed and therefore aesthetic issues are not relevant.

4.0 BASIS FOR CURENT VALUE FOR EACH FACTOR

4.1 Mobile Free Phase Formation

Both CCME (2008) and ESRD (2014) considered mobile free phase formation to be a relevant factor in setting management limits. The threshold at which free phase hydrocarbon starts to be mobile is often referred to as the residual saturation for that hydrocarbon fraction in a given soil type.

4.1.1 CCME (2008)

A narrative is provided in Section 5.3.1 of CCME (2008) discussing some of the thinking behind the limits adopted to manage this factor. The overall objective was to set concentration limits for each PHC fraction below which the presence of mobile free phase was considered unlikely. However, at the time there were no available relevant experimental data for PHC hydrocarbon fractions F1 to F4, and limits were extrapolated from more general observations on whole hydrocarbon products.

The approach adopted was semi-quantitative for PHC fractions F2 to F4, and somewhat more quantitative for F1 (though still not based on experimental data).

The approach for fractions F2 to F4 was semi-quantitative and based on some general statements attributed to Mercer and Cohen (1990) for a range of soils and petroleum hydrocarbon types that "mobile free-phase formation is often observed when 10% to 20% of the soil pore space contains hydrocarbons". CCME (2008) used this to estimate that the residual saturation limit occurs with total PHC concentrations on the order of 20,000 mg/kg to 30,000 mg/kg (2% to 3% total PHC by weight). A management decision was made to set a limit of 2% total PHC in soil, of which no more than 1% should be the sum of fractions F1 to F3, and 1% F4.

A higher level of concern was noted for F1 due to the higher mobility and solubility of this fraction and limits of 800 mg/kg and 700 mg/kg were set for F1 in fine and coarse soil, respectively based on considerations relating to the solubility of individual sub-fractions of F1.

Thus, the limits set by CCME (2008) to manage mobile free phase formation were:

1. F1: 800 mg/kg (fine soils) and 700 mg/kg (coarse soils);
2. F2+F3: 9,200 mg/kg (fine soils) and 9,300 mg/kg (coarse soils); and
3. F4: 10,000 mg/kg.

4.1.2 ESRD (2014)

ESRD (2014) management limits are based on a research document by PTAC (2013) (Also reported in Drozdowski *et al*., 2013) which determined that the lack of experimental data on the residual saturation for hydrocarbon fractions F1 to F4 was a data gap in the CCME analysis.

PTAC (2013) commissioned a program of experimental research to determine scientifically defensible values for the residual saturation of F2 and F3 in coarse and fine soil types. This program involved setting up soil in 1,000 ml glass cylinders, saturating the soil with F2 or F3 hydrocarbon, and allowing the soil to drain until no further mobile free phase was released. The concentration of hydrocarbon remaining in the soil was interpreted as the residual saturation for that hydrocarbon fraction and soil type. An additional check was made by flooding the equilibrated columns with water from below and determining whether further hydrocarbon could be mobilized. The residual saturation was revised downward to account for any hydrocarbon mobilized in this way.

Two phases of experimentation were undertaken. The experimental design for Phase 1 (range finding) included two soil types (coarse and fine), two hydrocarbon fractions (F2 and F3), two initial moisture conditions (dry, and field capacity) and 3 replicates of each condition (total 24 columns). The drainage period for Phase 1 was 7 days. The experimental design for Phase 2 (definitive) included two soil types (coarse and fine), two hydrocarbon fractions (F2 and F3), one initial moisture condition (field capacity) and 3 or 6 replicates of each condition (total 21 columns). The drainage period for Phase 2 was 21 days.

The thresholds recommended by PTAC (2013) and adopted by ESRD (2014) to prevent the risk of formation of mobile free phase PHC fractions F2 and F3 in coarse and fine soil are summarized below.

1. F2 in fine soils: 10,000 mg/kg;
2. F2 in coarse soils: 9,000 mg/kg;
3. F3 in fine soils: 14,000 mg/kg; and
4. F3 in coarse soils: 34,000 mg/kg.

4.2 Exposure of Workers in Trenches to PHC Vapours

Exposure of workers in trenches to PHC vapours was considered by CCME (2008), but not by ESRD (2014) since this factor was not considered relevant in the Green Area (Section 3.1).

CCME (2008) evaluated risks to workers in trenches using a vapour model published by Virginia Department of Environmental Quality (VDEQ, 2005). Two separate scenarios were evaluated:

- Vapour intrusion into a trench with width greater than depth (reflecting >45° sloped sidewalls). For this scenario it was assumed that workers could spend significant time in the trench, and the same toxicity reference values were applied as for indoor vapour inhalation.
- Vapour intrusion into a trench with depth greater than width, with assumed air exchange rate similar to residential buildings. It was assumed that workers would spend limited time in these trenches. For F2, model results were compared to the occupational exposure limit for jet fuel/kerosene in the absence of relevant short-term exposure limits for F2; the occupational exposure limit for gasoline was used for F1.

For both scenarios it was assumed that the PHC were in direct contact with the trench.

A value of 1,000 mg/kg was determined to be protective for both F1 and F2 for coarse and fine soils.

4.3 Fire and Explosion Hazards

Both CCME (2008) and ESRD (2014) considered fire and explosion hazards.

4.3.1 CCME (2008)

CCME used the VDEQ (2005) trench model to determine threshold concentrations for PHC fractions in soil below which the migration of hydrocarbon vapours into a nearby confined space was not a concern from a fire and explosion perspective.

Limiting concentrations were calculated for fractions F1 and F2 as follows:

1. F1: 1,700 mg/kg (fine soils) and 1,400 mg/kg (coarse soils); and
2. F2: 5,200 mg/kg (fine and coarse soils).

4.3.2 ESRD (2014)

ESRD (2014) management limits are based on a research document by PTAC (2013). PTAC (2013) took an experimental approach to evaluating threshold concentrations of PHC fractions F2 and F3 in soil in relation to fire and explosion hazards. PTAC (2013) conducted a simple ambient temperature flammability test by passing an open flame directly over a series of soil samples spiked with a range of concentrations of the hydrocarbon fraction being tested.

PTAC (2013) found that even at the maximum concentration tested, 64,000 mg/kg, neither F2 nor F3 spiked samples ignited in either soil type when a flame was applied. Subsequently a flame was applied directly to F2 and F3 product, and neither would ignite.

The conclusion of the PTAC (2013) work, therefore, was that fire and explosion hazards were not a concern for either F2 or F3 under any circumstances.

4.4 Effects on Buried Infrastructure

This factor was considered by CCME (2008) but was not considered relevant to a remote Green Area setting by ESRD (2014).

CCME (2008) noted that this issue was of potential concern, particularly in relation to the possibility of PHC entering water distribution systems. However, CCME (2008) referenced a review of all information available on this subject by Stantec (2003) and concluded that available data were not adequate at that time to derive meaningful thresholds for the PHC fractions on a generic basis. CCME (2008) recommended that potential effects of PHC on buried infrastructure should be addressed on a site-specific basis where utilities or other infrastructure are in contact with contaminated soil.

In summary, CCME (2008) flags this issue as being of potential concern, but recommend it be managed on a site-specific basis where potential issues arise.

4.5 Aesthetic Considerations

This factor was considered by CCME (2008) but was not considered relevant to a remote Green Area setting by ESRD (2014).

CCME (2008) flagged odours, visible effects on soil, effects on the taste of potable water and visible plant damage as potential issues but noted that aesthetic effects are somewhat subjective and may be highly dependent on site-specific factors. CCME (2008) did not set quantitative thresholds in relation to this issue due to lack of available data and the considerations noted above. CCME (2008) noted that other issues evaluated as part of management limits and/or other exposure pathways within the Tier 1 guidelines will generally be sufficient to manage aesthetic issues. However, aesthetic impacts should be addressed on a site-specific basis when they occur.

In summary, CCME (2008) flags this issue as being of potential concern, but recommend it be managed on a site-specific basis where issues arise.

4.6 Technological Factors

This factor was considered by CCME (2008) but was not considered relevant to a remote Green Area setting by ESRD (2014).

The term “Technological Factors” appears to be used by CCME (2008) to describe a set of thresholds for F3 that were adopted “without review” from the previous (2001) version of the document. These thresholds appear to be a catch-all for a range of potential issues including “toxic risk, aesthetics, effects on infrastructure and bioremedial capabilities”. Several of these issues are managed elsewhere within the CCME (2008) management limits or the Tier 1 guidelines. The exception is bioremedial capabilities. It is understood from discussions that took place around the time of the CCME (2008) document that these thresholds are related in some way to aged and weathered sites where bioremediation of F3 hydrocarbons had initially been successful but had “stalled” at concentrations in this range, but the details are now unclear, and not recorded in the CCME (2008, 2001) documentation. The F3 thresholds indicated in CCME (2008) are as follows:

1. F3: 2,500 mg/kg (coarse subsoils, agricultural and residential uses);
2. F3: 3,500 mg/kg (coarse subsoils, commercial and industrial uses);
3. F3: 3,500 mg/kg (fine subsoils, agricultural and residential uses); and,
4. F3: 5,000 mg/kg (fine subsoils, commercial and industrial uses).

In summary, CCME (2008) provides thresholds for “Technological Thresholds” for F3 only. These values may be based to some extent on practical considerations relating to bioremediation of F3 in soils, but the rationale provided in CCME (2008) is vague, and the current relevance of these values is unclear.

4.7 Hydrophobicity

This factor was considered by ESRD (2014) but was not included in the issues considered by CCME (2008).

When soils are exposed to high concentrations of hydrocarbons, they can become hydrophobic. Hydrophobic soils tend to repel water rather than allow it to penetrate, and this is clearly a condition that could impact the normal functioning of a soil and therefore should be avoided.

The ESRD (2014) approach to this issue was based on PTAC (2013) research using the molarity of ethanol droplet (MED) test on soil concentration series (coarse and fine) spiked with F2 and F3 hydrocarbons. In the MED test, water droplets with increasing concentrations of ethanol are placed on the surface of the soil, and the result of the test is the lowest concentration of ethanol that allows the droplet to penetrate the soil within 10 s. For non-hydrophobic soils, a droplet of pure water will be absorbed within 10s. In practice, therefore, this test was conducted by testing a concentration series of F2 or F3 spiked into coarse or fine soil. The highest concentration of hydrocarbon that did not cause any trace of hydrophobicity (*i.e.,* a drop of pure water would be absorbed within 10s) was deemed to be the conservative hydrophobicity threshold.

The results of the PTAC (2013) hydrophobicity testing of F2 and F3 hydrocarbons in fine and coarse soil were as follows:

1. F2 in fine soil, hydrophobicity threshold >64,000 mg/kg.
2. F2 in coarse soil, hydrophobicity threshold >64,000 mg/kg.
3. F3 in fine soil, hydrophobicity threshold approximately 40,000 mg/kg.
4. F3 in coarse soil, hydrophobicity threshold approximately 4,000 mg/kg.

4.8 Upwards Migration into Root Zone

ESRD (2014) and PTAC (2013) also investigated whether upwards migration of hydrocarbons from subsoil back up into the root zone might be a limiting consideration. This question had been previously investigated in a series of column experiments by Startsev (2009).

In the Startsev (2009) experiment, 2 m columns were packed with soil that was contaminated with either jet fuel or crude oil in the bottom 50 cm, and soil without any PHC in the top 1.5 m. Control columns had soil without PHC over the whole 2 m profile. Alfalfa was planted in the columns. The experiment was run for 15 months, during which time the above ground parts of the alfalfa were harvested 5 times. Appropriate moisture content for alfalfa growth was maintained in the test columns by supplying capillary water at the bottom of each column, and accordingly there was an upwards moisture gradient in the columns throughout the experiment. These experimental conditions represent a worst-case scenario for potential upwards movement due to the strong and continuous upwards moisture gradient. Actual conditions in Alberta soil would typically not have such a strong upwards moisture gradient.

Comparison of the chemical analysis of the contaminated 1.5 m to 2 m zone with the overlying 1.0 to 1.5 m zone indicated that, at most, trace amounts of PHC migrated up into the root zone over the 15-month duration of the experiment. Over this same time period there was significant upwards migration of salts through the soil columns in the fine soils experiment.

Overall, ESRD (2014) and PTAC (2013) concluded that upward migration of F2 or F3 hydrocarbons from subsoil up into the root zone was not a limiting concern in setting management limits for hydrocarbons at Green Area sites.

5.0 REASSESSMENT AND RECOMMENDATIONS FOR EACH FACTOR

5.1 Mobile Free Phase Formation

Mobile free phase formation is evaluated as a relevant consideration in all land uses, as the presence of free phase hydrocarbon is undesirable. This consideration should be included in setting management limits in all land uses and situations.

The ESRD (2014) approach to setting F2 and F3 thresholds for mobile free phase formation is based on PTAC (2013) data with a high degree of relevance to the question at hand, and has a high degree of scientific defensibility for the following reasons:

1. The thresholds are based on actual measurements of free phase mobility.
2. The experiments were conducted with F2 and F3 hydrocarbon fractions generated by distilling crude oil sourced from Alberta.
3. The coarse and fine soils used in the experiments were field-collected soils from Alberta.
4. Adequate replication was conducted.
5. Results were corrected for any free phase that could be re-mobilized by simulated changes of water table depth following initial equilibration.

These high-quality data were not available at the time of the CCME (2008) evaluation, and accordingly that study was obliged to extrapolate from a 1990 paper that made some general statements about residual saturation thresholds for unspecified whole hydrocarbon products in unspecified soil types.

Overall, it is clear that the PTAC (2013) data are more relevant and more scientifically defensible than the data on which the CCME (2008) evaluation was based. Accordingly, the ESRD (2014) thresholds are adopted in the current work and are relevant and applicable in all soil types and land uses.

5.2 Exposure of Workers in Trenches to PHC Vapours

The exposure of workers in trenches to PHC vapours is evaluated as a relevant consideration in all land uses except for remote Green Area. It is assumed that utility trenches will rarely be installed in areas classified as remote Green Area. The CCME (2008) limits for this factor (1,000 mg/kg for F2 for both coarse and fine soils) were established based on a trench vapour model published by VDEQ (2005). A range of trench scenarios were investigated including trenches with their width greater or less than their depth, and with the contaminated soil either at 30 cm distance or directly in contact with trench walls. Some details of the modelling scenarios considered are available in Meridian (2006), and subsequently, Meridian (2010) conducted a review of other possible modelling approaches.

There is significant uncertainty surrounding the CCME (2008) management limit of 1,000 mg/kg calculated for this factor. The two primary reasons for this uncertainty are:

1. The VDEQ model, and most of the other models identified by Meridian (2010) are based on diffusion of vapours through soil close to the trench wall. Such diffusion-based models tend to be extremely sensitive to the model parameters selected, including soil porosity, soil moisture, and particularly the assumed distance between contamination and trench wall.
2. A lack of field verified air exchange rate values for trenches. The CCME (2008) calculations adopt the recommended trench air exchange rates in the VDEQ model, which are 360/hour where trench width is greater than depth and 2/hour otherwise.

The current project significantly reduced these two primary uncertainties as follows.

A literature review was carried out to see whether better data on field verified air exchange rate values for trenches were available since the CCME (2008) work was completed. Thompson *et al*. (2017) conducted an empirical field study specifically to investigate the validity of the default air exchange rates of 360/hour and 2/hour in the VDEQ model. These authors measured the air exchange rate in five trenches all 3 feet wide and 8 feet deep in various orientations to the prevailing wind direction and under various conditions. They found an average air exchange rate of 46/hour and that figure is adopted here.

In order to reduce the uncertainty associated with diffusion-based models it was decided to measure the actual flux rates and vapour concentrations that occur when coarse- and fine-grained soil spiked with F2 is exposed to the air. Three phases of experiments were conducted by InnoTech Alberta as follows:

- Phase 1 measured the equilibrium headspace vapour concentrations of F2 in equilibrium with F2 spiked soils.
- Phase 2 measured how the transient headspace vapour concentrations of F2 increased over time in a static headspace in contact with F2 spiked soils.
- Phase 3 measured the F2 vapour concentration in flow-through cells containing F2 spiked soils with an air exchange rate of 46/hour.

Full experimental details are available in the InnoTech reports included in Appendix A (Phase 1) and Appendix B (Phases 2 and 3).

The InnoTech Phase 3 data were used, together with the updated trench air exchange rate noted above to calculate revised management limits for this factor. Full details of these calculations are provided in Appendix C. The revised management limits for F2 for the exposure of workers in trenches to PHC vapours factor are:

- Fine-grained soil: 17,000 mg/kg.
- Coarse-grained soil: 4,000 mg/kg.

These values are based on measured data for trench air exchange rate and F2 flux rate and a very simple box mixing model for trench air. As such, these values have a much lower uncertainty than the values developed in CCME (2008) and are adopted in the current work.

5.3 Fire and Explosion Hazards

Fire and explosion hazards are evaluated as a relevant consideration in all land uses, since it is clearly important that residual hydrocarbon concentrations are not present in soils at concentrations that could result in these risks.

Experimental work reported in PTAC (2013) confirmed that neither F2 nor F3 is flammable under ambient environmental conditions, and therefore there is no guideline required (NGR) in relation to this issue for F2 and F3. The experimental finding that F2 is not flammable when a flame is directly applied to the free product supersedes the F2 guideline of 5,200 mg/kg calculated indirectly by CCME (2008) using modelling approaches (see Section 4.3).

5.4 Effects on Buried Infrastructure

Effects on buried infrastructure are evaluated as a relevant consideration in all land uses except for remote Green Area, since it is important that residual hydrocarbon concentrations are not present in soils at concentrations that could result in these risks in areas where buried infrastructure could reasonably be expected.

CCME (2008) considered a review by Stantec (2003) that evaluated the data available at that time to support an evaluation of these risks. Stantec (2003) and CCME (2008) concluded that the data available at that time were not sufficient to enable a quantitative evaluation and recommended that any issues be dealt with on a site-specific basis. The current project collected additional empirical data to help identify whether the above approach is reasonable.

In Phase 2 of this project, additional data were gathered to strengthen the scientific rationale behind setting management limits for this consideration. The primary focus was on water distribution systems, consistent with the primary concern identified by CCME (2008). Of the other types of buried infrastructure listed by AEP (2022), it seems unlikely that the vulnerability to PHCs of steel or concrete infrastructure such as pilings, pipelines or foundations would be a limiting concern.

Considerations related to fibre-optic cable were included in a literature review in the InnoTech (2020) report (Appendix A). Information from utility companies indicated that fibre-optic cable is usually laid at depths shallower than 1.5 m where other exposure pathways such as the ecological direct contact pathway will typically limit PHC concentrations. In addition, fibre-optic cable is typically laid inside a protective conduit and will not generally be directly exposed to PHC-impacted soil.

Underground power cables were not explicitly considered in the InnoTech review, but it is assumed that, as with fibre-optic cable, power cable will normally be laid inside a protective conduit, and that the cable would not be directly exposed to PHCs in sub-surface soil.

For the reasons indicated above, experimental work in the InnoTech (2020) study focused on the possible effects of PHCs on water distribution piping. The two main concerns for water distribution piping exposed to PHCs in soil are possible physical deterioration of the pipe resulting in integrity issues, and potential infiltration of PHCs into the interior of the pipe where drinking water could be tainted. The InnoTech (2020) literature review indicated that the commonest materials used for water distribution piping in Alberta were polyvinyl chloride (PVC), high density polyethylene (HDPE), and fibre-reinforced plastic (FRP), with PVC being the commonest.

Full details of the experimental work conducted to investigate these two concerns are available in the InnoTech (2020) report (Appendix A). Two experimental programs were conducted. Key findings are summarized briefly below.

The intent of the first program was to assess possible degradation of water supply piping in the presence of F2 or F3 hydrocarbons. Coupons of PVC, HDPE, and FRP pipe material were incubated in pure F2 or F3 for 80 days. No significant changes were apparent to either the appearance of the coupons or to their physical properties over the incubation period.

The intent of the second program was to assess whether PHC F2 could infiltrate into water distribution piping. PVC piping was selected for this experiment as the literature review had indicated that PVC was the most common material used in Alberta for this purpose. No experiment was conducted with PHC F3, as F3 is effectively insoluble (AEP, 2022). Full details of the experimental setup are available in Appendix A. In summary, the experimental setup involved 15 cm lengths of 150 mm internal diameter water distribution piping with 11 mm wall thickness. The pipe sections were capped at both ends using an epoxy and silicone caulking and filled with water. Each pipe segment was surrounded by cotton batting soaked in F2. The pipes were incubated for 80 days and then water samples were collected and analyzed. There was no measurable infiltration of F2 from pure F2 in contact with the outside of the pipe into water inside the pipe when incubated for 80 days. This length of time is extremely conservative for how long water would be expected to remain stagnant in a water distribution system because a pipe of this size would be expected to supply many residences. In addition, exposing a water filled pipe to pure F2 is very conservative in relation to exposing a pipe to soil with F2 at a nominal level of 10,000 mg/kg, for example.

Given the findings from the experimental work presented in this report, there seems to be no realistic possibility that F2 infiltration into water distribution piping would be a concern under any circumstances. In addition, fibre-optic cable and underground power cable would normally be protected in a conduit and not directly exposed to PHC-impacted soil. Other buried infrastructure constructed from concrete or steel is considered highly unlikely to be adversely affected by PHCs in soil.

No change is therefore recommended from the CCME (2008) conclusion that effects on buried infrastructure are not expected, and any issues should be addressed on a site-specific basis.

5.5 Aesthetic Considerations

Aesthetic considerations are evaluated as a relevant issue in all land uses except for remote Green Area. CCME (2008) identified a range of aesthetic considerations potentially associated with high concentrations of residual PHC in soil. They identified some of these potential considerations as being sufficiently managed through various exposure pathways evaluated in the Tier 1 guideline framework (odour issues in indoor dwellings, tainting of drinking water, and visible plant damage). The remaining issues identified by CCME (2008) that would fall within the scope of a management limit were soil odours and visible effects on soil. CCME (2008) noted that aesthetic effects are somewhat subjective and may be highly dependent on site-specific factors. CCME (2008) did not set quantitative thresholds in relation to this issue due to lack of available data and the considerations noted above.

As noted by CCME (2008), these aesthetic issues are somewhat subjective and may be highly dependent on site-specific factors. Management limits typically are only ever limiting for subsoils below 1.5 or 3 m. Accordingly, the issue of odours and visible effects really only applies in a situation where subsoil is excavated or otherwise disturbed. Data on olfactory thresholds for PHC fractions in soil are not currently available. However, even if they were, it is unclear how to include these aesthetic considerations in a management limit value, given the above considerations and also the expectation that even if soils are disturbed or excavated and brought to surface, degradation of hydrocarbons will occur on soil surfaces exposed to the air.

CCME (2008) elected to retain aesthetics as a relevant consideration, but not to attempt to set a generic numerical threshold for this issue, and to manage any issues on a site-specific basis. On balance this still appears to be a reasonable and appropriate way to manage this issue and this approach is retained in the current work.

5.6 Technological Factors

As noted in Section 4.6, the term "Technological Factors" appears to be used by CCME (2008) to describe a set of thresholds for F3 that were adopted "without review" from the previous (2001) version of the document. No quantitative information is provided in CCME (2008) concerning how these thresholds were calculated beyond a vague statement referencing a range of potential issues including "toxic risk, aesthetics, effects on infrastructure and bioremedial capabilities". Since most of these issues are dealt with elsewhere in this document or in the Tier 1 guideline framework, "Technological Factors" were not included in the list of valid factors for calculating management limits for petroleum hydrocarbons.

5.7 Hydrophobicity

Hydrophobicity is evaluated as a relevant consideration for all land uses, since it is important that residual hydrocarbon concentrations are not present in soils at concentrations that could result in soils becoming hydrophobic.

The PTAC (2013) approach to setting F2 and F3 thresholds for hydrophobicity has a high degree of relevance to the question at hand, and has a high degree of scientific defensibility for the following reasons:

1. Hydrophobicity thresholds were determined experimentally using F2 and F3 hydrocarbon fractions generated by distilling crude oil sourced from Alberta.
2. The coarse and fine soils used in the experiments were field-collected soils from Alberta.
3. Adequate replication was conducted.

The PTAC (2013) hydrophobicity thresholds are adopted in the current work.

5.8 Upwards Migration into Root Zone

Upwards migration of hydrocarbon fractions from subsoil into the rooting zone is evaluated as a relevant consideration in all land uses, since this could result in possible future impact on plant growth, which would be undesirable.

Experimental work conducted by Startsev (2009) evaluated this consideration under worst case conditions (strong upward moisture gradient). Evaluation of the results of the Startsev (2009) work by PTAC (2013) indicated that at worst only trace amounts of hydrocarbon moved up into the rooting zone and therefore there is no guideline required (NGR) in relation to this issue for F2 and F3.

The relevance and scientific defensibility of the Startsev (2009) experimental work and the PTAC (2013) analysis are evaluated as high, based on the following:

1. The experimental setup with hydrocarbon contaminated soil placed in columns immediately below 1.5 m of clean rooting zone is relevant to real world situations.
2. Water was provided only to the base of the columns, resulting in a strong upward moisture gradient and therefore experimental results are conservative relative to most real-world conditions.
3. The experiments were run for a sufficient time period (15 months) to see significant upward transport of salts (conservative solutes) thus confirming that the lack of upwards hydrocarbon movement was a meaningful finding.
4. Adequate replication was conducted.

The PTAC (2013) finding that there is no guideline required (NGR) is retained in the current work in relation to the possibility of upward migration of F2 and F3 from subsoil into the rooting zone for F2 and F3.

6.0 RECOMMENDED UPDATED MANAGEMENT LIMITS FOR F2 AND F3

Based on currently available data and the discussion in Sections 4 and 5 of this document, the recommended relevant factors for setting management limits together with threshold values for each consideration summarized in Table 3. Overall recommended management limits for i) remote green zone areas, and ii) all other land uses are summarized in Table 4.

Table 3 Recommended Management Limit Components (mg/kg)

Consideration	F2		F3	
	Fine Soil	Coarse Soil	Fine Soil	Coarse Soil
Factors Relevant in All Land Uses				
Mobile free phase formation	10,000	9,000	14,000	34,000
Fire and explosion hazards	NGR	NGR	NGR	NGR
Hydrophobicity	>64,000	>64,000	40,000	4,000
Upwards migration of hydrocarbons into the root zone	NGR	NGR	NGR	NGR
Factors Relevant in All Land Uses Except Remote Green Area				
Exposure of workers in trenches to PHC vapours	17,000	4,000	NGR	NGR
Aesthetic considerations	SSB	SSB	SSB	SSB
Effects on buried infrastructure	SSB	SSB	SSB	SSB

Notes:
NGR = no guideline required
SSB = any issues should be managed on a site-specific basis

Table 4 Recommended Overall Management Limits(mg/kg)

Land Use	F2		F3	
	Fine Soil	Coarse Soil	Fine Soil	Coarse Soil
Remote Green Access	10,000	9,000	14,000	4,000
All Other Land Uses and Areas	10,000	4,000	14,000	4,000

7.0 CLOSURE

This report was prepared by Millennium EMS Solutions Ltd. ("MEMS") for the Petroleum Technology Alliance of Canada ("PTAC") and has been completed in accordance with the PTAC Technical Steering Committee's ("TSC") terms of reference. This report does not necessarily represent the views or opinions of PTAC or the PTAC members.

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APPENDIX A: INNOTECH ALBERTA 2020 CONTRACT RESEARCH REPORT

Petroleum Hydrocarbon Fractions 2 and 3: Evaluation of Management Limits

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3.

EXECUTIVE SUMMARY

In the Alberta Tier 1 guidelines, generic management limits for PHC F2 and F3 can often become limiting and potential drivers for remediation in the case that the eco-contact exposure pathway can be eliminated (*i.e.,* 1.5 m below ground surface). Based on a previous phase of this project, it was recommended that empirical testing be conducted to validate generic inputs for two factors that are used in calculating PHC F2 and F3 management limits: 1) potential exposure of workers in trenches to PHC F2 vapours, and 2) potential effects of PHC F2 and F3 on buried infrastructure.

To generate data for modelling vapours that could potentially accumulate in a trench, experimental testing was conducted to assess volatilization of PHC F2 alone and when spiked into fine- and coarse-grained soils with moisture levels representative of potential *in situ* conditions. Method development was conducted to measure both total PHC F2 vapours in headspace above distillate and spiked soil, as well as specific sub-fractions in the PHC F2 range (>nC_{10}-nC_{16}), including aliphatic and aromatic compounds in both the nC_{10-12} and nC_{12-16} ranges. Headspace concentrations were provided to MEMS as input parameters for trench models. Vapours from PHC F3 were not tested as concentrations were assumed to be very low given low volatility of compounds in the >nC_{16}-nC_{34} range.

Potential effects of PHC F2 and F3 on buried infrastructure, including water pipe and fibre optic cables, was assessed through a literature review followed by piping material incubation in PHC F2 and F3 distillate, and testing of water within one type of piping wrapped in PHC F2-soaked batting.

The literature review found that fibre optic cables are generally buried at depths shallower than the zone of interest for this project. Water piping, however, is buried a minimum of 2.59 m below curb top to avoid freezing, and is therefore at a depth below the eco-contact exposure pathway. It was found that polyvinyl chloride (PVC), high density polyethylene (HDPE) and fibre-reinforced plastic (FRP) are the most common polymer types used for water pipe, with PVC being the most common.

Representative pipe material (PVC, HDPE and FRP) was obtained with an inner diameter of 150 mm (6 in) and thickness required to withstand 150 kPa pressure (>1 cm). Coupons (4 cm^2) were cut and incubated for 80 days in pure PHC F2 and F3 distillate with water and no incubation as a control. Post-incubation, the coupons were weighed, tested for hardness and thickness, and examined under 10X magnification. Based on the average and standard deviation of three replicates, the majority of pre- and post-incubation metrics were not significantly different, with exception of the weight of HDPE incubated in PHC F2 (increase) and hardness decrease in PVC following incubation in both PHC F2 and F3. Notable differences could not be detected *via* observation of the coupons, with or without magnification.

Samples of water were taken from inside PVC pipe wrapped in PHC F2-soaked batting after 80 days. It was found that concentrations of PHC F2 in the water exceeded the Alberta Tier 1 groundwater remediation guideline of 1.1 mg/L, with an average concentration of 1.97 mg/L and with an elevated concentration (2.2 mg/L) in the control that was never exposed to PHC F2 distillate. Examination of chromatograms led to the conclusion that the source of PHC F2 was not distillate, but likely a chemical resulting from adhesive or, less likely, the PVC itself.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Petroleum Hydrocarbon Fractions 2 and 3: Evaluation of Management Limits

SIMONE LEVY

1.0 INTRODUCTION

1.1 Background

In 2019, Millennium EMS Solutions Ltd. (MEMS) was contracted by PTAC-AUPRF to complete the second phase of a 2018 PTAC project (18-RRRC-08) re-evaluating the management limits for F2 and F3 petroleum hydrocarbons (PHCs; MEMS, 2019). Two sets of management limits for PHC fractions F2 and F3 are currently applicable in Alberta; a generic set in the Alberta Tier 1 Soil and Groundwater Remediation guidelines (Tier 1; AEP, 2019) applicable to all land uses, and another set specific to remote parts of the province in the Green Area (AESRD, 2014). The generic management limits for PHC F2 and F3 can often become limiting and potential drivers for remediation in cases where the eco-contact exposure pathway can be eliminated.

Management limits for PHC fractions indicate concentrations where factors other than toxicity, such as aesthetics, mobile free-phase formation and explosion hazards may be of concern. The report from Phase 1 of this project recommended further investigation of the data supporting two of the retained factors: **1) potential exposure of workers in trenches to PHC F2 vapours** and **2) potential effects of PHC F2 and F3 on buried infrastructure**. The activities described herein were designed to provide additional data for those two factors for re-calculation of the management limits.

2.0 PART 1: EXPOSURE OF WORKERS IN TRENCHES TO PHC F2 VAPOURS

The CCME (2008) limits for exposure of workers in trenches were established based on a trench vapour model published by VDEQ (2005); however, the model and key default inputs do not appear to have been validated against real-world measurements (MEMS, 2019). Bench-scale experiments described here were designed to define input concentrations for the air mixing models within the air space of a utility trench. Input parameters for the models require both concentrations of PHC F2 and four PHC F2 sub-fractions: C_{10}-C_{12} aromatic compounds; C_{10}-C_{12} aliphatic compounds; $C_{>12}$-C_{16} aromatic compounds, and $C_{>12}$-C_{16} aliphatic compounds. Testing was not conducted with PHC F3 distillate due to low volatility of its sub-components.

Activities conducted in Part 1 of the project included:

- Characterization of pure PHC F2 distillate by gas chromatograph mass spectrometer (GC-MS) and flame ionization detector (GC-FID);
- Method development and range finding for headspace equilibrium setup;
- Testing headspace at equilibrium with pure PHC F2 distillate; and

- Testing evolution of PHC F2 vapours from coarse- and fine-grained soils spiked with PHC F2 distillate, with various moisture levels.

2.1 PHC F2 Distillate Characterization

2.1.1 Methods

A sample of previously-distilled PHC F2 was tested by injecting a liquid sample into a gas chromatograph – mass spectrometer (GC-MS; 25 m 0.25 mm column 0.25 µmMS5 film with single quad mass spec analyzer (Agilent brand)). Using the apex of nC_{10}, nC_{12} and nC_{16}, the aliphatic and aromatic concentrations of nC_{10}-nC_{12} and nC_{12}-nC_{16} were calculated using the Robinson whole oil method[1] (Robinson, 1971). This method is a baseline technique to resolve the mass spectrum into saturates and aromatic spectra in a sample within boiling point range of 200 to 1,100 F°. The method allows determination of up to 4 saturated and 21 aromatic compound types. It uses the low-resolution mass spectrum and the number average molecular weight, obtained from distillation data, of the unseparated sample.

The apex at each of nC_{10}, $nC_{12}$and nC_{16} was identified on the chromatograph to establish the concentration of PHC F2 parameters in distillate, as some compounds were present outside the C_{10}-C_{16} range.

The cut point and boiling point of the PHC F2 distillate were assessed following ASTM D2887 methodology (ASTM, 2019).

2.1.2 Results

The chromatogram provided in Figure 1 shows the distribution of components within the PHC F2 distillate. Most components (93.31%) fall between the apices of nC_{10} and nC_{16}, with approximately 3.63% below the apex of nC_{10} and 3.05% beyond the apex of nC_{16} (Table 1). Aliphatic and aromatic sub-fractions within total PHC F2 in the two desired ranges ($C_{10\text{-}12}$ and $C_{12\text{-}16}$) were also determined and are provided in Table 1. Appendix A includes full analysis in the form of cut points and boiling points for PHC F2, analyzed at inception of this project, and historical (2012) analyses of PHC F3.

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[1] . The method is known as the Robinson Whole Oil Method because in contrast to many other methods (such as D2786 or D3239) it does not require a prior separation of a sample into saturates and aromatic fractions. The method reports four saturated hydrocarbon types, twelve aromatic HC types, three thiophenic and six unidentified aromatic groups.

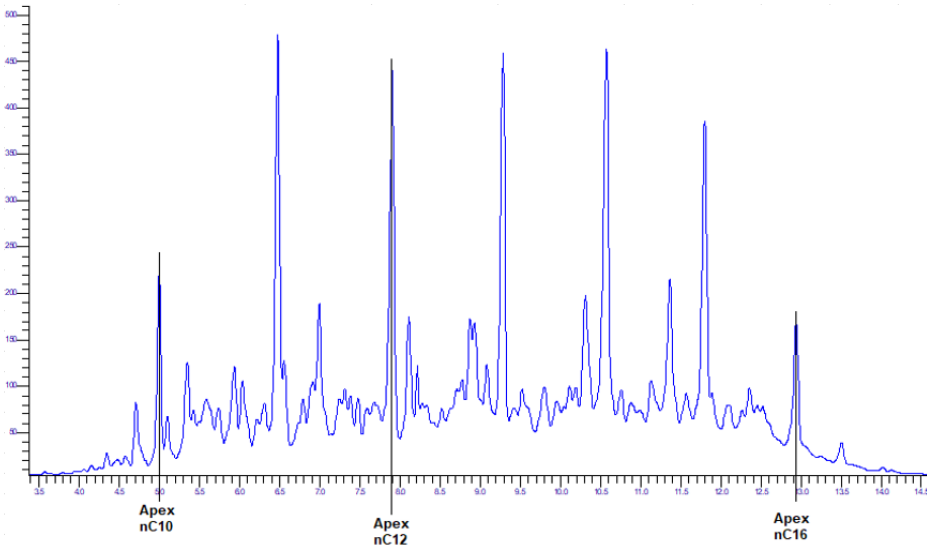

Figure 1. Analysis of PHC F2 distillate and indication of peak apex categories.

Table 1. Total PHC F2 hydrocarbon and sub-component weight % fraction in pure PHC F2 distillate, by apex to apex grouping (see Figure 1).

Component or sub-fraction	***$<C_{10}$ apex***	***nC_{10} apex - nC_{12} apex***	**nC_{12} apex - nC_{16} apex**	**$>nC_{16}$ apex**
	Wt%	**Wt%**	**Wt%**	**Wt%**
Total hydrocarbons	3.63	32.25	61.06	3.05
Aliphatic sub-fraction	2.2	21.8	38.9	1.6
Aromatic sub-fraction	1.4	10.4	22.2	1.5

2.2 Headspace method development and range finding

2.2.1 Methods

Three activities were conducted as part of method development and range finding, in support of the soil incubation experiments. All experiments were conducted at room temperature (~21°C), and the petri dish in Tedlar® bag setup was developed to maintain atmospheric pressure.

2.2.1.1 Headspace vapour distribution

To establish a maximum potential headspace concentration of PHC F2, 3 mL of PHC F2 distillate was placed in a petri dish inside a re-sealable 3L Tedlar® bag. The bag was evacuated by a vacuum and then filled with 1,500 mL of laboratory-grade air. The petri dish lid was removed, and the bag was incubated at room temperature for one week after which it was deemed that a maximum headspace concentration had been reached in the bag. A headspace sample was analyzed by removing 100 mL of headspace gas into a set of two thermal desorption tubes. The samples were analyzed *via* GC-FID. The results were used to establish 1) the ideal sample extraction volume for testing PHC F2 vapours while meeting required detection limits, and 2) optimizing capacity and number of thermal desorption tubes.

2.2.1.2 Headspace saturation above pure PHC F2

The second task in method development was designed to establish an ideal ratio of air to PHC F2 distillate for subsequent testing. Pure PHC F2 distillate (1.5 mL, approximate volume of PHC F2 in soil at 10,000 ppm in subsequent tests) was placed into a petri dish inside each of three sealed 3L Tedlar® bags. Each bag was evacuated by a vacuum and then filled with either 300 mL, 500 mL or 800 mL of laboratory-grade air. Petri dish lids were removed, and the bags were placed in a fume hood at room temperature (~21°C) for one week. Three thermal desorption tube sets (*i.e.,* one desorption tube, in line with a second one in case of breakthrough) were used to collect a 50 mL headspace gas sample. Samples were run on the GC-FID to determine the concentration of total hydrocarbon in headspace. Results were compared to identify an ideal headspace volume to: 1) ensure saturation at steady state, 2) leave space in the bag to allow expansion, and 3) to facilitate removal of the petri dish lid, which can be hindered with too small a bag or insufficient headspace.

2.2.1.3 Method reproducibility

Three replicate tests were set up using 1.5 mL of pure PHC F2 distillate in a petri dish inside a 3L Tedlar® bag with 500 mL of air injected following evacuation. After equilibrium was reached, 3 sets of thermal desorption tubes were collected from each bag. Average equilibrium concentrations (*e.g.,* total PHC and sub-fractions) were calculated from 3 replicated tests and will be used as input to the designated trench model for comparison against the exposure limits set out in Table C7 of the Tier 1 guidelines document (AEP, 2019): 1.0 mg/m^3 for aliphatic compounds and 0.2 mg/m^3 for aromatic compounds. Replicates of identical setup were also used to determine sample and method repeatability *via* standard deviation.

2.2.2 Results

2.2.2.1 Headspace vapour distribution

Based on the equilibrium testing setup described in section 2.1.2.1, the chromatogram output was overlain on the chromatogram of distillate analysis (Figure 2). The vapour above the F2 fraction does not have the same distribution as the original distillate due to higher volatility of parameters within the lower carbon range (C_{10}-C_{12}). As would be expected, the components below nC_{10} appear in the vapour phase and will affect the equilibrium of the F2 fraction.

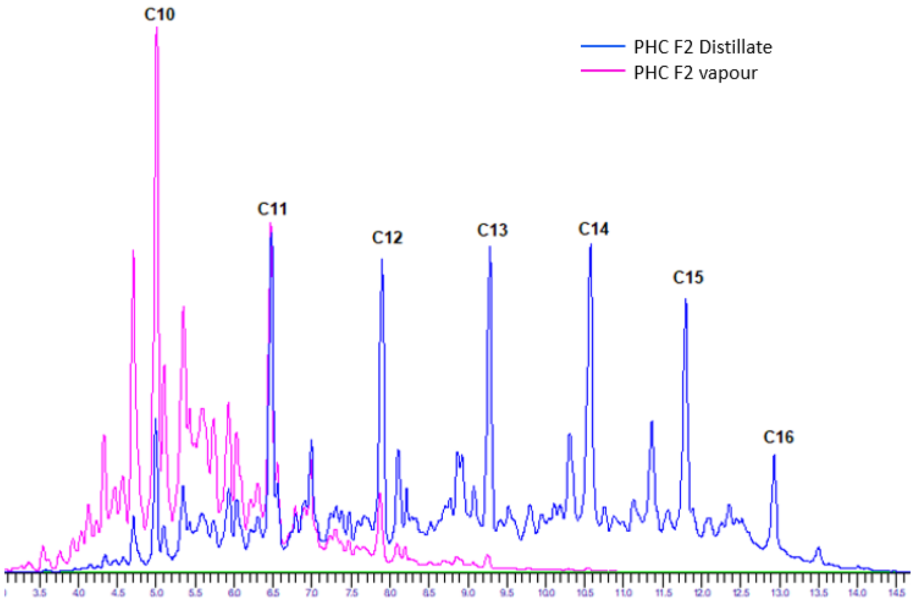

Figure 2. PHC F2 headspace vapour distribution.
PHC F2 distillate placed in petri dish within Tedlar® bag. Bag evacuated and lab-grade air injected. 100 mL headspace at steady state as assessed by PID.

2.2.2.2 Headspace saturation above pure PHC F2

The bags with differing headspace volumes (300, 500 and 800 mL) all had the same concentration and distribution of components (Figure 3). Based on this finding, it can be interpreted that the headspace was saturated with PHC F2 vapour, irrespective of the headspace volume. A headspace volume of 500 mL was recommended for subsequent tests based on slightly higher concentrations than 300 or 800 mL.

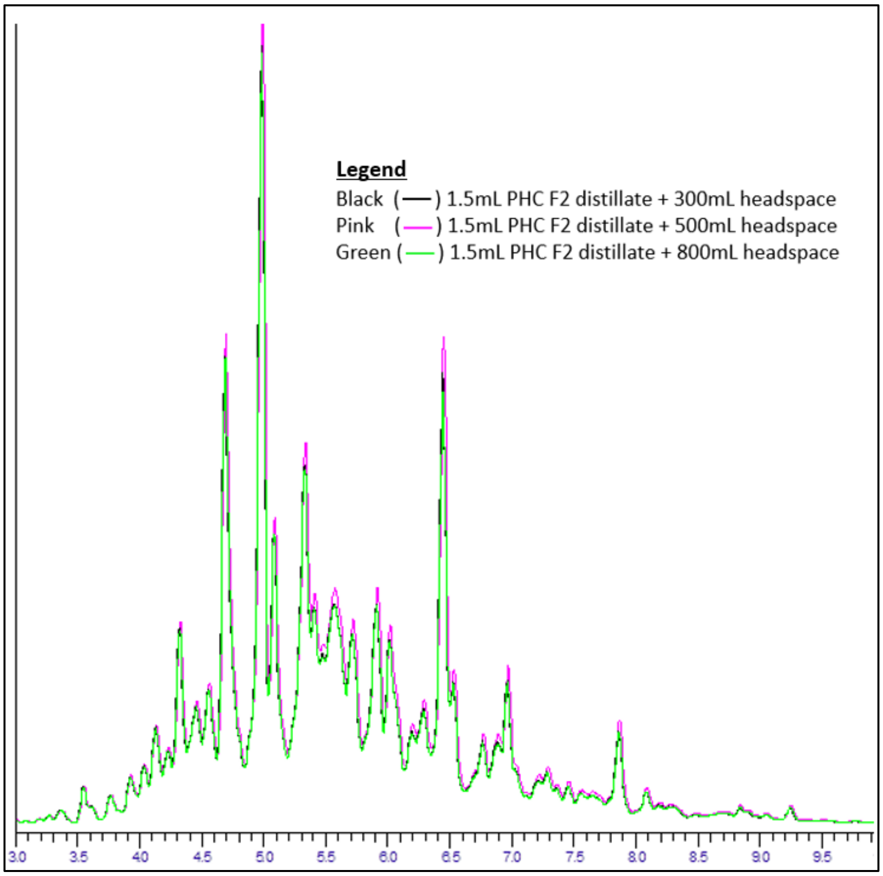

Figure 3. Overlain chromatograms of PHC F2 distillate in petri dishes within Tedlar® bags with differing volumes of injected headspace after complete evacuation.

2.2.2.3 Method reproducibility

The results in Table 2 show expected method deviations under ideal bench-scale setup for saturation with pure PHC F2 distillate. These results can be compared with results obtained from volatilization of PHC F2 in soil to determine whether variability between replicates is within an acceptable range.

Table 2. Total PHC F2 concentrations in headspace at steady state, with breakdown of aliphatic and aromatic components within C_{10-12} and C_{12-16} ranges.

Rep	PHC F2 (C_{10-16})	C_{10-12}			C_{12-16}		
		Total GC-FID	Aliphatic	Aromatic	Total GC-FID	Aliphatic	Aromatic
1	1.328	1.230	0.757	0.473	0.098	0.047	0.051
2	1.287	1.193	0.735	0.458	0.094	0.046	0.048
3	1.432	1.323	0.810	0.513	0.109	0.052	0.057
Average	**1.349**	**1.249**	**0.767**	**0.481**	**0.100**	**0.049**	**0.052**
St. Dev	0.067	0.067	0.039	0.028	0.008	0.003	0.005

2.3 Testing evolution of PHC F2 vapours from spiked soils

2.3.1 Methods

2.3.1.1 Setup and soil characterization

Setup photographs of spiked soil within petri dishes in Tedlar® bags are provided in Figure 4. Previously characterized coarse- and fine-grained soils were spiked with the PHC F2 distillate to a target of 10,000 mg/kg. The exact concentration was difficult to achieve, especially in coarse-grained soil, as some of distillate intended for spiking became adhered to the mixing container. Several attempts were made to accurately spike the soils. All work was conducted in a -14°C walk-in freezer to minimize losses through volatilization. Three representative samples of each batch of soil were taken and submitted for laboratory analysis to confirm PHC F2 concentrations and assess variability in each batch.

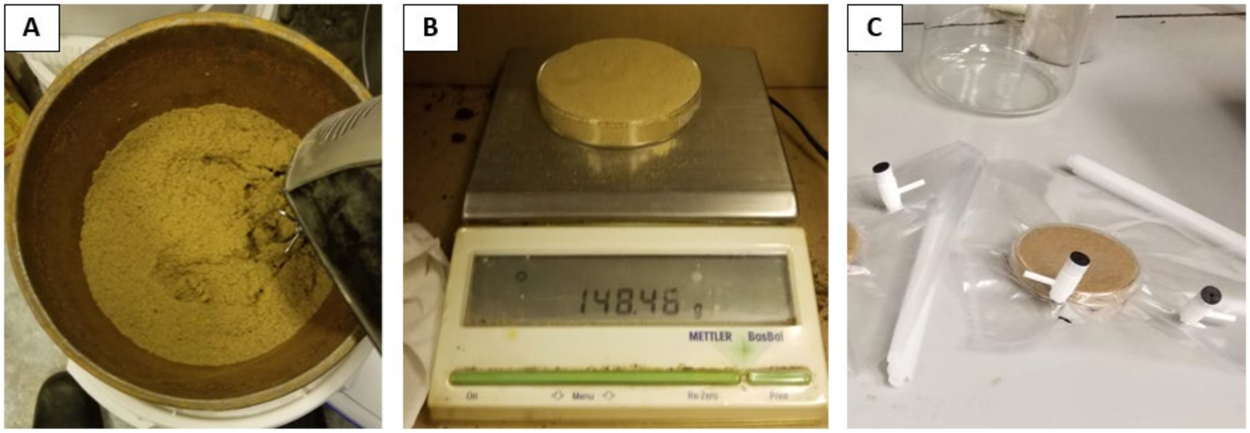

Figure 4. Experimental setup for spiked soils including mixing distillate into soil, weighing once in petri dish for density calculation, placement into Tedlar® bag, and evacuation.

A) spiking soil in a refrigerated vessel, within a -14°C walk-in freezer; B) weighing tailings in 100 mL glass petri dish; and C) Evacuating air from bags prior to adding known amount of laboratory-grade air.

Once spiking concentrations were in the desired range, the soils were moistened to representative field conditions. Coarse-grained soil with limited moisture holding capacity was moistened to approximately 1.5% by weight. Two moisture levels were created with fine-grained soil to represent soil in the unsaturated (14%) and saturated (24%) zones. Four replicates of each soil was placed into a 100 mL glass petri dish and compacted to a target density: Alberta Tier 1 guidelines' default soil bulk density estimates for undisturbed samples for coarse and fine soil are 1.7 kg/L and 1.4 kg/L (dry soil basis), respectively. Lids were placed on the petri dishes, which were then inserted into re-sealable Tedlar® bags. Bags were clamped prior to removing air using a vacuum hose. Soil moistening was conducted in a 4°C walk-in refrigerator.

2.3.1.2 Headspace analysis

'Time 0' was defined as the time when the petri dish lids were removed in the bag after 500 mL of lab-grade air was injected into each bag. One of the bags was monitored with a MiniRAE 3000 photoionization detector (PID) calibrated to isobutylene (Figure 5). The PID was used to monitor concentrations of volatile organic compounds (VOCs) in headspace. At steady state, or when the headspace VOC concentration plateaued in the bag monitored by PID (*i.e.,* average concentrations within approximately 10% variability over a predetermined period), headspace samples were taken from the 3 replicate bags for analysis by flame ionization detector (total VOCs) and gas chromatograph (PHC F2 sub-fractions).

Figure 5. Photoionization detector attached to Tedlar® bag containing spiked soil.
1 of 4 replicates containing PHC F2-spiked soil at approximately 10,000 mg/kg.

Where replicate samples were taken, the average and standard deviation of the replicates were calculated and reported. In some cases the standard deviation was reported as a percent of the average to compare the variability of results between sample types.

Aliphatic and aromatic components were analyzed on GC-MS data using the Robinson method (Robinson, 1971).

2.3.2 Results

2.3.2.1 Setup and soil characterization

The final soil concentrations of PHC F2 and the moisture levels as reported by the laboratory are provided in Table 3. Given difficulties in spiking the soils, it was not possible to achieve a uniform concentration in all soils. However, based on headspace saturation tests conducted in the earlier part of the experiment, the starting concentration in soil does not need to be calibrated as headspace would be saturated regardless.

The time to peak PID reading and the reading itself are also reported, in the case that trench vapour modeling could incorporate information on time to 'steady state' in a closed system.

2.3.2.2 Headspace analysis

Results of headspace analyses, including total PHC F2, nC_{10-12}, nC_{12-16}, and their aliphatic and aromatic sub-components, are provided in Table 3. Results will be used as model input parameters at which point interpretation can be made as to their impact.

Table 3. Summary of soil and headspace results for petri dish within Tedlar® bag setup.

Parameter or sub-component							Headspace concentration (μg/mL air)						
								nC_{10-12}			nC_{12-16}		
Soil Type	**Average soil moisture (%)**	**Average soil PHC F2 (mg/kg) (Standard deviation; % standard deviation)**	**Average Density in Petri Dish Reps**	**Time to peak PID reading (mins)**	**Peak PID reading (ppm equivalent)**	**Replicate**	**PHC F2 (nC_{10-16})**	**Total GC-FID**	**Aliphatic**	**Aromatic**	**Total GC-FID**	**Aliphatic**	**Aromatic**
Coarse	1.43	9,393 (1,111; 11.8%)	1.52	58	560	Control	0.003	0.003	-	-	<0.001	-	-
						1	1.136	0.999	0.657	0.342	0.137	0.068	0.069
						2	1.048	0.937	0.614	0.323	0.111	0.055	0.056
						3	0.887	0.804	0.527	0.277	0.083	0.043	0.040
						Average	**1.023**	**0.913**	**0.599**	**0.314**	**0.110**	**0.055**	**0.055**
						St. Dev	-	**0.081**	**0.054**	**0.027**	**0.022**	**0.010**	**0.012**
Fine	14.23	13,167 (499; 3.8%)	1.55	123	479	Control	0.006	0.006	-	-	<0.001	-	-
						1	1.006	0.883	0.561	0.323	0.123	0.062	0.061
						2	0.868	0.759	0.480	0.279	0.109	0.056	0.053
						3	0.912	0.790	0.518	0.272	0.122	0.064	0.059
						Average	**0.929**	**0.811**	**0.520**	**0.291**	**0.118**	**0.061**	**0.058**
						St. Dev	-	**0.053**	**0.033**	**0.023**	**0.006**	**0.003**	**0.003**
Fine	24.40	6,773 (153; 2.3%)	1.52	77	399	Control	0.002	0.002	-	-	<0.001	-	-
						1	0.280	0.231	0.078	0.153	0.049	0.021	0.028
						2	0.270	0.218	0.049	0.169	0.052	0.018	0.034
						3	0.314	0.248	0.067	0.181	0.066	0.026	0.040
						Average	**0.288**	**0.232**	**0.065**	**0.168**	**0.056**	**0.022**	**0.034**
						St. Dev	-	**0.012**	**0.012**	**0.011**	**0.007**	**0.003**	**0.005**

3.0 PART 2: EFFECTS OF PHC F2 AND F3 ON BURIED INFRASTRUCTURE

The previous review by MEMS also indicated a need for better understanding of the potential impact of PHC F2 and F3 hydrocarbons on buried infrastructure. The review and experiments described in this report aimed to identify the most common types of polymer used in buried infrastructure applications, and specifically those which might be buried at least 1.5 m bgs, such as water piping that is buried deeper to avoid impact in freeze-thaw cycles. Based on the review, the Part 2 testing program included obtaining representative material samples for testing potential material degradation when incubated in PHC F2 and F3 distillates, and potential impact to drinking water inside a typical pipe.

Activities conducted in Part 2 included:

- Literature review on buried infrastructure materials and depths;
- Incubation of piping material coupons in PHC F2 and F3 distillates; and
- Incubation of water in piping with a coating of PHC F2 distillate.

3.1 Literature Review on Buried Infrastructure Materials and Depths

3.1.1 Methods

Innotech Alberta's Corrosion Engineering group, with direction from the Reclamation group as needed, conducted a literature review and consultation with third parties to inform potential experiments on the impact of hydrocarbons to water piping and fibre optic cable materials. The review was completed as follows:

- Engineering and literature sources were reviewed, and relevant third parties (*e.g.,* TELUS, EPCOR) were consulted for information on the characteristics of water piping and fibre optic materials – polymer types, range of wall thickness, installation practices (*i.e.,* depth, outer covering of fibre optic cables).
- For each polymer type, physical and chemical specifications (*i.e.,* chemical compatibility, PHC diffusion rate, typical mechanical properties) were tabulated.
- Recommendations were provided as to potential testing of piping materials.

3.1.2 Results

The full review is included in Appendix B; a short outline is provided here.

A representative of TELUS provided information on material and installation of fibre optic cables. They indicated that fibre optic cables are typically made of poly-steel-poly (PSP) cables, installed within conduits made of high-density polyethylene (HDPE) and occasionally polyvinyl chloride (PVC). Cables are generally installed between 1.1 and 1.5 metres below ground surface. Based on this burial depth above the zone of interest for this project (>1.5 m bgs), a decision was made not to pursue direct testing of the potential impact of PHC F2 and F3 to fibre optic cables themselves; however, both HDPE and PVC were included for testing based on their prevalence in water piping.

Information on water piping was obtained through the Alberta Government's Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage Systems (Government of Alberta, 2012). The most common material types are PVC, HDPE and fibre-reinforced plastic (FRP), with PVC being the most common. Piping is generally buried a minimum of 2.59 m below curb top. The minimum inner diameter is 150 mm (6 in) based on a pressure rating of 150 kPa.

Chemical resistivity of PVC, HDPE and FRP were identified *via* literature sources. Select hydrocarbons were found to soften or swell the rigid structure of PVC, potentially weakening the structure to the point of allowing permeation of certain hydrocarbon types or components. Based on specifications provided by polymer manufacturers and the National Association of Corrosion Engineers (NACE International), resistivity ratings were established for PVC, HDPE and FRP. It should be noted that the testing temperatures for all three materials were generally at room temperature and above, with a minimum of 15°C. In many cases a lower chemical resistivity was reported at higher temperatures; however, in a water piping scenario, temperatures in soil below 2.5 m bgs would likely be lower than even 15°C.

Testing of the three most common material types (PVC, HDPE and FRP) *via* coupon incubation was recommended based on installation depths within the zone of interest (*i.e.,* below 1.5 m bgs) and potential susceptibility to hydrocarbon impact based on literature findings. Only PVC was used in the water incubation test.

3.2 Incubation of piping material coupons in PHC F2 and F3 distillates

3.2.1 Methods

Three polymer types were obtained from local suppliers, including polyvinyl chloride (PVC), high density polyethylene (HDPE) and fibre-reinforced plastic (FRP). Three replicates of each polymer type were cut into in 4 x 4 cm coupons, and were placed in sealed jars with pure PHC F2 and F3 distillates (Figure 6). Two controls were set up for each polymer type: no incubation and incubation in distilled water. After 80 days of incubation, coupons were removed from distillates and cleaned with a 1% Liquinox detergent solution. Surface changes were noted and photographs taken through a microscope at approximately 10X magnification. Weights (0.0001 g scale; ± 0.0003 g) of each coupon were taken pre- and post-incubation to determine if any material loss or absorption of distillate had occurred. Pre- and post-incubation coupon thickness was measured using calipers and results were compared from pre- and post-incubation. Hardness of all coupons was measured with a Shore D durometer, and incubated coupons were compared with equivalent controls (non-incubated and those incubated in water).

Where replicate samples were taken, the average and standard deviation of the replicates were calculated and reported.

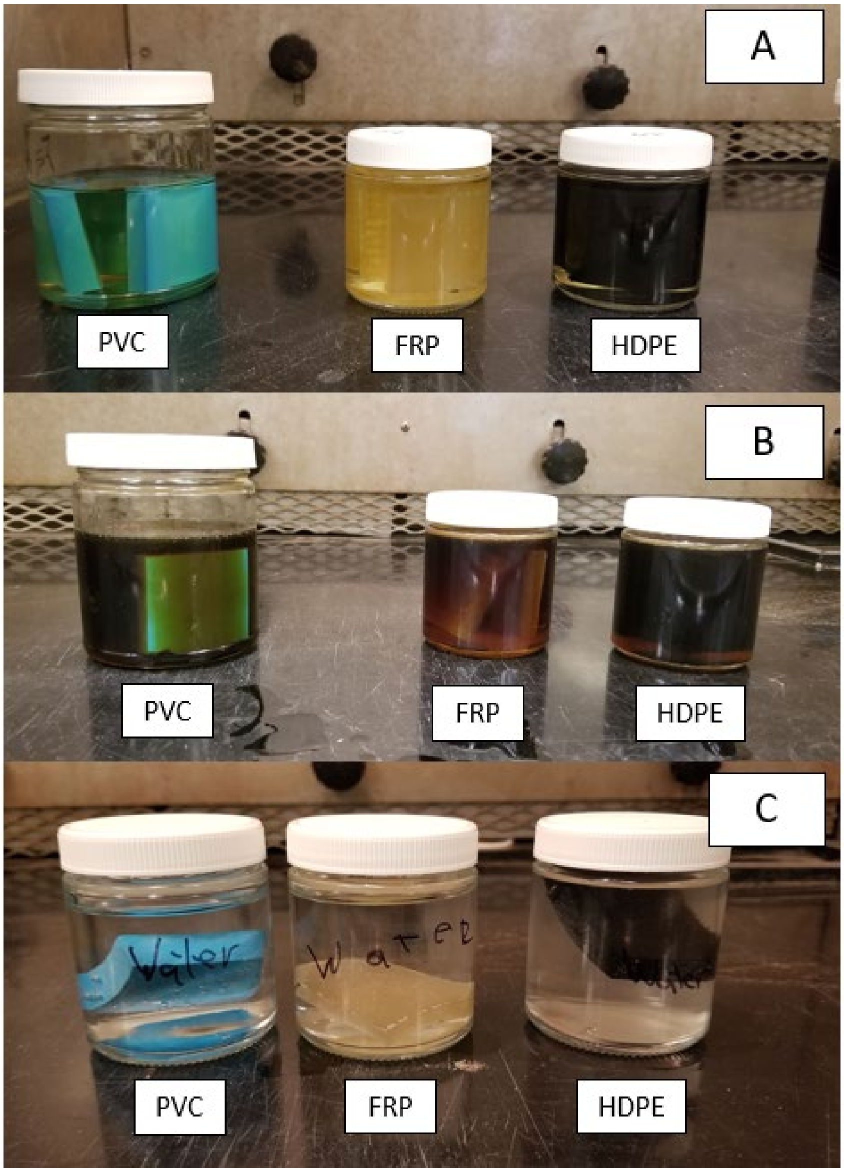

Figure 6. Polyvinyl chloride (PVC), fibre-reinforced plastic (FRP) and high density polyethylene (HDPE) coupons (5 x 5 cm) incubated in (A) PHC F2 distillate; (B) PHC F3 distillate; (C) water.

3.2.2 Results

Results are presented including visual observation and empirical testing of coupons.

3.2.2.1 Visual observation and magnification of post-incubation coupons

Based on visual observations, including those under 10X magnification, it appears that incubation in PHC F2 and F3 noticeable impact on PVC, HDPE and FRP coupons (Figure 7).

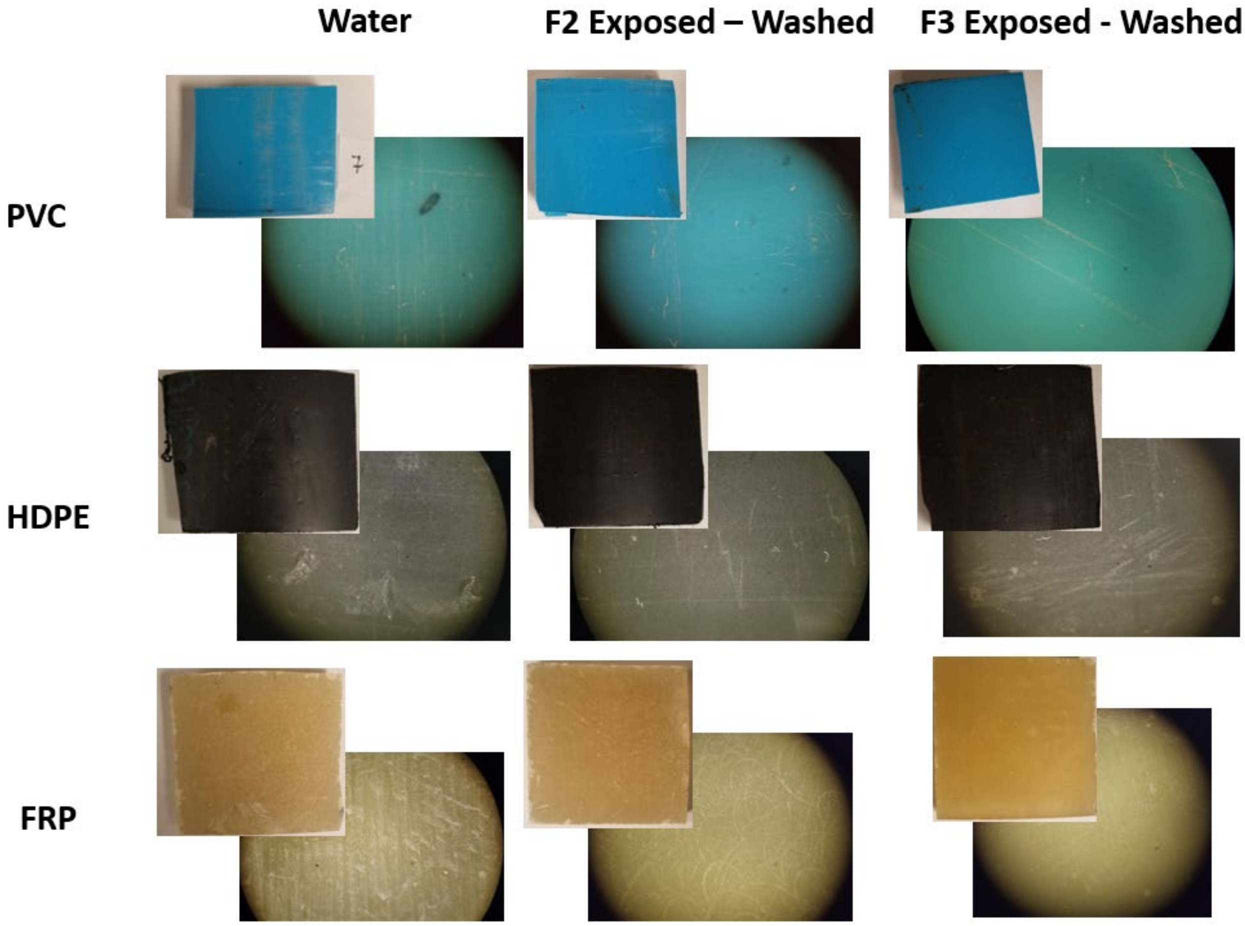

Figure 7. Photographs of one representative coupon of each polymer type post-incubation in water, PHC F2 or PHC F3 distillate. Photos of coupons (top right) overlain on magnified image of same coupon.

3.2.2.2 Empirical testing of coupons to compare weight, thickness and hardness pre- and post-incubation

Figure 8 shows the results of 16 cm^2 coupons incubated in PHC F2 and F3 distillates, water, and non-incubated. The difference in average weight and standard error (SEM) were compared. If the difference between the averages of the initial weight and final weight was greater than 1.96 SEM ($p < 0.05$) then the difference is considered statistically significant. HDPE exposed to PHC F2 showed a statistically significant difference in weight (3% and 2.6% increase in weight for after exposure and washed, respectively). This indicates that PVC may have F2 adsorbed onto the surface of the material. The other materials showed no reportable difference in weight. Standard errors were generally low (<10% of mean), and no significant trends are observed that would indicate the material was being altered through exposure to distillates.

The thickness of each coupon was measured with calipers after washing. The average, standard deviation (SD), and SEM were calculated for washed measurements. The difference in average thickness and standard error were compared. If the difference between the averages of the exposed coupon thickness and control was greater than 1.96 SEM ($p < 0.05$) then the difference is considered statistically significant. No coupons showed a reportable difference in thickness.

For Shore D hardness, each coupon was tested at 5 points after exposure (or control) and after washing. The average, SD, and SEM were compared to controls (and water exposed). If differences between F2 and F3 exposed were greater that 1.96 SEM ($p < 0.05$), the difference was considered statistically significant. PVC for both F2 and F3 showed a decrease in hardness (2.9% for F2 exposed and 5.4% for F3 exposed). The other materials showed no reportable difference in hardness.

Data corresponding to the graphs in Figure 8 is provided in Appendix C.

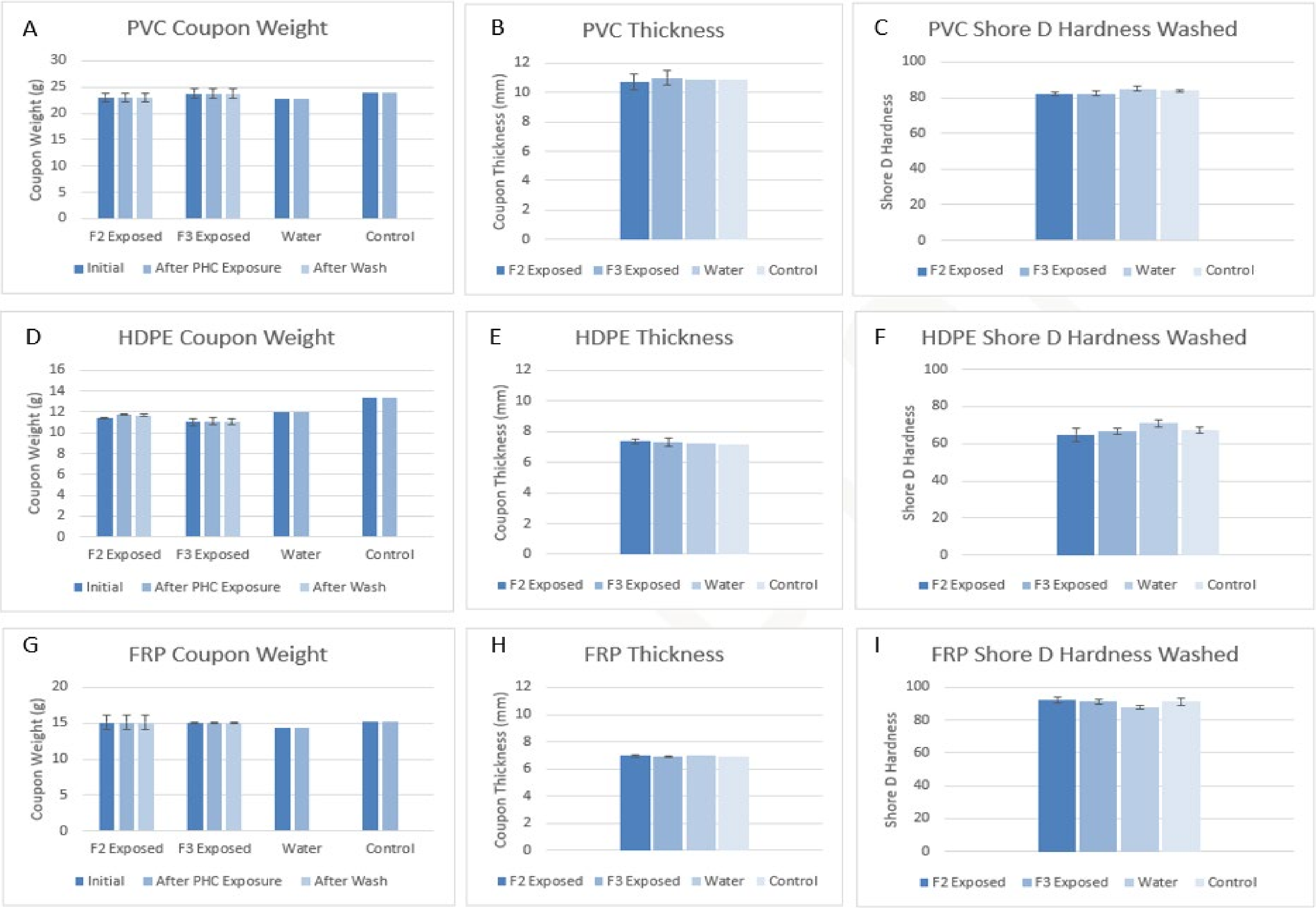

Figure 8. Graphs of average ± standard deviation (n = 3) for PVC (A-C), HDPE (D-F) and FRP (G-I) coupons incubated in PHC F2 and F3 distillates, water, and non-incubated (control).

3.3 Incubation of water in water piping with a coating of PHC F2 distillate

A second experiment aimed to determine whether water within piping could potentially be impacted by PHC F2; PHC F3 components were not tested as they are not soluble in water.

3.3.1 Methods

In the review described in 2.2.1, PVC was determined to be the most common polymer type for water piping. The minimum inner diameter of piping was 150 mm, with corresponding thickness of approximately 11 mm. The pipe was obtained and cut into 15 cm sections, which were then capped on both ends and sealed with Permatex Plastic Welder 2-part epoxy and silicone caulking, identified as a suitable sealant that would not leach hydrocarbons to the water and would not interact with PHC F2. The pipes were then wrapped in PHC F2-soaked cotton batting and covered in neoprene rubber. The incubation was carried out over 80 days. One water test from each of the 3 replicate pipes was submitted to Element Environmental Laboratories in Edmonton, Alberta, for analysis of PHC F2 concentration in water.

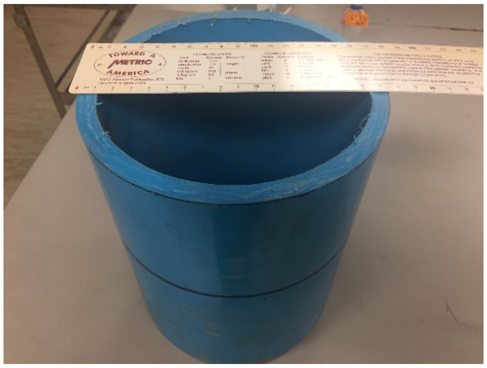

Figure 9. Cross section of PVC piping with ruler, showing piping diameter and thickness.

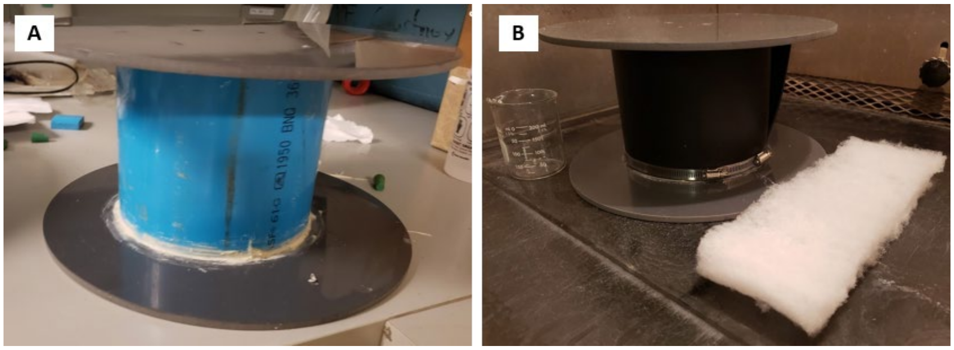

Figure 10. (A) Assembled piping incubation setup prior to installation of distillate-soaked batting and enclosure; (B) final setup including batting and closure.

3.3.2 Results

The results of water testing after incubation within PVC piping exposed to PHC F2 show that all parameters are below appropriate drinking water guidelines with exception of PHC F2 in one control and two out of three replicates exposed to PHC F2 (Table 4). Based on internal quality control protocol, it is not possible that samples were mixed up during sampling (*i.e.,* control swapped with 'PHC F2 exposed water column 2'), and the laboratory re-ran samples with the same results. Investigation was undertaken to identify whether the apparent detection of PHC F2 could related to chemicals leaching from the PVC, as another inconsistency was identified in the absence of PHC F1 in water, despite it having been identified in the distillate. It was deemed unlikely that PHC F2 could be leaching from PVC based on a brief review of literature (US EPA, 2002; Stantec, 2003).

PHC F2 analysis is not specific to petroleum hydrocarbons and identifies any compound eluting in the F2 range as PHC F2. Chromatograms of PHC F2 typically show a complex spectrum similar to Figure 1, reflecting the large number of hydrocarbon compounds present in PHC F2. The chromatograms from the apparent PHC F2 detections in the water within the incubated pipes are provided in Appendix D and are quite different, showing just a couplet of peaks near C13. This suggests that the cause of these apparent PHC F2 detections is two individual chemicals (or two similar isomers of one chemical) and not PHC F2. The identity of these two chemicals is not known, but possible sources include the adhesive used to attach the end cap of the pipe or, less likely, the PVC itself.

Table 4. Summary of analytical results for water incubated inside PVC piping wrapped in PHC F2-soaked batting for 80 days.

Bold values exceed relevant parameter guidelines.

Properties and Parameters	Analyte	Units	PHC F2 Exposed Water Column Rep 1	PHC F2 Exposed Water Column Rep 2	PHC F2 Exposed Water Column Rep 3	Control Water Column	Alberta Tier 1 Groundwater Remediation Guideline*
Hydrocarbons							
F1 Hydrocarbons (C_6 to C_{10})	F1 Hydrocarbons (C_6-C_{10}) (PHCF1_C_6-C_{10})	mg/L	<0.1	<0.1	<0.1	<0.1	2.2 (1)
F2 Hydrocarbons (C_{10} to C_{16})	F2c C_{10}-C_{16}	mg/L	**2.2**	**<0.1**	**1.5**	**2.2****	1.1 (1)
F3 Hydrocarbons (C_{16} to C_{34})	F3 C_{16}-C_{34}	mg/L	0.2	<0.1	<0.1	0.6	-
F3+ Hydrocarbons (C_{34+})	F3+ C_{34}+	mg/L	<0.1	<0.1	<0.1	<0.1	-
BTEX							
Benzene	F1 Benzene (71-43-2)	mg/L	<0.001	<0.001	<0.001	<0.001	0.005 (1)
Toluene	F1 Toluene (108-88-3)	mg/L	<0.0004	<0.0004	<0.0004	<0.0004	0.021
Ethylbenzene	F1 Ethylbenzene (100-41-4)	mg/L	<0.0010	<0.0010	<0.0010	<0.0010	0.0016 (1)
m,p,o-xylene	F1 m,p-Xylene (1330-20-7)	mg/L	<0.001	<0.001	<0.001	<0.001	0.02 (1)

Notes:

***** Values for Natural Areas - All Water Uses (coarse-grained soil)

**Elevated concentration of PHC F2 in 'Control' considered a discrepancy that could not be reconciled in this study.

Greyed out values are below detection limit

Bold values exceed Alberta Surface Water guidelines

Applicable Guidelines

Environmental Quality Guidelines for Alberta Surface Waters (Surface Water Guidelines; AEP, 2018) for the protection of freshwater aquatic life (PAL) and agricultural uses

Notes

All guidelines are structured as the most stringent unless otherwise specified

Nitrite guidelines based upon actual sample values associated with chloride concentrations

Sulfate guidelines based upon actual sample values associated with hardness concentrations

(1) Potable water

4.0 CONCLUSIONS

Method development was conducted to measure both total PHC F2 vapours in headspace above distillate and spiked soil, as well as specific sub-fractions in the PHC F2 range (>nC10-nC16), including aliphatic and aromatic compounds in both the nC10-12 and nC12-16 ranges. Headspace concentrations were provided to MEMS as input parameters for trench models. Vapours from PHC F3 were not tested as concentrations were assumed to be very low given low volatility of compounds in the >nC16-nC34 range.

A literature review of potential impact of PHC F2 and F3 on underground utilities found that fibre optic cables are generally buried at depths shallower than the zone of interest for this project (>1.5 m bgs), while water piping is buried a minimum of 2.59 m below curb top. The most common material types for water piping were found to be PVC, HDPE and FRP.

Representative pipe material of each type indicated (PVC, HDPE and FRP) was obtained with an inner diameter of 150 mm (6 in) and thickness required to withstand 150 kPa pressure (>1 cm). Coupons (4 cm2) were cut and incubated for 80 days in pure PHC F2 and F3 distillate with water and no incubation as a control. Post-incubation, the coupons were weighed, tested for hardness and thickness, and examined under 10X magnification. Based on the average and standard deviation of three replicates, pre- and post-incubation metrics were not significantly different, with exception of the weight of HDPE incubated in PHC F2 (increase) and hardness decrease in PVC following incubation in both PHC F2 and F3. Notable differences could not be detected *via* observation of the coupons, with or without magnification.

Samples of water were taken from inside PVC pipe wrapped in PHC F2-soaked batting after 80 days. It was found that concentrations of PHC F2 in the water exceeded the Alberta Tier 1 groundwater remediation guideline of 1.1 mg/L, with an average concentration of 1.97 mg/L and with an elevated concentration (2.2 mg/L) in the control that was never exposed to PHC F2 distillate. Examination of chromatograms led to the conclusion that the source of PHC F2 was not distillate, but likely a chemical resulting from adhesive or, less likely, the PVC itself.

5.0 RECOMMENDATIONS

Once existing trench vapour models have been run using input data from this experiment, it may be of use to further evaluate the models to ensure all assumptions are valid in a true trench scenario. There are several factors that may require further evaluation, such as whether the source of vapours is continuous from the soil, and true air exchange rates. Results could also be compared with field data, if available.

6.0 REFERENCES

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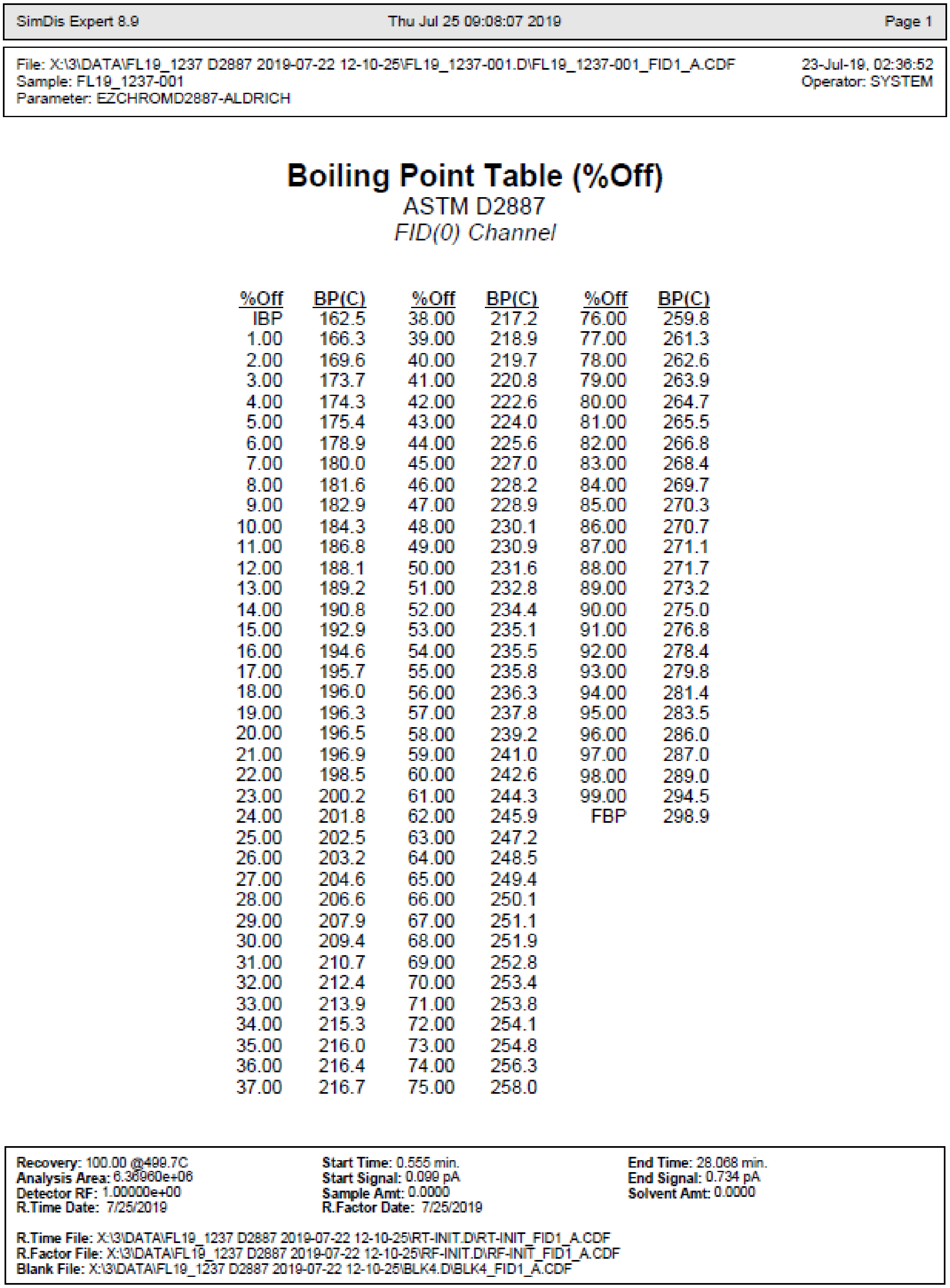
APPENDIX A: PHC F2 AND F3 DISTILLATE CHARACTERIZATION



SimDis Expert 8.9 Thu Jul 25 09:08:07 2019 Page 1

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Sample: FL19_1237-001
Parameter: EZCHROMD2887-ALDRICH

23-Jul-19, 02:36:52
Operator: SYSTEM

Boiling Point Table (%Off)

ASTM D2887

FID(0) Channel

%Off	BP(C)	%Off	BP(C)	%Off	BP(C)
IBP	162.5	38.00	217.2	76.00	259.8
1.00	166.3	39.00	218.9	77.00	261.3
2.00	169.6	40.00	219.7	78.00	262.6
3.00	173.7	41.00	220.8	79.00	263.9
4.00	174.3	42.00	222.6	80.00	264.7
5.00	175.4	43.00	224.0	81.00	265.5
6.00	178.9	44.00	225.6	82.00	266.8
7.00	180.0	45.00	227.0	83.00	268.4
8.00	181.6	46.00	228.2	84.00	269.7
9.00	182.9	47.00	228.9	85.00	270.3
10.00	184.3	48.00	230.1	86.00	270.7
11.00	186.8	49.00	230.9	87.00	271.1
12.00	188.1	50.00	231.6	88.00	271.7
13.00	189.2	51.00	232.8	89.00	273.2
14.00	190.8	52.00	234.4	90.00	275.0
15.00	192.9	53.00	235.1	91.00	276.8
16.00	194.6	54.00	235.5	92.00	278.4
17.00	195.7	55.00	235.8	93.00	279.8
18.00	196.0	56.00	236.3	94.00	281.4
19.00	196.3	57.00	237.8	95.00	283.5
20.00	196.5	58.00	239.2	96.00	286.0
21.00	196.9	59.00	241.0	97.00	287.0
22.00	198.5	60.00	242.6	98.00	289.0
23.00	200.2	61.00	244.3	99.00	294.5
24.00	201.8	62.00	245.9	FBP	298.9
25.00	202.5	63.00	247.2		
26.00	203.2	64.00	248.5		
27.00	204.6	65.00	249.4		
28.00	206.6	66.00	250.1		
29.00	207.9	67.00	251.1		
30.00	209.4	68.00	251.9		
31.00	210.7	69.00	252.8		
32.00	212.4	70.00	253.4		
33.00	213.9	71.00	253.8		
34.00	215.3	72.00	254.1		
35.00	216.0	73.00	254.8		
36.00	216.4	74.00	256.3		
37.00	216.7	75.00	258.0		

Recovery: 100.00 @499.7C
Analysis Area: 6.38960e+06
Detector RF: 1.00000e+00
R.Time Date: 7/25/2019

Start Time: 0.555 min.
Start Signal: 0.099 pA
Sample Amt: 0.0000
R.Factor Date: 7/25/2019

End Time: 28.068 min.
End Signal: 0.734 pA
Solvent Amt: 0.0000

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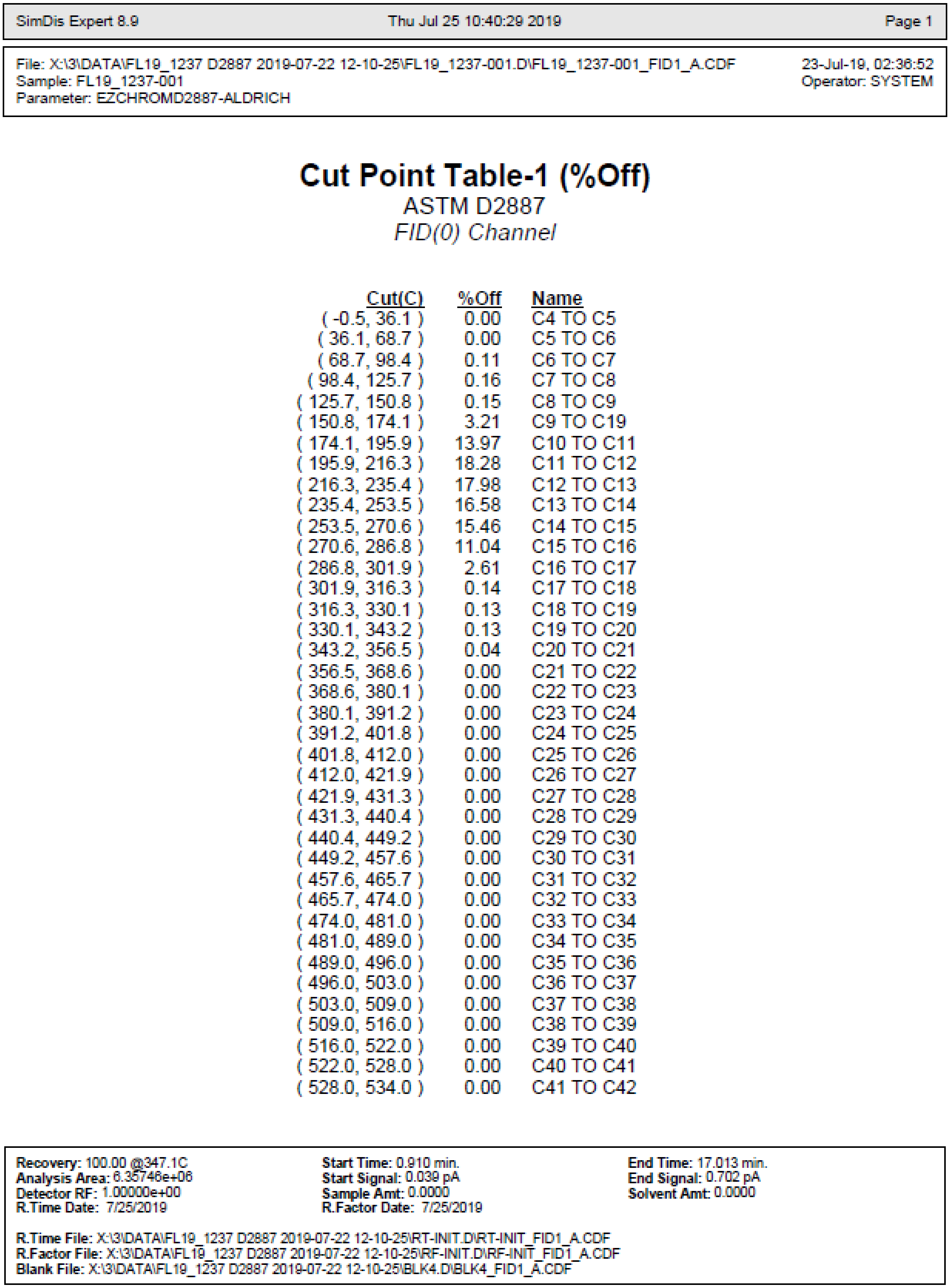

SimDis Expert 8.9 Thu Jul 25 10:40:29 2019 Page 1

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Parameter: EZCHROMD2887-ALDRICH

23-Jul-19, 02:36:52
Operator: SYSTEM

Cut Point Table-1 (%Off)

ASTM D2887

FID(0) Channel

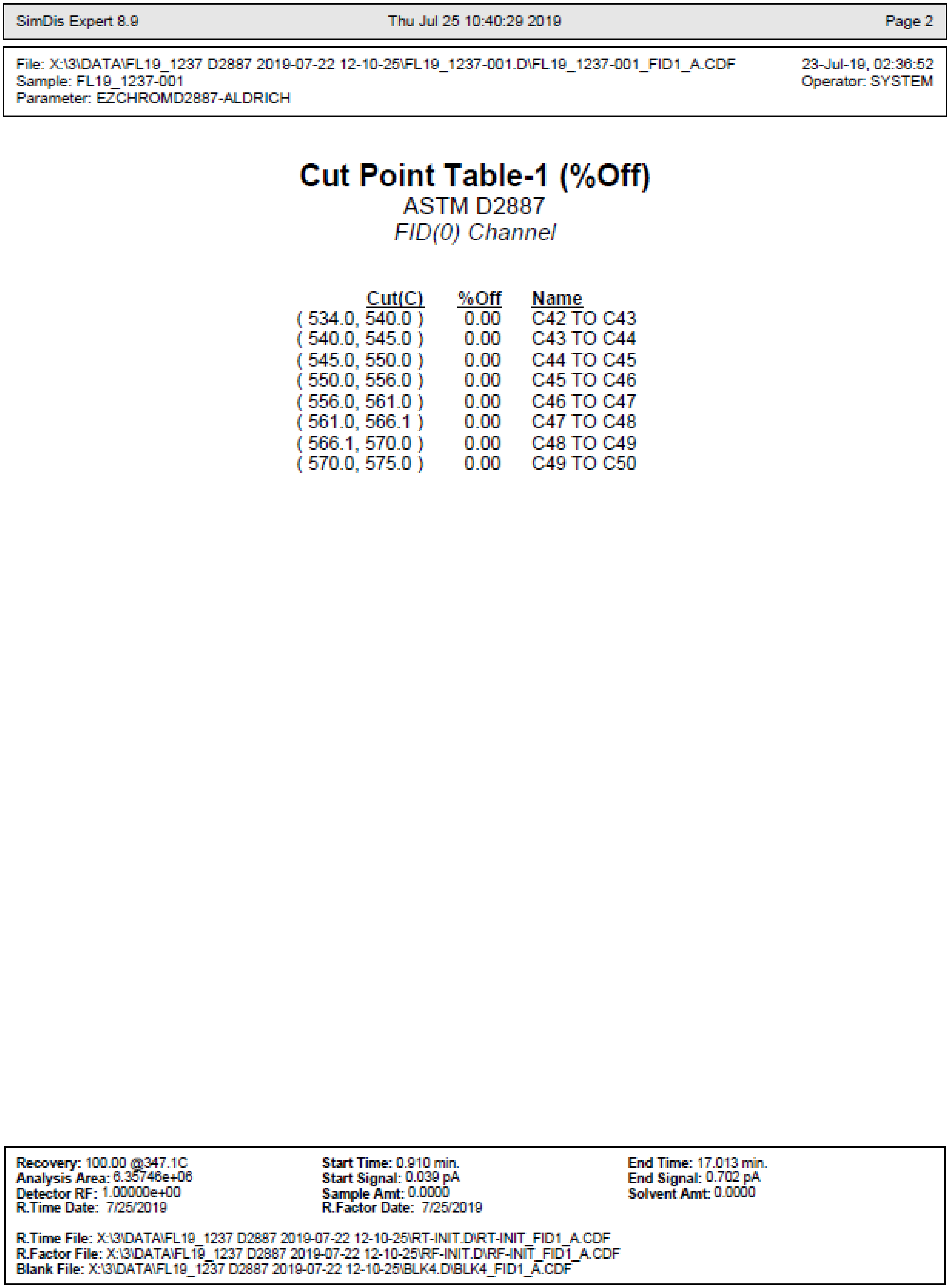
Cut(C)	%Off	Name
(-0.5, 36.1)	0.00	C4 TO C5
(36.1, 68.7)	0.00	C5 TO C6
(68.7, 98.4)	0.11	C6 TO C7
(98.4, 125.7)	0.16	C7 TO C8
(125.7, 150.8)	0.15	C8 TO C9
(150.8, 174.1)	3.21	C9 TO C19
(174.1, 195.9)	13.97	C10 TO C11
(195.9, 216.3)	18.28	C11 TO C12
(216.3, 235.4)	17.98	C12 TO C13
(235.4, 253.5)	16.58	C13 TO C14
(253.5, 270.6)	15.46	C14 TO C15
(270.6, 286.8)	11.04	C15 TO C16
(286.8, 301.9)	2.61	C16 TO C17
(301.9, 316.3)	0.14	C17 TO C18
(316.3, 330.1)	0.13	C18 TO C19
(330.1, 343.2)	0.13	C19 TO C20
(343.2, 356.5)	0.04	C20 TO C21
(356.5, 368.6)	0.00	C21 TO C22
(368.6, 380.1)	0.00	C22 TO C23
(380.1, 391.2)	0.00	C23 TO C24
(391.2, 401.8)	0.00	C24 TO C25
(401.8, 412.0)	0.00	C25 TO C26
(412.0, 421.9)	0.00	C26 TO C27
(421.9, 431.3)	0.00	C27 TO C28
(431.3, 440.4)	0.00	C28 TO C29
(440.4, 449.2)	0.00	C29 TO C30
(449.2, 457.6)	0.00	C30 TO C31
(457.6, 465.7)	0.00	C31 TO C32
(465.7, 474.0)	0.00	C32 TO C33
(474.0, 481.0)	0.00	C33 TO C34
(481.0, 489.0)	0.00	C34 TO C35
(489.0, 496.0)	0.00	C35 TO C36
(496.0, 503.0)	0.00	C36 TO C37
(503.0, 509.0)	0.00	C37 TO C38
(509.0, 516.0)	0.00	C38 TO C39
(516.0, 522.0)	0.00	C39 TO C40
(522.0, 528.0)	0.00	C40 TO C41
(528.0, 534.0)	0.00	C41 TO C42

Recovery: 100.00 @347.1C
Analysis Area: 6.35746e+06
Detector RF: 1.00000e+00
R.Time Date: 7/25/2019

Start Time: 0.910 min.
Start Signal: 0.039 pA
Sample Amt: 0.0000
R.Factor Date: 7/25/2019

End Time: 17.013 min.
End Signal: 0.702 pA
Solvent Amt: 0.0000

R.Time File: X:\3\DATA\FL19_1237 D2887 2019-07-22 12-10-25\RT-INIT.D\RT-INIT_FID1_A.CDF
R.Factor File: X:\3\DATA\FL19_1237 D2887 2019-07-22 12-10-25\RF-INIT.D\RF-INIT_FID1_A.CDF
Blank File: X:\3\DATA\FL19_1237 D2887 2019-07-22 12-10-25\BLK4.D\BLK4_FID1_A.CDF



SimDis Expert 8.9 Thu Jul 25 10:40:29 2019 Page 2

File: X:\3\DATA\FL19_1237 D2887 2019-07-22 12-10-25\FL19_1237-001.D\FL19_1237-001_FID1_A.CDF 23-Jul-19, 02:36:52
Sample: FL19_1237-001 Operator: SYSTEM
Parameter: EZCHROMD2887-ALDRICH

Cut Point Table-1 (%Off)

ASTM D2887

FID(0) Channel

Cut(C)	%Off	Name
(534.0, 540.0)	0.00	C42 TO C43
(540.0, 545.0)	0.00	C43 TO C44
(545.0, 550.0)	0.00	C44 TO C45
(550.0, 556.0)	0.00	C45 TO C46
(556.0, 561.0)	0.00	C46 TO C47
(561.0, 566.1)	0.00	C47 TO C48
(566.1, 570.0)	0.00	C48 TO C49
(570.0, 575.0)	0.00	C49 TO C50

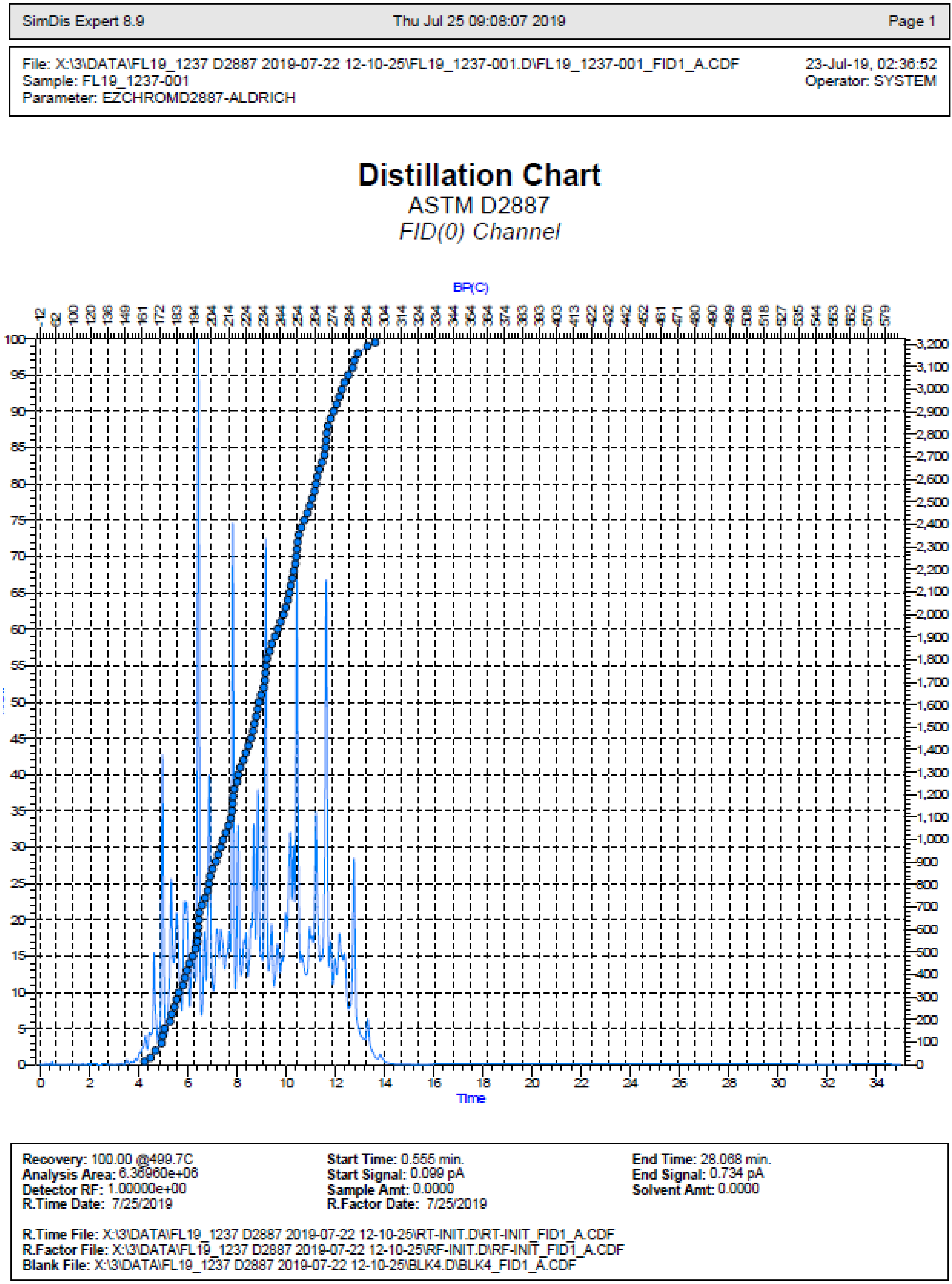
Recovery: 100.00 @347.1C
Analysis Area: 6.35746e+06
Detector RF: 1.00000e+00
R.Time Date: 7/25/2019

Start Time: 0.910 min.
Start Signal: 0.039 pA
Sample Amt: 0.0000
R.Factor Date: 7/25/2019

End Time: 17.013 min.
End Signal: 0.702 pA
Solvent Amt: 0.0000

R.Time File: X:\3\DATA\FL19_1237 D2887 2019-07-22 12-10-25\RT-INIT.D\RT-INIT_FID1_A.CDF
R.Factor File: X:\3\DATA\FL19_1237 D2887 2019-07-22 12-10-25\RF-INIT.D\RF-INIT_FID1_A.CDF
Blank File: X:\3\DATA\FL19_1237 D2887 2019-07-22 12-10-25\BLK4.D\BLK4_FID1_A.CDF

DRAFT



SimDis Expert 8.9 | Thu Jul 25 09:08:07 2019 | Page 1

File: X:\3\DATA\FL19_1237 D2887 2019-07-22 12-10-25\FL19_1237-001.D\FL19_1237-001_FID1_A.CDF
Sample: FL19_1237-001
Parameter: EZCHROMD2887-ALDRICH

23-Jul-19, 02:36:52
Operator: SYSTEM

Distillation Chart

ASTM D2887

FID(0) Channel

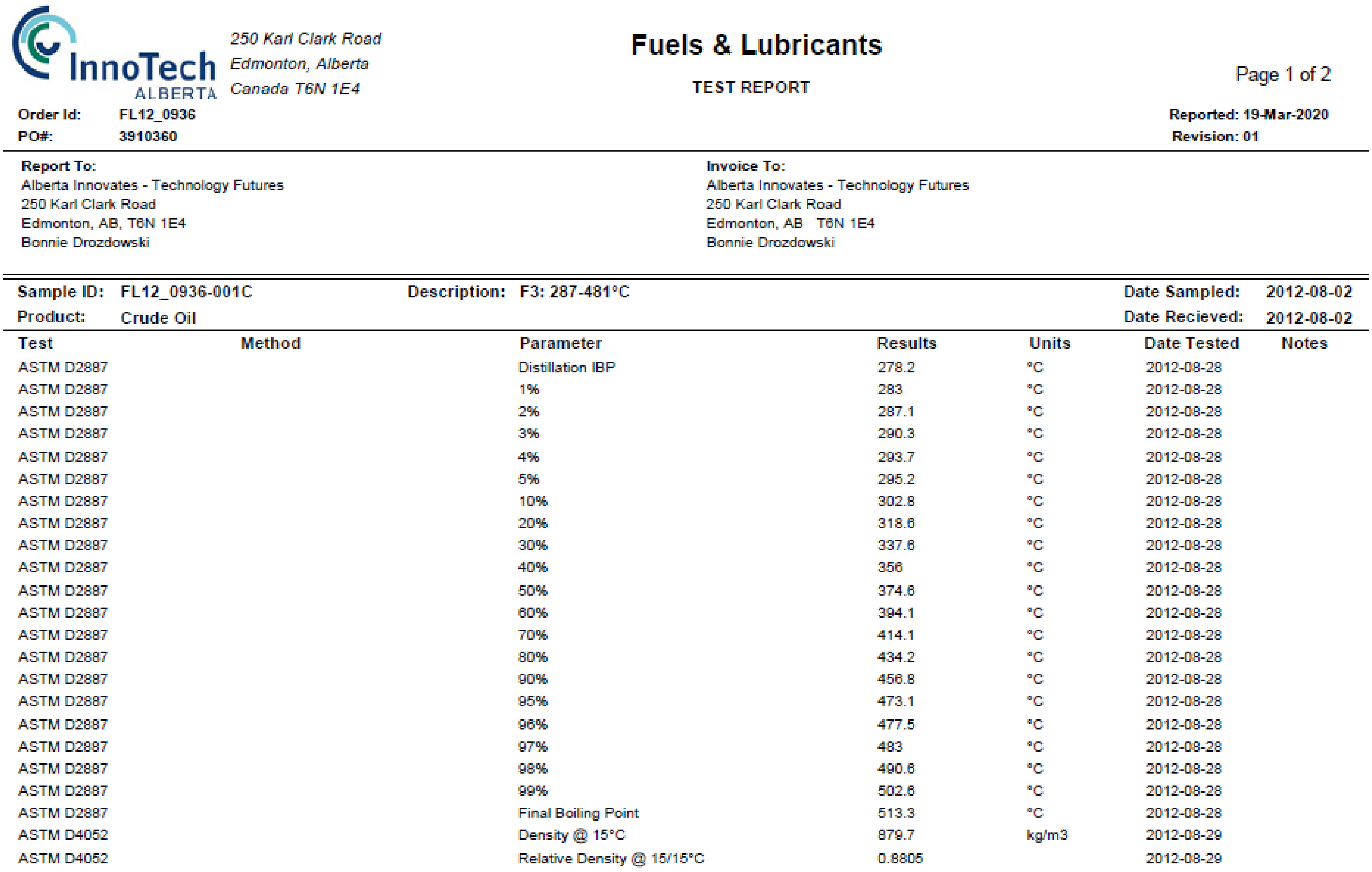
Recovery: 100.00 @499.7C
Analysis Area: 6.36960e+06
Detector RF: 1.00000e+00
R.Time Date: 7/25/2019

Start Time: 0.555 min.
Start Signal: 0.099 pA
Sample Amt: 0.0000
R.Factor Date: 7/25/2019

End Time: 28.068 min.
End Signal: 0.734 pA
Solvent Amt: 0.0000

R.Time File: X:\3\DATA\FL19_1237 D2887 2019-07-22 12-10-25\RT-INIT.D\RT-INIT_FID1_A.CDF
R.Factor File: X:\3\DATA\FL19_1237 D2887 2019-07-22 12-10-25\RF-INIT.D\RF-INIT_FID1_A.CDF
Blank File: X:\3\DATA\FL19_1237 D2887 2019-07-22 12-10-25\BLK4.D\BLK4_FID1_A.CDF

PHC F3 Distillate Characterization – 2012



250 Karl Clark Road
Edmonton, Alberta
Canada T6N 1E4

Fuels & Lubricants

TEST REPORT

Page 1 of 2

Order Id: FL12_0936
PO#: 3910360

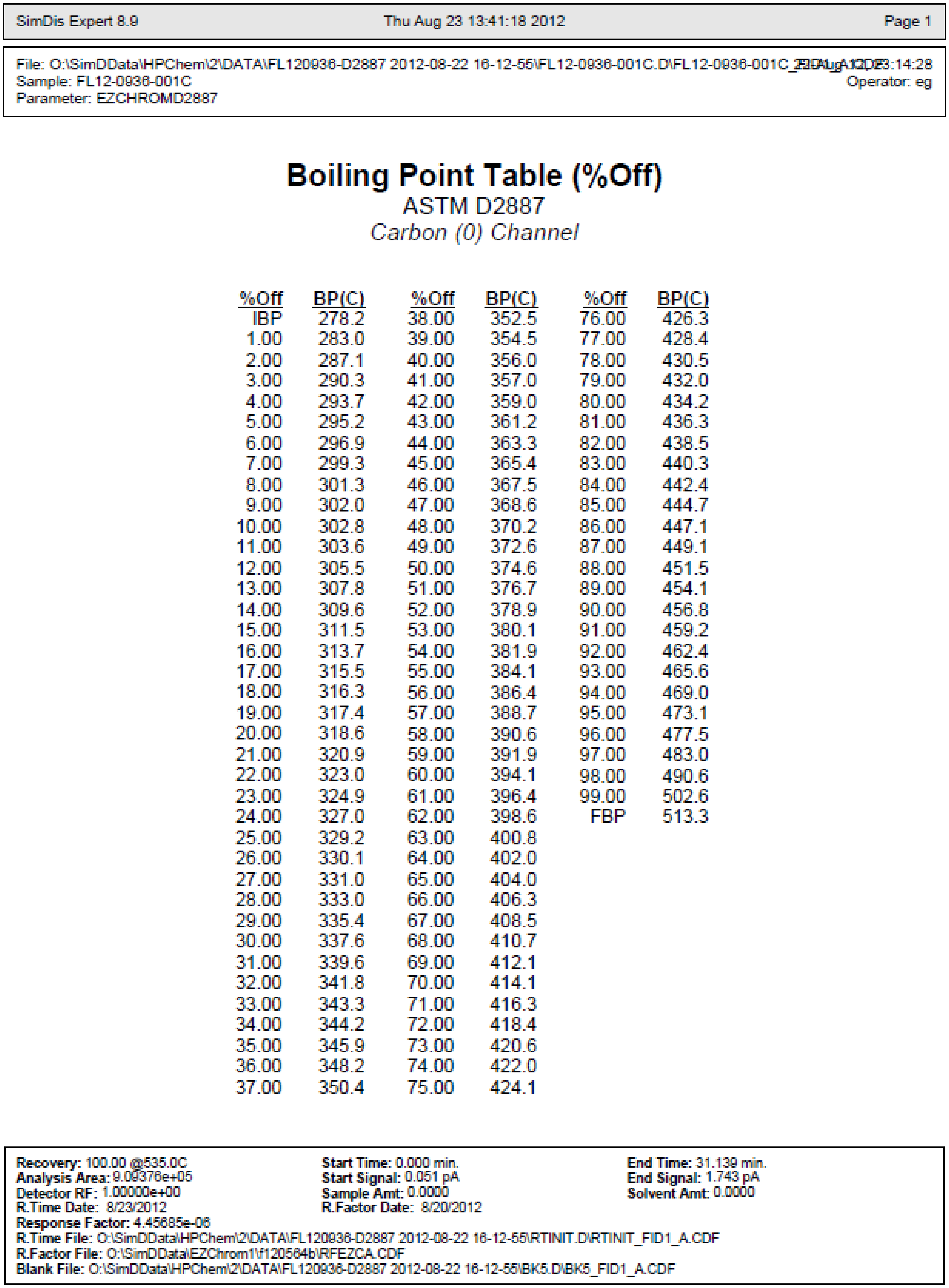
Reported: 19-Mar-2020
Revision: 01

Report To:
Alberta Innovates - Technology Futures
250 Karl Clark Road
Edmonton, AB, T6N 1E4
Bonnie Drozdowski

Invoice To:
Alberta Innovates - Technology Futures
250 Karl Clark Road
Edmonton, AB T6N 1E4
Bonnie Drozdowski

Sample ID: FL12_0936-001C
Description: F3: 287-481°C
Date Sampled: 2012-08-02
Product: Crude Oil
Date Recieved: 2012-08-02

Test	Method	Parameter	Results	Units	Date Tested	Notes
ASTM D2887		Distillation IBP	278.2	°C	2012-08-28	
ASTM D2887		1%	283	°C	2012-08-28	
ASTM D2887		2%	287.1	°C	2012-08-28	
ASTM D2887		3%	290.3	°C	2012-08-28	
ASTM D2887		4%	293.7	°C	2012-08-28	
ASTM D2887		5%	295.2	°C	2012-08-28	
ASTM D2887		10%	302.8	°C	2012-08-28	
ASTM D2887		20%	318.6	°C	2012-08-28	
ASTM D2887		30%	337.6	°C	2012-08-28	
ASTM D2887		40%	356	°C	2012-08-28	
ASTM D2887		50%	374.6	°C	2012-08-28	
ASTM D2887		60%	394.1	°C	2012-08-28	
ASTM D2887		70%	414.1	°C	2012-08-28	
ASTM D2887		80%	434.2	°C	2012-08-28	
ASTM D2887		90%	456.8	°C	2012-08-28	
ASTM D2887		95%	473.1	°C	2012-08-28	
ASTM D2887		96%	477.5	°C	2012-08-28	
ASTM D2887		97%	483	°C	2012-08-28	
ASTM D2887		98%	490.6	°C	2012-08-28	
ASTM D2887		99%	502.6	°C	2012-08-28	
ASTM D2887		Final Boiling Point	513.3	°C	2012-08-28	
ASTM D4052		Density @ 15°C	879.7	kg/m3	2012-08-29	
ASTM D4052		Relative Density @ 15/15°C	0.8805		2012-08-29	



SimDis Expert 8.9 Thu Aug 23 13:41:18 2012 Page 1

File: O:\SimDData\HPChem\2\DATA\FL120936-D2887 2012-08-22 16-12-55\FL12-0936-001C.D\FL12-0936-001C_FID1_A.CDF 23 Aug 2012 13:14:28
Sample: FL12-0936-001C Operator: eg
Parameter: EZCHROMD2887

Boiling Point Table (%Off)

ASTM D2887

Carbon (0) Channel

%Off	BP(C)	%Off	BP(C)	%Off	BP(C)
IBP	278.2	38.00	352.5	76.00	426.3
1.00	283.0	39.00	354.5	77.00	428.4
2.00	287.1	40.00	356.0	78.00	430.5
3.00	290.3	41.00	357.0	79.00	432.0
4.00	293.7	42.00	359.0	80.00	434.2
5.00	295.2	43.00	361.2	81.00	436.3
6.00	296.9	44.00	363.3	82.00	438.5
7.00	299.3	45.00	365.4	83.00	440.3
8.00	301.3	46.00	367.5	84.00	442.4
9.00	302.0	47.00	368.6	85.00	444.7
10.00	302.8	48.00	370.2	86.00	447.1
11.00	303.6	49.00	372.6	87.00	449.1
12.00	305.5	50.00	374.6	88.00	451.5
13.00	307.8	51.00	376.7	89.00	454.1
14.00	309.6	52.00	378.9	90.00	456.8
15.00	311.5	53.00	380.1	91.00	459.2
16.00	313.7	54.00	381.9	92.00	462.4
17.00	315.5	55.00	384.1	93.00	465.6
18.00	316.3	56.00	386.4	94.00	469.0
19.00	317.4	57.00	388.7	95.00	473.1
20.00	318.6	58.00	390.6	96.00	477.5
21.00	320.9	59.00	391.9	97.00	483.0
22.00	323.0	60.00	394.1	98.00	490.6
23.00	324.9	61.00	396.4	99.00	502.6
24.00	327.0	62.00	398.6	FBP	513.3
25.00	329.2	63.00	400.8		
26.00	330.1	64.00	402.0		
27.00	331.0	65.00	404.0		
28.00	333.0	66.00	406.3		
29.00	335.4	67.00	408.5		
30.00	337.6	68.00	410.7		
31.00	339.6	69.00	412.1		
32.00	341.8	70.00	414.1		
33.00	343.3	71.00	416.3		
34.00	344.2	72.00	418.4		
35.00	345.9	73.00	420.6		
36.00	348.2	74.00	422.0		
37.00	350.4	75.00	424.1		

Recovery: 100.00 @535.0C
Analysis Area: 9.09376e+05
Detector RF: 1.00000e+00
R.Time Date: 8/23/2012
Start Time: 0.000 min.
Start Signal: 0.051 pA
Sample Amt: 0.0000
R.Factor Date: 8/20/2012
End Time: 31.139 min.
End Signal: 1.743 pA
Solvent Amt: 0.0000
Response Factor: 4.45685e-06
R.Time File: O:\SimDData\HPChem\2\DATA\FL120936-D2887 2012-08-22 16-12-55\RTINIT.D\RTINIT_FID1_A.CDF
R.Factor File: O:\SimDData\EZChrom1\f120564b\RFEZCA.CDF
Blank File: O:\SimDData\HPChem\2\DATA\FL120936-D2887 2012-08-22 16-12-55\BK5.D\BK5_FID1_A.CDF

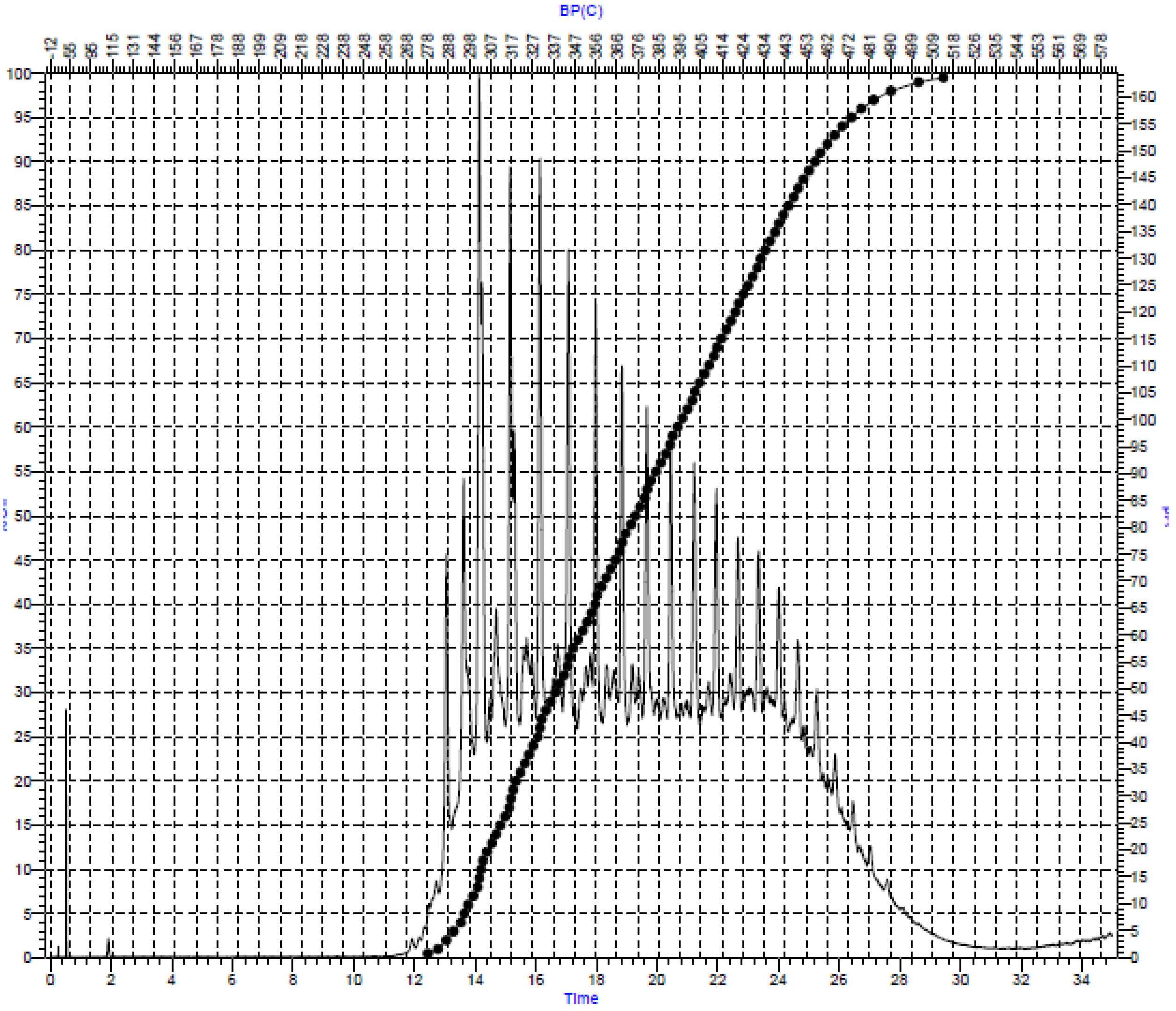
SimDis Expert 8.9	Thu Aug 23 13:41:18 2012	Page 1

File: O:\SimDData\HPChem\2\DATA\FL120936-D2887 2012-08-22 16-12-55\FL12-0936-001C.D\FL12-0936-001C_FID1_A.CDF 23 Aug 2012 13:14:28
Sample: FL12-0936-001C Operator: eg
Parameter: EZCHROMD2887

Distillation Chart

ASTM D2887

Carbon (0) Channel



Recovery: 100.00 @535.0C
Analysis Area: 9.09376e+05
Detector RF: 1.00000e+00
R.Time Date: 8/23/2012
Response Factor: 4.45685e-06
R.Time File: O:\SimDData\HPChem\2\DATA\FL120936-D2887 2012-08-22 16-12-55\RTINIT.D\RTINIT_FID1_A.CDF
R.Factor File: O:\SimDData\EZChrom1\f120564b\RFEZCA.CDF
Blank File: O:\SimDData\HPChem\2\DATA\FL120936-D2887 2012-08-22 16-12-55\BK5.D\BK5_FID1_A.CDF

Start Time: 0.000 min.
Start Signal: 0.051 pA
Sample Amt: 0.0000
R.Factor Date: 8/20/2012

End Time: 31.139 min.
End Signal: 1.743 pA
Solvent Amt: 0.0000

APPENDIX B: UTILITY DESIGN, SPECIFICATIONS AND POTENTIAL IMPACT DUE TO PETROLEUM HYDROCARBONS

1.0 Fibre Optic Cables and Other Buried Utilities

TELUS was contacted for information on materials and installation practices for fibre optic cables based on their prevalence throughout the province of Alberta. The TELUS representative, Manager of Environment, stated that in most cases fibre cable is placed in conduits, rather than direct buried.

Ducts are made of high-density polyethylene (HDPE) and occasionally PVC. Most cable applications are Prysmian LT2.0 Poly-Steel-Poly (PSP) cables. When asked about potential points of weakness, they stated that at joints, the conduits could be susceptible to hydrocarbon ingress and the cables could then be impacted. Main fibre ducts are typically buried between 1.1 and 1.5 metres below ground surface (m bgs); however, from the main line to individual residences they could be as shallow as 0.45 m bgs (Brian Daniel, *pers. comm*).

Based on the information provided, it was determined that fibre optic cables should be omitted from the testing program based on their installation above the zone of interest (*i.e.,* below 1.5 m bgs).

2.0 Municipal Waterworks

The Alberta Government's Standards and Guidelines for Municipal Waterworks, Wastewater and Storm Drainage Systems (GoA, 2012 a and b) provide a general design basis for municipal water distribution systems. The minimum depth of a water distribution pipe is specified as 2.5 m and the minimum inner diameter is 150 mm (6 in). Otherwise, pipelines are to be sized according to a minimum distribution pressure of 150 kPa [1, 2].

The cities of Edmonton and Calgary provide more specific design standards [3, 4]. There are four types of polymer pipes that can potentially be used: polyvinyl chloride (PVC), flexible polyvinyl chloride (FPVC), polyethylene (PE), and high-density polyethylene (HDPE). FPVC, PE, and HDPE pipes require approval on a project specific basis, whereas PVC does not. Approved pipe types are given in the design standards, including manufacturer, model, and nominal sizes; both cities use the same models for PVC and HDPE.

The minimum nominal pipe size for a water main in both cities is 100 mm (4 in), which is restricted to residential cul-de-sacs. Otherwise, nominal pipe sizes start at 150 mm (6 in). The depth of water mains below curb top is also given in the City of Edmonton's design standards based on the specific diameters given in Table B1.

Table B1. Depth of water mains

Diameter, mm (in)	Minimum depth of invert below curb top (m)
150 (6)	2.59
200 (8)	2.62
250 (10)	2.64
300 (12)	2.67
350 (14)	2.70
400 (16)	2.72
450 (18)	2.75

For the specified diameters above, pipe dimensions were tabulated according to inner diameter and thickness for each polymer type. For PVC and HDPE pipes, there are a variety of manufacturers and thus a dimension range is given (Tables B2 and B3) [5-13].

Table B2. PVC pipe dimension ranges.

NPS Size	Min ID, mm (in)	Max ID, mm (in)	Min Thickness, mm (in)	Max Thickness, mm (in)
6	149.10 (5.87)	165.61 (6.52)	9.73 (0.383)	16.43 (0.647)
8	202.95 (7.99)	217.17 (8.55)	12.75 (0.502)	15.98 (0.629)
10	248.77 (9.794)	266.19 (10.48)	15.65 (0.616)	19.76 (0.778)
12	295.81 (11.646)	316.74 (12.47)	16.59 (0.653)	23.09 (0.909)
14	345.44 (13.6)	373.13 (14.69)	15.49 (0.61)	21.59 (0.85)
16	392.684 (15.46)	424.18 (16.7)	17.68 (0.696)	24.61 (0.969)
18	454.66 (17.9)	475.49 (18.72)	19.81 (0.78)	19.81 (0.78)

Table B3. HDPE pipe dimension ranges.

NPS Size	Min ID, mm (in)	Max ID, mm (in)	Min Thickness, mm (in)	Max Thickness, mm (in)
6	135.86 (5.349)	141.50 (5.571)	15.29 (0.602)	15.93 (0.627)
8	176.78 (6.96)	185.55 (7.305)	19.91 (0.784)	20.90 (0.823)
10	220.45 (8.679)	227.61 (8.961)	24.82 (0.977)	25.63 (1.009)
12	261.37 (10.29)	270.76 (10.66)	30.48 (1.2)	29.44 (1.159)
14	287.02 (11.3)	313.69 (12.35)	32.33 (1.273)	35.33 (1.391)
16	328.17 (12.92)	356.87 (14.05)	36.96 (1.455)	40.18 (1.582)
18	369.06 (14.53)	399.80 (15.74)	41.55 (1.636)	45.03 (1.773)

EPCOR's distribution and transmission piping system comprises of 52.5% PVC, 0.3% HDPE, 0.2% fibre-reinforced plastic (FRP), with the remainder being non-polymeric materials. For the specified polymeric materials, PVC spans the largest size range, from 100 mm (4 in) to 900 mm (35.5 in), with 150 mm (6 in) being the smallest PVC distribution size and 100 mm (4 in) PVC being used for services.

3.0 Material Properties

The chemical properties of PVC and PE were investigated previously to determine the effect of structure on diffusion rate [14]. It was found that more polar penetrants showed higher permeation rates due to their ability to soften or swell the rigid structure of PVC. Alkanes and aliphatic hydrocarbons had less risk of permeation because their non-polarity decreased ability to soften PVC. Conversely, PE permeation rates were higher for aromatic and aliphatic hydrocarbons, alkanes with increased molar weight, and non-polar compounds in general. HDPE shows greater resistance than PE or LDPE although it is still susceptible to the compounds mentioned prior.

To quantify chemical resistance, a numerical rating was assigned to each compound as given in Table B4.

Table B4. Resistivity Ratings.

Rating	Resistivity
5	Resistant
3	Conditional/questionable
0	Not resistant

Tables B5-B7 show chemical resistance of polymers for select hydrocarbons based on manufacturer and NACE data [15-18]. Unless specified otherwise, the concentration of each compound is 100%. The total resistivity ratings summed up for PVC, HDPE, and FRP were 148, 91, and 104, respectively.

Table B5. Chemical Resistivity of PVC.

PHC Fraction	Chemical	Chemical Formula	Temperature Range (°C)	PVC Resistivity Rating
Unspecified (C<6)	Methane	CH_4	23 – 60	5
	Acetylene	C_2H_2	21 – 65	5
	Propane	C_3H_8	21 – 65	5
	Butadiene	C_4H_6	21 – 26 26 – 65	3 0
	Butane	C_4H_{10}	21 – 65	5
	Pentane	C_5H_{12}	23 – 60	3
	Natural gas	N/A	21 – 65	5
F1 (C6 - C10)	Benzene	C_6H_6	15 – 21 21 – 57 57 – 65	0 0 0
	Cyclohexane	C_6H_{12}	21 – 65	5
	Hexane	C_6H_{14}	21 – 65	0
	Trimethylpropane	C_6H_{14}	21 – 26 26 – 65	3 0
	Toluene	C_7H_8	21 – 51 51 – 65	0 0
	Heptane	C_7H_{16}	21 – 26 26 – 37 37 – 65	5 0 0
	Xylene	C_8H_{10}	23 – 60	0
	Gasoline	N/A	21 – 26 26 – 57 57 – 65	3 0 5

PHC Fraction	Chemical	Chemical Formula	Temperature Range (°C)	PVC Resistivity Rating
	Naphtha	N/A	15 – 21	5
			21 – 65	5
F2 (C10 - C16)	Naphthalene	$C_{10}H_8$	21 – 26	0
			26 – 65	0
	Jet fuels, general	N/A	15 – 21	5
			21 – 65	5
	Jet fuels, JP-4, JP-5	N/A	23 – 60	3
	Kerosene	N/A	15 – 21	5
			21 – 65	5
F3 (C16 - C34)	Diesel fuels	N/A	15 – 21	5
			21 – 65	5
	Lubricating oils	N/A	21 – 57	5
			57 – 65	3
	Motor oil	N/A	23 – 60	5
	Hydraulic oil	N/A	23	5
			60	0
	Transformer oil	N/A	15 – 21	5
			21 – 60	5
	Mineral oil	N/A	15 – 21	5
			21 – 150	5
	Paraffin	N/A	15 – 21	5
			21 – 65	5
	Silicone oil	N/A	23	5
			60	0

Table B6. Chemical Resistivity of HDPE.

PHC Fraction	Chemical	Chemical Formula	Temperature Range (°C)	HDPE Resistivity Rating
Unspecified (C<6)	Methane	CH_4	23 – 60	5
	Propane	C_3H_8	21 – 65	5
	Butadiene	C_4H_6	21 – 26	0
			26 – 65	0
	Butane	C_4H_{10}	21 – 65	3
	Pentane	C_5H_{12}	23 – 60	3
	Natural gas	N/A	21 – 65	5
F1 (C6 - C10)	Benzene	C_6H_6	15 – 21	3
			21 – 57	0
			57 – 65	0
	Cyclohexane	C_6H_{12}	21 – 65	0

PHC Fraction	Chemical	Chemical Formula	Temperature Range (°C)	HDPE Resistivity Rating
	Hexane	C_6H_{14}	21 – 65	0
	Trimethylpropane	C_6H_{14}	21 – 26	5
			26 – 65	3
	Toluene	C_7H_8	21 – 51	0
			51 – 65	0
	Heptane	C_7H_{16}	21 – 26	3
			26 – 37	0
			37 – 65	0
	Styrene	C_8H_8	21 – 26	0
			26 – 65	0
	Ethylbenzene	C_8H_{10}	15 – 21	0
	Xylene	C_8H_{10}	23 – 60	0
	Octane	C_8H_{18}	21 - 60	5
	Gasoline	N/A	21 – 26	3
			26 – 57	0
			57 – 65	0
	Naphtha	N/A	15 – 21	3
			21 – 65	0
F2 (C10 - C16)	Naphthalene	$C_{10}H_8$	21 – 26	0
			26 – 65	0
	Jet fuels, general	N/A	15 – 21	5
			21 – 65	3
	Kerosene	N/A	15 – 21	3
			21 – 65	0
	Stoddard solvent	N/A	21 – 26	5
			26 – 51	3
F3 (C16 - C34)	Diesel fuels	N/A	15 – 21	5
			21 – 65	0
	Fuel oils		15 – 21	5
			21 – 65	0
	Lubricating oils	N/A	21 – 57	0
			57 – 65	0
	Transformer oil	N/A	15 – 21	3
			21 – 60	0
	Mineral oil	N/A	15 – 21	5
			21 – 150	0
	Paraffin	N/A	15 – 21	5
			21 - 65	3

Table B7. Chemical Resistivity of FRP

PHC Fraction	Chemical	Chemical Formula	Temperature Range (°C)	FRP Resistivity Rating
F1 (C6 - C10)	Benzene	C_6H_6	15 - 21	3
			21 - 57	3
			57 - 65	0
	Hexane	C_6H_{14}	21 – 65	0
	Toluene	C_7H_8	15 - 21	5
			21 – 51	0
			51 – 65	5
	Heptane	C_7H_{16}	21 – 26	5
			26 – 37	5
			37 – 65	5
	Styrene	C_8H_8	21 - 26	0
	Xylene	C_8H_{10}	23 – 60	5
	Isooctane	C_8H_{18}	15 - 21	5
			21 - 65	0
	Gasoline	N/A	21 – 26	5
			26 – 57	5
			57 – 65	5
	Naphtha	N/A	21 - 65	5
F2 (C10 - C16)	Naphthalene	$C_{10}H_8$	21 - 26	5
	Diphenyl	$C_{12}H_{10}$	21 - 51	5
	Dodecene	$C_{12}H_{24}$	21 - 51	5
	Anthracene (10% concentration)	$C_{14}H_{10}$	15 - 21	3
	Kerosene	N/A	21 - 65	5
F3 (C16 - C34)	Diesel fuels	N/A	21 - 65	5
	Fuel oils		15 - 21	5
			21 - 65	5
	Transformer oil	N/A	21 - 60	5

Other various physical and mechanical properties for PVC and HDPE are given in Table B8 [19-20].

Table B8. Physical and mechanical properties of specified polymers.

Property	**PVC Value**	**HDPE Value**
Shore D hardness	80	59 - 64
Impact strength (20°)	20 kJ/m^2	26 – 35 kJ/m^2
Ultimate tensile strength	52 MPa	33 MPa
Elastic tensile modulus	3.0 – 3.3 GPa	9.7 – 13.8 GPa
Elongation at break	50 – 80%	600 – 1,350%
Softening point	80 – 84°C	125°C
Maximum continuous service temperature	60°C	82°C
Coefficient of thermal expansion	7 x 10^{-5} K	2.4 x 10^{-4} °C

Based on the above data and analysis, it was recommended that the potential impact of PHC F2 and F3 on PVC piping should be evaluated, as it is likely the most prevalent polymer used in Alberta's water distribution piping network. Although HDPE is not as widely used as PVC, it could also be evaluated as it is more susceptible to permeation by hydrocarbons and therefore posits the worst-case scenario. Likewise, it was recommended that the smallest pipe sizes (NPS 4 and 6) be tested.

4.0 APPENDIX B REFERENCES

Personal Communication via email: Brian Daniel, Manager, Environment, TELUS, Edmonton, AB. November 7, 2019.

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APPENDIX C: PVC, HDPE AND FRP COUPON WEIGHTS, SHORE D HARDNESS, AND THICKNESS

1.0 PVC, FRP AND HDPE Coupon Weights

		PVC Coupon Weight (g)		
	Coupon #	Initial Weight	After PHC Exposure	After Wash
F2 Exposed	#1	24.1678	24.1686	24.1657
	#2	22.4652	22.4677	22.4632
	#3	22.5206	22.5206	22.5193
F3 Exposed	#4	22.4330	22.4509	22.4345
	#5	24.4830	24.5052	24.4845
	#6	24.3325	24.3437	24.3331
Water	#7	22.7694	22.7881	
Control	#8	23.8547	23.8507	

		FRP Coupon Weight (g)		
	Coupon #	Initial Weight	After PHC Exposure	After Wash
F2 Exposed	#1	13.8202	13.8175	13.8141
	#2	16.1732	16.1699	16.1656
	#3	15.3120	15.3089	15.3043
F3 Exposed	#4	15.0620	14.9121	15.0420
	#5	15.0468	15.0729	15.0572
	#6	14.9024	15.0560	14.8978
Water	#7	14.3347	14.3878	
Control	#8	15.2205	15.2029	

		HDPE Coupon Weight (g)		
	Coupon #	Initial Weight	After PHC Exposure	After Wash
F2 Exposed	#1	11.4042	11.7713	11.7193
	#2	11.2983	11.6287	11.5821
	#3	11.5079	11.8639	11.8134
F3 Exposed	#4	11.4232	11.5320	11.5153
	#5	10.9088	11.0196	11.0028
	#6	10.7188	10.8190	10.8053
Water	#7	12.0097	12.0118	
Control	#8	13.3776	13.3763	

2.0 PVC, FRP AND HDPE Coupon Thickness

PVC

	Coupon #	Thickness (mm)
F2 Exposed	#1	11.22
	#2	10.21
	#3	10.72
F3 Exposed	#4	10.44
	#5	11.25
	#6	11.34
Water	#7	10.87
Control	#8	10.90

FRP

	Coupon #	Thickness (mm)
F2 Exposed	#1	6.91
	#2	7.09
	#3	6.87
F3 Exposed	#4	6.93
	#5	6.97
	#6	6.90
Water	#7	6.97
Control	#8	6.87

HDPE

	Coupon #	Thickness (mm)
F2 Exposed	#1	7.40
	#2	7.53
	#3	7.19
F3 Exposed	#4	7.62
	#5	7.09
	#6	7.29
Water	#7	7.22
Control	#8	7.16

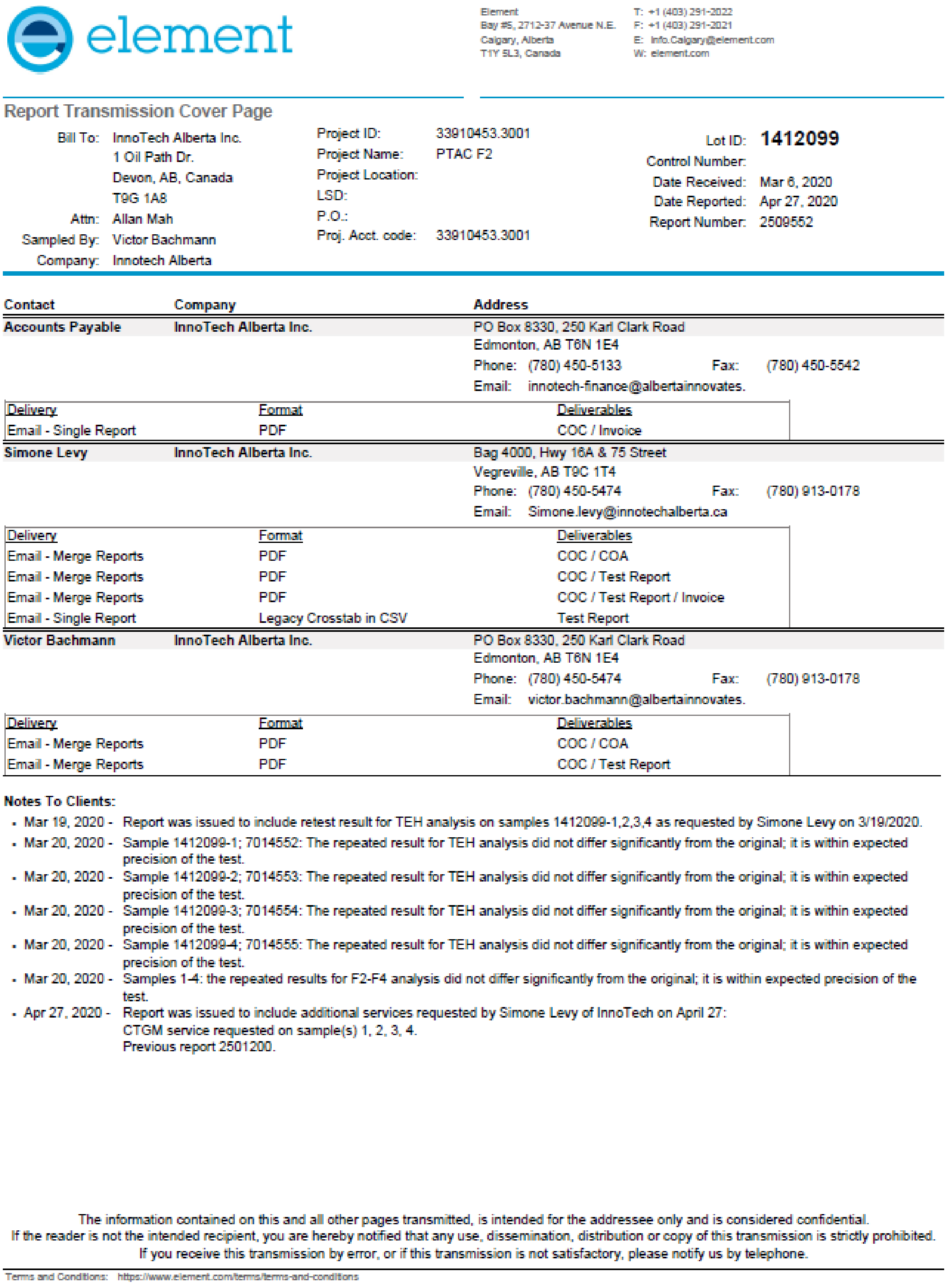
3.0 VC, FRP AND HDPE Coupon Shore D Hardness

		PVC Shore D Hardness Unwashed				PVC Shore D Hardness Washed			
	Coupon #	1	2	3	4	1	2	3	4
F2 Exposed	#1	82	82	82	80	81	81	82	82
	#2	83	81	81	82	84	82	82	82
	#3	81	81	81	83	82	81	82	83
F3 Exposed	#4	78	78	78	79	85	83	81	82
	#5	79	80	80	80	82	82	82	83
	#6	80	80	80	82	82	83	82	81
Water	#7	84	84	87	85				
Control	#8	84	84	83	85				

		FRP Shore D Hardness Unwashed				FRP Shore D Hardness Washed			
	Coupon #	1	2	3	4	1	2	3	4
F2 Exposed	#1	88	91	92	89	89	92	94	93
	#2	90	89	92	91	93	91	91	94
	#3	91	96	92	92	94	94	92	91
F3 Exposed	#4	89	88	87	92	91	91	91	89
	#5	91	90	90	91	91	91	94	92
	#6	89	91	92	91	90	90	92	94
Water	#7	86	89	88	89				
Control	#8	91	90	95	89				

		HDPE Shore D Hardness Unwashed				HDPE Shore D Hardness Washed			
	Coupon #	1	2	3	4	1	2	3	4
F2 Exposed	#1	68	62	69	63	66	69	63	62
	#2	72	70	66	68	64	63	68	64
	#3	64	70	74	72	68	61	68	63
F3 Exposed	#4	68	67	64	64	68	65	66	65
	#5	67	68	66	68	64	68	66	66
	#6	67	66	66	68	66	72	69	64
Water	#7	71	69	74	70				
Control	#8	66	70	68	66				

APPENDIX D: ORIGINAL LABORATORY REPORTS



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Report Transmission Cover Page

Bill To: InnoTech Alberta Inc.
1 Oil Path Dr.
Devon, AB, Canada
T9G 1A8
Attn: Allan Mah
Sampled By: Victor Bachmann
Company: Innotech Alberta

Project ID: 33910453.3001
Project Name: PTAC F2
Project Location:
LSD:
P.O.:
Proj. Acct. code: 33910453.3001

Lot ID: **1412099**
Control Number:
Date Received: Mar 6, 2020
Date Reported: Apr 27, 2020
Report Number: 2509552

Contact	Company	Address
Accounts Payable	**InnoTech Alberta Inc.**	PO Box 8330, 250 Karl Clark Road Edmonton, AB T6N 1E4 Phone: (780) 450-5133 Fax: (780) 450-5542 Email: innotech-finance@albertainnovates.

Delivery	Format	Deliverables
Email - Single Report	PDF	COC / Invoice

Contact	Company	Address
Simone Levy	**InnoTech Alberta Inc.**	Bag 4000, Hwy 16A & 75 Street Vegreville, AB T9C 1T4 Phone: (780) 450-5474 Fax: (780) 913-0178 Email: Simone.levy@innotechalberta.ca

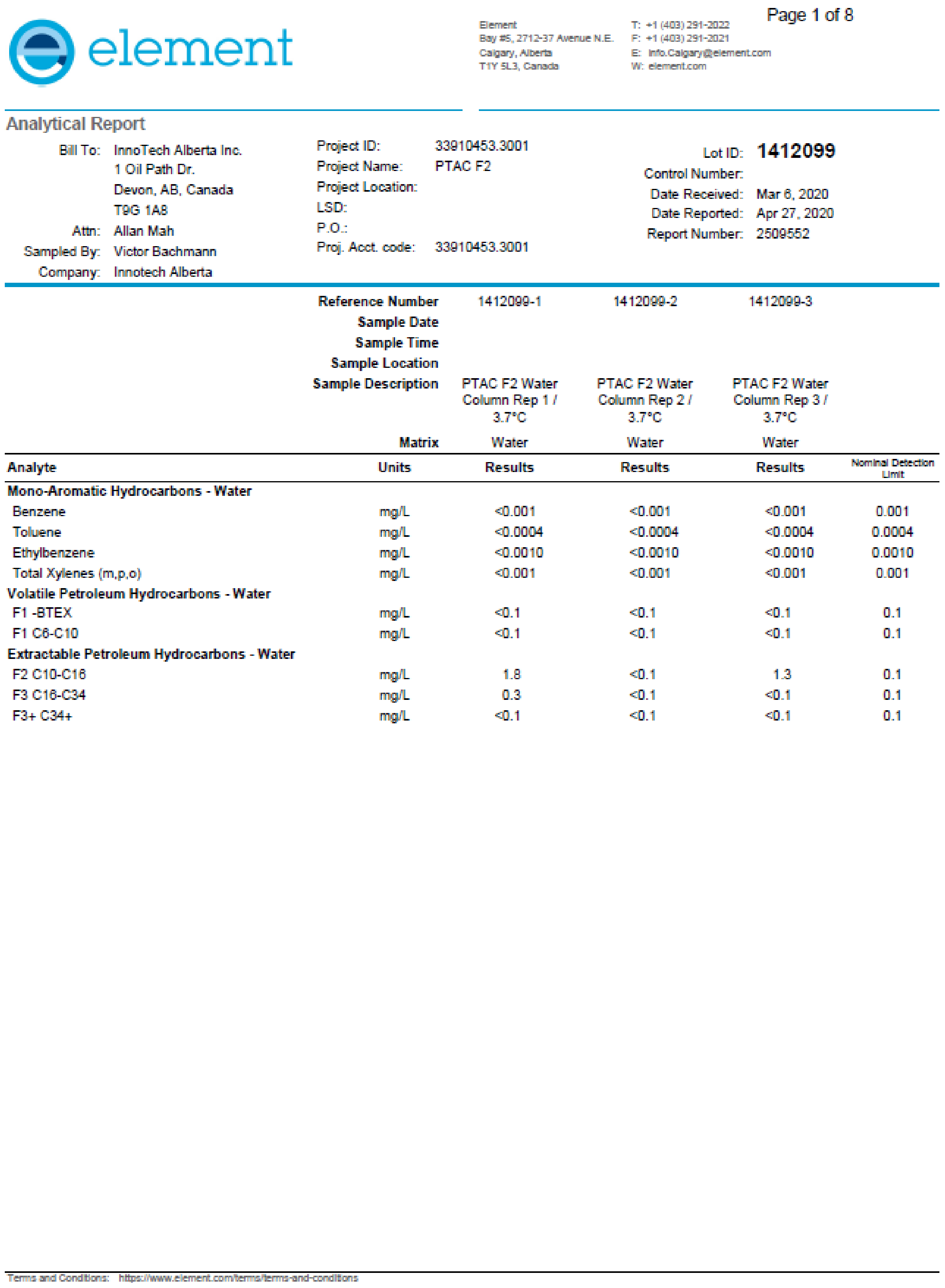
Delivery	Format	Deliverables
Email - Merge Reports	PDF	COC / COA
Email - Merge Reports	PDF	COC / Test Report
Email - Merge Reports	PDF	COC / Test Report / Invoice
Email - Single Report	Legacy Crosstab in CSV	Test Report

Contact	Company	Address
Victor Bachmann	**InnoTech Alberta Inc.**	PO Box 8330, 250 Karl Clark Road Edmonton, AB T6N 1E4 Phone: (780) 450-5474 Fax: (780) 913-0178 Email: victor.bachmann@albertainnovates.

Delivery	Format	Deliverables
Email - Merge Reports	PDF	COC / COA
Email - Merge Reports	PDF	COC / Test Report

Notes To Clients:

- Mar 19, 2020 - Report was issued to include retest result for TEH analysis on samples 1412099-1,2,3,4 as requested by Simone Levy on 3/19/2020.
- Mar 20, 2020 - Sample 1412099-1; 7014552: The repeated result for TEH analysis did not differ significantly from the original; it is within expected precision of the test.
- Mar 20, 2020 - Sample 1412099-2; 7014553: The repeated result for TEH analysis did not differ significantly from the original; it is within expected precision of the test.
- Mar 20, 2020 - Sample 1412099-3; 7014554: The repeated result for TEH analysis did not differ significantly from the original; it is within expected precision of the test.
- Mar 20, 2020 - Sample 1412099-4; 7014555: The repeated result for TEH analysis did not differ significantly from the original; it is within expected precision of the test.
- Mar 20, 2020 - Samples 1-4: the repeated results for F2-F4 analysis did not differ significantly from the original; it is within expected precision of the test.
- Apr 27, 2020 - Report was issued to include additional services requested by Simone Levy of InnoTech on April 27:
  CTGM service requested on sample(s) 1, 2, 3, 4.
  Previous report 2501200.



Page 1 of 8

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Analytical Report

Bill To: InnoTech Alberta Inc.
1 Oil Path Dr.
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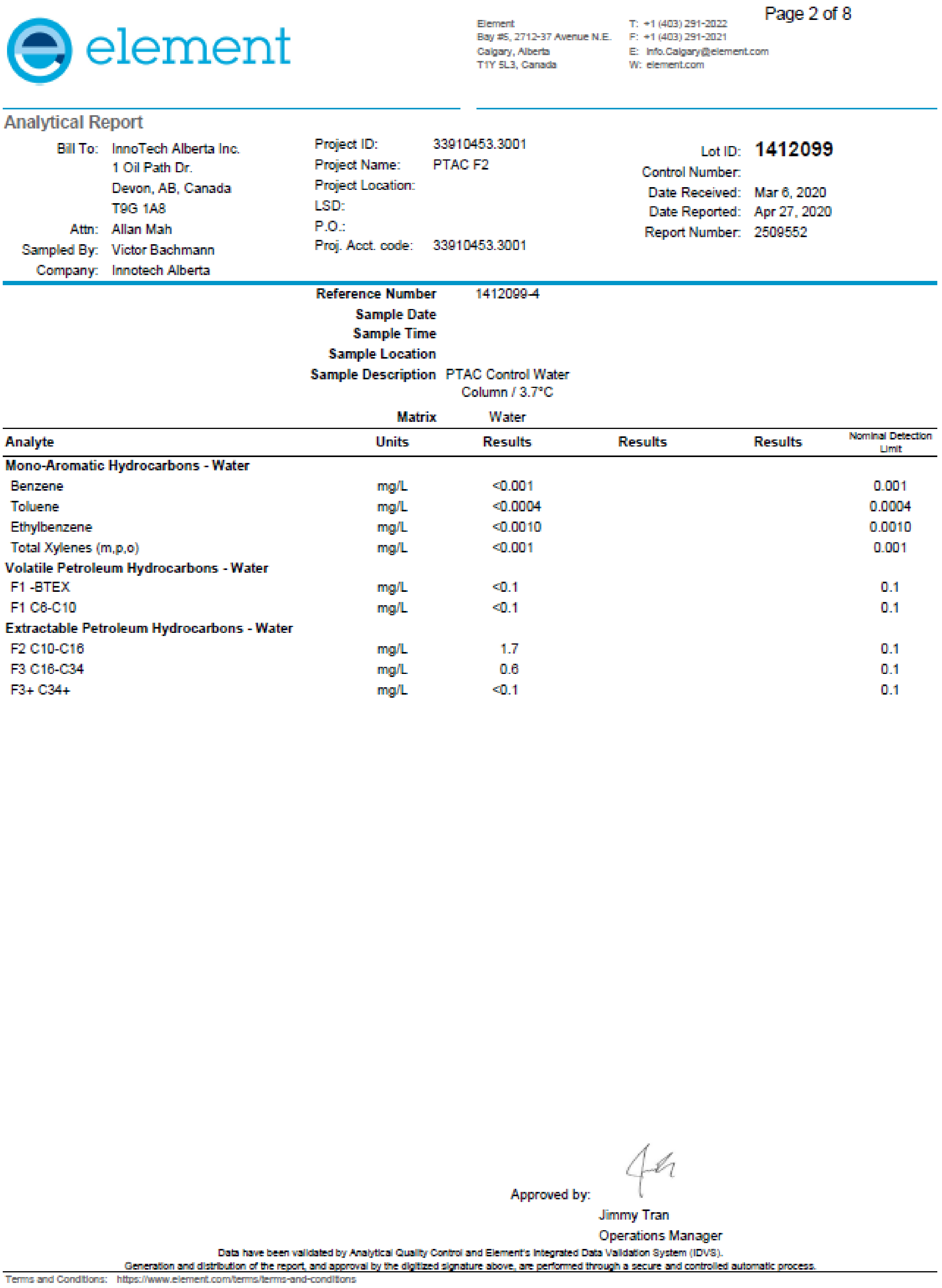
Attn: Allan Mah
Sampled By: Victor Bachmann
Company: Innotech Alberta

Project ID: 33910453.3001
Project Name: PTAC F2
Project Location:
LSD:
P.O.:
Proj. Acct. code: 33910453.3001

Lot ID: **1412099**
Control Number:
Date Received: Mar 6, 2020
Date Reported: Apr 27, 2020
Report Number: 2509552

	Reference Number	1412099-1	1412099-2	1412099-3	
	Sample Date				
	Sample Time				
	Sample Location				
	Sample Description	PTAC F2 Water Column Rep 1 / 3.7°C	PTAC F2 Water Column Rep 2 / 3.7°C	PTAC F2 Water Column Rep 3 / 3.7°C	
	Matrix	Water	Water	Water	
Analyte	**Units**	**Results**	**Results**	**Results**	Nominal Detection Limit
Mono-Aromatic Hydrocarbons - Water					
Benzene	mg/L	<0.001	<0.001	<0.001	0.001
Toluene	mg/L	<0.0004	<0.0004	<0.0004	0.0004
Ethylbenzene	mg/L	<0.0010	<0.0010	<0.0010	0.0010
Total Xylenes (m,p,o)	mg/L	<0.001	<0.001	<0.001	0.001
Volatile Petroleum Hydrocarbons - Water					
F1 -BTEX	mg/L	<0.1	<0.1	<0.1	0.1
F1 C6-C10	mg/L	<0.1	<0.1	<0.1	0.1
Extractable Petroleum Hydrocarbons - Water					
F2 C10-C16	mg/L	1.8	<0.1	1.3	0.1
F3 C16-C34	mg/L	0.3	<0.1	<0.1	0.1
F3+ C34+	mg/L	<0.1	<0.1	<0.1	0.1



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Company: Innotech Alberta

Project ID: 33910453.3001
Project Name: PTAC F2
Project Location:
LSD:
P.O.:
Proj. Acct. code: 33910453.3001

Lot ID: **1412099**
Control Number:
Date Received: Mar 6, 2020
Date Reported: Apr 27, 2020
Report Number: 2509552

Reference Number 1412099-4
Sample Date
Sample Time
Sample Location
Sample Description PTAC Control Water Column / 3.7°C

Matrix Water

Analyte	Units	Results	Results	Results	Nominal Detection Limit
Mono-Aromatic Hydrocarbons - Water					
Benzene	mg/L	<0.001			0.001
Toluene	mg/L	<0.0004			0.0004
Ethylbenzene	mg/L	<0.0010			0.0010
Total Xylenes (m,p,o)	mg/L	<0.001			0.001
Volatile Petroleum Hydrocarbons - Water					
F1 -BTEX	mg/L	<0.1			0.1
F1 C6-C10	mg/L	<0.1			0.1
Extractable Petroleum Hydrocarbons - Water					
F2 C10-C16	mg/L	1.7			0.1
F3 C16-C34	mg/L	0.6			0.1
F3+ C34+	mg/L	<0.1			0.1

Approved by:
Jimmy Tran
Operations Manager

Data have been validated by Analytical Quality Control and Element's Integrated Data Validation System (IDVS).
Generation and distribution of the report, and approval by the digitized signature above, are performed through a secure and controlled automatic process.

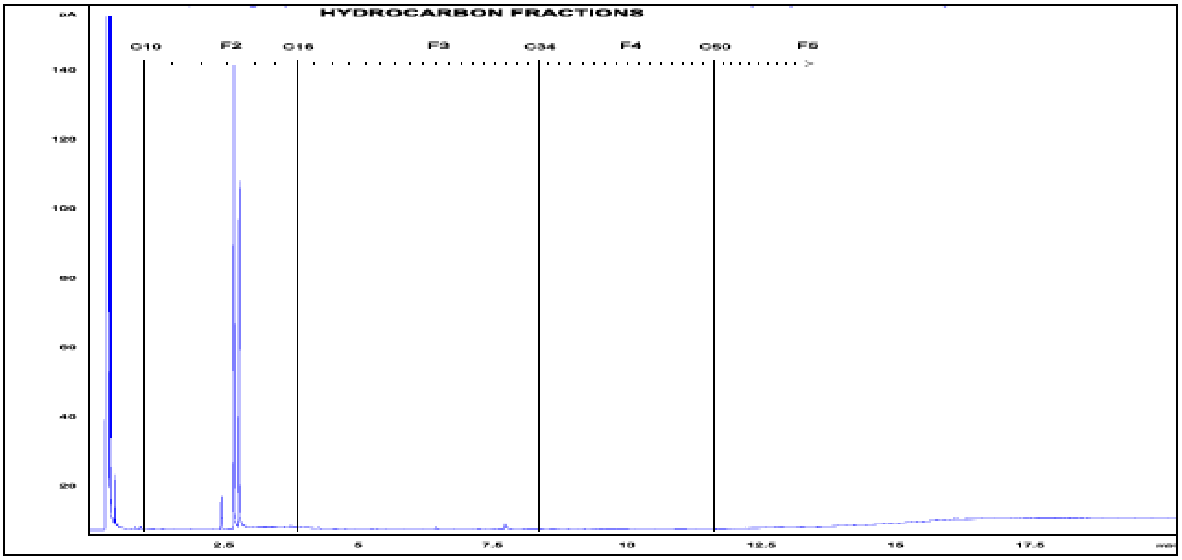
Chromatograms Results

Bill To: InnoTech Alberta Inc.
1 Oil Path Dr.
Devon, AB, Canada
T9G 1A8
Attn: Allan Mah
Sampled By: Victor Bachmann
Company: Innotech Alberta

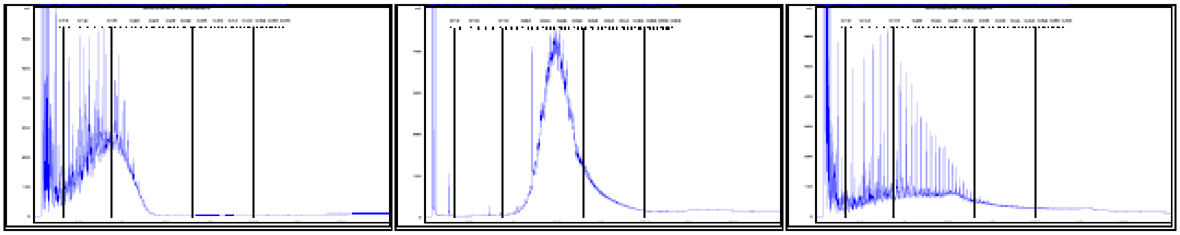
Project ID: 33910453.3001
Project Name: PTAC F2
Project Location:
LSD:
P.O.:
Proj. Acct. code: 33910453.3001

Lot ID: **1412099**
Control Number:
Date Received: Mar 6, 2020
Date Reported: Apr 27, 2020
Report Number: 2509552

Reference Number: 1412099-1
Sample Date:
Sample Description: PTAC F2 Water Column Rep 1 / 3.7°C
Location:
Matrix: Water



TYPICAL PRODUCT CHROMATOGRAMS



Winter Diesel

Motor Oil 10W30

Unweathered Crude

Product Carbon Number Ranges					
Gasoline	C4-C12	Kerosene	C7-C16	Lubricating Oils	C20-C40
Varsol	C8-C12	Diesel	C8-C22	Crude Oils	C3-C60+

Chromatograms Results

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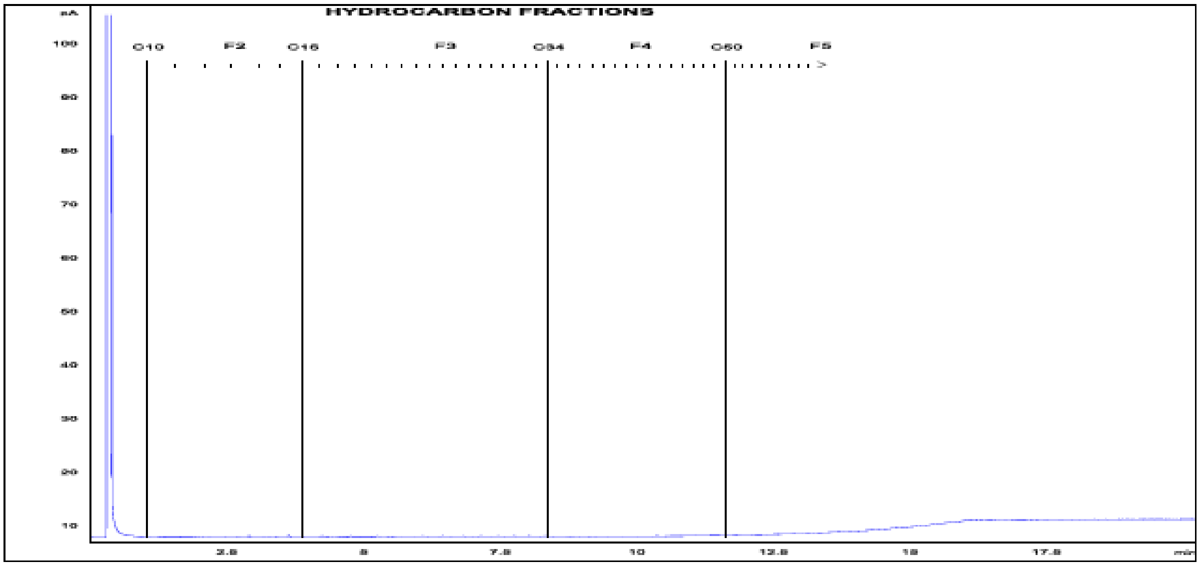
Attn: Allan Mah
Sampled By: Victor Bachmann
Company: Innotech Alberta

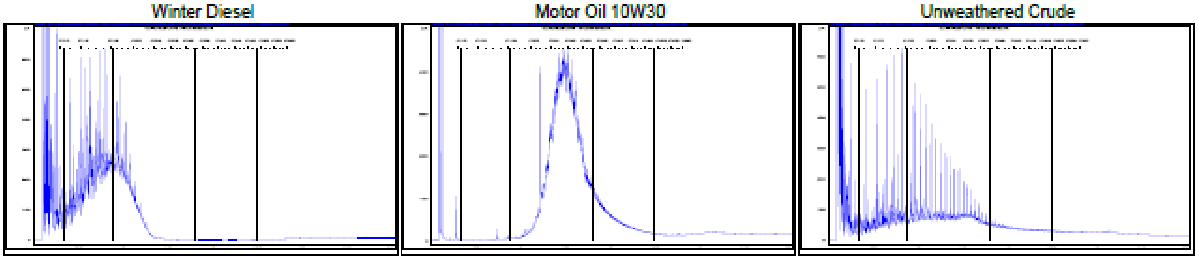
Project ID: 33910453.3001
Project Name: PTAC F2
Project Location:
LSD:
P.O.:
Proj. Acct. code: 33910453.3001

Lot ID: **1412099**
Control Number:
Date Received: Mar 6, 2020
Date Reported: Apr 27, 2020
Report Number: 2509552

Reference Number: 1412099-2
Sample Date:
Sample Description: PTAC F2 Water Column Rep 2 / 3.7°C
Location:
Matrix: Water



TYPICAL PRODUCT CHROMATOGRAMS



Product Carbon Number Ranges

Gasoline	C4-C12	Kerosene	C7-C16	Lubricating Oils	C20-C40
Varsol	C8-C12	Diesel	C8-C22	Crude Oils	C3-C60+

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Bill To: InnoTech Alberta Inc.
1 Oil Path Dr.
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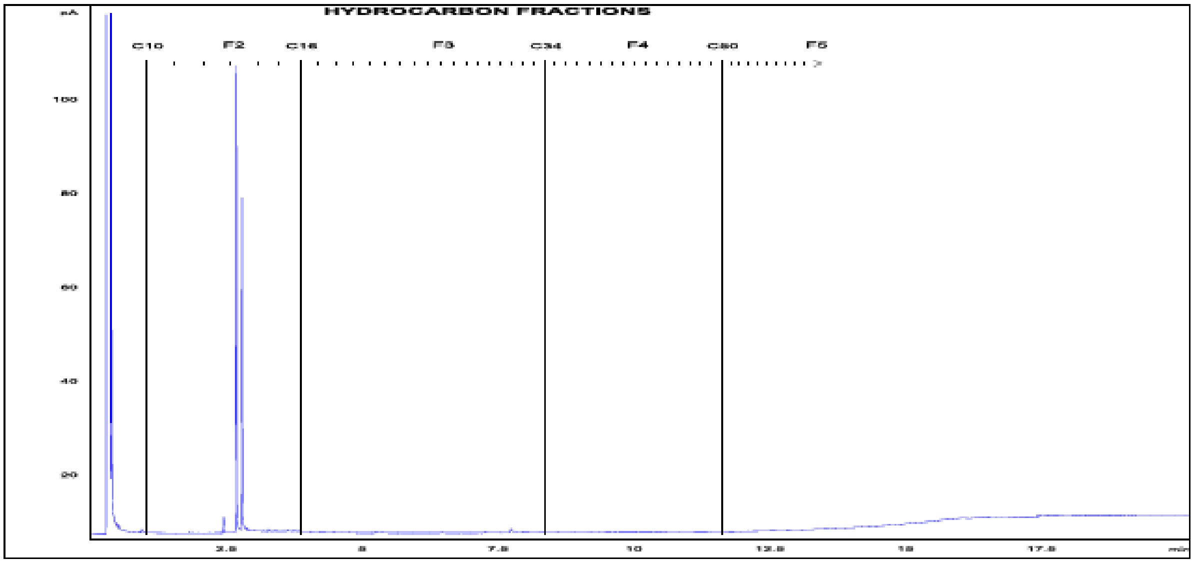
Attn: Allan Mah
Sampled By: Victor Bachmann
Company: Innotech Alberta

Project ID: 33910453.3001
Project Name: PTAC F2
Project Location:
LSD:
P.O.:
Proj. Acct. code: 33910453.3001

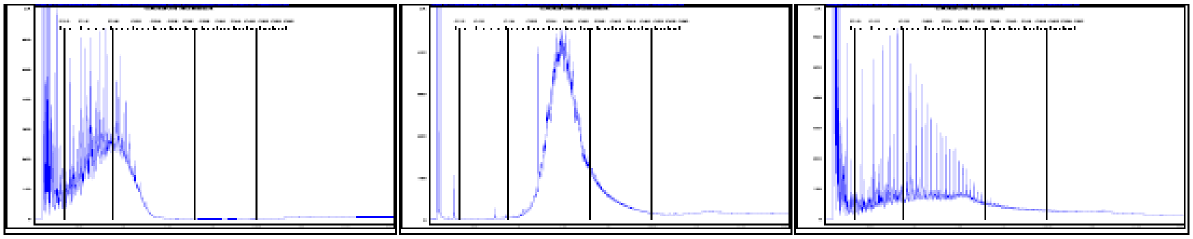
Lot ID: **1412099**
Control Number:
Date Received: Mar 6, 2020
Date Reported: Apr 27, 2020
Report Number: 2509552

Reference Number: 1412099-3
Sample Date:
Sample Description: PTAC F2 Water Column Rep 3 / 3.7°C
Location:
Matrix: Water



TYPICAL PRODUCT CHROMATOGRAMS

Winter Diesel
Motor Oil 10W30
Unweathered Crude



Product Carbon Number Ranges

Gasoline	C4-C12	Kerosene	C7-C16	Lubricating Oils	C20-C40
Varsol	C8-C12	Diesel	C8-C22	Crude Oils	C3-C60+

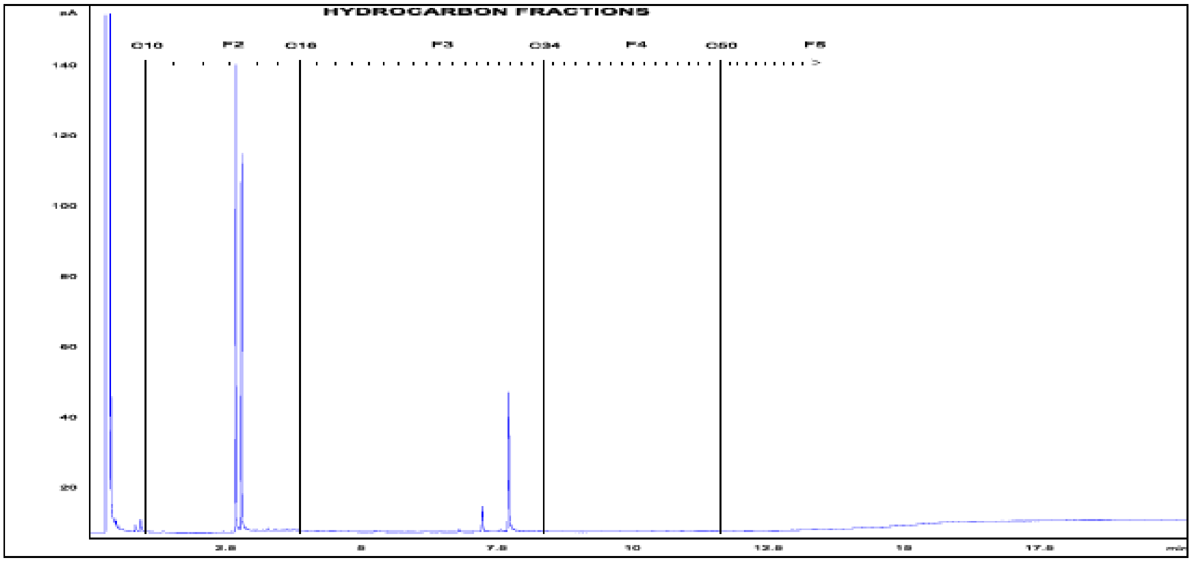
Chromatograms Results

Bill To: InnoTech Alberta Inc.
1 Oil Path Dr.
Devon, AB, Canada
T9G 1A8
Attn: Allan Mah
Sampled By: Victor Bachmann
Company: Innotech Alberta

Project ID: 33910453.3001
Project Name: PTAC F2
Project Location:
LSD:
P.O.:
Proj. Acct. code: 33910453.3001

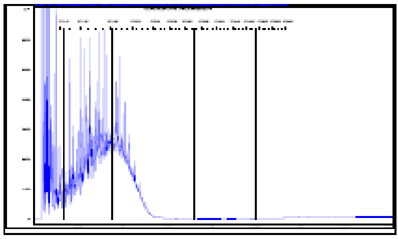
Lot ID: **1412099**
Control Number:
Date Received: Mar 6, 2020
Date Reported: Apr 27, 2020
Report Number: 2509552

Reference Number: 1412099-4
Sample Date:
Sample Description: PTAC Control Water Column / 3.7°C
Location:
Matrix: Water

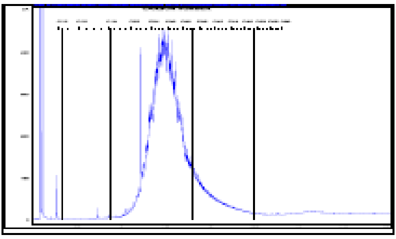


TYPICAL PRODUCT CHROMATOGRAMS

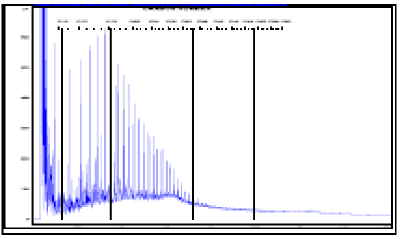
Winter Diesel



Motor Oil 10W30

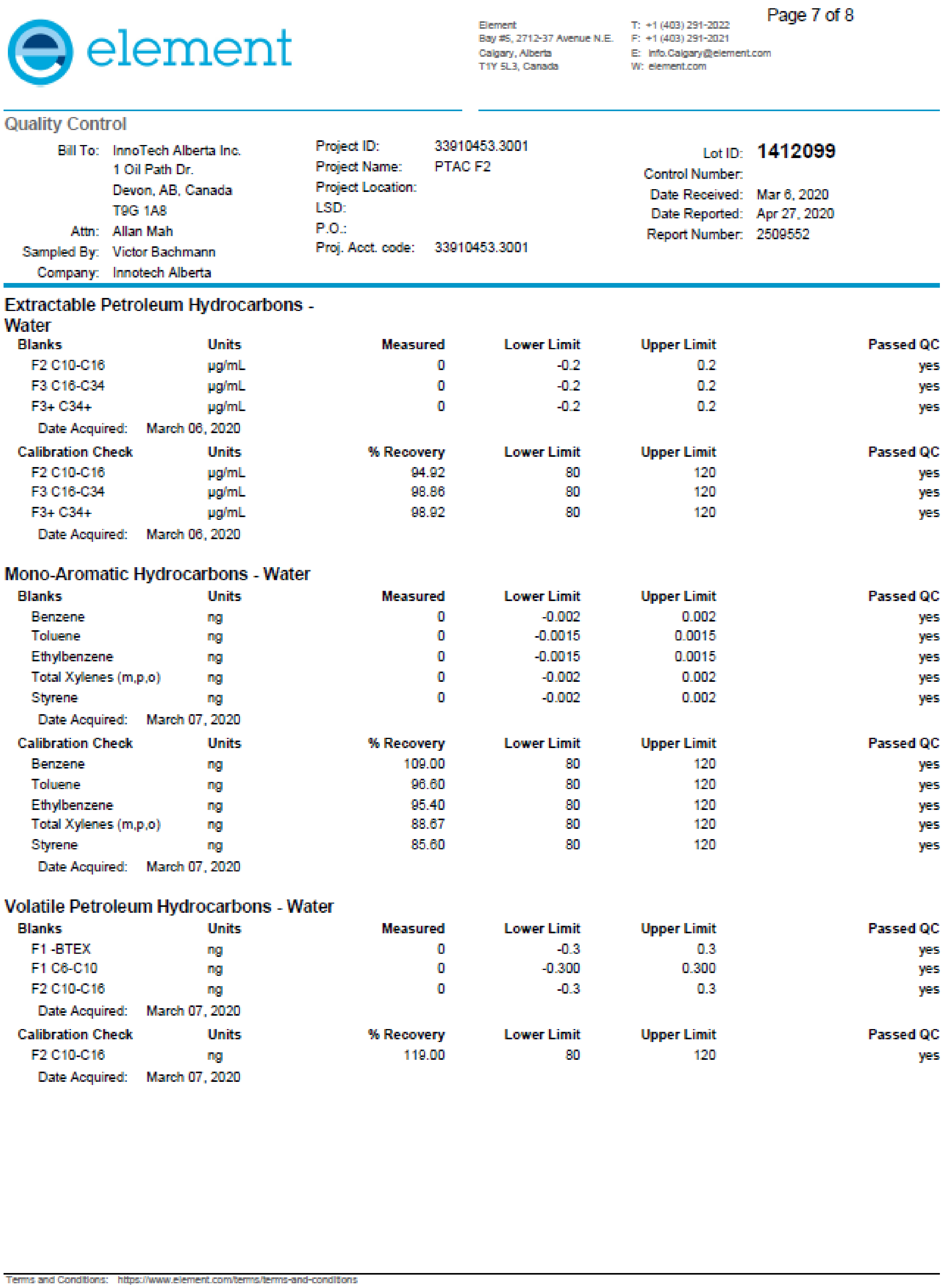


Unweathered Crude



Product Carbon Number Ranges

Gasoline	C4-C12	Kerosene	C7-C16	Lubricating Oils	C20-C40
Varsol	C8-C12	Diesel	C8-C22	Crude Oils	C3-C60+



Page 7 of 8

element

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Quality Control

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Attn: Allan Mah
Sampled By: Victor Bachmann
Company: Innotech Alberta

Project ID: 33910453.3001
Project Name: PTAC F2
Project Location:
LSD:
P.O.:
Proj. Acct. code: 33910453.3001

Lot ID: **1412099**
Control Number:
Date Received: Mar 6, 2020
Date Reported: Apr 27, 2020
Report Number: 2509552

Extractable Petroleum Hydrocarbons - Water

Blanks	**Units**	**Measured**	**Lower Limit**	**Upper Limit**	**Passed QC**
F2 C10-C16	µg/mL	0	-0.2	0.2	yes
F3 C16-C34	µg/mL	0	-0.2	0.2	yes
F3+ C34+	µg/mL	0	-0.2	0.2	yes

Date Acquired: March 06, 2020

Calibration Check	**Units**	**% Recovery**	**Lower Limit**	**Upper Limit**	**Passed QC**
F2 C10-C16	µg/mL	94.92	80	120	yes
F3 C16-C34	µg/mL	98.86	80	120	yes
F3+ C34+	µg/mL	98.92	80	120	yes

Date Acquired: March 06, 2020

Mono-Aromatic Hydrocarbons - Water

Blanks	**Units**	**Measured**	**Lower Limit**	**Upper Limit**	**Passed QC**
Benzene	ng	0	-0.002	0.002	yes
Toluene	ng	0	-0.0015	0.0015	yes
Ethylbenzene	ng	0	-0.0015	0.0015	yes
Total Xylenes (m,p,o)	ng	0	-0.002	0.002	yes
Styrene	ng	0	-0.002	0.002	yes

Date Acquired: March 07, 2020

Calibration Check	**Units**	**% Recovery**	**Lower Limit**	**Upper Limit**	**Passed QC**
Benzene	ng	109.00	80	120	yes
Toluene	ng	96.60	80	120	yes
Ethylbenzene	ng	95.40	80	120	yes
Total Xylenes (m,p,o)	ng	88.67	80	120	yes
Styrene	ng	85.60	80	120	yes

Date Acquired: March 07, 2020

Volatile Petroleum Hydrocarbons - Water

Blanks	**Units**	**Measured**	**Lower Limit**	**Upper Limit**	**Passed QC**
F1 -BTEX	ng	0	-0.3	0.3	yes
F1 C6-C10	ng	0	-0.300	0.300	yes
F2 C10-C16	ng	0	-0.3	0.3	yes

Date Acquired: March 07, 2020

Calibration Check	**Units**	**% Recovery**	**Lower Limit**	**Upper Limit**	**Passed QC**
F2 C10-C16	ng	119.00	80	120	yes

Date Acquired: March 07, 2020

Methodology and Notes

Bill To: InnoTech Alberta Inc.
1 Oil Path Dr.
Devon, AB, Canada
T9G 1A8
Attn: Allan Mah
Sampled By: Victor Bachmann
Company: Innotech Alberta

Project ID: 33910453.3001
Project Name: PTAC F2
Project Location:
LSD:
P.O.:
Proj. Acct. code: 33910453.3001

Lot ID: **1412099**
Control Number:
Date Received: Mar 6, 2020
Date Reported: Apr 27, 2020
Report Number: 2509552

Method of Analysis

Method Name	Reference	Method	Date Analysis Started	Location
BTEX-CCME - Water	US EPA	* Volatile Organic Compounds in Various Sample Matrices Using Equilibrium Headspace Analysis/Gas Chromatography Mass Spectrometry, 5021/8260	Mar 7, 2020	Element Calgary
TEH-CCME - Water	EPA/CCME	* Separatory Funnel Liquid-liquid Extraction/CCME, EPA 3510/CCME	Mar 19, 2020	Element Calgary

** Reference Method Modified*

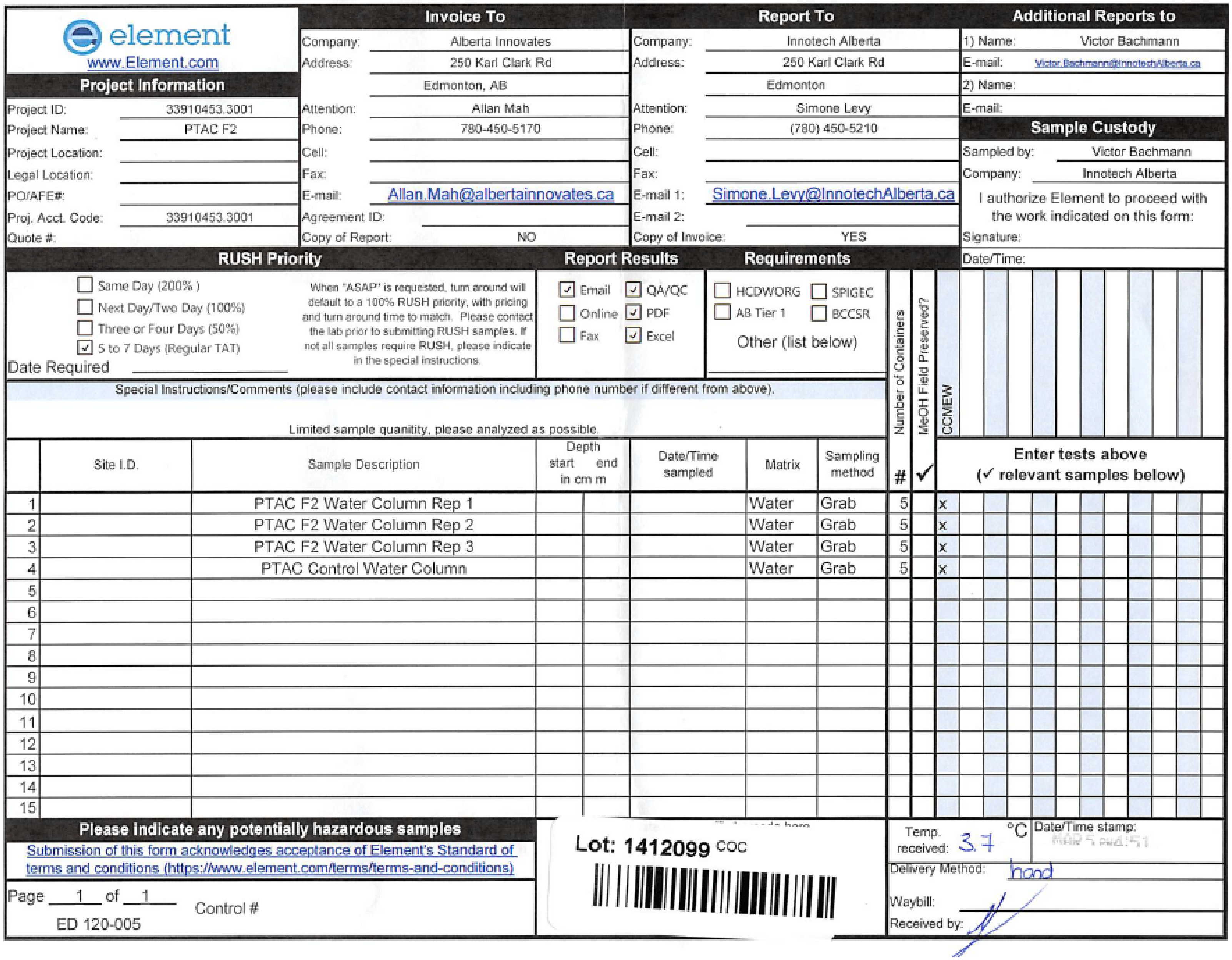
References

EPA/CCME	Environmental Protection Agency Test Methods - US/CCME
US EPA	US Environmental Protection Agency Test Methods

Comments:

- Mar 19, 2020 - Report was issued to include retest result for TEH analysis on samples 1412099-1,2,3,4 as requested by Simone Levy on 3/19/2020.
- Mar 20, 2020 - Sample 1412099-1; 7014552: The repeated result for TEH analysis did not differ significantly from the original; it is within expected precision of the test.
- Mar 20, 2020 - Sample 1412099-2; 7014553: The repeated result for TEH analysis did not differ significantly from the original; it is within expected precision of the test.
- Mar 20, 2020 - Sample 1412099-3; 7014554: The repeated result for TEH analysis did not differ significantly from the original; it is within expected precision of the test.
- Mar 20, 2020 - Sample 1412099-4; 7014555: The repeated result for TEH analysis did not differ significantly from the original; it is within expected precision of the test.
- Mar 20, 2020 - Samples 1-4: the repeated results for F2-F4 analysis did not differ significantly from the original; it is within expected precision of the test.
- Apr 27, 2020 - Report was issued to include additional services requested by Simone Levy of InnoTech on April 27:
  CTGM service requested on sample(s) 1, 2, 3, 4.
  Previous report 2501200.

Please direct any inquiries regarding this report to our Client Services group.
Results relate only to samples as submitted.
The test report shall not be reproduced except in full, without the written approval of the laboratory.



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Project Information

Project ID: 33910453.3001
Project Name: PTAC F2
Project Location:
Legal Location:
PO/AFE#:
Proj. Acct. Code: 33910453.3001
Quote #:

Invoice To

Company: Alberta Innovates
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Fax:
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Agreement ID:
Copy of Report: NO

Report To

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Cell:
Fax:
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E-mail 2:
Copy of Invoice: YES

Additional Reports to

1) Name: Victor Bachmann
E-mail: Victor.Bachmann@InnotechAlberta.ca
2) Name:
E-mail:

Sample Custody

Sampled by: Victor Bachmann
Company: Innotech Alberta
I authorize Element to proceed with the work indicated on this form:
Signature:
Date/Time:

RUSH Priority

☐ Same Day (200%)
☐ Next Day/Two Day (100%)
☐ Three or Four Days (50%)
☑ 5 to 7 Days (Regular TAT)
Date Required

When "ASAP" is requested, turn around will default to a 100% RUSH priority, with pricing and turn around time to match. Please contact the lab prior to submitting RUSH samples. If not all samples require RUSH, please indicate in the special instructions.

Report Results

☑ Email ☑ QA/QC
☐ Online ☑ PDF
☐ Fax ☑ Excel

Requirements

☐ HCDWORG ☐ SPIGEC
☐ AB Tier 1 ☐ BCCSR
Other (list below)

Special Instructions/Comments (please include contact information including phone number if different from above).

Limited sample quanitity, please analyzed as possible.

	Site I.D.	Sample Description	Depth start in cm m	Depth end	Date/Time sampled	Matrix	Sampling method	Number of Containers #	MeOH Field Preserved? ✓	CCMEW
1		PTAC F2 Water Column Rep 1				Water	Grab	5		x
2		PTAC F2 Water Column Rep 2				Water	Grab	5		x
3		PTAC F2 Water Column Rep 3				Water	Grab	5		x
4		PTAC Control Water Column				Water	Grab	5		x
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										

Enter tests above
(✓ relevant samples below)

Please indicate any potentially hazardous samples

Submission of this form acknowledges acceptance of Element's Standard of terms and conditions (https://www.element.com/terms/terms-and-conditions)

Page 1 of 1 Control #
ED 120-005

Lot: 1412099 COC

Temp. received: 3.7 °C
Date/Time stamp: MAR 5 PM4:51
Delivery Method: hand
Waybill:
Received by:

APPENDIX B: INNOTECH ALBERTA 2022 CONTRACT RESEARCH REPORT

Petroleum Hydrocarbon Fraction 2: Evaluation of Management Limit – Flux Rate Experiment Summary (Phase 3)

Prepared by:

Simone Levy and Victor Bachmann, InnoTech Alberta

InnoTech Alberta

250 Karl Clark Road

Edmonton, Alberta   T6N 1E4

Canada

May 30, 2022

DISCLAIMER

CITATION

This report may be cited as:

Levy, S. and Bachmann, V., 2022. Petroleum Hydrocarbon Fraction 2: Evaluation of Management Limits – Flux Rate Experiment Summary (Phase 3). InnoTech Alberta, Edmonton, Alberta. 25 pp.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Management limits for Petroleum Hydrocarbon (PHC) fractions indicate concentrations where factors other than toxicity, such as aesthetics, mobile free-phase formation and explosion hazards may be of concern. Two sets of management limits for PHC fractions F2 (C_{10}-C_{16}) and F3 ($C_{>16}$-C_{34}) are currently applicable in Alberta; a generic set in the Alberta Tier 1 Soil and Groundwater Remediation guidelines (Tier 1; AEP, 2019) applicable to all land uses, and another set specific to remote parts of the Green Area (AESRD, 2014). The generic management limits for PHC F2 and F3 can often become limiting and potential drivers for remediation in the case that the eco-contact exposure pathway can be eliminated.

In 2018, Millennium EMS Solutions Ltd. (MEMS) was contracted by PTAC-AUPRF to complete a project entitled 'Re-evaluating the management limits for F2 and F3 petroleum hydrocarbons – Phase 1 and 2' (PTAC AUPRF#18-RRRC-08; Millennium EMS Solutions Ltd., 2019). To meet the recommendations from Phase 1 of the project, further investigation of data supporting potential exposure of workers in trenches to PHC F2 vapours was undertaken. In 2020, MEMS completed project 19-RRRC-08 with a report entitled *Re-Evaluation of F2 and F3 Petroleum Hydrocarbon Management Limits – Phase 2 (*Millennium EMS Solutions Ltd., 2020). As part of the project, MEMS sub-contracted InnoTech to conduct experiments to generate equilibrium vapour concentrations for PHC F2 aliphatic and aromatic sub-fractions. The concentrations generated through the experiments were used by MEMS as input parameters for air mixing models simulating the air space of a utility trench. Revised threshold values for the Exposure of Workers in Trenches to PHC F2 vapours were then calculated and used to inform management limits.

Phase 2 resulted in a recommendation to establish flux rates of F2 sub-fractions from the surface of soil samples to further support recommended management limits. As opposed to maximum headspace concentrations at equilibrium (which were derived in Phase 2), empirical flux rates can be combined with trench air exchange rates in a simple model to calculate the 'trench worker scenario' management limit component with a higher degree of confidence. Phase 3, reported herein, builds on the previous experimental work and Phase 2 recommendations. Phase 3 measured F2 flux rates from the surface of fine- and coarse-grained soils containing approximately 10,000 mg/kg PHC F2. Phase 3 was completed in two parts: Part 1 included assessing the flux rate from samples within Tedlar® bags (i.e., a closed system), while Part 2 assessed the flux rate in an open system configuration with a controlled air exchange rate (i.e., controlled air exchange).

In general, headspace concentrations reported by the photoionization detector were not consistent with those collected for analysis by flame ionization detector. Flux rate experiments were conducted in two different ways: within a closed system using Tedlar® bags, and an open air exchange system more closely emulating a trench scenario. The data will be used as empirical input parameters for guideline derivation and the results from the two experimental designs will be compared to establish optimal experimental setup for the needs of this project.

2.0 METHODS

Method development and range finding for appropriate setup were reused from the previous Phase 2 project conducted by InnoTech for MEMS (InnoTech Alberta, 2020), including:

- Characterization of pure PHC F2 distillate by gas chromatograph mass spectrometer (GC-MS) and flame ionization detector (GC-FID)
- Method development and range finding for headspace equilibrium setup
- Testing headspace at equilibrium with pure PHC F2 distillate

Coarse- and fine-grained soil samples were spiked to approximately 10,000 mg/kg with PHC F2 distillate. In Part 1 of these experiments, samples were incubated in Tedlar® bags and headspace vapour samples were taken periodically from the headspace for analysis by FID of total VOCs, PHC F2 and the following sub-fractions:

- C_{10}-C_{12} aromatic compounds
- C_{10}-C_{12} aliphatic compounds
- $C_{>12}$-C_{16} aromatic compounds
- $C_{>12}$-C_{16} aliphatic compounds

In Part 2, a flow-through system was designed using a mass flow controller to introduce air into a 500 mL jar containing spiked soil. Periodic samples were also taken for analysis of the same components.

The experiments followed the tasks described below, including calibration of a photoionization detector (PID) for monitoring headspace combustible vapour concentrations (CVCs), soil spiking and analysis, flux rate experiments, and data analysis.

2.1 Soil spiking

Previously characterized coarse- and fine-grained soils (Appendix A) were spiked with PHC F2 distillate (characterization reported in InnoTech Alberta, 2020) to a target of 10,000 mg/kg as requested by MEMS. Spiking was conducted in a -14°C walk-in freezer to minimize losses through volatilization. Soils were moistened to approximately 14% (w/w) in fine-grained soil and 1.5% (w/w) in coarse-grained soil, based on their respective water holding capacities. Following spiking, one random grab sample of each batch of soil was taken and submitted for laboratory analysis of BTEX and PHC F1-F4 components to confirm the concentration.

2.2 Experimental Setup

2.2.1 Part 1 - Closed System

Once spiking results were received and deemed satisfactory by MEMS, soil was placed into 100 mL glass petri dishes (Diameter 89mm, Surface Area 62.2cm^2; Part 1; Figure 1), compacted and weighed for calculation of bulk density. Petri dish samples were prepared as follows for 3 replicated 'runs' of the flux rate experiment:

- Bag 1: 1 sample for headspace monitoring via PID (petri dish + 200 mL lab grade air in Tedlar bag);
- Bag 2: 1 sample for headspace sampling (petri dish + 200 mL lab grade air in Tedlar bag); and,
- Sufficient soil to submit samples for soil analysis of BTEX and PHC F1-F4 parameters (reported as Run 1/2/3 – C/F).

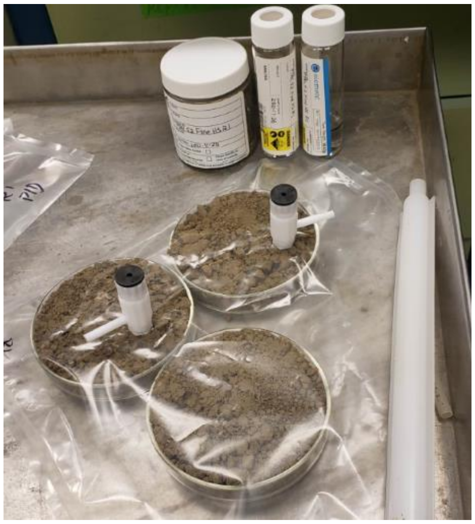

Figure 1. Experimental setup: soil compacted in glass petri dishes within a Tedlar® bag.

For each soil type, 3 repetitions in duplicate (2x) of a petri dish was place inside a tedlar bag (total of 12 bags and petri dishes) and immediately evacuated of headspace using a manual 1 L syringe, taking care not to over-pressurize the bags. Samples were maintained in a -15°C freezer until they were transferred to a 4°C fridge for 24-hours. Samples were removed from the fridge to laboratory air temperature (~21°C) for 4 hours prior to starting experiments.

2.2.2 Part 2 - Controlled Air Exchange

2.2.2.1 Controlled Air Exchange Evaluation

The second part of the experiment included the use of a mass flow controller (MFC; Alicat Scientific MC-Series[1]). Preliminary trials were conducted to refine the experimental setup as follows:

1) Ensure the mass flow controller (MFC; Alicat Scientific MC-Series[2]) can accurately and consistently deliver air to a vessel at the desired flow rate (46 air exchanges per hour[3]).
2) Conduct range finding to confirm that volatile organic carbon (VOC) concentrations in headspace are within a suitable range for analysis by GC-FID (Gas chromatography with flame

---

[1] Alicat Scientific MC-Series Gas Mass Flow Controllers rapidly reach setpoints and maintain stable control of mass flow, volumetric flow, or pressure across a flow range of 0.01% to 100% of full scale https://www.alicat.com/models/mc-gas-mass-flow-controllers/

[2] Alicat Scientific MC-Series Gas Mass Flow Controllers rapidly reach setpoints and maintain stable control of mass flow, volumetric flow, or pressure across a flow range of 0.01% to 100% of full scale https://www.alicat.com/models/mc-gas-mass-flow-controllers/

[3] Flow rate to be determined based on container headspace volume.

ionization detection) over the 60-minute experiment. Use data to select an optimally sized vessel based on soil to headspace ratio (500 mL or 1 L).

3) Confirm that air introduced into the vessel will circulate adequately to effectively exchange the headspace by conducting a smoke test.

To address points 1) and 2), fine-grained PHC F2-spiked soils remaining from Part 1 were placed into 500 mL and 1 L vessels to 16 mm thickness. The Alicat was connected to a supplied airline and set to a flow rate of 46L/hour (23 air exchanges an hour), introducing air into the vessels. No fluctuation was observed on the Alicat read-out, which was indicative of its ability to consistently deliver air to the vessels at the target rate. Range finding samples were taken from headspace of each vessel at 60 minutes and analyzed for total PHC. Concentrations were within acceptable range for analysis well above detectable limits. Based on results, the 500 ml vessel was selected for the full experiment.

To address point 3), a smoke test was performed to evaluate air flow within the vessel containing PHC F2-spiked soil. The Alicat was daisy chained to two 500 mL vessels. The first jar (connected to the Alicat) was filled with smoke and connected to the second jar for observation. The Alicat was connected to a supplied airline and set to a flow rate of 46L/hour (23 air exchanges an hour). A light was projected through the observation jar to observe the smoke flow pattern. At the selected flow rate, the smoked air flowed into the observation and covered the bottom of the jar (Figure 2a). The whole volume of the observation vessel filled with smoked air before exiting through the exhaust port (Figure 2b).

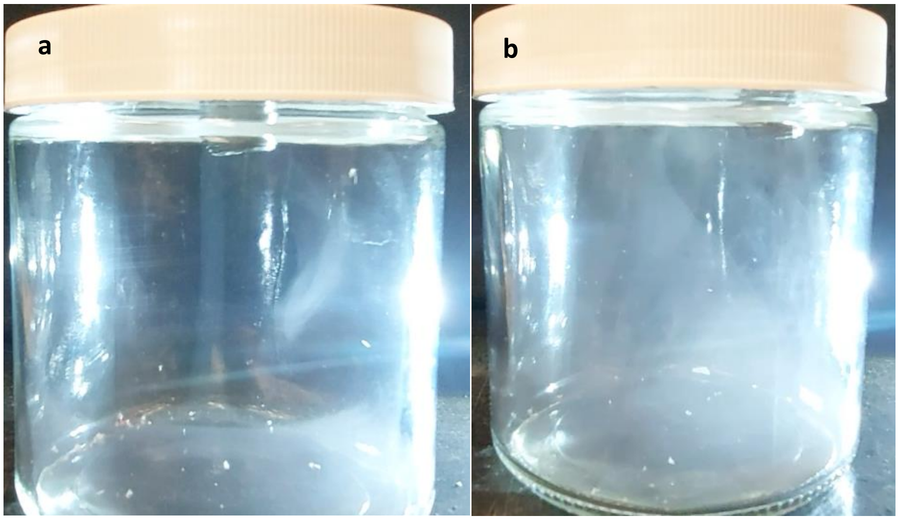

Figure 2. Testing the flow of air through the 500ml vessels using smoke. A) The initial path of air into the test vessel from the top port flows to the bottom and covers the bottom of the vessel. B) The smoke fills the vessel as it travels out of the vessel through the exhaust port.

2.2.2.2 Experimental Setup

Coarse-grained soils were used from Part 1, while fine-grained soils were freshly spiked for Part 2 experiments due to insufficient quantity. Experiments were conducted in triplicate for each of the soil types.

Soil was placed into the bottom of a pre-weighed 500 mL jar and was compacted to a total height of 16 mm, equivalent to soil in petri dishes in Part 1. Each jar was then re-weighed for soil bulk density calculation. The jar lids were fitted with inflow and outflow ports. The inflow port was used to connect an air input tube through an Alicat mass flow controller (MFC)[4], which drew laboratory grade air from a cylinder at an equivalent flow rate of ~46 air exchanges per hour. A MiniRAE 3000 photoionization detector (PID), previously calibrated to hexane at concentrations of approximately 200 and 1,000 ppm, was used to monitor the headspace by inserting a tube into the outflow. Two soil types were tested (fine and coarse) in 3 repetitions for each soil type. The bulk spiked soils were stored in a -14°C freezer. One day before each experiment, the spiked soil was transferred to a 4°C fridge to thaw. Samples were prepared in the 500 mL vessels the day of each run(s) and stored in the 4°C fridge. The samples were removed from the fridge approximately an hour before the start of each run to allow them to reach room temperature (21°C).

2.3 Flux Rate Experiments

2.3.1 Part 1 - Closed System

A MiniRAE 3000 photoionization detector (PID) was calibrated to hexane at concentrations of approximately 200 and 1,000 ppm. The instrument was used to monitor Bag 1 headspace by inserting a tube into the port in the Tedlar® bag (Figure 3).

At 'time 0', 2 L of laboratory grade air was injected into Bag 1 for headspace monitoring via PID and Bag 2 for sampling. The PID cycles 500 mL per minute, but analysis is non-destructive and the sample volume is returned to the bag.

Four samples were taken from bag 2 over the flux duration based on the volatile organic compounds (VOCs) on PID output curves (Figure 3). For each sample, one thermal desorption tube set (*i.e.* one desorption tube in line with a second one in case of breakthrough) were used to collect a 25 mL headspace gas sample (total removal of 100 mL from 2 L headspace). The tube set was used to determine the concentration of total hydrocarbons by GC-FID and was used to determine the aromatic/aliphatic composition by ASTM D2786 (ASTM, 2016; modified).

Figure 3. PID connected to Tedlar bag containing a petri dish filled with spiked soil.

Experiments were run three times, referred to as Run 1, 2 and 3 with a designation for coarse- (- C) or fine-grained (- F). From the three runs for each respective soil type, average concentrations of total VOCs

---

[4] Alicat Scientific MC-Series Gas Mass Flow Controllers rapidly reach setpoints and maintain stable control of mass flow, volumetric flow, or pressure across a flow range of 0.01% to 100% of full scale https://www.alicat.com/models/mc-gas-mass-flow-controllers/

in headspace at select sample time points were averaged and a standard deviation calculated. These were plotted on a graph with the PID curve presented as mol/mol (units).

Data from headspace samples was submitted for calculation of aliphatic and aromatic concentrations of nC_{10}-nC_{12} and nC_{12}-nC_{16} following the Robinson whole oil method[5] (Robinson, 1971). This was conducted using the apex of nC_{10}, nC_{12} and nC_{16}, the aliphatic and aromatic concentrations of nC_{10}-nC_{12} and nC_{12}-nC_{16}. This method is a baseline technique to resolve the mass spectrum into saturates and aromatic spectra in a sample within boiling point range of 200 to 1,100 F°. The method allows determination of up to 4 saturated and 21 aromatic compound types. It uses the low-resolution mass spectrum and the number average molecular weight, obtained from distillation data, of the unseparated sample.

Compound classes are as follows:

Saturates:

- Paraffins
- Monocycloparaffins
- Dicycloparaffins
- Tricycloparaffins

Aromatics:

- Alkylbenzenes
- Aromatic Sulfur
- Benzocycloalkanes
- Benzodicycloalkanes
- Benzonaphthiophenes
- Benzothiophenes
- Benzpyrenes/Perylenes
- Chrysenes
- CnH2n-32/CnH2n-46
- CnH2n-36/CnH2n-26S
- CnH2n-38/CnH2n-28S
- CnH2n-40/CnH2n-30S
- CnH2n-42/CnH2n-32S
- CnH2n-44/CnH2n-34S
- Diaromatics
- Dibenzanthracenes
- Dibenzothiophenes
- Fluorenes
- Monoaromatics
- Naphthalenes
- Naphthocycloalkanes
- Pentaaromatics
- Phenanthrenes
- Phenanthrocycloalkanes
- Pyrenes/Benzofluorenes
- Tetraaromatics
- Triaromatics
- Unidentified

2.3.2 Part 2 - Controlled Air Exchange

At 'time 0', coverings (used to minimize volatilization of VOCs) were removed, lids were secured onto jars, and the air supply was connected via MFC (Figure 4). Headspace samples were taken from each replicate at 15, 30 and 60 minutes after exposing soil to atmosphere. For each headspace sample, one thermal desorption tube set (*i.e.* one desorption tube, in line with a second one in case of breakthrough) was used to collect a 25 mL headspace gas sample. The tube set was used to determine the concentration of total hydrocarbons by GC-FID. Data was analyzed for aromatic/aliphatic composition by ASTM D2786 (ASTM, 2016; modified) from each of the samples at 60 minutes only based on direction from MEMS.

---

[5] The method is known as the Robinson Whole Oil Method because in contrast to many other methods (such as D2786 or D3239), it does not require a prior separation of a sample into saturates and aromatic fractions. The method reports four saturated hydrocarbon types, twelve aromatic HC types, three thiophenic and six unidentified aromatic groups.

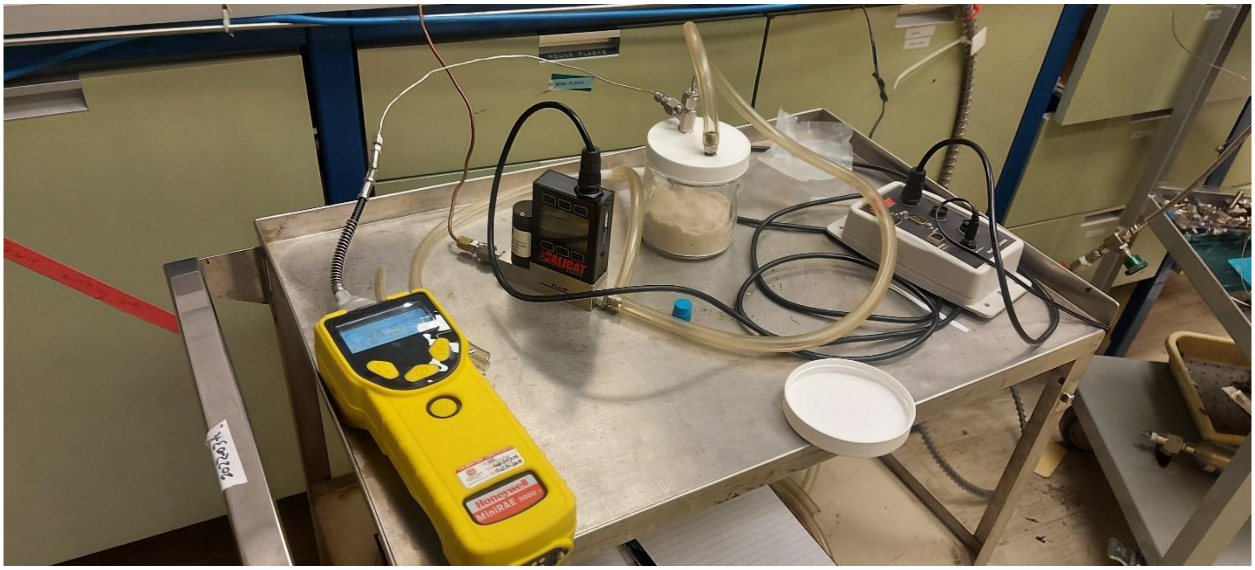

Figure 4. Experimental setup, controlled air exchange with coarse-grained soil.

3.0 RESULTS AND DISCUSSION

Results of the trial are summarized in the following sections. Original laboratory reports are included in Appendix B. A summary of average headspace concentrations from all experiments are included in Appendix C.

3.1 Part 1 – Flux Rate in Closed System

3.1.1 Soil spiking and preparation

Results of spiking coarse- and fine-grained soils with PHC F2 distillate are provided in Table 1, including composite samples taken directly following spiking (post-spike composite) and samples representative of soil at the start time of each run (Run 1/2/3 – C or – F). The post-spike spike composite was collected after the soil samples were spiked and moistened. Samples associated with a run were collected at the same time as filling the petri dishes for the associated run.

Table 1. Laboratory analytical results for PHC F2-spiked soil samples; average and composite results for PHC F2 highlighted in blue as the parameter of interest.

Sample description	Moisture	Soil Bulk Density	Benzene (mg/kg)	Toluene (mg/kg)	Ethylbenzene (mg/kg)	Xylenes (mg/kg)	PHC F1 (mg/kg)	PHC F2 (mg/kg)	PHC F3 (mg/kg)	PHC F4 (mg/kg)
Coarse-grained soil										
Post-spike composite	3.29	n/a	n/a	n/a	n/a	n/a	n/a	10,100	225	<100
Run 1 - C	2.14	1.15	<0.005	0.53	0.029	0.32	230	6,820	146	<100
Run 2 - C	2.34	1.15	<0.005	0.46	0.025	0.3	278	7,300	157	<100
Run 3 - C	2.32	1.15	<0.005	0.47	0.026	0.32	301	7,320	153	<100
Run 1-3 - C Average (PRSD*)	**2.27 (4)**	**1.15**	**<0.005**	**0.49 (6)**	**0.027 (6.30)**	**0.31 (3.0)**	**270 (11)**	**7,146 (3)**	**152 (3)**	**<100**
Fine-grained soil										
Post-spike composite	12.2	n/a	n/a	n/a	n/a	n/a	n/a	13,200	253	<100
Run 1 - F	12.4	1.94	<0.005	0.27	<0.005	0.17	230	8,100	364	<100
Run 2 - F	12.3	1.82	<0.005	0.33	0.015	0.25	341	8,020	358	<100
Run 3 - F	12.3	1.65	<0.005	0.16	0.008	0.14	126	12,200	537	<100
Run 1-3 - F Average ((PRSD*))	**12.33 (0.4)**	**1.81 (6.6)**	**<0.005**	**0.25 (28)**	**0.012 (29.17)**	**0.19 (24)**	**232 (38)**	**9,440 (21)**	**420 (20)**	**<100**

* Percent Relative Standard Deviation

A decrease in total PHC F2 was seen between the initial sample at the time of spiking and the samples tested after storage and transfer into petri dishes in both soil types. Total PHC F2 decreased by 29.2% and 28.4% in coarse- and fine-grained soils, respectively. Based on this data, to ensure accurate starting concentrations, samples were submitted for analysis following the same preparation steps as those in the experiments (*i.e.,* transfer to petri dishes and evacuation of headspace within Tedlar® bag).

In coarse-grained soils, concentrations of PHC F2 were relatively consistent with a percent relative standard deviation (%RSD) of 3.23%; however, one elevated concentration was reported for fine-grained soil (Run 3-F), resulting in a %RSD of 20.68% for PHC F2 and high variability in other measured parameters. The sample with elevated PHC F2 and other hydrocarbon components may have been the result of inconsistent spiking of PHC F2 distillate into soil, which can be particularly challenging in fine-grained soil. However, it is notable that headspace concentrations measured with sample Run 3-F were in the same concentration range as the previous two runs.

3.1.2 Flux Rate Experiments

Results for time to equilibrium and flux rates experiments are provided in the following sections. These include PID versus GC-FID results and general correlation through experiments; hydrocarbon compounds in headspace over time in three replicated experiments for each soil type; and an evaluation of the ratio of saturate and aromatic sub-fractions to evaluate consistency.

3.1.2.1 Coarse-grained soil

Total PHC concentrations as measured by GC-FID were plotted with a representative curve of headspace vapour concentrations as measured by PID in ppm (mol/mol; Figure 5 and Appendix C). Orange circles represent the average total PHC concentration in headspace of the 3 replicate runs at or around the sample time indicated. Error bars represent standard deviation of replicates. At point 4 (1:30:00), only 2 replicates were averaged as the third was compromised due to equipment malfunction. In Figure 5, the standard deviation was relatively small for two sample points (point 2 and 3) and is not visible on the graph.

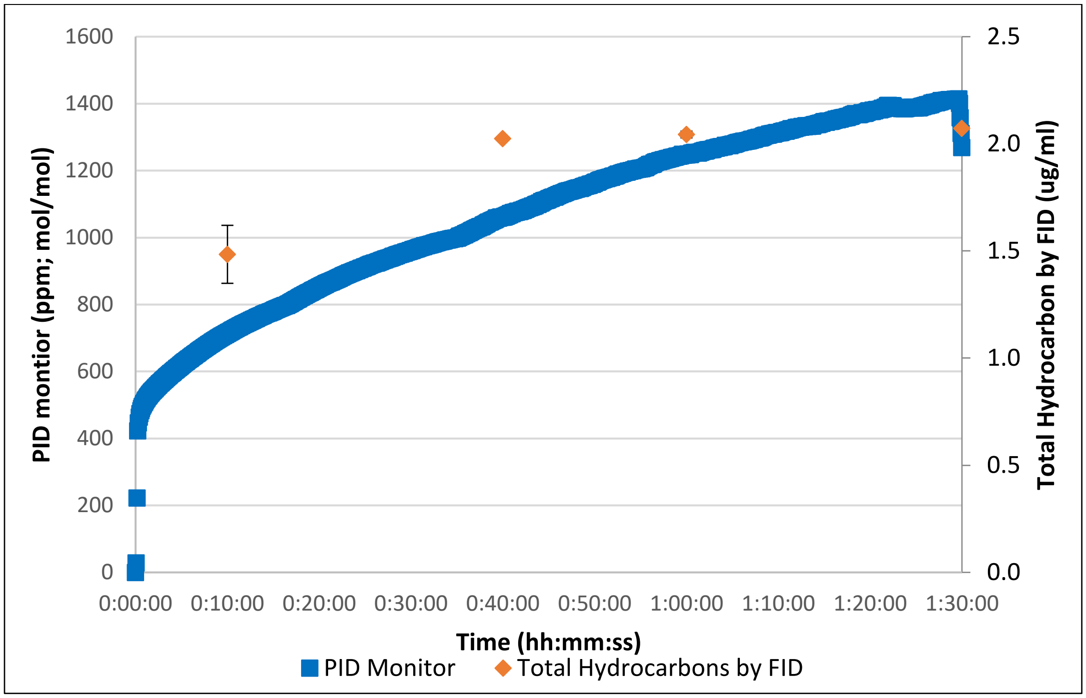

Figure 5. Representative coarse-grained soil monitored via photoionization detector (PID) plotted with average total PHC vapour in headspace +/- standard deviation (n=3 where SD shown); note, error bars on points 2 and 3 not visible at 0.005 and 0.02, respectively; n=2 for point 4, no SD calculated.

Analytical results from the GC-FID generally follow the trend of those measured by PID. Units of PID (ppmv or mol/mol) and GC-FID (µg/mL) concentrations differ, and it was determined that conversion of PID data to match FID units may introduce error based on assumptions around molecular weights of the compounds in headspace. The PID curve in Figure 5 was chosen as that most representative of the GC-FID results curve; however, there was some variation in the curves generated by the PID despite consistent calibration. It is therefore not recommended that concentrations from the PID be used as the basis for reporting. However, the PID curve was used to determine approximate time to equilibrium for timing samples for GC-FID analysis, targeting the relatively flat portion of the curve.

A full dataset of headspace analyses for coarse-grained soil samples is provided in Table 2; select parameters and sub-fractions will be used by MEMS as model input parameters.

Table 2. Summary of results of headspace PHC analyses by GC-FID, including sub-fractions, for flux rate experiments for coarse-grained soils.

Replicated experiment and sample point on PID Curve	Sample Time on PID Curve	Sample Lab ID	Total PHC	PHC F2	nC$_{10}$apex-nC$_{12}$apex			nC$_{12}$apex-nC$_{16}$apex		
					Total	Saturate sub-fraction	Aromatic sub-fraction	Total	Saturate sub-fraction	Aromatic sub-fraction
			µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL
Run 1 - C										
time 1	00:51	FL21-2006-006	0.631	0.484	0.417	-	-	0.067	-	-
time 2	03:00	FL21-2006-007	0.872	0.665	0.581	0.436	0.145	0.084	0.065	0.019
time 3	06:00	FL21-2006-008	1.23	0.942	0.797	0.596	0.201	0.145	0.111	0.033
time 4	08:30	FL21-2006-009	1.57	1.202	1.053	0.785	0.268	0.149	0.113	0.036
time 5	45:00	FL21-2006-010	2.02	1.502	1.370	1.034	0.336	0.132	0.100	0.032
Run 2 - C										
time 1	0:10:00	FL21-2006-011	1.328	0.970	0.864	0.634	0.231	0.106	0.081	0.025
time 2	0:40:00	FL21-2006-012	2.027	1.472	1.332	0.962	0.370	0.139	0.099	0.040
time 3	1:00:00	FL21-2006-013	2.055	1.498	1.362	0.987	0.375	0.136	0.097	0.039
time 4	1:30:00	FL21-2006-014	-	-	-	-	-	-	-	-
Run 3 - C										
time 1	0:10:00	FL21-2006-015	1.559	1.135	1.018	0.739	0.279	0.116	0.087	0.030
time 2	0:40:00	FL21-2006-016	2.028	1.449	1.328	0.961	0.367	0.120	0.088	0.033
time 3	1:00:00	FL21-2006-017	2.032	1.446	1.329	0.963	0.366	0.116	0.085	0.031
time 4	1:30:00	FL21-2006-018	2.072	1.512	1.377	0.995	0.382	0.135	0.099	0.036

Note: Data omitted from analysis from cells highlighted grey based on timing or sampling error

The average and standard deviation of the saturate and aromatic portions of each sub-fraction were calculated for the purpose of evaluating consistency. Table 3 provides a ratio of each sub-fraction to the total PHC F2 components. Results presented in Table 3 are ratios (as opposed to concentrations). Saturates and aromatics are ratios of corresponding fractions, and fractions are ratios of total F2. Data indicated as "incomplete dataset" and "time-based outlier" in Run 1-C were due to challenges in establishing sampling time points based on inconsistent PID readings; standard timing for samples was established in Runs 2 and 3. In Run 2-C, the syringe malfunctioned and a sample could not be obtained.

Table 3. Average and standard deviation of saturate and aromatic portions of nC_{10}-C_{12} and nC_{12}-C_{16} in headspace with coarse-grained soil samples. (**Note**: Data omitted from analysis from cells highlighted grey based on timing or sampling error).

Replicated experiment and sample point on PID Curve	**Sample Lab ID**	**Sample Time on PID Curve**	**nC_{10}apex-nC_{12}apex : Total PHC F2**	**nC_{12}apex-nC_{16}apex : Total PHC F2**	**nC_{10}apex-nC_{12}apex**		**nC_{12}apex-nC_{16}apex**	
					Saturates to Total PHC F2	**Aromatic to Total PHC F2**	**Saturates to Total PHC F2**	**Aromatic to Total PHC F2**
			Ratios					
Run 1-C								
time 1	FL21-2006-006	00:51	Data omitted - incomplete dataset					
time 2	FL21-2006-007	03:00	Data omitted - time-based outlier					
time 3	FL21-2006-008	06:00	Data omitted - time-based outlier					
time 4	FL21-2006-009	08:30	0.876	0.124	0.745	0.255	0.761	0.239
time 5	FL21-2006-010	45:00	0.912	0.088	0.755	0.245	0.761	0.239
Run 2-C								
time 1	FL21-2006-011	0:10:00	0.891	0.109	0.733	0.267	0.766	0.234
time 2	FL21-2006-012	0:40:00	0.905	0.095	0.722	0.278	0.711	0.289
time 3	FL21-2006-013	1:00:00	0.909	0.091	0.724	0.276	0.714	0.286
time 4	FL21-2006-014	1:30:00	-	-	-	-	-	-
Run 3-C								
time 1	FL21-2006-015	0:10:00	0.897	0.103	0.726	0.274	0.746	0.254
time 2	FL21-2006-016	0:40:00	0.917	0.083	0.723	0.277	0.729	0.271
time 3	FL21-2006-017	1:00:00	0.919	0.081	0.725	0.275	0.731	0.269
time 4	FL21-2006-018	1:30:00	0.911	0.089	0.722	0.278	0.732	0.268
Average (PRSD*)			**0.904 (1.53)**	**0.096 (14.4)**	**0.731 (1.60)**	**0.269 (4.3)**	**0.739 (2.8)**	**0.261 (7.82)**

* Percent relative standard deviation

Based on the averages and relative percent deviation of proportions of each sub-fraction within the headspace hydrocarbon vapour components, it is interpreted that ratios of saturate to aromatic sub-fractions are sufficiently consistent between replicates to negate the need for analysis of each replicate when samples are taken over a time of relatively consistent flux (*i.e.*, flat part of curve).

3.1.2.2 Fine-grained soil

Total PHC concentrations as measured by GC-FID were plotted with a representative curve of headspace vapour concentrations as measured by PID (Figure 6). Orange circles represent the average total PHC concentration in headspace of the 3 replicate runs at or around the sample time indicated. Error bars represent standard deviation of replicates.

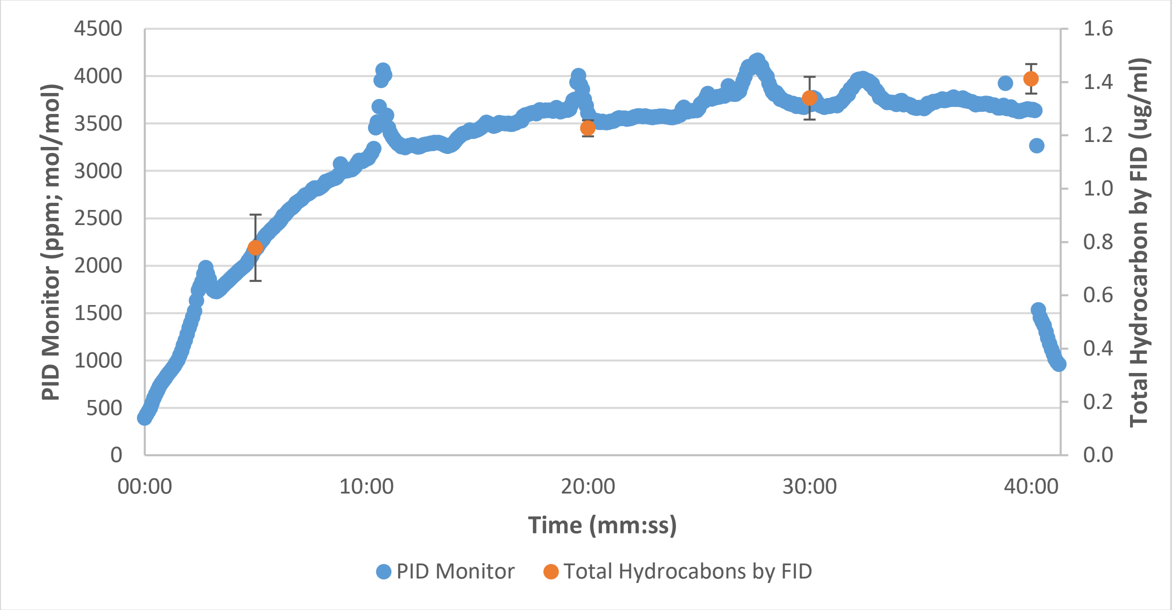

Figure 6. Representative coarse-grained soil monitored via photoionization detector (PID) plotted with average total PHC vapour in headspace +/- standard deviation (n=3).

The PID and GC-FID curves are more aligned in experiments with fine-grained soils, and the curve and timing points differed from those in experiments with coarse-grained soils. The flux rate from each soil type is therefore unique and warrants exploration in any future experiments. It is notable that total headspace VOCs were higher in coarse-grained soil experiments (max. ~2.0 µg/mL) compared with those with fine-grained soils (max. ~1.5 µg/mL); in addition, the time to equilibrium was not reached at 1:30:00 with coarse-grained soils but reached a maximum concentration in fine-grained soils after approximately 20:00. This may be associated with migration of PHC F2 components through the soil to headspace, with greater retardation and retention in fine-grained soils.

A full dataset of headspace analyses for fine-grained soil samples is provided in Table 4.

Table 4. Summary of results of headspace PHC analyses by GC-FID, including sub-fractions, for flux rate experiments with fine-grained soils.

Replicated experiment and sample point on PID Curve	Sample Time on PID Curve	Sample Lab ID	Total PHC	PHC F2	nC$_{10}$apex-nC$_{12}$apex			nC$_{12}$apex-nC$_{16}$apex		
					Total	Saturate sub-fraction	Aromatic sub-fraction	Total	Saturate sub-fraction	Aromatic sub-fraction
			µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL
Run 1 - F										
time 1	05:00	FL21-2006-019	0.902	0.683	0.614	0.443	0.170	0.069	0.056	0.012
time 2	20:00	FL21-2006-020	1.210	0.915	0.830	0.603	0.227	0.085	0.067	0.018
time 3	30:00	FL21-2006-021	1.270	0.964	0.880	0.640	0.240	0.084	0.067	0.017
time 4	40:00	FL21-2006-022	1.37	1.077	0.978	0.714	0.263	0.099	0.076	0.022
Run 2 - F										
time 1	0:05:00	FL21-2006-023	0.653	0.521	0.465	0.3445	0.1202	0.057	0.043	0.014
time 2	0:20:00	FL21-2006-024	1.208	0.955	0.867	0.639	0.228	0.088	0.067	0.021
time 3	0:30:00	FL21-2006-025	1.427	1.132	1.020	0.744	0.275	0.112	0.085	0.027
time 4	0:40:00	FL21-2006-026	-	-	-	-	-	-	-	-
Run 3 - F										
time 1	0:05:00	FL21-2006-027	0.779	0.631	0.557	0.4021	0.1544	0.075	0.056	0.019
time 2	0:20:00	FL21-2006-028	1.261	1.008	0.908	0.657	0.251	0.100	0.076	0.024
time 3	0:30:00	FL21-2006-029	1.321	1.050	0.952	0.689	0.263	0.098	0.075	0.024
time 4	0:40:00	FL21-2006-030	1.451	1.148	1.040	0.755	0.284	0.108	0.082	0.026

The average and standard deviation of the saturate and aromatic portions of each sub-fraction were calculated for the purpose of evaluating consistency. Table 5 provides a ratio of each sub-fraction to the total PHC F2 components (as opposed to concentrations). Saturates and aromatics are ratios of corresponding fraction, and fractions are ratios of total F2.

Table 5. Average and standard deviation of saturate and aromatic portions of nC_{10}-C_{12} and nC_{12}-C_{16} in headspace with coarse-grained soil samples.

Replicated experiment and sample point on PID Curve	**Sample Lab ID**	**Sample Time on PID Curve**	**nC10apex-nC12apex: total PHC F2**	**nC12apex-nC16apex: total PHC F2**	**nC_{10}apex-nC_{12}apex**		**nC_{12}apex-nC_{16}apex**	
					Saturates to total PHC F2	**Aromatic to total PHC F2**	**Saturates to total PHC F2**	**Aromatic to total PHC F2**
			Ratios					
Run 1-F								
time 1	FL21-2006-019	05:00	0.899	0.101	0.722	0.278	0.820	0.180
time 2	FL21-2006-020	20:00	0.907	0.093	0.726	0.274	0.784	0.216
time 3	FL21-2006-021	30:00	0.913	0.087	0.727	0.273	0.793	0.207
time 4	FL21-2006-022	40:00	0.908	0.092	0.731	0.269	0.774	0.226
Run 2-F								
time 1	FL21-2006-023	0:05:00	0.891	0.109	0.741	0.259	0.753	0.247
time 2	FL21-2006-024	0:20:00	0.908	0.092	0.737	0.263	0.758	0.242
time 3	FL21-2006-025	0:30:00	0.901	0.099	0.730	0.270	0.756	0.244
time 4	FL21-2006-026	0:40:00						
Run 3-F								
time 1	FL21-2006-027	0:05:00	0.882	0.118	0.723	0.277	0.751	0.249
time 2	FL21-2006-028	0:20:00	0.901	0.099	0.724	0.276	0.757	0.243
time 3	FL21-2006-029	0:30:00	0.906	0.094	0.724	0.276	0.758	0.242
time 4	FL21-2006-030	0:40:00	0.906	0.094	0.726	0.274	0.757	0.243
Average (PRSD*)			**0.902 (0.98)**	**0.098 (9.1)**	**0.728 (0.82)**	**0.272 (2.2)**	**0.769 (2.8)**	**0.231 (9.4)**

* Percent relative standard deviation

Based on the averages and relative percent deviation of proportions of each sub-fraction within the headspace hydrocarbon vapour components, it is interpreted that ratios of saturate to aromatic sub-fractions are sufficiently consistent between replicates to negate the need for analysis of each replicate when samples are taken over a time of relatively consistent flux *(i.e.*, flat part of curve).

3.2 Part 2 – Controlled Air Exchange

3.2.1 Soil spiking and preparation

Results of spiking fine-grained soils with PHC F2 distillate are provided in Table 6, including composite samples taken directly following spiking (post-spike composite) and samples representative of soil at the start time of each run (Run 4/5/6 – C or – F). An additional composite sample was taken of the coarse-grained soil spiked in Part 1. All coarse runs were done on the same day and were set up at the same time. The analytical sample was collected during the setup of those 3 runs. The fine runs were done over the course of 2 days and each was set up before their respective runs. A fine soil sample was collected for analysis during the set up of each run. A composite sample was collected during the runs to confirm F2 concentration.

Table 6. Laboratory analytical results for PHC F2-spiked soil samples; average and composite results for PHC F2 highlighted in blue as the parameter of interest.

Sample Description	**Moisture (%)**	**Soil Bulk Density**	**Benzene**	**Tol-uene**	**Ethyl-benzene**	**Xylenes**	**PHC F1**	**PHC F2**	**PHC F3**	**PHC F4**
			(mg/kg)							
Fine-grained soil										
Post-spike composite	13.2	n/a	<0.005	<0.02	0.019	0.26	454	7,690	135	<100
Run 4 - F	12.6		<0.005	<0.02	0.02	0.24	313	7,090	125	<100
Run 5 - F	11.9		<0.005	<0.02	0.014	0.2	310	8,550	137	<100
Run 6 - f	12.5		<0.005	<0.02	0.013	0.2	348	8,530	150	<100
Run 4-6 Average (PRSD*)	**12.33**		**<0.005**	**<0.02**	**0.0157 (19.73)**	**0.21 (8.84)**	**324 (17.25)**	**8057 (684)**	**137 (10)**	**<100**
Coarse-grained soil										
Run 7-9 – C (composite)	**2.23**		**0.011**	**0.45**	**0.043**	**0.48**	**622**	**5,660**	**94**	**<100**

* Percent relative standard deviation

In fine-grained soils, concentrations of PHC F2 showed some variability with a percent relative standard deviation (%RSD) of 10%. There was not sufficient coarse-grained soil available to run replicated analyses, and they were previously run in Part 1. A composite sample was taken of remaining coarse-grained soil, which was similar in concentration to the original concentration (10,100 mg/kg) but slightly higher than the average of three composites taken in Part 1 (7,146 mg/kg).

3.2.2 Flux Rate Experiments

Results for time to equilibrium and flux rates experiments are provided in the following sections. These include PID versus GC-FID results; hydrocarbon compounds in headspace over time in three replicated experiments for each soil type; and an evaluation of the ratio of saturate and aromatic sub-fractions to evaluate consistency (Table 7).

3.2.2.1 Coarse-grained soil

Total PHC concentrations as measured by GC-FID were plotted with a representative curve of headspace vapour concentrations as measured by PID in ppm (mol/mol; Figure 7). Orange circles represent the average total PHC concentration in headspace of the 3 replicate runs at the sample time indicated. Error bars represent standard deviation of replicates.

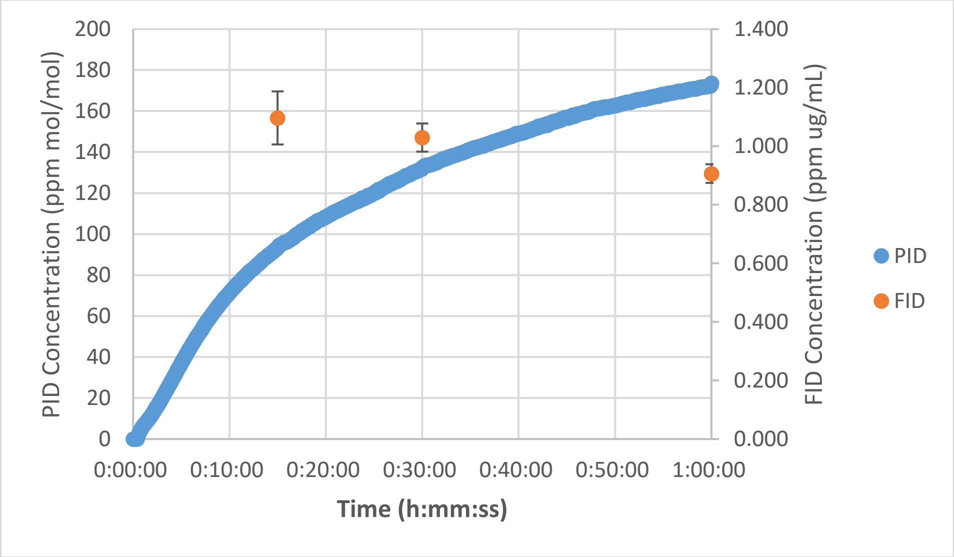

Figure 7. Representative coarse-grained soil monitored via photoionization detector (PID) plotted with average total PHC vapour in headspace +/- standard deviation (n=3).

Analytical results from the GC-FID seem to oppose those measured by PID. Units of PID (ppmv or mol/mol) and GC-FID (µg/mL) concentrations differ, and it was determined that conversion of PID data to match FID units may introduce error based on assumptions around molecular weights of the compounds in headspace. It is therefore not recommended that concentrations from the PID be used as the basis for reporting.

Table 7. Summary of results of headspace PHC analyses by GC-FID, including sub-fractions, for flux rate experiments with coarse-grained soils.

Replicated experiment and sample time from inception	**Sample Lab ID**	**Total PHC**	**PHC F2**	**nC_{10}apex-nC_{12}apex**			**nC_{12}apex-nC_{16}apex**		
				Total	**Saturate sub-fraction**	**Aromatic sub-fraction**	**Total**	**Saturate sub-fraction**	**Aromatic sub-fraction**
		µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL
Run 4 - C									
15 min	FL22-0554-004	**1.008**	**0.789**	**0.704**	-	-	**0.085**	-	-
30 min	FL22-0554-005	**0.962**	**0.749**	**0.645**	-	-	**0.104**	-	-
60 min	FL22-0554-006	**0.865**	**0.690**	**0.571**	**0.419**	**0.152**	**0.119**	**0.086**	**0.034**
Run 5 - C									
15 min	FL22-0554-007	**1.061**	**0.806**	**0.690**	-	-	**0.116**	-	-
30 min	FL22-0554-008	**1.056**	**0.842**	**0.687**	-	-	**0.155**	-	-
60 min	FL22-0554-009	**0.913**	**0.731**	**0.601**	**0.441**	**0.160**	**0.130**	**0.094**	**0.036**
Run 6 - C									
15 min	FL22-0554-010	**1.221**	**0.934**	**0.796**	-	-	**0.138**	-	-
30 min	FL22-0554-011	**1.070**	**0.845**	**0.696**	-	-	**0.149**	-	-
60 min	FL22-0554-012	**0.942**	**0.756**	**0.618**	**0.452**	**0.166**	**0.139**	**0.100**	**0.038**

3.2.2.2 Fine-grained soil

Total PHC concentrations as measured by GC-FID were plotted with a representative curve of headspace vapour concentrations as measured by PID. Orange circles represent the average total PHC concentration in headspace of the 3 replicate runs at or around the sample time indicated. Error bars represent standard deviation of replicates.

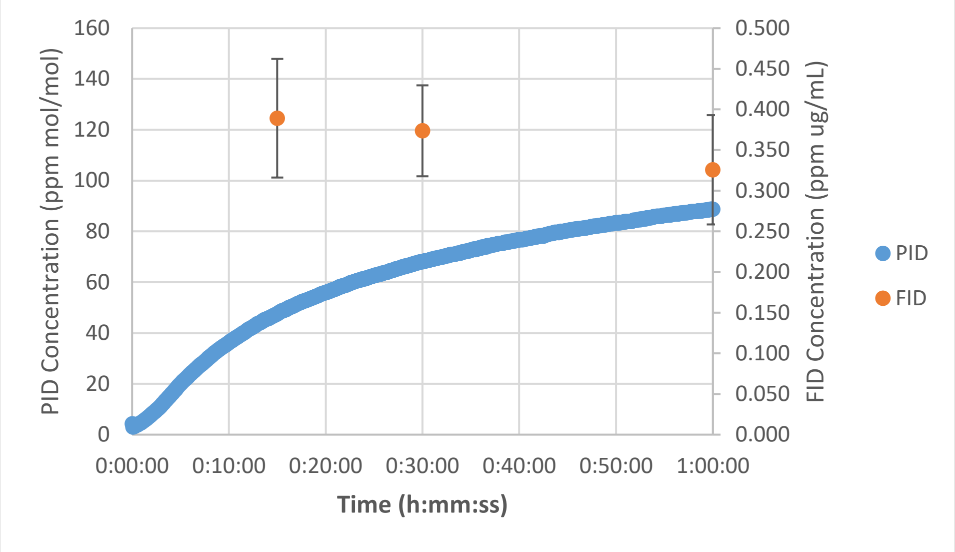

Figure 8. Representative fine-grained soil monitored via photoionization detector (PID) plotted with average total PHC vapour in headspace +/- standard deviation (n=3).

The PID and GC-FID curves followed a similar pattern to those shown in Figure 5, where results from the GC-FID seem to oppose those measured by PID. It is therefore not recommended that concentrations from the PID be used as the basis for reporting.

A full dataset of headspace analyses for fine-grained soil samples is provided in Table 8. Results of the saturate and aromatic sub-fractions for nC_{10}apex-nC_{12}apex and nC_{12}apex-nC_{16}apex are relatively consistent between fine-grained soil replicates, with the exception of the saturate sub-fraction in run 4-F.

Table 8. Summary of results of headspace PHC analyses by GC-FID, including sub-fractions, for flux rate experiments with fine-grained soils.

Replicated experiment and sample time from inception	Sample Lab ID	Total PHC	PHC F2	nC_{10}apex-nC_{12}apex			nC_{12}apex-nC_{16}apex		
				Total	Saturate sub-fraction	Aromatic sub-fraction	Total	Saturate sub-fraction	Aromatic sub-fraction
		µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL
Run 4 - F									
15 min	FL22-0554-013	**0.286**	**0.212**	**0.174**	Not requested	Not requested	**0.037**	Not requested	Not requested
30 min	FL22-0554-014	**0.298**	**0.228**	**0.172**	Not requested	Not requested	**0.056**	Not requested	Not requested
60 min	FL22-0554-015	**0.235**	**0.178**	**0.132**	**0.067**	**0.064**	**0.046**	**0.026**	**0.020**
Run 5 - F									
15 min	FL22-0554-016	**0.434**	**0.334**	**0.276**	Not requested	Not requested	**0.058**	Not requested	Not requested
30 min	FL22-0554-017	**0.393**	**0.314**	**0.245**	Not requested	Not requested	**0.069**	Not requested	Not requested
60 min	FL22-0554-018	**0.347**	**0.264**	**0.198**	**0.113**	**0.085**	**0.066**	**0.041**	**0.025**
Run 6 - F									
15 min	FL22-0554-019	**0.447**	**0.366**	**0.281**	Not requested	Not requested	**0.085**	Not requested	Not requested
30 min	FL22-0554-020	**0.430**	**0.310**	**0.256**	Not requested	Not requested	**0.053**	Not requested	Not requested
60 min	FL22-0554-021	**0.395**	**0.292**	**0.227**	**0.128**	**0.100**	**0.065**	**0.039**	**0.026**

4.0 CONCLUSIONS

In both parts 1 and 2 of the experiments, headspace concentrations reported by the PID were not consistent with those collected for analysis by flame ionization detector. The reason for this discrepancy could not be determined. The FID results were deemed to me more dependable than the PID values, and therefore only the FID results are recommended to be carried forward for guideline development.

In parts 1 and 2, flux rate experiments were conducted in two different ways: within a closed system using Tedlar® bags, and an open air exchange system more closely emulating a trench scenario. The data will be used as empirical input parameters for guideline derivation and the results from the two experimental designs will be compared to establish optimal experimental setup for the needs of this project.

5.0 REFERENCES

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Robinson, C.J., 1971. Low-resolution mass spectrometric determination of aromatics and saturates in petroleum fractions, Analytical Chemistry Vol. 43, No. 11: 1425-1434.

APPENDIX A. Soil Characterization

Fine- and coarse-grained soils used in the experiments are classified as loam and sand, respectively, with additional characterization information provided in Tables A1 and A2. Fine-grained soils were obtained from an uncontaminated field site and represent typical topsoil in Alberta. Coarse-grained soil was pure silica sand, representing a soil type with minimal potential retention of volatile hydrocarbon compounds.

Table A1. Soil texture and water holding capacity.

		Sand	**Silt**	**Clay**	**Water Holding Capacity**		
	Texture	50mm-2mm	2mm-50mm	>2mm	Field Capacity	Wilting Point	AWHC
		% by weight			vol %		
Fine	Loam	30	48	22	28.43	12.24	16.19
Coarse	Sand	97	<0.1	3	4.33	1.39	2.94

Table A2. Detailed salinity.

	Salinity													Total Carbon
	Saturated Paste Extract Data													
	pH	EC	SAR	Sat'n	Ca		Mg		Na		K			
	H_2O	dS/m		%	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	meq/L	mg/kg	TGR	%
Fine	7.5	1.625	0.5	48	13.465	129.4	6.785	39.35	1.725	19	0.235	4.5	<0.1	0.36
Coarse	6.55	0.075	0.4	27.5	0.205	1.1	0.105	0.35	0.15	1	0.06	<1	<0.1	<0.05

APPENDIX B. Original Laboratory Reports

Coarse-grained soil

Replicated experiment and sample time from inception	Sample Lab ID	Total VOC	PHC F2	nC_{10}apex-nC_{12}apex			nC_{12}apex-nC_{16}apex		
				Total	Saturate sub-fraction	Aromatic sub-fraction	Total	Saturate sub-fraction	Aromatic sub-fraction
		µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL
Run 4 - C									
15 min	FL22-0554-004	1.008	0.789	0.704	Not requested	Not requested	0.085	Not requested	Not requested
30 min	FL22-0554-005	0.962	0.749	0.645	Not requested	Not requested	0.104	Not requested	Not requested
60 min	FL22-0554-006	0.865	0.690	0.571	Pending	Pending	0.119	Pending	Pending
Run 5 - C									
15 min	FL22-0554-007	1.061	0.806	0.690	Not requested	Not requested	0.116	Not requested	Not requested
30 min	FL22-0554-008	1.056	0.842	0.687	Not requested	Not requested	0.155	Not requested	Not requested
60 min	FL22-0554-009	0.913	0.731	0.601	Pending	Pending	0.130	Pending	Pending
Run 6 - C									
15 min	FL22-0554-010	1.221	0.934	0.796	Not requested	Not requested	0.138	Not requested	Not requested
30 min	FL22-0554-011	1.070	0.845	0.696	Not requested	Not requested	0.149	Not requested	Not requested
60 min	FL22-0554-012	0.942	0.756	0.618	Pending	Pending	0.139	Pending	Pending

Fine-grained soil

Replicated experiment and sample time from inception	Sample Lab ID	Total VOC	PHC F2	nC_{10}apex-nC_{12}apex			nC_{12}apex-nC_{16}apex		
				Total	Saturate sub-fraction	Aromatic sub-fraction	Total	Saturate sub-fraction	Aromatic sub-fraction
		µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL	µg/mL
Run 4 - F									
15 min	FL22-0554-013	0.286	0.212	0.174	Not requested	Not requested	0.037	Not requested	Not requested
30 min	FL22-0554-014	0.298	0.228	0.172	Not requested	Not requested	0.056	Not requested	Not requested
60 min	FL22-0554-015	0.235	0.178	0.132			0.046		
Run 5 - F									
15 min	FL22-0554-016	0.434	0.334	0.276	Not requested	Not requested	0.058	Not requested	Not requested
30 min	FL22-0554-017	0.393	0.314	0.245	Not requested	Not requested	0.069	Not requested	Not requested
60 min	FL22-0554-018	0.347	0.264	0.198			0.066		
Run 6 - F									
15 min	FL22-0554-019	0.447	0.366	0.281	Not requested	Not requested	0.085	Not requested	Not requested
30 min	FL22-0554-020	0.43	0.31	0.256	Not requested	Not requested	0.053	Not requested	Not requested
60 min	FL22-0554-021	0.395	0.292	0.227			0.065		

Report Id	2685100	2685100
Lot Id	1532501	1532501
Lot Reference Number	1	2
Sample Id	7742660	7742661
Client Project Number		
Client Project Name		
Client Project Location		
Client Project Legal Location		
Client Project PO	64381	64381
Client Project Account Code	43110161.3001	43110161.3001
Received Date	2021-11-01	2021-11-01
Sample Location		
Sampling Method	Comp	Comp
Sampled By	Victor Bachmann	Victor Bachmann
Sampling Company	Innotech Alberta	Innotech Alberta
Site Id		
Sample Description	Coarse F2	Fine F2
Sample Date	2021-10-28	2021-10-28
Sampled Time	00:00:00.0000000	00:00:00.0000000
Sample Depth		
Sample Depth Unit		
Legal Location		
Description 2		
Completed Date	2021-11-02	2021-11-02
Matrix	Soil	Soil

Report Restults Group	**Method Reference**	**Analyte**	**Descriptor**	**Unit**	**Detection Limit**	Result Text	Result Text
Extractable Petroleum		Extraction Date	Total Extractables			1-Nov-21	1-Nov-21
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F2c C10-C16	Dry Weight	mg/kg	25	10100	13200
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F3c C16-C34	Dry Weight	mg/kg	50	225	253
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F4c C34-C50	Dry Weight	mg/kg	100	<100	<100
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F4HTGCc C34-	Dry Weight	mg/kg	100	<100	<100
Extractable Petroleum		% C50+		%		<5	<5
Silica Gel Cleanup		Silica Gel Cleanup				Done	Done
Soil % Moisture		Moisture	Soil % Moisture	% by weight		3.29	12.20

Course	Sand	Total	F2 fraction
		ppm (ug/mL)	ppm (ug/mL)
EXP 1			
time 1	FL21-2006-006	**0.631**	**0.484**
time 2	FL21-2006-007	**0.872**	**0.665**
time 3	FL21-2006-008	**1.23**	**0.942**
time 4	FL21-2006-009	**1.57**	**1.202**
time 5	FL21-2006-010	**2.02**	**1.502**
EXP 2			
time 1	FL21-2006-011	**1.328**	**0.970**
time 2	FL21-2006-012	**2.027**	**1.472**
time 3	FL21-2006-013	**2.055**	**1.498**
time 4	FL21-2006-014	**No sample was pulled**	**error in sampling**
EXP 3			
time 1	FL21-2006-015	**1.559**	**1.135**
time 2	FL21-2006-016	**2.028**	**1.449**
time 3	FL21-2006-017	**2.032**	**1.446**
time 4	FL21-2006-018	**2.072**	**1.512**

Fine	Sand	Total	F2 fraction
		ppm (ug/mL)	ppm (ug/mL)
EXP 1			
time 1	FL21-2006-019	**0.902**	**0.683**
time 2	FL21-2006-020	**1.210**	**0.915**
time 3	FL21-2006-021	**1.270**	**0.964**
time 4	FL21-2006-022	**1.37**	**1.077**
EXP 2			
time 1	FL21-2006-023	**0.653**	**0.521**
time 2	FL21-2006-024	**1.208**	**0.955**
time 3	FL21-2006-025	**1.427**	**1.132**
time 4	FL21-2006-026	**No sample was pulled**	**error in sampling**
EXP 3			
time 1	FL21-2006-027	**0.779**	**0.631**
time 2	FL21-2006-028	**1.261**	**1.008**
time 3	FL21-2006-029	**1.321**	**1.050**
time 4	FL21-2006-030	**1.451**	**1.148**

nC10apex-nC12apex	nC10apex-nC12apex	nC10apex-nC12apex
total	saturates	aromatic
ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)
0.417	Not requested	Not requested
0.581	0.436	0.145
0.797	0.596	0.201
1.053	0.785	0.268
1.370	1.034	0.336
0.864	0.634	0.231
1.332		
1.362	0.987	0.375
1.018	0.739	0.279
1.328	0.961	0.367
1.329	0.963	0.366
1.377	0.995	0.382

nC10apex-nC12apex	nC10apex-nC12apex	nC10apex-nC12apex
total	saturates	aromatic
ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)
0.614		
0.830		
0.880		
0.978		
0.465	0.3445	0.1202
0.867	0.639	0.228
1.020	0.744	0.275
0.557	0.4021	0.1544
0.908	0.657	0.251
0.952	0.689	0.263
1.040	0.755	0.284

nC12apex-nC16apex	nC12apex-nC16apex	nC12apex-nC16apex
total	saturates	aromatic
ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)
0.067	Not requested	Not requested
0.084	0.065	0.019
0.145	0.111	0.033
0.149	0.113	0.036
0.132	0.100	0.032
0.106	0.081	0.025
0.139		
0.136	0.097	0.039
0.116	0.087	0.030
0.120	0.088	0.033
0.116	0.085	0.031
0.135	0.099	0.036

nC12apex-nC16apex	nC12apex-nC16apex	nC12apex-nC16apex
total	saturates	aromatic
ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)
0.069		
0.085		
0.084		
0.099		
0.057	0.043	0.014
0.088	0.067	0.021
0.112	0.085	0.027
0.075	0.056	0.019
0.100	0.076	0.024
0.098	0.075	0.024
0.108	0.082	0.026

Report Id	2704855	2704855	2704855
Lot Id	1543347	1543347	1543347
Lot Reference Number	1	2	3
Sample Id	7835614	7835615	7835616
Client Project Number			
Client Project Name			
Client Project Location			
Client Project Legal Location			
Client Project PO	64381	64381	64381
Client Project Account Code			
Received Date	2021-12-16	2021-12-16	2021-12-16
Sample Location			
Sampling Method	Comp	Comp	Comp
Sampled By	Victor Bachmann	Victor Bachmann	Victor Bachmann
Sampling Company	Innotech	Innotech	Innotech
Site Id			
Sample Description	PTAC F2 Coarse R1	PTAC F2 Coarse R2	PTAC F2 Coarse R3
Sample Date	2021-12-08	2021-12-10	2021-12-10
Sampled Time	11:00:00.0000000	10:00:00.0000000	14:30:00.0000000
Sample Depth			
Sample Depth Unit			
Legal Location			
Description 2			
Completed Date	2021-12-18	2021-12-18	2021-12-18
Matrix	Soil	Soil	Soil

Report Restults Group	**Method Reference**	**Analyte**	**Descriptor**	**Unit**	**Detection Limit**	Result Text	Result Text	Result Text
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Benzene	Dry Weight	mg/kg	0.005	<0.005	<0.005	<0.005
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Toluene	Dry Weight	mg/kg	0.02	0.53	0.46	0.47
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Ethylbenzene	Dry Weight	mg/kg	0.005	0.029	0.025	0.026
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Total Xylenes	Dry Weight	mg/kg	0.03	0.32	0.30	0.32
Mono-Aromatic Hydrocarbons -		Methanol Field				Yes	Yes	Yes
Volatile Petroleum	CCME [CWS PHCS TIER 1]	F1 C6-C10	Dry Weight	mg/kg	10	231	279	302
Volatile Petroleum	CCME [CWS PHCS TIER 1]	F1 -BTEX	Dry Weight	mg/kg	10	230	278	301
Extractable Petroleum		Extraction Date	Total Extractables			17-Dec-21	17-Dec-21	17-Dec-21
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F2c C10-C16	Dry Weight	mg/kg	25	6820	7300	7320
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F3c C16-C34	Dry Weight	mg/kg	50	146	157	153
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F4c C34-C50	Dry Weight	mg/kg	100	<100	<100	<100
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F4HTGCc C34-	Dry Weight	mg/kg	100	<100	<100	<100
Extractable Petroleum		% C50+		%		<5	<5	<5
Silica Gel Cleanup		Silica Gel Cleanup				Done	Done	Done
Soil % Moisture		Moisture	Soil % Moisture	% by weight		2.14	2.34	2.32

Report Id	2710281	2710281	2710281
Lot Id	1546784	1546784	1546784
Lot Reference Number	1	2	3
Sample Id	7859156	7859157	7859158
Client Project Number			
Client Project Name			
Client Project Location			
Client Project Legal Location			
Client Project PO	64381	64381	64381
Client Project Account Code			
Received Date	2022-01-13	2022-01-13	2022-01-13
Sample Location			
Sampling Method	Comp	Comp	Comp
Sampled By	Victor Bachmann	Victor Bachmann	Victor Bachmann
Sampling Company	Innotech Alberta	Innotech Alberta	Innotech Alberta
Site Id			
Sample Description	PTAC F2 Fine R1 Jan 22	PTAC F2 Fine HS R2	PTAC F2 Fine HS R3
Sample Date	2022-01-06	2022-01-10	2022-01-10
Sampled Time	00:00:00.0000000	00:00:00.0000000	00:00:00.0000000
Sample Depth			
Sample Depth Unit			
Legal Location			
Description 2			
Completed Date	2022-01-15	2022-01-15	2022-01-15
Matrix	Soil	Soil	Soil

Report Restults Group	**Method Reference**	**Analyte**	**Descriptor**	**Unit**	**Detection Limit**	Result Text	Result Text	Result Text
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Benzene	Dry Weight	mg/kg	0.005	<0.005	<0.005	<0.005
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Toluene	Dry Weight	mg/kg	0.02	0.27	0.33	0.16
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Ethylbenzene	Dry Weight	mg/kg	0.005	<0.005	0.015	0.008
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Total Xylenes	Dry Weight	mg/kg	0.03	0.17	0.25	0.14
Mono-Aromatic Hydrocarbons -		Methanol Field				Yes	Yes	Yes
Volatile Petroleum	CCME [CWS PHCS TIER 1]	F1 C6-C10	Dry Weight	mg/kg	10	230	342	126
Volatile Petroleum	CCME [CWS PHCS TIER 1]	F1 -BTEX	Dry Weight	mg/kg	10	230	341	126
Extractable Petroleum		Extraction Date	Total Extractables			14-Jan-22	14-Jan-22	14-Jan-22
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F2c C10-C16	Dry Weight	mg/kg	25	8100	8020	12200
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F3c C16-C34	Dry Weight	mg/kg	50	364	358	537
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F4c C34-C50	Dry Weight	mg/kg	100	<100	<100	<100
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F4HTGCc C34-	Dry Weight	mg/kg	100	<100	<100	<100
Extractable Petroleum		% C50+		%		<5	<5	<5
Silica Gel Cleanup		Silica Gel Cleanup				Done	Done	Done
Soil % Moisture		Moisture	Soil % Moisture	% by weight		12.40	12.30	12.30

Fuels and Lubricants

TEST REPORT ATTACHMENT

course	Sand	Total	F2 fraction	nC10apex-nC12apex	nC10apex-nC12apex	nC10apex-nC12apex	nC12apex-nC16apex	nC12apex-nC16apex	nC12apex-nC16apex
				total	saturates	aromatic	total	saturates	aromatic
		ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)
EXP 1									
15 min	FL22-0554-004	**1.008**	**0.789**	**0.704**	Not requested	Not requested	**0.085**	Not requested	Not requested
30 min	FL22-0554-005	**0.962**	**0.749**	**0.645**	Not requested	Not requested	**0.104**	Not requested	Not requested
60 min	FL22-0554-006	**0.865**	**0.690**	**0.571**	**0.419**	**0.152**	**0.119**	**0.086**	**0.034**
EXP 2									
15 min	FL22-0554-007	**1.061**	**0.806**	**0.690**	Not requested	Not requested	**0.116**	Not requested	Not requested
30 min	FL22-0554-008	**1.056**	**0.842**	**0.687**	Not requested	Not requested	**0.155**	Not requested	Not requested
60 min	FL22-0554-009	**0.913**	**0.731**	**0.601**	**0.441**	**0.160**	**0.130**	**0.094**	**0.036**
EXP 3									
15 min	FL22-0554-010	**1.221**	**0.934**	**0.796**	Not requested	Not requested	**0.138**	Not requested	Not requested
30 min	FL22-0554-011	**1.070**	**0.845**	**0.696**	Not requested	Not requested	**0.149**	Not requested	Not requested
60 min	FL22-0554-012	**0.942**	**0.756**	**0.618**	**0.452**	**0.166**	**0.139**	**0.100**	**0.038**

fine	Sand	Total	F2 fraction	nC10apex-nC12apex	nC10apex-nC12apex	nC10apex-nC12apex	nC12apex-nC16apex	nC12apex-nC16apex	nC12apex-nC16apex
				total	saturates	aromatic	total	saturates	aromatic
		ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)
EXP 1									
15 min	FL22-0554-013	**0.286**	**0.212**	**0.174**	Not requested	Not requested	**0.037**	Not requested	Not requested
30 min	FL22-0554-014	**0.298**	**0.228**	**0.172**	Not requested	Not requested	**0.056**	Not requested	Not requested
60 min	FL22-0554-015	**0.235**	**0.178**	**0.132**	**0.067**	**0.064**	**0.046**	**0.026**	**0.020**
EXP 2									
15 min	FL22-0554-016	**0.434**	**0.334**	**0.276**	Not requested	Not requested	**0.058**	Not requested	Not requested
30 min	FL22-0554-017	**0.393**	**0.314**	**0.245**	Not requested	Not requested	**0.069**	Not requested	Not requested
60 min	FL22-0554-018	**0.347**	**0.264**	**0.198**	**0.113**	**0.085**	**0.066**	**0.041**	**0.025**
EXP 3									
15 min	FL22-0554-019	**0.447**	**0.366**	**0.281**	Not requested	Not requested	**0.085**	Not requested	Not requested
30 min	FL22-0554-020	**0.430**	**0.310**	**0.256**	Not requested	Not requested	**0.053**	Not requested	Not requested
60 min	FL22-0554-021	**0.395**	**0.292**	**0.227**	**0.128**	**0.100**	**0.065**	**0.039**	**0.026**

Report Id	2697766
Lot Id	1539063
Lot Reference Number	1
Sample Id	7796159
Client Project Number	
Client Project Name	
Client Project Location	
Client Project Legal Location	
Client Project PO	64381
Client Project Account Code	
Received Date	2021-11-26
Sample Location	
Sampling Method	Comp
Sampled By	Victor Bachmann
Sampling Company	Innotech Alberta
Site Id	
Sample Description	PTAC F2 Fine HS R1
Sample Date	2021-11-26
Sampled Time	00:00:00.0000000
Sample Depth	
Sample Depth Unit	
Legal Location	
Description 2	
Completed Date	2021-11-29
Matrix	Soil

Report Restults Group	**Method Reference**	**Analyte**	**Descriptor**	**Unit**	**Detection Limit**	Result Text
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Benzene	Dry Weight	mg/kg	0.005	<0.005
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Toluene	Dry Weight	mg/kg	0.02	0.14
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Ethylbenzene	Dry Weight	mg/kg	0.005	0.015
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Total Xylenes	Dry Weight	mg/kg	0.03	0.30
Mono-Aromatic Hydrocarbons -		Methanol Field				Yes
Volatile Petroleum	CCME [CWS PHCS TIER 1]	F1 C6-C10	Dry Weight	mg/kg	10	207
Volatile Petroleum	CCME [CWS PHCS TIER 1]	F1 -BTEX	Dry Weight	mg/kg	10	207
Extractable Petroleum		Extraction Date	Total Extractables			27-Nov-21
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F2c C10-C16	Dry Weight	mg/kg	25	10100
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F3c C16-C34	Dry Weight	mg/kg	50	411
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F4c C34-C50	Dry Weight	mg/kg	100	<100
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F4HTGCc C34-	Dry Weight	mg/kg	100	<100
Extractable Petroleum		% C50+		%		<5
Silica Gel Cleanup		Silica Gel Cleanup				Done
Soil % Moisture		Moisture	Soil % Moisture	% by weight		12.40

					Report Id	2704855	2704855	2704855
					Lot Id	1543347	1543347	1543347
					Lot Reference Number	1	2	3
					Sample Id	7835614	7835615	7835616
					Client Project Number			
					Client Project Name			
					Client Project Location			
					Client Project Legal Location			
					Client Project PO	64381	64381	64381
					Client Project Account Code			
					Received Date	2021-12-16	2021-12-16	2021-12-16
					Sample Location			
					Sampling Method	Comp	Comp	Comp
					Sampled By	Victor Bachmann	Victor Bachmann	Victor Bachmann
					Sampling Company	Innotech	Innotech	Innotech
					Site Id			
					Sample Description	PTAC F2 Coarse R1	PTAC F2 Coarse R2	PTAC F2 Coarse R3
					Sample Date	2021-12-08	2021-12-10	2021-12-10
					Sampled Time	11:00:00.0000000	10:00:00.0000000	14:30:00.0000000
					Sample Depth			
					Sample Depth Unit			
					Legal Location			
					Description 2			
					Completed Date	2021-12-18	2021-12-18	2021-12-18
					Matrix	Soil	Soil	Soil
Report Restults Group	**Method Reference**	**Analyte**	**Descriptor**	**Unit**	**Detection Limit**	Result Text	Result Text	Result Text
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Benzene	Dry Weight	mg/kg	0.005	<0.005	<0.005	<0.005
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Toluene	Dry Weight	mg/kg	0.02	0.53	0.46	0.47
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Ethylbenzene	Dry Weight	mg/kg	0.005	0.029	0.025	0.026
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Total Xylenes	Dry Weight	mg/kg	0.03	0.32	0.30	0.32
Mono-Aromatic Hydrocarbons -		Methanol Field				Yes	Yes	Yes
Volatile Petroleum	CCME [CWS PHCS TIER 1]	F1 C6-C10	Dry Weight	mg/kg	10	231	279	302
Volatile Petroleum	CCME [CWS PHCS TIER 1]	F1 -BTEX	Dry Weight	mg/kg	10	230	278	301
Extractable Petroleum		Extraction Date	Total Extractables			17-Dec-21	17-Dec-21	17-Dec-21
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F2c C10-C16	Dry Weight	mg/kg	25	6820	7300	7320
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F3c C16-C34	Dry Weight	mg/kg	50	146	157	153
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F4c C34-C50	Dry Weight	mg/kg	100	<100	<100	<100
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F4HTGCc C34-	Dry Weight	mg/kg	100	<100	<100	<100
Extractable Petroleum		% C50+		%		<5	<5	<5
Silica Gel Cleanup		Silica Gel Cleanup				Done	Done	Done
Soil % Moisture		Moisture	Soil % Moisture	% by weight		2.14	2.34	2.32

					Report Id	2738126	2738126	2738126	2738126	2738126
					Lot Id	1565211	1565211	1565211	1565211	1565211
					Lot Reference Number	1	2	3	4	5
					Sample Id	8011302	8011303	8011304	8011305	8011306
					Client Project Number	PTAC F2 Flux	PTAC F2 Flux	PTAC F2 Flux	PTAC F2 Flux	PTAC F2 Flux
					Client Project Name					
					Client Project Location					
					Client Project Legal Location					
					Client Project PO					
					Client Project Account Code	43110161.3001	43110161.3001	43110161.3001	43110161.3001	43110161.3001
					Received Date	2022-04-14	2022-04-14	2022-04-14	2022-04-14	2022-04-14
					Sample Location					
					Sampling Method					
					Sampled By					
					Sampling Company					
					Site Id					
					Sample Description	PTAC F2 Flux Coarse	PTAC F2 Flux Fine R1	PTAC F2 Flux Fine R2	PTAC F2 Flux Fine R3	PTAC F2 Flux Comp
					Sample Date	2022-04-06	2022-04-11	2022-04-11	2022-04-12	2022-04-12
					Sampled Time	00:00:00.0000000	00:00:00.0000000	00:00:00.0000000	00:00:00.0000000	00:00:00.0000000
					Sample Depth					
					Sample Depth Unit					
					Legal Location					
					Description 2					
					Completed Date	2022-04-17	2022-04-17	2022-04-17	2022-04-17	2022-04-17
					Matrix	Soil	Soil	Soil	Soil	Soil
Report Restults Group	**Method Reference**	**Analyte**	**Descriptor**	**Unit**	**Detection Limit**	Result Text	Result Text	Result Text	Result Text	Result Text
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Benzene	Dry Weight	mg/kg	0.005	0.011	<0.005	<0.005	<0.005	<0.005
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Toluene	Dry Weight	mg/kg	0.02	0.45	<0.02	<0.02	<0.02	<0.02
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Ethylbenzene	Dry Weight	mg/kg	0.005	0.043	0.020	0.014	0.013	0.019
Mono-Aromatic Hydrocarbons -	US EPA [5021/8260]	Total Xylenes	Dry Weight	mg/kg	0.03	0.48	0.24	0.20	0.20	0.26
Mono-Aromatic Hydrocarbons -		Methanol Field				Yes	Yes	Yes	Yes	Yes
Volatile Petroleum	CCME [CWS PHCS TIER 1]	F1 C6-C10	Dry Weight	mg/kg	10	623	313	310	348	454
Volatile Petroleum	CCME [CWS PHCS TIER 1]	F1 -BTEX	Dry Weight	mg/kg	10	622	313	310	348	454
Extractable Petroleum		Extraction Date	Total Extractables			15-Apr-22	15-Apr-22	15-Apr-22	15-Apr-22	15-Apr-22
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F2c C10-C16	Dry Weight	mg/kg	25	5660	7090	8550	8530	7690
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F3c C16-C34	Dry Weight	mg/kg	50	94	125	137	150	135
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F4c C34-C50	Dry Weight	mg/kg	100	<100	<100	<100	<100	<100
Extractable Petroleum	CCME [CWS PHCS TIER 1]	F4HTGCc C34-	Dry Weight	mg/kg	100	<100	<100	<100	<100	<100
Extractable Petroleum		% C50+		%		<5	<5	<5	<5	<5
Silica Gel Cleanup		Silica Gel Cleanup				Done	Done	Done	Done	Done
Soil % Moisture		Moisture	Soil % Moisture	% by weight		2.23	12.60	11.90	12.50	13.20

element
www.Element.com

Project Information

Project ID:
Project Name:
Project Location:
Legal Location:
PO/AFE#: 64381
Proj. Acct. Code:
Quote #:

Invoice To

Company: Alberta Innovates
Address: 250 Karl Clark Rd NW
Edmonton, AB
Attention: Allan Mah
Phone:
Cell: 780.450.5170
Fax:
E-mail 1: Allan.Mah@albertainnovates.ca
Agreement ID: 92141
Copy of Report: No

Report To

Company: Innotech Alberta
Address: 250 Karl Clark Rd.
Edmonton, AB
Attention: Simone Levy
Phone: 780-450-5210
Cell:
Fax:
E-mail 1: Simone.Levy@InnotechAlberta.ca
E-mail 2:
Copy of Invoice: YES

Additional Reports to

1) Name:
E-mail:
2) Name:
E-mail:

Sample Custody

Sampled by: Victor Bachmann
Company: Innotech Alberta
I authorize Element to proceed with the work indicated on this form:
Signature:
Date/Time:

RUSH Priority

☐ Same Day (200%)
☐ Next Day/Two Day (100%)
☑ Three or Four Days (50%)
☐ 5 to 7 Days (Regular TAT)
Date Required

When "ASAP" is requested, turn around will default to a 100% RUSH priority, with pricing and turn around time to match. Please contact the lab prior to submitting RUSH samples. If not all samples require RUSH, please indicate in the special instructions.

Report Results

☑ Email ☑ QA/QC
☐ Online ☑ PDF
☐ Fax ☑ Excel

Requirements

☐ HCDWORG ☐ SPIGEC
☐ AB Tier 1 ☐ BCCSR
Other (list below)

Special Instructions/Comments (please include contact information including phone number if different from above).

	Site I.D.	Sample Description	Depth start in cm m	end	Date/Time sampled	Matrix	Sampling method	Number of Containers #	MeOH Field Preserved? ✓	CCCMEC
1		PTAC F2 Fine HS R1			2011/11/26 0:00	soil	Comp	3	x	x
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										

Enter tests above
(✓ relevant samples below)

RUSH
S-8194, ULINE, 800-295-5510

Please indicate any potentially hazardous samples

Submission of this form acknowledges acceptance of Element's Standard of terms and conditions (https://www.element.com/terms/terms-and-conditions)

Page 1 of 1 Control #
ED 120-005

Lot: 1539063 COC

Temp. received: 3 3 °C
Date/Time stamp:
Delivery Method: NOV 26 PM5:05
Waybill:
Received by: SW

element

Element
Bay #5, 2712-37 Avenue N.E.
Calgary, Alberta
Canada, T1Y 5L3

T: +1 (403) 291-2022
F: +1 (403) 291-2021
E: info.Calgary@element.com
W: www.element.com

Confirmation of Service Request

Lot ID: 1539063
Number of Samples: 1
Printed Date: Dec 02, 2021

Please verify the following service request. If you have corrections or questions, please contact Client Services. No response to this confirmation of analysis will signify all services listed below are accurate.

Report To:	**Invoice To:**	**Bill Paid by:**
Attn: Simone Levy	Attn: Allan Mah	Attn: Accounts Payable
InnoTech Alberta Inc.	InnoTech Alberta Inc.	InnoTech Alberta Inc.
Bag 4000	1 Oil Path Dr.	PO Box 8330
Hwy 16A & 75 Street	Devon, AB T9G 1A8	250 Karl Clark Road
Vegreville, AB T9C 1T4	Phone: (780) 987-8635	Edmonton, AB T6N 1E4
Phone: (780) 450-5474	Fax: (780) 450-5333	Phone: (780) 450-5133
Fax: (780) 913-0178		Fax: (780) 450-5542

Agreement Id	92141	**Control Id**	
Project Id		**Report Due Date**	Dec 02, 2021
Project Name		**Received Date**	Nov 26, 2021
Project Location		**Sampled By**	Victor Bachmann
Legal Location		**Sampling Company**	Innotech Alberta
PO#	64381	**Est. Disposal Date**	Jan 01, 2022
Proj. Acct. Code			

RUSH

Service Information

Sample Id	**1** **7796159**	**Service**	**Service Name**
		CCMEC	CCME Hydrocarbons: BTEX, F1-F4 in Soil by Cold Extraction
Date Sampled	Nov 26, 2021 12:00	DISP	Environmental Disposal Fee
Priority	Rush 50%		
Sample Description	PTAC F2 Fine HS R1		
Temp: Received	3.3 °C		

Other Billable Services	**Service**	**Service Name**	**Quantity**
	SUP-	VOC Coring Device	1.00
	SUP-MEOH	MEOH Vial	2.00

Service Count

Service Name	Service Code	Quantity
CCME Hydrocarbons: BTEX, F1-F4 in Soil by Cold Extraction	CCMEC	1
Environmental Disposal Fee	DISP	1
MEOH Vial	SUP-MEOH	2
VOC Coring Device	SUP-CORER	1

Notes

If required for invoice approval, please sign and return to the address indicated at the top of the page.

(Signature) ________________________________

element

Element
Bay #5, 2712-37 Avenue N.E.
Calgary, Alberta
Canada, T1Y 5L3

T: +1 (403) 291-2022
F: +1 (403) 291-2021
E: info.Calgary@element.com
W: www.element.com

Confirmation of Service Request

Lot ID: 1539063

Number of Samples: 1

Printed Date: Dec 02, 2021

Please verify the following service request. If you have corrections or questions, please contact Client Services. No response to this confirmation of analysis will signify all services listed below are accurate.

Report Delivery Plan

Contact	Company	Address
Simone Levy	InnoTech Alberta Inc.	Bag 4000, Hwy 16A & 75 Street Vegreville, AB T9C 1T4 Phone: (780) 450-5474 Fax: (780) 913-0178 Email: Simone.levy@innotechalberta.ca

Delivery	Format	Deliverables
Email - Merge Reports	PDF	COA / COC
Email - Merge Reports	PDF	COC / Test Report
Email - Single Report	Standard Crosstab Without Tabs	Test Report

element

Element
7217 Roper Road NW
Edmonton, Alberta
T6B 3J4, Canada

T: +1 (780) 438-5522
F: +1 (780) 434-8586
E: info.Edmonton@element.com
W: www.element.com

Report Transmission Cover Page

Bill To:	InnoTech Alberta Inc. PO Box 8330 250 Karl Clark Road Edmonton, AB, Canada T6N 1E4
Attn:	Les Spink
Sampled By:	
Company:	

Project ID:	PTAC F2 Flux
Project Name:	
Project Location:	
LSD:	
P.O.:	
Proj. Acct. code:	43110161.3001

Lot ID:	**1565211**
Control Number:	
Date Received:	Apr 14, 2022
Date Reported:	Apr 21, 2022
Report Number:	2738126

Contact	Company	Address
Accounts Payable	**InnoTech Alberta Inc.**	PO Box 8330, 250 Karl Clark Road Edmonton, AB T6N 1E4 Phone: (780) 450-5133 Fax: (780) 450-5542 Email: innotech-finance@albertainnovates.

Delivery	Format	Deliverables
Email - Single Report	PDF	COC / Invoice

Contact	Company	Address
Les Spink	**InnoTech Alberta Inc.**	PO Box 8330, 250 Karl Clark Road Edmonton, AB T6N 1E4 Phone: (780) 450-5033 Fax: (780) 450-5083 Email: leslie.spink@albertainnovates.ca

Delivery	Format	Deliverables
Email - Merge Reports	PDF	COC / Invoice

Contact	Company	Address
Simone Levy	**InnoTech Alberta Inc.**	Bag 4000, Hwy 16A & 75 Street Vegreville, AB T9C 1T4 Phone: (780) 450-5474 Fax: (780) 913-0178 Email: Simone.levy@innotechalberta.ca

Delivery	Format	Deliverables
Email - Merge Reports	PDF	COC / COA
Email - Merge Reports	PDF	COC / Test Report
Email - Merge Reports	PDF	COC / Test Report / Invoice
Email - Single Report	Standard Crosstab Without Tabs	Test Report

Notes To Clients:

element

Element
7217 Roper Road NW
Edmonton, Alberta
T6B 3J4, Canada

T: +1 (780) 438-5522
F: +1 (780) 434-8586
E: info.Edmonton@element.com
W: www.element.com

Analytical Report

Bill To: InnoTech Alberta Inc.
PO Box 8330
250 Karl Clark Road
Edmonton, AB, Canada
T6N 1E4
Attn: Les Spink
Sampled By:
Company:

Project ID: PTAC F2 Flux
Project Name:
Project Location:
LSD:
P.O.:
Proj. Acct. code: 43110161.3001

Lot ID: **1565211**
Control Number:
Date Received: Apr 14, 2022
Date Reported: Apr 21, 2022
Report Number: 2738126

		Reference Number	1565211-1	1565211-2	1565211-3	
		Sample Date	Apr 06, 2022	Apr 11, 2022	Apr 11, 2022	
		Sample Time	NA	NA	NA	
		Sample Location				
		Sample Description	PTAC F2 Flux Coarse	PTAC F2 Flux Fine R1	PTAC F2 Flux Fine R2	
		Matrix	Soil	Soil	Soil	
Analyte		**Units**	**Results**	**Results**	**Results**	Nominal Detection Limit
Mono-Aromatic Hydrocarbons - Soil						
Benzene	Dry Weight	mg/kg	0.011	<0.005	<0.005	0.005
Toluene	Dry Weight	mg/kg	0.45	<0.02	<0.02	0.02
Ethylbenzene	Dry Weight	mg/kg	0.043	0.020	0.014	0.005
Total Xylenes (m,p,o)	Dry Weight	mg/kg	0.48	0.24	0.20	0.03
Methanol Field Preservation			Yes	Yes	Yes	
Volatile Petroleum Hydrocarbons - Soil						
F1 C6-C10	Dry Weight	mg/kg	623	313	310	10
F1 -BTEX	Dry Weight	mg/kg	622	313	310	10
Extractable Petroleum Hydrocarbons - Soil						
Extraction Date	Total Extractables		15-Apr-22	15-Apr-22	15-Apr-22	
F2c C10-C16	Dry Weight	mg/kg	5660	7090	8550	25
F3c C16-C34	Dry Weight	mg/kg	94	125	137	50
F4c C34-C50	Dry Weight	mg/kg	<100	<100	<100	100
F4HTGCc C34-C50+	Dry Weight	mg/kg	<100	<100	<100	100
% C50+		%	<5	<5	<5	
Silica Gel Cleanup						
Silica Gel Cleanup			Done	Done	Done	
Soil % Moisture						
Moisture	Soil % Moisture	% by weight	2.23	12.60	11.90	

Analytical Report

Bill To:	InnoTech Alberta Inc. PO Box 8330 250 Karl Clark Road Edmonton, AB, Canada T6N 1E4	Project ID:	PTAC F2 Flux	Lot ID:	**1565211**
		Project Name:		Control Number:	
		Project Location:		Date Received:	Apr 14, 2022
		LSD:		Date Reported:	Apr 21, 2022
		P.O.:		Report Number:	2738126
Attn:	Les Spink	Proj. Acct. code:	43110161.3001		
Sampled By:					
Company:					

Reference Number	1565211-4	1565211-5
Sample Date	Apr 12, 2022	Apr 12, 2022
Sample Time	NA	NA
Sample Location		
Sample Description	PTAC F2 Flux Fine R3	PTAC F2 Flux Comp
Matrix	Soil	Soil

Analyte		Units	Results	Results	Results	Nominal Detection Limit
Mono-Aromatic Hydrocarbons - Soil						
Benzene	Dry Weight	mg/kg	<0.005	<0.005		0.005
Toluene	Dry Weight	mg/kg	<0.02	<0.02		0.02
Ethylbenzene	Dry Weight	mg/kg	0.013	0.019		0.005
Total Xylenes (m,p,o)	Dry Weight	mg/kg	0.20	0.26		0.03
Methanol Field Preservation			Yes	Yes		
Volatile Petroleum Hydrocarbons - Soil						
F1 C6-C10	Dry Weight	mg/kg	348	454		10
F1 -BTEX	Dry Weight	mg/kg	348	454		10
Extractable Petroleum Hydrocarbons - Soil						
Extraction Date	Total Extractables		15-Apr-22	15-Apr-22		
F2c C10-C16	Dry Weight	mg/kg	8530	7690		25
F3c C16-C34	Dry Weight	mg/kg	150	135		50
F4c C34-C50	Dry Weight	mg/kg	<100	<100		100
F4HTGCc C34-C50+	Dry Weight	mg/kg	<100	<100		100
% C50+		%	<5	<5		
Silica Gel Cleanup						
Silica Gel Cleanup			Done	Done		
Soil % Moisture						
Moisture	Soil % Moisture	% by weight	12.50	13.20		

Approved by: RL Neumann

Randy Neumann, BSc
Division Director

Quality Control

Bill To: InnoTech Alberta Inc.
PO Box 8330
250 Karl Clark Road
Edmonton, AB, Canada
T6N 1E4
Attn: Les Spink
Sampled By:
Company:

Project ID: PTAC F2 Flux
Project Name:
Project Location:
LSD:
P.O.:
Proj. Acct. code: 43110161.3001

Lot ID: **1565211**
Control Number:
Date Received: Apr 14, 2022
Date Reported: Apr 21, 2022
Report Number: 2738126

Extractable Petroleum Hydrocarbons - Soil

Blanks	**Units**	**Measured**	**Lower Limit**	**Upper Limit**	**Passed QC**
F2c C10-C16	µg/mL	0	-10	10	yes
F3c C16-C34	µg/mL	0	-30	30	yes
F4c C34-C50	µg/mL	0	-20	20	yes
F4HTGCc C34-C50+	µg/mL	0	-20	20	yes

Date Acquired: April 15, 2022

Calibration Check	**Units**	**% Recovery**	**Lower Limit**	**Upper Limit**	**Passed QC**
F2c C10-C16	µg/mL	100.10	80	120	yes
F3c C16-C34	µg/mL	101.02	80	120	yes
F4c C34-C50	µg/mL	98.96	80	120	yes
F4HTGCc C34-C50+	µg/mL	95.11	80	120	yes

Date Acquired: April 15, 2022

Matrix Spike	**Units**	**% Recovery**	**Lower Limit**	**Upper Limit**	**Passed QC**
F2c C10-C16	mg/kg	81	70	130	yes
F3c C16-C34	mg/kg	87	70	130	yes
F4c C34-C50	mg/kg	85	70	130	yes
F4HTGCc C34-C50+	mg/kg	84	70	130	yes

Date Acquired: April 15, 2022

Mono-Aromatic Hydrocarbons - Soil

Blanks	**Units**	**Measured**	**Lower Limit**	**Upper Limit**	**Passed QC**
Benzene	ng	0	-0.005	0.005	yes
Toluene	ng	0	-0.06	0.06	yes
Ethylbenzene	ng	0	-0.030	0.030	yes
Total Xylenes (m,p,o)	ng	0	-0.09	0.09	yes
Styrene	ng	0	-0.030	0.030	yes

Date Acquired: April 15, 2022

Calibration Check	**Units**	**% Recovery**	**Lower Limit**	**Upper Limit**	**Passed QC**
Benzene	ng	104.50	80	120	yes
Toluene	ng	98.17	80	120	yes
Ethylbenzene	ng	109.80	80	120	yes
m,p-Xylene	ng	115.56	80	120	yes
Total Xylenes (m,p,o)	ng	114.91	80	120	yes
Styrene	ng	96.17	80	120	yes

Date Acquired: April 15, 2022

Volatile Petroleum Hydrocarbons - Soil

Blanks	**Units**	**Measured**	**Lower Limit**	**Upper Limit**	**Passed QC**
F1 C6-C10	ng	0	-10	10	yes

Date Acquired: April 15, 2022

Methodology and Notes

Bill To:	InnoTech Alberta Inc. PO Box 8330 250 Karl Clark Road Edmonton, AB, Canada T6N 1E4	Project ID:	PTAC F2 Flux	Lot ID:	**1565211**
		Project Name:		Control Number:	
		Project Location:		Date Received:	Apr 14, 2022
		LSD:		Date Reported:	Apr 21, 2022
		P.O.:		Report Number:	2738126
Attn:	Les Spink	Proj. Acct. code:	43110161.3001		
Sampled By:					
Company:					

Method of Analysis

Method Name	Reference		Method	Date Analysis Started	Location
BTEX-CCME - Soil	CCME	*	Reference Method for Canada-Wide Standard for PHC in Soil, CWS PHCS TIER 1	Apr 15, 2022	Element Calgary
BTEX-CCME - Soil	US EPA	*	Volatile Organic Compounds in Various Sample Matrices Using Equilibrium Headspace Analysis/Gas Chromatography Mass Spectrometry, 5021/8260	Apr 15, 2022	Element Calgary
TEH-CCME-Soil (Shake)	CCME	*	Reference Method for Canada-Wide Standard for PHC in Soil, CWS PHCS TIER 1	Apr 15, 2022	Element Calgary

** Reference Method Modified*

References

CCME	Canadian Council of Ministers of the Environment
US EPA	US Environmental Protection Agency Test Methods

element
www.Element.com

Project Information

Project ID: PTAC F2 Flux
Project Name:
Project Location:
Legal Location:
PO/AFE#:
Proj. Acct. Code: 43110161.3001
Quote #: 92141

Invoice To

Company: Alberta Innovates
Address: 250 Karl Clark Rd NW
Edmonton, AB
Attention: Les Spink
Phone:
Cell: 780.450.5033
Fax:
E-mail 1: les.spink@albertainnovates.ca
Agreement ID: 92141
Copy of Report: No

Report To

Company: Innotech Alberta
Address: 250 Karl Clark Rd.
Edmonton, AB
Attention: Simone Levy
Phone: 780-450-5210
Cell:
Fax:
E-mail 1: Simone.Levy@InnotechAlberta.ca
E-mail 2:
Copy of Invoice: YES

Additional Reports to

1) Name: Victor Bachmann
E-mail: :or.Bachmann@innotechalbert
2) Name:
E-mail:

Sample Custody

Sampled by:
Company:
I authorize Element to proceed with the work indicated on this form:
Signature:
Date/Time:

RUSH Priority

☐ Same Day (200%)
☐ Next Day/Two Day (100%)
☐ Three or Four Days (50%)
☑ 5 to 7 Days (Regular TAT)

Date Required

When "ASAP" is requested, turn around will default to a 100% RUSH priority, with pricing and turn around time to match. Please contact the lab prior to submitting RUSH samples. If not all samples require RUSH, please indicate in the special instructions.

Report Results

☑ Email ☑ QA/QC
☐ Online ☑ PDF
☐ Fax ☑ Excel

Requirements

☐ HCDWORG ☐ SPIGEC
☐ AB Tier 1 ☐ BCCSR
Other (list below)

Special Instructions/Comments (please include contact information including phone number if different from above).

	Site I.D.	Sample Description	Depth start in cm	Depth end m	Date/Time sampled	Matrix	Sampling method	Number of Containers #	MeOH Field Preserved? ✓	CCMEC
1		PTAC F2 Flux Coarse			2022/4/6 0:00			3	x	x
2		PTAC F2 Flux Fine R1			2022/4/11 0:00			3	x	x
3		PTAC F2 Flux Fine R2			2022/4/11 0:00			3	x	x
4		PTAC F2 Flux Fine R3			2022/4/12 0:00			3	x	x
5		PTAC F2 Flux Comp			2022/4/12 0:00			3	x	x
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										

Enter tests above
(✓ relevant samples below)

Please indicate any potentially hazardous samples

Submission of this form acknowledges acceptance of Element's Standard of terms and conditions (https://www.element.com/terms/terms-and-conditions)

Page 1 of 1
Control #
ED 120-005

Indicate lot # or affix b

Lot: 1565211 COC

Temp. received: -3.3 °C
Date/Time stamp: APR 14 PM12:00
Delivery Method: hand
Waybill:
Received by: Dm

Coarse	Lab ID	Total	F2 fraction	nC10apex-nC12apex	nC10apex-nC12apex	nC10apex-nC12apex	nC12apex-nC16apex	nC12apex-nC16apex	nC12apex-nC16apex
				total	saturates	aromatic	total	saturates	aromatic
		ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)
EXP 1									
time 1	FL21-2006-006	**0.631**	**0.484**	0.417	Not requested	Not requested	0.067	Not requested	Not requested
time 2	FL21-2006-007	**0.872**	**0.665**	0.581	0.436	0.145	0.084	0.065	0.019
time 3	FL21-2006-008	**1.23**	**0.942**	0.797	0.596	0.201	0.145	0.111	0.033
time 4	FL21-2006-009	**1.57**	**1.202**	1.053	0.785	0.268	0.149	0.113	0.036
time 5	FL21-2006-010	**2.02**	**1.502**	1.370	1.034	0.336	0.132	0.100	0.032
EXP 2									
time 1	FL21-2006-011	**1.328**	**0.970**	0.864	0.634	0.231	0.106	0.081	0.025
time 2	FL21-2006-012	**2.027**	**1.472**	1.332	0.962	0.370	0.139	0.099	0.040
time 3	FL21-2006-013	**2.055**	**1.498**	1.362	0.987	0.375	0.136	0.097	0.039
time 4	FL21-2006-014	**No sample was pulled**	**error in sampling**						
EXP 3									
time 1	FL21-2006-015	1.559	1.135	1.018	0.739	0.279	0.116	0.087	0.030
time 2	FL21-2006-016	2.028	1.449	1.328	0.961	0.367	0.120	0.088	0.033
time 3	FL21-2006-017	2.032	1.446	1.329	0.963	0.366	0.116	0.085	0.031
time 4	FL21-2006-018	2.072	1.512	1.377	0.995	0.382	0.135	0.099	0.036

Fine	Lab ID	Total	F2 fraction	nC10apex-nC12apex	nC10apex-nC12apex	nC10apex-nC12apex	nC12apex-nC16apex	nC12apex-nC16apex	nC12apex-nC16apex
				total	saturates	aromatic	total	saturates	aromatic
		ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)	ppm (ug/mL)
EXP 1									
time 1	FL21-2006-019	**0.902**	**0.683**	0.614	0.443	0.170	0.069	0.056	0.012
time 2	FL21-2006-020	**1.210**	**0.915**	0.830	0.603	0.227	0.085	0.067	0.018
time 3	FL21-2006-021	**1.270**	**0.964**	0.880	0.640	0.240	0.084	0.067	0.017
time 4	FL21-2006-022	**1.37**	**1.077**	0.978	0.714	0.263	0.099	0.076	0.022
EXP 2									
time 1	FL21-2006-023	**0.653**	**0.521**	0.465	0.3445	0.1202	0.057	0.043	0.014
time 2	FL21-2006-024	**1.208**	**0.955**	0.867	0.639	0.228	0.088	0.067	0.021
time 3	FL21-2006-025	**1.427**	**1.132**	1.020	0.744	0.275	0.112	0.085	0.027
time 4	FL21-2006-026	**No sample was pulled**	**error in sampling**						
EXP 3									
time 1	FL21-2006-027	**0.779**	**0.631**	0.557	0.4021	0.1544	0.075	0.056	0.019
time 2	FL21-2006-028	**1.261**	**1.008**	0.908	0.657	0.251	0.100	0.076	0.024
time 3	FL21-2006-029	**1.321**	**1.050**	0.952	0.689	0.263	0.098	0.075	0.024
time 4	FL21-2006-030	**1.451**	**1.148**	1.040	0.755	0.284	0.108	0.082	0.026

APPENDIX C. Summary of Headspace Analytical Results

Average and standard deviation for headspace results by time point are provided in Tables C1 to C4.

Table C1. Part 1 Coarse-grained soil experiment – average and standard deviation by sampling time.

Replicated experiment and sample time from inception	**Total PHC**		**PHC F2**		**nC_{10}apex-nC_{12}apex**						**nC_{12}apex-nC_{16}apex**					
					Total		**Saturate sub-fraction**		**Aromatic sub-fraction**		**Total**		**Saturate sub-fraction**		**Aromatic sub-fraction**	
	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev
10 min	**1.484**	**0.135**	**1.102**	**0.119**	**0.979**	**0.101**	0.719263	0.07766	0.259314	0.025493	**0.124**	**0.022**	0.093754	0.016956	0.029972	0.005399
40 min	**2.024**	**0.005**	**1.474**	**0.026**	**1.343**	**0.023**	0.985698	0.0418	0.357783	0.019094	**0.131**	**0.010**	0.095747	0.0069	0.03482	0.004737
60 min	**2.043**	**0.016**	**1.472**	**0.037**	**1.346**	**0.023**	**0.975**	**0.017**	**0.371**	**0.007**	**0.126**	**0.014**	**0.091**	**0.008**	**0.035**	**0.005**
90 min	**2.072**	**n/a**	**1.512**	**n/a**	**1.377**	**n/a**	**0.995**	**n/a**	**0.382**	**n/a**	**0.135**	**n/a**	**0.099**	**n/a**	**0.036**	**n/a**

Table C2. Part 1 Fine-grained soil experiment – average and standard deviation by sampling time.

Replicated experiment and sample time from inception	**Total PHC**		**PHC F2**		**nC_{10}apex-nC_{12}apex**						**nC_{12}apex-nC_{16}apex**					
					Total		**Saturate sub-fraction**		**Aromatic sub-fraction**		**Total**		**Saturate sub-fraction**		**Aromatic sub-fraction**	
	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev
5 min	**1.484**	**0.124**	**0.612**	**0.082**	**0.545**	**0.075**	0.396621	0.049618	0.148375	0.025667	**0.067**	**0.009**	0.051727	0.007897	0.014969	0.003236
20 min	**2.024**	**0.030**	**0.959**	**0.047**	**0.868**	**0.039**	0.632842	0.027728	0.235408	0.013114	**0.091**	**0.008**	0.069652	0.005342	0.021286	0.003003
30 min	**2.043**	**0.080**	**1.048**	**0.084**	**0.950**	**0.070**	**0.691**	**0.052**	**0.259**	**0.018**	**0.098**	**0.014**	**0.075**	**0.009**	**0.023**	**0.005**
40 min	**2.072**	**0.055**	**1.112**	**0.050**	**1.009**	**0.044**	**0.735**	**0.029**	**0.274**	**0.015**	**0.103**	**0.007**	**0.079**	**0.004**	**0.024**	**0.003**

Table C3. Part 2 Coarse-grained soil experiment – average and standard deviation by sampling time.

Replicated experiment and sample time from inception	**Total VOC**		**PHC F2**		**nC$_{10}$apex-nC$_{12}$apex**						**nC$_{12}$apex-nC$_{16}$apex**					
					Total		**Saturate sub-fraction**		**Aromatic sub-fraction**		**Total**		**Saturate sub-fraction**		**Aromatic sub-fraction**	
	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev
Coarse Average																
15 min	**1.097**	**0.091**	**0.843**	**0.065**	**0.730**	**0.047**	Not requested		Not requested		**0.113**	**0.022**	Not requested		Not requested	
30 min	**1.030**	**0.048**	**0.812**	**0.045**	**0.676**	**0.022**	Not requested		Not requested		**0.136**	**0.023**	Not requested		Not requested	
60 min	**0.907**	**0.032**	**0.726**	**0.027**	**0.596**	**0.019**	**0.437**	**0.014**	**0.159**	**0.006**	**0.129**	**0.008**	**0.093**	**0.006**	**0.036**	**0.002**

Table C4. Part 2 Fine-grained soil experiment – average and standard deviation by sampling time.

Replicated experiment and sample time from inception	**Total VOC**		**PHC F2**		**nC$_{10}$apex-nC$_{12}$apex**						**nC$_{12}$apex-nC$_{16}$apex**					
					Total		**Saturate sub-fraction**		**Aromatic sub-fraction**		**Total**		**Saturate sub-fraction**		**Aromatic sub-fraction**	
	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev	µg/mL	stdev
Fine Average																
15 min	**0.389**	**0.073**	**0.304**	**0.067**	**0.244**	**0.049**	Not requested		Not requested		**0.060**	**0.020**	Not requested		Not requested	
30 min	**0.374**	**0.056**	**0.284**	**0.039**	**0.224**	**0.037**	Not requested		Not requested		**0.059**	**0.007**	Not requested		Not requested	
60 min	**0.326**	**0.067**	**0.244**	**0.049**	**0.186**	**0.040**	**0.103**	**0.026**	**0.083**	**0.015**	**0.059**	**0.009**	**0.035**	**0.006**	**0.023**	**0.003**

APPENDIX C: F2 MANAGEMENT LIMITS FOR TRENCH WORKER SCENARIO CALCULATIONS

Appendix C – F2 Management Limit Calculations - Trench Worker Scenario

Table of Contents

List of Tables

List of Figures

1.0 PURPOSE AND OVERVIEW

This Appendix provides details of the calculations for the PHC F2 management limit component for the trench worker scenario.

The PHC F2 management limit for the trench worker scenario is the concentration of F2 in coarse or fine soil that will not result in unacceptable exposure for hypothetical workers in a trench cut through F2 impacted soil.

Previous work (CCME, 2008) calculated this management limit using:

1. A diffusion model (VDEQ, 2005) to estimate the flux rate of F2 at the trench face.
2. Assumed air exchange rates for the trench.
3. Occupational exposure limits for kerosene/jet fuel.
4. A simple box model to describe the mixing of F2 vapours and trench air.

There was significant uncertainty in the management limits calculated by CCME (2008) primarily related to elements 1 and 2 above. Both these elements have been refined in the current work and the current calculations are based on measured data rather than assumed or modelled values. The current work calculates the management limit using:

1. Measured, rather than modelled F2 flux rates.
2. Trench air exchange rates based on actual measurements in physical trenches.
3. Occupational exposure limits for kerosene/jet fuel.
4. A simple box model to describe the mixing of F2 vapours and trench air.

For these reasons, the management limit values calculated in this Appendix have significantly less uncertainty than the values calculated by CCME (2008).

2.0 MANAGEMENT LIMIT CALCULATION

The four elements noted above are required in order to calculate the PHC F2 management limit component for the trench worker scenario. These elements are discussed in the following sections.

2.1 Determining F2 Flux Rates from Flow-Through Test Results

InnoTech (2020, 2022) completed three phases of lab-based investigations related to measuring the flux rate of F2 from the surface of F2-spiked soils.

- Phase 1 measured the equilibrium headspace vapour concentrations of F2 in equilibrium with F2 spiked soils.
- Phase 2 measured how the transient headspace vapour concentrations of F2 increased over time in a static headspace in contact with F2 spiked soils.
- Phase 3 measured the F2 vapour concentration in flow-through cells containing F2 spiked soils with an air exchange rate of 46/hour.

Full experimental details are available in the InnoTech reports included in Appendix A (Phase 1) and Appendix B (Phases 2 and 3).

Phase 1 was conducted as a range finding experiment. Phase 2 showed how the F2 concentration changed in headspace air over time. However, Phase 3, which measured the F2 vapour concentration in flow-through cells containing F2 spiked soils provides the most direct measurement of F2 flux rates at the soil surface and the results of Phase 3 are used here to calculate representative F2 flux rates at the surface of fine- and coarse-grained soils spiked with F2.

In Phase 3, fine- and coarse-grained soils were spiked with F2 at a nominal concentration of 10,000 mg/kg. Soil samples were taken immediately prior to conducting the Phase 3 flux rate experiments and analyzed for F2 hydrocarbons. Mean measured F2 concentrations at the start of the Phase 3 flux rate experiments were:

- Fine Soil: 8,057 mg/kg (average of 3 replicates, InnoTech, 2022, Appendix B, Table 6).
- Coarse Soil: 5,660 mg/kg (composite of 3 replicates, InnoTech, 2022, Appendix B, Table 6).

Spiked soils were compacted into the base of 500 ml flow-through containers (3 replicates each for fine- and coarse-grained soils). At time 0, air flow was started through the containers at 23 L/hour (46 air exchanges/hour). Air samples were withdrawn at 15 min, 30 min and 60 min and analyzed for F2 by GC-FID. Analytical results are summarized in Tables 7 and 8 of Appendix B and illustrated graphically in Figure 1 below.

As seen in Figure 1, the F2 concentration is the flow-through cells is higher for the coarse- than the fine-grained soil, and the concentrations for both fine- and coarse-grained soils decrease slightly over the 60 minutes of the experiment. This is interpreted as being related to depletion of F2 in the surficial soil layers.

For the purposes of the current report, it is assumed that workers would not enter a freshly dug trench for at least the first hour due to the necessity of providing shoring to ensure trench stability and therefore the data from 60 minutes are used as the departure point for calculating management limits.

Based on the data provided in Tables 7 and 8 of Appendix B, the mean F2 vapour concentrations in the flow-through cells at 60 minutes in this experiment are:

- Fine Soil: mean 60-minute vapour concentration = 0.245 ug/ml (n=3).
- Coarse Soil: mean 60-minute vapour concentration = 0.726 ug/ml (n=3).

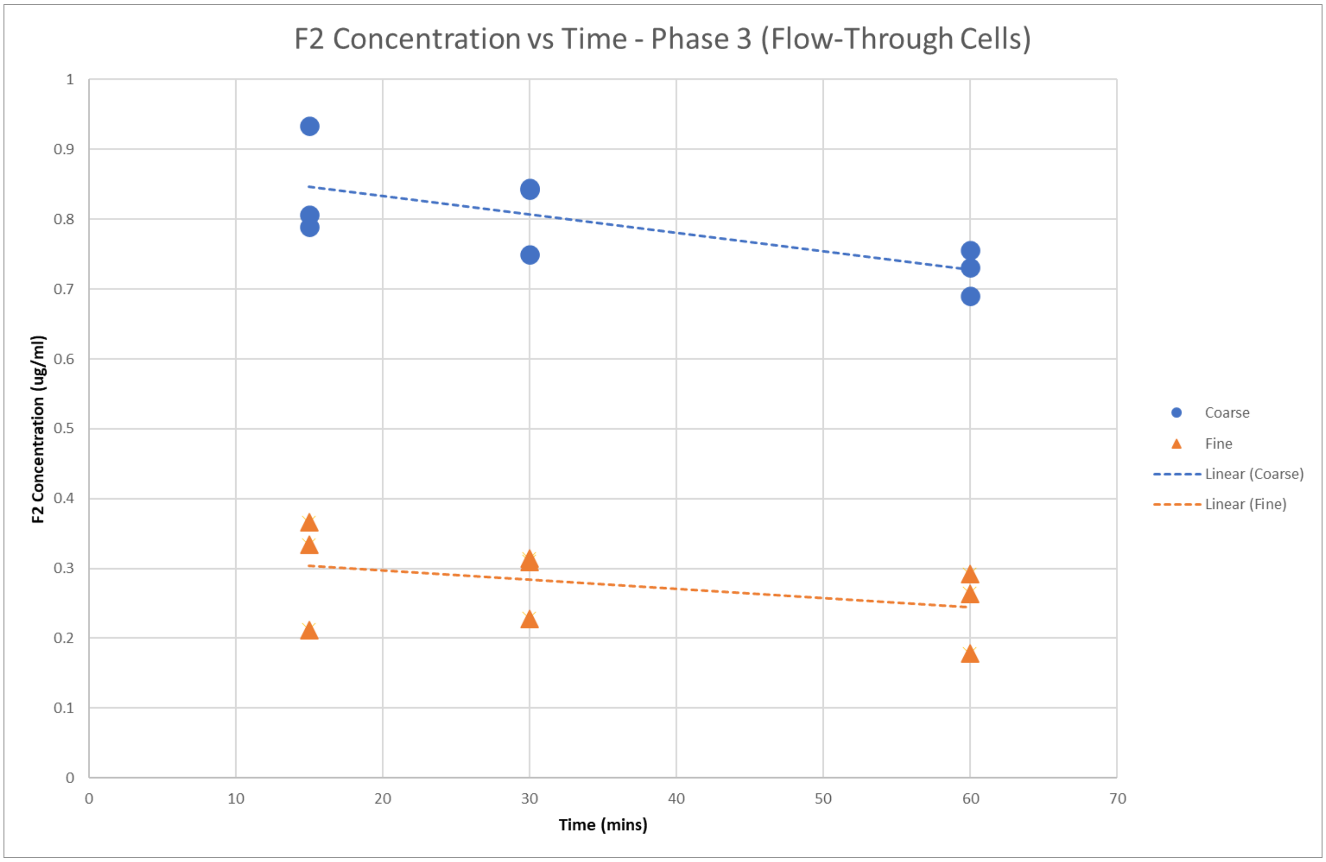

Figure C-1 F2 Concentration vs. Time in Flow-Through Cells

The air in the flow-through cell is constantly being changed, and therefore the concentration of F2 in the cell is proportional to the flux rate at which F2 is entering the airspace from the soil surface. Knowing the air exchange rate in the cell (ACH_C) and the surface area of the spiked soil in the cell (A_C) allows the F2 flux rate from the soil surface into the airspace to be calculated from first principles as follows. Note that in the following equations and definitions, the subscript $_C$ is used throughout to identify parameter values that relate to the flow-through cell. This is done to avoid confusion with similar parameters and equations that will be used for similar processes in the trench box model in Section 2.4, for which the subscript $_T$ will be used.

The time (T_C) taken for the air to be changed once in the flow-through cell is given by:

$$T_C = \frac{1}{ACH_C} \qquad \text{Equation 1}$$

Where ACH_C is the air exchange rate. If the F2 flux rate at the soil surface is F_C mg/m^2/hour, then the mass (M_C) of F2 entering the cell over the period of one air exchange is given by

$$M_C = F_C \cdot A_C \cdot T_C \qquad \text{Equation 2}$$

where A_C is the surface area of the spiked soil in the flow-through cell. The F2 vapour concentration, C_{VC}, in the cell is therefore given by:

$$C_{VC} = \frac{M_C}{V_C} = \frac{F_C \cdot A_C \cdot T_C}{V_C} \qquad \text{Equation 3}$$

Re-arranging this equation to solve for the flux rate, F_C gives:

$$F_C = \frac{C_{VC} \cdot V_C \cdot ACH_C}{A_C} \qquad \text{Equation 4}$$

Where:

F_C = flux rate of F2 from soil surface into the air of the flow-through cell (mg/m^2/hour)
C_{VC} = vapour concentration of F2 in the airspace of the flow-though cell (mg/m^3)
V_C = volume of the flow-though cell (m^3)
ACH_C = air exchange rate in the flow-though cell (exchanges per hour)
A_C = surface area of spiked F2 soil in the flow-though cell (m^2)

Parameter values used in the flux rate calculation are summarized in Table C-1. Values are provided in the units in which they were measured (to allow comparison with the data in Appendix B) as well as being converted to the appropriate units for the above equation.

Table C-1 Parameter Values Relating to the Flow-Through Cell

Parameter	Fine Soil		Coarse Soil	
	Measurement Units	Calculation Units	Measurement Units	Calculation Units
Mean F2 vapour concentration in flow-through cell (C_C)	0.245 ug/ml	245 mg/m^3	0.726 ug/ml	726 mg/m^3
Volume of flow-through cell (V_C)	500 ml	0.0005 m^3	500 ml	0.0005 m^3
Air exchange rate (ACH_C)	46 exch/hour	46 exch/hour	46 exch/hour	46 exch/hour
Soil surface area (A_C)	50.3 cm^2	0.00503 m^3	50.3 cm^2	0.00503 m^3

Substituting these values in the above equation yields the F2 flux rates for the flow-through experiments at the 60-minute time point:

- Fine soil: F2 flux rate in flow-through cell = 1,120 mg/m^2/hour
- Coarse soil: F2 flux rate in flow-through cell = 3,320 mg/m^2/hour

2.2 Trench Air Exchange Rate

The CCME (2008) calculations adopt the recommended trench air exchange rates in the VDEQ model, which are 360/hour where trench width is greater than depth and 2/hour otherwise. Neither of these air exchange rates were based on measured values in actual trenches. Since that time, some high-quality research has been done measuring actual air exchange rates in trenches constructed for the purpose. Thompson et al. (2017) conducted an empirical field study specifically to investigate the validity of the default air exchange rates of 360/hour and 2/hour in the VDEQ model. These authors measured the air exchange rate in five trenches all 3 feet wide and 8 feet deep in various orientations to the prevailing wind direction and under various conditions. Their methodology involved filling each trench with carbon dioxide and measuring the decrease of carbon dioxide concentration over time under various conditions of prevailing wind. Trench air exchange rates during these field studies ranged from 34 to 79 per hour with an average of 46 per hour for trenches with a ratio of width to depth that is less than one. Their average air exchange rate of 46/hour is adopted here.

2.3 Occupational Exposure Limits for Kerosene/Jet Fuel

In the absence of an established acute/sub-chronic inhalation reference value for F2, the 2008 PHC CWS used occupational exposure limits as a reference point to set management limits for the worker in a trench scenario (Meridian, 2006). This approach is retained here.

Kerosene is a petroleum hydrocarbon distillate which is obtained from the fractional distillation of petroleum between 150 and 275 °C. Kerosene predominantly consists of molecules containing between 9 and 16 carbon atoms (Shepherd et al., 2000) and thus closely resembles the range of F2. Accordingly, occupational exposure limits for kerosene are adopted here for setting management limits for the trench worker scenario.

Available occupational inhalation limits for kerosene (summarized in OSHA, 2022) include:

- NIOSH (National Institute for Occupational Safety and Health): The recommended airborne exposure limit (REL) for kerosene is 100 mg/m^3 averaged over a 10-hour work shift.
- ACGIH (American Conference of Governmental Industrial Hygienists): The threshold limit value (TLV) for kerosene and jet fuels is 200 mg/m^3 averaged over an 8-hour work shift.
- US EPA (United States Environmental Protection Agency): The US EPA has set an Acute Exposure Guideline Level-1 (AEGL-1) of 290 mg/m^3 for military jet fuels JP-5 and JP-8 (similar in composition to kerosene and F2).
- In addition, NRC (2003) set a permissible exposure level (PEL) of 350 mg/m^3 for the military jet fuel JP-8 (similar in composition to kerosene and F2).

In this document, the lowest of the above values, the NIOSH REL of 100 mg/m^3 was selected as the reference point for setting management limits for the trench worker inhalation scenario.

2.4 Box Model – Mixing F2 Vapours and Trench Air

In the current work, a simple box model is used to describe the mixing of F2 vapours with air in the trench. CCME (2008) indicated that vapour/air mixing in the trench was addressed using a simple box model, however the equation for that model was not provided in CCME (2008) and therefore the equation for a simple box model is developed from first principles here.

The primary assumptions of the box model are that the concentration of vapours, in this case F2, in the trench is controlled by:

- the flux of F2 from the trench walls;
- complete mixing of the F2 vapours with trench air; and,
- trench air being regularly replaced based on the air exchange rate for the trench.

These processes are illustrated in Figure 2 below.

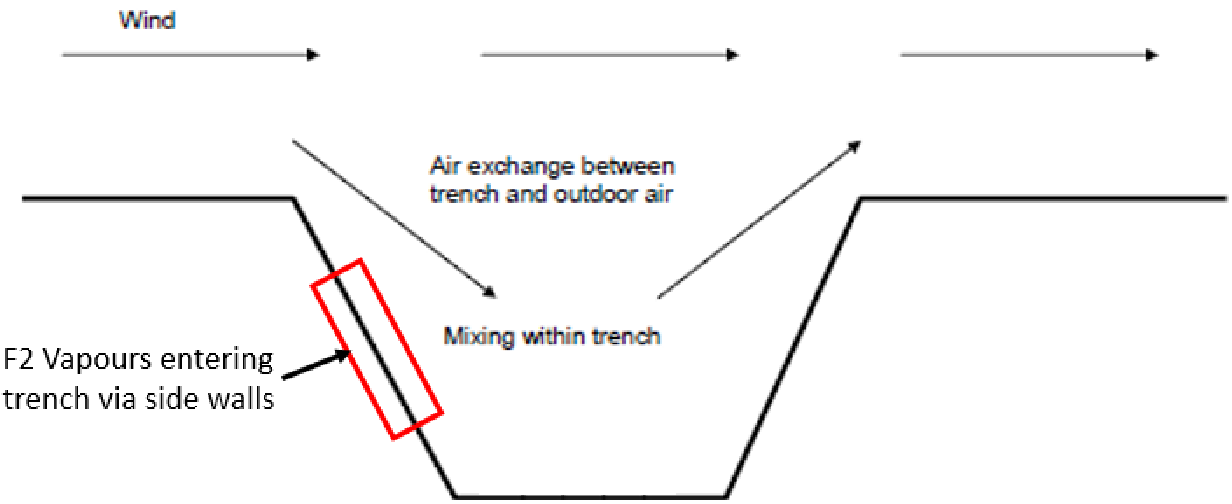

Figure C-2 **Trench Box Model**

The equation for the trench box model has a similar basis to the model developed for the flow-through cell in Section 2.1 above. Several of the parameters are similar and the subscript $_T$ is used in this section to identify parameters that relate to the trench model rather than the cell model.

The time (T_T) taken for the air to be changed once in the trench is given by

$$T_T = \frac{1}{ACH_T} \qquad \text{Equation 5}$$

Where ACH_T is the air exchange rate in the trench. If the F2 flux rate at the trench face is F_T mg/m^2/hour, then the mass (M_T) of F2 entering the trench in the time taken for one air exchange is given by

$$M_T = F_T \cdot A_T \cdot T_T \qquad \text{Equation 6}$$

where A_T is the trench surface area with F2 impacted soil. For the purposes of these calculations, it is assumed that the F2 soil impacts extend over the full length (L) and depth (D) of both sidewalls of the trench but not the base or ends of the trench. Accordingly, the trench surface area with F2 impacted soil (A_T) is given by:

$$A_T = 2 \cdot L \cdot D \qquad \text{Equation 7}$$

The volume of the trench (V_T) is given by:

$$V_T = L \cdot D \cdot W \qquad \text{Equation 8}$$

Where L, D, and W are the length, depth, and width of the trench, respectively.

The F2 flux rate in the flow-though cells was determined in Section 2.1 above, and just needs to be scaled by the ratio of the F2 concentration in soil surrounding the trench (C_{ST}) to the spiked F2 soil concentration used in the flow-through cell experiments (C_{SC}):

$$F_T = F_C \cdot \frac{C_{ST}}{C_{SC}} \qquad \text{Equation 9}$$

The F2 vapour concentration in the trench, C_{VT}, is therefore given by:

$$C_{VT} = \frac{M_T}{V_T} = \frac{F_T \cdot A_T \cdot T_T}{V_T} \qquad \text{Equation 10}$$

This can be re-organized by combining equations 5, 6, 7, 8 and 9 to give:

$$C_{VT} = \frac{2 \cdot F_C \cdot C_{ST}}{C_{SC} \cdot W \cdot ACH_T} \qquad \text{Equation 11}$$

And re-arranged to give the soil concentration surrounding the trench C_{ST} in terms of parameters who:

$$C_{ST} = \frac{C_{VT} \cdot C_{SC} \cdot W \cdot ACH_T}{2 \cdot F_C} \qquad \text{Equation 12}$$

Where:

C_{ST} = F2 soil concentration surrounding the trench (mg/kg)

C_{VT} = F2 vapour concentration in the trench (mg/m^3)

C_{SC} = spiked F2 soil concentration in the flow-through cell (mg/kg)

W = width of trench (m)

ACH_T = air exchange rate in the trench (exchanges per hour)

F_C = F2 flux rate determined in the tests in the flow-through cell, and corresponding to the soil concentration Csc noted above (mg/m^2/hour)

C_{ST} = volume of the flow-though cell (m^3)

2.5 Calculation of Management Limit

The management limits for fine- and coarse-grained soils can now be calculated from equation 12 by setting the F2 vapour concentration in the trench to the occupational exposure limit identified in Section 2.3 and substituting appropriate values for the other parameters as indicated in Table C-2 below.

Table C-2 Parameter Values Relating to the Trench

Parameter and Corresponding Symbol in Equation 12	Parameter Value		Source
	Fine Soil	Coarse Soil	
Occupational exposure limit (C_{VT})	100 mg/m^3	100 mg/m^3	Section 2.3
Spiked F2 soil concentration in flow-through cell (C_{SC})	8,057 mg/kg	5,660 mg/kg	Section 2.1
Trench width (W)	1 m	1 m	See below
Air exchange rate in trench (ACH_T)	46 exchanges/hour	46 exchanges/hour	Section 2.2
F2 flux rate from flow-through tests (F_C)	1,120 mg/m^2/hour	3,320 mg/m^2/hour	Section 2.1

The trench width (W) was set at 1 m which was assumed to be the narrowest trench that it was realistic for a worker to enter. Greater values for W in equation 12 would result in higher values for management limit, and thus using the smallest realistic value for W is conservative.

Substituting the values from Table C-2 into equation 12 allows the following values to be calculated for the F2 management limits protective of the worker in trench scenario (rounded to the nearest 1,000 mg/kg):

- Fine Soil: Management limit = 17,000 mg/kg
- Coarse Soil: Management limit = 4,000 mg/kg

3.0 REFERENCES

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